An Annotated Bibliography on Schema Integration for Mobile Databases[*]

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Abstract

Mobile workstations and personal digital assistants (PDAs) provide data within easy reach wherever the mobile user goes. However, limitations of mobile computing call for different methods of networking and connectivity. Furthermore, connectivity refers not only to the physical connection of autonomous machines but that of autonomous database systems. This annotated bibliography, generated from previous research in ([46]), may be useful to interested researchers.

[46] provides a survey of some schema integration methods for distributed and multidatabase systems, discussed in the context of mobile database systems. *Schema integration* is the process of combining the whole or part of several database schemas for the purpose of combining data from multiple sources into a single source. This can be done by generating a single *global schema*, generating several *federated schemas*, or a short-lived composite schema constructed for the sake of a transaction expressed using some *multidatabase language*. Systems with a global schema or federated schemas provide better performance since the integrated schema is static and can be re-used again and again. However, integration gets more complex as the number of participating schemas increase. This is the result of *semantic heterogeneity*, the resolution of which commonly requires human intervention, making it difficult to automate. Multidatabase language systems require on-demand schema integration, since a static integrated schema does not exist. It is understood that the queries were formulated with the integration logic embedded into the query. However, performance is slow since each query requires integration.

If good semantic representations can be developed, automatic integration will become more feasible. Rather than requiring a user (e.g. the DBA) to analyze the component schemas and perform the integration manually or interactively, the integration may be performed automatically and reliably by an intelligent component.

Further research is recommended along two areas: using an agent-based mobile transaction broker, and further work on semantic representation and analysis. The mobile transaction broker, which can perform the query task on behalf of a mobile host, should be an agent executing in a non-mobile host. Thus, it is not hampered by frequent disconnections and the short battery lives, which occur in mobile computing environments. Work on data semantics is also of significance in resolving conflicts between non-heterogeneous schemas.

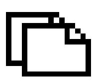
The interested reader may refer to [46] for more details on this study, which resulted in this bibliography. The references in the annotated bibliography have been classified, relative to the area of study (on schema integration), as one or several of:

1. *Advanced concepts* embody materials that discuss details of some advanced concept in distributed databases, schema integration or mobile databases.
2. *Background information* refer to materials that discuss concepts not directly related to schema integration but may be useful to the interested researcher.
3. *Specific applications* refer to literature in which concepts related to schema integration or mobile databases are applied to specific models or prototypes.
4. *Traditional concepts* embody those articles or books that discuss the basic theories and concepts of schema integration, distributed databases or mobile databases.

Classification Icons: (from bitmap files included in XFree86 from Slackware Linux)


advanced concepts


specific applications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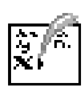
traditional concepts

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This paper was written using LaTeX.

References

[1] R. Alonso. Database system issues in nomadic computing. In *ACM SIGMOD 1993*, pages 388–392. ACM, 1993.
Discusses basic database systems issues in nomadic or mobile computing environments.

[2] R. Alonso and V. S. Mani. A pen-based database interface for mobile computers.
Authors are from the Matsushita Information Technology Laboratory, 2 Research Way, 3rd Floor, Princeton NJ 08540. This paper discusses a GUI for database systems using a pen-based mobile computer that uses the PenPoint operating system.

[3] G. K. Attaluri, D. P. Bradshaw, N. Cburn, P. A. Larson, P. Martin, A. Silberschatz, J. Slonim, and Q. Zhu. The cords multidatabase project. *IBM Systems Journal*, 34(1):39–59, 1995.
Discusses CORDS and how it handles, among other issues, schema integration. It features scalability, transparency, and it uses agents for standardized interface to component databases, known as CDSs or component data sources. The schema integration support does not include automatic conflict resolution, but rather provides useful tools for the user performing the integration.

