Developing a Secure Online Java-based Data Analysis and Visualization Tool

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Summary

We describe the design and development of a web-based data analysis and visualization tool that integrates back-end security and data analysis support with flexible front-end query and visualization support, including a variety of common and uncommon data views. Component technologies include Java servlets, Java-based data visualization modules, and probabilistic modeling, reasoning, and machine learning data analysis tools. This paper describes the design and development of our prototype tool, SOJDAV (Secure Online Java-based Data Analysis and Visualization), as an example to ground our discussion of the practice of creating such tools. The front-end components of SOJDAV are designed to enable dynamic visualization of data over the Internet. Intuitive, dynamic data visualization supports a broad range of distributed research and education goals. SOJDAV's back-end components provide varying levels of privileged access to data, models and analysis tools. These back-end components are created using web server and servlet technology to insulate the main database from unauthorized access and corruption, while maintaining the integrity of valuable research data. Back-end tools have access to both a comprehensive cleansed database of meaningful relational data and models derived from statistical and Bayesian network integrations of this data. Our prototype implementation of SOJDAV has been deployed to support medical research into time-critical patient care.

Keywords: Multi-component system, research and educational aid, probabilistic and statistical analysis, web-based flexible analysis and visualization

1 Introduction

Even though modern hardware and database systems have made it possible to store gigabytes of information, it can be difficult to fully exploit the information in a large database with complicated structure. Developing systems with secure access to important data and intuitive data visualizations can help a wide range of users effectively employ and analyze information. This paper introduces a prototype web-based tool – A Secure Online Java-based Data Analysis and Visualization Tool (SOJDAV) – that provides a novice user an ability to construct both simple and complex queries to analyze data, and secures important data through varying levels of privileged access. Queries may include probabilistic modeling and reasoning via Bayesian and Naïve Bayesian networks. This tool is aimed towards wide spectrum of users, especially novices with limited computer expertise and limited knowledge of the inner structuring of the database. We provide details of the integration of component technologies used to create SOJDAV to inform the practice of developing similar tools.

1.1 Motivation and Goals

The primary motivation for developing SOJDAV is to provide a distributed research resource for inventing new techniques in time-critical patient care in emergency center trauma management [16, 19, 17, 18, 4, 3, 12, 5]. To be useful to medical practitioners and researchers as well as computer scientists the tool must provide an intuitive interface. To provide secure distributed access to private data across a variety of users with varying levels of authority the tool must implement a flexible security solution. To accomplish these goals, SOJDAV provides intuitive access to data by providing custom visualization of data views, secure access to software tools and private data over public networks, and remote access and remote deployment of component tools. The additional goal of this paper is to provide enough information regarding our prototype tool so software practitioners can build similar tools.

The Internet has made possible large-scale dissemination and round-the-clock availability of information. With this accessibility come security and privacy issues. By carefully controlling access, SOJDAV protects valuable research data while the flexible component-based architecture permits the integration of a variety of back-end resources.

1.2 Database Visualization

Formally, *database visualization* is any procedure performed by a computer program that integrates data from different sources and then transforms the data into images. As described in [9], the database visualization process consists of the following three steps:

1. Retrieving Data from Data Source – data source can be of different types and can be located locally or distributed over the network
2. Mapping – transform original data into a geometric representation of the data to provide the visual representation
3. Rendering and Displaying – display data in various formats

As proposed in [6], a database visualization tool usually has three functions: data visualization, data manipulation, and data analysis. In addition to providing basic functionalities, our tool integrates probabilistic data via Bayesian and Naïve Bayesian network modeling, learning, and inference.

1.3 Approach

Our approach to designing and developing SOJDAV derives from its data sources and intended users. Our data sources include a comprehensive medical database and a series of probabilistic networks derived from this database. Our intended users include medical personnel, medical researchers, and computer science researchers. As each one of our anticipated users requires different software tools and interacts with our primary data sources at different levels, SOJDAV has been developed as an integration of multiple front-end and back-end technology components.

Our multiple-component solution follows the Java Enterprise Edition (J2EE) [13] standard for deploying multi-tier applications. Developing our tool using general-purpose enterprise software development tools, rather than specialized component-building software, permits us to use a range of commercial software applications designed to interoperate in enterprise environments. Additionally, enterprise development tools such as servlets provide a straightforward way to make use of existing applications not originally designed for enterprise environments. Moreover, basing our multiple-component architecture on general-purpose tools does not preclude us from incorporating special-purpose software components. The foundation of this secure distributed solution enhances the features of component tools. Our multiple-component solution integrates database access, secure web server and servlet software, statistical analysis and data visualization, and probabilistic data integration support via Bayesian network modeling, learning and inference.

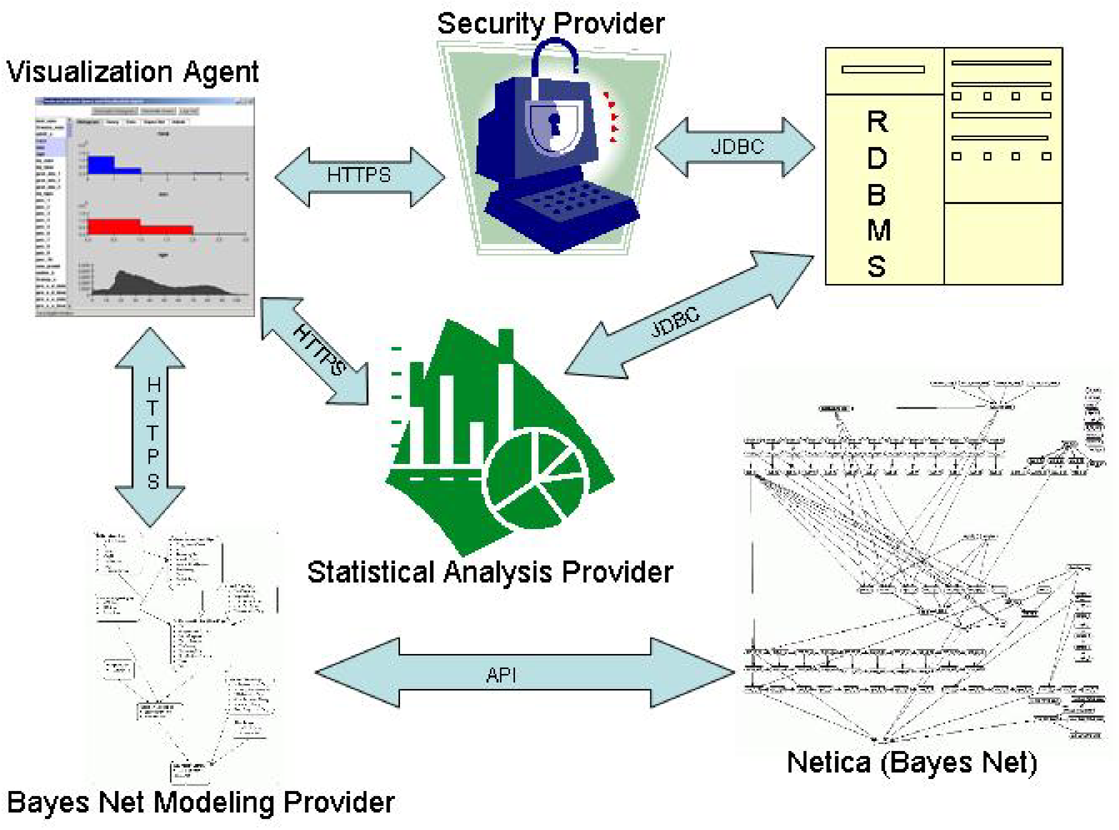


Figure 1: Interaction of various components of our approach

Figure 1 depicts the various components implementing our multiple-component solution. These components are deployed across a distributed system consisting of one or more Web servers and multiple client machines. A Visualization component co-resides with a client browser and interacts with server-based Security component, Statistical Analysis component, and Modeling and Inference components. A Visualization component never interacts directly with back-end resources such as the relational database management system (RDBMS) or Probabilistic Modeler. This architecture prevents unauthorized access to valuable resources and hence protects data integrity. Furthermore, communication between any components takes place over secure channels to ensure integrity and confidentiality.

