

# A Practical Implementation of a Real-time Intrusion Prevention System for Commercial Enterprise Databases

ULF T. MATTSSON

Chief Technology Officer

Protegrity

ulf.mattsson@protegrity.se <http://www.protegrity.com>

*Abstract:* - Modern intrusion detection systems are comprised of three basically different approaches, host based, network based, and a third relatively recent addition called procedural based detection. The first two have been extremely popular in the commercial market for a number of years now because they are relatively simple to use, understand and maintain. However, they fall prey to a number of shortcomings such as scaling with increased traffic requirements, use of complex and false positive prone signature databases, and their inability to detect novel intrusive attempts. This intrusion detection system interacts with the access control system to deny further access when detection occurs and represent a practical implementation addressing these and other concerns. This paper presents an overview of our work in creating a practical database intrusion detection system. Based on many years of Database Security Research, the proposed solution detects a wide range of specific and general forms of misuse, provides detailed reports, and has a low false-alarm rate. Traditional commercial implementations of database security mechanisms are very limited in defending successful data attacks. Authorized but malicious transactions can make a database useless by impairing its integrity and availability. The proposed solution offers the ability to detect misuse and subversion through the direct monitoring of database operations inside the database host, providing an important complement to host-based and network-based surveillance. Suites of the proposed solution may be deployed throughout a network, and their alarms man-aged, correlated, and acted on by remote or local subscribing security services, thus helping to address issues of decentralized management.

*Key-Words:* - Isolation, Intrusion Tolerance, Database Security, Encryption, GLBA, HIPAA.

## 1 Introduction

Most companies solely implement perimeter-based security solutions, even though the greatest threats are from internal sources. Additionally, companies implement network-based security solutions that are designed to protect network resources, despite the fact that the information is more often the target of the attack. Recent development in information-based security solutions addresses a defense-in-depth strategy and is independent of the platform or the database that it protects. As organizations continue to move towards digital commerce and electronic supply chain management, the value of their electronic information has increased correspondingly and the potential threats, which could compromise it, have multiplied. With the advent of networking, enterprise-critical applications, multi-tiered architectures and web access, approaches to security have become far more sophisticated. A span of research from authorization [9, 28, 14], to inference control [1], to multilevel secure databases [33, 31], and to multi-level secure transaction processing [3], addresses primarily how to protect the security of a database, especially its confidentiality. However, limited solutions has been

presented on how to practically implement a solution to survive successful database attacks, which can seriously impair the integrity and availability of a database. Experience with data-intensive applications such as credit card billing, has shown that a variety of attacks do succeed to fool traditional database protection mechanisms. One critical step towards attack resistant database systems is intrusion detection, which has attracted many researchers [7, 21, 13, 10, 23, 26, 22, 17, 18]. Intrusion detection systems monitor system or network activity to discover attempts to disrupt or gain illicit access to systems. The methodology of intrusion detection can be roughly classed as being either based on statistical profiles [15, 16, 30] or on known patterns of attacks, called signatures [11, 8, 27, 12, 32]. Intrusion detection can supplement protection of network and information systems by rejecting the future access of detected attackers and by providing useful hints on how to strengthen the defense. However, intrusion detection has several inherent limitations: Intrusion detection makes the system attack-aware but not attack-resistant, that is, intrusion detection itself cannot maintain the integrity and availability of the database in face of

attacks. Achieving accurate detection is usually difficult or expensive. The false alarm rate is high in many cases. The average detection latency in many cases is too long to effectively confine the damage. To overcome the limitations of intrusion detection, a broader perspective is introduced, saying that in addition to detecting attacks, countermeasures to these successful attacks should be planned and deployed in advance. In the literature, this is referred to as survivability or intrusion tolerance. In this paper, we will address a useful technique for database intrusion prevention, and present the design of a practical system, which can do attack prevention.

## 2 Problem Formulation

In order to protect information stored in a database, it is known to store sensitive data encrypted in the database. To access such encrypted data you have to decrypt it, which could only be done by knowing the encryption algorithm and the specific decryption key being used. The access to the decryption keys could be limited to certain users of the database system, and further, different users could be given different access rights. Specifically, it is preferred to use a so-called granular security solution for the encryption of databases, instead of building walls around servers or hard drives. In such a solution, which is described in this paper, a protective layer of encryption is provided around specific sensitive data-items or objects. This prevents outside attacks as well as infiltration from within the server itself. This also allows the security administrator to define which data stored in databases are sensitive and thereby focusing the protection only on the sensitive data, which in turn minimizes the delays or burdens on the system that may occur from other bulk encryption methods. Most preferably the encryption is made on such a basic level as in the column level of the databases. Encryption of whole files, tables or databases is not so granular, and does thus encrypt even non-sensitive data. It is further possible to assign different encryption keys of the same algorithm to different data columns. With multiple keys in place, intruders are prevented from gaining full access to any database since a different key could protect each column of encrypted data.

