

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

**Fabio Grandi**

IEIIT.BO-CNR and DEIS

Alma Mater Studiorum – Università di Bologna  
Viale Risorgimento 2, I-40136, Bologna, ITALY

Email: fgrandi@deis.unibo.it

## 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; Tsostras & 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 Nørnvåg, “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 Nørnvåg, “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 Nørnvåg, “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 Nørnvåg, “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.
- [15] Kjetil Nørnvåg, “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.
- [16] Kjetil Nørnvåg, “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.
- [17] Kjetil Nørnvåg, “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 (August 2003), Norway, LNCS Vol. 2769, Springer-Verlag, Heidelberg, pp. 511–522, 2003.
- [18] Peter Buneman, Sanjeev Khanna, Keishi Tajima, Wang Chiew Tan, “Archiving Scientific Data”, *ACM Trans. on Database Systems*, Vol. 29, No. 1, pp. 2–42, 2004.
- [19] Kjetil Nørnvåg, “Supporting Temporal Text-Containment Queries in Temporal Document Databases”, *Data & Knowledge Engineering*, Vol. 49, No. 1, pp. 105–125, 2004.
- [20] Curtis Dyreson, Hui-ling Lin, Yingxia Wang, “Managing Versions of Web Documents in a Transaction-time Web Server”, *Proc. of Intl’ Conf. on World Wide Web (WWW 2004)*, New York (*to be held May 2004*), NY.
- [21] Fusheng Wang, Xing Zhou, Carlo Zaniolo, “Temporal Information Management Using XML” (Demo-Poster), *Proc. of 23rd Intl’ Conf. on Conceptual Modeling (ER 2004)*, Shanghai (November 2004), China. LNCS Vol. 3288, Springer-Verlag, Heidelberg, pp. 858–859, 2004.

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.

- [22] 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.
- [23] 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.

- [24] 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.
- [25] 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.
- [26] 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.
- [27] 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.
- [28] Elisa Quintarelli, “Model-Checking Based Data Retrieval: An Application to Semistructured and Temporal Data” Ph.D. Thesis, Politecnico di Milano, Italy, 2002.
- [29] 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.
- [30] Yannis Stavarakas, Manolis Gergatsoulis, Christos Doulkeridis, Vassilis Zafeiris, “Accommodating 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.
- [31] Kjetil Nørnvåg, 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.
- [32] Manolis Gergatsoulis, Yannis Stavarakas, “Representing Changes in XML Documents using Dimensions”, *Proc. of XML Database Symposium (XSym 2003)* (in conj. with VLDB 2003), Berlin (September 2003), Germany, LNCS Vol. 2824, Springer-Verlag, Heidelberg, pp. 208–222, 2003.
- [33] Manolis Gergatsoulis, Yannis Stavarakas, 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 Stavarakas, 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 Stavarakas, 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] Alexander Zipf, Sven Krüger, “TGML - Extending GML by Temporal Constructs - A Proposal for a Spatiotemporal Framework in XML”, *Proc. of 9th ACM Intl' Symposium on Advances in Geographical Information Science (ACM-GIS 2001)*, Atlanta (November 2001), GA, ACM Press, New York, pp. 94–99, 2001.
- [16] 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.
- [17] 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.
- [18] 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.
- [19] 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.
- [20] Dengfeng Gao, Richard T. Snodgrass, “Syntax, Semantics, and Query Evaluation of the  $\tau$ XQuery Temporal XML Query Language”, Technical Report, TIMECENTER TR-72, 2003, <http://www.cs.auc.dk/research/DP/tdb/TimeCenter/>.
- [21] Haitao Liu, “ $\tau$ DOM: A Time-Aware API for Managing Temporal XML Documents”, Technical Report, TIMECENTER TR-74, 2003, <http://www.cs.auc.dk/research/DP/tdb/TimeCenter/>.
- [22] 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.
- [23] 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.
- [24] 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.
- [25] 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.
- [26] 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 (October 2003), Greece, LNAI Vol. 2780, Springer-Verlag, Heidelberg, pp. 36–40, 2003.

- [27] 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 (December 2003), Italy, IEEE Computer Society Press, Los Alamitos, pp. 93–102, 2003.
- [28] François Bry, Bernhard Lorenz, Hans Jürgen Ohlbach, Stephanie Spranger, “On Reasoning on Time and Location on the Web”, *Proc. of Intl’ Workshop on Principles and Practice of Semantic Web Reasoning (PPSWR 2003)* (in conj. with ICLP ’03), Mumbai (December 2003), India, LNCS Vol. 2901, Springer-Verlag, Heidelberg, pp. 69–83, 2003.
- [29] Carlo Combi, Sara Migliorini, Barbara Oliboni, Rosalba Rossato, “From Semi-structured Multimedia Temporal Graphs to XML (Extended Abstract)”, *Proc. of Natl’ Conf. on Advanced Database Systems (SEBD 2004)*, S. Margherita di Pula (June 2004), Italy, LITHOSgrafiche, Cagliari, pp. 70–77, 2004.
- [30] Paolo Atzeni and Pierlugi Del Nostro, “Towards the Management of Time in Data-intensive Web Sites”, *Proc. of 3rd Intl’ Workshop on Evolution and Change in Data Management (ECDM 2004)* (in conj. with ER 2004), Shanghai (November 2004), China. LNCS Vol. 3289, Springer-Verlag, Heidelberg, pp. 390–401, 2004.
- [31] 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.
- [32] Robin L. Kullberg, “Dynamic Timelines: Visualizing Historical Information in Three Dimensions”, Master Thesis, MIT, Cambridge, MA, 1995.
- [33] 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.
- [34] 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.
- [35] 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.
- [36] 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/>.
- [37] 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.
- [38] 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.

- [39] 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.
- [40] 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.
- [41] 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.
- [42] 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.
- [43] 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.
- [44] Andrea Setzer, Robert J. Gaizauskas, “Building a Temporally Annotated Corpus for Information Extraction”, *Proc. of Workshop on Information Extraction Meets Corpus Linguistics* (in conj. with LREC 2000), Athens (May 2000), Greece, 2000.
- [45] Andrea Setzer, Robert J. Gaizauskas, “Annotating Events and Temporal Information in Newswire Texts”, *Proc. of 2nd Intl’ Conf. on Language Resources and Evaluation (LREC 2000)*, Athens (June 2000), Greece, 2000.
- [46] 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.
- [47] 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.
- [48] 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/>.
- [49] 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.aria.dne.ac.uk/>.
- [50] 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/>.
- [51] Inderjeet Mani, George Wilson, “Robust Temporal Processing of News”, *Proc. of 38th Annual Meeting of the Association for Computational Linguistics (ACL 2000)*, Hong Kong (October 2000), China, 2000.



- [52] 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.
- [53] Andrea Setzer, “Temporal Information in Newswire Articles: An Annotation Scheme and Corpus Study”, Ph.D. Thesis, Univeristy of Sheffield, UK, 2001.
- [54] 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.
- [55] 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.
- [56] 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/>.
- [57] Frank Schilder, Christopher Habel, “From Temporal Expressions To Temporal Information: Semantic Tagging of News Messages”, *Proc. of Workshop on Temporal and Spatial Information Processing* (in conj. with ACL 2001). Toulouse (July 2001), France, pp. 65–72, 2001.
- [58] 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.
- [59] 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.
- [60] 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.
- [61] Carlos Monroy, “Augmenting Cognition through Information Visualization Using a Timeline Viewer”, Masters of Computer Science Project Report, Texas A&M Univeristy, TX, 2002.
- [62] 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.
- [63] Franco Niccolucci, “XML and the Future of Humanities Computing”, *ACM SIGAPP Applied Computing Review* (special issue on “First European Workshop on XML and Knowledge Management”), Vol. 10, No. 1, pp. 43–47, Spring 2002.
- [64] Andrea Setzer, Robert J. Gaizauskas, “On the Importance of Annotating Temporal Event-Event Relations in Text”, *Proc. of Intl’ Workshop on Annotation Standards for Temporal Information in Natural Language* (in conj. with LREC 2002), Las Palmas – Canary Islands (May 2002), Spain, pp. 52–60, 2002.

- [65] 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.
- [66] 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.
- [67] Adrian Graham, Hector Garcia-Molina, Andreas Paepcke, Terry Winograd, “Extreme Temporal Photo Browsing”, *Proc. of 2nd Intl’ Workshop on Visual Interfaces to Digital Libraries* (in conj. with JCDL ’02), Portland (July 2002), OR, ACM Press, New York, pp. 81–97, 2002.
- [68] Carlos Monroy, Rajiv Kochumman, Richard Furuta, and Eduardo Urbina, “Interactive Timeline Viewer (ItLv): A Tool to Visualize Variants Among Documents”, *Proc. of 2nd Intl’ Workshop on Visual Interfaces to Digital Libraries* (in conj. with JCDL ’02), Portland (July 2002), OR, <http://vw.indiana.edu/visual02/>.
- [69] Carlos Monroy, Rajiv Kochumman, Richard Furuta, Eduardo Urbina, Erendira Melgoza, Arpita Goenka, “Visualization of Variants in Textual Collations to Analyze the Evolution of Literary Works in The Cervantes Project”, *Proc. of 6th European Conf. on Research and Advanced Technology for Digital Libraries (ECDL 2002)*, Rome (September 2002), Italy, LNCS Vol. 2458, Springer-Verlag, Heidelberg, pp. 638–653, 2002.
- [70] Carlos Monroy, Richard Furuta, Enrique Mallen, “Visualizing and Exploring Picasso’s World”, *Proc. of ACM/IEEE Joint Conf. on Digital Libraries (JCDL 2003)*, Houston (May 2003), TX, IEEE Computer Society Press, Los Alamitos, pp. 173–175, 2003.
- [71] Inderjeet Mani, Barry Schiffman, Jianping Zhang, “Inferring Temporal Ordering of Events in News”, *Proc. of Human Language Technology Conference of the North American Chapter of the Association for Computational Linguistics (HLT-NAACL 2003)*, Edmonton (May-June 2003), Canada, 2003.
- [72] James Pustejovsky, Inderjeet Mani, “Annotation of Temporal and Event Expressions” (tutorial), *Proc. of Human Language Technology Conference of the North American Chapter of the Association for Computational Linguistics (HLT-NAACL 2003) – Tutorials*, Edmonton (May-June 2003), Canada, p. 6, 2003.
- [73] The Perseus Digital Library Homepage, <http://www.perseus.tufts.edu/>
- A strictly related field concerns the addition of the (validity) temporal dimension to virtual environments (e.g. temporal VRML extensions).
- [74] D. Brent Henderson, H. Lawrence McKague, “Spatio-Temporal Visualization of Earthquake Hypocenters Over the Internet Using VRML”, *Proc. ACSM/ASPRS Annual Convention & Exposition – Vol. 2, Technical Papers*, Seattle (April 1997), WA, pp. 369–373, ACSM & ASPRS, Bethesda, 1997.
- [75] Askan Striepe, Christian Quintus, Ingo Braun, Anja Kutzner, Andreas Knoche, Leonie Schäfer, Birgit Böhme, Uta Simmons, “Time-Travels in Virtual Online Landscapes: New Presentation Possibilities with Online Virtual Reality” *Proc. of Museums and the Web: An International Conference*, Toronto (April 1998), Ontario, Archives & Museum Informatics, Pittsburgh, PA, 1998.

- [76] Isabelle Mirbel, Barbara Pernici, Timos Sellis, Michalis Vazirgiannis, “ECA Rules as Modeling Approach for Interactive Spatio-temporal Application Contexts (the VRML Case)”, *Proc. Chorochronos Workshop*, Aalborg (June 1998), Denmark, Chorochronos Project, <http://www.dbnet.ece.ntua.gr/~choros/>.
- [77] Hartmut Luttermann, Manfred Grauer, “VRML-based Presentation of Spatio-temporal Business and Scientific Data with WWW Browsers” (in German), *Proc. of 28th Annual Conf. of the German Informatics Society (GI Jahrestagung '98)*, Magdeburg (September 1998), Germany, Springer-Verlag, Heidelberg, pp. 57–66, 1998.
- [78] Hartmut Luttermann, Manfred Grauer, “VRML History: Storing and Browsing Temporal 3D-Worlds”, *Proc. of 4th Symposium on The Virtual Reality Modeling Language (VRML '99)*, Paderborn (February 1999), Germany, ACM Press, New York, pp. 153–160, 1999.
- [79] Hartmut Luttermann, Manfred Grauer, “Using Interactive, Temporal Visualizations for WWW-based Presentation and Exploration of Spatio-Temporal Data”, *Proc. of Intl' Workshop on Spatio-Temporal Database Management (SSTDM '99)*, Edinburgh (September 1999), Scotland, LNCS Vol. 1678, Springer-Verlag, Heidelberg, pp. 100–118, 1999.
- [80] Maria Elena Bonfigli, Antonella Guidazzoli, “A WWW Virtual Museum for Improving the Knowledge of the History of a City”, *Proc. of Festival of Virtual Reality in Archaeology* (in conj. with CAA'98), Barcelona (March 1998), Spain, BAR Vol. S843, ArchaeoPress, Oxford, England, 2000.
- [81] Maria Elena Bonfigli, Luigi Calori, Antonella Guidazzoli, “Nu.M.E.: a WWW Virtual Historic Museum of the City of Bologna”, *Proc. of 15th ACM Symposium on Applied Computing (SAC 2000) – Volume 2*, Como (March 2000), Italy, ACM Press, New York, pp. 956–961, 2000.
- [82] Maria Elena Bonfigli, Luigi Calori, Antonella Guidazzoli, Massimo Alessio Mauri, Maura Melotti, “Tailored Virtual Tours in Cultural Heritage Worlds”, *Proc. of ACM SIGGRAPH 2000 – Conference Abstracts and Applications*, New Orleans (July 2000), LA, ACM Press, New York, p. 264, 2000.
- [83] Hartmut Luttermann, Lilli Henriette Langner, “An Approach for the Temporal Extension of XML-based Document Types by the Example of X3D” (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. 273–282, 2000.
- [84] The Nu.M.E. Homepage, Italy, <http://www.cineca.it/nume/>.
- [85] The VRML History Homepage, <http://www-winfo.uni-siegen.de/vrmlHistory/docs/>.

### 2.3 Bitemporal (Transaction and Valid Time)

In the temporal database literature, bitemporal means transaction plus valid time data. Some papers address both time dimensions also in the World Wide Web context. Additional time dimensions (e.g. user-defined times) are also considered in some works.

- [1] Fabio Grandi, Maria Rita Scalas, “Extending Temporal Database Concepts to the World Wide Web”, *Proc. of 6th Natl' Conf. on Advanced Database Systems (SEBD '98)*, Portonovo (June 1998), Italy, Miliani, Ancona, pp. 919–922, 1998.

- [2] Fabio Grandi, Maria Rita Scalas, “Extending Temporal Database Concepts to the World Wide Web”, in The Dagstuhl Seminar Researchers, “Summary of Current Work”, in *Temporal Databases: Research and Practice*, LNCS Vol. 1399, Springer-Verlag, Heidelberg, pp. 418–419, 1999.
- [3] Curtis E. Dyreson, Michael H. Böhlen, Christian S. Jensen, “Capturing and Querying Multiple Aspects of Semistructured Data”, *Proc. of 25th Intl’ Conf. on Very Large Data Bases (VLDB ’99)*, Edinburgh (September 1999), Scotland, Morgan Kaufmann, San Francisco, pp. 290–301, 1999.
- [4] Gerhard F. Knolmayer, Thomas Myrach, “Concepts of Bitemporal Database Theory and the Evolution of Web Documents”, Technical Report, Working Paper No. 127, Inst. of Inf. Systems, University of Bern, Switzerland, August 2000.
- [5] Gerhard F. Knolmayer, Thomas Myrach, “The Representation of Different Time Dimensions of Web Documents through Meta-Data” (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. 283–290, 2000.
- [6] Pierluigi Del Nostro, “The Temporal Component in the Development of Web Sites” (in Italian), Master Thesis, Faculty of Engineering, University of Rome III, Italy, 2001.
- [7] Diana Ballarin, “XML and Temporal Databases. Foundations and Research Lines” (in Italian), Master Thesis, Faculty of Sciences, University of Udine, Udine, Italy, 2001.
- [8] Gerhard F. Knolmayer, Thomas Myrach, “Concepts of Bitemporal Database Theory and the Evolution of Web Documents” *Proc. of 34th Annual Hawaii Intl’ Conf. on System Sciences (HICSS-34) – Track 7*, Maui (January 2001), Hawaii, IEEE Computer Society Press, Los Alamitos, pp. 2649–2658, 2001.
- [9] Thomas Myrach, “The Temporal Dimensions of Documents in the World Wide Web” (in German), *Proc. of Workshop on Time Management in Internet*, Bad Honnef (March 2001), Germany, GMD, Sankt Augustin, Germany, pp. 41–46, July 2001.
- [10] Manuk G. Manukyan, Leonid A. Kalinichenko, “Temporal XML”, *Proc. of 5th East European Conf. on Advances in Databases and Information Systems (ADBIS ’01) – Vol. 1, Research Communications*, Vilnius (September 2001), Lithuania, pp. 143–155, 2001.
- [11] Erica Zanon, “Temporal Information and Semistructured Data: A Proposal for New Temporal Dimensions with Application to XML Documents” (in Italian), Master Thesis, Faculty of Sciences, University of Udine, Udine, Italy, 2002.
- [12] Sabrina De Capitani di Vimercati, “An Authorization Model for Temporal XML Documents”, *Proc. of 17th ACM Symposium on Applied Computing (SAC ’02)*, Madrid (March 2002), Spain, ACM Press, New York, pp. 1088–1093, 2002.
- [13] Shuohao Zhang, “Temporal XML and Temporal Aggregates in XQuery”, Master Thesis, School of Electrical Engineering and Computer Science, Washington State University, May 2002.
- [14] Paolo Atzeni, “Time: A Coordinate for Web Site Modelling” (invited talk), *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. 1–7, 2002.
- [15] Barbara Oliboni, “Blind Queries and Constraints: Representing Flexibility and Time in Semistructured Data” Ph.D. Thesis, Politecnico di Milano, Italy, 2003.

- [16] Marco Bergonzini, “TeX System: A System for the Temporal Management of Normative Texts” (*in Italian*), Master Thesis, Faculty of Engineering, University of Modena and Reggio Emilia, Italy, 2003.
- [17] Fabio Grandi, Federica Mandreoli, Paolo Tiberio, Marco Bergonzini, “A Temporal Data Model and System Architecture for the Management of Normative Texts (Extended Abstract)”, *Proc. of Natl’ Conf. on Advanced Database Systems (SEBD 2003)*, Cetraro (June 2003), Italy, Rubbettino, Soveria Mannelli, pp. 169–178, 2003.
- [18] Carlo Combi, Barbara Oliboni, Elisa Quintarelli, “A Graph-Based Model for Semistructured Temporal Data” (poster), *Proc. of Intl’ Conf. on Ontologies, Databases and Applications of Semantics (ODBASE 2003)* (part of the “On The Move to Meaningful Internet Systems – OTM 2003 Confederated Workshops), Catania (November 2003), Italy, LNCS Vol. 2889, Springer-Verlag, Heidelberg, pp. 22–23, 2003.
- [19] Fabio Grandi, Federica Mandreoli, Paolo Tiberio, Marco Bergonzini, “A Temporal Data Model and Management System for Normative Texts in XML Format”, *Proc. of 5th Intl’ Workshop on Web Information and Data Management (WIDM 2003)* (in conj. with CIKM 2003), New Orleans (November 2003), LA, ACM Press, New York, pp. 29–38, 2003.
- [20] Enrico Ronchetti, “Efficient Querying of Temporal XML Documents and Application to the Legal Field” (*in Italian*), Master Thesis, Faculty of Engineering, University of Modena and Reggio Emilia, Italy, 2004.
- [21] Faiz Currim, Sabah Currim, Curtis Dyreson, Richard T. Snodgrass, “A Tale of Two Schemas: Creating a Temporal Schema from a Snapshot Schema with  $\tau$ XSchema”, *Proc. of 10th Intl’ Conf. on Extending Database Technology (EDBT 2004)*, Heraklion – Crete (March 2004), Greece, LNCS Vol. 2992, Springer-Verlag, Heidelberg, pp. 348–365, 2004.
- [22] Carlo Combi, Barbara Oliboni, Elisa Quintarelli, “Specifying Temporal Data Models for Semistructured Data by a Constraint-based Approach”, *Proc. of 19th ACM Symposium on Applied Computing (SAC ’04)*, Nicosia (March 2004), Cyprus, ACM Press, New York, pp. 1103–1108, 2004.
- [23] Fusheng Wang, Carlo Zaniolo, “XBiT: An XML-based Bitemporal Data Model”, *Proc. of 23rd Intl’ Conf. on Conceptual Modeling (ER 2004)*, Shanghai (November 2004), China. LNCS Vol. 3288, Springer-Verlag, Heidelberg, pp. 810–824, 2004.

## 2.4 Non-Temporal Versioning

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.

- [1] Cesare Maioli, Stefano Sola, Fabio Vitali, “Versioning for Distributed Hypertext Systems”, *Proc. of Hypermedia ’94*, Pretoria (March 1994), South Africa, 1994.
- [2] David G. Durand, Anja Haake, David Hicks, Fabio Vitali (eds.), *Proceedings of the Workshop on Versioning in Hypertext Systems* (held in conj. with ACM European Conf. on Hypermedia Technology - ECHT ’94, Edinburgh, Scotland, September 1994), <http://cs-people.bu.edu/dgd/workshop/>.