In Section 3 we describe the design of each component depicted in Figure 1 and the architecture that permits these components to interoperate and transfer information securely across public networks. Our solution provides both back-end security and data integration support and front-end query and visualization support. We motivate the design of this multiple-component system in the context of our larger medical research and education efforts in Section 2. Section 4 provides details on the design and implementation of SOJDAV; while section 5 demonstrates a simple user interaction scenario. We discuss the effectiveness of this system and identify future directions in Section 6.

2 Building and Analyzing the Core Database

A valuable research database motivates our work and provides the core of our system development. Our work revolves around a comprehensive medical database derived from a large data file from the Pennsylvania Trauma Systems Foundations

Registry containing 412 attributes of medical information on 169,512 patients admitted to twenty seven trauma centers in Pennsylvania between 1986 and 1999. Information collected on each patient can be broadly classified into the following categories:

- Patient General Information
- Patient Clinical Data
- Process of Acute Care
- Timestamps of various processes

In the development of this database, we detected and corrected over 1000 data entry errors in non-temporal fields and an additional 5500 errors in time and date fields. Using a probabilistic context-driven approach [4, 5], we identified and corrected four classes of error in our dataset: (1) general typographical errors, (2) non-domain-specific errors (e.g. calculation errors), (3) domain-specific errors, and (4) errors in the temporal ordering of time and date fields. The resulting cleansed and validated database is now being used to provide statistical studies and probabilistic models to help us better understand the effect of time delays on patient outcome.

The visualization tool described in this paper assists users with manual decision-making and exploratory analysis of the data and probabilistic models derived from the data. Users have varying levels of secure data access that permit them to query and extract information from this database. We developed this tool, in part, to provide distributed access to the data and models to researchers outside our core research team. Confidentiality and privacy restrictions require us to provide a solution with varying levels of secure data access.

This system has already been used to develop new medical knowledge. In one study [3], we show that the time to laparotomy for intra-abdominal bleeding from trauma does affect survival for delays in ED up to 90 minutes. Additional exploratory research includes investigating the use of machine learning algorithms to automatically extract models from the data to provide a clearer picture of the significance of certain parameters in the data. Models explored include naïve Bayes and decision tree classifiers.

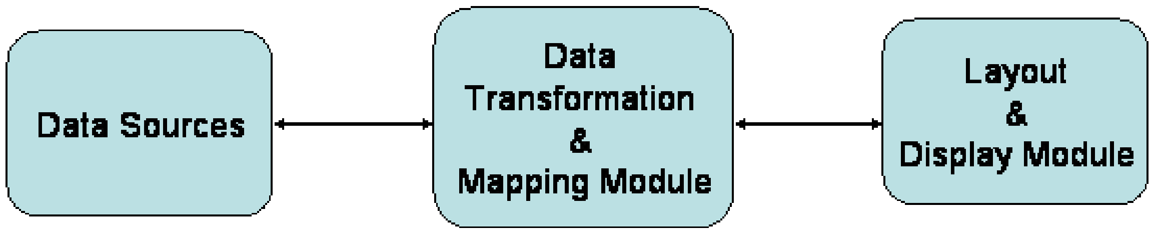


Figure 2: Data Modeling and Mapping

We apply a non-domain-specific transformation as the initial step of building our visualization components, as depicted in Figure 2. In this approach, we provide a data mapping that transforms data to structures that can be used in visualization. During this data mapping procedure, all trivial and unwanted information is filtered out and interesting information is transformed into a structured form, such as a histogram. The data mapping procedure takes place in two different steps: (1)

transform the original data into Java objects and (2) incorporate the Java objects into the visualization component. As part of our visualization front-end, SOJDAV makes use of a widely known histogram plotter API known as JAS API [7].

3 Infrastructures and Architecture

In this section we describe our approach to designing and developing SOJDAV. We begin this section by reviewing the component technology. Inspired by its central promise, ‘write once, run anywhere’, we chose to build our solution based on Java software platform. Our development effort concentrated on well-established sound methods and proven technology including the Java Enterprise Edition (J2EE) [13] standard for deploying multi-tier applications. Multi-tier component architectures promote minimal interdependence amongst components. The resulting system satisfies our requirements for flexible, intuitive use as well as permitting robust and error-free software component deployment in real-world distributed environments.

3.1 System Infrastructure

Java Enterprise Edition (J2EE) defines a standard for developing multi-tier applications in which all pieces of the application are portable across platforms and servers. Key components of this standard are *servlets* to extend and enhance Web servers, *Java server pages* to create dynamic Web content, and *Enterprise JavaBeans* for deploying server-side as well as client-side components. J2EE provides multiple messaging options, performance, scalability, and security.

Since we chose to develop a multiple-component solution, the J2EE [13] platform was the ideal choice as it supports distributed applications that take advantage of a wide range of new and evolving technologies, while simplifying development through a component-based application model. This component-based solution permits implementation of all necessary logic at the server-side, providing a simple and clear interface to the user-end. Also, in compliance with the J2EE architecture, our solution defines a *client tier*, a *middle tier* or Web container, and a *back-end tier* or Enterprise Information System (EIS) tier [13] as shown in Figure 3.

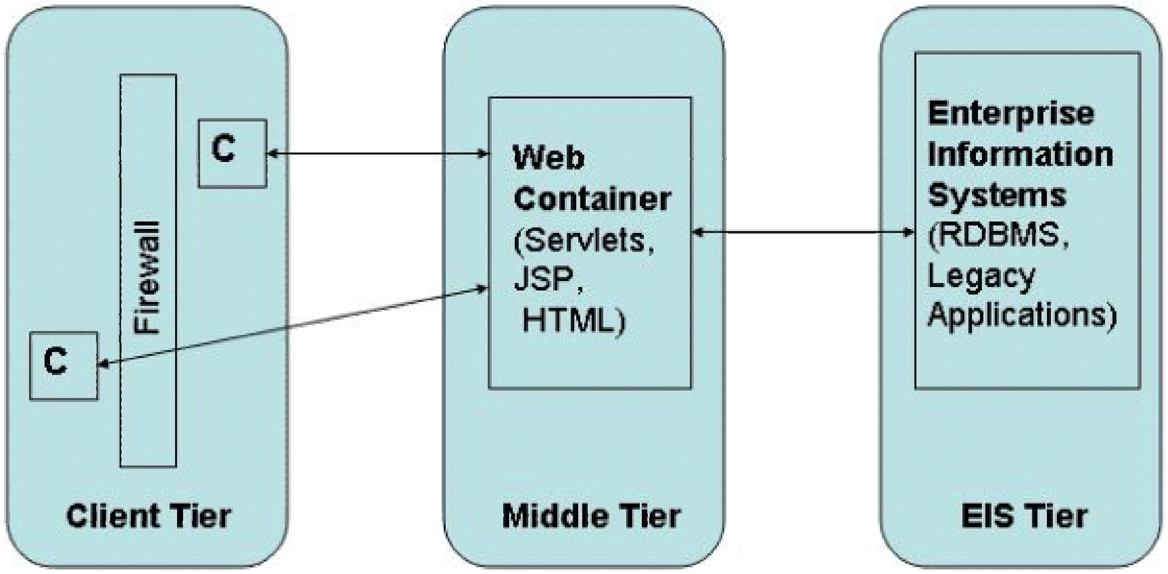

C
Firewall
C
Client Tier
Web Container (Servlets, JSP, HTML)
Middle Tier
Enterprise Information Systems (RDBMS, Legacy Applications)
EIS Tier

Figure 3: The 3-tier multi- component architecture

The client tier supports a variety of client types, both outside and inside of corporate firewalls [13, 1]. In our solution the client tier consists of Java applets [8] launched from within WWW browsers. A client accesses the middle tier primarily using Web standards, such as HTTP, HTTPS, HTML, and XML. More specific details of the architecture of the novel client-tier component deployed in our solution is provided in Section 3.2.

