Multidimensional Data Analysis Facilities and Challenges: A Survey for Data Analysis Tools

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ABSTRACT
Data is one of the most important aspects of any commercial or research organization. Different technical processes are applied to extract information from data. This information gets transformed into knowledge for further decision making. Today many data analysis tools are available in the market which helps to convert data into useful information. The primary focus of these tools is to provide beneficial and helpful results to its users as per their requirements. The key to analyze any data is lies in its multidimensional structure. The new wave of technology has changed the form and volume of data. There is also a significant change in the type of users, it has been observed that non- technical data miners as target users of various analytical tools. Hence, in today's world, it is essential for these analysis tools to adapt themselves to the changing needs of both the users and the technology and be updated with new statistical techniques, data mining algorithms and machine learning methodologies. In this paper, focus is on the advantages and challenges faced by some of the data analysis tools due to the change in form and volume of data.

Keywords
Multidimensional Data Analysis, Data Analysis Tools, Data Mining, Statistical Methods, Machine Learning.

1. INTRODUCTION
In recent years business intelligence tools have become a guide for market researchers. They give them profound knowledge and a cutting edge over their counterparts in marketplace. However, successful implementation of such BI tools, to combat market pressures is an arduous task. As the frequency of data generation has increased, the volume of data to be analysed has also increased. The addition of users with different skill sets makes it more difficult analyse the huge volumes of data.

Decision making is not only based on analysis of current data, but also on analysis of both historical and aggregated data. The main objective of any data analysis is ad hoc querying or ad hoc reporting. The analytical tools can achieve it by data modeling on a variety of domains. Multidimensional data modeling is used to perform ad hoc analysis. Cube is a widely used structure for maintaining the multidimensional data for analysis.

Multidimensional analysis is an informational analysis on large data used for decision support systems and statistical inference. It considers different relationships, each of which represents a dimension to find interesting information. It also groups the data into dimensions and measures. Dimensions are informational entities, on which data is analyzed to answer questions for decision making. Generally, dimensions have a hierarchical structure, with some additional features like sequential information or complex relationships between the dimensional entities.

OLAP (online analytical processing) can gain fast access to shared multidimensional information. OLAP analyzes metrics in different dimensions such as time, region, product, gender etc. that can be used for complex calculations, trend analysis and sophisticated data modeling. It is useful for business planning, resource allocation, forecasting, market share analysis, reporting etc., required for better decision making. OLAP is the technology behind several business intelligence applications.

Cube architecture is the most traditional data structure used in OLAP. In Multidimensional OLAP known as MOLAP, data is stored in a multidimensional cube. Data is in proprietary formats and is not always in a relational database. The Multidimensional Database Management Systems (MDBMS) are used to define and store data cubes in special data structures namely dimensions and cubes. MDBMS use array based storage structures and access routines to efficiently store and retrieve data cubes. It can perform complex calculations easily as all possible calculations are pre-generated at cube building stage. The cubes are optimal for slicing and dicing operations and fast data retrieval. They are optimized for data access using efficient data engines, indexes and access routines.

This paper includes the discussion on some of the popular and representative tools in the market. This study considers both paid and open source tools. Section 2 focuses on the facilities provided by the tools whereas section 3 talks about the challenges faced by these tools.

2. Multidimensional Data Analysis Tools: Facilities
Multidimensional model is the basis of all BI tools. It is incorporated in their design and implementation. Each BI tool has some special features to suit its users but quite similar in implementation. These tools can be compared using their architecture, reporting facility, analysis facilities, user management and optimization.

2.1 Paid Licensed Products

2.1.1 MicroStrategy
MicroStrategy provides a rich set of functionalities ranging from OLAP Services and Report Services to narrowcast capabilities, all of which are exposed using unified Web interface. MicroStrategy architecture offers a full range of business intelligence (BI) functionalities on a single services-

oriented architecture, so that its customers are satisfied with all their BI requirements without any additional system integration [5].