- [3] Fabio Vitali, David G. Durand, “Using Versioning to Provide Collaboration on the WWW”, *Proc. of 4th Intl’ World Wide Web Conf. (WWW4)*, Boston (December 1995), MA, <http://www.w3.org/Conferences/WWW4/>.
- [4] Kenji Ota, Kenji Takahashi, Kazuchika Sekiya, “Version Management with Meta-level Links via HTTP/1.1,” Internet Draft, 1996 (*expired May 1997*).
- [5] Fabio Vitali, David G. Durand, “Using Versioning to Support Collaboration on the WWW,” *World Wide Web Journal*, Vol. 1, No. 1, pp. 37–50, 1996.
- [6] Wojciech Cellary, David G. Durand, Anja Haake, David L. Hicks, Fabio Vitali, E. James Whitehead Jr., “Things Change: Deal with it! Versioning, Cooperative Editing and Hypertext” (panel), *Proc. of 7th ACM Conf. on Hypertext (Hypertext’96)*, Washington (March 1996), DC, ACM Press, New York, p. 259, 1996.
- [7] Judith A. Slein, Fabio Vitali, E. James Whitehead Jr., David G. Durand, “Requirements for Distributed Authoring and Versioning on the World Wide Web,” *ACM Standard View*, Vol. 1, No. 5, pp. 17–24, 1997.
- [8] Ian Sommerville, Tom Rodden, Paul Rayson, Andrew Kirby, Alan J. Dix, “Supporting Information Evolution on the WWW”, *World Wide Web*, Vol. 1, No. 1, pp. 45–54, 1998.
- [9] E. James Whitehead Jr., Meredith Wiggins, “WEBDAV: IETF Standard for Collaborative Authoring on the Web”, *IEEE Internet Computing*, Vol. 2, No. 5, pp. 34–40, 1998.
- [10] Fabio Vitali, “Versioning Hypermedia”, *ACM Computing Surveys*, Vol. 31, No. 4es, p. 24, 1999.
- [11] Lars Bendix, Fabio Vitali, “VTML for Fine-Grained Change Tracking in Editing Structured Documents”, *Proc. of 9th Intl’ Symposium on System Configuration Management (SCM ’99)*, Toulouse (September 1999), France, LNCS Vol. 1675, Springer-Verlag, Heidelberg, pp. 139–156, 1999.
- [12] Shu-Yao Chien, Vassilis J. Tsotras, Carlo Zaniolo, “A Comparative Study of Version Management Schemes for XML Documents”, Technical Report, TIMECENTER TR-51, 2000, <http://www.cs.auc.dk/research/DP/tdb/TimeCenter/>.
- [13] Shu-Yao Chien, Vassilis J. Tsotras, Carlo Zaniolo, “Version Management of XML Documents”, *Proc. of 3rd Intl’ Workshop on The World Wide Web and Databases (WebDB 2000) – Informal Proceedings* (in conj. with SIGMOD 2000), Dallas (May 2000), TX, pp. 75–80, <http://www.research.att.com/conf/webdb2000/PAPERS/5c.ps>.
- [14] Shu-Yao Chien, Vassilis J. Tsotras, Carlo Zaniolo, “Version Management of XML Documents”, *The World Wide Web and Databases, Third International Workshop – Selected Papers*, LNCS Vol. 1997, Springer-Verlag, Heidelberg, pp. 184–200, 2001.
- [15] Shu-Yao Chien, Vassilis J. Tsotras, Carlo Zaniolo, “XML Document Versioning”, *SIGMOD Record*, Vol. 30, No. 3, pp. 46–53, 2001.
- [16] Shu-Yao Chien, Vassilis J. Tsotras, Carlo Zaniolo, “Copy-Based versus Edit-Based Version Management Schemes for Structured Documents”, *Proc. of 11th Intl’ Workshop on Research Issues in Data Engineering: Document Management for Data Intensive Business and Scientific Applications (RIDE-DM ’01)* (in conj. with ICDE ’01), Heidelberg (April 2001), Germany, IEEE Computer Society Press, Los Alamitos, pp. 95–102, 2001.

- [17] James J. Hunt, Jürgen Reuter, “Using the Web for Document Versioning: An Implementation Report for Delta-V”, *Proc. of 23rd Intl’ Conf. on Software Engineering (ICSE 2001)*, Toronto (May 2001), Ontario, IEEE Computer Society Press, Los Alamitos, pp. 507–513, 2001.
- [18] E. James Whitehead Jr., “Design Spaces for Link and Structure Versioning”, *Proc. of 12th ACM Conf. on Hypertext and Hypermedia (HT’01)*, Århus (August 2001), Denmark, ACM Press, New York, pp. 195–204, 2001.
- [19] Shu-Yao Chien, Vassilis J. Tsotras, Carlo Zaniolo, “Efficient Management of Multiversion Documents by Object Referencing”, *Proc. of 27th Intl’ Conf. on Very Large Data Bases (VLDB ’01)*, Rome (September 2001), Italy, Morgan Kaufmann, San Francisco, pp. 291–300, 2001.
- [20] Shu-Yao Chien, Vassilis J. Tsotras, Carlo Zaniolo, Donghui Zhang, “Storing and Querying Multiversion XML Documents Using Durable Node Numbers”, *Proc. of 2nd Intl’ Conf. on Web Information Systems Engineering (WISE ’01) – Volume 1*, Kyoto (December 2001), Japan, IEEE Computer Society Press, Los Alamitos, pp. 232–244, 2001.
- [21] Shu-Yao Chien, Vassilis J. Tsotras, Carlo Zaniolo, Donghui Zhang, “Efficient Complex Query Support for Multiversion XML Documents”, *Proc. of 8th Intl’ Conf. on Extending Database Technology (EDBT 2002)*, Prague (March 2002), Czech Republic, LNCS Vol. 2287, Springer-Verlag, Heidelberg, pp. 161–178, 2002.
- [22] Edith Cohen, Haim Kaplan, Tova Milo, “Labeling Dynamic XML Trees”, *Proc. of 21st ACM SIGACT-SIGMOD-SIGART Symposium on Principles of Database Systems (PODS 2002)*, Madison (June 2002), WI, ACM Press, New York, pp. 271–281, 2002.
- [23] Raymond K. Wong, Nicole Lam, “An Efficient Content-Based Version Management System for XML Documents”, *Proc. 2nd Annual Conf. for Standards and Process in Publishing (Open Publish ’02)*, Sydney (July/August 2002), NSW, 2002.
- [24] Raymond K. Wong, Nicole Lam, “Managing and Querying Multi-Version XML Data with Update Logging”, *Proc. ACM Symposium on Document Engineering (DocEng ’02)* (in conj. with CIKM 2002), McLean (November 2002), VA, 2002.
- [25] Shu-Yao Chien, Vassilis J. Tsotras, Carlo Zaniolo, “Efficient Management of Multiversion XML Documents”, *VLDB Journal*, Vol. 11, No. 4, pp. 332–353, December 2002.
- [26] Boualem Benatallah, Mehregan Mahdavi, Phuong Nguyen, Quan Z. Sheng, Lionel Port, Bill McIver, “An Adaptive Document Version Management Scheme”, *Proc. of 15th Intl’ Conf. on Advanced Information Systems Engineering (CAiSE 2003)*, Klagenfurt/Velden (June 2003), Austria, LNCS Vol. 2681, Springer-Verlag, Heidelberg, pp. 46–62, 2003.
- [27] Hyoseop Shin, Andrei V. Popov, “A Lightweight XML Repository Supporting Dynamic Partial Update of XML Data”, *Proc. of 9th Intl’ Conf. on Database Systems for Advances Applications (DASFAA 2004)* Jeju Island (March 2004), Korea, LNCS Vol. 2973, Springer-Verlag, Heidelberg, pp. 220–225, 2004.
- [28] Hyon Hee Kim, Seung-Soo Park: “A Semantics-Based Versioning Scheme for Multimedia Data”, *Proc. of 9th Intl’ Conf. on Database Systems for Advances Applications (DASFAA 2004)* Jeju Island (March 2004), Korea, LNCS Vol. 2973, Springer-Verlag, Heidelberg, pp. 277–288, 2004.

- [29] Zografoula Vagena, Vassilis J. Tsotras, “Path-expression Queries over Multiversion XML Documents”, *Proc. of 6th Intl. Workshop on the Web and Databases (WebDB’03)* San Diego (June 2003), CA, pp. 49–54, 2003.
- [30] Zografoula Vagena, Mirella M. Moro, Vassilis J. Tsotras, “Supporting Branched Versions on XML Documents”, *Proc. of 14th International Workshop on Research Issues on Data Engineering: Web Services for E-Commerce and E-Government (RIDE-WS-ECEG 2004)* (in conj. with ICDE ’04), Boston (March 2004), MA, IEEE Computer Society Press, Los Alamitos, pp. 137–144, 2004.
- [31] The Web-based Distributed Authoring and Versioning (WebDAV) Resource Page, <http://www.webdav.org/>.
- [32] The IETF Delta-V Working Group Homepage (Versioning Extensions to WebDAV), <http://www.webdav.org/deltav/>.
- A second stream of non-temporal versioning research involves the design and implementation of (multidimensional) *context-dependent* Web resources, supporting for example personalization, location-based services, multi-device and multi-lingual presentations, etc. We can include here the proposal of the IHTML (Intensional HTML) Web authoring language. Since this is a large bibliography, we tried to collect references most relevant to data-intensive applications (or also considering temporal aspects).
- [33] Taner Yildirim, “Intensional HTML”, Master Thesis, Dept. of Computer Science, University of Victoria, BC, 1997.
- [34] Monica m.c. Schraefel, “ConTexts: Intensional Document Creation, Delivery and Retrieval”, *Proc. 1997 IEEE Pacific Rim Conf. on Communications, Computers and Signal Processing (PACRIM ’97)* Victoria (August 1997), BC, IEEE Press, Piscataway, NJ, pp. 417–419, 1997.
- [35] Gord D. Brown, “Intensional HTML 2: A Practical Approach”, Master Thesis, Dept. of Computer Science, University of Victoria, BC, 1998.
- [36] Anne Brüggemann-Klein, Stefan Hermann, Derick Wood, “Context and Caterpillars and Structured Documents”, *Proc. of 4th Intl’ Workshop on Principles of Digital Document Processing (PODDP 1998)*, Saint Malo (March 1998), France, LNCS Vol. 1481, Springer-Verlag, Heidelberg, pp. 1–9, 1998.
- [37] William W. Wadge, Gord D. Brown, Monica m.c. Schraefel, Taner Yildirim, “Intensional HTML”, *Proc. of 4th Intl’ Workshop on Principles of Digital Document Processing (PODDP 1998)*, Saint Malo (March 1998), France, LNCS Vol. 1481, Springer-Verlag, Heidelberg, pp. 128–139, 1998.
- [38] Shueh-Cheng Hu, Richard Furuta, “A Tool for Maintaining Multi-variant Hypertext Documents”, *Proc. of 7th Intl’ Conf. on Electronic Publishing (EP ’98)*, Saint Malo (March/April 1998), France, LNCS Vol. 1375, Springer-Verlag, Heidelberg, pp. 525–536, 1998.
- [39] Gord D. Brown, “Intensional HTML 2: Design and Implementation”, *Proc. of 11th Intl’ Symposium on Languages for Intensional Programming (ISLIP’98)*, Palo Alto (May 1998), CA, University of Victoria, 1998.
- [40] Anne Brüggemann-Klein, Stefan Hermann, Derick Wood, “The Visual Specification of Context”, *Proc. of IEEE Forum on Research and Technology Advances in Digital Libraries (ADL ’99)*, Baltimore (May 1999), MD, IEEE Computer Society Press, Los Alamitos, pp. 28–36, 1999.



- [41] Stefano Ceri, Piero Fraternali, Andrea Maurino, Stefano Paraboschi, “One-to-One Personalization of Data-Intensive Web Sites”, *Proc. of 2nd Intl’ Workshop on The World Wide Web and Databases (WebDB 1999) – Informal Proceedings* (in conj. with SIGMOD ’99), Philadelphia (June 1999), PA, <http://www-rocq.inria.fr/~cluet/WEBDB/paraboschi.ps>.
- [42] Stefano Ceri, Piero Fraternali, Stefano Paraboschi, “Data-Driven, One-To-One Web Site Generation for Data-Intensive Applications”, *Proc. of 25th Intl’ Conf. on Very Large Data Bases (VLDB’99)*, Edinburgh (September 1999), Scotland, Morgan Kaufmann, San Francisco, pp. 615–626, 1999.
- [43] Maria Elena Bonfigli, Giorgio Casadei, Paola Salomoni, “Adaptive Intelligent Hypermedia using XML” *Proc. of 15th ACM Symposium on Applied Computing (SAC 2000) – Volume 2*, Como (March 2000), Italy, ACM Press, New York, pp. 922–926, 2000.
- [44] Monica m.c. Schraefel, “Tuning In: a Link Rhetoric for Versionable Web Document” (Poster), *Proc. of 11th ACM Conf. on Hypertext (HYPERTEXT 2000)*, San Antonio (May/June 2000), TX, ACM Press, New York, 2000.
- [45] Stefano Ceri, Piero Fraternali, Aldo Bongio, “Web Modeling Language (WebML): A Modeling Language for Designing Web Sites”, *Computer Networks*, Vol. 33, No. 1–6 (Proc. of WWW9), pp. 137–157, June 2000.
- [46] Masahiro Hori, Goh Kondoh, Kouichi Ono, Shin’ichi Hirose, Sandeep K. Singhal, “Annotation-based Web Content Transcoding”, *Computer Networks*, Vol. 33, No. 1–6 (Proc. of WWW9), pp. 197–211, June 2000.
- [47] John Plaice, Paul Swoboda, Ammar Alammari, “Building Intensional Communities Using Shared Contexts” *Proc. of 3rd Intl’ Workshop on Distributed Communities on the Web (DCW 2000)*, Quebec City (June 2000), Quebec, LNCS Vol. 1830, Springer-Verlag, Heidelberg, pp. 55–64, 2000.
- [48] William W. Wadge, “Intensional Markup Language”, *Proc. of 3rd Intl’ Workshop on Distributed Communities on the Web (DCW 2000)*, Quebec City (June 2000), Quebec, LNCS Vol. 1830, Springer-Verlag, Heidelberg, pp. 82–89, 2000.
- [49] Yannis Stavarakas, Manolis Gergatsoulis, Panos Rondogiannis, “Multidimensional XML”, *Proc. of 3rd Intl’ Workshop on Distributed Communities on the Web (DCW 2000)*, Quebec City (June 2000), Quebec, LNCS Vol. 1830, Springer-Verlag, Heidelberg, pp. 100–109, 2000.
- [50] Monica m.c. Schraefel, “ConTexts: Adaptable Hypermedia”, *Proc. of Intl’ Conf. on Adaptive Hypermedia and Adaptive Web-Based Systems (AH 2000)*, Trento (August 2000), Italy, LNCS Vol. 1892, Springer-Verlag, Heidelberg, pp. 369–374, 2000.
- [51] Yannis Stavarakas, Manolis Gergatsoulis, Theodoros Mitakos, “Representing Context-Dependent Information Using Multidimensional XML”, *Proc. of 4th European Conf. on Research and Advanced Technology for Digital Libraries (ECDL 2000)*, Lisbon (September 2000), Portugal, LNCS Vol. 1923, Springer-Verlag, Heidelberg, pp. 368–371, 2000.
- [52] Angela Bonifati, Stefano Ceri, Piero Fraternali, Andrea Maurino, “Building Multi-device, Content-Centric Applications Using WebML and the W3I3 Tool Suite”, *Proc. of 2nd Intl’ Workshop on the World Wide Web and Conceptual Modeling (WCM2000)* (in conj. with ER 2000), Salt Lake City (October 2000), Utah LNCS Vol. 1921, Springer-Verlag, Heidelberg, pp. 64–75, 2000.

- [53] Marcus Flehmig, “Data-Driven, XML-Based Web Management in Highly Personalized Environments (Position Paper)”, *Proc. of Intl’ Workshop on Information Integration on the Web (WIIW 2001)*, Rio de Janeiro (April 2001), Brazil, pp. 81–88, 2001.
- [54] Fabiana Ruas, Wagner Meira Jr., Paulo Araújo, Flávia Ribeiro, “Modeling Web Site Personalization Strategies”, *Proc. of Intl’ Workshop on Information Integration on the Web (WIIW 2001)*, Rio de Janeiro (April 2001), Brazil, pp. 89–95, 2001.
- [55] Beat Signer, Michael Grossniklaus, Moira C. Norrie, “Java Framework for Database-Centric Web Site Engineering”, *Proc. of 4th Workshop on Web Engineering (WebE’2001)* (in conj. with WWW10), Hong Kong (May 2001), China, 2001.
- [56] Rune Hjelsvold, Subu Vdaygiri, Yves Léauté, “Web-based Personalization and Management of Interactive Video”, *Proc. of 10th World Wide Web Conf. (WWW10)*, Hong Kong (May 2001), China, ACM Press, New York, pp. 129–139, 2001.
- [57] Christian S. Jensen, Anders Friis-Christensen, Torben Bach Pedersen, Dieter Pfoser, Simonas Saltenis, Nectaria Tryfona, “Location-based Services: A Database Perspective”, *Proc. of 8th Scandinavian Research Conf. on Geographical Information Science (ScanGIS 2001)*, Ås (June 2001), Norway, Agricultural University of Norway, Ås, pp. 59–68, 2001.
- [58] Manolis Gergatsoulis, Yannis Stavrakas, Dimitri Karteris, “Incorporating Dimensions to XML and DTD”, *Proc. of 12th Intl’ Conf. on Database and Expert Systems Applications (DEXA 2001)*, Munich (September 2001), Germany, LNCS Vol. 2113, Springer-Verlag, Heidelberg, pp. 646–656, 2001.
- [59] Manolis Gergatsoulis, Yannis Stavrakas, Dimitri Karteris, Athina Mouzaki, Dimitris Sterpis, “A Web-based System for Handling Multidimensional Information through MXML”, *Proc. of 5th East-European Conference on Advances in Databases and Information Systems (ADBIS 2001)*, Vilnius (September 2001), Lithuania, LNCS Vol. 2151, Springer-Verlag, Heidelberg, pp. 352–365, 2001.
- [60] Mario Cannataro, Alfredo Cuzzocrea, Andrea Pugliese, “A Multidimensional Approach for Modelling and Supporting Adaptive Hypermedia Systems”, *Proc. of 2nd Intl’ Conf. on Electronic Commerce and Web Technologies (EC-Web 2001)*, Munich (September 2001), Germany, LNCS Vol. 2115, Springer-Verlag, Heidelberg, pp. 132–141, 2001.
- [61] Jin-Cheon Na, Richard Furuta, “Dynamic Documents: Authoring, Browsing, and Analysis Using a High-Level Petri Net-Based Hypermedia System”, *Proc. of 10th ACM Symposium on Document Engineering (DocEng ’01)* (in conj. with CIKM 2001), Atlanta (November 2001), GA, ACM Press, New York, pp. 38–47, 2001.
- [62] Stefano Ceri, Piero Fraternali, Aldo Bongio, Marco Brambilla, Sara Comai, Maristella Matera, *Designing Data-Intensive Web Applications*, Morgan Kaufmann, San Francisco, CA, 2002.
- [63] Ioannis T. Kassios, Monica m.c. Schraefel, “Noema: A Metalanguage for Scripting Versionable Hypertexts”, *Proc. of 4th Intl’ Conf. on Distributed Communities on the Web (DCW 2002)*, Sydney (April 2002), NSW, 2002, LNCS Vol. 2468, Springer-Verlag, Heidelberg, p. 228–239, 2002.
- [64] Yannis Stavrakas, Manolis Gergatsoulis, “Multidimensional Semistructured Data: Representing Context-Dependent Information on the Web”, *Proc. of 14th Intl’ Conf. on Advanced Information Systems Engineering (CAiSE 2002)*, Toronto (May 2002), Ontario, LNCS Vol. 2348, Springer-Verlag, Heidelberg, pp. 183–199, 2002.

- [65] Marco Brambilla, Sara Comai, Piero Fraternali, “Hypertext Semantics for Web Applications”, *Proc. of Natl’ Conf. on Advanced Database Systems (SEBD ’02)*, Portoferraio – Isola d’Elba (June 2002), Italy, Centro Stampa 2P, Florence, pp. 73–86, 2002.
- [66] Vassilis Zafeiris, Christos Doulkeridis, Yannis Stavarakas, Manolis Gergatsoulis, ”An Infrastructure for Manipulating Multidimensional Semistructured Data”, *Proc. of 1st Hellenic Data Management Symposium (HDMS 2002)*, Athens (July 2002), Greece, 2002.
- [67] Mario Cannataro, Alfredo Cuzzocrea, Andrea Pugliese, “XAHM: an Adaptive Hypermedia Model Based on XML”, *Proc. of 14th Intl’ Conf. on Software Engineering and Knowledge Engineering (SEKE 2002)*, Ischia (July 2002), Italy, ACM Press, New York, pp. 627–634, 2002.
- [68] Donatella Castelli, Carlo Meghini, Pasquale Pagano, “Foundations of a Multidimensional Query Language for Digital Libraries”, *Proc. of 6th European Conf. on Research and Advanced Technology for Digital Libraries (ECDL 2002)*, Rome (September 2002), Italy, LNCS Vol. 2458, Springer-Verlag, Heidelberg, pp. 251–265, 2002.
- [69] Richard Furuta, Jin-Cheong Na, “Applying caT’s Programmable Browsing Semantics to Specify World-Wide Web Documents that Reflect Place, Time, Reader, and Community”, *Proc. of ACM Symposium on Document Engineering (DocEng ’02)* (in conj. with CIKM 2002), McLean (November 2002), VA, 2002.
- [70] Moira C. Norrie, Alexios Palinginis, “From State to Structure: an XML Web Publishing Framework” (Short Paper), *Proc. of 15th Intl’ Conf. on Advanced Information Systems Engineering (CAiSE’03)*, Klagenfurt/Velden (June 2003), Austria, LNCS Vol. 2681, Springer-Verlag, Heidelberg, pp. 421–436, 2003.
- [71] Moira C. Norrie, Alexios Palinginis, “Empowering Databases for Context-Dependent Information Delivery”, *Proc. of Ubiquitous Mobile Information and Collaboration Systems (UMICS 2003)* (in conj. with CAiSE 2003), Klagenfurt/Velden (June 2003), Austria, 2003.
- [72] Moira C. Norrie, Alexios Palinginis, “Versions for Context Dependent Information Services”, *Proc. of 11th Intl’ Conf. on Cooperative Information Systems (CoopIS 2003)* (part of the “On The Move to Meaningful Internet Systems – Federated Conferences” OTM ’03), Catania (November 2003), Italy, LNCS Vol. 2888, Springer-Verlag, Heidelberg, pp. 503–515, 2003.
- [73] Rodrigo Giacomini Moro, Renata de Matos Galante, Carlos Alberto Heuser, “A Version Model for Supporting Adaptation of Web Pages”, *Proc. of 6th Intl’ Workshop on Web Information and Data Management (WIDM 2004)* (in conj. with CIKM 2004), Washington (*to be held November 2004*), DC.

In this list we should also add the special issue on “The Adaptive Web” of the *Communications of the ACM* (Vol. 45, No. 5, May 2002) and *most* of the papers presented at a series of conferences/workshops started in 2000, on “*Adaptive Hypermedia and Adaptive Web-Based Systems (AH)*”, including: AH’2000 (Trento, Italy, August 2000), AH’2001 (Aarhus, Denmark, August 2001) and AH’2002 (Malaga, Spain, May 2002). AH’2003 will have sessions proposed at three conferences (WWW’03 – Budapest, Hungary, May 2003; UM’03 – Johnstown, PA, June 2003; HT’03 – Nottingham, UK, August 2003). As indirect reference, links to the home pages and table of contents of the AH conferences can be found from the DBLP bibliography at URL <http://www.informatik.uni-trier.de/~ley/db/conf/ah/>. Proceedings have been published so far by Springer-Verlag (LNCS 1892, LNCS 2266, LNCS 2347).

*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

Several recent works are focused on the management of updates of Web resources like XML repositories. No time dimension nor versioning is usually considered.