The middle tier supports client services through the use of Web containers, and business logic component services through Enterprise JavaBeans^{tm} (EJB) containers. This tier essentially hosts both presentation and business logic, and it uses standard application programming interfaces (APIs) to access the EIS tier resources [1] as depicted in Figure 4. A servlet, which is a program that extends the functionality of a Web server, serves as a Web container in this tier [13]. Servlets can be thought of as applets at the server side that communicate with the components at the client side to provide dynamic and interactive content to the user. In our application we are careful to provide secure middle tier components.

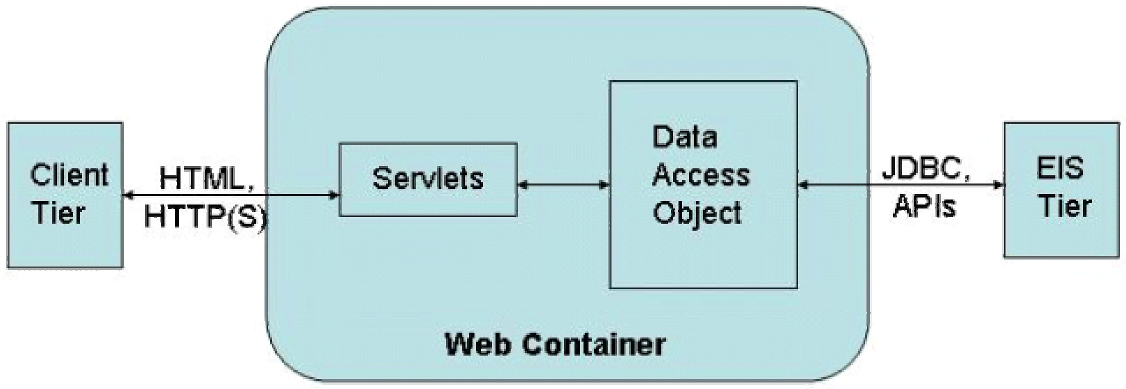


Figure 4: Web container components and interactions

The middle tier components make use of the Secure Socket Layer (SSL) protocol to provide privacy and security over the Internet. SSL uses highly secure encryption to allow client-server applications to communicate in a way that does not permit eavesdropping or tampering [13]. Additionally, in this protocol servers are always authenticated and clients are optionally authenticated for genuineness.

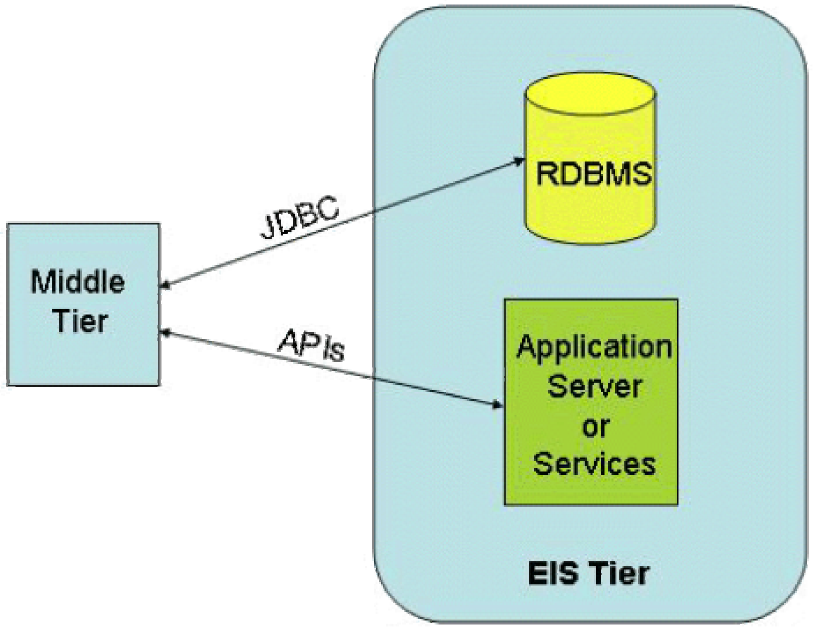


Figure 5: Enterprise Information System (EIS) tier components

The back-end or EIS tier supports access to existing information systems by means of standard APIs, such as the Java Database Connectivity (JDBC) API. As depicted in Figure 5, Relational Database Management Systems (RDBMS) and Legacy Applications are examples of EIS tier resources. The SOJDAV EIS tier uses PostgreSQL Server as the RDBMS for primary medical data storage, Weka APIs to support Naïve Bayesian networks, and Netica tm APIs to support probabilistic inference and storage of Bayesian networks. Since applets on the client tier do not have direct access to the resources on EIS tier, the middle tier is designed as a secure intermediary between the front- and back-ends.

3.2 System Architecture

In order to restrict clients' direct access to data sources, SOJDAV is based on a distributed asynchronous process communication architecture. This architecture follows the client-server model for distribution of services and interoperability, while permitting multiple clients to simultaneously access the services. In this architecture, a client process provides a graphical user interface to visualize the information. A server process performs most of the computation and generally resides on a different machine. Figure 6 shows the general architecture of our tool.

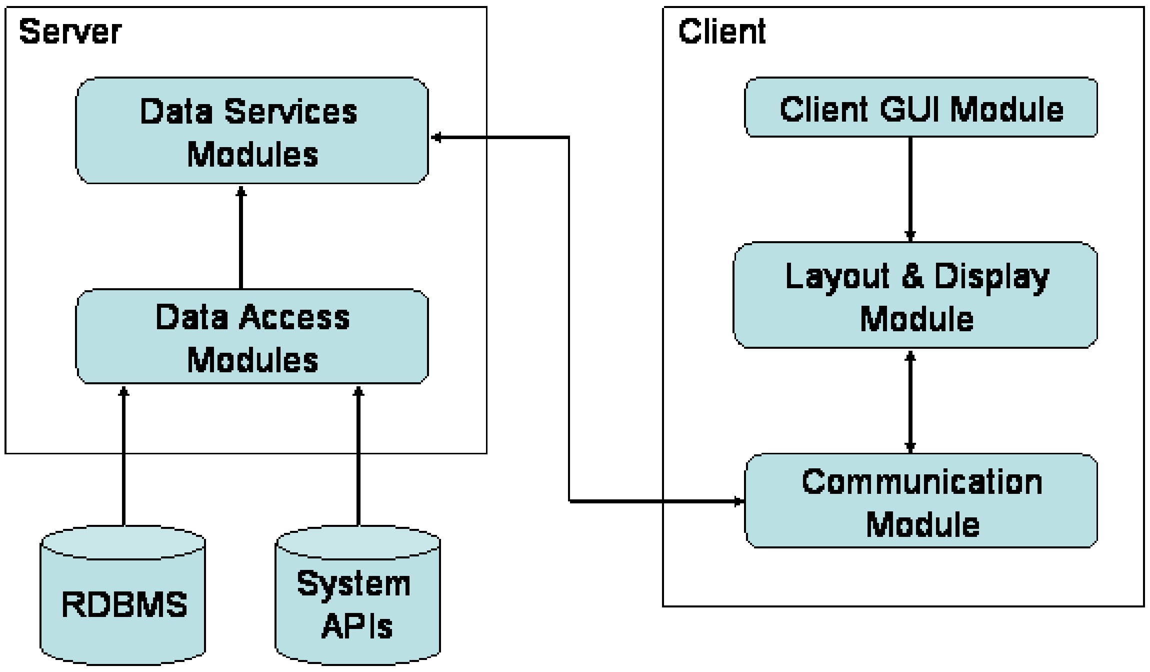


Figure 6: System Architecture

3.2.1 Client Side Modules

A client module renders a graphical user interface, transforms the intermediate data into displayable data and displays data graphically. Additionally, it communicates with a server to retrieve intermediate data. In SOJDAV, a client consists of following three modules:

1. **Client Graphical User Interface Module**

   This module provides a graphical user interface for users to interact with our tool. This module helps a user to formulate a query to retrieve data as well as providing an interface to enter evidence for reasoning with probabilistic networks. It also provides alternative display modes for data.

