Financial Data Visualization in 3D on Immersive Virtual Reality Displays

A Case-Study for Data Storytelling and Information Visualization of Financial Data of Australia's Energy Sector

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Abstract. Within the scope of this publication, we present a design prototype for the 3D visualization of financial data of Australia's Energy sector with a large scale immersive virtual reality environment. We review existing 3D visualization approaches in finance industry; discuss the technical setup of the prototype; explore design considerations; and approaches to make financial information understandable for everyone. We conclude with a discussion about the potential that immersive virtual environments provide to support the understanding of market events, as well as the exploration of large multidimensional data-sets.

1 Introduction

Financial market data is complex and requires data presentations that go far beyond simple charts of price data for an instrument. Traditionally financial market data is expressed through dashboards containing charts, news-tickers, trading desks, and other relevant information to support users in gaining an understanding of happenings on the market. Typical visualizations include pricing data, charts, fundamentals, market research, news, alerts, social media data, 3rd party informational content, and enable trading functionality.

Despite the trend towards fully computerized algorithmic trading systems (e.g. [1]) - humans are still a major factor in making trading decisions and are required to quickly

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develop an overview of the current market situations and events taking place. Today's systems present information predominately in the 2D space. We would like to explore the additional opportunities enabled by adding a 3rd dimension for information presentation. We also would like to support humans in gaining easy understanding and knowledge of the current market situation. This also implies faster and better decision making concerning trading decisions. In addition, this will help allow individuals from outside the financial industry to quickly process and understand complex information in a visual manner.

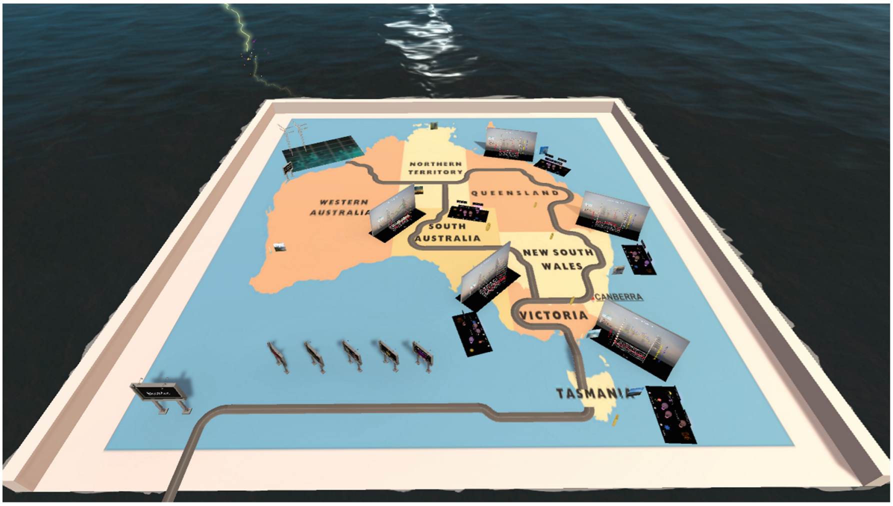

Fig. 1. Screenshot of the final implementation.

To illustrate the potential of 3D, immersive environments, and data storytelling, we have been developing a proof-of-concept implementation we call "ElectrAus", a tool to visualize publicly available data from the Australian energy market. The objective of the proof-of-concept implementation was to illustrate new concepts in data visualization such as:

- Utilization of immersive environments and large screens for financial data visualization;
- Experimentation with data storytelling;
- Creating an understandable visualization for the general public;
- Additional insights and analytics through 3D display;
- Interactivity to create more engagement and allowing to dig in data materials;

1.1 Related Works

Research in financial markets is broad and includes asset pricing, market behavior research, trading algorithms, text/sentiment analysis (see e.g. [2, 3, 4]) and the investigation of social media in trading [5]. Within the scope of this paper, we attempt to apply solutions emerging from utilizing immersive 3D technologies for financial visualization. We give an overview of current research works independently targeted towards investors, operators, or end-users. However, the paper rounds up by presenting our prototype (see Fig. 1) of our prototype, targeted towards end-users. This prototype illustrates the potential of applying 3D visualization for data storytelling in immersive virtual reality environments. It can be considered an example of *Serious Storytelling* – using an environment to tell "stories beyond entertainment purpose" and in serious application contexts [6].

