# 3Dify: Extruding Common 2D Charts with Timeseries Data

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## ABSTRACT

3D charts are not commonly used in financial services. We hypothesize unfamiliarity as well as costs such as navigation negatively affect acceptance. We review chart use in financial visualization research and in practice. We instead create 3D financial visualizations by starting with well-known canonic 2D charts used extensively in financial services, then extend them into the third dimension with timeseries data. We literally embed the 2D view into the the 3D scene with the 2D scene as a reference starting point; and also constrain interaction and add depth cues to facilitate comprehension. Usage, feedback, and ongoing extensions indicate a successful approach.

**Index Terms:** Human-centered computing—Visualization—Visualization techniques—Treemaps; Human-centered computing—Visualization—Visualization design and evaluation methods

## 1 INTRODUCTION

We were tasked by an multinational financial firm to create engaging 3D data visualizations of financial data for use on a dozen high-resolution large scale displays (($\geq$4k)) such as multiscreen meeting room displays, multitouch interactive walls, and a CAVE-like immersive studio. The usage scenario was to create an interactive ambient display to engage people passing by - financial professionals, executives, staff, guests and the occasional educational group.

The firm had previously created two 3D financial visualizations and a set of 2D financial visualizations for these screens. None were considered successful:

- One of the prior 3D visualizations was a highly animated novel representation of stock market data. However, this visualization was lacking in supporting cues such as axes and labels to facilitate decoding. For people passing by, a long description was difficult to deliver, thus these viewers were unaware of the encoding. As such, this visualization was considered indecipherable and dismissed as art.
- Another prior 3D visualization was an organized 3D bar chart, highly texture mapped with scenic effects. Entity labels clearly identified the bars, however, cues such as ticks, axes and grids were missing and different textures were applied per bar. Thus it was decodable, but difficult to get a sense of relative comparisons. Furthermore, this landscape could be viewed from a wide variety of viewpoints, thus requiring viewer effort to reorient themselves each time they approached the visualization.
- The 2D visualizations followed familiar financial chart types, however, they lacked any visceral excitement and did not generate any interactive engagement. Viewers were readily able to understand the content, but were not inclined to do more.

The project team included technical staff, financial charting experts, and visualization experts. The key requirements for this 3D financial visualization project were:

- **Ease of understanding the representation**. Given the ambient use, the visualizations needed to be comprehended immediately - without training, tutorials or complex legends.
- **Ease of interaction.** The team wanted people to interactively engage with the content. All displays afforded interaction, such as multitouch, gesture, or mouse. If users interacted, then they were engaged with the content.
- **No extra devices.** The solution needed to work without requiring 3D glasses, VR, AR, and so on. Mobile AR was dismissed, as there were deemed potential issues with data security and license rights to third party data.

To arrive at a successful application, we decided to start with a review of many possible design approaches, including 3D financial visualizations and well-understood 2D financial charts (described in section 2, Background). Based on this, we then created alternative designs and extensible design framework for set of 3D visualizations (section 3 and 4), and incremental validation through reviews of user logs, user feedback and project guidance (section 5). Our primary contribution is a framework for 3D visualizations which are literally 2D point-in-time charts extruded with timeseries data into the third dimension.

## 2 BACKGROUND

A wide variety of financial visualizations exist, in peer-reviewed academic research, software startups and by financial professionals. 3D financial visualization is not new and has met with varied success over the years.

### 2.1 3D financial visualization by academia and startups

Many financial visualizations are collected on survey websites, such as financevis.net [12] and regvis.net [31]. Lugmayr et al specifically surveys VR and AR financial visualizations [28]. These 3D financial visualizations can be organized as follows:

**Aligned multi-component 3D visualizations:** Wright [53] presents numerous capital markets examples including fixed income portfolios, options trading, global cashflows, credit risk and market risk; all of which contain multiple 3D visualization components all visually aligned. For example, a stock order view ( [26] fig. 2.1) aligns disparate datasets including a 3D distribution of limit orders, a 3D timeline of trades, and a 3D cumulative distribution of trade volume along an aligned price axis, time axis, and volume axis.

**3D Surfaces:** Many financial instruments, i.e. futures, forwards, options and other derivatives can be modeled as multi-dimensional functions and thus plotted as surfaces in a 3D space, such as Feiner

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and Beshers early VR Worlds within worlds [15]or Gresh et al's currency options [18]. 3D financial surfaces are popular, also available in major financial software such as Bloomberg and Eikon.