[4] C. Batini, M. Lenzerini, and S. B. Navathe. A comparative analysis of methodologies for database schema integration. In A. Gupta, editor, *Integration of Information Systems: Bridging Heterogeneous Databases*, pages 72–112. IEEE Press, 1989.
Originally appeared in ACM Computing Surveys, 18(4), Dec. 1986. This paper compares a number of schema integration methodologies. Included are seven methods developed from 1979 to 1987. The comparison focuses on the design phases, integration processing strategies, conflict resolution, interschema properties, and resolution of other problems encountered in schema integration.

[5] F. Bennett, T. Richardson, and A. Harter. Teleporting – making applications mobile. In *Workshop on Mobile Computing Systems and Applications*. IEEE Computer Society Technical Committee on Operating Systems, December 1994.
Discusses basic issues of mobile applications. An application is allowed to teleport by providing a means for it to remain active and connected to whatever hosts it is connected to despite its movement from one area to another, though it requires that the connection be severed from the origin and re-connected to whatever location is accessible.

[6] A. R. Bobak. *Distributed and Multi-Database Systems*. Multiscience Press, Bantam Books, 1993.
Is a very good reference for theories, concepts and developments in distrbuted and multidatabase systems. Contains actual cases of existing systems, be they commercial or non-commercial prototypes.

[7] A. Bouguettaya and A. Delis. On mobile database management systems. Paper Draft, School of Information Systems, Queensland University of Technology, Gardens Point Campus, 2 George St., GPO Box 2434, Brisbane 4001, Queensland, Australia, November 1994.
Discusses issues on mobile database management systems tackling general issues.

[8] Y. Breitbart. Multidatabase interoperability. In A. R. Hurson, M. W. Bright, and S. H. Pakzad, editors, *Multidatabase Systems: An Advanced Solution for Global Information Sharing*, chapter 1, pages 41–48. IEEE Computer Society Press, 1993.
Originally appeared in SIGMOD Record, 19(3), Sept. 1990, pp. 53-60. Presents a review of multidatabase issues and current work on multidatabase systems such as MULTIBASE, MRDSM, a superview approach, and DeMichiel's approach on schema integration.

[9] Y. Breitbart, P. L. Olson, and G. R. Thompson. Database integration in a distributed heterogeneous database system. In A. R. Hurson, M. W. Bright, and S. H. Pakzad, editors, *Multidatabase Systems: An Advanced Solution for Global Information Sharing*, chapter 5, pages 231–240. IEEE Computer Society Press, 1993.
Originally appeared in Proc. Second Int'l Conf. on Data Eng., Feb. 1986,pp. 301-310. Describes the integration methodology used in the Amoco Distributed Database System or ADDS, which uses an integrated data model. A composite database schema approach is taken. Various techniques to resolve data conflicts is described.

[10] M. W. Bright, A. R. Hurson, and S. H. Pakzad. A taxonomy and current issues in multidatabase systems. In A. R. Hurson, M. W. Bright, and S. H. Pakzad, editors, *Multidatabase Systems: An Advanced Solution for Global Information Sharing*, chapter 1, pages 3–12. IEEE Computer Society Press, 1993.
Originally appeared in IEEE Computer, 25(3), Mar. 1992, pp. 50-60. Multidatabases are defined and compared to related systems such as federated systems, distributed systems, interoperable systems and homogeneous multidatabase systems. Design approaches, language features for language systems, and existing projects are also discussed.

[11] P. E. Cannata. The irresistible move towards interoperable database systems. In A. R. Hurson, M. W. Bright, and S. H. Pakzad, editors, *Multidatabase Systems: An Advanced Solution for Global Information Sharing*, chapter 6, pages 369–372. IEEE Computer Society Press, 1993.
Originally appeared in Proc. First Int'l Workshop on Interoperability in Multidatabase Systems, 1991, pp. 2-5. Briefly discusses issues to consider for the future of interoperable databases. There is mention of existing trends as well as an overview of the Carnot architecture for interoperable databases.

