

# CURRENT STATUS OF R&D IN TRUSTED DATABASE MANAGEMENT SYSTEMS<sup>1</sup>

Bhavani Thuraisingham

The MITRE Corporation, Burlington Road, Bedford, MA

Since the Air Force Summer Study in 1982 [AFSB83], several R&D efforts in Trusted Database Management Systems (TDBMSs) have been initiated. These include efforts in (i) Trusted Relational DBMS, (ii) Trusted Object-Oriented DBMS, (iii) Trusted Distributed DBMS, (iv) Trusted High Performance DBMS, and (v) other TDBMS research topics such as inference and aggregation, polyinstantiation, concurrency control, and auditing. In this paper, we provide a global view of TDBMS R&D.<sup>2</sup>

TDBMS technology evolved from computer security technology, and relational database technology.<sup>3</sup> The earliest published work on TDBMS was the design of the Hinke Schaefer architecture [HINK75], where database data is stored in single level operating system segments and access to these segments is controlled by the operating system. Some of the other early work in the late 70's and early 80's included the data model developed by IP Sharp Associates [GROH76], the Ph.D. Thesis of Deborah Downs at U.C.L.A. [DOWN80], and the Naval Surveillance Model developed at MITRE [GRAU82].

These developments eventually led to the Air Force Summer Study which took place in 1982 [AFSB83]. At that summer study, three groups were formed. The first group focused on near-term approaches to designing a TDBMS. They defined three approaches for designing a TDBMS: (i) the integrity lock approach, where a trusted filter is used to mediate between an untrusted front-end user interface and an untrusted back-end DBMS, (ii) the distributed approach, where a trusted front-end machine is connected to untrusted back-end DBMS machines, each operating at a single level, and (iii) the kernelized approach, where the DBMS controls access to its own objects. The second group focused on security issues for military message systems, and the third group focused on research issues such as inference and aggregation. Following the Air Force Summer Study, some early TDBMS prototypes, mainly based on the integrity lock approach, were developed at MITRE [GRAU84, GRAU85, BURN86]. Some comments on the vulnerability of the integrity lock approach are documented in [DENN84, DENN85].

While these early developments contributed to the advancement of TDBMS R&D to a great extent, it was the SeaView project, carried out by SRI, that has provided a focal point for database security [DENN86a, DENN87, DENN88, LUNT88a, LUNT90a]. The SeaView project was initiated as a longer-term solution to the design and development of a high assurance TDBMS. The project addressed some difficult issues such as element level classification and polyinstantiation.<sup>4</sup> Parallel efforts on developing a high assurance TDBMS were also initiated by the Honeywell group (now called Secure Computing Technology Center), involved with the Lock Data Views project [DILL86, DWYE87, DWYE88, STAC88, HAIG90, STAC90, STAC91], and TRW's ASD-Views Project [JACK88, GARV88]. Researchers involved in these three projects also investigated solutions to problems such as inference<sup>5</sup> [DENN86b, MORG87, THUR87, HINK88, LUNT89a].

Another effort which focused on the near-term approach to developing a TDBMS is the SDDBMS

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<sup>1</sup> This paper will also be published in CIPHER Newsletter.

<sup>2</sup> We have tried to include most of the efforts to the best of our knowledge. The paper also provides an extensive bibliography which will serve as a reference guide for anyone interested in database security. We have listed most of the relevant papers. However, due to the numerous papers that have been published on this topic, many interesting papers may have been omitted. In addition to the references listed in this paper, papers on database security have been published in the Proceedings of the IEEE Symposia on Security and Privacy, Proceedings of the National Computer Security Conferences, Proceedings of the Computer Security Application Conferences, the series on Database Security: Status and Perspective by North Holland, and the Proceedings of the Computer Security Foundations Workshops. Papers on database security have also been published in the journal Computers and Security, Elsevier Science Publishers. A survey of the developments in database security is given in [THUR89a].

<sup>3</sup> For a discussion on computer security technology, we refer to [GASS88]. A DoD security policy which has influenced much of the work in computer security is reported in [BELL75].

<sup>4</sup> Polyinstantiation is the mechanism proposed by the SeaView project to address signalling channels. It enables two different tuples with the same primary key to exist at different security levels.

<sup>5</sup> Users could pose sets of queries and infer information to which they are not authorized. This problem is known as the inference problem.

project by Unisys [OCON88, JENS89]. This TDBMS utilized the distributed approach defined by the Air Force Summer Study Group.<sup>6</sup> A recent TDBMS design is that of SWORD by the RSRE group (now called DRA) in the United Kingdom [WISE89, WISE90]. The designers of SWORD have argued that in many instances polyinstantiation could cause serious operational problems and, therefore, have proposed alternate approaches.

While the various designs and prototypes of TDBMSs were being developed, the National Computer Security Center (NCSC) held an invitational workshop in 1986 [NCSC86] to initiate an effort to produce an interpretation of the Trusted Computer Systems Evaluation Criteria (TCSEC) [TCSE85] for database management systems. This interpretation is called the Trusted Database Interpretation (TDI). Much work was done during the past few years in producing this document, which was published in 1991 [TDI91].

