

# 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; Tsotras & Kumar, *ACM SIGMOD Record* **25**:1, 1996; Wu, Jajodia & Sean Wang, in *Temporal Databases: Research and Practice*, Springer LNCS 1399, 1998), two ones on spatio-temporal databases (Al-Taha, Snodgrass & Soo, *ACM SIGMOD Record* **22**:1, 1993; Al-Taha, Snodgrass & Soo, *Intl' Journal of Geographical Inf. Sys.* **8**:1, 1994), two ones on spatio-temporal data mining (Roddick & Spiliopoulou, *ACM SIGKDD Explorations* **1**:1, 1999; Roddick, Hornsby & Spiliopoulou, *Proc. TSDM 2000 Intl' Workshop*, Springer LNCS 2007, 2000), one on schema evolution (Roddick, *ACM SIGMOD Record* **21**:4, 1992), and one on (temporal) indeterminacy (Dyreson, in *Uncertainty Management in Information Systems*, Kluwer, 1996).

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

## 2 PAPERS

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

### 2.1 Transaction Time

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

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

- [1] Tom Dalling, “Versioning of Web Resources”, Honour’s Thesis, James Cook University, Australia, 1998.
- [2] Claudio Cristofori, Fabio Grandi, Federica Mandreoli, Maria Rita Scalas, “Management of Temporal Versions of World Wide Web Resources along Transaction Time”, Technical Report, T6-R03, INTER-DATA Project, 1998, (*in Italian*), <http://www.difa.unibas.it/users/gmecca/interdata/>.
- [3] Claudio Cristofori, “Temporal Extensions of the World Wide Web Technology” (*in Italian*), Master Thesis, Faculty of Engineering, University of Bologna, Italy, 1999.
- [4] Tony Allan, Gayle Allan, “Temporal and Version Extensions to XML and the W3C Document Object Model” (Poster), *Proc. of 8th Intl’ WWW Conf. (WWW8) – Posters*, Toronto (May 1999), Ontario, 1999, <http://www8.org/>.
- [5] Curtis E. Dyreson, “Transaction-Time World-Wide Web (WWW) Server”, in The Dagstuhl Seminar Researchers, “Summary of Current Work”, in *Temporal Databases: Research and Practice*, LNCS Vol. 1399, Springer-Verlag, Heidelberg, p. 416, 1999.
- [6] Stefan Zapf, Thomas Myrach, “A Prototype for the Support of Temporal Aspects of Web Administration on the Basis of a Repository” (*in German*), *Proc. of Workshop on Application of Concepts of Temporal Data Management in Database Systems and World Wide Web (ZobIS)* (in conj. with MobIS-Fachtagung 2000), Siegen (October 2000), Germany, Gesellschaft für Informatik, Bonn, pp. 291–297, 2000.
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- [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.

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- [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.
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- [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.

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- [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/>.
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- [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.
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- [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.
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- [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.
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- [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.
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- 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.
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- [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.
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- [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.
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## 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.

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

## 2.5 Updates on the Web

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

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## 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.

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## 2.7 Navigation Time

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

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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>.

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

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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.

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## 2.9 WWW Evolution

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

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A related research field, more focused on technical aspects and aiming at a development of Web technologies, concerns the *Web dynamics*. The Web dynamics field has been initiated by the *Intl’ Workshop on Web Dynamics* (London, England, January 2001, co-located with ICDT ’01), <http://www.dcs.bbk.ac.uk/webDyn/>. The field has been surveyed by Mark Levene and Alexandra 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.

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## 2.10 Other Time Aspects

Several efforts involve standardization of temporal expressions to be used on the Web (e.g. as metadata). For instance, the issue has been addressed by the W3C Consortium, and is part of the XML-Schema datatype definitions. Metadata carrying temporal information have also been considered in the TEI, Dublin Core, MUC and EAD initiatives. In the Open Archives Initiative, (transaction-time) *datestamps* are used for *selective harvesting* of metadata. A specialized markup language (TimeML) for temporal and event expressions has also been developed.

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### 3 Acknowledgments

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