2. **Layout and Display Module**

   The Layout and Display module is responsible for rendering all graphical components for a user. The module initially sets up a graphical user interface based on a user's access level. Once user formulates a query and requests data or histograms, this module converts intermediate data into appropriate displayable format. This module also provides a user flexibility in how a chosen histogram can be viewed. Upon user selection, this module repaints a histogram to accommodate user selection.

3. **Communication Module**

   This module bridges the gap between client and server in our tool. This module resides with a client and provides methods to communicate with server. Communication between client and server takes place over Secure Socket Layer using HTTP.

3.2.2 Server Side Modules

Server side modules are responsible for interacting with database systems as well as other application servers or services. In SOJDAV, a server consists of two sets of modules:

1. **Data Services Modules**

   The Data Services Modules consist of several Java servlets. Servlets are designed for a specific purpose. Upon a client's request, servlets will interact with the appropriate Data Access Module to obtain raw data. They are also responsible for formatting raw data in order to transmit it to a client.

2. **Data Access Modules**

   The Data Access Modules retrieve and filter raw data from the data sources and provide refined data to the appropriate Data Services Module. As data sources can be of various types, our tool supports databases as well as various probabilistic modelers. When databases are used as a data source, we use JDBC-ODBC to access data sources. Similarly, we use Netica API and Weka API to access probabilistic modeler data sources and machine learning and probabilistic reasoning services.

4 System Design and Implementation

4.1 Client Components

Comprehensive, cleansed, and easily accessible large medical research databases are rare resources. After putting forth the considerable effort to produce our database we further understand its value to ourselves and the greater health care and medical research communities. As mentioned earlier, we have already employed and are continuing to employ this system to discover new medical knowledge [3].

Providing intuitive and visual access to this data multiplies its value. Our goal in designing a flexible client component is to provide convenient access to this data for medical research. Our experience extracting data through manually constructing queries and manually transferring data across independent applications informed our user interface component and architecture design decisions.

The information retrieval process usually starts by formulating a query. The query specifies which attributes of the data are desired and what filters to apply on records containing these attributes. Query results are presented to the user, who then evaluates the results and poses new queries. If the results are inadequate, the user can re-specify the query and re-submit to obtain a refined result. This process is known as refinement. There are many powerful query languages, such as SQL, to provide this standard functionality. However, the potential audience of medical researchers is much larger than the audience of researchers who have also been trained in a formal query specification language. SOJDAV's flexible client is designed with an intuitive interface as an alternative to formal query specification languages for novice users, while retaining the power of formal languages for advanced users. Importantly, our client design maintains the security of our data when accessed remotely.

As our client components are written entirely using Java and Java Beans with a modular approach, it is easy to scale for more functionality. It also provides a secure communication channel and does not require any specific platform to run.

4.2 Server Components

Our server components consist of several servlets that communicate with client and back-end components. Servlets are Java programs that run on a server's Java virtual machine (JVM) and communicate with back-end components by means of standard APIs. SOJDAV uses JDBC-ODBC APIs to communicate with Database systems and Netica and Weka APIs to communicate with probabilistic inference and machine learning systems to provide Bayesian network and Naïve Bayes network modeling, respectively.

As with our client components, our server components are designed with a modular approach. As a result, our system is flexible to change in one part of a module without affecting the whole system. Also, a user can add more servlets that can communicate with various legacy systems using their own APIs. This functionality increases usability of our tool design in various domains.

4.3 Relational and Probabilistic Back-Ends

The server-side EIS tier interacts with a variety of third party systems through their specific application programming interfaces. Systems that we are using include a relational database system and software that permits efficient probabilistic inference on Bayesian networks and machine learning using Naïve Bayes classifiers. In this section, we describe these systems in further detail

4.3.1 Relational Database Management System

The trauma data is stored, organized, and manipulated through a relational database management system called PostgreSQL. Use of a RDBMS to manage data objects automatically enforces data integrity, data recovery in case of loss, and data dependencies. In addition, such database systems may be accessed through standard query language interfaces. These query language interfaces may be embedded in high-level programming languages. Java Database Connectivity (JDBC) – Open Database Connectivity (ODBC) provides a means to access databases through programs written in the Java high-level programming language. Through JDBC-ODBC, the use of a Java-based EIS tier allows efficient communication between the server-component and the database system. All data requests emanating from the user are captured by the EIS tier and passed onto the database system for fulfillment.

4.3.2 Probabilistic Inference Systems

Bayesian Network

Bayesian networks provide intuitive and efficient methods for capturing and manipulating probabilistic relationships between data. These representations have been used effectively in medical domains since their inception. For example, the HEPAR project [10, 11] employed a Bayesian network to predict one of 16 liver disorders. Another example is a system called ALARM [2] that uses a Bayesian network connecting 8 diagnoses, 16 findings, and 13 intermediate variables. The system monitors patient conditions in medical centers and sounds an alarm for distress.