- [1] Birgit Pröll, Werner Retschitzegger, Harald Sighart, Heinrich Starck, “Ready for Prime Time: Pre-Generation of Web Pages in TIScover”, *Proc. of 3rd Intl’ Workshop on The World Wide Web and Databases (WebDB 1999) – Informal Proceedings* (in conj. with SIGMOD 1999), Philadelphia (June 1999), PA, pp. 67–72, <http://www-rocq.inria.fr/~cluet/WEBDB/tiscover.ps>.
- [2] Birgit Pröll, Heinrich Starck, Werner Retschitzegger, Harald Sighart, “Ready for Prime Time: Pre-Generation of Web Pages in TIScover”, *Proc. of 8th ACM Intl’ Conf. on Information and Knowledge Management (CIKM ’99)*, Kansas City (November 1999), MO, ACM Press, New York, pp. 63–68, 1999.
- [3] Budi Surjanto, Norbert Ritter, Henrik Loeser, “XML Content Management Based on Object-Relational Database Technology”, *Proc. of 1st Intl’ Conf. on Web Information Systems Engineering (WISE 2000) – Volume I*, Hong Kong (June 2000), China, IEEE Computer Society Press, Los Alamitos, pp. 70–79, 2000.
- [4] Laurent Mignet, “Control of Changes of Semistructured Data” (*in French*), Ph.D. Thesis, CNAM, Paris, France, 2001.
- [5] Michael Schrefl, Elisabeth Kapsammer, Werner Retschitzegger, Birgit Pröll, “Self-Maintaining Web Pages - An Overview”, *Proc. of 12th Australasian Database Conf. (ADC ’01)*, Gold Coast (January 2001), Australia, IEEE Computer Society Press, Los Alamitos, pp. 83–90, 2001.
- [6] Torsten Grabs, Klemens Böhm, Hans-Jörg Schek, “Scalable Distributed Query and Update Service Implementations for XML Document Elements”, *Proc. of 11th Intl’ Workshop on Research Issues in Data Engineering: Document Management for Data Intensive Business and Scientific Applications (RIDE-DM ’01)* (in conj. with ICDE ’01), Heidelberg (April 2001), Germany, IEEE Computer Society Press, Los Alamitos, pp. 35–42, 2001.
- [7] Igor Tatarinov, Zachary G. Ives, Alon Y. Halevy, Daniel S. Weld, “Updating XML”, *Proc. of ACM Intl’ Conf. on Management of Data (SIGMOD 2001)*, Santa Barbara (May 2001), CA, ACM Press, New York, pp. 413–424, 2001.
- [8] Amélie Marian, Serge Abiteboul, Gréégory Cobena, Laurent Mignet, “Change-Centric Management of Versions in an XML Warehouse”, *Proc. of 27th Intl’ Conf. on Very Large Data Bases (VLDB ’01)*, Rome (September 2001), Italy, Morgan Kaufmann, San Francisco, pp. 581–590, 2001.
- [9] Emmanuel Pietriga, Jean-Yves Vion-Dury, Vincent Quint, “VXT: A Visual Approach to XML Transformations”, *Proc. of 10th ACM Symposium on Document Engineering (DocEng ’01)* (in conj. with CIKM 2001), Atlanta (November 2001), GA, ACM Press, New York, pp. 1–10, 2001.
- [10] Raymond K. Wong, “The Extended XQL for Querying and Updating Large XML Databases”, *Proc. of ACM Symposium on Document Engineering (DocEng ’01)* (in conj. with CIKM 2001), Atlanta (November 2001), GA, ACM Press, New York, pp. 95–104, 2001.
- [11] Maria Adriana V. L. Abrão, Béatrice Bouchou, Mírian Halfeld Ferrari Alves, Dominique Laurent, “Updating XML Data: The Constraints Propagation”, *Proc. of 6th Annual Meeting of the Ph.D. School on Health, Science and Technology*, University of Tours, France, May 2002.

- [12] Denio Duarte, Béatrice Bouchou, Mírian Halfeld Ferrari Alves, Dominique Laurent, “XML Views: Update and Validation”, *Proc. of 6th Annual Meeting of the Ph.D. School on Health, Science and Technology*, University of Tours, France, May 2002.
- [13] Raghav Kaushik, Philip Bohannon, Jeffrey F. Naughton, Pradeep Shenoy, “Updates for Structure Indexes”, *Proc. of 28th Conference on Very Large Data Bases (VLDB 2002)*, Hong Kong (August 2002), China, Morgan Kaufmann, San Francisco, pp. 239–250, 2002.
- [14] Sang-Kyun Kim, Myungcheol Lee, and Kyu-Chul Lee, “Immediate and Partial Validation Mechanism for the Conflict Resolution of Update Operations in XML Databases”, *Proc. of 3rd Intl’ Conf. on Web-Age Information Management (WAIM ’02)*, Beijing (August 2002), China, LNCS Vol. 2419, Springer-Verlag, Heidelberg, pp. 387–396, 2002.
- [15] Bintou Kane, Hong Su, Elke A. Rundensteiner, “Consistently Updating XML Documents Using a Incremental Constraint Check Queries”, *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. 39–50.
- [16] Torsten Grabs, Klemens Böhm, Hans-Jörg Schek, “XMLTM: Efficient Transaction Management for XML Documents”, *Proc. of 11th ACM Intl’ Conf. on Information and Knowledge Management (CIKM 2002)*, McLean (November 2002), VA, ACM Press, New York, pp. 142–152, 2002.
- [17] Franky Lam, Nicole Lam, Raymond K. Wong, “Efficient Synchronization for Mobile XML Data”, *Proc. of 11th ACM Intl’ Conf. on Information and Knowledge Management (CIKM 2002)*, McLean (November 2002), VA, ACM Press, New York, pp. 153–160, 2002.
- [18] Hong Su, Bintou Kane, Victor Chen, Cuong Diep, De Ming Guan, Jennifer Look, Elke A. Rundensteiner, “A Lightweight Constraint Check Framework for Consistently Updating XML Documents”, *Proc. of 4th Intl’ Workshop on Web Information and Data Management (WIDM 2002)* (in conj. with CIKM 2002), McLean (November 2002), VA, ACM Press, New York, pp. 1–8, 2002.
- [19] Béatrice Bouchou and Mírian Halfeld Ferrari Alves, “XML Dossiers and Update Operations: an Incremental Validation Method”, Technical Report, N. 270, LI/Université de Tours, 2003.
- [20] Li Lu, Guoren Wang, Mengchi Liu, “XML-RL Update Language”, *Proc. of 15th Intl’ Conf. on Advanced Information Systems Engineering – Short papers (CAiSE’03 Forum)*, Klagenfurt/Velden (June 2003), Austria, University of Maribor Press, Maribor, Slovenia, pp. 1–4, 2003.
- [21] Guoren Wang, Mengchi Liu, Li Lu, “Extending XML-RL with Update”, *Proc. of 7th Intl’ Database Engineering and Applications Symposium (IDEAS 2003)*, Hong Kong (July 2003), China, IEEE Computer Society Press, Los Alamitos, pp. 66–75, 2003.
- [22] Torsten Grabs, Hans-Jörg Schek, “PowerDB-XML: Scalable XML Processing with a Database Cluster”, in *Intelligent Search on XML Data: Applications, Languages, Models, Implementations and Benchmarks*, LNCS Vol. 2818, Springer-Verlag, Heidelberg, pp. 193–206, 2003.
- [23] Torsten Grabs, Hans-Jörg Schek, “PowerDB-XML: a Platform for Data-Centric and Document-Centric XML Processing”, *Proc. of XML Database Symposium (XSym 2003)* (in conj. with VLDB 2003), Berlin (September 2003), Germany, LNCS Vol. 2824, Springer-Verlag, Heidelberg, pp. 100–117, 2003.

- [24] Béatrice Bouchou and Mírian Halfeld Ferrari Alves, “Updates and Incremental Validation of XML Documents”, *Proc. of 9th Intl’ Workshop on Data Base Programming Languages (DBLP’03)*, Potsdam (September 2003), Germany, LNCS Vol. 2921, Springer-Verlag, Heidelberg, pp. 216–232, 2003.
- [25] Li Lu, Mengchi Liu, Guoren Wang, “XML-RL Update Language”, *Proc. of CAiSE 2003 Forum – Short Paper proceedings*, Klagenfurt/Velden (June 2003), Austria, WP Vol. 74, CEUR-WS, Aachen, Germany, 2003.
- [26] Guoren Wang, Mengchi Liu, Li Lu, “Extending XML-RL with Update”, *Proc. of Intl’ Database Engineering and Applications Symposium (IDEAS 2003)*, Hong Kong (July 2003), China, IEEE Computer Society Press, Los Alamitos, pp. 66–75, 2003.
- [27] Mengchi Liu, Li Lu, Guoren Wang, “A Declarative XML-RL Update Language”, *Proc. of 22nd Intl’ Conf. on Conceptual Modeling (ER2003)*, Chicago (October 2003), IL, LNCS Vol. 2813, Springer-Verlag, Heidelberg, pp. 506–519, 2003.
- [28] Ling Wang, Elke A. Rundensteiner, “On the Updatability of XML Views Published over Relational Data”, *Proc. of 23rd Intl’ Conf. on Conceptual Modeling (ER 2004)*, Shanghai (November 2004), China. LNCS Vol. 3288, Springer-Verlag, Heidelberg, pp. 795–809, 2004.
- [29] The XML:DB XUpdate Working Group Homepage, <http://www.xmldb.org/xupdate/>.
- [30] The XML:DB SiXDML Working Group Homepage, <http://www.xmldb.org/sixdml/>.
- [31] The Apache Xindice Homepage, <http://xml.apache.org/xindice/>.
- [32] The IBM DB2 XML Extender Homepage, <http://www-3.ibm.com/software/data/db2/extenders/xmlext/>.
- [33] The Oracle9i XML DB Homepage, <http://otn.oracle.com/tech/xml/xmldb/>.
- [34] The Sonic (formerly eXcelon) eXtensible Information Server Homepage, [http://www.sonicsoftware.com/products/additional\\_software/extensible\\_information\\_server/](http://www.sonicsoftware.com/products/additional_software/extensible_information_server/).
- [35] The Tamino XML Server Homepage, <http://www.softwareag.com/tamino/>.
- [36] The X-Hive/DB Homepage, <http://www.xhive.com/>.
- [37] The XMLGlobal GoXML DB Homepage, <http://www.xmlglobal.com/prod/db/>.

The last seven references concern commercial systems supporting native XML updates.

Several works specifically deal with the detection (and measurement) of changes in Internet/Web resources.

- [38] Fred Douglass, Thomas Ball, “Tracking and Viewing Changes on the Web”, *Proc. of USENIX Annual Technical Conf.*, San Diego (January 1996), CA, USENIX, Berkeley, pp. 165–176, 1996.
- [39] Thomas Ball, Fred Douglass, “An Internet Difference Engine and its Applications”, *Proc. of 41st IEEE Computer Society Intl’ Conf. (COMPCON ’96) – Digest of Papers*, Santa Clara (February 1996), CA, IEEE Computer Society Press, Los Alamitos, pp. 71–76, 1996.
- [40] Fred Douglass, Thomas Ball, Yih-Farn Chen, Eleftherios Koutsofios, “WebGUIDE: Querying and Navigating Changes in Web Repositories”, *Computer Networks*, Vol. 28. No. 7–11 (Proc. WWW5), pp. 1335–1344, 1996.

- [41] Elliot Berk, “HtmlDiff: A Differencing Tool for HTML Documents”, Student Project, COS 461, Princeton University, December 1996.
- [42] Fred Douglass, “Experiences with the AT&T Internet Difference Engine” (invited talk), *Proc. of 22nd Intl’ Conf. for the Resource Management & Performance Evaluation of Enterprise Computing System (CMG ’96)*, San Diego (December 1996), CA, CMG, Turnersville, NJ, p. 10, 1996.
- [43] David S. Rosenblum, Alexander L. Wolf, “A Design Framework for Internet-Scale Event Observation and Notification”, *Proc. of 6th European Conf. on Foundations of Software Engineering held jointly with 5th ACM SIGSOFT Symposium on Software Engineering*, Zurich (September 1997), Switzerland, ACM Press, New York, pp. 344–360, 1997.
- [44] Yih-Farn Chen, Eleftherios Koutsofios, “WebCiao: A Website Visualization and Tracking System”, *Proc. of World Conf. on the WWW and Internet (WebNet97)*, Toronto (October 1997), Ontario, AACE, Norfolk, VA, 1997.
- [45] Fred Douglass, Anja Feldmann, Balachander Krishnamurthy, Jeffrey C. Mogul, “Rate of Change and Other Metrics: a Live Study of the World Wide Web”, *Proc. of USENIX Symposium on Internet Technologies and Systems (USITS ’97)*, Monterey (December 1997), CA, USENIX, Berkeley, 1997.
- [46] Fred Douglass, Thomas Ball, Yih-Farn Chen, Eleftherios Koutsofios, “The AT&T Internet Difference Engine: Tracking and Viewing Changes on the Web”, *World Wide Web*, Vol. 1, No. 1, pp. 27–44, 1998.
- [47] Calton Pu, Ling Liu, “Update Monitoring: The CQ project” (invited paper), *Proc. of 2nd Intl’ Conf. on Worldwide Computing and Its Applications (WWCA ’98)*, Tsukuba (March 1998), Japan, LNCS Vol. 1368, Springer-Verlag, Heidelberg, pp 396–411, 1998.
- [48] Ling Liu, Calton Pu, Wei Tang, Dave Buttler, John Biggs, Paul Benninghoff, Wei Han, Fenghua Yu, “CQ: A Personalized Update Monitoring Toolkit”, *Proc. of ACM Intl’ Conf. on Management of Data (SIGMOD ’98) – Demonstrations*, Seattle (June 1998), WA, ACM Press, New York, pp. 547–549, 1998.
- [49] Santi Saeyor, Mitsuru Ishizuka, “WebBeholder: A Revolution in Tracking and Viewing Changes on The Web by Agent Community”, *Proc. of World Conf. on the WWW and Internet (WebNet98)*, Orlando (October 1998), FL, AACE, Norfolk, VA, 1998.
- [50] Ling Liu, Calton Pu, Wei Tang, “Conquer: A Continual Query System for Update Monitoring in the WWW”, *Intl’ Journal of Computer Systems, Science and Engineering*, Vol. 14, No. 2, pp. 99–112, 1999.
- [51] Francisco Curbera, David A. Epstein, “Fast Differentiation and Update of XML Data”, *Proc. of XML Application Developers Conf. (XTech’99)*, San Jose (Mar 1999), CA, GCA/IDEAlliance, Alexandria, VA, 1999.
- [52] Santi Saeyor, Mitsuru Ishizuka, “Multi-modal Presentation of Changes in Web Repositories”, *Proc. of World Conf. on Educational Multimedia, Hypermedia & Telecommunications (ED-MEDIA’99)*, Seattle (June 1999), WA, AACE, Norfolk, VA, 1999.
- [53] Santi Saeyor, Mitsuru Ishizuka, “Adaptive Changes Monitoring Service in Web Repositories Based on Agent Games”, *Proc. of World Conf. on Educational Multimedia, Hypermedia and Telecommunications (ED-MEDIA’99)*, Seattle (June 1999), WA, AACE, Norfolk, VA, pp. 1589–1590, 1999.

- [54] Santi Saeyor, Mitsuru Ishizuka, “Adaptive Service to Monitor Changes in Web Repositories Based on Game Analysis”, *Proc. of 3rd World Multiconf. on Systemics, Cybernetic and Information and 5th Intl’ Conf. on Information Systems Analysis and Synthesis (SCI-ISAS’99) – Volume V*, Orlando (July 1999), FL, IIS, Caracas, pp. 254–260, 1999.
- [55] Santi Saeyor, Mitsuru Ishizuka, “Formation of Cooperative Behavior among Information Agents in Web Repository Change Monitoring Service”, *Proc. 3rd Intl’ Conf. on Cooperative Information Agents (CIA ’99)*, Uppsala (July 1999), Sweden, LNCS Vol. 1652, Springer-Verlag, Heidelberg, pp. 101–112, 1999.
- [56] Ling Liu, Calton Pu, Wei Tang, “Continual Queries for Internet Scale Event-Driven Information Delivery”, *IEEE Trans. on Knowledge and Data Engineering* (special issue on “Web Technology”), Vol. 11, No. 4, pp. 610–628, July/August 1999.
- [57] Santi Saeyor, Mitsuru Ishizuka, “Cooperative Matchmaking of Requests Among Distributed Change Monitoring Service Agents”, *Proc. 1999 IEEE Pacific Rim Conf. on Communications, Computers and Signal Processing (PACRIM’99)*, Victoria (August 1999), BC, IEEE Press, Piscataway, NJ, pp. 266–269, 1999.
- [58] Santi Saeyor, Mitsuru Ishizuka, “Multi-modal Presentation of Changes in Web Repositories”, *Proc. of World Conf. on the WWW and Internet (WebNet99) – Volume 1*, Honolulu (October 1999), Hawaii, AACE, Norfolk, VA, pp. 544–549, 1999.
- [59] Carsten Lanquillon, Ingrid Renz, “Adaptive Information Filtering: Detecting Changes in Text Streams”, *Proc. of 8th ACM Intl’ Conf. on Information and Knowledge Management (CIKM ’99)*, Kansas City (November 1999), MO, ACM Press, New York, pp. 538–544, 1999.
- [60] Ling Liu, Calton Pu, Wei Tang, “Supporting Internet Applications beyond Browsing: Trigger Processing and Change Notification (Extended Abstract)”, *Proc. of 5th Intl’ Computer Science Conference – Internet Applications (ICSC ’99)*, Hong Kong (December 1999), China, LNCS Vol. 1749, Springer-Verlag, Heidelberg, pp. 294–304, 1999.
- [61] Sourav S. Bhowmick, Wee Keong Ng, Ee-Peng Lim, “Detecting and Representing Relevant Web Deltas Using Web Join”, *Proc. of 20th Intl’ Conf. on Distributed Computing Systems (ICDCS 2000)*, Taipei (April 2000), Taiwan, IEEE Computer Society Press, Los Alamitos, pp. 255–262, 2000.
- [62] Nahur M. Fonseca, Rodolfo S.F. Resende, Wagner Meira Jr., “Dynamic Aspects of Documents of the Brazilian Web”, *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. 133–137, 2000.
- [63] Ling Liu, Calton Pu, Wei Tang, “Correction to “Continual Queries for Internet Scale Event-Driven Information Delivery” ”, *IEEE Trans. on Knowledge and Data Engineering*, Vol. 12, No. 5, p. 861, September/October 2000.
- [64] Santi Saeyor, Mitsuru Ishizuka, “WebBeholder: A Source of Community Interests and Trends based on Cooperative Change Monitoring Service on the Web”, *Proc. of 26th Annual Conf. of the IEEE Industrial Electronics Society (IECON-2000) – Volume 3*, Nagoya (October 2000), Japan, IEEE Press, Piscataway, NJ, pp. 1656–1661, 2000.
- [65] Yih-Farn Chen, Fred Douglass, Huale Huang, Kiem-Pong Vo, “TopBlend: An Efficient Implementation of HtmlDiff in Java”, *World Conf. on the WWW and Internet (WebNet2000)*, San Antonio (November 2000), TX, AACE, Norfolk, VA, pp. 88–94, 2000.



- [66] Ling Liu, Calton Pu, Wei Tang, “WebCQ: Detecting and Delivering Information Changes on the Web”, *Proc. of 9th ACM Intl’ Conf. on Information and Knowledge Management (CIKM 2000)*, McLean (November 2000), VA, ACM Press, New York, pp. 512–519, 2000.
- [67] Benjamin Nguyen, Serge Abiteboul, Grégory Cobena, Laurent Mignet “Query Subscription in an XML Webhouse”, *Proc. of 1st DELOS Workshop on Information Seeking, Searching and Querying in Digital Libraries*, Zurich (December 2000), Switzerland, ERCIM, Sophia-Antipolis, pp. 109–114, 2000.
- [68] Santi Saeyor, Mitsuru Ishizuka, “Resource Management for WWW Change Monitoring Service Prototype based on Cooperative Agent Community”, *Proc. 3rd Intl’ Conf. on Information Networking (ICOIN-14)*, Hsingchu (January 2001), Taiwan, IEEE Computer Society Press, Los Alamitos, 2001.
- [69] Seung Jin Lim, Yiu-Kai Ng, “An Automated Change Detection Algorithm for HTML Documents Based on Semantic Hierarchies”, *Proc. of 17th Intl’ Conf. on Data Engineering (ICDE 2001)*, Heidelberg (April 2001), Germany, IEEE Computer Society Press, Los Alamitos, pp. 303–312, 2002.
- [70] Benjamin Nguyen, Serge Abiteboul, Grégory Cobena, Mihaï Preda, “Monitoring XML Data on the Web”, *Proc. of ACM Intl’ Conf. on Management of Data (SIGMOD 2001)*, Santa Barbara (May 2001), CA, ACM Press, New York, pp. 437–448, 2001.
- [71] David Buttler, Ling Liu, Calton Pu, Henrique Paques, Wei Han, Wei Tang, “OminiSearch: a Method for Searching Dynamic Content on the Web”, *Proc. of ACM Intl’ Conf. on Management of Data (SIGMOD 2001) – Demos*, Santa Barbara (May 2001), CA, ACM Press, New York, p. 604, 2001.
- [72] Robin La Fontaine, “A Delta Format for XML: Identifying Changes in XML Files and Representing the Changes in XML”, *Proc. of Intl’ Conf. XML Europe 2001*, Berlin (May 2001), Germany, IDEAlliance, Alexandria, 2001.
- [73] Avigdor Gal, Jonathan Eckstein, “Managing Periodically Updated Data in Relational Databases: A Stochastic Modeling Approach”, *Journal of the ACM*, Vol. 48, No. 6, pp. 1141–1183, 2001.
- [74] Lipyeow Lim, Min Wang, Sriram Padmanabhan, Jeffrey Scott Vitter, Ramesh C. Agarwal, “Characterizing Web Document Change”, *Proc. of 2nd Intl’ Conf. on Web-Age Information Management (WAIM 2001)*, Xi’an (July 2001), China, LNCS Vol. 2118, Springer-Verlag, Heidelberg, pp. 133–144, 2001.
- [75] Sergio Flesca, Filippo Furfaro, Elio Masciari, “Meaningful Change Detection on the Web”, *Proc. of 12th Intl’ Conf. on Database and Expert Systems Applications (DEXA 2001)*, Munich (September 2001), Germany, LNCS Vol. 2113, Springer-Verlag, Heidelberg, pp. 22–31, 2001.
- [76] Khoo Khyou Bun, Mitsuru Ishizuka, “Information Area Tracking and Changes Summarizing in WWW”, *Proc. of World Conf. on the WWW and Internet (WebNet 2001)*, Orlando (October 2001), FL, AACE, Norfolk, VA, pp. 680–685, 2001.
- [77] Grégory Cobena, Serge Abiteboul, Amélie Marian, “Detecting Changes in XML Documents”, *Proc. of 18th Intl’ Conf. on Data Engineering (ICDE 2002)*, San Jose (February 2002), CA, IEEE Computer Society Press, Los Alamitos, pp. 41–52, 2002. Also in *Proc. of 17th Journées Bases de Données Avancées (BDA 2001)*, Agadir (October 2001), Morocco, 2001.
- [78] Grégory Cobena, Talel Abdessalem, Yassine Hinnach, “A Comparative Study for XML Change Detection”, Technical Report, Verso Rep. No. 221, INRIA, Rocquencourt, France, 2002.
- [79] Norman S. Matloff, “Estimation of Internet File-Access/ Modification Rates from Incomplete Data”, Technical Report, Dept. of Computer Science, University of California at Davis, CA, 2002.