1.2 Theoretical Considerations

Besides the development of a design concept, the main objective of data visualization within financial industries is to enhance effective decision making, based on the following three cornerstones:

- Which information is important?
- What is the most effective way to communicate information?
- How is information accuracy ensured when market dynamics are changing rapidly?

While answers to the first question are mostly user-driven, there is common information in the financial market that would be important to most users. In the context of this paper, information such as demand, supply and pricing of electricity are fundamental to both investors and market operators. However, the structure of the data is complex and effective communication via visualization becomes crucial. Communication strategies depend greatly on the trade-off between short run information versus long run trend. For ultra-high frequency traders, short run information is crucial while for market operators, the intra-daily and weekly variations are more informative. Therefore, an ideal framework should be able to provide "multiple" stories, which allows users to select the "story" that is most *appealing* to them.

2 Method and Approach

For the purpose of this research work, we follow a typical *design research* approach of a review of current 3D projects (background research), prototype development, and evaluation. This publication presents our prototype and its evaluation. The goal of the project was to develop a prototype which would display financial market data in an immersive 3D environment. Financial market data is often extremely dynamic and readily available in high-frequencies. Information and trading providers such as Bloomberg or Reuters provide live market information to subscribers which is often used to make investment decisions. Recently there has been increased interest surrounding virtual reality and 3D technology in presenting this dynamic data beyond traditional visualization techniques which are often presented in time-series using various charts or variations of heatmaps. Interest in this area has been driven by the needs of industry professionals, in particular traders who often rely on multiple physical trading screens to keep up-to-date with high-frequency data and information as soon as it becomes publicly available. One of the goals of this project was to visualize dynamic data in a manner which allows for easy summarization.

3 Background Research: Review of 3D Projects

Table 1 illustrates a set of different projects and approaches utilizing 2D and 3D means of visualizing of financial data. They utilize different visualization technologies, interaction modalities, and 3D features.

In principle we can characterize current approaches into (1) 3D visualizations moving traditional visualization techniques, such as heatmaps, charts, or scatterplots into the 3D space; and (2) projects providing innovative attempts and providing new solution towards the value that 3D allows. Especially the latter category of projects is rather fascinating, as these projects make use of a new media technology to present data allowing viewers another angle and perspective on data. Adding new dimensions, spatial relationships, geographic meaning, and creating more appealing and easier to understand visualization provide many new opportunities for understanding and interpreting the underlying data. However, one of the main questions remains – what added value does 3D give, and where is 3D useful in the context of financial visualization.

Table 1. Overview of various projects related to 3D visualizations in financial industries.

Project	Description	3D features	Interaction	Technology	Ref.
Thomson Reuters Eikon	Traditional trading desk with some standard 3D features	Combining heatmaps and 3D plotting	Traditional interaction methods	2D screens	[7]
Citi Holographic Workstation	Augmented reality workstation for financial trading	AR, combination of 2D elements and AR	Voice, gesture, keyboard	HoloLens and 2D screens (AR+2D)	[8]
Comarch	Trading desks with a futuristic 'game' alike look for wealth management	Cross-media visualization of banking data		2D screen	[9, 10]
QuantVR	City environment with streets as metaphor for visualization of the stock market	Tree maps modeled in 3D and advanced visualizations of trades as comets, ticker tubes, etc	Typical 3D navigation and interaction modalities	Displaying of 3D scenes on screen	[11]
InVizble	3D environment emphasizing of typical market data in 3D	Very advanced 3D representations of Kepler views, grid array Views, 3D scatter plots, tube views	Typical 3D navigation and interaction modalities	Display of 3D scenes on screens, also enabling head mounted displays or other modalities	[12]
ScienceGL	Scientific tool to visualize stock information in three dimensions	Information and science centered tool to visualize heatmaps, line graphs, etc. in 3D	Simple interaction modalities related to interacting with charts	Representation of data in 3D	[13]