### 2.1 New Requirements

The complexity of this task was dramatically increased by the introduction of multi-platform integrated software solutions, the proliferation of

remote access methods and the development of applications to support an increasing number of business processes. In the "good old days", files and databases contained fewer types of information (e.g., payroll or accounting data) stored in centralized locations, which could only be accessed, by a limited number of individuals using a handful of controlled access methods. As more types of information were migrated to electronic formats (and ever more databases proliferated, often with little planning), there was a simultaneous increase in the number of users, access methods, data flows among components and the complexity of the underlying technology infrastructure. Add to this the demand from users forever more sophisticated uses of information (data mining, CRM, etc.), which are still evolving, and the management's enhanced awareness of the value of its information. Database intrusion tolerance can mainly be enforced at two possible levels: database level and transaction level. Although transaction level methods cannot handle database level attacks, it is shown that in many applications where attacks are enforced mainly through malicious transactions transaction level methods can tolerate intrusions in a much more effective and efficient way. Database level intrusion tolerance techniques can be directly integrated into an intrusion tolerance framework with the ability to back out from a malicious database transaction. Two levels of intrusion response behavior may be deployed; an intrusion into the database system as such, or an intrusion to the actual data. In the first case focus is on preventing from further malicious activities, i.e. you have had an attack but it is handled by next layer of security. In the second the behavior is a rollback of the data written, to handle the attack afterwards. The importance of privacy and security of sensitive data stored in relational databases is fueled by strong new legislation and the continuing push toward Web-accessible data. These products and services allow organizations to comply with data-privacy regulations, requirements and guidelines such as the recently enacted U.S. Gramm-Leach-Bliley Act (GLBA)...significantly affecting financial institutions and insurance companies; the U.S. Health Information Portability and Accountability Act (HIPAA)...covering the healthcare industry; the European Directive 95/46/EC on data protection, and E.U./U.S. Safe Harbor considerations; Canada's Personal Information Protection and Electronic Document Act (PIPEDA); Germany's Federal Data Protection Act; the UK Data Protection Act; Australia's Privacy Act); the Japan JIS Q 15001:1999 Requirements for Compliance Program on Personal

Information Protection; the U.S. Software and Information Industry Association (SIIA) - An Electronic Citadel - A Method for Securing Credit Card and Private Consumer Data in E-Business Sites; the BITS (the technology group for the Financial Services Roundtable) Voluntary Guidelines for Aggregation Services; and potentially much more..

### **3 Problem Solution**

In the above-mentioned solutions the security administrator is responsible for setting the user permissions. Thus, for a commercial database, the security administrator operates through a middle-ware application, the access control system (ACS), which provides authentication, encryption and decryption services. The ACS is tightly coupled to the database management system (DBMS) of the database. The ACS controls access in real-time to the protected elements of the database. Such a security solution provides separation of the duties of a security administrator from a database administrator (DBA). The DBA's role could for example be to perform usual DBA tasks, such as extending tablespaces etc, without being able to see (decrypt) sensitive data. The SA could then administer privileges and permissions, for instance add or delete users. For most commercial databases, the database administrator has privileges to access the database and perform most functions, such as changing password of the database users, independent of the settings by the system administrator. An administrator with root privileges could also have full access to the database. This is an opening for an attack where the DBA can steal all the protected data without any knowledge of the protection system above. The attack is in this case based on that the DBA impersonates another user by manipulating that users password, even though a hash algorithm enciphers the user's password. An attack could proceed as follows. First the DBA logs in as himself, and then the DBA reads the hash value of the users password and stores this separately. Preferably the DBA also copies all other relevant user data. By these actions the DBA has created a snapshot of the user before any altering. Then the DBA executes the command "ALTER USER username IDENTIFIED BY newpassword". The next step is to log in under the user name "username" with the password "newpassword" in a new session. The DBA then resets the user's password and other relevant user data with the previously stored hash value. Thus, it is important to

further separate the DBA's and the SA's privileges. For instance, if services are outsourced, the owner of the database contents may trust a vendor to administer the database. Then the role of the DBA belongs to an external person, while the important SA role is kept within the company, often at a high management level. Thus, there is a need for preventing a DBA to impersonate a user in an attempt to gain access to the contents of the database. The DBA attack prevention described here is specific to databases with internal authentication. Databases that utilizes external (OS level) authentication provides a level of separation of duties, and the database encryption system, or intrusion prevention system, can verify that the database session is properly authenticated by the external authentication system before any decryption of sensitive data is allowed.