**Other 3D spatialized datasets:** Other 3D financial visualizations focus on a singular dataset and define a Cartesian space, mapping financial attributes to spatial, visual and textual variables: for example, 3D scatterplots (e.g. Xiong et al [54]); 3D tables (e.g. Strausfeld [41]); multi-dimensional glyphs (e.g. Kirkland et al [23]); simple 3D timeseries (e.g. [1, 16]) or more complex 3D timeseries ribbons (e.g. Roberts varying line width and color per segment [34]). Microsoft's Sandance directly spatializes atomic visual elements in 2D and 3D and could be easily used for financial data such as stocks or bonds [32].

The spatialization may indirectly map datapoints to spatial coordinates such as 3D treemaps [20], 3D force-directed graphs [13], 3D trees [37], or spheres [8]. Fidelity's VR StockCity creates neighborhoods of stocks as 3D bars, texture-mapped as buildings [4].

**Physical spaces, VR and AR spaces:** The New York Stock Exchange created a 3D VR version of their physical trading floor [11]. In VR/AR, Wall Street Journal's stock market on Magic Leap anchors a 3D scatterplot in a human-sized space [22]. In-vizible creates handheld 3D AR scatterplots of financial data.

**3D Workspaces of 2D screens and 3D charts**. Some 3D financial visualization environments place many 2D screens (watchlists, newsfeeds, spreadsheets, tv) in a larger 3D virtual space, increasing the bounds beyond the limitation of a 2D screen. Examples range from purely 2D screens in 3D, such as Bloomberg screens [36]; or combinations of 2D screens and 3D charts such as 3D treemaps (QuantVR [10]), 3D scatterplots (Citi Holographic Workstation [2]), or 3D surfaces (DxFeed [3]).

## 2.2 Charts from financial professionals

Instead of industry and academic researchers' financial visualizations, another approach is to consider the what charts and graphs financial analysts actually routinely create and use.

We had access to the firm's internal charting team and their charts. All charts were 2D and predominantly timeseries charts (line charts or bar charts). A variety of other 2D charts were also used, including: bar charts, scatterplots, distributions, line charts (for financial structures such as yield curves and forward curves), rank-order charts, variable width bar charts and a text chart.

We also compared those to 25 online chart-dense financial publications created by central banks, global investment banks and capital markets advisory firms intended for external use - typically financial clients. [**?**, 5–7, 9, 14, 19, 24, 27, 30, 33, 38–40, 42–50, 52, 55]

These financial publications contained more than 1300 charts, predominantly using a few key chart types as summarized in Table 1. By far, the publications are dominated by timeseries charts (using lines, bars or on a few occasions, dots) comprising 71% of all charts. Second most frequent at 16.7% are categorical bar charts, including simple bar charts, stacked bars and clustered bars. Appearing in at least two publications are scatterplots, pie charts, range plots, curves, histograms, maps and heatmaps. All these prior chart types account for 99.5% of all published professional financial charts. Note that there were no 3D charts, not even a single 3D surface, nor 3D pie chart.

We also note that the 2016 book *Visualizing Financial Data* [35] includes a wide variety of 2D capital markets visualizations. Only one visualization type in the book is 3D – a 3D surface for a financial option.