- [80] Ling Liu, Wei Tang, David Buttler, Calton Pu, “Information Monitoring on the Web: A Scalable Solution”, *World Wide Web*, Vol. 5, No. 4, pp. 263–304, 2002.
- [81] Junghoo Cho, Alexandros Ntoulas, “Effective Change Detection Using Sampling”, *Proc. of 28th Conference on Very Large Data Bases (VLDB 2002)*, Hong Kong (August 2002), China, Morgan Kaufmann, San Francisco, pp. 514–525, 2002.
- [82] Serge Abiteboul, “Issues in Monitoring the Web” (invited talk), *Proc. of 13th Intl’ Conf. on Database and Expert Systems Applications (DEXA 2002)* Aix-en-Provence (September 2002), France, LNCS Vol. 2453, Springer-Verlag, Heidelberg, pp. 1–8, 2002.
- [83] Greégory Cobena, “Change Management of Semi-structured Data on the Web”, Ph.D. Thesis, École Polytechnique, Palaiseau, France, 2003.
- [84] Yuan Wang, David J. DeWitt, Jin-Yi Cai, “X-Diff: An Effective Change Detection Algorithm for XML Documents”, *Proc. of 19th Intl’ Conf. on Data Engineering (ICDE 2003)*, Bangalore (March 2003), India, IEEE Computer Society Press, Los Alamitos, 2003.
- [85] Sourav S. Bhowmick, Sanjay Kumar Madria, Wee Keong Ng, “Detecting and Representing Relevant Web Deltas in WHOWEDA”, *IEEE Trans. on Knowledge and Data Engineering*, Vol. 15, No. 2, pp. 423–441, March/April 2003.
- [86] Wei Tang, Ling Liu, Calton Pu, “Trigger Grouping: A Scalable Approach to Large Scale Information Monitoring”, *Proc. of 2nd IEEE Intl’ Symposium on Network Computing and Applications (NCA 2003)*, Cambridge (April 2003), MA, IEEE Computer Society Press, Los Alamitos, pp. 148–155, 2003.
- [87] Dennis Fetterly, Mark Manasse, Marc Najork, Janet L. Wiener, “A Large-Scale Study of the Evolution of Web Pages”, *Proc. of 12th Intl’ Conf. on World Wide Web (WWW 2003)*, Budapest (May 2003), Hungary, ACM Press, New York, pp. 669–678, 2003.
- [88] Naveen Pandrangi, Jyoti Jacob, Anoop Sanka, Sharma Chakravarthy, “WebVigiL: User Profile-Based Change Detection for HTML/XML Documents”, *Proc. of 20th British Natl’ Conf. on Databases (BNCOD 2003)*, Coventry (July 2003), UK, LNCS Vol. 2712, Springer-Verlag, Heidelberg, pp. 38–57, 2003.
- [89] Junghoo Cho, Hector Garcia-Molina, “Estimating Frequency of Change”, *ACM Trans. on Internet Technology*, Vol. 3, No. 3, pp. 256–290, August 2003.
- [90] Sergio Flesca, Elio Masciari, “Efficient and Effective Web Change Detection”, *Data & Knowledge Engineering*, Vol. 46, No. 2, pp. 203–224, August 2003.
- [91] Jyoti Jacob, Alpa Sachde, Sharma Chakravarthy, “CX-DIFF: A Change Detection Algorithm for XML Content and Change Presentation Issues for WebVigiL”, *Proc. of 1st Intl’ Workshop on XML Schema and Data Management (XSDM 03)* (in conj. with ER 2003), Chicago (October 2003), USA, LNCS Vol. 2814, Springer-Verlag, Heidelberg, pp. 273–284, 2003.
- [92] Sanjay Kumar Madria, Yan Chen, Sourav S. Bhowmick, “DiffXML: Change Detection in XML Data”, *Proc. of 11th Intl’ Conf. on Cooperative Information Systems (CoopIS 2003)* (part of the “On The Move Federated Conferences” OTM ’03), Catania (November 2003), Italy.

- [93] Lakshmith Ramaswamy, Arun Iyengar, Ling Liu, Fred Douglass, “Techniques for Efficient Fragment Detection in Web Pages” (Poster), *Proc. of 12th ACM International Conference on Information and Knowledge Management (CIKM '03)*, New Orleans (November 2003), LA, ACM Press, New York, pp. 516–519.
- [94] Yan Chen, Sanjay Kumar Madria, Sourav S. Bhowmick, “DiffXML: Change Detection in XML Data”, *Proc. of 9th Intl' Conf. on Database Systems for Advances Applications (DASFAA 2004)* Jeju Island (March 2004), Korea, LNCS Vol. 2973, Springer-Verlag, Heidelberg, pp. 289–301, 2004.
- [95] Jyoti Jacob, Alpa Sachde, Sharma Chakravarthy, “CX-DIFF: A Change Detection Algorithm for XML Content and Change Presentation Issues for WebVigil”, *Data & Knowledge Engineering*, 2004 (*in press*).
- [96] The AT&T Internet Difference Engine Homepage,  
<http://www.research.att.com/sw/tools/aide/>.
- [97] The ChangeDetection Free Service Homepage, <http://www.changedetection.com/>.
- [98] The HtmlDiff Homepage, <http://www.htmldiff.com/>.
- [99] The NetMind Homepage, <http://www.netmind.com>.
- [100] The TracerLock Homepage, <http://www.peacefire.org/tracerlock>.
- [101] The Versim Differencing Toolkit Homepage, <http://www.versim.com/>.
- [102] The WebBeholder Homepage, <http://www.miv.t.u-tokyo.ac.jp/~santi/research/>.
- [103] The Website News Homepage, <http://www.research.att.com/~chen/web-demo/>.
- [104] The WebSprite Homepage, <http://www.websprite.com>.
- [105] The Webwhacker Homepage, <http://www.webwhacker.com>.
- [106] The XML TreeDiff Homepage, <http://www.alphaworks.ibm.com/tech/xmltreediff>.
- [107] The XML Diff and Merge Tool Homepage,  
<http://www.alphaworks.ibm.com/tech/xmldiffmerge>.
- [108] The XyDiff Homepage,  
<http://www-rocq.inria.fr/~cobena/cdrom/www/xydiff/eng.htm>.
- [109] The DeltaXML.com Homepage, <http://www.deltaxml.com/>.
- Some works also considered modification or evolution of the *schema* of semistructured data.
- [110] Roger L. Costello, John C. Schneider, “Challenge of XML Schemas - Schema Evolution”, The “XML Schemas: Best Practices” Homepage, 2000, <http://www.xfront.org/EvolvableSchemas.html>.
- [111] Li Chen, Kajal T. Claypool, Elke A. Rundensteiner, “SERFing the Web: The Re-Web Approach for Web Re-structuring”, *World Wide Web*, Vol. 3, No. 2, pp. 95–109, 2000.
- [112] Adriana Marotta, Regina Motz, Raúl Ruggia, “Managing Source Schema Evolution in Web Warehouses”, *Proc. of Intl' Workshop on Information Integration on the Web (WIIW 2001)*, Rio de Janeiro (April 2001), Brazil, pp. 148–155, 2001.

- [113] Hong Su, Diane Kramer, Li Chen, Kajal T. Claypool, Elke A. Rundensteiner, “XEM: Managing the Evolution of XML Documents”, *Proc. of 11th Intl’ Workshop on Research Issues in Data Engineering: Document Management for Data Intensive Business and Scientific Applications (RIDE-DM ’01)* (in conj. with ICDE ’01), Heidelberg (April 2001), Germany, IEEE Computer Society Press, Los Alamitos, pp. 103–110, 2001.
- [114] Elisa Bertino, Giovanna Guerrini, Marco Mesiti, Luigi Tosetto, “Evolving a Set of DTDs According to a Dynamic Set of XML Documents”, *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. 45–66, 2002.
- [115] Bernadette Farias Lóscio and Ana Carolina Salgado, “Evolution of XML-based Mediation Queries in a Data Integration Systems”, *Proc. of 3rd Intl’ Workshop on Evolution and Change in Data Management (ECDM 2004)* (in conj. with ER 2004), Shanghai (November 2004), China. LNCS Vol. 3289, Springer-Verlag, Heidelberg, pp. 402–414, 2004.

## 2.6 Time in Web Warehousing

Several papers, including many from the previous section, deal with the management of (virtual) Web warehouses or (materialized) views over semistructured data. Temporal aspects, either related to data modifications or to information contents, are often considered. These range from the (valid) time dimension involved in multidimensional data modeling and OLAP, to security issues and maintenance of temporal consistency of the information in the warehouse. Similar aspects are also involved in the maintenance of dynamically generated Web pages.

- [1] Dragomir R. Radev, “RENDEZVOUS: A WWW Synchronization System”, *Proc. of 2nd World Wide Web Conference (WWW2)*, Chicago (October 1994), IL, 1994, <http://archive.ncsa.uiuc.edu/SDG/IT94/IT94Info.html>.
- [2] Chengjie Liu, Pei Cao, “Maintaining Strong Cache Consistency in the World Wide Web”, *Proc. of 17th Intl’ Conf. on Distributed Computing Systems (ICDCS ’97)*, Baltimore (May 1997), MA, IEEE Computer Society Press, Los Alamitos, pp. 12–21, 1997.
- [3] Lukas C. Faulstich, Myra Spiliopoulou, Volker Linnemann, “WIND: A Warehouse for Internet Data”, *Proc. 15th British Conf. on Databases (BNCOD ’97)*, London (July 1997), England, LNCS Vol. 1271, Springer-Verlag, Heidelberg, pp. 169–183, 1997.
- [4] Antonio Si, Hong Va Leong, “On Page Coherence for Dynamic HTML Pages” (Poster), *Proc. of 2nd ACM International Conference on Digital Libraries (DL ’97)*, Philadelphia (July 1997), PA, ACM Press, New York, pp. 263–264, 1997.
- [5] Gerhard Knolmayer, Thomas Buchberger, “Maintaining Temporal Integrity of World Wide Web Pages”, *Proc. of IFIP TC-11 Working Group 11.5 1st Working Conf. on Integrity and Internal Control in Information Systems – Vol. 1: Increasing the Confidence in Information Systems*, Zurich (December 1997), Switzerland, IFIP 109, Kluwer Academic Publishers, Boston, pp. 43–63, 1997.
- [6] Antonio Si, Hong Va Leong, Stanley M.T. Yau, “Maintaining Page Coherence for Dynamic HTML Pages”, *Proc. of 13th ACM symposium on Applied Computing (SAC ’98)*, Atlanta (February/March 1998), GA, ACM Press, New York, pp. 767–773, 1998.

- [7] Pei Cao, Chengjie Liu, “Maintaining Strong Cache Consistency in the World Wide Web”, *IEEE Trans. on Computers*, Vol. 47, No. 4, pp. 445–457, 1998.
- [8] Arturo Crespo, Hector Garcia-Molina, “Archival Storage for Digital Libraries”, *Proc. of 3rd ACM Intl’ Conf. on Digital Libraries (ACM DL ’98)*, Pittsburgh (June 1998), PA, ACM Press, New York, pp. 69–78, 1998.
- [9] Serge Abiteboul, Jason McHugh, Michael Rys, Vasilis Vassalos, Janet L. Wiener, “Incremental Maintenance for Materialized Views over Semistructured Data”, *Proc. of 24rd Intl’ Conf. on Very Large Data Bases (VLDB’98)*, New York (August 1998), Morgan Kaufmann, San Francisco, pp. 38–49, 1998.
- [10] Lukas C. Faulstich, Myra Spiliopoulou, “Building HyperView Wrappers for Publisher Web-sites”, *Proc. of 2nd European Conf. on Digital Libraries (ECDL’98)*, Heraclion – Crete (September 1998), Greece, LNCS Vol. 1513, Springer-Verlag, Heidelberg, pp. 115–134, 1998.
- [11] Ken C. K. Lee, Hong Va Leong, Antonio Si, “Incremental Maintenance for Dynamic Database-Derived HTML Pages in Digital Libraries”, *Proc. of 7th ACM Intl’ Conf. on Information and Knowledge Management (CIKM ’98)*, Bethesda (November 1998), MA, ACM Press, New York, pp. 20–29, 1998.
- [12] Raghav Srinivasan, Chao Liang, Krithi Ramamritham, “Maintaining Temporal Coherency of Virtual Data Warehouses”, *Proc. of 19th IEEE Symposium on Real-Time Systems (RTSS’98)*, Madrid (December 1998), Spain, IEEE Computer Society Press, Los Alamitos, pp. 60–70, 1998.
- [13] Serge Abiteboul, “On Views and XML”, *Proc. of 18th ACM SIGACT-SIGMOD-SIGART Symposium on Principles of Database Systems (PODS ’99)*, Philadelphia (June 1999), PA, ACM Press, New York, pp. 1–9, 1999.
- [14] Serge Abiteboul, Bernd Amann, Sophie Cluet, Adi Eyal, Laurent Mignet, Tova Milo, “Active Views for Electronic Commerce”, *Proc. of 25th Intl’ Conf. on Very Large Data Bases (VLDB’99)*, Edinburgh (September 1999), Scotland, Morgan Kaufmann, San Francisco, pp. 138–149, 1999.
- [15] Serge Abiteboul, Vincent Aguilera, Sébastien Ailleret, Bernd Amann, Sophie Cluet, Brendan Hills, Frédéric Hubert, Jean-Claude Mamou, Amélie Marian, Laurent Mignet, Tova Milo, Cassio Souza dos Santos, Bruno Tessier, Anne-Marie Vercoustre, “XML Repository and Active Views Demonstration”, *Proc. of 25th Intl’ Conf. on Very Large Data Bases (VLDB’99) – Demonstrations*, Edinburgh (September 1999), Scotland, Morgan Kaufmann, San Francisco, pp. 742–745, 1999.
- [16] Serge Abiteboul, “On Views and XML”, *ACM SIGMOD Record*, Vol. 28, No. 4, pp. 30–38, December 1999.
- [17] Annika Hinze, Daniel Faensen, “A Unified Model of Internet Scale Alerting Services”, *Proc. of 5th Intl’ Computer Science Conference – Internet Applications (ICSC ’99)*, Hong Kong (December 1999), China, LNCS Vol. 1749, Springer-Verlag, Heidelberg, pp. 284–293, 1999.
- [18] Lukas C. Faulstich, Myra Spiliopoulou, “Building HyperView Wrappers for Publisher Web-sites”, *Intl’ Journal on Digital Libraries* (special issue “In the Tradition of Alexandrian Scholars”), Vol. 3, NO. 1, pp. 3–18, 2000.
- [19] Brian Cooper, Hector Garcia-Molina, “InfoMonitor: Unobtrusively Archiving a World Wide Web Server”, Technical Report 2000-15, Dept. of Computer Science, Stanford University, 2000, <http://dbpubs.stanford.edu/>.

- [20] Yan Zhu, Christof Bornhövd, Doris Sautner, Alejandro P. Buchmann, “Materializing Web Data for OLAP and DSS”, Technical Report DVS-TR00-1, Dept. of Computer Science, TU Darmstadt, Germany, 2000.
- [21] Junghoo Cho, Hector Garcia-Molina, “Synchronizing a Database to Improve Freshness”, *Proc. of ACM Intl’ Conf. on Management of Data (SIGMOD 2000)*, Dallas (May 2000), TX, ACM Press, New York, pp. 117–128, 2000.
- [22] Jianjun Chen, David J. DeWitt, Feng Tian, Yuan Wang, “NiagaraCQ: A Scalable Continuous Query System for Internet Databases”, *Proc. of ACM Intl’ Conf. on Management of Data (SIGMOD 2000)*, Dallas (May 2000), TX, ACM Press, New York, pp. 379–390, 2000.
- [23] Yan Zhu, Christof Bornhövd, Doris Sautner, Alejandro P. Buchmann, “Materializing Web Data for OLAP and DSS”, *Proc. of 1st Intl’ Conf. on Web-Age Information Management (WAIM 2000)*, Shanghai (June 2000), China, LNCS Vol. 1846, Springer-Verlag, Heidelberg, pp. 201–214, 2000.
- [24] Arturo Crespo, Hector Garcia-Molina, “Modeling Archival Repositories for Digital Libraries”, *Proc. of 4th European Conf. on Digital Libraries (ECDL 2000)*, Lisbon (September 2000), Portugal, LNCS Vol. 1923, Springer-Verlag, Heidelberg, pp. 190–205, 2000.
- [25] Junghoo Cho, Hector Garcia-Molina, “The Evolution of the Web and Implications for an Incremental Crawler”, *Proc. of 26th Intl’ Conf. on Very Large Data Bases (VLDB ’2000)*, Cairo (September 2000), Egypt, Morgan Kaufmann, San Francisco, pp. 200–209, 2000.
- [26] Miranda Chan, Hong Va Leong, Antonio Si, “Incremental Update to Aggregated Information for Data Warehouses over Internet”, *Proc. of 3rd ACM Intl’ Workshop on Data warehousing and OLAP (DOLAP 2000)*, McLean (November 2000), VA, ACM Press, New York, pp. 57–64, 2000.
- [27] Laurent Mignet, Mihai Preda, Serge Abiteboul, Bernd Amann, Amélie Marian, “Acquisition and Maintenance of XML Data from the Web”, Technical Report, Verso Rep. No. 188, INRIA, Rocquencourt, France, 2001.
- [28] Haifeng Liu, Wee Keong Ng, Ee-Peng Lim, “Improving the Fairness of Timely Refresh of Web Views” (Poster), *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. 152–153, 2001.
- [29] Pavan Deolasee, Amol Katkar, Ankur Panchbudhe, Krithi Ramamritham, Prashant J. Shenoy, “Adaptive Push-Pull of Dynamic Web Data: Better Resiliency, Scalability and Coherency”, *Proc. of 10th World Wide Web Conference (WWW10)*, Hong Kong (May 2001), China, ACM Press, New York, pp. 265–274, 2001.
- [30] Luis Francisco-Revilla, Frank M. Shipman III, Richard Furuta, Unmil Karadkar, Avital Arora, “Managing Change on the Web”, *Proc. of ACM/IEEE Joint Conf. on Digital Libraries (JCDL 2001)*, Roanoke (June 2001), VA, ACM Press, New York, pp. 67–76, 2001.
- [31] Daniel Faensen, Lukas Faulstich, Heinz Schweppe, Annika Hinze, Alexander Steidinger, “Hermes: a Notification Service for Digital Libraries”, *Proc. of ACM/IEEE Joint Conf. on Digital Libraries (JCDL 2001)*, Roanoke (June 2001), VA, ACM Press, New York, pp. 373–380, 2001.
- [32] Yan Zhu, Christof Bornhövd, Alejandro P. Buchmann, “Data Transformation for Warehousing Web Data” (invited paper), *Proc. of 3rd Intl’ Workshop on Advanced Issues of E-Commerce and Web-Based information Systems (WECWIS’01)*, San Jose (June 2001), CA,

- [33] Serge Abiteboul, Omar Benjelloun, Tova Milo, “Towards a Flexible Model for Data and Web Services Integration”, *Proc. Intl’ Workshop on Foundations of Models for Information Integration (FMII-2001) – 10th Intl’ Workshop on Foundations of Models and Languages for Data and Objects (FMLDO)*, Viterbo (September 2001), Italy, 2001, <http://www.fmldo.org/FMII-2001/proceedings.html> (to be published by Springer-Verlag).
- [34] Serge Abiteboul, Omar Benjelloun, Tova Milo, Ioana Manolescu, Roger Weber, “Active XML: A Data-Centric Perspective on Web Services”, Technical Report, Verso Rep. No. 213, INRIA, Rocquencourt, France, 2002.
- [35] Yan Zhu, Alejandro Buchmann, “Evaluating and Selecting Web Sources as External Information Resources of a Data Warehouse”, Technical Report DVS-TR02-1, Dept. of Computer Science, TU Darmstadt, Germany, 2002.
- [36] Vijayalakshmi Atluri, Avigdor Gal, “An Authorization Model for Temporal and Derived Data: Securing Information Portals”, *ACM Trans. on Information and System Security*, Vol. 5, No. 1, pp. 62–94, 2002.
- [37] Manish Bhide, Krithi Ramamritham, Prashant J. Shenoy, “Efficiently Maintaining Stock Portfolios Up-to-Date on the Web”, *Proc. of 12th International Workshop on Research Issues on Data Engineering: Engineering E-Commerce/E-Business Systems (RIDE-2EC ’02)* (in conj. with ICDE ’02), San Jose (February 2002), CA, IEEE Computer Society Press, Los Alamitos, pp. 60–65, 2002.
- [38] Shetal Shah, Krithi Ramamritham, Prashant J. Shenoy, “Maintaining Coherency of Dynamic Data in Cooperating Repositories”, *Proc. of 28th Conference on Very Large Data Bases (VLDB 2002)*, Hong Kong (August 2002), China, Morgan Kaufmann, San Francisco, pp. 526–537, 2002.
- [39] Kurt Maly, Mohammad Zubair, Michael L. Nelson, “Repository Synchronization in the OAI Framework”, *Proc. of ACM/IEEE Joint Conf. on Digital Libraries (JCDL 2003)*, Houston (May 2003), TX, IEEE Computer Society Press, Los Alamitos, pp. 191–198, 2003.
- [40] Junghoo Cho, Hector Garcia-Molina, “Effective Page Refresh Policies for Web Crawlers”, *ACM Trans. on Database Systems*, 2003 (in press).

Temporal aspects, detection and management of changes, updating and versioning of Web resources have also been considered together in the context of comprehensive projects involving repositories/warehouses of web sources<sup>1</sup>. These projects are introduced and described in the references which follow.

- [41] Ee-Peng Lim, Wee Keong Ng, Fengqiong Qin, Xiangzhou Ye, “A Data Warehousing System for Web Information”, *Proc. of 1st Asian Digital Library Workshop*, Hong Kong (August 1998), China, 1998.
- [42] Sourav S. Bhowmick, Wee Keong Ng, Ee-Peng Lim, “Web Warehousing: Design and Issues”, *Intl’ Workshop on Data Warehousing and Data Mining (DWDM ’98)* (in conj. with ER ’98), Singapore (November 1998), LNCS Vol. 1552, Springer-Verlag, Heidelberg, pp. 93–104, 1998.
- [43] Yan Zhu, “A Framework for Warehousing the Web Contents”, *Proc. of 5th Intl’ Computer Science Conference – Internet Applications (ICSC ’99)*, Hong Kong (December 1999), China, LNCS Vol. 1749, Springer-Verlag, Heidelberg, pp. 83–92, 1999.
- [44] Jun Hirai, Sriram Raghavan, Hector Garcia-Molina, Andreas Paepcke, “WebBase: a Repository of Web pages”, *Computer Networks*, Vol. 33, No. 1–6 (Proc. WWW9), pp. 277–293, June 2000.

<sup>1</sup>Also some of the papers in the previous section actually deal with more than one such aspects; for the sake of classification, their taxonomy is based on what has been judged the main focus, though sometimes somehow arbitrarily.

- [45] Lucie Xyleme (pseudonym for the design team), “A Dynamic Warehouse for XML Data of the Web”, *IEEE Data Engineering Bulletin*, Vol. 24, No. 2, pp. 40–47, June 2001.
- [46] Serge Abiteboul, Sophie Cluet, Guy Ferran, Marie-Christine Rousset, “The Xyleme Project”, *Computer Networks*, Vol. 39, No. 3, pp. 225–238, 2002.
- [47] The WebBase Project Homepage,  
<http://www-diglib.stanford.edu/~testbed/doc2/WebBase/>.
- [48] The Whoweda Project Homepage,  
<http://pipe.cais.ntu.edu.sg:8000/~whoweda/overview.htm>.
- [49] The Xyleme Project Homepage, <http://www-rocq.inria.fr/verso/xyleme/>.