#### **3.1 A New Approach**

The solution protects the data in storage in a database. The architecture is built on top of a traditional COTS (Commercial-Of-The-Shelf) DBMS. Within the framework, the Intrusion Detector identifies malicious transactions based on the history kept (mainly) in the log. The Intrusion Assessor locates the damage caused by the detected transactions. The Intrusion Protector prevents the damage using a rollback. The Intrusion Manager restricts the access to the objects that have been identified by the Intrusion Assessor as 'under attack', and unlocks an object after it is cleared by the security officer. The Policy Enforcement Agent (PEA) (a) functions as a filter for normal user transactions that access critical fields in the database, and (b) is responsible for enforcing system-wide intrusion prevention policies. For example, a policy may require the PEA to reject every new transaction submitted by a user as soon as the Intrusion Detector finds that the user submits a malicious transaction. It should be noticed that the system is designed to do all the intrusion prevention work on the fly without the need to periodically halt normal transaction processing.

#### **3.2 Intrusion Prevention Solution**

The method allows for a real time prevention of intrusion by letting the intrusion detection process interact directly with the access control system, and change the user authority dynamically as a result of the detected intrusion. The hybrid solution combines benefits from database encryption toolkits and

secure key management systems. The hybrid solution also provides a single point of control for database intrusion prevention, audit, privacy policy management, and secure and automated encryption key management (FIPS 140 Level 3). The Database Intrusion Prevention is based on 'context checking' against a protection policy for each critical database column, and prevents internal attacks also from root, DBA, or 'buffer overflow attacks', by automatically stopping database operations that are not conforming to the Database Intrusion Prevention Policy rules. The Database Intrusion Prevention and alarm system enforces policy rules that will keep any malicious application code in a sand box regarding database access. The policy enforcement system, integrated with an external network authentication system, perform the following basic checking:

- Session Authentication and Session Encryption.
- Software Integrity, Data Integrity, and Meta Data Integrity.
- Time of Access, and other policy rules.

In database security, it is a well-known problem to avoid attacks from persons who have access to a valid user-ID and password. Such persons cannot be denied access by the normal access control system, as they are in fact entitled to access to a certain extent. Such persons can be tempted to access improper amounts of data, by-passing the security. Such persons can be monitored and controlled by this database intrusion prevention system and automatically be locked out from database operations that are not conforming to the Database Intrusion Prevention Policy rules. Other solutions in this problem area have been suggested:

*Network-Based Detection* - Network intrusion monitors are attached to a packet-filtering router or packet sniffer to detect suspicious behavior on a network as they occur. They look for signs that a network is being investigated for attack with a port scanner, that users are falling victim to known traps like .url or .lnk, or that the network is actually under an attack such as through SYN flooding or unauthorized attempts to gain root access (among other types of attacks). Based on user specifications, these monitors can then record the session and alert the administrator or, in some cases, reset the connection. Some examples of such tools include Cisco's NetRanger and ISS' RealSecure as well as some public domain products like Klaxon that focus on a narrower set of attacks.

*Server-Based Detection* - These tools analyze log, configuration and data files from individual servers as attacks occur, typically by placing some type of agent on the server and having the agent report to a central console. Some examples of these tools include Axent's OmniGuard Intrusion Detection (ITA), Security Dynamic's Kane Security Monitor and Centrax's eNTrax as well as some public domain tools that perform a much narrower set of functions like Tripwire which checks data integrity. Tripwire will detect any modifications made to operating systems or user files and send alerts to ISS' RealSecure product. RealSecure will then conduct another set of security checks to monitor and combat any intrusions.