[12] A. F. Cardenas. Heterogeneous distributed database management. In A. Gupta, editor, *Integration of Information Systems: Bridging Heterogeneous Databases*, pages 251–263. IEEE Press, 1989.
Originally appeared in Proc. IEEE, 75(5), May 1987, pp. 588-600. This paper discusses the HD-DBMS which provides interoperability among heterogeneous databases that avoids unload/load procedures. Two global models, a global conceptual model and a global internal model, are discussed.

[13] S. Ceri, B. Pernici, and G. Wiederhold. Distributed database design methodologies. In A. R. Hurson, M. W. Bright, and S. H. Pakzad, editors, *Multidatabase Systems: An Advanced Solution for Global Information Sharing*, chapter 4, pages 166–179. IEEE Computer Society Press, 1993.
Originally appeared in Proc IEEE, 75(5), May 1987, pp. 533-546. The DATAID-D top-down methodology, as well as a general bottom-up design methodology for distributed databases are described. The specific use of generalization hierarchies for building the global schema is clear, as examples were also shown.

[14] C. J. Date. *An Introduction to Database Systems*. Systems Programming Series. Addison-Wesley Publishing Company, Inc., fifth edition, 1990.
This textbook is a comprehensive source of concepts in database theory as a whole. The latter chapters present some discussions on basic theories in distributed databases, however.

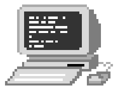
[15] S. M. Deen, R. R. Amin, and M. C. Taylor. Data integration in distributed databases. In A. R. Hurson, M. W. Bright, and S. H. Pakzad, editors, *Multidatabase Systems: An Advanced Solution for Global Information Sharing*, chapter 5, pages 255–259. IEEE Computer Society Press, 1993.
Originally appeared in IEEE Trans. on Software Eng., SE-13(7), July 1987, pp. 860-864. This paper briefly discusses the PRECI Algebraic Language (PAL), which can be used to generate union-compatible views.

[16] L. G. DeMichiel. Performing operations over mismatched domains. In A. R. Hurson, M. W. Bright, and S. H. Pakzad, editors, *Multidatabase Systems: An Advanced Solution for Global Information Sharing*, chapter 1, pages 103–112. IEEE Computer Society Press, 1993.
Originally appeared in Proc. Fifth Int'l Conf. on Data Eng., 1989, pp. 36-45. The author describes a method of schema integration over mismatched domains using virtual attributes and domain mapping. This is a general method that may be applied whether a global schema approach or a federated approach is taken.

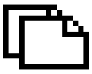
[17] A. Dogac, C. Dengi, E. Killic, G. Ozcan, S. Nural, C. Evrendilek, U. Halici, B. Arpinar, P. Koksal, N. Kesim, and S. Mancuhan. Metu interoperable database system. *SIGMOD Record*, 24(3):56–61, September 1995.
Discusses the METU Interoperable Database System (MIND), a heterogeneous multidatabase system with an architecture that is based on the OMG distributed object management model. The approach taken is object-oriented, so that differences between local databases is hidden.The integrated schema is built as a view over export schemas.

[18] D. Fang, J. Hammer, and D. McLeod. The identification and resolution of semantic heterogeneity in multidatabase systems. In A. R. Hurson, M. W. Bright, and S. H. Pakzad, editors, *Multidatabase Systems: An Advanced Solution for Global Information Sharing*, chapter 3, pages 52–59. IEEE Computer Society Press, 1993.
Originally appeared in Proc. First Int'l Workshop on Interoperability in Multidatabase Systems, 1991, pp. 136-143. Discusses semantic heterogeneity that occur in different levels of abstraction, as well as solutions proposed in the Remote-Exchange project. The kernel object data model (KODM) is used as a common data model. A remote database is integrated such that it appears to be part of the local database to make access transparent, with the assistance of a semantic dictionary.