## 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.

- [1] James E. Pitkow, Krishna A. Bharat, “Webviz: A Tool For World-Wide Web Access Log Analysis”, *Proc. of 1st World Wide Web Conf. (WWW1)*, Geneva (May 1994), Switzerland, pp. 271–277, Elsevier Science BV, Amsterdam, 1994.
- [2] Chris Johnson, “Time and the Web: Representing and Reasoning about Temporal Properties of Interaction with Distributed Systems”, *Proc. of 10th BCS-HCI Conf. on People and Computers (HCI’95)*, Huddersfield (August 1995), UK, Cambridge University Press, pp. 39–50, 1995.
- [3] Ming-Syan Chen, Jong Soo Park, Philip S. Yu, “Efficient Data Mining for Path Traversal Patterns in Distributed Systems”, *Proc. of 16th Intl’ Conf. on Distributed Computing Systems (ICDCS ’96)*, Hong Kong (May 1996), China, IEEE Computer Society Press, Los Alamitos, pp. 385–393, 1996.
- [4] Mark S. Ackerman, Daniel Billsus, Scott Gaffney, Seth Hettich, Gordon Khoo, Dong Joon Kim, Raymond Klefstad, Charles Lowe, Alexius Ludeman, Jack Muramatsu, Kazuo Omori, Michael J. Pazzani, Douglas Semler, Brian Starr, Paul Yap, “Learning Probabilistic User Profiles: Applications for Finding Interesting Web Sites, Notifying Users of Relevant Changes to Web Pages, and Locating Grant Opportunities”, *AI Magazine*, Vol. 18, No. 2, pp. 47–56, 1997.
- [5] Cyrus Shahabi, Amir M. Zarkesh, Jafar Adibi, Vishal Shah, “Knowledge Discovery from Users Web-Page Navigation”, *Proc. of 7th International Workshop on Research Issues on Data Engineering (RIDE ’97)* (in conj. with ICDE ’97), Birmingham (February 1997), England, IEEE Computer Society Press, Los Alamitos, pp. 20–29, 1997.
- [6] Michael J. Pazzani, Daniel Billsus, “Learning and Revising User Profiles: The Identification of Interesting Web Sites”, *Machine Learning*, Vol. 27, No. 3, pp. 313–331, 1997.
- [7] Linda Tauscher, Saul Greenberg, “Revisitation Patterns in World Wide Web Navigation”, *Proc. of Intl’ ACM Conf. on Human Factors in Computing Systems (CHI ’97)*, Atlanta (March 1997), GA, ACM Press, New York, pp. 399–406, 1997.



- [8] Andruid Kerne, “CollageMachine: Temporality and Indeterminacy in Media Browsing via Interface Ecology”, *Proc. of Intl’ ACM Conf. on Human Factors in Computing Systems (CHI ’97) – Interactive Posters*, Atlanta (March 1997), GA, ACM Press, New York, pp. 238–239, 1997.
- [9] Robert W. Cooley, Bamshad Mobasher, Jaideep Srivastava, “Web Mining: Information and Pattern Discovery on the World Wide Web”, *Proc. of 9th IEEE Intl’ Conf. on Tools with Artificial Intelligence (ICTAI’97)*, Newport Beach (November 1997), CA, IEEE Computer Society Press, Los Alamitos, pp. 558–567, 1997.
- [10] Kun-Lung Wu, Philip S. Yu, Allen Ballman, “SpeedTracer: A Web Usage Mining and Analysis Tool”, *IBM Systems Journal*, Vol. 37, No. 1, pp. 89–105, 1988.
- [11] Ming-Syan Chen, Jong Soo Park, Philip S. Yu, “Efficient Data Mining for Path Traversal Patterns”, *IEEE Trans. on Knowledge and Data Engineering*, Vol. 10, No. 2, pp. 209–221, 1998.
- [12] Myra Spiliopoulou, Lukas Faulstich, “WUM - A Tool for WWW Utilization Analysis”, *Proc. of 1st Intl’ Workshop on The World Wide Web and Databases (WebDB ’98) – Selected Papers* (in conj. with EDBT 1998), Valencia (March 1998), Spain, LNCS Vol. 1590, Springer-Verlag, pp. 184–203, 1998.
- [13] Alex G. Büchner, Maurice D. Mulvenna, “Discovering Internet Marketing Intelligence through Online Analytical Web Usage Mining”, *SIGMOD Record*, Vol. 27, No. 4, pp. 54–61, 1998.
- [14] Osmar R. Zaiane, Man Xin, Jiawei Han, “Discovering Web Access Patterns and Trends by Applying OLAP and Data Mining Technology on Web Logs”, *Proc. of 5th IEEE Forum on Research and Technology Advances in Digital Libraries (ADL ’98)*, Santa Barbara (April 1998), CA, IEEE Computer Society Press, Los Alamitos, pp. 19–29, 1998.
- [15] Alex G. Büchner, Maurice D. Mulvenna, “Discovering Internet Marketing Intelligence through Online Analytical Web Usage Mining”, *ACM SIGMOD Record*, Vol. 27, No. 4, pp. 54–61, 1998.
- [16] Robert W. Cooley, Bamshad Mobasher, Jaideep Srivastava, “Data Preparation for Mining World Wide Web Browsing Patterns”, *Knowledge and Information Systems*, Vol. 1, No. 1, pp. 5–32, 1999.
- [17] Olfa Nasraoui, Raghu Krishnapuram, Anupam Joshi, “Mining Web Access Logs Using a Fuzzy Relational Clustering Algorithm based on a Robust Estimator” (Poster), *Proc. of 8th Intl’ WWW Conf. (WWW8) – Posters*, Toronto (May 1999), Ontario, 1999, <http://www8.org/>.
- [18] Olfa Nasraoui, Raghu Krishnapuram, Anupam Joshi, “Relational Clustering Based on a New Robust Estimator with Applications to Web Mining”, *Proc. of 18th North American Fuzzy Information Society (NAFIPS ’99)* Syracuse (June 1999), NY, pp. 705–709, 1999.
- [19] Myra Spiliopoulou, Lukas C. Faulstich, Karsten Winkler, “A Data Miner Analyzing the Navigational Behaviour of Web Users”, *Proc. of Workshop on Machine Learning in User Modelling* (in conj. with ACAI ’99), Chania – Crete, (July 1999), Greece.
- [20] Olfa Nasraoui, Hichem Frigui, Raghu Krishnapuram, Anupam Joshi, “Mining Web Access Logs Using Relational Competitive Fuzzy Clustering”, *Proc. of 8th Intl’ Fuzzy Systems Association World Congress (IFSA 99)*, Taipei (August 1999), China, LNCS Vol. 1677, Springer-Verlag, Heidelberg, pp. 892–901, 1999.
- [21] Florent Masseglia, Pascal Poncelet, Rosine Cicchetti, “WebTool: An Integrated Framework for Data Mining”, *Proc. of 10th Intl’ Conf. on Database and Expert Systems Applications (DEXA 1999)*, Florence (August/September 1999), Italy, LNCS Vol. 1677, Springer-Verlag, Heidelberg, pp. 892–901, 1999.

- [22] Myra Spiliopoulou, “Data Mining for the Web” (Tutorial), *Proc. of 3rd European Conf. on Principles and Practice of Knowledge Discovery in Databases (PKDD’99)*, Prague (September 1999), Czech Republic, LNAI Vol. 1704, Springer-Verlag, Heidelberg, pp. 588–589, 1999.
- [23] James E. Pitkow, Peter Pirolli, “Mining Longest Repeating Subsequences to Predict World Wide Web Surfing”, *Proc. of 2nd USENIX Symposium on Internet Technologies and Systems (USITS’99)*, Boulder (October 1999), Colorado.
- [24] Karuna P. Joshi, Anupam Joshi, Yelena Yesha, Raghu Krishnapuram, “Warehousing and Mining Web Logs”, *Proc. of 2nd Workshop on Web Information and Data Management (WIDM’99)* (in conj. with CIKM ’99), Kansas City (November 1999), MO, ACM Press, New York, pp. 63–68, 1999.
- [25] Dwi H. Widyantoro, Thomas R. Ioerger, John Yen, “An Adaptive Algorithm for Learning Changes in User Interests”, *Proc. of 8th ACM Intl’ Conf. on Information and Knowledge Management (CIKM ’99)*, Kansas City (November 1999), MO, ACM Press, New York, pp. 405–412, 1999.
- [26] Robert W. Cooley, “Discovery and Applications of Usage Patterns from Web Data”, PhD Thesis, University of Minnesota, 2000.
- [27] Vinodkumar P. Kizhakke, “Mir: A Tool For Visual Presentation Of Web Access Behavior”, Master Thesis, University of Florida, Gainesville, 2000.
- [28] Bryan Wong, Gary Marsden,, “Using Access Information in the Dynamic Visualisation of Web Sites”, Technical Report, CS00-18-00, Dept. of Computer Science, University of Cape Town, South Africa, 2000.
- [29] Jaideep Srivastava, Robert W. Cooley, Mukund Deshpande, Pang-Ning Tan, “Web Usage Mining: Discovery and Applications of Usage Patterns from Web Data”, *SIGKDD Explorations*, Vol. 1, No. 2, pp. 12–23, 2000.
- [30] Olfa Nasraoui, Hichem Frigui, Raghu Krishnapuram, Anupam Joshi, “Extracting Web User Profiles Using Relational Competitive Fuzzy Clustering”, *Intl’ Journal on Artificial Intelligence Tools*, Vol. 9, No. 4, pp. 509–526, 2000.
- [31] Sheng-Tun Li, “Web Mining for Discovering Spatio-Temporal Patterns”, *Proc. of ICDCS Workshop of Knowledge Discovery and Data Mining in the World-Wide Web 2000*, Taipei (April 2000), Taiwan, pp. F58–F64, 2000.
- [32] Karuna P. Joshi, Anupam Joshi, Raghu Krishnapuram, “On Mining Web Access Logs”, *Proc. of Workshop on Research Issues in Data Mining and Knowledge Discovery (DMKD 2000)* (in conj. with SIGMOD 2000), Dallas (May 2000), TX, ACM Press, New York, pp. 63–69, 2000.
- [33] Igor V. Cadez, David Heckerman, Christopher Meek, Padhraic Smyth, Steven White, “Visualization of Navigation Patterns on a Web Site Using Model Based Clustering”, *Proc. of 6th ACM SIGKDD Intl’ Conf. on Knowledge Discovery and Data Mining (KDD 2000)*, Boston (August 2000), MA, ACM Press, New York, pp. 280-284, 2000.
- [34] Florent Masseglia, Pascal Poncelet, Maguelonne Teisseire, “Web Usage Mining: How to Efficiently Manage New Transactions and New Clients” *Proc. of 4th European Conf. on Principles and Practice of Knowledge Discovery in Databases (PKDD 2000)*, Lyon (September 2000), France, LNCS Vol. 1910, Springer-Verlag, Heidelberg, pp. 530–535, 2000.

- [35] Juhnyoung Lee, Mark Podlaseck, “Visualization and Analysis of Clickstream Data of Online Stores with a Parallel Coordinate System”, Electronic Edition (Springer LINK) *Proc. of 1st Intl’ Conf. on Electronic Commerce and Web Technologies (EC-Web 2000)*, London (September 2000), England, LNCS Vol. 1875, Springer-Verlag, Heidelberg, pp. 145–154, 2000.
- [36] José Borges, Mark Levene, “An Heuristic to Capture Longer User Web Navigation Patterns”, *Proc. of 1st Intl’ Conf. on Electronic Commerce and Web Technologies (EC-Web 2000)*, London (September 2000), England, LNCS Vol. 1875, Springer-Verlag, Heidelberg, pp. 155–164, 2000.
- [37] Jesper Andersen, Anders Giversen, Allan H. Jensen, Rune S. Larsen, Torben Bach Pedersen, and Janne Skyt, “Analyzing Clickstreams Using Subsessions”, *Proc. of 3rd ACM Intl’ Workshop on Data Warehousing and OLAP (DOLAP 2000)*, Washington (November 2000), DC, ACM Press, New York, pp. 25–32, 2000.
- [38] Janne Skyt, “Analyzing Clickstreams Using Subsessions”, in *Specification-based Techniques for the Reduction of Temporal and Multidimensional Data* (Ch. 5), Ph.D. Thesis, Dept. of Computer Science, Aalborg University, Denmark, 2001.
- [39] Bruce J. McKenzie, Andy Cockburn, “An Empirical Analysis of Web Page Revisitation”, *Proc. of 34th Annual Hawaii Intl’ Conf. on System Sciences (HICSS-34) – Track 5*, Maui (January 2001), Hawaii, IEEE Computer Society Press, Los Alamitos, p. 5019, 2001.
- [40] Charles X. Ling, Jianfeng Gao, Huajie Zhang, Weining Qian, HongJiang Zhang, “Mining Generalized Query Patterns from Web Logs”, *Proc. of 34th Annual Hawaii Intl’ Conf. on System Sciences (HICSS-34) – Track 5*, Maui (January 2001), Hawaii, IEEE Computer Society Press, Los Alamitos, p. 5020, 2001.
- [41] Harry Hochheiser, Ben Shneiderman, “Using Interactive Visualizations of WWW Log Data to Characterize Access Patterns and Inform Site Design”, *Journal of the American Society for Information Science and Technology*, Vol. 52, No. 4, pp. 331–343, 2001.
- [42] Jon Becher, Ron Kohavi, “E-Commerce and Clickstream Mining” (Tutorial), *Proc. of 1st SIAM Intl’ Workshop on Web Mining (SDM ’01)* (in conj. with SDM ’01), Chicago (April 2001), IL, SIAM, Philadelphia, 2001.
- [43] Bettina Berendt, Bamshad Mobasher, Myra Spiliopoulou, John Wiltshire, “Measuring the Accuracy of Sessionizers for Web Usage Analysis”, *Proc. of 1st SIAM Intl’ Workshop on Web Mining* (in conj. with SDM ’01), Chicago (April 2001), IL, SIAM, Philadelphia, pp. 7–14, 2001.
- [44] Paulo Batista, Mário J. Silva, “Web Access Mining form an On-line Newspaper Logs”, *Proc. of 12th Intl’ Meeting of the Euro Working Group on Decision Support Systems (EWG-DSS 2001)*, Cascais (May 2001), Portugal, 2001.
- [45] Andy Cockburn, Bruce J. McKenzie, “What Do Web Users Do? An Empirical Analysis of Web Use”, *Intl’ Journal of Human Computer Studies*, Vol. 54, No. 6, pp. 903–922, June 2001.
- [46] H. Cenk Ozmutlu, Amanda Spink, “Time-Based Analysis of Search Data Logs”, *Proc. of 2nd Intl’ Conf. on Internet Computing (IC’2001)*, Las Vegas (June 2001), NV, CSREA Press, Las Vegas, pp. 41–46, 2001.
- [47] Pavel Berkhin, Jonathan D. Becher, Dee Jay Randall, “Interactive Path Analysis of Web Site Traffic”, *Proc. of ACM SIGKDD Intl’ Conf. on Knowledge Discovery and Data Mining (KDD ’01)*, San Francisco (August 2001), CA, ACM Press, New York, pp. 441–419, 2001.

- [48] Ernesto Damiani, Barbara Oliboni, Elisa Quintarelli, Letizia Tanca, “Modeling Users’ Navigation History”, *Proc. of Intl’ Workshop on Intelligent Techniques for Web Personalization (ITWP ’01)* (in conj. with IJCAI-01), Seattle (August 2001), WA, 2001.
- [49] Ron Kohavi, “Mining E-Commerce Data: The Good, the Bad, and the Ugly” (invited talk at Industrial Track), *Proc. of 7th ACM SIGKDD Intl’ Conf. on Knowledge Discovery and Data Mining (KDD ’01)*, San Francisco (August 2001), CA, ACM Press, New York, pp. 8–13, 2001.
- [50] Steffan Baron, Myra Spiliopoulou, “Monitoring Change in Mining Results”, *Proc. of 3rd Intl’ Conf. on Data Warehousing and Knowledge Discovery (DaWaK ’01)*, Munich (September 2001), Germany, LNCS Vol. 2114, Springer-Verlag, Heidelberg, pp. 51–60, 2001.
- [51] Cyrus Shahabi, Farnoush Banaei Kashani, Javed Faruque, Adil Faisal, “Feature Matrices: A Model for Efficient and Anonymous Web Usage Mining”, *Proc. of 2nd Intl’ Conf. on Electronic Commerce and Web Technologies (EC-Web 2001)*, Munich (September 2001), Germany, LNCS Vol. 2115, Springer-Verlag, Heidelberg, pp. 280–294, 2001.
- [52] Florent Masseglia, Maguelonne Teisseire, Pascal Poncelet, “Real Time Web Usage Mining: A Heuristic Based Distributed Miner”, *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. 288–297, 2001.
- [53] Florent Masseglia, Maguelonne Teisseire, Pascal Poncelet, “Real Time Web Usage Mining: A Heuristic Based Distributed Miner”, *Proc. of 12 Intl’ Workshop on Research Issues in Data Engineering: Engineering E-Commerce/E-Business Systems (RIDE-2EC 2002)*, San Jose (February 2002), CA, IEEE Computer Society Press, Los Alamitos, pp. 169–174, 2002.
- [54] Joseph Fong, Jianhan Zhu, “Online Web Mining Transactions Association Rules Using Frame Metadata Model”, *Journal of Applied System Studies* (special issue on “WEB Information Systems Applications”), Vol. 3, No. 2, 2002.
- [55] Jian Pei, Jiawei Han, Behzad Mortazavi-Asl, Hua Zhu, “Mining Access Patterns Efficiently from Web Logs”, *Proc. of 4th Pacific-Asia Conf. on Knowledge Discovery and Data Mining (PAKDD 2000)*, Kyoto (April 2000), Japan, LNCS Vol. 1805, Springer-Verlag, Heidelberg, pp. 396–407, 2000.
- [56] Paulo Batista, Mário J. Silva, “Mining Web Access Logs of an On-line Newspaper”, *Proc. of 2nd Intl’ Workshop on Recommendation and Personalization in eCommerce (RPeC’02)* (in conj. with AH 2002), Malaga (May 2002), Spain, University of Malaga, 2002.
- [57] Søren E. Jespersen, Jesper Thorhauge, Torben Bach Pedersen, “A Hybrid Approach to Web Usage Mining”, *Proc. of 4th Intl’ Conf. on Data Warehousing and Knowledge Discovery (DaWaK ’02)*, Aix-en-Provence (September 2002), France, LNCS Vol. 2454, Springer-Verlag, Heidelberg, pp. 73–82, 2002.
- [58] Devanshu Dhyani, Sourav S. Bhowmick, Wee Keong Ng, “Modelling and Predicting Web Page Accesses Using Burrell’s Model”, *Proc. of 3rd Intl’ Conf. on E-Commerce and Web Technologies (EC-Web 2002)*, Aix-en-Provence (September 2002), France, LNCS Vol. 2455, Springer-Verlag, Heidelberg, pp. 172–181, 2002.
- [59] Marcos André Gonçalves, Ming Luo, Rao Shen, Mir Farooq Ali, Edward A. Fox, “An XML Log Standard and Tool for Digital Library Logging Analysis”, *Proc. of 6th European Conf. on Research and Advanced Technology for Digital Libraries (ECDL 2002)*, Rome (September 2002), Italy, LNCS Vol. 2458, Springer-Verlag, Heidelberg, pp. 129–143, 2002.

- [60] Robert W. Cooley, “The Use of Web Structure and Content to Identify Subjectively Interesting Web Usage Patterns”, *ACM Trans. on Internet Technology*, Vol. 3, No. 2, pp. 93–116, May 2003.
- [61] Zhixiang Chen, Ada Wai-Chee Fu, Frank Chi-Hung Tong, “Optimal Algorithms for Finding User Access Sessions from Very Large Web Logs”, *World Wide Web*, Vol. 6, No. 3, pp. 259–279, September 2003.
- [62] Mathias Géry, M. Hatem Haddad, “Evaluation of Web Usage Mining Approaches for User’s Next Request Prediction”, *Proc. of 5th Intl’ Workshop on Web Information and Data Management (WIDM 2003)* (in conj. with CIKM 2003), New Orleans (November 2003), LA, ACM Press, New York, pp. 74–81, 2003.
- [63] Søren E. Jespersen, Torben Bach Pedersen, Jesper Thorhauge, “Evaluating the Markov Assumption for Web Usage Mining”, *Proc. of 5th Intl’ Workshop on Web Information and Data Management (WIDM 2003)* (in conj. with CIKM 2003), New Orleans (November 2003), LA, ACM Press, New York, pp. 82–89, 2003.
- [64] Richard Wheeldon, Mark Levene, “The Best Trail Algorithm for Assisted Navigation of Web Sites”, *Proc. of 1st Latin American Web Congress (LA-WEB’03)*, Santiago (November 2003), Chile, IEEE Computer Society Press, Los Alamitos, p. 166, 2003.
- [65] Maged El-Sayed, Carolina Ruiz, Elke A. Rundensteiner, “FS-Miner: Efficient and Incremental Mining of Frequent Sequence Patterns in Web logs”, *Proc. of 6th Intl’ Workshop on Web Information and Data Management (WIDM 2004)* (in conj. with CIKM 2004), Washington (*to be held November 2004*), DC.
- [66] Hongyu Liu, Evangelos Milios, Jeannette Janssen, “Probabilistic Models for Focused Web Crawling”, *Proc. of 6th Intl’ Workshop on Web Information and Data Management (WIDM 2004)* (in conj. with CIKM 2004), Washington (*to be held November 2004*), DC.
- [67] Qingzhao Tan, Yiping Ke, Wilfred Ng, “WUML: A Web Usage Manipulation Language for Querying Web Log Data” *Proc. of 23rd Intl’ Conf. on Conceptual Modeling (ER 2004)*, Shanghai (November 2004), China. LNCS Vol. 3288, Springer-Verlag, Heidelberg, pp. 567–581, 2004.

This list should also include *most* of the papers presented at the workshop series on “*Web Usage Analysis and User Profiling (WEBKDD)*”, held in conjunction with KDD Conferences: WEBKDD’99 (San Diego, CA, August 1999), WEBKDD’00 (Boston, MA, August 2000), WEBKDD’01 (San Francisco, CA, August 2001), WEBKDD’02 (Edmonton, Alberta, July 2002), WEBKDD’03 (Washington, DC, August 2003) and WEBKDD’04 (Seattle, WA, August 2004). For the sake of brevity, we provide an indirect reference: links to the home pages and table of contents of the WEBKDD workshops can be found from the KDD page (URL <http://www.informatik.uni-trier.de/~ley/db/conf/kdd/>) in the DBLP bibliography. Extended versions of papers presented at WEBKDD 2000 are also contained in the special issue on “Web Mining” of *Data Mining and Knowledge Discovery* (Vol. 6, No. 1, January 2002, edited by Kohavi, Masand, Spiliopoulou & Srivastava). Another related special issue of the journal (Vol. 5, No. 1/2, January 2001, edited by Kohavi & Provost) was devoted to “Applications of Data Mining to Electronic Commerce”. A workshop on “Web Data Mining” was held at the “*1st SIAM Intl’ Conf. on Data Mining*” (Chicago, IL, April 2001) followed by a workshop on “Web Analytics” in conjunction with the second edition (Arlington, VA, April 2002), and a special session on “Web Mining” was organized at the *2003 Intl’ Conf. on Internet Computing* (Las Vegas, NV, June 2003). Moreover, two special sessions on “Webclickstream analysis” have been organized at the “*Data Mining 2002*” Conference (Bologna, Italy, September 2002). Finally, a list of pointers to “Web Mining and Web Usage Mining” software tools can be found at URL <http://www.kdnuggets.com/software/web.html>.