(*continued*)

Table 1. (*continued*)

Project	Description	3D features	Interaction	Technology	Ref.
Stock City (Fidelity Labs)	City representation of investor portfolios	3D city models representing stocks, prices, and information about stocks	Typical 3D navigation and interaction modalities	Display of 3D scenes on 2D screens	[14]
VRPPortunity (Salesforce)	Creative approach towards visualizing stock information	Utilization of physical dynamics, color and animations to illustrate information	Advanced interaction and navigation modalities	Display of 3D, and 2.5D models to visualize information	[15]
Bloomberg Terminal	Arrangement of 2D display in an 3D environment	Utilization of 3D to make use of the limited screen space through arranging virtual 2D monitors in 3D	Simple 3D navigation and interaction models	Simple 3D representation of 2D screens	[16, 17]
DXFeed	Representation of technical stock data through AR in an office space	Similar to other tools offering 3D functionality to represent 2D information	Interaction based on AR	Display of stock data in an augmented office space	[18]
Nirvaniq Labs	Metaphors for representing stock information through maps, 3D charts, 3D line charts, and other advanced modalities	Very advanced re-thought representations of typical stock exchange tools as charts, line charts, or maps. Sophisticating use of new representations.	Efficient utilization of 3D navigation and interaction modalities	Typical 3D technology, however, the strength of the project is the advanced representation through enhancing traditional 2D representation	[19]
Looker	Utilization of HMDs to explore financial data	Exploration of traditional charts in a 3D space	Typical HMD based interaction modalities and interaction devices	HMD based environment	[20]

4 Prototype Development of ElectrAus

The goal of the prototype was to illustrate an immersive, interactive 3D visualization on large scale 3D displays, considering the following variables as part of the visualization:

- average price/day based on price given in defined intervals;
- ratio of renewable energy to traditional energy generation e.g. coal powered generated electricity;

- demand and supply of electricity over time at different frequencies;
- scheduled demand and supply based on different regions;
- net electricity import between interconnected regions.

Settlement Date	Dispatch Price ($/MWh)	Scheduled Demand (MW)	Scheduled Generation (MW)	Semi Scheduled Generation (MW)	Net Import (MW)	Type
09/02/2018 00:00	68.99	7977.25	7643.344	100.796	-199.84	Actual
09/02/2018 00:05	67.11332	7920.76	7614.528	99.202	-169.39	Actual
09/02/2018 00:10	59.04981	7821.55	7469.15	96.82	-231.5	Actual
09/02/2018 00:15	84.21912	7855.74	7515.505	96.485	-197.89	Actual
09/02/2018 00:20	77.3176	7827.72	7422.253	93.977	-270.84	Actual
09/02/2018 00:25	68.98995	7806.98	7425.212	90.098	-249.17	Actual
09/02/2018 00:30	68.55261	7697.29	7256.23	90.9	-307.21	Actual
09/02/2018 00:35	68.99	7710.7	7178.887	84.083	-409.53	Actual
09/02/2018 00:40	76.19568	7756.77	7160.862	77.328	-468.7	Actual
09/02/2018 00:45	73.81824	7705.78	7151.415	73.525	-439.07	Actual
09/02/2018 00:50	68.99	7602.13	7053.973	72.097	-435.1	Actual
09/02/2018 00:55	69.0773	7589.23	7063.58	67.46	-418.22	Actual
09/02/2018 01:00	69.07602	7527.85	7039.043	60.007	-387.47	Actual
09/02/2018 01:05	69.0585	7343.1	6856.633	56.807	-389.53	Actual
09/02/2018 01:10	70.0895	7370.88	6798.114	55.826	-469.94	Actual
09/02/2018 01:15	69.04793	7224.25	6731.867	50.953	-402.55	Actual
09/02/2018 01:20	74.42	7312.87	6715.222	49.138	-500.34	Actual
09/02/2018 01:25	70.09038	7283.93	6715.695	48.705	-474.35	Actual
09/02/2018 01:30	69.12643	7228.32	6664.251	46.289	-479.17	Actual
09/02/2018 01:35	87.00001	7207.56	6674.551	46.199	-439.59	Actual
09/02/2018 01:40	81.44933	7227.62	6551.211	45.399	-580.38	Actual
09/02/2018 01:45	76.00119	7169.81	6399.086	41.774	-678.04	Actual