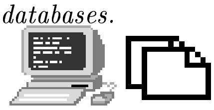
[19] P. Fankhauser and E. J. Neuhold. Knowledge based integration of heterogeneous databases. In D. K. Hsiao, E. J. Neuhold, and R. Sacks-Davis, editors, *IFIP DS-5 Semantics of Interoperable Database Systems*, volume 1, pages 150–170. Lorne, Victoria, Australia, November 1992.
This paper discusses the use of fuzzy logic to determine the relationship between objects in a database. The method is based on the terminological relationship between objects.



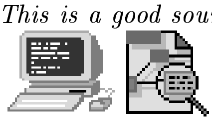
[20] V. D. Gligor and G. L. Luckenaugh. Interconnecting heterogeneous database management systems. In A. R. Hurson, M. W. Bright, and S. H. Pakzad, editors, *Multidatabase Systems: An Advanced Solution for Global Information Sharing*, chapter 2, pages 134–144. IEEE Computer Society Press, 1993.
Originally appeared in IEEE Computer, 17(1), Jan. 1984, pp. 33-43. Discusses a 3-level architectural model for interconnecting heterogeneous DBMSs, which includes the approach taken by several projects (CSIN, UCLA, XDM, MULTIBASE). The paper concentrates more on the cooperation protocols in transaction management, rather than on the schema integration or language aspects.



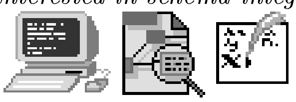
[21] P. M. D. Gray and N. W. Paton K. G. Kulkarni. *Object-Oriented Databases: A Semantic Data Model Approach*. Prentice Hall International Series in Computer Science. Prentice Hall International (UK) Ltd, 1992.
Is a good source of information on semantic data models and theories and design of object-oriented databases.



[22] R. Gruber, F. Kaashoek, B. Liskov, and L. Shrira. Disconnected operation in the thor object-oriented database system. In *Proceedings of the IEEE Workshop on Mobile Computing Systems and Applications*. IEEE, December 1994.
This paper discusses Thor, an Object-Oriented Database System that is capable of disconnected operation. This is a good source of information about significant issues in mobile database design.

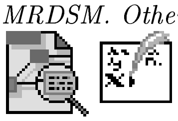


[23] A. Gupta, editor. *Integration of Information Systems: Bridging Heterogeneous Databases*. IEEE Press, 1989.
A considerable collection of papers on database integration, distributed database systems, multidatabse systems, including a few that deal with schema integration. This is a major reference for those who are interested in schema integration or distributed databases in general.



[24] D. K. Hsiao and M. N. Kamel. Heterogeneous databases: Proliferations, issues, and solutions. In A. R. Hurson, M. W. Bright, and S. H. Pakzad, editors, *Multidatabase Systems: An Advanced Solution for Global Information Sharing*, chapter 2, pages 60–77. IEEE Computer Society Press, 1993.
Originally appeared in IEEE Trans. on Knowledge and Data Eng., 1(1), Mar. 1989, pp. 45-62. Discusses the issues of heterogeneous databases, applications, the proliferation of monomodel and monolingual systems, and problems associated with them. Solutions are also proposed based on either a hardware or software approach.

[25] A. R. Hurson, M. W. Bright, and S. H. Pakzad, editors. *Multidatabase Systems: An Advanced Solution for Global Information Sharing*, chapter 5, pages 217–230. IEEE Computer Society Press, 1993.
Current state of research in multidatabase projects, with more detailed discussion on MULTIBASE and MRDSM. Other methodologies are categorized in given tables classifying them by system type.



[26] A. R. Hurson, M. W. Bright, and S. H. Pakzad, editors. *Multidatabase Systems: An Advanced Solution for Global Information Sharing*, chapter 2, pages 49–51. IEEE Computer Society Press, 1993.
A brief text that presents a tabular taxonomy of multidatabase systems and related systems.

[27] A. R. Hurson, M. W. Bright, and S. H. Pakzad, editors. *Multidatabase Systems: An Advanced Solution for Global Information Sharing*. IEEE Computer Society Press, 1993.
Collection of papers on distributed database systems, multidatabase systems. This is a major reference for those who are studying classical and commercial distributed database designs or prototypes.