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

- [68] Peter Doemel, “WebMap - A Graphical Hypertext Navigation Tool”, *Proc. of 2nd Intl’ World Wide Web Conf. (WWW2)*, Chicago (October 1994), IL, pp. 785–789, 1994, <http://archive.ncsa.uiuc.edu/SDG/IT94/IT94Info.html>.
- [69] Eric Z. Ayers, John T. Stasko, “Using Graphic History in Browsing the World Wide Web”, Technical Report, GIT-CC-95-12, College of Computing, Georgia Institute of Technology, Atlanta, Ga, March 1995.
- [70] Sougata Mukherjea, James D. Foley, “Visualizing the World-Wide Web with the Navigational View Builder”, *Computer Networks and ISDN Systems*, Vol. 27, No. 6 (Proc. of WWW3), pp. 1075–1087, 1995.
- [71] Eric Z. Ayers, John T. Stasko, “Using Graphic History in Browsing the World Wide Web”, *Proc. of 4th Intl’ World Wide Web Conf. (WWW4)*, Boston (December 1995), MA, <http://www.w3.org/Conferences/WWW4/>.
- [72] Linda Tauscher, “Evaluating History Mechanisms: An Empirical Study of Reuse Patterns in World Wide Web Navigation”, MSc Thesis, Dept. of Computer Science, University of Calgary, AL, 1996.
- [73] Steve Jones, Andy Cockburn, “A Study of Navigational Support Provided by World Wide Web Browsing Applications”, *Proc. of 7th ACM Conf. on Hypertext (Hypertext’96)*, Washington (March 1996), DC, ACM Press, New York, p. 161–169, 1996.
- [74] Carlos Baquero, Jorge Portugal Andrade, “Web Core - Forward and Backward Browsing in a Multi-grain Web Representation” (Poster), *Proc. of 5th Intl’ World Wide Web Conf. (WWW5)*, Paris (May 1996), France, 1996.
- [75] Linda Tauscher, Saul Greenberg, “How People Revisit Web Pages: Empirical Findings and Implications for the Design of History Systems”, *Intl’ Journal of Human-Computer Studies*, Vol. 47, No. 1, pp. 97–137, 1997.
- [76] Udi Manber, Michael Smith, Burra Gopal, “WebGlimpse – Combining Browsing and Searching”, *Proc. of USENIX Annual Technical Conf.*, Anaheim, (January 1997), CA, USENIX, Berkeley, pp. 195–206, 1997.
- [77] Ron R. Hightower, Laura T. Ring, Jonathan I. Helfman, Benjamin B. Bederson, James D. Hollan, “Graphical Multiscale Web Histories: A Study of PadPrints”, *Proc. of ACM Intl’ Conf. on Hypertext (Hypertext’98)*, Pittsburgh (June 1998), PA, ACM Press, New York, pp. 58–65, 1998.
- [78] Hiroshi Sawai, Hayato Ohwada, Fumio Mizoguchi, “Designing a browser with the function of ”WebMap””, *Proc. of 12th Annual Conf. of Japanese Society for Artificial Intelligence*, Waseda (June 1998), Japan, Waseda University, 1998.
- [79] Emmanuel Frécon, Gareth Smith, “WEBPATH – A Three Dimensional Web History”, *Proc. of IEEE Symposium on Information Visualization (InfoVis ’98)*, Research Triangle Park (October 1998), NC, IEEE Computer Society Press, Los Alamitos, pp. 3–10, 1998.
- [80] Hiroshi Sawai, Hayato Ohwada, Fumio Mizoguchi, “Incorporating a Navigation Tool into a WWW Browser”, *Proc. of 1st Intl’ Conf. on Discovery Science*, Fukuoka (December 1998), Japan, LNCS Vol. 2490, Springer-Verlag, Heidelberg, pp. 453–454, 1998.

- [81] Soumen Chakrabarti, David Gibson, Kevin S. McCurley, “Surfing the Web Backwards”, *Computer Networks*, Vol. 31, No. 11–16 (Proc. of WWW8), pp. 1679–1693, May 1999.
- [82] Saul Greenberg, Andy Cockburn, “Getting Back to Back: Alternate Behaviors for a Web Browser’s Back Button”, *Proc. of 5th Annual Human Factors and the Web Conference*, Gaithersburg (June 1999), MD, NIST, Gaithersburg, 1999.
- [83] Andy Cockburn, Saul Greenberg, Bruce McKenzie, Michael Jasonsmith, Shaun Kaasten, “WebView: A Graphical Aid for Revisiting Web Pages”, *Proc. of Australian Conference on Human Computer Interaction (OZCHI’99)*, Wagga Wagga (November 1999), Australia, 1999.
- [84] Shaun Kaasten, Saul Greenberg, “Designing an Integrated Bookmark / History System for Web Browsing”, *Proc. of Workshop on History Keeping in Computer Applications*, College Park (December 1999), MD, University of Maryland, College Park, 1999.
- [85] Andy Cockburn, Saul Greenberg, “Issues of Page Representation and Organisation in Web Browsers Revisitation Tools”, *Australian Journal of Information Systems*, Vol. 7, No. 2, pp. 120–127, May 2000.
- [86] Ronald Fagin, Anna R. Karlin, Jon M. Kleinberg, Prabhakar Raghavan, Sridhar Rajagopalan, Ronitt Rubinfeld, Madhu Sudan, Andrew Tomkins, “Random Walks with “Back Buttons” (Extended Abstract), *Proc. of 32nd Annual ACM Symposium on Theory of Computing (STOC 2000)*, Portland (May 2000), OR, ACM Press, New York, pp. 484–493, 2000.
- [87] Ralph A. Grayson, K. M. George, “A Persistent History Navigation Assistant”, *Proc. of 2nd Intl’ Conf. on Internet Computing (IC 2000)*, Las Vegas (June 2000), NV, CSREA Press, Las Vegas, pp. 41–46, 2000.
- [88] Rajiv Gandhi, Benjamin B. Bederson, Girish Kumar, Ben Shneiderman, “Domain Name Based Visualization of Web Histories in a Zoomable User Interface”, *Proc. of 11th Intl’ Workshop on Database and Expert Systems Applications (DEXA Workshop 2000)*, London (September 2000), England, IEEE Computer Society Press, Los Alamitos, pp. 591–598, 2000.
- [89] Shaun Kaasten, “Integrating Back, History and Bookmarks in Web Browsers”, Master Thesis, Department of Computer Science, University of Calgary, AL, 2001.
- [90] Shaun Kaasten, Saul Greenberg, “Integrating Back, History and Bookmarks in Web Browsers”, *ACM Conference of Human Factors in Computing Systems (CHI ’01) – Extended Abstracts*, Seattle (March/April 2001), WA, ACM Press, New York, pp. 379–380, 2001.
- [91] Tamer Nadeem, Bill Killam, “A Study of Three Browser History Mechanisms for Web Navigation”, *Proc. of Intl’ Conf. on Information Visualisation (IV 2001)*, London (July 2001), England, IEEE Computer Society Press, Los Alamitos, pp. 13–21, 2001.
- [92] Andy Cockburn, Bruce J. Mckenzie, Michael Jasonsmith, “Pushing Back: Evaluating a New Behaviour for the Back and Forward Buttons in Web Browsers”, *Intl’ Journal of Human Computer Studies*, Vol. 57, No. 5, pp. 397–414, 2002.

The temporal dimension explicitly used for historical queries in Web warehouses concerns the time the warehouse is built. Hence, it corresponds to the navigation time with respect to the source Web sites (but also to the “transaction” time in the warehousing system). It was also called *visible time* by some authors.

- [93] Yinyan Cao, Ee-Peng Lim, Wee Keong Ng, “Storage Management of a Historical Web Warehousing System”, *Proc. of 11th Intl’ Conf. on Database and Expert Systems Applications (DEXA 2000)*, London (September 2000), England, LNCS Vol. 1873, Springer-Verlag, Berlin, pp. 457–466, 2000.
- [94] Yinyan Cao, Ee-Peng Lim, Wee Keong Ng, “On Warehousing Historical Web Information”, *Proc. of 19th Intl’ Conf. on Conceptual Modeling (ER 2000)*, Salt Lake City (October 2000), Utah, LNCS Vol. 1920, Springer-Verlag, Heidelberg, pp. 253–266, 2000.
- [95] Ee-Peng Lim, Wee Keong Ng, “A Warehousing-based Digital Library Architecture for Web Information”, *Proc. of 3rd Intl’ Conf. on Asian Digital Library*, Seoul (December 2000), Korea, 2000.
- [96] Daniel Gomes, João Campos, Mário J. Silva, “Versus: A Model for a Web Repository”, *Proc. of 4th Natl’ Conf. on Computer Networks (CRC’01)*, Covilhã (November 2001), Portugal, 2001.
- [97] Walter Ebner, “Temporal Web Management” (*in German*), Dr.rer.soc.oec. Thesis, Wirtschaftsuniversität, Vienna, Austria, 2002.
- [98] Daniel Gomes, João Campos, Mário J. Silva, “Versus: A Web Repository”, *Proc. of Workshop on Distributed Data & Structures (WDAS-2002)*, Paris (March 2002), France, 2002.
- [99] João Campos, “Versus: a Web Data Repository with Time Support”, Master Thesis, Faculty of Sciences, University of Lisbon, Portugal, September 2002
- [100] Juan Manuel Pérez, Mara José Aramburu Cabo, Rafael Berlanga Llavori, “XRL: A XML-Based Query Language for Advanced Services in Digital Libraries”, *Proc. of 13th Intl’ Conf. on Database and Expert Systems Applications (DEXA 2002)* Aix-en-Provence (September 2002), France, LNCS Vol. 2453, Springer-Verlag, Heidelberg, pp. 300–309, 2002.
- [101] Kjetil Nørnvåg, “Temporal XML Data Warehouses: Challenges and Solutions”, *Proc. of Workshop on Knowledge Foraging for Dynamic Networking of Communities and Economies*, Shiraz (October 2002), Iran, 2002.
- [102] Yinyan Cao, Ee-Peng Lim, Wee Keong Ng, “Data Model for Warehousing Historical Web Information”, *Information & Software Technology*, Vol. 45, No. 6, pp. 315–334, 2003.

Furthermore, we have to reference here also the various Internet archiving initiatives, consisting in building large archival libraries of Web pages, by storing periodic backup copies of Web sites. Such an archive—e.g. the “Internet Archive” featuring the *WayBackMachine*— can be provided with a temporal search engine and, in practice, represents a Web warehouse with support of transaction time (which corresponds to the navigation time the Web pages were accessed to be copied). The following (incomplete) references can also be used as starting points for the retrieval of further information on a topic gaining a growing interest, not only in the scientific community. A series of international workshops (co-located with ECDL conferences) on “*Web Archiving*” also started in 2001, whereas an international conference on “*Preservation and Long Term Accessibility of Digital Materials*” was held in York, England, December 2000.

- [103] Brewster Kahle, “Preserving the Internet”, *Scientific American*, pp. 82–84, March 1997 (also republished in the April 2002 issue).
- [104] Jun Rekimoto, “Time-machine Computing: A Time-centric Approach for the Information Environment”, *Proc. of 12th Annual ACM Symposium on User Interface Software and Technology (UIST ’99)*, Asheville (November 1999), NC, ACM Press, New York, pp. 45–54, 1999.



- [105] Valerie C. Chavez-Demoulin, Armin S. A. Roehrl, R. Alexander Roehrl, Anna Weinberg, "The WEB Archives: A Time-machine in Your Pocket!", *Proc. of The Internet Archive Colloquium 2000*, San Francisco (March 2000), CA, 2000.
- [106] Allan Arvidson, Krister Persson, Johan Mannerheim, "The Kulturarw3 Project - The Royal Swedish Web Archiw3e - An Example of "Complete" Collection of Web Pages", *Proc. of 66th Annual Conf. of Intl' Federation of Library Association (IFLA66)*, Jerusalem (August 2000), Israel, 2000.
- [107] William Y. Arms, Roger Adkins, Cassy Ammen, Allene Hayes, "Collecting and Preserving the Web: The Minerva Prototype", *RLG DigiNews*, Vol. 5, No. 2, April 2001.
- [108] Juha Hakala, "Collecting and Preserving the Web: Developing and Testing the NEDLIB Harvester", *RLG DigiNews*, Vol. 5, No. 2, April 2001.
- [109] Warwick Cathro, Colin Webb and Julie Whiting, "Archiving the Web: The PANDORA Archive at the National Library of Australia", *Proc. Conf. on Preserving the Present for the Future - Strategies for the Internet*, Copenhagen (June 2001), Denmark, 2001.
- [110] Vicky Reich, David S. H. Rosenthal, "LOCKSS: A Permanent Web Publishing and Access System", *D-Lib Magazine*, Vol. 7, No. 6, June 2001, <http://www.dlib.org/>.
- [111] Serge Abiteboul, Grégory Cobena, Julien Masanes, Gerald Sedrati, "A First Experience in Archiving the French Web", *Proc. of 6th European Conf. on Research and Advanced Technology for Digital Libraries (ECDL 2002)*, Rome (September 2002), Italy, LNCS Vol. 2458, Springer-Verlag, Heidelberg, pp. 1–15, 2002.
- [112] Andreas Rauber, Andreas Aschenbrenner, Oliver Witvoet, "Austrian On-Line Archive Processing: Analyzing Archives of the World Wide Web", *Proc. of 6th European Conf. on Research and Advanced Technology for Digital Libraries (ECDL 2002)*, Rome (September 2002), Italy, LNCS Vol. 2458, Springer-Verlag, Heidelberg, pp. 16–31, 2002.
- [113] The Digital Preservation Coalition Homepage, <http://www.dpconline.org/>.
- [114] The Internet Archive Homepage, <http://www.archive.org>.
- [115] The Kulturarw<sup>3</sup> Project Homepage, <http://www.kb.se/kw3/ENG/Default.htm>.
- [116] The LOCKSS Homepage, <http://lockss.stanford.edu/>.
- [117] The MINERVA Web Preservation Project Homepage, <http://www.loc.gov/minerva/>.
- [118] The NEDLIB Project Homepage, <http://www.kb.nl/coop/nedlib/>.
- [119] The Nordic Web Archive Homepage, <http://nwa.nb.no/>.
- [120] The PANDORA Archive Homepage, <http://pandora.nla.gov.au/index.html>.

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).

- [121] Will Hill, Mark Rosenstein, Larry Stead, “Community and History-of-Use Navigation”, *Proc. of 2nd World Wide Web Conference (WWW2)*, Chicago (October 1994), IL, 1994, <http://archive.ncsa.uiuc.edu/SDG/IT94/IT94Info.html>.
- [122] James E. Pitkow, Margaret M. Recker, “A Simple Yet Robust Caching Algorithm Based on Dynamic Access Patterns”, *Proc. of 2nd World Wide Web Conference (WWW2)*, Chicago (October 1994), IL, 1994, <http://archive.ncsa.uiuc.edu/SDG/IT94/IT94Info.html>.
- [123] Lara D. Catledge, James E. Pitkow, “Characterizing Browsing Strategies in the World-Wide Web”, *Computer Networks and ISDN Systems*, Vol. 27, No. 6 (Proc. of WWW3), pp. 1065–1073, April 1995.
- [124] Henry Lieberman, “Letizia: An Agent That Assists Web Browsing”, *Proc. of 14th Intl’ Joint Conf. on Artificial Intelligence (IJCAI) – Vol. 1*, Montreal (August 1995), Quebec, Morgan Kaufmann, San Francisco, pp. 924–929, 1995.
- [125] Tak Woon Yan, Matthew Jacobsen, Hector Garcia-Molina, Umeshwar Dayal, “From User Access Patterns to Dynamic Hypertext Linking”, *Computer Networks and ISDN Systems*, Vol. 28, No. 7–11 (Proc. of WWW5), pp. 10007–1014, May 1996.
- [126] Venkata N. Padmanabhan, Jeffrey C. Mogul, “Using Predictive Prefetching to Improve World Wide Web Latency”, *Computer Communication Review*, Vol. 26, No. 3, July 1996.
- [127] Marco Balabanović, “An Adaptive Web Page Recommendation Service”, *Proc. of 1st Intl’ Conf. on Autonomous Agents*, Marina del Rey (February 1997), CA, ACM Press, New York, pp. 378–385, 1997.
- [128] Carlos R. Cunha, Carlos F.B. Jaccoud, “Determining WWW User’s Next Access and Its Application to Pre-fetching”, Technical Report, TR-95-011, CS Dept, Boston University, March 1997.
- [129] Carlos R. Cunha, Carlos F.B. Jaccoud, “Determining WWW User’s Next Access and Its Application to Pre-fetching”, *Proc. of 2nd IEEE Symposium on Computers and Communications (ISCC’97)*, Alexandria (July 1997), Egypt, IEEE Computer Society Press, Los Alamitos, pp. 6–11, 1997.
- [130] Mike Perkowitz, Oren Etzioni, “Adaptive Web Sites: an AI Challenge”, *Proc. of 15th Intl’ Joint Conf. on Artificial Intelligence (IJCAI ’97) – Volume 1*, Nagoya (August 1997), Japan, Morgan Kaufmann, San Francisco, pp. 16–23, 1997.
- [131] Marco Balabanović, “Learning to Surf: MultiAgent Systems for Adaptive Web Page Recommendation” Ph.D. Thesis, Dept. of Computer Science, Stanford University, CA, 1998.
- [132] Liren Chen, Katia P. Sycara, “WebMate: A Personal Agent for Browsing and Searching”, *Proc. of 2nd Intl’ Conf. on Autonomous Agents*, Minneapolis (May 1998), MN, ACM Press, New York, pp. 132–139, 1998.
- [133] Mike Perkowitz, Oren Etzioni, “Adaptive Web Pages: Automatically Synthesizing Web Pages”, *Proc. of 16th Natl’ Conf. on Artificial Intelligence and 10th Conf. on Innovative Applications of Artificial Intelligence (AAAI/IAAI ’98)*, Madison (July 1998), WI, The MIT Press, Cambridge, pp. 727–732, 1998.

- [134] Anupam Joshi, Raghu Krishnapuram, “Robust Fuzzy Clustering Methods to Support Web Mining”, *Proc. of Workshop on Research Issues in Data Mining and Knowledge Discovery (DMKD’98)* (in conj. with SIGMOD 1998), Seattle (June 1998), WA, pp. 15:1–15:8, 1998.
- [135] Wen-Syan Li, Yi-Leh Wu, Corey Bufi, Kevin Chang, Divyakant Agrawal, Yoshinori Hara, “Power-Bookmarks: An Advanced Web Bookmark Database System and its Information Sharing and Management”, *Proc. of 5th Intl’ Conf. on Foundations of Data Organization and Algorithms (FODO ’98)*, Kobe (November 1998), Japan, 1998.
- [136] Paul Barford, Azer Bestavros, Adam Bradley, Mark Crovella, “Changes in Web Client Access Patterns: Characteristics and Caching Implications”, *World Wide Web*, Vol. 2, No. 1–2, pp. 15–28, 1999.
- [137] Myra Spiliopoulou, “The Laborious Way from Data Mining to Web Mining”, *International Journal of Computer Systems Science & Engineering*, Vol. 14 (special issue on “Semantics of the Web”), pp. 113–126, March 1999.
- [138] Craig E. Wills, Mikhail Mikhailov, “Towards a Better Understanding of Web Resources and Server Responses for Improved Caching”, *Computer Networks*, Vol. 31, No. 11–16 (Proc. of WWW8), pp. 1231–1243, May 1999.
- [139] Mike Perkowitz, Oren Etzioni, “Towards Adaptive Web Sites: Conceptual Framework and Case Study”, *Computer Networks*, Vol. 31, No. 11–16 (Proc. of WWW8), pp. 1245–1258, May 1999.
- [140] Franck Rousseau, J. Antonio García-Macías, José Valdeni de Lima, Andrzej Duda, “User Adaptable Multimedia Presentations for the World Wide Web”, *Computer Networks*, Vol. 31, No. 11–16 (Proc. of WWW8), pp. 1273–1290, May 1999.
- [141] Wen-Syan Li, Quoc Vu, Divyakant Agrawal, Yoshinori Hara, Hajime Takano, “PowerBookmarks: A System for Personalizable Web Information Organization, Sharing, and Management”, *Computer Networks*, Vol. 31, No. 11–16 (Proc. of WWW8), pp. 1375–1389, May 1999.
- [142] Wen-Syan Li, Quoc Vu, Edward Y. Chang, Divyakant Agrawal, Kyoji Hirata, Sougata Mukherjea, Yi-Leh Wu, Corey Bufi, Kevin Chen-Chuan Chang, Yoshinori Hara, Reiko Ito, Yutaka Kimura, Kazuyuki Shimazu, Yukiyoshi Saito, “PowerBookmarks: A System for Personalizable Web Information Organization, Sharing, and Management”, *Proc. of ACM Intl’ Conf. on Management of Data (SIGMOD ’99)*, Philadelphia (June 1999), PA, ACM Press, New York, pp. 565–567, 1999.
- [143] Mike Perkowitz, Oren Etzioni, “Adaptive Web Sites: Conceptual Cluster Mining”, *Proc. of 16th Intl’ Joint Conf. on Artificial Intelligence (IJCAI ’99) – Volume 1*, Stockholm (July/August 1999), Sweden, Morgan Kaufmann, San Francisco, pp. 264–269, 1999.
- [144] Artur Czumaj, Ian Finch, Leszek Gąsieniec, Alan Gibbons, Paul H. Leng, Wojciech Rytter, Michele Zito, “Efficient Web Searching Using Temporal Factors”, *Proc. of 6th Intl’ Workshop on Algorithms and Data Structures (WADS ’99)*, Vancouver (August 1999), British Columbia, LNCS Vol. 1663, Springer-Verlag, Heidelberg, pp. 294–305, 1999.
- [145] Athena I. Vakali, “A Web-Based Evolutionary Model for Internet Data Caching”, *Proc. of DEXA ’99 Workshop W09: Network-Based Information Systems (NBIS’99)*, Florence (September 1999), Italy, IEEE Computer Society Press, Los Alamitos, pp. 650–654, 1999.
- [146] Florent Masseglia, Maguelonne Teisseire, Pascal Poncelet, “Using Data Mining Techniques on Web Access Logs to Dynamically Improve Hypertext Structure”, *ACM SigWeb Letters*, Vol. 8, No. 3, pp. 13–19, October 1999.