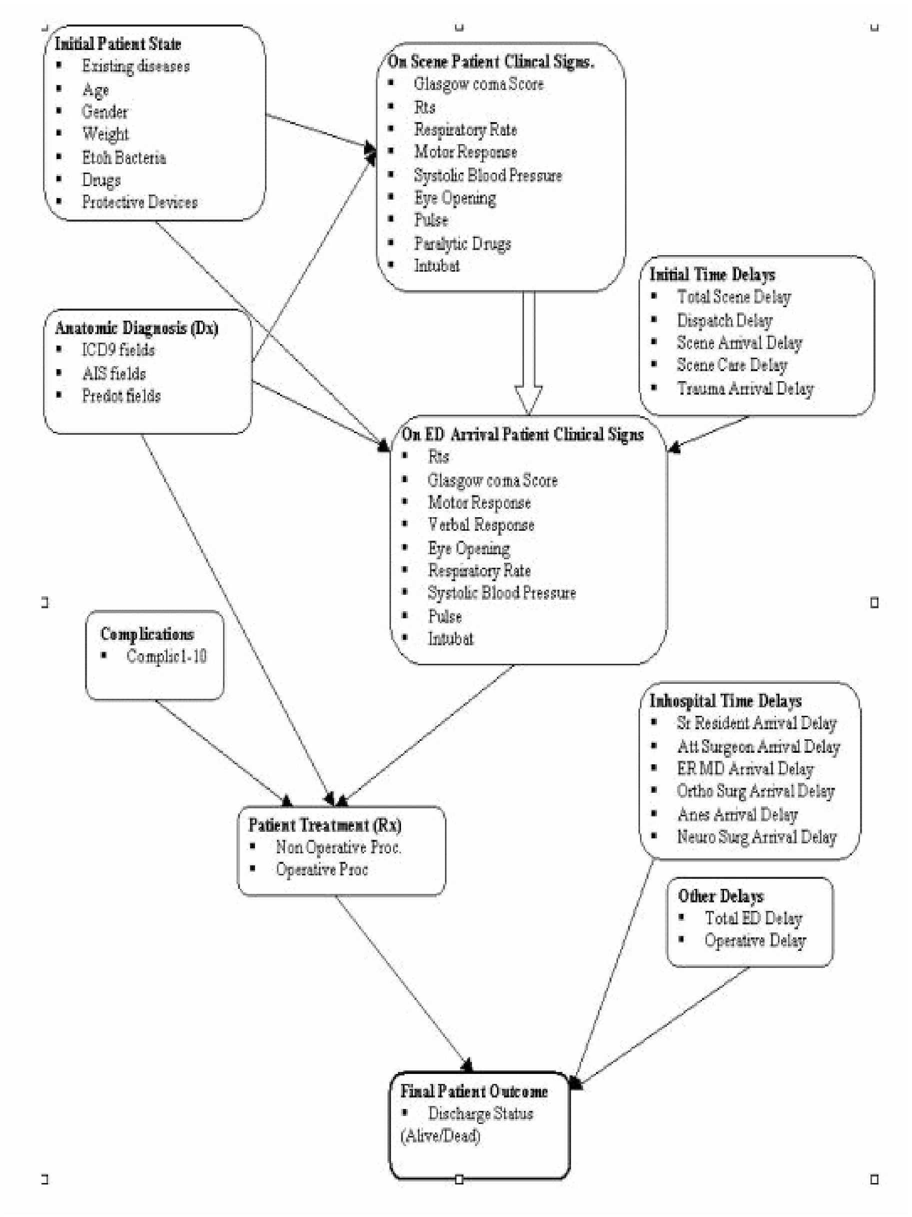


Figure 7: A high level representation of our Bayesian network

We have constructed a series of Bayesian networks to capture the probabilistic relationships in our trauma data. These networks vary in structural complexity, speed of inference, predictive capability, and required expert knowledge [4]. A medical expert (co-author John R. Clarke, M.D., Trauma Surgeon and Professor of Surgery) and pertinent medical literature provided expert knowledge. These networks are being used for further study into the effects of time delay on patient outcome. A high-level description of the data and general structure of the relationships between attributes is given in Figure 7.

An example Bayesian network constructed in this work is shown in Figure 8. This Bayesian network contains 129 nodes encompassing information on patient pre-hospital care, clinical signs, disease diagnosis fields, operative and non-operative procedures and final patient outcome. The parameters (i.e. conditional probability tables (CPT)) were learned from 148,502 records present in the medical database using a Bayesian MAP machine learning algorithm. The complete algorithm appears in [15]. Further detail on the construction of this network is available in [4]. Within our multiple-component solution, Netica serves as the back-end implementing our Bayesian network component. This commercial software permits graphical construction of the network, efficient learning of the parameters using the algorithm described above, and probabilistic inference using a junction tree (join tree of cliques) algorithm [14].

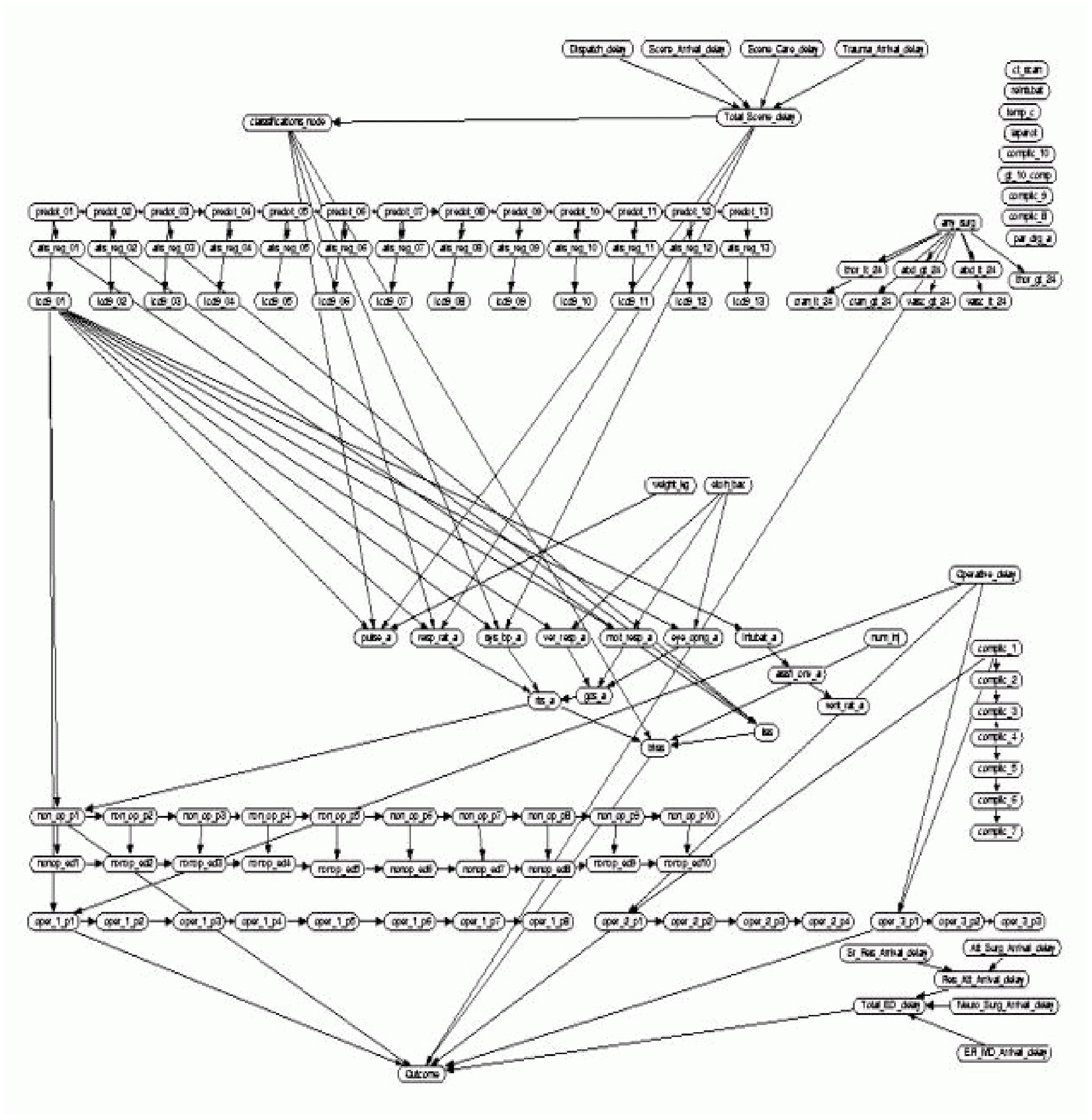


Figure 8: The deployed Bayesian network constructed using expert domain knowledge

Using our visualization front-end component, evidence can be entered for any of the nodes for which data is observed. A middle tier component securely relays evidence to a back-end component that interacts with Netica through its specialized API. The probability distribution that results from such a query (typically over patient outcome) is communicated back to the user component and displayed through the visualization graphical user interface. Our system allows the user to select any node for evidence gathering and probabilistic inference. This puts at the disposal of the user an expert prediction and diagnosis service that uses a large real-life medical data set to compute its results. In addition to functioning as a research tool, the network can provide valuable support in making time-critical decisions in the trauma center.