[28] W. Klas, P. Fankhauser, and P. Muth. Database integration using the open object-oriented database system VODAK. In O. Bukhres and A. K. Elmagarmid, editors, *Object Oriented Multidatabase Systems: A Solution for Advanced Applications*. Prentice Hall, Englewood Cliffs, N.J., 1995.
This paper presents VODAK, an o-o database systems capable of database integration. It discusses the use of KODIM, a federated approach to integration for semantic integration which assist incremental integration and features dynamic maintenance of integrated schemas despite external schema evolution.

[29] H. F. Korth. *Database system concepts*. McGraw-Hill computer science series. McGraw-Hill, New York, second edition, 1991.
This textbook is a good source of basic concepts of database theory and some advanced topics including distributed database systems.

[30] R. Krishnamurthy, W. Litwin, and W. Kent. Interoperability of heterogeneous databases with schematic discrepancies. In A. R. Hurson, M. W. Bright, and S. H. Pakzad, editors, *Multidatabase Systems: An Advanced Solution for Global Information Sharing*, chapter 3, pages 118–125. IEEE Computer Society Press, 1993.
Originally appeared in Proc. First Int'l Workshop on Interoperability in Multidatabase Systems, 1991, pp. 144-151. Discusses the issues and solutions associated with schematic discrepancies. Solutions proposed focus on the multidatabase language features on higher order DML expressions and higher order views.

[31] S. J. Lai, A. Zaslavsky, G. P. Martin, and L. H. Yeo. Cost efficient adaptive protocol with buffering for advanced mobile database applications. In T. W. Ling and Y. Masunaga, editors, *Proceedings of the Fourth International Conference on Database Systems for Advanced Applications (DASFAA '95)*, Singapore, April 1995. World Scientific Publishing Co. Pte Ltd.
This paper discusses an adaptive queueing protocol which is designed to work with many applications. Packet transmission cost is minimized by combining multiple packets into one packet, thereby saving on space used by packet headers and transaction headers.

[32] W. Litwin. From databases to multidatabases: Why and how. In A. R. Hurson, M. W. Bright, and S. H. Pakzad, editors, *Multidatabase Systems: An Advanced Solution for Global Information Sharing*, chapter 1, pages 13–40. IEEE Computer Society Press, 1993.
Originally appeared in Proc. Sixth British Nat'l Conf. on Databases,Cambridge Univ. Press, New York, N.Y., 1988, pp. 161-188. Discusses design issues of multidatabases, and how traditional database design methods are not appropriate. A general multidatabase architecture, with language features, is also given. Related systems are briefly mentioned and compared, and multidatabase language features are specified. Commercial and industrial prototypes such as Sybase, Empress V2, Distributed Ingres or Ingres Star, Oracle V5, UNISYS Mermaid, GTE Calida, DQS/Multistar, and Interoperable database systems. Research issues are also discussed briefly.

[33] W. Litwin and A. Abdellatif. Multidatabase interoperability. In A. R. Hurson, M. W. Bright, and S. H. Pakzad, editors, *Multidatabase Systems: An Advanced Solution for Global Information Sharing*, chapter 4, pages 180–188. IEEE Computer Society Press, 1993.
Originally appeared in IEEE Computer, 19(12), Dec 1986, pp. 10-18. Discusses MRDSM and the approach taken in designing this multidatabse language system with a federated approach.

[34] A. Motro. Supverviews: Virtual integration of multiple databases. In A. R. Hurson, M. W. Bright, and S. H. Pakzad, editors, *Multidatabase Systems: An Advanced Solution for Global Information Sharing*, chapter 5, pages 292–305. IEEE Computer Society Press, 1993.
Originally appeared in IEEE Trans. on Software Eng., SE-13(7), July 1987, pp. 785-798. Virtual databases are used in this approach to schema integration for a global schema multidatabase. The superview is one of the earliest accepted facilities for schema integration.