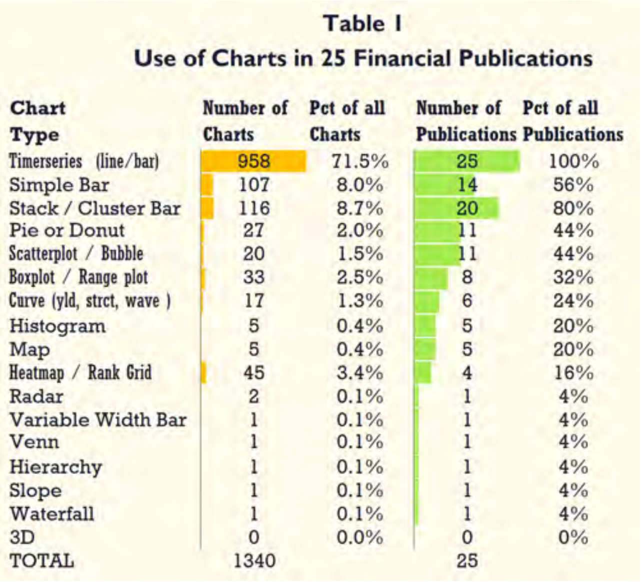

Table I

Use of Charts in 25 Financial Publications

| Chart Type | Number of Charts | Pct of all Charts | Number of Publications | Pct of all Publications |
|---|---|---|---|---|
| Timerseries (line/bar) | 958 | 71.5% | 25 | 100% |
| Simple Bar | 107 | 8.0% | 14 | 56% |
| Stack / Cluster Bar | 116 | 8.7% | 20 | 80% |
| Pie or Donut | 27 | 2.0% | 11 | 44% |
| Scatterplot / Bubble | 20 | 1.5% | 11 | 44% |
| Boxplot / Range plot | 33 | 2.5% | 8 | 32% |
| Curve (yld, strct, wave ) | 17 | 1.3% | 6 | 24% |
| Histogram | 5 | 0.4% | 5 | 20% |
| Map | 5 | 0.4% | 5 | 20% |
| Heatmap / Rank Grid | 45 | 3.4% | 4 | 16% |
| Radar | 2 | 0.1% | 1 | 4% |
| Variable Width Bar | 1 | 0.1% | 1 | 4% |
| Venn | 1 | 0.1% | 1 | 4% |
| Hierarchy | 1 | 0.1% | 1 | 4% |
| Slope | 1 | 0.1% | 1 | 4% |
| Waterfall | 1 | 0.1% | 1 | 4% |
| 3D | 0 | 0.0% | 0 | 0% |
| TOTAL | 1340 | | 25 | |

Similarly, the authors had the opportunity to review a commercial financial services data provider's analysis software used by more than 100,000 financial professionals. We found more than 100 different screens with visualizations, including timeseries charts, scatterplots, graphs, pie charts, multi-level pie charts, small multiples of sparklines, and so on. The only 3D visualization in the system was an interactive 3D surface.

The reader should note that this does not imply financial professionals use low-dimensional data: consider the 2D market profile charts which may encode data via x, y, position and multi-dimensional glyphs using color (including hue and brightness of the foreground or background), alphabetic character (a-z), alphabetic case (upper/lower), and additional enhancements such as bold or superscripts depending of the software vendor.

## 3 ANALYSIS, DESIGN AND DEVELOPMENT

There is a mismatch between researchers' 3D financial visualizations, and the findings of the charts used by financial professionals in their tools and their publications. Furthermore, for our application, our target use was ambient consumption with occasional brief casual interaction by the financial professional. This use case had more in common with the professional financial publications, wherein viewers perused publications quickly and therefore rely mostly on well-known chart types. As such, we were inclined to focus on 2D charts as a point of entry to 3D charts.

## 3.1 2D charts as a starting point

We focused on the traditional 2D chart types from professional publications as our starting point. We hypothesized that canonic 2D financial charts would be instantly recognizable to most viewers. That is, recognizable 2D charts have lower cognitive load than a 3D scene requiring orientation between three different axes as well as the use of color and other encodings which are all vying for limited short-term memory resources, in addition to other environmental distractions.

With the exception of timeseries charts, almost all the other charts show data at a point in time. And given the dominance of timeseries charts, we considered approaches to add temporal data to pre-existing 2D charts:

**Animation**: 2D charts can be animated over time to indicate temporal data. However, 2D animation shows only one timeslice at a time. This makes it difficult to see the timeseries, and relies on limited capacity short-term memory thereby making it difficult to perceive temporal patterns.

**Data Comics**: Related to animation are data comics which can be sequenced to convey time (e.g. [51]). Such an approach, however, would require either creating both 2D point-in-time charts and 2D timeseries charts and either displaying them simultaneously (reducing the space for each chart type) or displaying them sequentially (requiring memory between frames). Neither approach was desirable to the client as a simultaneous view would make the screen cluttered, reduce font sizes, and take more effort to read; whereas sequential animation would increase reliance on short term memory to recall the context of the previous scene and would have narrative discontinuity if a viewer approached mid-story.