Naïve Bayes Classifier

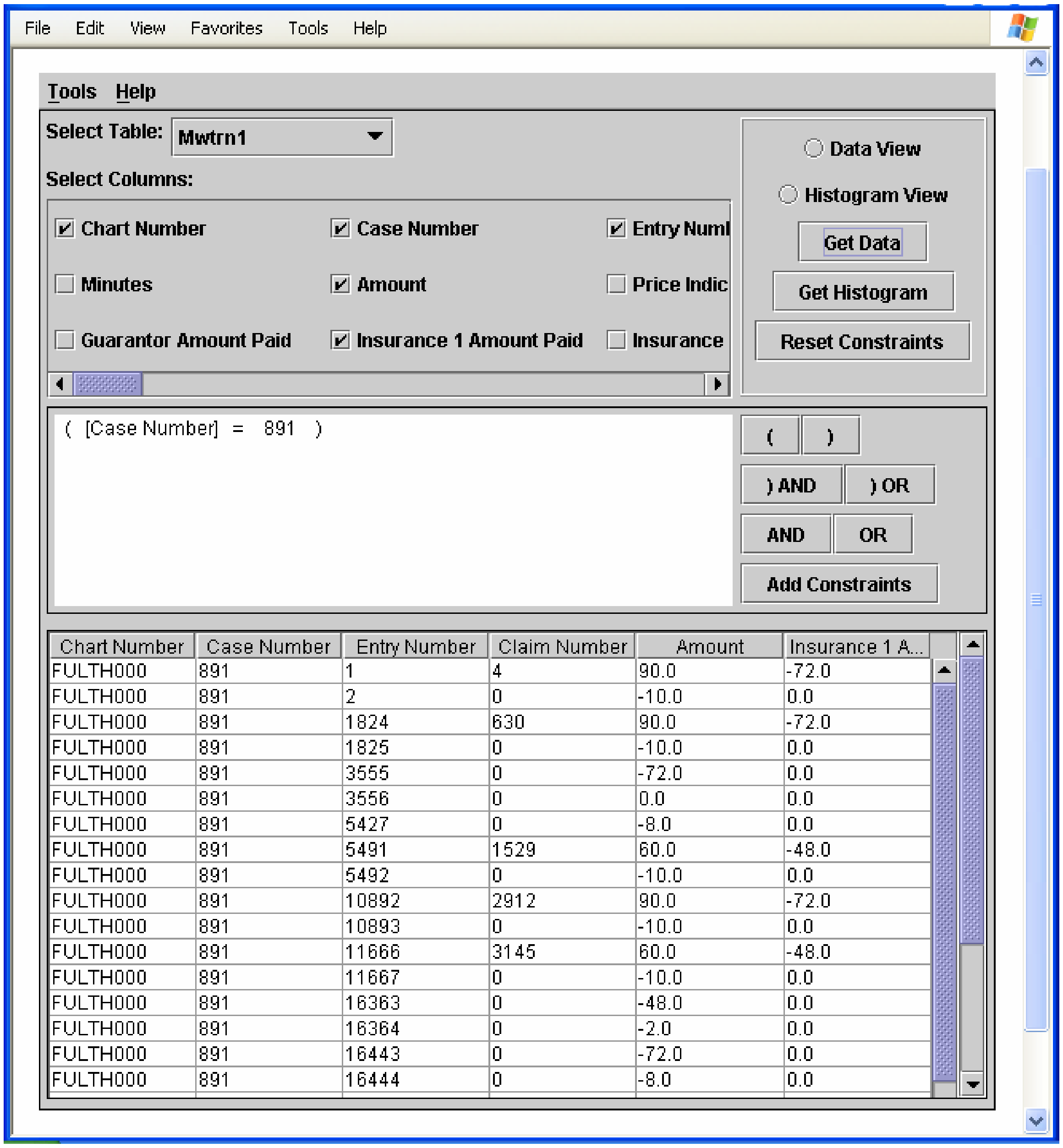
The Naïve Bayes Classifier is a highly practical algorithm for classifying a target value given a set of attributes. We use the Naïve Bayes Classifier to classify if a patient is going to live or die based on 147 attributes such as age, pulse, and predot values. The target value set V is {Live, Die}. The attribute set A $< a_1, a_2, \ldots , a_n >$ is a tuple of n attributes (here n is 147). Each attribute contains a value for the patient's age, sex, pulse, etc. The standard Naïve Bayesian classification algorithm is used to classify the most likely outcome, given an attribute tuple. This algorithm assumes that attribute values are conditionally independent given the target value (the naïve approach). Simple conditional probabilities of each combination of attribute and outcome, $P(a_i \mid v_j)$, are automatically learned from a subset of the medical database. A second subset of the database is used to verify the accuracy of the learned classifier. In one result, we learned a Naïve Bayes classifier with a 90% prediction accuracy.

5 System Demonstrations

This section provides demonstration views of our prototype tool, SOJDAV. Before using this tool, a potential user is manually validated and given a user account with a certain access level from the administrator of the system.

The client component provides secure access to the database through role-based authentication and encryption. A user must first be authenticated to start a new session. This is done using the standard login-password combination mechanism. This security mechanism is motivated by the crucial need to prevent unauthorized users from accessing valuable research data. Upon successful login, the user will be able to interact with the database, Bayesian network or Naïve Bayes network. A role-based access policy provides varying levels of privileged access. Certain features of the user interface are disabled depending upon the role or privilege level of the user, permitting secure operation for a wide spectrum of users.

One view of the graphical user interface of our client component is depicted in Figure 9. This panel allows generation of charts and formulation of queries for data. As our goal is to provide a flexible and intuitive client component, a graphical user interface module renders all attributes for the user to choose. With the single click of a button, user will be presented with raw data in a tabular format, as shown in Figure 9. The back-end database for demonstration purpose comprises a restricted set of records, not representative of our confidential medical data.



Select Table: Mwtrn1

Select Columns:

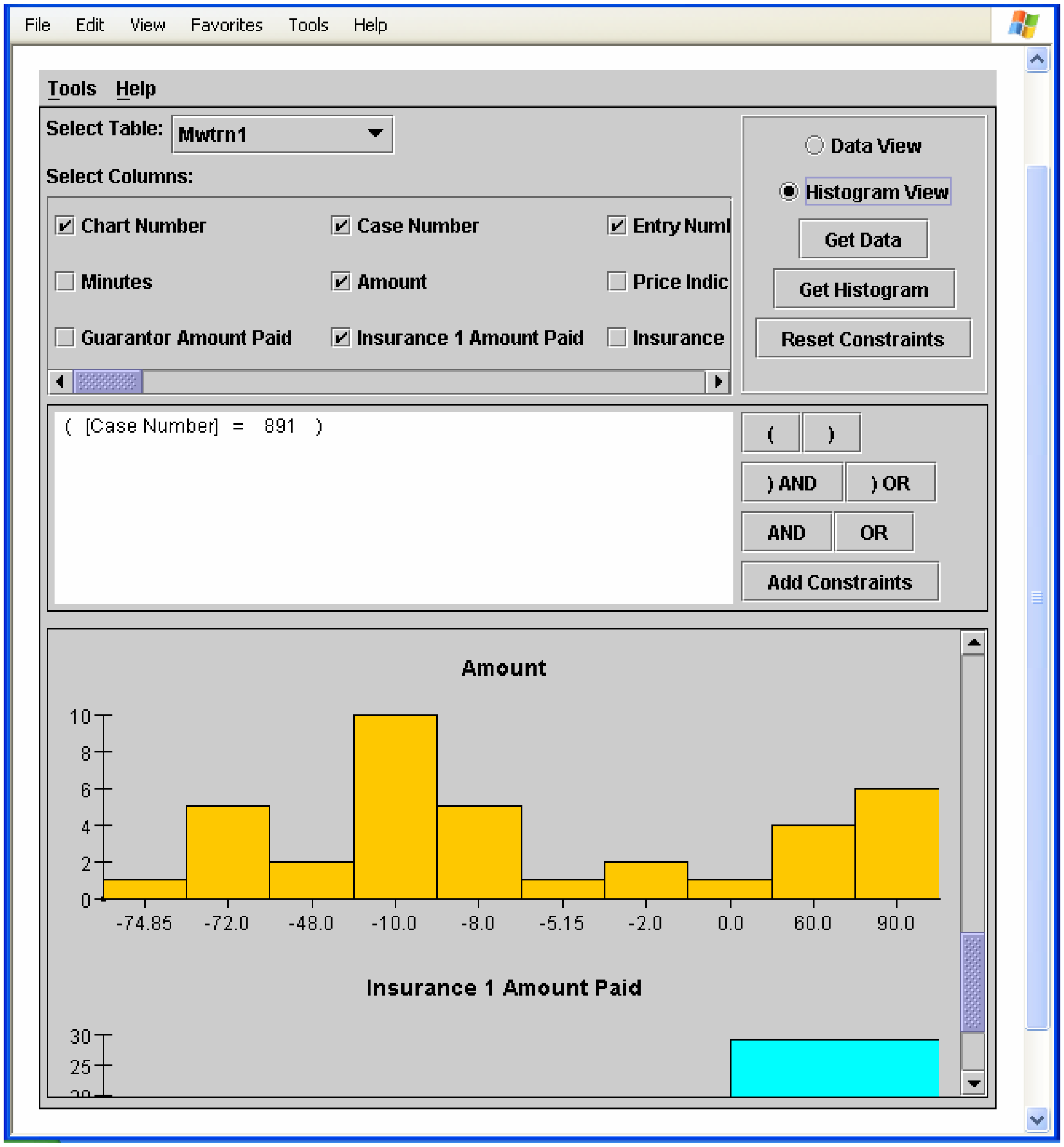
[✓ Chart Number] [✓ Case Number] [✓ Entry Numl]
Minutes [✓ Amount] Price Indic
Guarantor Amount Paid [✓ Insurance 1 Amount Paid] Insurance