*Security Query and Reporting Tools* - These tools query NOS logs and other related logs for security events or they glean logs for security trend data. Accordingly, they do not operate in real-time and rely on users asking the right questions of the right systems. A typical query might be how many failed authentication attempts have we had on these NT servers in the past two weeks." A few of them (e.g., SecurIT) perform firewall log analysis. Some examples of such tools include Bindview's EMS/NOSadmin and Enterprise Console, SecureIT's SecureVIEW and Security Dynamic's Kane Security Analyst.

### **3.3 Inference Detection**

A variation of conventional intrusion detection is detection of specific patterns of information access, deemed to signify that an intrusion is taking place, even though the user is authorized to access the information. A method for such inference detection, i.e. a pattern oriented intrusion detection, is disclosed in US patent 5278901 to Shieh et al.

None of these solutions are however entirely satisfactory. The primary drawback is that they all concentrate on already effected queries, providing at best information that an attack has occurred.

### **3.4 Intrusion Prevention Profile**

By defining at least one intrusion detection profile, each comprising at least one item (column access) access rate, associating each user with one of the profiles, receiving a query from a user, comparing a result of the query with the item access rates defined in the profile associated with the user, determining whether the query result exceeds the item access rates, and in that case notifying the access control

system to alter the user authorization, thereby making the received request an unauthorized request, before the result is transmitted to the user. According to this method, the result of a query is evaluated before it is transmitted to the user. This allows for a real time prevention of intrusion, where the attack is stopped even before it is completed. This is possible by letting the intrusion detection process interact directly with the access control system, and change the user authority dynamically as a result of the detected intrusion. The item access rates can be defined based the number of rows a user may access from an item, e.g. a column in a database table, at one time, or over a certain period of time. In a preferred implementation, the method further comprises accumulating results from performed queries in a record, and determining whether the accumulated results exceed any one of the item access rates. The effect is that on one hand, a single query exceeding the allowed limit can be prevented, but so can a number of smaller queries, each one on its on being allowed, but when accumulated not being allowed. It should be noted that the accepted item access rates not necessarily are restricted to only one user. On the contrary, it is possible to associate an item access rate to a group of users, such as users belonging to the same access role (which defines the user's level of security), or connected to the same server. The result will be restricting the queries accepted from a group of users at one time or over a period of time. The user, role and server entities are not exclusive of other entities which might benefit from a security policy. According to an implementation of the method, items subject to item access rates are marked in the database, so that any query concerning the items automatically can trigger the intrusion detection process. This is especially advantageous if only a few items are intrusion sensitive, in which case most queries are not directed to such items. The selective activation of the intrusion detection will then save time and processor power. According to another implementation of the method, the intrusion detection policy further includes at least one inference pattern, and results from performed queries are accumulated in a record, which is compared to the inference pattern, in order to determine whether a combination of accesses in the record match the inference policy, and in that case the access control system is notified to alter the user authorization, thereby making the received request an unauthorized request, before the result is transmitted to the user. This implementation provides a second type of intrusion detection, based

on inference patterns, again resulting in a real time prevention of intrusion.

## 4 Related Work

There is a variety of related research efforts that explore what one can do with audit data to automatically detect threats to the host. An important work is MIDAS [50], as it was one of the original applications of expert systems—in fact using P-BEST—to the problem of monitoring user activity logs for misuse and anomalous user activity. CMDS, by SAIC, demonstrated another application of a forward-chaining expert-system, CLIPS, to a variety of operating system logs [48]. USTAT [39] offered another formulation of intrusion heuristics using state transition diagrams [46], but by design remained a classic forward-chaining expert system inference engine. ASAX [37] introduced the Rule-based Sequence Evaluation Language (RUSSEL) [42], which is tuned specifically for the analysis of host audit trails. Recent literature from the RAID conferences, as well as IEEE Security and Privacy, the DARPA program on survivability that concentrated on detecting and surviving attacks, and a large scale DARPA project called DemVal, are dealing with the survivability of a database. The idea of attack prevention, that will not allow access after a threshold is reached, is also discussed in the SRI Apache IDs system. The approach is sometimes also called application level intrusion detection, rather than procedural intrusion detection.