**3D**: Timeseries data can be added to the 2D charts in the third dimension (going into the screen). This approach is essentially similar to the financial datasets set out in 3D Cartesian space (prior section: *Other 3D spatialized datasets*), of which we were suspect. Perhaps there were issues with these prior charts that had been overlooked?

We were well aware that 3D visualization of abstract data is challenging. Users must pay extra costs such as occlusion, potential spatial ambiguity, loss of accuracy with perspective, non-intuitive interaction, and so on. In general, many data visualization experts recommend against the use of 3D unless the data is inherently 3D (such as 3D volumetric data or 2D surfaces with additional height data) [29].

In looking at other 3D visualizations, we noted several potential issues:

- **Poor 2D views.** These other 3D Cartesian visualizations were designed for 3D use without regard to 2D viewpoints. As these visualizations are conceived entirely in 3D, planes that correspond to a (well-known) 2D view are not apparent. While the view could be rotated to view the scene head-on for a 2D view, the remaining 3D scene was behind thereby cluttering the 2D view, creating overlapping labels, overplotting data, and otherwise making the 2D viewpoint unrecognizable and unusable.

- **Disorientation**. Navigation in some of these visualizations was unconstrained: the viewer could view the scene from upside-down or behind. Freeform navigation allowed for conventions to be broken, for example, timeseries always run from left-to-right in 2D, but is reversed in 3D if the scene is viewed from behind.

- **Perspective cues.** Scenes in these other charts often use some visual perspective cues to facilitate better estimation of sizes. However, other confounding issues occur, for example, two surfaces or two lines of the same pixel color at different depths can become ambiguous. This can be solved with 3D depth cues such as fog.

- **Text ambiguity.** In some scenes, text can be difficult to read, due to overlap, occlusion, lack of differentiation to background, and so on. Further, some text labels are difficult to associate with their corresponding mark, for example, billboarded screen text may not have a cue associating it with a particular mark, or otherwise potentially ambigiuous with multiple marks.

### 3.2 2D charts extruded with time data

We hypothesized by starting with the canonic 2D view, then carefully adding 3D – only when rotated – would provide an immediately recognizable starting point, and allow 3D temporal information to be added incrementally. Only one additional dimension – time – is added, making it easy to conceptualize the addition without significantly increasing cognitive load. In addition, more data content is accessible than visible in the 2D view.

In Figure 1, the canonic 2D view for five common charts are shown on the left. All five are *point-in-time* charts - that is the data indicates the value at a point in time, typically the most recent

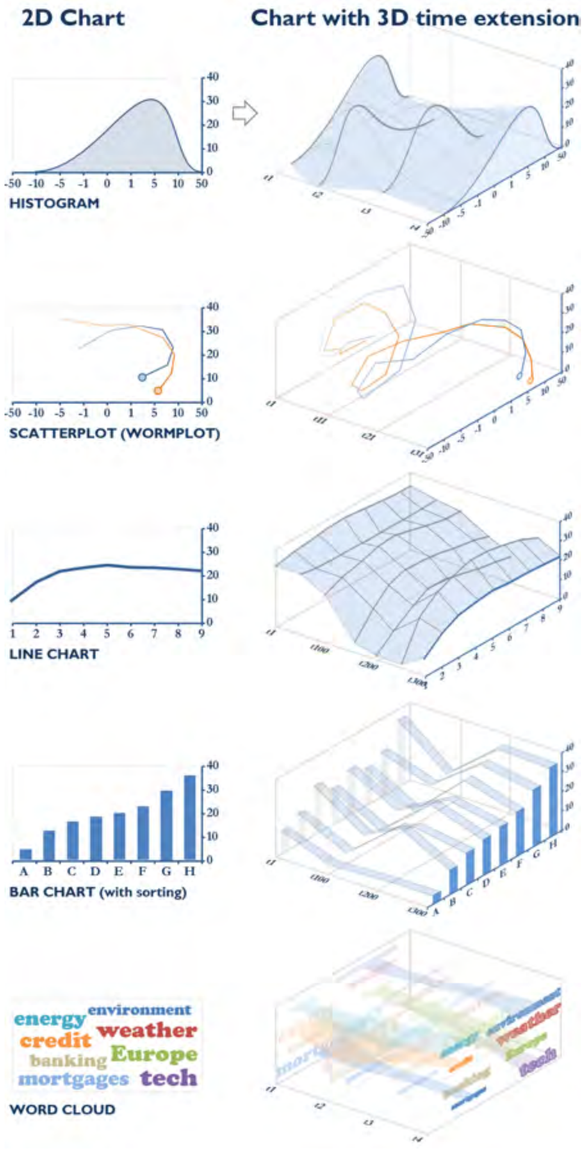

Figure 1: Five common 2D visualizations, and their 3D counterparts with added timeseries data.