([Case Number] = 891)

Chart Number	Case Number	Entry Number	Claim Number	Amount	Insurance 1 A...
FULTH000	891	1	4	90.0	-72.0
FULTH000	891	2	0	-10.0	0.0
FULTH000	891	1824	630	90.0	-72.0
FULTH000	891	1825	0	-10.0	0.0
FULTH000	891	3555	0	-72.0	0.0
FULTH000	891	3556	0	0.0	0.0
FULTH000	891	5427	0	-8.0	0.0
FULTH000	891	5491	1529	60.0	-48.0
FULTH000	891	5492	0	-10.0	0.0
FULTH000	891	10892	2912	90.0	-72.0
FULTH000	891	10893	0	-10.0	0.0
FULTH000	891	11666	3145	60.0	-48.0
FULTH000	891	11667	0	-10.0	0.0
FULTH000	891	16363	0	-48.0	0.0
FULTH000	891	16364	0	-2.0	0.0
FULTH000	891	16443	0	-72.0	0.0
FULTH000	891	16444	0	-8.0	0.0

Figure 9: Data View of Data Manipulator

As stated earlier, SOJDAV provides a user an ability to generate histograms for selected attributes. Figure 10 shows a frequency histogram for attribute “Amount”, restricted to records with specified criteria.



Select Table: Mwtrn1

Select Columns:

- [✓] Chart Number
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- [✓] Entry Numl
- [ ] Minutes
- [✓] Amount
- [ ] Price Indic
- [ ] Guarantor Amount Paid
- [✓] Insurance 1 Amount Paid
- [ ] Insurance

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( [Case Number] = 891 )
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Figure 10: Histogram View of Data Manipulator

The refinement process can proceed rapidly from presentation of initial histograms of data. A straightforward interface, shown in Figure 11 and Figure 12, helps the user to refine a query to focus on aspects of interest. This interface permits the user to build complex queries from simple connectives, such as Boolean operators.

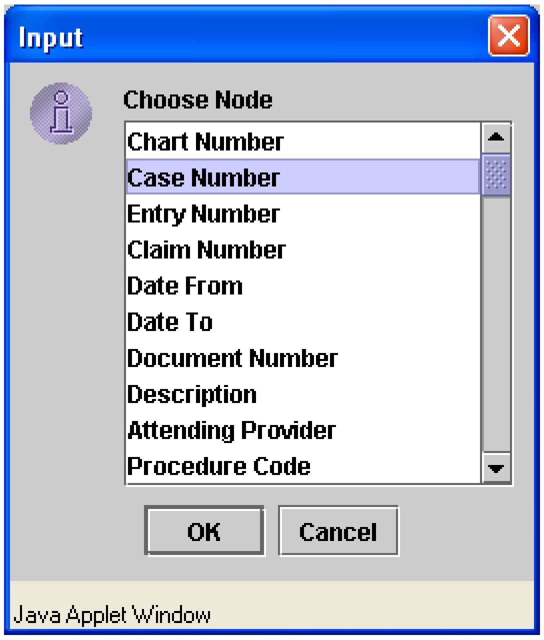
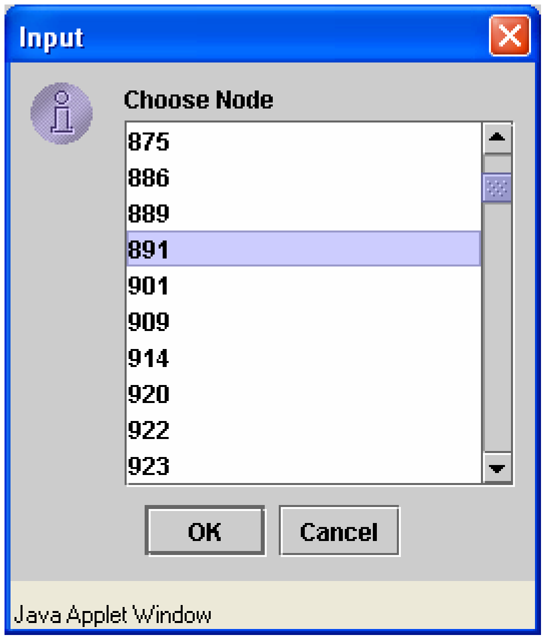


Chart Number
Case Number
Entry Number
Claim Number
Date From
Date To
Document Number
Description
Attending Provider
Procedure Code



875
886
889
891
901
909
914
920
922
923

Figure 11: Attribute Selection Window

Figure 12: Attribute Value Selection Window

The graphical nature of this query construction circumvents the need to learn a complex query programming language. Once a query has been refined using this simple method, the initial frequency histograms are dynamically updated with the click of a button to reflect the new constraints.

More advanced users are not limited to this visual querying. Users with knowledge of formal query languages can directly type in the query in the constraints field of the panel. Arbitrarily complex queries can be constructed using this input method. As depicted in Figure 9, results are provided in tabular format to permit easy storage and transfer to custom-designed user analysis tools. For example, tabular results can be automatically saved as spreadsheets to make use of the sophisticated built-in analysis tools of commercial spreadsheet applications. This feature is available only to privileged users to ensure the integrity of our database, and the privacy of the data.