Architecture: MicroStrategy delivers all five styles of BI, i.e. data mining and advanced analysis, visual and OLAP analysis, enterprise reporting, dashboards and scorecards, mobile apps and alerts.MicroStrategy customers can add various "Service Modules" to the core engine to incrementally extend its functionality. MicroStrategy BI platform is designed to be deployed seamlessly in the cloud, enabling IT departments to create hosted BI applications without losing any BI functionality [5]. The layered architecture separates the data access logic from the presentation and control logic, providing a more efficient internal workflow. The underlying architectural design establishes a single, unified object model to define and construct objects that represent any business. These objects are dynamically assembled and re-assembled by a platform of seventeen distinct products in response to any business question or user action.

Reports: MicroStrategy Report Services™ is a plug-n-play extension to Intelligence Server providing pixel-perfect, print-perfect, and page-perfect app, dashboard, visual analysis, report design and distribution through MicroStrategy Mobile, Web, Office, Desktop, and Distribution Services. [5]

MicroStrategy reports use of falters that specify the conditions that data must meet to be included in report or metric. Users can also toggle between grids and graphs. The users can rearrange report layouts by pivoting rows, columns and pages. These reports allow users to drill into the objects at any level.

Analysis: Data mining techniques are fully integrated in the MicroStrategy. The integration of data mining models from other applications is accomplished by importing Predictive Model Mark up Language (PMML) into the metadata repository, and automatically creating a predictive metric .PMML is an XML-based industry standard developed by the Data Mining Group (DMG) to describe predictive models. It supports many different data mining algorithms, including Neural Networks, Clustering, Regression, Decision Trees, and Association. MicroStrategy is the first Business Intelligence platform to support the PMML standard. [4/fig5-20]

Data Mining Services have added numerous scoring algorithms to MicroStrategy's BI platform. It has an extensive library of over 270 analytic functions. MicroStrategy facilitates its users by providing algorithms like, Regression, Neural Network, Decision Tree, Clustering / Segmentation, Time series analysis, Association Rules, Monte Carlo simulation. Business analysts can perform further analysis, such as slicing-and-dicing data, ad hoc report creation, drilling, pivoting and sorting on the predictive reports.

User Management: Once a user has been authenticated, the BI system enforces security policies governing the functionality, reports, and data for which the user is authorized. Authorization refers to a three-dimensional process by which an application determines, application functionality privileges, object access permissions and data access security. MicroStrategy architecture dynamically calculates privileges, permissions, and security filters to create an aggregate user profile after the user logs in. Users are not granted the same rights to all application functionalities, reports and data.

Optimizations: MicroStrategy stores data in a data warehouse. An increase in the number of users can affect the query performance and this is avoided using multi-level shared caching. In MicroStrategy 9, In-Memory Cubes were introduced to overcome the limitations of caching. Thus, opening up the technology to a wider range of reports. In-Memory Cubes have more flexible query characteristics than caches, but as the cubes reside in main memory, they have the performance characteristics of caches. As In-Memory cubes reduce the computational distance effectively, they provide a consistent 1-5 seconds wait time for 40%-60% of the reports in the BI application. In-memory cubes instantiate part of this data model into the Intelligence Server memory space. This gives users fast, sophisticated OLAP functionality thereby providing full access to the entire enterprise data warehouse.

To optimize query performance MicroStrategy uses caching of data and a special feature called query advisor [24]. New Intelligent Cubes are either manually created by simply executing the source report or created automatically when the report is scheduled. Once created, the Intelligence cubes may be loaded into the memory automatically as per the needs, else they are discarded. Intelligent cubes contain attributes commonly requested during drilling. This feature enhances report performance as the OLAP Services return results without querying the data warehouse[5].MicroStrategy incorporates RDBMS optimizations while generating SQL like, Dynamic indices, statistics, hints, partitioning, clustering, parallel queries, volatile tables, derived tables, common table expressions, materialized views and parameterized queries. MicroStrategy uses these optimization features through: Multi-pass SQL, Aggregate Awareness, Very Large Database (VLDB) properties.

MicroStrategy can answer analytical questions that cannot be answered with a single SQL query block using the Multi-pass SQL feature. It transparently navigates aggregate tables, and dynamically directs queries to summary tables without the need to specify a table whilst writing a query. Once the tables are included in the application, Intelligent Server automatically evaluates all the potential options for producing results and chooses the best aggregate tables for a query each time the SQL is generated. The MicroStrategy BI platform automatically ensures that each query leverages the high-end capabilities of the database through VLDB (Very Large Database) properties for the databases.