## 5 Conclusion

While the existing paradigms of computer security are still very useful and serve perfectly well in their capacities, there has existed a gap in the computer security space. Our technology and approach fills that gap by providing practical application based intrusion detection and response. We suggest that this gives The Hybrid the unique ability to detect and halt completely novel attacks that have yet to be seen on the Internet, and better yet, we have the ability to protect the first person to see a new attack or exploit. No one needs to be sacrificed to the new virus or worm anymore. In essence, we have learned to solve the right problem. Removing all software vulnerabilities is clearly an unsolvable problem. Providing restrictive and onerous barriers to software use makes the software uncomfortable and difficult to use. Monitoring and controlling program execution at run time through behavioral control is the missing piece in the security puzzle. The

complete puzzle has three pieces; data control (encryption), access control, and behavioral control.

In conclusion, while the overall complexity of the security program has dramatically increased, enterprises can still implement effective security solutions by integrating sound external protection and internal security controls with appropriate security audit procedures. There are no guarantees that any one approach will be able to deal with new and innovative intrusions in increasingly complex technical and business environments. However, implementation of an integrated security program which is continuously audited and monitored provides the multiple layers of protection needed to maximize protection as well as historical information to support management decision-making and future policy decisions. This solution protects the data during transport, providing security from the server to the client. The client device requires a means of accessing the secure data, and a means of access control and secure storage of locally held information. The implementation for Laptops and PDAs provides mandatory access control, secure local storage of sensitive data and key management capabilities. This solution includes a method for detecting intrusion in a database, managed by an access control system, comprising defining at least one intrusion detection profile, each comprising at least one item access rate and associating each user with one of the profiles. Further, the method determines whether a result of a query exceeds any one of the item access rates defined in the profile associated with the user, and, in that case, notifies the access control system to alter the user authorization, thereby making the received request an unauthorized request, before the result is transmitted to the user. The method allows for a real time prevention of intrusion by letting the intrusion detection process interact directly with the access control system, and change the user authority dynamically as a result of the detected intrusion.

The GLBA/OCC and the VISA U.S.A. CISP requirements as well as other requirements in the Health Care Industry, and Safe Harbor will require a unique demonstration of cooperative and open but protected communication, storing information among individuals and organizations across competitive lines and regulatory boundaries safeguarding non-public personal information. Information sharing among reliable and reputable experts can help institutions reduce the risk of information

system intrusions. The OCC encourages management to participate in information-sharing mechanisms as part of an effort to detect and respond to intrusion and vulnerabilities. Financial institutions have to work together in an unprecedented fashion with other financial institutions, service providers, software vendors, trade associations, regulators, and other industries to share information and strategies to respond to legal requirements and media reports or perceptions that could decrease public confidence in the financial services industry. With the introduction of regulatory privacy acts like the U.S. Gramm-Leach-Bliley Act, the U.S. HIPAA, the U.S. FDA 21 CFR 11 and the E.U. member states privacy laws, companies are being mandated to provide more detailed information regarding the usage and access of customer and consumer data.

#### References:

- [1] M. R. Adam. *Security-Control Methods for Statistical Database: A Comparative Study*. ACM Computing Surveys, 21(4), 1989.
- [2] P. Ammann, S. Jajodia, and P. Liu. *Recovery from malicious trans-actions*. IEEE Transactions on Knowledge and Data Engineering, 2001. To appear.
- [3] V. Atluri, S. Jajodia, and B. George. *Multilevel Secure Transaction Processing*. Kluwer Academic Publishers, 1999.
- [4] D. Barbara, R. Goel, and S. Jajodia. *Using checksums to detect data corruption*. In Proceedings of the 2000 International Conference on Extending Data Base Technology, Mar 2000.
- [5] P. A. Bernstein, V. Hadzilacos, and N. Goodman. *Concurrency Control and Recovery in Database Systems*. Addison-Wesley, Reading, MA, 1987.
- [6] S. B. Davidson. *Optimism and consistency in partitioned distributed database systems*. ACM Transactions on Database Systems, 9(3):456-581, September 1984.
- [7] D.E.Denning. *An intrusion-detection model*. IEEE Trans. on Software Engineering, SE-13:222-232, February 1987.
- [8] T.D. Garvey and T.F. Lunt. *Model-based intrusion detection*. In Proceedings of the 14th National Computer Security Conference, Baltimore, MD, October 1991.