[35] A. Mukherjee and D. P. Siewiorek. Mobility: A medium for computation, communication and control. In *Workshop on Mobile Computing Systems and Applications*. IEEE Computer Society Technical Committee on Operating Systems, December 1994.
This position paper discusses basic issues of mobile computing. A taxonomy of applications is also presented, along with existing models of mobile computing.

[36] E. Pitoura and B. Bhargava. Maintaining consistency of data in mobile distributed environments.
Authors are from the Department of Computer Science, Purdue University, West Lafayette, IN 47907-1398. A shorter version of this paper appeared in the 15th International Conference on Distributed Computing Systems (ICDCS95). Discusses issues of mobile computing and how database consistency can be maintained. It also discusses transactions on mobile systems with weak and strict semantics.

[37] E. Pitoura and B. Bhargava. Dealing with mobility: Issues and research challenges.
Technical Report CSD-TR-93-070, Department of Computer Science, Purdue University, West Lafayette, IN 47907, November 1993. Identifies and discusses issues in mobile computing.

[38] E. Pitoura and B. Bhargava. A framework for providing consistent and recoverable agent-based access to heterogeneous mobile databases. *SIGMOD Record*, 24(3):44–49, September 1995.
An agent-based architectural model is discussed to implement mobile databases that are functional, robust and recoverable.

[39] S. Ram and V. Ramesh. A blackboard-based cooperative system for schema integration. *IEEE Expert*, pages 56–62, June 1995.
This paper describes an AI-based framework for schema integration. The framework allows a smooth cooperation between human users and software components as knowledge sources in the system's performance of schema integration. Powerful and well-designed, but the actual software AI component that can make conflict resolution decisions is not discussed.

[40] F. Saltor, M. G. Castellanos, and M. Garcia-Solaco. Overcoming schematic discrepancies in interoperable databases. In D. K. Hsiao, E. J. Neuhold, and R. Sacks-Davis, editors, *IFIP DS-5 Semantics of Interoperable Database Systems*, volume 1, pages 184–198, Lorne, Victoria, Australia, November 1992. IFIP and CITRI and Australian Computer Society and La Trobe University.
This paper discusses a method of overcoming schematic discrepancies using a framework of two dimensions: generalization and aggregation. The method, however, is applied only to relational and object databases, and do not consider update operations. There is no apparent application for schema integration if the databases to integrate are of different data models.

[41] A. Sheth and V. Kashyap. So far (schematically) yet so near (semantically). In D. K. Hsiao, E. J. Neuhold, and R. Sacks-Davis, editors, *IFIP DS-5 Semantics of Interoperable Database Systems*, volume 1, pages 282–301, Lorne, Victoria, Australia, November 1992. IFIP and CITRI and Australian Computer Society and La Trobe University.
This paper defines a model of specifying semantic relationships between objects, using the concept of semantic proximity. It is shown that semantic proximity can be used to measure the relationship between objects despite the presence of various types of discrepancies and conflicts. This provides a means of resolving semantic heterogeneity by providing the means to relate schematically different but semantically related objects.

[42] A. P. Sheth and H. Marcus. Schema analysis and integration: Methodology, techniques and prototype toolkit. Technical Memorandum TM-STS-019981/1, Bell Communications Research, March 1992.
Discusses BERDI, a tool for schema analysis and integration. BERDI is an X Windows application which assists the integrator interactively in schema integration. The authors maintain that conflict resolution cannot be carried out automatically by any system. Designer and users must work with the system closely.