- [147] Bamshad Mobasher, Robert W. Cooley, Jaideep Srivastava, “Creating Adaptive Web Sites Through Usage-based Clustering of URLs”, *Proc. of 3rd IEEE Intl’ Workshop on Knowledge and Data Engineering Exchange (KDEX’99)*, Chicago (November 1999), IL, IEEE Computer Society Press, Los Alamitos, pp. 19–25, 1999.
- [148] Arnd Kohrs, Bernard Mérialdo, “Improving Collaborative Filtering with Multimedia Indexing Techniques to Create User-adapting Web Sites”, *Proc. of 7th ACM Intl’ Conf. Multimedia – Vol. 1*, Orlando (November 1999), FL, ACM Press, New York, pp. 27–36, 1999.
- [149] Bettina Berendt, Myra Spiliopoulou, “Analysis of Navigation Behaviour in Web Sites Integrating Multiple Information Systems”, *VLDB Journal*, Vol. 9, No. 1 (special issue on “Databases and the Web”), pp. 56–75, 2000.
- [150] Mike Perkowitz, Oren Etzioni, “Towards Adaptive Web Sites: Conceptual Framework and Case Study”, *Artificial Intelligence*, Vol. 118, No. 1–2, pp. 245–275, 2000.
- [151] Xiaobin Fu, Jay Budzik, Kristian J. Hammond, “Mining Navigation History for Recommendation”, *Proc. of Intl’ Conf. on Intelligent User Interfaces (IUI 2000)*, New Orleans (January 2000), LA, ACM Press, New York, pp. 106–112, 2000.
- [152] Olfa Nasraoui, Hichem Frigui, Raghu Krishnapuram, Anupam Joshi, “Extracting Web User Profiles using Relational Competitive Fuzzy Clustering”, *Intl’ Journal of Artificial Intelligence Tools*, Vol. 9, No. 4, 2000.
- [153] Shudong Jin, Azer Bestavros, “GreedyDual\* Web Caching Algorithm: Exploiting the Two Sources of Temporal Locality in Web Request Streams”, *Proc. of 5th Intl’ Workshop on Web Caching and Content Delivery*, Lisbon (May 2000), Portugal, TERENA, Amsterdam, <http://www.terena.nl/conf/wcw/Proceedings/proceedings.html>.
- [154] Shudong Jin, Azer Bestavros, “Temporal Locality in Web Request Streams: Sources, Characteristics, and Caching Implications” (Poster), *Proc. of ACM Intl’ Conf. on Measurement and Modeling of Computer Systems (Sigmetrics 2000)*, Santa Clara (June 2000), CA, ACM Press, New York, pp. 110–111, 2000.
- [155] Weifeng Zhang, Xu Baowen, William Song, Hongji Yang, Kecheng Liu, “Data Mining Algorithms for Web Pre-Fetching”, *Proc. of 1st Intl’ Conf. on Web Information Systems Engineering (WISE 2000) – Volume II*, Hong Kong (June 2000), China, IEEE Computer Society Press, Los Alamitos, pp. 34–38, 2000.
- [156] Beat Signer, Antonia Erni, and Moira C. Norrie, “A Personal Assistant for Web Database Caching”, *Proc. of 12th Intl’ Conf. on Advanced Information Systems Engineering (CAiSE 2000)*, Stockholm (June 2000), Sweden, LNCS Vol. 1789, Springer-Verlag, Heidelberg, pp. 64–78, 2000.
- [157] Mario Cannataro, Andrea Pugliese, “An XML-Based Architecture for Adaptive Web Hypermedia Systems Using a Probabilistic User Model”, *Proc. of 4th Intl’ Database Engineering and Applications Symposium (IDEAS 2000)*, Yokohoma (September 2000), Japan, IEEE Computer Society Press, Los Alamitos, pp. 257–265, 2000.
- [158] Maurice D. Mulvenna, Sarabjot S. Anand, Alex G. Büchner, “Personalization on the Net Using Web Mining: Introduction”, *Communications of the ACM*, Vol. 43, No. 8, pp. 122–125, August 2000.

- [159] Myra Spiliopoulou, “Web Usage Mining for Web Site Evaluation”, *Communications of the ACM* (special section on “Personalization Technologies with Data Mining”), Vol. 43, No. 8, pp. 127–134, August 2000.
- [160] Bamshad Mobasher, Robert W. Cooley, Jaideep Srivastava, “Automatic Personalization Based on Web Usage Mining”, *Communications of the ACM*, Vol. 43, No. 8, pp. 142–151, August 2000.
- [161] Shudong Jin, Azer Bestavros, “Sources and Characteristics of Web Temporal Locality”, *Proc. of IEEE/ACM Intl’ Symposium on Modeling, Analysis and Simulation of Computer and Telecommunication Systems (MASCOTS 2000)*, San Francisco (August 2000), CA, IEEE Computer Society Press, Los Alamitos, pp. 28–35, 2000.
- [162] Anirban Mahanti, Derek L. Eager, Carey L. Williamson, “Temporal Locality and its Impact on Web Proxy Cache Performance”, *Performance Evaluation*, Vol. 42, No. 2–3, pp. 187–203, September 2000.
- [163] Athena I. Vakali, “LRU-based Algorithms for Web Cache Replacement”, *Proc. of 1st Intl’ Conf. on Electronic Commerce and Web Technologies (EC-Web 2000)*, London (September 2000), England, LNCS Vol. 1875, Springer-Verlag, Heidelberg, pp. 409–418, 2000.
- [164] Bamshad Mobasher, Honghua Dai, Tao Luo, Yuqing Sun, Jiang Zhu, “Integrating Web Usage and Content Mining for More Effective Personalization”, *Proc. of 1st Intl’ Conf. on Electronic Commerce and Web Technologies (EC-Web 2000)*, London (September 2000), England, LNCS Vol. 1875, Springer-Verlag, Heidelberg, pp. 165–176, 2000.
- [165] Tapan Kamdar, Anupam Joshi, “On Creating Adaptive Web Servers Using Weblog Mining”, Technical Report, TR-CS-00-05, Department of Computer Science and Electrical Engineering, University of Maryland, Baltimore, MD, November 2000.
- [166] Hidenari Kiyomitsu, Atsunori Takeuchi, Katsumi Tanaka, “Web Reconfiguration by Spatio-Temporal Page Personalization Rules Based on Access Histories”, *Proc. of 2001 Symposium on Applications and the Internet (SAINT 2001)*, San Diego (January 2001), CA, IEEE Computer Society Press, Los Alamitos, pp. 75–84, 2001.
- [167] Shudong Jin, Azer Bestavros, “GreedyDual\* Web Caching Algorithm: Exploiting the Two Sources of Temporal Locality in Web Request Streams”, *Intl’ Journal of Computer Communications*, Vol. 24, No. 2, pp. 174–183, February 2001.
- [168] Artur Czumaj, Ian Finch, Leszek Gąsieniec, Alan Gibbons, Paul H. Leng, Wojciech Rytter, Michele Zito, “Efficient Web Searching Using Temporal Factors”, *Theoretical Computer Science*, Vol. 262, No. 1–2, pp. 569–582, July 2001.
- [169] Athena I. Vakali, “Proxy Cache Replacement Algorithms: A History-Based Approach”, *World Wide Web*, Vol. 4, No. 4, pp. 277–297, 2001.
- [170] Qiang Yang, Henry Hanning Zhang, “Integrating Web Prefetching and Caching Using Prediction Models”, *World Wide Web*, Vol. 4, No. 4, pp. 299–321, 2001.
- [171] Raghu Krishnapuram, Anupam Joshi, Olfa Nasraoui, Liyu Yi, “Low Complexity Fuzzy Relational Clustering Algorithms for Web Mining”, *IEEE Trans. on Fuzzy Systems*, Vol. 9, No. 4, pp. 596–607, 2001.

- [172] Myra Spiliopoulou, Carsten Pohle, “Data Mining for Measuring and Improving the Success of Web Sites”, *Data Mining and Knowledge Discovery* (special issue on “E-Commerce”), Vol. 5, No. 1/2, pp. 85–114, 2001.
- [173] Bernardo Magnini, Carlo Strapparava, “Improving User Modelling with Content-Based Techniques”, *Proc. of 8th Intl’ Conf. on User Modeling (UM 2001)*, Sonthofen (July 2001), Germany , pp. 74–83, 2001.
- [174] Francesco Bonchi, Fosca Giannotti, Cristian Gozzi, Giuseppe Manco, Mirco Nanni, Dino Pedreschi, Chiara Renso, Salvatore Ruggieri “Web Log Data Warehousing and Mining for Intelligent Web Caching”, *Data & Knowledge Engineering*, Vol. 39, No. 2 (special issue on “Building Web Warehouse for Semi-structured Data”), pp. 165–189, November 2001.
- [175] Yongqiao Xiao, Margaret H. Dunham, “Efficient Mining of Traversal Patterns”, *Data & Knowledge Engineering*, Vol. 39, No. 2 (special issue on “Building Web Warehouse for Semi-structured Data”), pp. 191–214, November 2001.
- [176] Bamshad Mobasher, Honghua Dai, Tao Luo, Miki Nakagawa, “Effective Personalization Based on Association Rule Discovery from Web Usage Data” *Proc. of 3rd Intl’ Workshop on Web Information and Data Management (WIDM ’01)*, Atlanta (November 2001), GA, ACM Press, New York, pp. 9–15, 2001.
- [177] Yi-Hung Wu, Arbee L. P. Chen, “Prediction of Web Page Accesses by Proxy Server Log”, *World Wide Web*, Vol. 5, No. 1, pp. 67–88, 2002.
- [178] Bamshad Mobasher, Honghua Dai, Tao Luo, Miki Nakagawa, “Discovery and Evaluation of Aggregate Usage Profiles for Web Personalization”, *Data Mining and Knowledge Discovery*, Vol. 6, No. 1, pp. 61–82, 2002.
- [179] Ling Feng, Qing Li, Hoi Yuen Leung, “Effective Allocation of Database Buffers by Mining Users’ Access Histories”, *Journal of Applied System Studies* (special issue on “WEB Information Systems Applications”), Vol. 3, No. 2, 2002.
- [180] Weifeng Zhang, Xu Baowen, William Song, Hongji Yang, “Pre-Fetching Web Pages through Data Mining Based Prediction”, *Journal of Applied System Studies* (special issue on “WEB Information Systems Applications”), Vol. 3, No. 2, 2002.
- [181] Timothy K. Shih, Shi-Kuo Chang, Jianhua Ma, Runhe Huang, “Web Learning Assessment and Adaptive Tutoring”, *Journal of Applied System Studies* (special issue on “WEB Information Systems Applications”), Vol. 3, No. 2, 2002.
- [182] Olfa Nasraoui, Raghu Krishnapuram, “An Evolutionary Approach to Mining Robust Multi-Resolution Web Profiles and Context Sensitive URL Associations”, *Intl’ Journal of Computational Intelligence and Applications*, Vol. 2, No. 3, pp. 339–348, 2002.
- [183] Olfa Nasraoui, Raghu Krishnapuram, “One Step Evolutionary Mining of Context Sensitive Associations and Web Navigation Patterns”, *Proc. of 2nd SIAM Conf. on Data Mining (SDM’02)*, Arlington (April 2002), VA, SIAM, Philadelphia, pp. 531–547, 2002.
- [184] Richard Furuta, Jin-Cheon Na, “Applying Programmable Browsing Semantics within the Context of the World-Wide Web”, *Proc. of 12th ACM Conf. on Hypertext and Hypermedia (HT’02)* College Park (June 2002), MD, ACM Press, New York, pp. 23–24, 2002.

- [185] Lakshmish Ramaswamy, Ling Liu, “A New Document Placement Scheme for Cooperative Caching on the Internet”, *Proc. of 22nd Intl’ Conf. on Distributed Computing Systems (ICDCS 2002)*, Vienna (July 2002), Austria, IEEE Computer Society Press, Los Alamitos, pp. 95–103, 2002.
- [186] Xin Chen, Xiaodong Zhang, “A Popularity-Based Prediction Model for Web Prefetching”, *Proc. of 31st Intl’ Conf. on Parallel Processing (ICPP 2002)*, Vancouver (August 2002), BC, IEEE Computer Society Press, Los Alamitos, pp. 296–304, 2002.
- [187] Unmil P. Karadkar, Jin-Cheon Na, Richard Furuta, “Employing Smart Browsers to Support Flexible Information Presentation in Petri Net-Based Digital Libraries”, *Proc. of 6th European Conf. on Research and Advanced Technology for Digital Libraries (ECDL 2002)*, Rome (September 2002), Italy, LNCS Vol. 2458, Springer-Verlag, Heidelberg, pp. 324–337, 2002.
- [188] Olfa Nasraoui, Raghu Krishnapuram, “A New Evolutionary Approach to Web Usage and Context Sensitive Associations Mining”, *Intl. Journal of Computational Intelligence and Applications*, Vol. 2, No. 3 (special issue on “Internet Intelligent Systems”), pp. 339-348, Sep. 2002.
- [189] Unmil P. Karadkar, Jin-Cheon Na, Richard Furuta, “A Framework for Flexible Information Presentation in Digital Collections”, *Proc. of 5th Intl’ Conf. on Asian Digital Libraries (ICADL 2002)*, Singapore (December 2002), LNCS Vol. 2555, Springer-Verlag, Heidelberg, pp. 467–468, 2002.
- [190] Bamshad Mobasher, Honghua Dai, Tao Luo, Miki Nakagawa, “Using Sequential and Non-Sequential Patterns in Predictive Web Usage Mining Tasks”, *Proc. of 2002 IEEE Intl’ Conf. on Data Mining (ICDM 2002)*, Maebashi City (December 2002), Japan, IEEE Computer Society Press, Los Alamitos, pp. 669–672, 2002.
- [191] Olfa Nasraoui, Raghu Krishnapuram, Anupam Joshi, Tapan Kamdar, “Automatic Web User Profiling and Personalization using Robust Fuzzy Relational Clustering”, in *E-Commerce and Intelligent Methods* (J. Segovia, P. Szczepaniak, M. Niedzwiedzinski eds.), SFSC Vol. 105, Springer-Verlag, Heidelberg, pp. 233-261, 2002.
- [192] Andy Cockburn, Saul Greenberg, Steve Jones, Bruce J. McKenzie, Michael Moyle, “Improving WEB Page Revisitation: Analysis, Design and Evaluation”, *IT & Society*, Vol. 3, No. 1, pp. 159–183, Winter 2003.
- [193] Magdalini Eirinaki, Michalis Vazirgiannis, “Web Mining for Web Personalization”, *ACM Trans. on Internet Technology*, Vol. 3, No. 1, pp. 1–27, February 2003.
- [194] Xin Chen, Xiaodong Zhang, “A Popularity-Based Prediction Model for Web Prefetching”, *IEEE Computer*, Vol. 36, No. 3, pp. 63–70, 2003.
- [195] Ioana Stanoi, George A. Mihaila, Sriram Padmanabhan, “A Framework for the Selective Dissemination of XML Documents based on Inferred User Profiles”, *Proc. of 19th Intl’ Conf. on Data Engineering (ICDE 2003)*, Bangalore (March 2003), India, IEEE Computer Society Press, Los Alamitos, pp. 531–542, 2003.
- [196] Olfa Nasraoui, Carlos Rojas, “From Static to Dynamic Web Usage Mining: Towards Scalable Profiling and Personalization with Evolutionary Computation” (invited paper), *Proc. of Workshop on Information Technology*, Rabat (March 2003), Morocco, 2003.
- [197] Qiang Yang, Haining Henry Zhang, “Web-Log Mining for Predictive Web Caching”, *IEEE Trans. on Knowledge and Data Engineering*, Vol. 15, No. 4, pp. 1050–1053, July/August 2003.

- [198] Joannis Vlahakis, Magdalini Eirinaki, Sarabjot Singh Anand, “IKUM: An Integrated Web Personalization Platform based on Content Structures and Usage Behavior”, *Proc. of Intl’ Workshop on Intelligent Techniques for Web Personalization (ITWP’03)* (in conj. with IJCAI-03), Acapulco (August 2003), Mexico.
- [199] Magdalini Eirinaki, Michalis Vazirgiannis, Iraklis Varlamis, “SEWeP: Using Site Semantics and a Taxonomy to Enhance the Web Personalization Process”, *Proc. of 9th ACM SIGKDD Intl’ Conf. on Knowledge Discovery and Data Mining (KDD 2003)*, Washington (August 2003), DC, ACM Press, New York, pp. 99–108, 2003.
- [200] Miriam Baglioni, U. Ferrara, Andrea Romei, Salvatore Ruggieri, Franco Turini, “Preprocessing and Mining Web Log Data for Web Personalization”, *Proc. of 8th Natl’ Conf. of the Italian Association for Artificial Intelligence (AI\*IA 2003)*, Pisa (September 2003), Italy, LNCS Vol. 2829, Springer-Verlag, Heidelberg, pp. 237–249, 2003.
- [201] Xin Chen, Xiaodong Zhang, “Accurately Modeling Workload Interactions for Deploying Prefetching in Web Servers”, *Proc. of 32nd Intl’ Conf. on Parallel Processing (ICPP 2003)*, Kaohsiung (October 2003), Taiwan, IEEE Computer Society Press, Los Alamitos, pp. 427–435, 2003.
- [202] Chung-Ming Huang, Tz-Heng Hsu, “A User-Aware Prefetching Mechanism for Video Streaming”, *World Wide Web*, Vol. 6, No. 4, pp. 353–374, December 2003.
- [203] Lakshmish Ramaswamy, Ling Liu, “An Expiration-Age Based Document Placement Scheme for Cooperative Web Caching”, *IEEE Transactions on Knowledge and Data Engineering*, Vol. 16, No. 5, pp. 585–600, May 2004.
- [204] Edmond HaoCun Wu, Michael K. Ng, Joshua Zhexue Huang, “On Improving Website Connectivity by Using Web-Log Data Streams”, *Proc. of 9th Intl’ Conf. on Database Systems for Advances Applications (DASFAA 2004)* Jeju Island (March 2004), Korea, LNCS Vol. 2973, Springer-Verlag, Heidelberg, pp. 352–364, 2004.
- [205] Jiming Liu, Shiwu Zhang, Jie Yang, “Characterizing Web Usage Regularities with Information Foraging Agents”, *IEEE Transactions on Knowledge and Data Engineering*, Vol. 16, No. 5, pp. 566–584, May 2004.
- [206] Magdalini Eirinaki, Charalampos Lampos, Stratos Paulakis, Michalis Vazirgiannis, “Web Personalization Integrating Content Semantics and Navigational Patterns”, *Proc. of 6th Intl’ Workshop on Web Information and Data Management (WIDM 2004)* (in conj. with CIKM 2004), Washington (to be held November 2004), DC.
- [207] Massimiliano Albanese, Antonio Picariello, Carlo Sansone, Lucio Sansone, “Web Personalization based on Static and Dynamic User Behavior”, *Proc. of 6th Intl’ Workshop on Web Information and Data Management (WIDM 2004)* (in conj. with CIKM 2004), Washington (to be held November 2004), DC.

Relevant papers can also be found in the special issue on “Context in Information Retrieval” of the *Information Processing & Management* journal (Vol. 38, No. 5, September 2002, edited by Cool & Spink).

## 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.semanticweb.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). A comprehensive ontology of time has also been developed by the DAML-Time effort (<http://www.cs.rochester.edu/~ferguson/daml/>).

Furthermore, some papers specifically deal with evolution and versioning of ontologies.

- [1] Jeff Heflin, James Hendler, Sean Luke, “Coping with Changing Ontologies in a Distributed Environment”, *Proc. of Workshop on Ontology Management* (in conj. with AAAI-1999), Orlando (July 1999), FL, AAAI/MIT Press, Menlo Park, pp. 74–79, 1999.
- [2] Jeff Heflin, James Hendler, “Dynamic Ontologies on the Web”, *Proc. of 17th Natl’ Conf. on Artificial Intelligence (AAAI-2000)*, Austin (August 2000), TX, AAAI/MIT Press, Menlo Park, pp. 443–449, 2000.
- [3] Michel C. A. Klein, Dieter Fensel, “Ontology Versioning for Semantic Web”, *Proc. of 13th Intl’ Semantic Web Working Workshop (SWWS’01)*, Stanford (July/August 2002), CA, pp. 75–91, 2001.
- [4] Michel C. A. Klein, “Supporting Evolving Ontologies on the Internet”, *EDBT Workshops 2002: 597-606 Proc. of Young Researchers Workshop (YRWS)* (in conj. with EDBT’2002), Prague (March 2002), Czech Republic, LNCS Vol. 2490, Springer-Verlag, Heidelberg, pp. 597–606, 2002.
- [5] Ying Ding, Dieter Fensel, Michel C. A. Klein, Borys Omelayenko, “The Semantic Web: Yet Another Hip?”, *Data & Knowledge Engineering*, Vol. 41, No. 2–3, pp. 205–227, June 2002.
- [6] Michel C. A. Klein, Dieter Fensel, Atanas Kiryakov, Damyan Ognyanov, “Comparing and Versioning Ontologies (Poster)”, *Collected Posters of 1st Intl’ Semantic Web Conf. (ISWC2002)*, Chia Laguna (June 2002), Italy, 2002.
- [7] Atanas Kiryakov, Damyan Ognyanov, “Tracking Changes in RDF(S) Repositories”, *Proc. of Workshop on Knowledge Transformation for the Semantic Web (KTSW)* (in conj. with ECAI 2002) Lyon (July 2002), France, pp. 27–25, 2002.
- [8] Michel C. A. Klein, Dieter Fensel, Atanas Kiryakov, Damyan Ognyanov, “Ontology Versioning and Change Detection on the Web”, *Proc. of 13th Intl’ Conf. on Knowledge Engineering and Knowledge Management. Ontologies and the Semantic Web (EKAW 2002)*, Sigüenza (October 2002), Spain, LNCS Vol. 2473, Springer-Verlag, Heidelberg, pp. 197–212, 2002.
- [9] Ljiljana Stojanovic, Alexander Maedche, Boris Motik, Nenad Stojanovic, “User-Driven Ontology Evolution Management”, *Proc. of 13th Intl’ Conf. on Knowledge Engineering and Knowledge Management. Ontologies and the Semantic Web (EKAW 2002)*, Sigüenza (October 2002), Spain, LNCS Vol. 2473, Springer-Verlag, Heidelberg, pp. 285–300, 2002.
- [10] Damyan Ognyanov, Atanas Kiryakov, “Tracking Changes in RDF(S) Repositories”, *Proc. of 13th Intl’ Conf. on Knowledge Engineering and Knowledge Management. Ontologies and the Semantic Web (EKAW 2002)*, Sigüenza (October 2002), Spain, LNCS Vol. 2473, Springer-Verlag, Heidelberg, pp. 373-378, 2002.
- [11] Michel C. A. Klein, Atanas Kiryakov, Damyan Ognyanov, Dieter Fensel, “Finding and Characterizing Changes in Ontologies”, *Proc. of 21st Intl’ Conf. on Conceptual Modeling (ER 2002)*, Tampere (October 2002), Finland, LNCS Vol. 2503, Springer-Verlag, Heidelberg, pp. 79–89, 2002.