- [9] P. P. Griffiths and B. W. Wade. *An Authorization Mechanism for a Relational Database System*. ACM Transactions on Database Systems, 1(3):242–255, September 1976.
- [10] P. Helman and G. Liepins. *Statistical foundations of audit trail analysis for the detection of computer misuse*. IEEE Transactions on Software Engineering, 19(9):886–901, 1993.
- [11] K. Ilgun. *Ustat: A real-time intrusion detection system for unix*. In Proceedings of the IEEE Symposium on Security and Privacy, Oak-land, CA, May 1993.
- [12] K. Ilgun, R.A. Kemmerer, and P.A. Porras. *State transition analysis: A rule-based intrusion detection approach*. IEEE Transactions on Software Engineering, 21(3):181–199, 1995.
- [13] R. Jagannathan and T. Lunt. *System design document: Next generation intrusion detection expert system (nides)*. Technical report, SRI International, Menlo Park, California, 1993.
- [14] S. Jajodia, P. Samarati, V. S. Subrahmanian, and E. Bertino. *A unified framework for enforcing multiple access control policies*. In Proceedings of ACM SIGMOD International Conference on Management of Data, pages 474–485, May 1997.
- [15] H. S. Javitz and A. Valdes. *The sri ides statistical anomaly detector*. In Proceedings IEEE Computer Society Symposium on Security and Privacy, Oakland, CA, May 1991.
- [16] H. S. Javitz and A. Valdes. *The nides statistical component description and justification*. Technical Report A010, SRI International, March 1994.
- [17] T. Lane and C.E. Brodley. *Temporal sequence learning and data reduction for anomaly detection*. In Proc. 5th ACM Conference on Computer and Communications Security, San Francisco, CA, Nov 1998.
- [18] Wenke Lee, Sal Stolfo, and Kui Mok. *A data mining framework for building intrusion detection models*. In Proc. 1999 IEEE Symposium on Security and Privacy, Oakland, CA, May 1999.
- [19] P. Liu, S. Jajodia, and C.D. McCollum. *Intrusion confinement by isolation in information systems*. Journal of Computer Security, 8(4):243–279, 2000.
- [20] P. Luenam and P. Liu. *Odam: An on-the-fly damage assessment and repair system for commercial database applications*. In Proc. 15th IFIP WFG11.3 Working Conference on Database and Application Security, Ontario, Canada, July 2001.
- [21] T. Lunt, A. Tamaru, F. Gilham, R. Jagannathan, C. Jalali, H. S. Javitz, A. Valdes, P. G. Neumann, and T. D. Garvey. *A real time intrusion detection expert system (ides)*. Technical report, SRI International, Menlo Park, California, 1992.
- [22] Teresa Lunt and Catherine McCollum. *Intrusion detection and response research at DARPA*. Technical report, The MITRE Corporation, McLean, VA, 1998.
- [23] T.F. Lunt. *A Survey of Intrusion Detection Techniques*. Computers & Security, 12(4):405–418, June 1993.
- [24] J. McDermott and D. Goldschlag. *Storage jamming*. In D.L. Spooner, S.A. Demurjian, and J.E. Dobson, editors, Database Security IX: Status and Prospects, pages 365–381. Chapman & Hall, London, 1996.
- [25] J. McDermott and D. Goldschlag. *Towards a model of storage jamming*. In Proceedings of the IEEE Computer Security Foundations Workshop, pages 176–185, Kenmare, Ireland, June 1996.
- [26] B. Mukherjee, L. T. Heberlein, and K.N. Levitt. *Network intrusion detection*. IEEE Network, pages 26–41, June 1994.
- [27] P.A. Porras and R.A. Kemmerer. *Penetration state transition analysis: A rule-based intrusion detection approach*. In Proceedings of the 8th Annual Computer Security Applications Conference, San Antonio, Texas, December 1992.
- [28] F. Rabitti, E. Bertino, W. Kim, and D. Woelk. *A model of authorization for next generation database systems*. ACM Transactions on Database Systems, 16(1):88–131, 1994.
- [29] P. Liu S. Ingsriswang. *Aaid: An application aware transaction level database intrusion detection system*. Technical report, Department of Information Systems, UMBC, Baltimore, MD, 2001.
- [30] D. Samfat and R. Molva. *Idamn: An intrusion detection architecture for mobile networks*. IEEE Journal of Selected Areas in Communications, 15(7):1373–1380, 1997.
- [31] R. Sandhu and F. Chen. *The multilevel relational (mlr) data model*. ACM Transactions on Information and Systems Security, 1(1), 1998.
- [32] S.-P. Shieh and V.D. Gligor. *On a pattern-oriented model for intrusion detection*. IEEE Transactions on Knowledge and Data Engineering, 9(4):661–667, 1997.
- [33] M. Winslett, K. Smith, and X. Qian. *Formal query languages for secure relational databases*. ACM Transactions on Database Systems, 19(4):626–662, 1994.
- [34] The U.S. Health Information Portability and Accountability Act (HIPAA) - compliance by October 2002 [www.hipaacomply.com](http://www.hipaacomply.com)
- [35] The European Union 95/46/EC Directive on Data Privacy - compliance October 1998 - and

individual EU member state privacy legislation - various compliance dates  
[http://europa.eu.int/comm/internal\\_market/en/dataprot/](http://europa.eu.int/comm/internal_market/en/dataprot/)