[43] J. M. Smith, P. A. Bernstein, U. Dayal, N. Goodman, T. Landers, K. W. T. Lin, and E. Wong. Multibase – integrating heterogeneous distributed database systems. In A. Gupta, editor, *Integration of Information Systems: Bridging Heterogeneous Databases*, pages 163–175. IEEE Press, 1989.
Originally appeared in Proc. of AFIPS, 1981, pp. 487-499. This paper describes Multibase. *It allows the integration of several pre-existing and heterogeneous databases. Multibase has a three-level schema architecture built bottom up: unmodified local host schemas at the bottom, an integration schema and one local schema per database in the middle, and the global schema on top. Each local schema is defined in the functional data model for uniformity, whereas the local host schemas remain in their original forms. The query processing design is also presented.*

[44] P. N. Smith and S. L. Guengerich. *Client/Server Computing.* SAMS Publishing Professional Reference Series. SAMS Publishing (A Division of Prentice Hall Computer Publishing), second edition, 1994.
A book that provides introductory and detailed information about client/server systems.

[45] W. Staniszkis. Integrating heterogeneous databases. In A. Gupta, editor, *Integration of Information Systems: Bridging Heterogeneous Databases*, pages 231–250. IEEE Press, 1989.
Originally appeared in State of the Art Report on Relational Databases, Pergamon Press Ltd, Chap 16, 1986, pp. 229-287. This is a report of the state of the art in relational database research. It summarizes the desirable features of a good database system, which includes a need for good semantic representation for multidatabases. Mention is made about current (at time of writing) research work on multidatabase systems, including ADDS, Mermaid, Multibase, NDMS and others. A general multidatabase system architecture is also presented. This report also summarizes a general set of phases for multidatabase design.

[46] J. Tan. Schema integration for mobile databases. In Dr. Arkady Zaslavsky, editor, *Proceedings of the First Australian Workshop on Mobile Computing, Databases and Applications.* Department of Computer Technology, Monash University, February 1996.
Discusses a number of existing schema integration methods and examines their applicability for mobile database systems.

[47] G. Thomas, G. R. Thompson, C-W. Chung, E. Barkmeyer, F. Carter, M. Templeton, S. Fox, and B. Hartman. Heterogeneous distributed database systems for production use. In A. R. Hurson, M. W. Bright, and S. H. Pakzad, editors, *Multidatabase Systems: An Advanced Solution for Global Information Sharing*, chapter 5, pages 306–335. IEEE Computer Society Press, 1993.
Originally appeared in ACM Computing Surveys, 22(3), Sept. 1990, pp. 237-266. Discusses and compares a number of production-use distributed database systems including the Amoco Distributed Database System (ADDS), DATAPLEX, IMDAS, Ingres, Mermaid, MULTIBASE and SYBASE. The discussion focuses on schema integration, query and transaction management, as well as the administration of each system.

[48] J. Patrick Thompson. *Data with semantics : data models and data management.* Van Nostrand Reinhold, New York, 1989.
A very good book on semantic data models, which discussed the theoretic basis of semantic data models.

[49] M. Tresch and M. H. Scholl. Schema transformation without database reorganization. *SIGMOD Record*, 22(1):21–27, March 1993.
Discusses the advantage of using schema transformation, instead of actual database reorganization in cases of schema evolution. Preserving database independence (or local autonomy) this way is less expensive than actual reorganization due to schema modification. They present examples of schema transformation applied to object-oriented database schemas.

[50] V. Ventrone and S. Heiler. Semantic heterogeneity as a result of domain evolution. In A. R. Hurson, M. W. Bright, and S. H. Pakzad, editors, *Multidatabase Systems: An Advanced Solution for Global Information Sharing*, chapter 3, pages 113–117. IEEE Computer Society Press, 1993.
Originally appeared in SIGMOD Record, 20(4), Dec. 1991, pp. 16-20. Problems of semantic heterogeneity are discussed as results of domain evolution, and general solutions are proposed to avoid them or solve them if they occur.

[51] J. Widom and S. Ceri, editors. *Active Database Systems: Triggers and Rules for Advanced Database Processing.* Morgan Kaufmann Publishers, Inc., 340 Pine Street, Sixth Floor, San Francisco, CA 94104-3205, USA, 1996.
An extensive source of information about the basics of active database systems and the state of current research about the subject. It includes a detailed discussion of existing research prototypes of active database systems. Both theoretical and practical topics are covered.

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