- [12] Michel C. A. Klein, Ying Ding, Dieter Fensel, Borys Omelayenko, “Ontology Management: Storing, Aligning and Maintaining Ontologies”, in *Towards the Semantic Web: Ontology-Driven Knowledge Management* (J. Davies, D. Fensel, F. van Harmelen eds.), John Wiley & Sons, New York, 2003.
- [13] John Davies, Alistair Duke, Audrius Stonkus, “OntoShare: Evolving Ontologies in a Knowledge Sharing System” in *Towards the Semantic Web: Ontology-Driven Knowledge Management* (J. Davies, D. Fensel, F. van Harmelen eds.), John Wiley & Sons, New York, 2003.
- [14] Alexander Maedche, Boris Motik, Ljiljana Stojanovic, Rudi Studer, Raphael Volz, “An Infrastructure for Searching, Reusing and Evolving Distributed Ontologies”, *Proc. of 12th Intl’ Conf. on World Wide Web (WWW 2003)*, Budapest (May 2003), Hungary, ACM Press, New York, pp. 439–448, 2003.
- [15] Djamel Benslimane, Ahmed Arara, “The Multirepresentation Ontologies: a Contextual Description Logics Approach”, *Proc. of 15th Intl’ Conf. on Advanced Information Systems Engineering – Short papers (CAiSE’03 Forum)*, Klagenfurt/Velden (June 2003), Austria, University of Maribor Press, Maribor, Slovenia, pp. 145–148, 2003.
- [16] Natalya F. Noy, Michel C. A. Klein, “Ontology Evolution: Not the Same as Schema Evolution”, *Knowledge and Information Systems*, Vol. 5, 2003 (*in press*).
- [17] Heiner Stuckenschmidt, Michel C. A. Klein, “Integrity and Change in Modular Ontologies”, *Proc. of 18th Intl’ Joint Conf. on Artificial Intelligence (IJCAI 2003)*, Acapulco (August 2003), Mexico.
- [18] Michel C. A. Klein, Natalya F. Noy, “A Component-Based Framework for Ontology Evolution”, *Proc. of Intl’ Workshop on Ontologies and Distributed Systems* (in conj. with IJCAI 2003), Acapulco (August 2003), Mexico.
- [19] Jorge Santos, Steffen Staab, “Engineering a Complex Ontology with Time”, *Proc. of Intl’ Workshop on Ontologies and Distributed Systems* (in conj. with IJCAI 2003), Acapulco (August 2003), Mexico.
- [20] Ljiljana Stojanovic, Alexander Maedche, Nenad Stojanovic, Rudi Studer, “Ontology Evolution as Reconfiguration-Design Problem Solving”, *Proc. of 2nd Intl’ Conf. on Knowledge Capture (K-CAP 2003)* (in conj. with ISWC 2003), Sanibel Islands (October 2003), FL, ACM Press, New York, pp. 162–171, 2003.
- [21] Raphael Volz, Steffen Staab, Boris Motik, “Incremental Maintenance of Materialized Ontologies”, *Proc. of 2nd Intl’ Conf. on Ontologies, Databases and Applications of Semantics for Large Scale Information Systems (ODBASE 2003)* (part of the “On The Move to Meaningful Internet Systems” – OTM 2003 Confederated Conferences), Catania (November 2003), Italy, LNCS Vol. 2888, Springer-Verlag, Heidelberg, pp. 707–724, 2003.
- [22] Gábor Nagypál, Boris Motik, “A Fuzzy Model for Representing Uncertain, Subjective, and Vague Temporal Knowledge in Ontologies”, *Proc. of 2nd Intl’ Conf. on Ontologies, Databases and Applications of Semantics for Large Scale Information Systems (ODBASE 2003)* (part of the “On The Move to Meaningful Internet Systems” – OTM 2003 Confederated Conferences), Catania (November 2003), Italy, LNCS Vol. 2888, Springer-Verlag, Heidelberg, pp. 906–923, 2003.
- [23] Carlo Wouters, Tharam S. Dillon, J. Wenny Rahayu, Elizabeth Chang, Robert Meersman, “Ontologies on the MOVE”, *Proc. of 9th Intl’ Conf. on Database Systems for Advances Applications (DASFAA 2004)* Jeju Island (March 2004), Korea, LNCS Vol. 2973, Springer-Verlag, Heidelberg, pp. 812–823, 2004.

[24] Li Quin, Vijayalakshmi Atluri, “Ontology-Guided Change Detection to the Semantic Web” *Proc. of 23rd Intl’ Conf. on Conceptual Modeling (ER 2004)*, Shanghai (November 2004), China. LNCS Vol. 3288, Springer-Verlag, Heidelberg, pp. 624–638, 2004.

An “Intl’ Workshops on Semantic Web Personalization” (in conj. with AAAI 2004), will take place in San Jose, California, July 2004.

## 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.

The following are some papers that deal with the evolution of the Web development and usage.

- [1] Sally Hambridge, Jeffrey C. Sedayao, “Horses and Barn Doors: Evolution of Corporate Guidelines for Internet Usage”, *Proc. of 7th USENIX Systems Administration Conf. (LISA VII)*, Monterey (November 1993), CA, USENIX, Berkeley, pp. 9–16, 1993.
- [2] Barry M. Leiner (ed.), Special issue on Internet Technology of the *Communications of the ACM* (Vol. 37, No. 8), August 1994.
- [3] James E. Pitkow, Colleen M. Kehoe, “Emerging Trends in the WWW User Population”, *Communications of the ACM*, Vol. 39, No. 6, pp. 106–108, June 1996.
- [4] James E. Pitkow, Peter Pirolli, “Life, Death, and Lawfulness on the Electronic Frontier”, *Proc. of Intl’ ACM Conf. on Human Factors in Computing Systems (CHI ’97)*, Atlanta (March 1997), GA, ACM Press, New York, pp. 383–390, 1997.
- [5] Guy L. Steele, “Java and the Evolution of Web Software”, *Proc. of 19th Intl’ Conf. on Software Engineering*, Boston (May 1997), MA, ACM Press, New York, p. 538, 1997.
- [6] Ed H. Chi, James E. Pitkow, Jock D. Mackinlay, Peter Pirolli, Rich Gossweiler, Stuart K. Card, “Visualizing the Evolution of Web Ecologies”, *Proc. of Intl’ ACM Conf. on Human Factors in Computing Systems (CHI ’98)*, Los Angeles (April 1998), CA, ACM Press, New York, pp. 400–407, 1998.
- [7] Linda Schamber, Terry Sullivan, “Winners and Survivors: The Evolution of Community Digital Networks”, *Proc. of 1999 Mid-Year Conf. of the American Society for Information Science (ASIS ’99) – Evaluating Networked Information: Methods, Strategies, and Issues*, Pasadena (May 1999), CA.
- [8] Bernardo A. Huberman, Lada A. Adamic, “Internet: Growth Dynamics of the World Wide Web”, *Nature*, Vol. 401, pp. 131, September 1999.
- [9] Edward Vielmetti, “The (R)evolution of Web Services”, *IEEE Communications Magazine*, Vol. 37, No. 9, pp. 92–94, September 1999.
- [10] Sebastian M. Maurer, Bernardo A. Huberman, “Competitive Dynamics of Web Sites”, Technical Report, HP Labs, 2000, <http://www.hpl.hp.com/research/idl/projects/ecommerce/>.
- [11] Anders Johansen, Didier Sornette, “Download Relaxation Dynamics on the WWW Following Newspaper Publication of URL”, *Physica A: Statistical Mechanics and its Applications*, Vol. 276, No. 1–2, pp. 338–345, February 2000.

- [12] Brian E. Brewington, George Cybenko, “Keeping up with the Changing Web”, *IEEE Computer*, Vol. 33, No. 5, pp. 52–58, May 2000.
- [13] Brian E. Brewington, George Cybenko, “How Dynamic is the Web?”, *Computer Networks*, Vol. 33, No. 1–6 (Proc. of WWW9), pp. 257–276, June 2000.
- [14] Narushide Shiode, “A Brief History of Cyberspace: Evolution of Information Spaces”, *Proc. of 10th Annual Internet Society Conf. (INET 2000) – Posters*, Yokohama (July 2000), Japan, <http://www.casa.ucl.ac.uk/naru/2000330/>.
- [15] Unmil Karadkar, Luis Francisco-Revilla, Richard Furuta, Hao-wei Hsieh, Frank M. Shipman III, “Evolution of the Walden’s Paths Authoring Tools”, *Proc. of World Conf. on the WWW and Internet (Web-Net2000)*, San Antonio (October 2000), TX, AACE, Norfolk, VA, 2000.
- [16] Bernardo A. Huberman, *The Laws of the Web – Patterns in the Ecology of Information*, MIT Press, Cambridge, 2001.
- [17] Steve Lawrence, David M. Pennock, Gary William Flake, Robert Krovetz, Frans Coetzee, Eric J. Glover, Finn Nielsen, Andries Kruger, C. Lee Giles, “Persistence of Web References in Scientific Research”, *IEEE Computer*, Vol. 34, No. 2, pp. 26–31, 2001.
- [18] Naohiro Matsumura, Yukio Ohsawa, Mitsuru Ishizuka, “Future Direction of Communities on the Web”, *New Frontiers in Artificial Intelligence – Joint JSAI 2001 Workshop*, Matsue City (May 2001), Japan, LNAI 2253, Springer-Verlag, Heidelberg, p. 435–443, 2001.
- [19] Luis Francisco-Revilla, Frank M. Shipman III, Richard Furuta, Unmil Karadkar, Avital Arora, “Perception of Content, Structure, and Presentation Changes in Web-based Hypertext”, *Proc. of 12th ACM Conf. on Hypertext and Hypermedia (HT’01)* Århus (August 2001), Denmark, ACM Press, New York, pp. 205–214, 2001.
- [20] Chris Kenyon, “The Evolution of Web-Caching Markets”, *IEEE Computer*, Vol. 34, No. 11, pp. 128–130, 2001.
- [21] Dominique Vaufreydaz, Mathias Géry, “Internet Evolution and Progress in Full Automatic French Language Modelling”, *Proc. of 7th IEEE Workshop on Automatic Speech Recognition and Understanding (ASRU’01)*, Madonna di Campiglio (December 2001), Italy, IEEE Computer Society Press, Los Alamitos, pp. 363–366, 2001.
- [22] Mark Levene, Trevor Fenner, George Loizou, Richard Wheeldon, “A Stochastic Model for the Evolution of the Web”, *Computer Networks*, Vol. 39, No. 3, pp. 277–287, 2002.
- [23] Henry Kim, “Predicting How Ontologies for the Semantic Web Will Evolve”, *Communications of the ACM*, Vol. 45, No. 2, pp. 48–54, February 2002.
- [24] Laurent Mignet, Denilson Barbosa, Pierangelo Veltri, “The XML Web: a First Study”, *Proc. of 12th Intl’ Conf. on World Wide Web (WWW 2003)*, Budapest (May 2003), Hungary, ACM Press, New York, pp. 271–279, 2003.
- [25] Ravi Kumar, Jasmine Novak, Prabhakar Raghavan, Andrew Tomkins, “On the Bursty Evolution of Blogspace”, *Proc. of 12th Intl’ Conf. on World Wide Web (WWW 2003)*, Budapest (May 2003), Hungary, ACM Press, New York, pp. 568–576, 2003.

An online collection of articles concerning the history of the Web can be retrieved from the “Internet Society” Web site at URL: <http://www.isoc.org/internet/history/>.

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 Poulouvassilis 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 & Poulouvassilis) 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.htm>. 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), while a third edition is planned for May 2004 (New York, NY, in conj. with WWW 2004), [www.dcs.bbk.ac.uk/webDyn3/](http://www.dcs.bbk.ac.uk/webDyn3/). Levene and Poulouvassilis also wrote a book on the topic: *Web Dynamics – Adapting to Change in Content, Size, Topology and Use*, Springer-Verlag, 2004.

Other papers deal with the evolution of single Web sites (e.g. software engineering case studies) or of Web site and service types.

- [26] Paul Warren, Cornelia Boldyreff, Malcolm Munro, “The Evolution of Websites”, *Proc. of 7th Intl’ Workshop on Program Comprehension*, Pittsburgh (May 1999), PA, IEEE Computer Society Press, Los Alamitos, pp. 178–185, 1999.
- [27] Ed H. Chi, Stuart K. Card, “Sensemaking of Evolving Web Sites Using Visualization Spreadsheets”, *Proc. of IEEE Symposium on Information Visualization (InfoVis ’99)*, San Francisco (October 1999), CA, IEEE Computer Society Press, Los Alamitos, pp. 18–27, 1999.
- [28] Lars Bo Eriksen, Carina Ihlström, “Evolution of the Web News Genre - the Slow Move beyond the Print Metaphor”, *Proc. of 33rd Annual Hawaii Intl’ Conf. on System Sciences (HICSS-33)*, Maui (January 2000), Hawaii, IEEE Computer Society Press, Los Alamitos, pp. 864–873, 2000.
- [29] Shannon L. Fowler, Anne-Marie J. Novack, Michael J. Stillings, “The Evolution of a Manufacturing Web Site”, *Computer Networks*, Vol. 33, No. 1–6 (Proc. of WWW9), pp. 365–376, June 2000.
- [30] Filippo Ricca, Paolo Tonella, “Web Site Analysis: Structure and Evolution” *Proc. of Intl’ Conf. on Software Maintenance (ICSM 2000)*, San Jose (October 2000), CA, IEEE Computer Society Press, Los Alamitos, pp. 76–86, 2000.
- [31] Uri Hanani, Ariel J. Frank, “The Parallel Evolution of Search Engines and Digital Libraries: Their Convergence to the Mega-Portal”, *Proc. of Intl’ Conf. on Digital Libraries: Research and Practice*, Kyoto (November 2000), Japan, IEEE Computer Society Press, Los Alamitos, pp. 211–218, 2000.
- [32] Filippo Ricca, Paolo Tonella, “Understanding and Restructuring Web Sites with ReWeb”, *IEEE Multi-Media*, Vol. 8, No. 2, pp. 40–51, 2001.
- [33] Dickson K. W. Chiu, Qing Li, Kamalakar Karlapalem, “Web-Based Workflow Evolution in ADOME-WFMS”, *Proc. of 2nd Intl’ Conf. on Web-Age Information Management (WAIM 2001)*, Xi’an (July 2001), China, LNCS Vol. 2118, Springer-Verlag, Heidelberg, pp. 377–389, 2001.
- [34] Ludmila Cherkasova, Magnus Karlsson, “Dynamics and Evolution of Web Sites: Analysis, Metrics and Design Issues”, *Proc. of Symposium on Computers and Communications*, Hammamet (July 2001), Tunisia, IEEE Computer Society Press, Los Alamitos, pp. 64–71, 2001.

In this list we must include the proceedings of a workshop series started in 1999, the “*Intl’ Workshops on Web Site Evolution (WSE)*”, including: WSE’99 (Atlanta, GA, October 1999), WSE’2000 (Zurich, Switzerland, March 2000), WSE’2001 (Florence, Italy, November 2001), WSE’2002 (Montreal, Quebec, October 2002) and WSE’03 (Amsterdam, The Netherlands, September 2003). The 6th edition will be held in Chicago, IL, September 2004. Since 2001, WSE have been co-located with the “*IEEE Intl’ Conf. on Software Maintenance (ICSM)*” and proceedings have been published by the IEEE Computer Society Press. More information (including proceedings of the first editions) can be found on the Web site <http://www.websiteevolution.org/>.

## 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. A specialized markup language (TimeML) for temporal and event expressions has also been developed.

- [1] “Date and Time Formats”, W3C Consortium Note, <http://www.w3.org/TR/NOTE-datetime>.
- [2] Nancy Chinchor, “MUC-7 Named Entity Task Definition”, September 1997, [http://www.itl.nist.gov/iaui/894.02/related\\_projects/muc/proceedings/ne\\_task.html](http://www.itl.nist.gov/iaui/894.02/related_projects/muc/proceedings/ne_task.html)
- [3] C. Michael Sperberg-McQueen, “Regular Expression for Dates”, *Markup Languages*, Vol. 1, No. 4, pp. 20–26, Fall 1999.
- [4] Eric Howland, David Niergarth, “Regular Expressions for Checking Dates”, *Markup Languages*, Vol. 2, No. 2, pp. 126–132, Spring 2000.
- [5] Tex Texin, “Understanding ISO 8601 Date and Time Formats”, *Proc. of 18th Intl’ Unicode Conf. (IUC18)* (in conj. with WWW10), Hong Kong (April 2001), China, <http://www.unicode.org/iuc/iuc18/>.
- [6] Graham Klyne, Chris Newman, “Date and Time on the Internet: Timestamps”, Network Working Group, RFC 3339, July 2002, <ftp://ftp.rfc-editor.org/in-notes/rfc3339.txt>.
- [7] Stephanie Spranger, “Representation of Temporal Knowledge for Web-Based Applications ” (*in German*), Diploma Thesis, Ludwig Maximilians University, Munich, Germany, 2002.
- [8] James Pustejovsky, José M. Castaño, Robert Ingria, Roser Saur, Robert J. Gaizauskas, Andrea Setzer, Graham Katz, “TimeML: Robust Specification of Event and Temporal Expressions in Text”, *Proc. of 5th Workshop on Computational Semantics (IWCS-5)*, Tilburg (January 2003), The Netherlands.
- [9] James Pustejovsky, José M. Castaño, Robert Ingria, Roser Sauri, Robert J. Gaizauskas, Andrea Setzer, Graham Katz, Dragomir R. Radev, “TimeML: Robust Specification of Event and Temporal Expressions in Text”, in *New Directions in Question Answering – Papers from 2003 AAAI Spring Symposium*, AAAI Press, Menlo Park, pp. 28–34, 2003.
- [10] Charles E. Campbell, Andrew Eisenberg, Jim Melton, “XML Schema”, *Sigmod Record*, Vol. 32, No. 2, pp. 96–101, June 2003.

- [11] François Bry, Stephanie Spranger, “Temporal Constructs for a Web Language”, *Proc. of 4th Workshop on Interval Temporal Logics and Duration Calculi* (in conj with ESSLLI’03), Vienna (August 2003), Austria.
- [12] “XML Schema Part 2: Datatypes”, W3C Consortium Recommendation, <http://www.w3.org/TR/xmlschema-2/>.
- [13] The “Text Encoding Initiative” Homepage, <http://www.tei-c.org/>.
- [14] “Dublin Core Qualifiers”, DCMI Recommendation, <http://dublincore.org/documents/2000/07/11/dcmes-qualifiers/>.
- [15] “The Open Archives Initiative Protocol for Metadata Harvesting”, OAI Protocol Specification, <http://www.openarchives.org/OAI/openarchivesprotocol.html>.
- [16] The “Encoded Archival Description (EAD)” Homepage, <http://www.loc.gov/ead/>.
- [17] “International Date Format Campaign”, <http://www.saqgara.demon.co.uk/datefmt.htm>.
- [18] The TimeML Homepage, <http://www.cs.brandeis.edu/~jamesp/arda/time/>.
- [19] “TimeML: Markup Language for Temporal and Event Expressions”, Oasis Cover Pages, <http://xml.coverpages.org/timeML.html>, 2004.
- 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.
- [20] Steven R. Newcomb, Neill A. Kipp, Victoria T. Newcomb, “The “HyTime” Hypermedia/Time-based Document Structuring Language,” *Communications of the ACM*, Vol. 34, No. 11, pp. 67–83, November 1991.
- [21] Lynda Hardman, Dick C. A. Bulterman, Guido van Rossum, “The Amsterdam Hypermedia Model: Adding Time and Context to the Dexter Model”, *Communications of the ACM*, Vol. 37, No. 2, pp. 50–62, February 1994.
- [22] Patrick Schmitz, Jin Yu, Peter Santangeli, “Timed Interactive Multimedia Extensions for HTML (HTML+TIME) – Extending SMIL into the Web Browser”, Technical Report (W3C Note), W3C Consortium, 1998, <http://www.w3.org/TR/NOTE-HTMLplusTIME>.
- [23] Franck Rousseau, Andrzej Duda, “Synchronized Multimedia for the WWW”, *Computer Networks*, Vol. 30, No. 1–7 (Proc. of WWW7), pp. 417–429, April 1998.
- [24] Lynda Hardman, Jacco van Ossenbruggen, K. Sjoerd Mullender, Lloyd Rutledge, Dick C. A. Bulterman, “Do You Have the Time? Composition and Linking in Time-based Hypermedia”, *Proc. of 10th ACM Conf. on Hypertext and Hypermedia (HT’99)*, Darmstadt (February 1999), Germany, ACM Press, New York, pp. 189–196, 1999.
- [25] Niels Olof Bouvin, René Schade, “Integrating Temporal Media and Open Hypermedia on the World Wide Web”, *Computer Networks*, Vol. 31, No. 11–16 (Proc. of WWW8), pp. 1453–1465, May 1999.

- [26] Isabelle Mirbel, Barbara Pernici, Timos K. Sellis, S. Tserkezoglou, Michalis Vazirgiannis, “Checking the Temporal Integrity of Interactive Multimedia Documents”, *VLDB Journal*, Vol. 9, No. 2, pp. 111–130, 2000.
- [27] Jon Heggland, “Hypermedia Annotations for Temporal Media”, *Proc. of 1st NTNU Computer Science Graduate Student Conf. (NTNU CSGSC 2001)* Trondheim (May 2001), Norway, Norwegian University of Science and Technology, <http://csgsc.idi.ntnu.no/2001/>.
- [28] Kevin R. Page, Don Cruickshank, David De Roure, “Its About Time: Link Streams as Continuous Metadata”, *Proc. of 12th ACM Conf. on Hypertext and Hypermedia (HT’01)* Århus (August 2001), Denmark, ACM Press, New York, pp. 93–102, 2001.
- [29] Jon Heggland, “OntoLog: Temporal Annotation Using Ad Hoc Ontologies and Application Profiles”, *Proc. of 6th European Conf. on Research and Advanced Technology for Digital Libraries (ECDL 2002)*, Rome (September 2002), Italy, LNCS Vol. 2458, Springer-Verlag, Heidelberg, pp. 118–128, 2002.
- [30] Utz Westermann, Wolfgang Klas, “An Analysis of XML Database Solutions for the Management of MPEG-7 Media Descriptions”, *ACM Computing Surveys*, Vol. 35, No. 4, pp. 331-373, December 2003.
- [31] Philippa Gardner, Sergio Maffei, “Modelling Dynamic Web Data”, *Proc. of 9th Intl’ Workshop on Data Base Programming Languages (DBLP’03)*, Potsdam (September 2003), Germany, LNCS Vol. 2921, Springer-Verlag, Heidelberg, pp. 130–146, 2003.
- [32] The Synchronized Multimedia Integration Language (SMIL) Homepage, W3C Consortium, <http://www.w3c.org/AudioVideo/>.
- A workshop on “Time for the Web” was held in San Francisco, July 2003 (in conj. with the SEKE 2003 Conf.). Although the main topics of the workshop are hypermedia synchronization and temporal verification and validation, also different Web aspects involving time have been considered.
- Finally, according to some authors, the Web itself has developed its own time dimensions (e.g. “Internet time”, “virtual time”, etc).
- [33] Rob Kitchin, *Cyberspace: The World in the Wires*, John Wiley & Sons, New York, 1998.
- [34] Heejin Lee, Jonathan Liebenau, “Time and the Internet at the Turn of the Millennium”, *Time & Society*, Vol. 9, No. 1, pp. 43–56, 2000.

### 3 Acknowledgments

This bibliography could not have been compiled (i.e. in reasonable time) without the existence and availability of the World Wide Web and, in particular, without the Google search engine, the ACM Digital Library and the IEEE Xplore service, and all the priceless information supplied by Michael Ley’s DBLP Computer Science Bibliography and the NEC CiteSeer Research Index.