[36] EU/US Safe Harbor - compliance 11/1/2000  
[www.export.gov/safeharbor](http://www.export.gov/safeharbor)

[http://europa.eu.int/comm/internal\\_market/en/dataprot/modelcontracts/index.htm](http://europa.eu.int/comm/internal_market/en/dataprot/modelcontracts/index.htm)

[37] J. Habra, B. Le Charlier, A. Mounji, and I. Mathieu. ASAX: Software architecture and rule-based language for universal audit trail analysis. In Y. Deswarte et al., editors, *Computer Security – Proceedings of ESORICS 92*, volume 648 of LNCS, pages 435–450, Toulouse, France, Nov. 23–25, 1992. Springer-Verlag.

[38] L. T. Heberlein et al. A network security monitor. In *Proceedings of the 1990 IEEE Symposium on Security and Privacy*, pages 296–304, Oakland, California, May 7–9, 1990.

[39] K. Ilgun. USTAT: A real-time intrusion detection system for UNIX. In *Proceedings of the 1993 IEEE Symposium on Security and Privacy*, pages 16–28, Oakland, California, May 24–26, 1993.

[40] U. Lindqvist and P. A. Porras. Detecting computer and network misuse through the production-based expert system toolset (P-BEST). In *Proceedings of the 1999 IEEE Symposium on Security and Privacy*, pages 146–161, Oakland, California, May 9–12, 1999.

[41] R. Lippmann, J. W. Haines, D. J. Fried, J. Korba, and K. Das. Analysis and results of the 1999 DARPA off-line intrusion detection evaluation. In H. Debar, L. M´e, and S. F. Wu, editors, *Recent Advances in Intrusion Detection (RAID 2000)*, volume 1907 of LNCS, pages 162–182, Toulouse, France, Oct. 2–4, 2000. Springer-Verlag.

[42] A. Mounji. *Languages and Tools for Rule-Based Distributed Intrusion Detection*. PhD thesis, Institut d’Informatique, University of Namur, Belgium, Sept. 1997.

[43] P. G. Neumann and P. A. Porras. Experience with EMERALD to date. In *Proceedings of the 1st Workshop on Intrusion Detection and Network Monitoring*, Santa Clara, California, Apr. 9–12, 1999. The USENIX Association.

[44] A. One. Smashing the stack for fun and profit. *Phrack Magazine*, 7(49), Nov. 8, 1996.  
<http://www.fc.net/phrack/files/p49/p49-14>.

[45] J. Picciotto. The design of an effective auditing subsystem. In *Proceedings of the 1987 IEEE Symposium on Security and Privacy*, pages 13–22, Oakland, California, Apr. 27–29, 1987.

[46] P. A. Porras and R. A. Kemmerer. Penetration state transition analysis: A rule-based intrusion

detection approach. In *Proceedings of the Eighth Annual Computer Security Applications Conference*, pages 220–229, San Antonio, Texas, Nov. 30–Dec. 4, 1992.

[47] P. A. Porras and P. G. Neumann. EMERALD: Event monitoring enabling responses to anomalous live disturbances. In *Proceedings of the 20th National Information Systems Security Conference*, pages 353–365, Baltimore, Maryland, Oct. 7–10, 1997. National Institute of Standards and Technology/National Computer Security Center.

[48] P. Proctor. Audit reduction and misuse detection in heterogeneous environments: Framework and application. In *Proceedings of the Tenth Annual Computer Security Applications Conference*, pages 117–125, Orlando, Florida, Dec. 5–9, 1994.

[49] T. H. Ptacek and T. N. Newsham. Insertion, evasion, and denial of service: Eluding network intrusion detection. Technical report, Secure Networks, Inc., Calgary, Alberta, Canada, Jan. 1998.  
<http://www.clark.net/~roesch/idspaper.html>.