timeperiod in financial chart uses. On the right of the diagram is the equivalent 3D visualization, with the 2D chart strongly retained at the front-right; and with timeseries data extending backwards (with time shown on the bottom-left axis). Note the 2D chart, when rotated, retains the expected labels, ticks, borders and text oriented in the plane of the 2D chart.

The added time data can then be represented as appropriate for each chart. For example, for the distributions, each time slice show the distribution, plus a transparent 3D surface joining the distributions together, to aid perceiving how distributions shift over time. The wormplot shows a line twisting back in time like a corkscrew. The yield curve (line chart) simply repeats back with each timestep forming a 3D surface. Discrete bars have discrete timeseries lines extending back from each bar: periods of highs and lows are visible. The word cloud, while not appearing in the review of financial charts, was an emerging area of interest for the client, as they had experimented with some variant charts depicting news topics and the 3D variant of the word cloud shows time slices with each topic word, and a shaded area corresponding to relative importance of the topic word over time, similar to a themeriver visualization.

### 3.3 Camera constraints and 2D snap

From past experience with 3D, we have noted that some users are easily confused by 3D navigation of a scene and unexpected orientations. Therefore, our camera motion was constrained to an octant as shown by the yellow shaded area in Figure 2. The viewer can only rotate the scene within the yellow octant, thereby accessing a 2D front view, 2D side view and 2D top view; and a 3D scene in between. Note that the front 2D view is the canonic point-in-time chart, while the side 2D view is a canonic financial timeseries chart. The top view is not a canonic 2D chart, but typically showed a flattened color-coded view akin to a heatmap (e.g. histogram, surface and timeseries).

When the camera approaches any of the 2D views, the camera snaps to the 2D view and all the non-relevant 3D chart content (data, grids, ticks, axes labels), is removed when the view is at the 2D viewpoint while retaining the expected 2D chart content thereby creating a perfectly flat, canonic 2D version of that chart with no extraneous items in the scene. A smooth animated transition compresses and fades out the extraneous 3D items so that the transition appears natural, not jarring.

Further, the user only has control over rotation and cannot zoom nor pan the chart. Our viewer algorithm automatically translates the chart while rotating such that the 2D scene and the 3D scene mostly fills the viewport regardless of the viewpoint. This protects the user from complex scene navigation via combinations of pan, zoom and rotate.

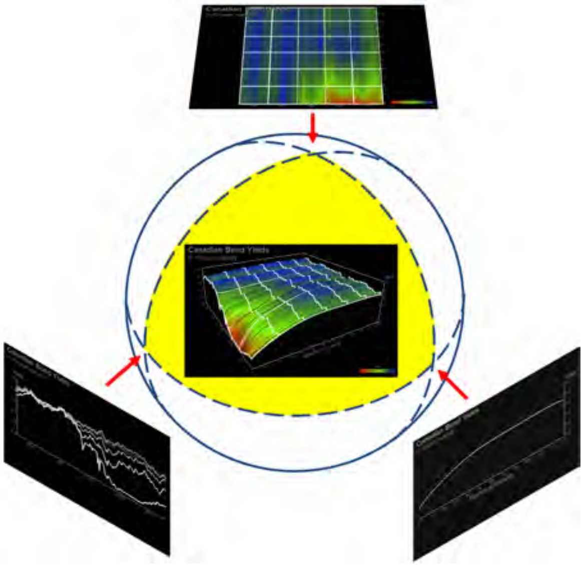

Figure 2: The 2D charts occur at the limits of the viewer contraints: a 3D view occurs in-between the 2D viewpoints; and at the 2D viewpoint all items associated with the depth are turned off, leaving only the 2D canonic chart.

### 3.4 3D cues

Without VR, AR nor 3D glasses, we could not rely on binocular depth cues. In ambient use, we could not rely on user interactions such as rotation to trigger motion parallax as a depth cue.