Fig. 2. Example input data for the prototype.

4.1 Australian Energy Market Data

Data used for the project was obtained from publicly available data published by the *Australian Energy Market Operator (AEMO)*.[1] There are two main distinct geographically located and administered energy markets for which data is readily available from AEMO. The first is the *National Electricity Market (NEM)* which connects the following States: Queensland, New South Wales (including the Australian Capital Territory), Victoria, South Australia, and Tasmania. The other large market for which data is readily available is the *Wholesale Electricity Market (WEM)* in the *South West Interconnected System (SWIS)* which applies only to Western Australia.

The electricity market in Australia is well suited as a starting point to data visualization, as data is provided in 5-min or 30-min intervals[2]. The proof of concept was built around a 1-day time period in 5-min intervals for the different states' electricity markets in Australia. However, the interval can be extended to longer time periods (by aggregating or finding an average price) with the potential to summarize and compare multiple markets and multiple variables. The ticks or interval times for data are frequent enough to present meaningful information for a single day which can easily be extended to information of shorter intervals (e.g. millisecond intervals for some data such as foreign exchange rates in well traded currencies).

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[1] Available from: https://www.aemo.com.au/.

[2] Data is available in 5-min intervals for the National Electricity Market and 30-min intervals for the South West Interconnected System.

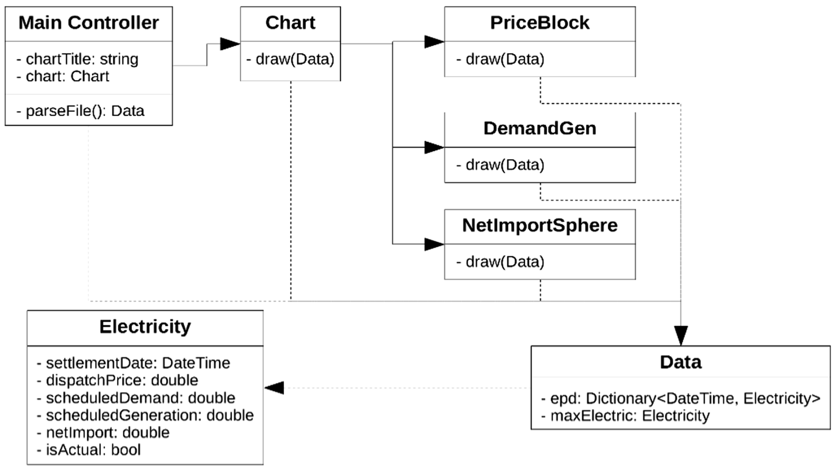


Fig. 3. Class diagram of the overall software modules.

4.2 Data and Variables

The project presents visualized information of the following different electricity market variables which allows for high level summarization of numerically-based data. For the purposes of this project some of the intricate market microstructure is aggregated (see Fig. 2):

- **Dispatch Price:** price determined in 5-min intervals for the NEM, which are averaged to spot prices over a 30-min interval;
- **Scheduled Demand:** electrical power requirement (in megawatts, or MW) which includes scheduled generation, interconnected import/exports including losses and regional scheduled loads;
- **Scheduled Generation:** energy generated and sent out by all scheduled generators (in megawatts, or MW);
- **Net Import:** the net power imported/exported by the relevant region at its inter-regional boundaries;

Figure 2 presents a snapshot of the information that was used in the project. The information comprises of 5-min intervals or settlement dates.