2.1.2 IBM Cognos

IBM Cognos business intelligence solutions enhance the ability to understand and react quickly to information. Cognos solutions can satisfy needs throughout the user community and ensure that everyone can work and collaborate on a consistent set of data. Cognos has several products, providing information to all levels of the organization (how-in proper way, when-at right time, and where-at proper place) that is needed to make faster and better aligned decisions. Cognos BI provides a unified workspace for business intelligence and analytics which the entire organization can use, to answer key business questions and outperform the competition.

Architecture: The Cognos Platform is built on a web-based service-oriented-architecture (SOA) that is designed for scalability, availability, and openness. This n-tiered architecture is made up of three server tiers, the web tier, the application tier, and the data tier. These tiers are based on business functions and can be separated by network firewalls. The Cognos platform provides the ability to deliver all information from wherever it resides and isolates the user from technological complexity.IBM cognos architecture is based on a typical three-tiered web architecture that consists of the web server, application server and data server [18].

The Cognos platform provides a single point of access to all data sources. Cognos uses star or snowflake schema to model the data. It performs complex data modelling, using Cognos Framework Manager; Cognos Cube Designer, or Cognos Transformer. It has a separate data modeller to generate the metadata which is derived from one or more data sources, and can be published to Cognos BI in the form of a package. The Cognos platform provides integration with enterprise authentication, single sign-on (SSO) solutions and a central place to control the access and authorization for all IBM Cognos BI objects, capabilities, and data.Cognos analytics is compatible with multidimensional and relational data sources from various companies, such as Oracle, SAP, Microsoft, and more [17].

Reports: IBM Cognos analytics reporting is a web based tool that professionals can use to build sophisticated, multiple-page, multiple-query reports against multiple databases. With Cognos Analytics – Reporting, users can create reports required by their organization, such as invoices, statements, weekly sales and inventory reports. This reporting tool features various components that the user can use to create highly interactive and informative reports. It provides features like, lists, crosstabs, charts, maps to enhance visualization. It provides a query object so that the user can extract and filter data for displaying in the reports. Cognos Analytics Reporting basically provides two reporting styles, relational reporting and dimensional reporting. In relational reporting, data summarization can be done using headers and footers in lists, summary functions, and detail aggregation. Relational Reporting mainly focuses on data representation with summary or detail filters.

In dimensional reporting, OLAP data sources can be used. Dimensional data is represented by crosstabs, maps, and charts. This data is shown in Cognos Analytics - Reporting in dimensions, hierarchies, levels, and members. The options for drilling up and drilling down are enabled in dimensional reports [8]

User Management: To ensure data security, IBM Cognos allows users to access only those job functions which they need to perform. IBM Cognos administration is a powerful administration tool that is an inherent component of IBM Cognos BI [25].

Analysis: In IBM Cognos data mining capabilities are provided through an extension of Cognos, i.e. IBM SPSS (Statistical Package for Social Sciences). With Cognos Analysis studio, users can explore and analyse data on different dimensions of their business. Users can also compare data to spot trends or anomalies in performance. Cognos Analysis Studio provides access to dimensional, online analytical processing, and dimensionally modelled relational data sources. Advanced data analysis tasks, can be performed using IBM SPSS tool which is dedicated to data analysis. Cognos can be easily integrated with the SPSS so that professionals can use the required features from both the tools [9], [10]. SPSS includes modules for data analysis. These include descriptive statistics such as frequencies, central tendency, plots, charts and lists; and sophisticated inferential and multivariate statistical procedures such as analysis of variance (ANOVA), factor analysis, cluster analysis, and categorical data analysis [11].

Optimization: As data volumes grow, analysing the data with speed-of-thought performance can be challenging. Even with modern data warehouse technology, some operations require significant computation or data movement. This computation or movement creates delays and reduces the satisfaction of business users who want to perform the analysis. There are various ways to accomplish performance over large volumes of data, from self-contained cubes to large in-memory appliances, different vendors are employing variations of similar methodologies to give business users timely response times. The Cognos dynamic cubes technology aims to give maximum flexibility of memory usage and accelerates the interactive analysis over terabytes of data, giving user the ability to evolve their deployments over time.