Depth cues included perspective cues such as grids on floors and walls to help locate items within Cartesian space, and a light fog to help differentiate foreground and background - for example, lines crossing themselves in the wormplot would appear more saturated in the foreground and more washed out in the background. Creating surfaces, such as ribbons on the extruded bar chart, or a loft between two curves in the wormplot, allowed for the use of lighting cues – such as change in brightness and subtle specular highlights to help indicate the orientation of any patch.

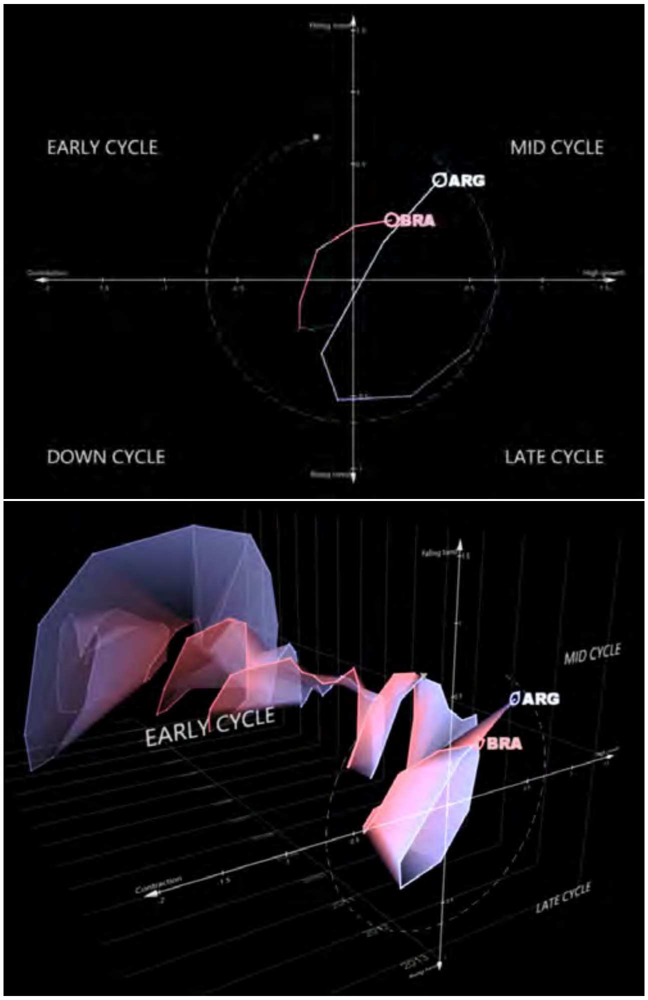

Figure 3: 2D and 3D view of the wormplot.

We could use expected 2D chart cues to our advantage: expected plot area borders, tick label conventions, and grid lines, facilitate the perceiving the flat 2D visualization within the 3D visualization, then additional grid lines, ticks, and borders extending in depth, (and appearing only when rotated), facilitate the interpretation of the transition from 2D to 3D.

Figure 3 shows the wormplot in 2D and 3D. In the 2D chart, note the variety of supporting structure around the data points: axes, ticks, a diagrammatic arrow, quadrant labels, axis labels, tick labels, extents labels. In the 3D rotated view, all the 2D chart elements remain visible in the 2D plane, now with the 3D wormplot extending back to the left in time. A much longer timeseries can be shown with the 3D space. Regular time grid lines and labels step back measuring out the 3D space. The lofted surface between the lines allows for the light to help define shape. The fog helps fade items in the distance and differentiate the overlaps.

### 3.5 Interaction and ambient animation

Viewers can directly interact with the scene, such as rotating the viewpoints, selecting individual series for highlight, changing the dataset, changing the date range and so on.

Specific visualizations types have relevant interactions. For example, in figure 4, the bar chart shows n bars. Rotated into 3D, patterns across the ribbons are difficult to perceive in the arbitrary alphabetic ordering of the lines. In the lower image, the viewer has sorted the countries by their most recent value – relationships between adjacent lines are more apparent and occlusion is reduced.

Note that the original labels associated with the 2D bars are removed from the display once the rotation starts to approach the top view as the 2D bar labels would no longer be legible. Further, some labels are no longer relevant to the new viewpoint (e.g. the vertical axis from the point in time bar chart). Labels associated with the top view are visible. This allows us to retain labels oriented to 2D planes within the scene as opposed to billboard text which can become occluded as the scene approaches a 2D viewpoint.