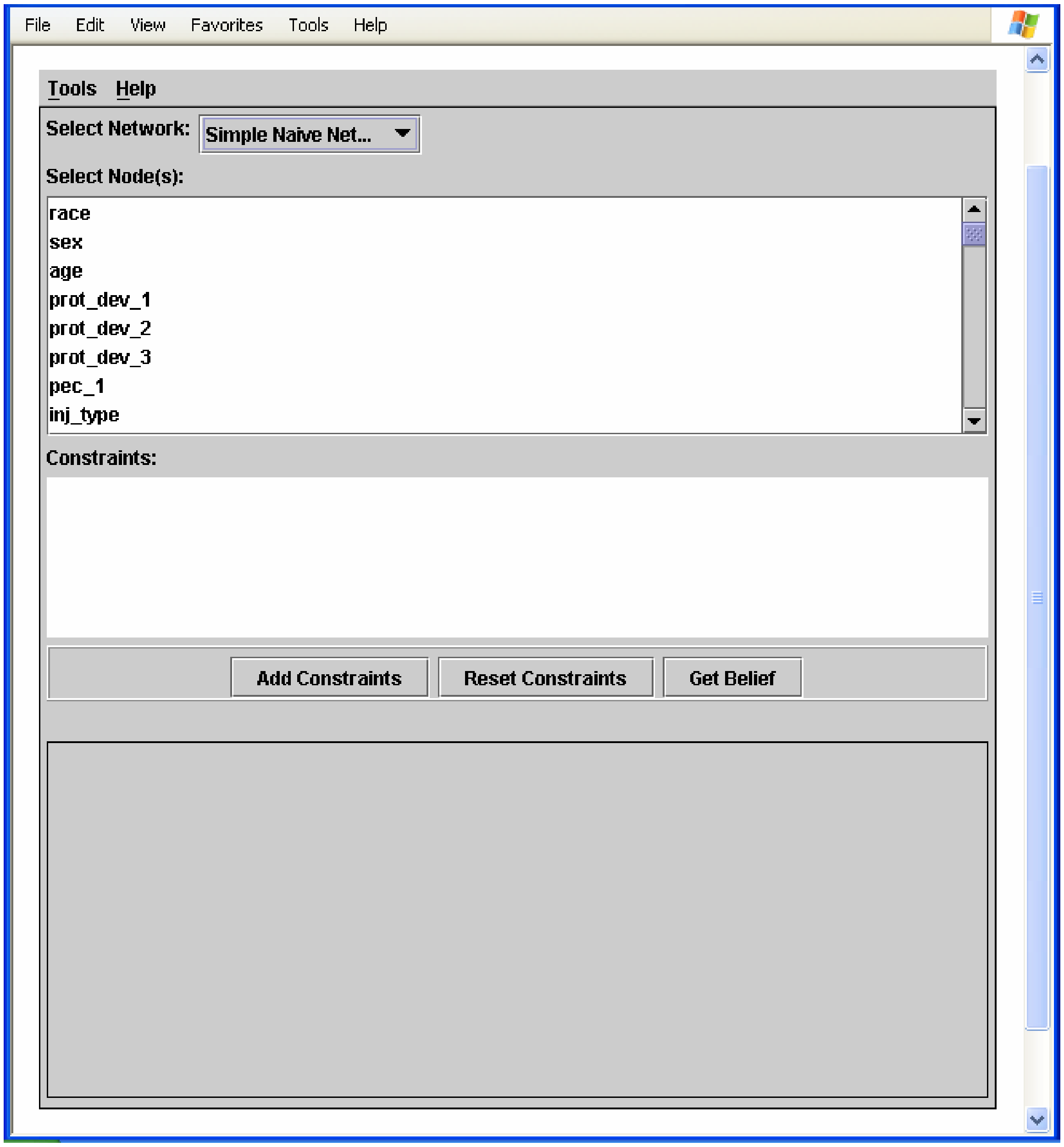


Figure 13: Initial View of Naïve Network Panel

In addition to standard statistical manipulation, data visualization, and complex query formation, our client component also provides an interface for entering evidence in the form of patient parameters and obtaining probabilistic predictions. This probabilistic inference is carried out using Bayesian network and Naïve Bayes network back-ends as described in Section 4.3. The client component permits both evidence accumulation for user-selected nodes in a Bayesian network and extraction of prediction and/or diagnoses on query nodes from the network. Furthermore, a user is able to use a Naïve Bayes classifier to classify a target value given a set of attributes as described in Section 4.3. Figure 13 shows a panel that allows a user to visually enter the values of a selected attribute. A user can add as many of attributes as desired, and provide constraints on records. The bottom half of this panel displays the outcome of the classifier (not shown).

6 Discussions and Future Work

This paper presents the design and development of a web-based data analysis and visualization tool that integrates back-end security and data analysis support with flexible front-end query and visualization support. We motivate this design through a prototype tool, SOJDAV, that provides distributed secure access to a valuable medical research database and probabilistic models derived from this database. Dynamic visualization of information through the use of graphs coupled with user-friendly interfaces allows easy cognizance of data for the user and promotes ease of use of our system. Ease of use does not limit the functionality available to advanced and privileged users.

We present a multiple-component solution that follows the Java Enterprise Edition (J2EE) standard for deploying multi-tier applications. The detailed description of the development of our tool helps inform the practice of creating similar tools. Through the application of Secure Socket Layers and password-based authentication, data flowing through the relatively insecure Internet is made immune to common unauthorized activities. SSL is the de-facto standard of Internet security and meets the challenges faced by our application. SOJDAV employs Java Servlets and Beans, a large-scale Relational Database Management System, and third-party software for probabilistic inference and machine learning.

The Internet has revolutionized the notion of availability, making most services accessible any time. The large spectrum of end-users and the various uses necessitate high availability of our system. This increased availability may translate to more effective use of our medical database in solving problems of time-critical patient care.

Choosing to base our multiple-component architecture on general-purpose tools does not preclude us from adding special-purpose intelligent components or software tools in the future. Furthermore, our approach is based on public domain protocols and standards and does not use any proprietary code in the core system. Our experience indicates that development is simplified if third-party software provides a Java API. However, if a Java API is not available, back-end software with non-Java APIs can be accommodated by building Java code to interact with these APIs.

The development of this system can be duplicated by anyone interested in building similar systems. An Appendix is provided with links to tools used.

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Appendix A: List of Figures

Appendix B: Installation Help

SOJDAV is developed using servlets and JavaServer Pages and so must be installed on a server with a servlet container. We used Tomcat 5.x server to demonstrate the prototype of our tool. SOJDAV must also be used in conjunction with a network database and appropriate drivers and/or APIs.

B1. Technology Required

- J2SE 1.4.2 SDK, J2EE 1.4 SDK

  These can be downloaded from Java Technology's website – http://java.sun.com/. Follow the installation instructions provided to properly install and configure appropriate variables such as Classpath.

- Webserver

  To demonstrate prototype of our system we have used Tomcat 5.x server, which can be obtained from Jakarta's website – http://jakarta.apache.org/tomcat/. Follow installation instructions provided along with the documentation to install Tomcat webserver and configure appropriate variables.

  After installation, modify server.xml file that provide SSL support as well as run server on desired port. Instructions to modify server.xml and web.xml files found under config folder can be found in Tomcat documentation.

  Unpack the provided zip file under webapps folder of Tomcat to install SOJDAV. Restart the Tomcat server to deploy our tool properly.

- Database

  We use PostgreSQL to host data at the back-end. However, it is not entirely necessary to use any particular database to run our tool. PostgreSQL can be downloaded freely from it's website at http://www.postgresql.org/. Obtain the documentation from the same website and follow installation instruction to properly install and configure database system.

Upon successful installation, create necessary database to host data. Once database is created, user will need to create ODBC connection named "DiscTrauma". This connection should be made available to Tomcat (see Tomcat's Administrator Guide). Also place a jar file containing JDBC-ODBC APIs in lib directory of Tomcat.

- NeticaJ APIs

  In order to provide a probabilistic inference support, we used NeticaJ APIs from Norsys. It can be freely obtained from Norsys's website at http://www.norsys.com/. Installation instructions are provided with downloaded file. Follow these instructions to install and configure appropriate variables properly. Place a jar file containing APIs in lib directory of Tomcat.

- Weka API

  Additional probabilistic modeling and machine learning support is provided by the Weka API. It can be freely obtained from http://www.cs.waikato.ac.nz/ml/weka/. Installation instructions are provided. Place a jar file containing APIs in lib directory of Tomcat.