Cognos dynamic cubes technology helps to leverage the core strengths of an enterprise data warehouse (EDW) and take the EDW to the next level of performance for analytics, while making the deploying and tuning easier and faster. The metadata is used to model dynamic cubes and save cube definitions in a project [19]. Dynamic cubes are in-memory OLAP containers. Cognos dynamic cubes can take advantage of any relational tables that contain pre-aggregated data which represents the value of measures from the fact table, summarized by members from one or more dimensions, at a level of aggregation higher than those represented by the fact table. It can route queries for measure values, if appropriate, to these aggregate tables to improve query performance.

Cognos dynamic cube supports features like, dimensions, multiple hierarchies per dimension, level attributes, parent-child (recursive) hierarchies, time hierarchies, including automatic creation of relative time members, calculated (dimensional) members and measures, member security, aggregate cubes, virtual cubes. The basis for performance of Cognos dynamic cubes is its various in-memory caches, and its use of database summary tables. A Cognos dynamic cube uses five caches, each with a separate purpose. Cognos dynamic cube uses the power of aggregate to enhance the query performance. It uses the pre - computed database aggregate tables. Cognos dynamic cubes bring the aggregate routing logic into its query engine where the multi-dimensional OLAP context is preserved and determine whether to route for aggregation [7].

2.1.3 Business Object

BUSINESSOBJECTS (BO) is an integrated query, reporting and analysis solution for business professionals that allow users to access data in the corporate databases directly on a desktop. It helps to present and analyze this information in a BO document [2]. BO also offers consulting and education services. Business object specializes in the data from the financial domain.

Architecture: BO has a business-intelligent, semantic layer that isolates you from the technical issues of the database. This semantic layer is called a universe. BO XI is a multiple tier, a product based on server comprising several logical servers. These servers run on windows services, and all of them can be installed on one machine or distributed over multiple machines. Each of them can run as a multiple processor as per requirement. The main objective of the BO is to analyze data to help professionals to make the decision-making process more effective. It provides facilities like, slicing, dicing of the data and drilling across the dimensions. To perform these tasks, an OLAP server is provided. The architecture of the business objects shows that, data cube is further divided into two cubes, a SAP data warehouse and a pure OLAP cube. The actual data sources are stored separately and can communicate with the cubes through the semantic layer [2].

The BO enterprise's technological architecture constitutes a set of tiers maximized for tasks and operations. The five tiers which constitute the architecture are, client tier, intelligence tier, processing tier, data tier, and application tier [3].

The data tier, contains data sources which has information used in reports and documents. This tier is handled by the BO enterprise XI system which supports a broad range of corporate databases. BO requires data providers for each type of data source. These data providers need to be separately installed to handle the data [2].

BO also provides a facility to view the contents of an OLAP server and select the data that can be displayed in the report. OLAP servers are multidimensional databases that store summarized data, ready for business analysis. BO supports the following OLAP servers: Microsoft OLAP Services, Hyperion Essbase, IBM DB2 OLAP Server, Informix MetaCube, and Oracle Express.

BO makes it easy to access this data, because it uses business terms that are familiar to its users, and not technical database terms like SQL. Users often do not require any knowledge of the database structure or technology [2]. BO provides the facility to absorb data from various data sources like, relational database, multidimensional databases, text files, spreadsheets and packaged applications such as SAP.

Reports: BO can create multidimensional reports. It also provides a facility to store and present the data in the form of tables. The tables present data in a row wise or column wise pattern. Crosstab table is available in Business Object. In this table, data is displayed in columns and rows, corresponding data appears at the intersection of the columns and rows; this part of the crosstab is called the body. The body typically displays numerical data.

BO has a very powerful and easy-to-use charting feature which enables its users to produce sophisticated and visually appealing charts to display a simple summary data or represent complex relationships in it. BO has five basic chart types.

Analysis: With BO users can analyze data at different levels of detail and with different viewpoints. BO addresses all the multidimensional needs, and allows to work directly on the data. It caters all the needs of multidimensional data analysis.BO provides on-report analysis, where the user directly works on the data in the report using drag and drop or simple mouse clicks. An optional component in BO enables multidimensional analysis in Drill mode. It uses OLAP servers that are databases storing summarized data, ready for business analysis. BO Slice and Dice mode, allow to organize data for analysis in the slice and dice panel.