[50] M. M. Sebring, E. Shellhouse, M. E. Hanna, and R. A. Whitehurst. Expert systems in intrusion detection: A case study. In *Proceedings of the 11th National Computer Security Conference*, pages 74–81, Baltimore, Maryland, Oct. 17–20, 1988. National Institute of Standards and Technology/National Computer Security Center.

[51] Sun Microsystems, Inc., 901 San Antonio Road, Palo Alto, CA 94303, USA. SunSHIELD Basic Security Module Guide, Solaris 7, Oct. 1998. Part No. 805-2635-10.

[52] U.S. Department of Defense. *Trusted Computer System Evaluation Criteria*, Dec. 1985. DoD 5200.28-STD.

[53] A. Valdes and K. Skinner. Adaptive, model-based monitoring for cyber attack detection. In H. Debar, L. M´e, and S. F. Wu, editors, *Recent Advances in Intrusion Detection (RAID 2000)*, volume 1907 of LNCS, pages 80–92, Toulouse, France, Oct. 2–4, 2000. Springer-Verlag.

[54] U. T. Mattsson, and T. Valfridsson. An automated method to minimize the risk for exposure of encryption keys and encrypted database information. EPC Patent number – 00/975134.8.

[55] U. T. Mattsson. A method for implementation of encryption in a 24 by 7 production database. US Patent number 09/712 926.

[56] U. T. Mattsson. A method for detecting and preventing intrusions in commercial databases. EPC Patent number EP 01127906.4.

[57] U. T. Mattsson. A method for protecting databases against internal attacks. Sweden Patent number 0004189-7.



[58] U. T. Mattsson. Basic Data Type transparent method for storing and transporting of encrypted data. US Patent number 09/721 942.

[59] U. T. Mattsson. A method for combining software based encryption and hardware based encryption and key management. US Patent number 09/712 941.

[60] UK's Data Protection Act - Compliance March 1, 2000 [www.dataprotection.gov.uk](http://www.dataprotection.gov.uk)

[61] Canada's Personal Information Protection and Electronic Document Act (PIPEDA) Compliance 1/1/2001 to 1/1/2004 [www.privcom.gc.ca](http://www.privcom.gc.ca)

[42] Australia's Privacy Act – Compliance by December 21, 2001 [www.privacy.gov.au](http://www.privacy.gov.au)

[63] The VISA U.S.A. Cardholder Information Security Program (CISP) – Compliance May 1, 2001 [http://usa.visa.com/business/merchants/cisp\\_in\\_dexhtml](http://usa.visa.com/business/merchants/cisp_in_dexhtml)

[64] The VISA International Account Information Security Standards (AIS) and Best Practices Guide <https://www.visa.com/nt/gds/main.html>

[65] The U.S. Software and Information Industry Association (SIIA) - An Electronic Citadel - A Method for Securing Credit Card and Private Consumer Data in E-Business Sites [www.sii.net/sharedcontent/divisions/ebus/citadel.pdf](http://www.sii.net/sharedcontent/divisions/ebus/citadel.pdf)

[66] The BITS (the technology group for the Financial Services Roundtable) Voluntary Guidelines for Aggregation Services [www.bitsinfo.org/FinalAggregationBook051601.pdf](http://www.bitsinfo.org/FinalAggregationBook051601.pdf)

[67] The U.S. Gramm-Leach-Bliley Act (GLBA) (TITLE V--Consumer Privacy), regulated by the SEC, FTC, FDIC, OCC, OTS, FRB, NAIC, and NCUA, which covers a broad range of financial services and virtually affects any company who accepts credit cards - compliance July 1st, 2001 [www.complianceheadquarters.com/Privacy/Privacy\\_Research/privacy\\_research.html](http://www.complianceheadquarters.com/Privacy/Privacy_Research/privacy_research.html)

[68] EU member state privacy legislations see [http://europa.eu.int/comm/internal\\_market/en/dataprot/law/impl.htm](http://europa.eu.int/comm/internal_market/en/dataprot/law/impl.htm)

[69] Germany's Federal Data Protection Act (Der Bundesbeauftragte für den Datenschutz) - compliance May 23, 2001 [www.bfd.bund.de](http://www.bfd.bund.de)

[70] Sweden's Personal Data Act (Personuppgiftslagen - PuL) - compliance October 1, 2001 [www.datainspektionen.se](http://www.datainspektionen.se)