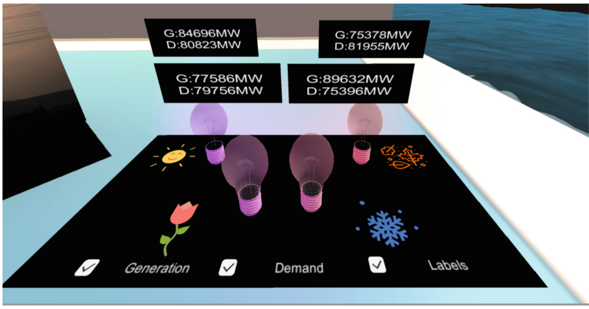
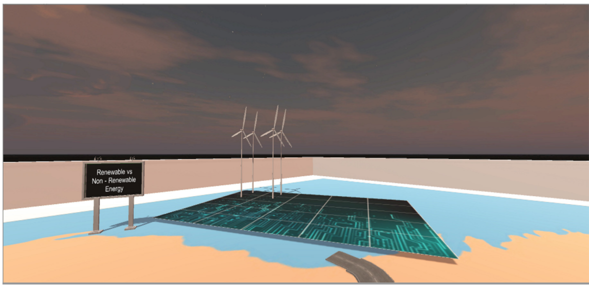
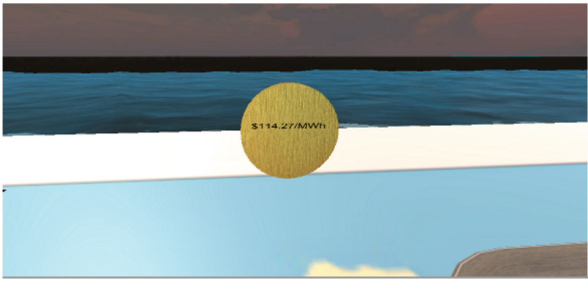
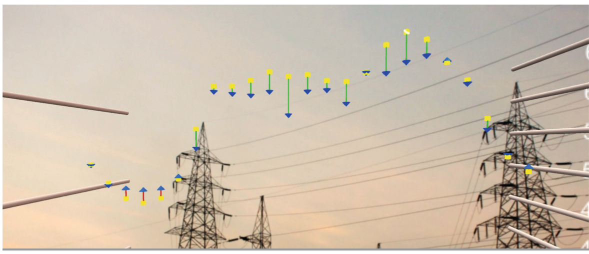
4.3 System Architecture

The system has been developed using the Unity 3D game engine [21]. Besides the components from Unity, we developed a CSV file parsing module, simple data analytics, a 3D charting library, and created 3D models for the prototype. A basic class diagram is illustrated in Fig. 3.

4.4 Design Considerations

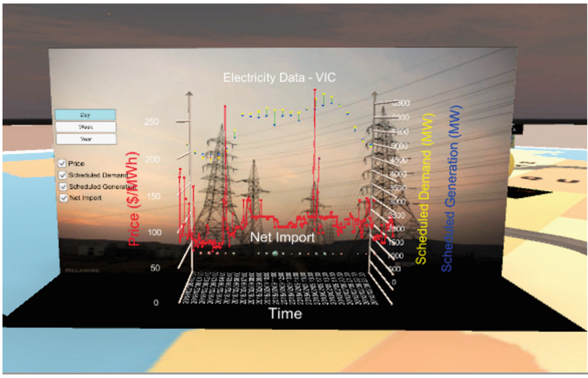
The following design guidelines have been applied in designing the prototype (see Table 2):