BusinessMiner (BM) is another optional component that allows users to analyze data using data mining technology. BM enables to discover the hidden patterns and relationships in the data. Using powerful statistical methods, it can quickly and automatically find patterns in customer behavior.

To analyze the data, BO provides a facility to break down the data and view it from different angles and different levels of detail. It also provides the slice – and – dice mode which enables the user to switch the position of data in a report.

User management: BO provides account management which involves all tasks related to creating, mapping, changing, and organizing user and group information. By default, there are three types of accounts, administrator, guest and SMAdmin. Groups are collections of users who share the same account privileges; therefore, groups can be created based on department, role, or location. Groups help to change the rights for users in one place instead of modifying the rights for each user account individually. The object rights can also be assigned to a group or groups. By default, there are six group accounts, administrator, everyone, QaaWS group designer, report conversion tool users, translators, and universe designer users [15].

Optimization: BO universe hint is one of the options to improve the report / query performance by forcing to optimize the database servers in different ways. If a user has a complex report query which has more tables and complex joins, BO universe level hint would help to reduce the report refresh time at query level [20]. To optimize the query performance, BO makes use of indexes to generate the query [21].

2.2 Open source Tools

2.2.1 Tableau

Tableau is a business analytics tool used for creating a wide variety of interactive data visualizations. The software is available as a free version (Tableau Public) as well as a more robust full-scale version. Tableau can be used to create a wide variety of interactive visualizations that allow users to better explore temporal, spatial, topical, and network data. The drag-and-drop interface makes it easy to explore data without needing any advanced programming skills. Dashboards allow users to combine multiple views of their data into one analytics tool [12].

Architecture: Tableau has a highly scalable, n-tier client-server architecture that serves mobile clients, web clients and desktop-installed software. The architecture of tableau consists of, data layer, made up of data warehouse, data marts, files and cubes. The second layer is a layer of connectors which helps in communication with the components of data layer. The next component of the architecture is a server layer which includes application server, VizQL server and the data server. The gateway layer connects the servers to the client system [22].

Tableau desktop users can upload Excel, Access, .txt, and .csvfiles. Visualizations can be embedded into websites, hosted online, or exported as PDFs or image files. Tableau is available for both Windows and Mac [12]. Tableau can connect to hundreds of data sources using connectors, both live and in-memory, without any programming. Notable connectors include: Redshift, Cloudera Hadoop, SQL Server, Salesforce, Google Analytics & Google Sheets, MongoDB, PDF files, spatial files, Dropbox, Amazon Athena and more [16].

Reports: Tableau Software was founded on the idea that data analysis and subsequent reports should not be isolated activities but should be integrated into a single visual analysis process—one that lets its users to quickly identify patterns in their data and shift views on the fly to follow their train of thought. Tableau combines data exploration and data visualization in an easy-to-use application that anyone can learn quickly. [14]

Analysis: Tableau possesses a rich set of capabilities to enable quick, iterative analysis and comparison of segments. It allows users to explore how changing a value or set of values affects the output of their analysis. This could be used to test different theories, to highlight important scenarios for colleagues, or to investigate new business possibilities. Tableau also supports time series analysis. When working with time series, it's often necessary to smooth or perform

other temporal calculations. Tableau possesses a rich feature set designed to simplify common time-series operations such as moving averages, year-over-year calculations, and running totals. Tableau possesses several native modelling capabilities, including Trending and Forecasting [23].

User Management: Tableau provides permissions to users to maintain security. The permissions are granted to: view, web edit, write/web save, download/web save as, delete, filter, add comments, view comments, view summary data, view underlying data, export image and share customized views[13].

Optimization: Tableau includes several optimized data connectors for databases such as Microsoft Excel, SQL Server, Oracle, Teradata, Vertica, Cloudera Hadoop, and many more. Tableau is the front-end analytics client to many of the largest databases in the world. Tableau has optimized each connector to take advantage of the unique characteristics of each of the data sources. Tableau offers a fast, in-memory Data Engine that is optimized for analytics. Users can connect to their data and then, with one click, extract the data to bring it in-memory in Tableau. The Tableau view performance is directly related to the speed of the underlying structure of the database. While multi-dimensional databases generally perform best, a relational database with a clean star schema or an analytics-optimized database will outperform most of the other highly-normalized transaction-oriented databases [14].