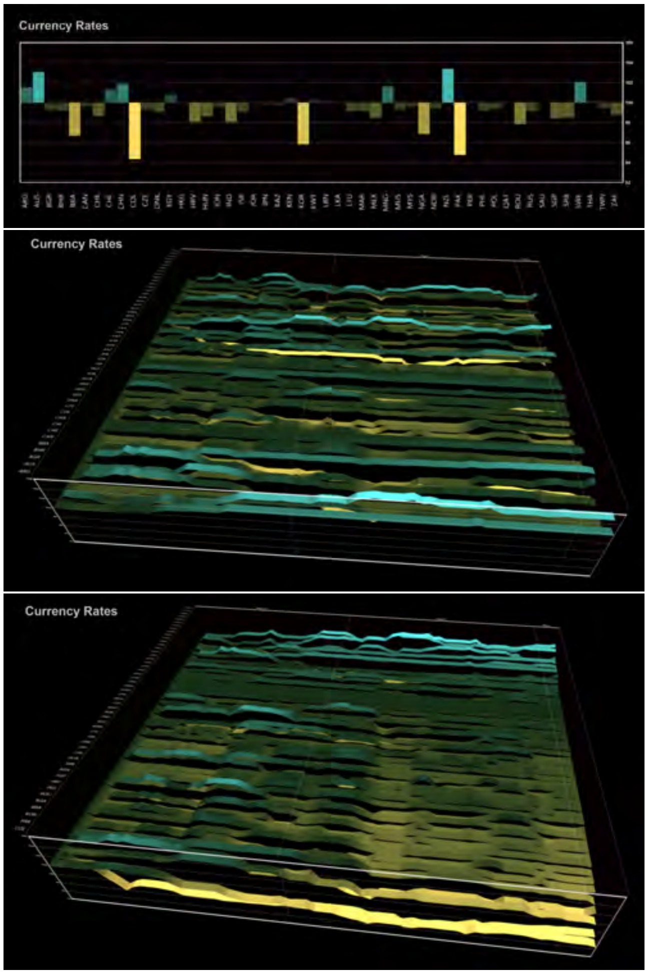

Figure 4: Bar chart, rotated with timeseries then sorted.

Animation is used when the system was in ambient mode to engage users with different datasets and encourage interaction. A bouncing-ball animation technique toggles datasets, and toggled views between 2D and 3D. The automated animation adds the benefit of a smooth animated transition between 2D and 3D, thereby adding motion parallax as a cue to facilitate perception of scene depth.

### 3.6 Extensions to VR, AR, Mobile and 3D Printing

While the system was primarily intended for ambient displays, we also adapted the system for use in the CAVE-like environment, including gesture interactions. One immediate observation was that the visualizations were designed to be roughly like a squashed cube in proportion (as shown diagrammatically in Figure 1), based on displays that were typically 16:9 or 4:3. The CAVE-like environment had a much more pronounced aspect ratio (very wide at 12:3), resulting a cube with a lot of unused whitespace; or being immersed in the center of the cube, neither of which was useful. VR and AR were not taken further, although we hypothesize the cubes may be very engaging in AR.

Mobile was not pursued beyond some prototype tablet implementations as there were additional licensing costs for real-time financial content (market data, news, etc).

One interesting area investigated was the extension to 3D printing. Some types of 3D visualizations are difficult to 3D print, e.g. 3D scatterplots, as the points or lines need to be supported. Since most of the representations in our system created ribbons or surfaces that were touching floors and walls, it was feasible to give these thickness and export these 3D scenes into 3D print files. We experimented with a 3D printed surface, including changing print materials to create grid-lines within the larger area of the printed surface. The larger surface area was printed in translucent material which allowed for experimentation with lighting effect. Primarily to save costs, the supporting walls were instead exported and CNC-cut via thin plywood (as shown in Figure 5).

Figure 5: 3D print of a financial curve over time. Same dataset as Figure 2.

## 4 DISCUSSION

It was unknown whether viewers would use the 3D capabilities: by default, the 2D cannonic view was initially shown when picking any dataset. We implemented a bouncing-ball style overlay when the visualization was in ambient mode to show interactions such as menu taps to change datasets, selection highlights, 3D rotation, and other interactions.