Table 2. Overview of designs used in our 3D visualization

Visualization Designs of Various Variables	Variables involved in the Visualization Designs
	Visualization of electricity demand and generation throughout seasons
	Ratio of renewable energy produced in Australia symbolized as wind turbines
	Average price/day symbolized through a coin
	Scheduled electricity demand and generation

(*Continued*)

Table 2. (*Continued*)

	Main chart to display data (dispatch price, scheduled demand and generation, net import)
	Electricity net import

- Kevin Lynch's architectural guidelines for city planning (e.g. path, edges, district, nodes, landmarks and focus points) [22];
- Guidelines for color palette creation for visualizing stock market data in a 3D immersive environment (e.g. contrast, visual clues, palette, gradients, …);
- Development of symbols and semiotics of different 3D models to illustrate the essentials of this data (e.g. objects, colors, positive/negative events, ratios, seasonal differences, sustainable energy);
- Migration of 2D charts into the 3D space and providing additional information through efficient utilization of the 3D space;

5 Evaluation and Conclusions

5.1 Prototype Evaluation

One potential measurement on the success of the proposed framework is to evaluate its effectiveness on providing timely and accurate information to decision makers. The variables considered should provide holistic information for suppliers to better manage electricity supply through the day as well as important insight for investors on the difference in demand between different regions. Thus, evaluation can be in the form of feedback from both investors and electricity market operators.

Figure 4 illustrates the current prototype displayed on the Cylinder Display at the Curtin HIVE (Hub for Immersive Visualisation and eResearch). The current prototype represents an initial trial prototype for further investigation and testing.

Fig. 4. Visualization in the Cylinder Display at the Curtin HIVE (Hub for Immersive Visualisation and eResearch).

5.2 Added Value of 3D for Financial Visualization

We concluded, that the main advantages for using 3D, VR, and immersive technologies in finance are:

1. presentation of large amounts of data in a limited space;
2. overcomes space limitations due to a restricted physical space;
3. additional data supporting meaningful additions of information;
4. support of cognitive functions as e.g. pre-attentive processing;
5. easier knowledge and information discovery;
6. visual appealing presentation of qualitative and quantitative data;
7. representing inherently complex data in simplified ways;

Financial market data is inherently complex. For instance, the current application area consists of data from electricity generator i in region j at time t This represents a typical multi-index data with hierarchical structure in the first two indexes. Informative presentations of these data types have always been challenging, especially when the presentations are restricted to 2D format.

3D visualization allows the presentation of large amounts of data in a limited space environment. It also allows effective combinations of both quantitative and qualitative data, which provide users with a holistic view of available information. Despite a limited physical available space, users can explore the data from different angles and perspectives, which is not possible in a 2D space representation. The added dimension also allows adding more data to support the presentation data and add meaningful additions to the data. Simple navigation facilities support data exploration, and by adding more complex interactive elements, the engagement process of a user can be increased. Despite the additional dimension requiring a higher cognitive load, it supports pre-attentive processing of the environment by humans [23]. The use of a virtual 3D environment also allows separation of different sets of data in an intuitive way. However, for the user of the system, quantitative data is presented in a form that it is more visually appealing. This is a clear advantage e.g. if the system is designed for end-users without a solid expertise in financial data. For professionals, e.g. regulators, a data presentation in 3D eases the process of discovering irregularities. Professionals benefit from additional dimensions allowing, data to be presented in a limited physical space in a way that supports cognition and makes the data easier to understand.

5.3 Future Work

We especially would like to investigate how 3D supports (1) the exploration of large amounts of multidimensional financial information and data; (2) data storytelling; (3) extend the current prototype to a fully functional real-time data display in immersive environments; (4) how 3D visualization affects the understanding and cognitive efforts to understand underlying data in the context of *Cognitive Big Data* [24, 25] and (5) adequate intelligent interaction designs (see e.g. [26, 27]) through creative thinking and design thinking [28–30].

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