3. MULTIDIMENSIONAL DATA ANALYSIS TOOLS: CHALLENGES

The primary focus of any product is to adapt to the changing business needs. The data analysis tools are no different and need to evolve as well. There are still some areas of improvement for all the tools in the market today. In today's advanced technical world, data analysis needs to be supported by the various statistical techniques like univariate and bivariate techniques, time series analysis and much more. Data mining techniques including descriptive and predictive data mining and various machine learning techniques are also pillars for complete data analysis solution. Most of the tools provide all of these techniques, but the user often needs to install separate components of the tools to get the required functionality. This may highly de motivate the non – technical users or researchers. Table 1 summarizes some of the challenges for these tools.

Table 1. Multidimensional data analysis tools

Sr. No.	Name	Important features for optimization	Challenges
1	MicroStrategy	Intelligent cube for optimized performance	Though optimized, the time required to generate the cube is high and there is a steep learning curve
2	IBM Cognos	Dynamic cube concept used for optimization	It needs skilled professionals to work on dynamic cubes.
3	Business object	Uses Hint objects and indexing for optimization	Need to install separate components for each feature
4	Tableau	Optimized data connectors, in – memory data engine	Cube handling is done by MDX. A Steep learning curve.

Reporting and visualization is a key aspect of any data analysis system. There are loads of tools providing interactive and fancy reporting facilities and dashboards to showcase the result of the analysis. They have filtering options to select specific data. In case of multidimensional data analysis, reporting facilitates slicing, dicing and aggregations on the data. Representation of various aggregation functions is often difficult in reporting. Analysing data is an ad - hoc process, the analysis needs may also change frequently and preparing one dashboard or one complete report may require considerable efforts. Thus, it is difficult for users to perform this task at a higher frequency.

Most of the tools store data in a cube to perform multidimensional data analysis. Cubes are used to store the aggregations on the multidimensional hierarchical data. Some of the tools use various memory efficient techniques like memory caching to manage the memory space effectively. Although a cube itself can come with some unwanted side effects. The biggest disadvantage of cube architecture is the limitation on the data it can handle. All calculations are performed when the cube is built. It is not possible to include a large amount of data in the cube because of space and time limitations. To derive data from large databases, only summary-level information is included in the cube. It requires an additional investment of space and time. In this case, a user is not expected to change his requirement of different types of aggregation functions frequently. Some applications generate data at micro second level; generation of cube for such data, for different aggregation functions is practically very difficult.

It is observed from the study, that all these tools are composed of small separate components to accomplish the various data analysis life cycle tasks. The user needs to install all the components of a tool to make the complete use of a product.

One more important aspect also needs to remember is the price for a licensed version of a tool. Generally, a company needs to provide a single user, against each license of the product. Though open sources are available in the market, if the user wants to upgrade to the full range of the product, he may need to pay for it [18].

4. CONCLUSION AND FUTURE SCOPE

A rapid change in technology is affecting every aspect of the business and research domain, in terms of data analysis requirements. To cope with this change, data analysis tools need to be penetrable. They need to be in the hands of both the technical and non-technical community and provide the in depth and complete data analysis without getting affected.

This paper presents study of the some of the popular data analysis tools. It is observed during the study that the main point of concern is the data absorption in the system. Generally, data is stored in the system and a multidimensional data cube is created for analysis. This solution is suitable for organizations that have the same type of data and work in the same domain. But it may be more cumbersome for those where the data changes frequently, in the same or different domains, and for entirely different analysis requirements. Product cost also matters if are search community is the target

user. Though a good range of open source data analysis products are available, it provides a limited set of facilities in their free versions. The other nuisance is that the non – technical data miners face challenges to work these tools as their operational features are divided in separate components. It seems there is a considerable future scope for research in technology, such that it delivers a complete data mining and machine learning solution which avoids the time consuming process of generation of data cube. Also the scope is there in building a technology which provides the multidimensional data analysis solution on a single platform with user friendly and integrated components.

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