We also implemented event logging to collect statistics on which interactions were most used and whether interactions to rotate the scene from 2D to 3D were used at all. This interaction logging data was collected on multiple occasions throughout the project, two snapshots are shown in Table 2. 3D rotation was the top interaction at nearly 40%, which indicated to the clients that the 3D interaction was well used. We did not have direct access to the users: anecdotal evidence from the project managers indicated positive response to all interaction and the 3D among different communities of viewers, such as staff, executive guests, and the educational visits.

In retrospect, there is some uncertainty as to how the 3D rotation is being used. For example, are subsequent 3D interactions being used to assist with 3D scene depth perception by creating motion parallax, or is the 3D interaction being frequently used in conjunction with interactions such as selection and highlight of items?

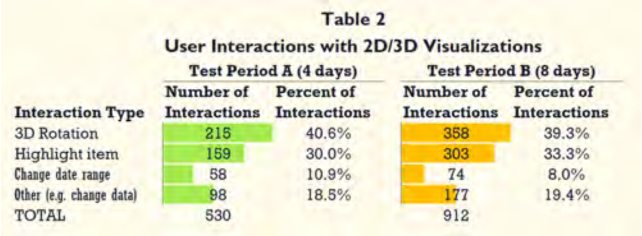

**Table 2**

**User Interactions with 2D/3D Visualizations**

| | Test Period A (4 days) | | Test Period B (8 days) | |
|---|---|---|---|---|
| **Interaction Type** | **Number of Interactions** | **Percent of Interactions** | **Number of Interactions** | **Percent of Interactions** |
| 3D Rotation | 215 | 40.6% | 358 | 39.3% |
| Highlight item | 159 | 30.0% | 303 | 33.3% |
| Change date range | 58 | 10.9% | 74 | 8.0% |
| Other (e.g. change data) | 98 | 18.5% | 177 | 19.4% |
| TOTAL | 530 | | 912 | |

Another source of validation was user feedback through the project sponsors. They had opportunity to observe many viewers on site. They provided a variety of insights from use, including:

- Senior executives, who on occasion stop and explore the visualization.
- Analysts, who are excited at a whole new way of understanding their data, i.e. a new mental model.
- Visitors, who express awe and interest in visualization, starting engaging conversations.
- Educational visits, being highly engaged to explore the range of interactions.

The project sponsors also validated the approach through scope and funding. The initial project scope was for only two 2D-3D visualizers; the scope expanded to five visualizers, plus extensions for VR, mobile and 3D printing.

## 5 CONCLUSION AND FUTURE WORK

We believe that the explicit focus on familiar 2D charts as entry points to 3D visualizations was highly critical to the project success and expansion of scope. A recent article on Builtin.com asks: “Is VR the next frontier in data visualization?” [17] Curiously, there is a 30 year history of financial VR but 3D has only had narrow successes, such as 3D surfaces. Based on this project, we believe that widespread use of 3D data visualization in financial services will need to leverage incremental approaches bridging the gap between 2D and 3D – to facilitate adoption of 3D – and will need compelling additional value-added content highly desired by financial professionals – such as the very highly popular analysis of timeseries data.

Recommendations for future work should include a more formal evaluation to measure the benefit of embedded 2D canonic charts within the 3D visualizations. For example, does the initial 2D starting point plus animation offer incremental benefit over simply embedded 2D charts? Or, does maintaining all elements within the plane of the 2D chart within 3D scene aid understanding or hinder legibility?

Mobile is an area of great interest, particularly to senior executives. Mobile provides additional capabilities, such as rich local interaction, and the ability to restrict data based on user. This avenue is leading towards new mobile applications with different functionality.

Theoretically, it is desirable to generalize this approach more formally across 2D point-in-time charts extended with timeseries data. Some 2D visualizations, such as the scatterplot and bar chart represent individual items, whereas the distribution represents data aggregations. We inherently understood that some 2D chart types would not necessarily be effective when extruded with time. For example, stacked bar charts, radar plots, and pie charts would have serious issues with occlusion. Choropleth maps don’t seem to have a timseries extension: while space-time cubes are promising (e.g. [21, 25]), they are inherently based on point criteria, not area encoding. Similarly, interactions were specific to each 2D chart type, but should also be generalizable.

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