R&D on trusted relational DBMS, together with the effort on the TDI, provided the foundation for several vendors to incorporate multilevel security into their DBMS products. As a result, we have products by various corporations including Oracle (Trusted Oracle), Sybase (Secure SQL Server), Teradata (Teradata Release 5), Informix (Online Secure Informix), ITI (Trusted Rubix), DEC (Secure RDB), and Atlantic Research Corporation (Trudata).<sup>7</sup> These products are targeted to be evaluated using the TDI.<sup>8</sup>

Several research efforts on trusted non-relational DBMSs are also in progress. The most popular secure non-relational data model that is being studied is the object-oriented data model. The earliest work on multilevel object-oriented data models was published by Keefe, Tsai, and Thuraisingham [KEEF88a]. Their approach was to incorporate security into the data model utilized by SMALLTALK (trademark of ParcPlace Systems). Since then, a burst of activities on secure object-oriented data models followed (see KEEF88b, MEAD88, MILL89, LUNT89b, JAJO90a, KEEF89a, KEEF89b, THUR89b, THUR89c, THUR89d, THUR90a, GARV90, SAND91).<sup>9</sup> These models studied the simple

properties of an object. In [THUR90b], some issues on handling composite and complex objects in a multilevel environment were investigated. Issues on using the object-oriented approach to securing multimedia database management systems are being investigated at MITRE [THUR90c]. Security issues for an object model which supports n-ary relationships are described in [MORG90].

Some progress has been made on trusted distributed database management systems (TDDDBMS) during the past few years at MITRE. The initial investigation included security issues in homogeneous DDBMS as well as developing a prototype for secure distributed query processing. Simulation studies on secure query processing and concurrency control algorithms have also been conducted. An investigation of security issues in heterogeneous DDBMS has also begun. The results on TDDDBMSs can be found in [RUBI90a, RUBI90b, RUBI91, THUR90d]. Some work on concurrency control in a TDDDBMS has been reported recently in [GREE91].

Two of the problems present in TDBMSs that are getting considerable attention are (i) Polyinstantiation and (ii) Inference and Aggregation. The SeaView project developed a multilevel relational data model which supported polyinstantiation [DENN87]. Jajodia and Sandhu examined the data model utilized by SeaView and identified problems with that model. Subsequently, they proposed an alternate update semantics utilizing polyinstantiation [JAJO90b, JAJO90c, JAJO90d, JAJO91a]. Later, Lunt proposed a modified version of the original SeaView model based on the notion of dynamic multivalued dependencies [LUNT90b]. In [JAJO90e, JAJO91b], Jajodia and Sandhu have disagreed with this modified version of the SeaView model. In the meantime, Wiseman at RSRE [WISE89, WISE90] has seriously questioned the use of polyinstantiation in multilevel relations and he has proposed ways of avoiding polyinstantiation. Other work includes LDV's approach to polyinstantiation [HAIG90] and Burns' proposal on alternatives to polyinstantiation [BURN90, BURN91].

Inference is another area where different approaches have been proposed to handle it. The early works on this problem were by Denning, Morgenstern, Thuraisingham, and Hinke [DENN86, MORG87, THUR87, HINK88]. While most approaches proposed that the multilevel database should be designed correctly to handle potential unauthorized inferences, Thuraisingham et al. proposed approaches for handling inferences during query processing (THUR87, THUR88, KEEF89c). However, the more recent work of Thuraisingham, Ford, and Collins, at MITRE, take an integrated approach to the inference problem (THUR89e, FORD90, COLL90, THUR91a). That is, the inference problem is handled during database design, during database

<sup>6</sup> Note that although this approach is a distributed approach, it is a design approach for a trusted centralized DBMS. The data is distributed based on security levels.

<sup>7</sup> Note that the product name is written in parenthesis following the name of the company.

<sup>8</sup> Papers on some of these products have been published in the proceedings of the NCS conferences and the Computer Security Applications Conferences. A discussion is also given in [CAMP91].

<sup>9</sup> Additional papers on multilevel security issues for object-oriented systems were presented at the Workshop on object-oriented database security organized by T.

Lunt at Karlsruhe, Germany in April 1990. The collection of papers presented is referenced in [EISS90].

updates, as well as during database query operation. The use of expert system techniques to handle the inference problem was proposed initially by Ford Aerospace Corporation [BUCZ89] and later by MITRE and SRI [THUR91b, THUR91c, GARV91]. The use of a conceptual data model for representing and reasoning about multilevel applications has been investigated in [SMIT90, THUR90e]. Complexity results on the inference problem are given in [THUR90f]. Recently, Binns has shown that by polyinstantiating data one introduces security violations via inference [BINN91].

While much work has been done on the inference problem, very little work has been done on the aggregation problem. The most notable work on this problem is by T. Y. Lin [LIN90] at California State University. Some work has also been carried out at NRL by C. Meadows [MEAD90]. At the 3rd RADC Database Security Workshop, it was debated whether aggregation was a special form of inference.<sup>10</sup>

Security issues for high performance database management systems are also being investigated. The most notable effort is Teradata's work on securing the database machine DBC 1012. NRL has initiated a program for investigating the use of parallel architectures for developing a Trusted DBMS [FROS88]. Other efforts on TDBMS, preliminary in nature, are on auditing [JAJ089, SCHA89], DBMS integrity [SCHE86, HAIG87, SAND90], and operating system support for TDBMS [GRAU89]. Discretionary security issues for TDBMSs are described in [LUNT88b].<sup>11</sup> Research efforts on the security impact on concurrency control are also in progress [JAJ090f, KEEF90, MAIM90, THUR90d]). Issues on the design of a knowledge base management system are described in [THUR90g] (based on the relational data model), [BERS90] (based on the rule-based model), and [GARV90] (based on the object-oriented data model). Preliminary work on multilevel deductive database management systems is reported in [THUR90h]. Other multilevel data models that have received some attention include the entity relationship model [GAJN88] and the functional data model [THUR89f].

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<sup>10</sup> Draft companion documents to the TDI on Inferences and Aggregation have also been written.

<sup>11</sup> Numerous other papers on discretionary security for DBMSs have been published since the 70's. We do not list them here as our main focus is on multilevel security.

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