THE UNIVERSITY OF SYDNEY

Assignment Coversheet – GROUP ASSIGNMENT

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Assignment Details:

Assignment Title	**Who is leading the mobile device market?**				
Assignment number	**2**				
Unit of Study Tutor	**Anjali Singh**				
Group or Tutorial ID	**1**				
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Membership

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Who is leading the mobile device market?

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***Abstract* — With the advancements of technology, a plethora of companies have introduced new variations of mobile devices in the market. Some companies sustained the competition and led the market, while others did not. This report discusses the new types of devices, the leading companies, and the most successful one inferred from the 'mobile device dataset' through different visualizations. It gives a detailed description of the utilization of axes arrangements, visual variables, interactions, and multi-views used to display the visual evidence.**

Keywords — mobile devices, market, model name, release year, RAM, CPU clock, storage capacity, dimensions

I. INTRODUCTION

Mobile devices are defined as portable computing devices with a set of specific features accessible on a single screen [1]. Mobile manufactures have been trying to lead the market by releasing different versions of devices with cutting edge technologies inclusive of design, integration and support through performance, usability, and portability.

Studies have shown that there is a huge impact of CPU design patterns on the performance of the mobile device, energy consumption and overall user experience [2]. The basic arrangement of storage of data in a device involves semiconductor memory which can be retrieved from any location, irrespective of its volatility, thus it is known as random access memory (RAM) [3]. The storage capacity of the mobile device is another important aspect to determine the data holding capacity and manageability during runtime [4]. Therefore, the performance metric of mobile devices can be measured using a combination of these three features.

Along with the performance metrics, the next-generation mobile devices also focus on the device size and screen. The usability of those devices is also largely dependent on its physical features such as depth, display length, display width and diagonal, which form a metric for the portability of the mobile device and the usability of those devices. Therefore, in this report we will focus on the three-performance metrics mentioned above, as well as the physical attributes as our Key Performance Indicator (KPI) to find the new types of mobile devices, the companies that tried to lead the new markets, and finally, our Key Goal Indicator (KGI), which is finding the most successful company to lead the market from 1989-2012.

A. Data Preprocessing

The dataset consists of three separate excel sheets namely: 'Normalized Product Data' (3162 rows X 16 columns), 'Model-Company (2903 rows X 5 columns)' and 'Company ID'(213 rows X 4 columns). After the loading the csv sheets into the database, the primary keys, and foreign keys of all the three tables were identified. The missing data in sheet 2 was filled using the data from sheet 1. As for the second step, the company id in model-company is a mix of old id and new id, we joined it with the third sheet for it to have one to one relationship with others. If we observe the product data, all company names are given by the first word, except the "Sony Ericsson" products. Lastly, we joined all the records to get the final dataset, which is equal to the size of the first sheet (3162). Detailed programming for this section can be referenced from the author's GitHub page [11].

II. NEW TYPES OF DEVICES – PERFORMANCE

In this section, three attributes including CPU, RAM, and Storage will be used to discuss the market leading devices from the performance aspect of view. Since these three attributes are normalized, they can be considered in the same vector space which can be displayed in visualization with a fair distribution. To present the models together, a 3D visualization was created, as shown in figure 1. In this chart, the x-axis represents the normalized CPU value, the y-axis represents the normalized Storage value, and the z-axis represents the normalized RAM value.

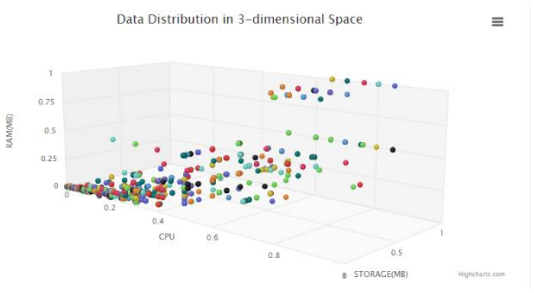

Fig. 1. Data plots in 3-dimensional space

The distribution of the data in the above figure tells some interesting facts. It is fair to see that there is a lot of points close to the origin, and these are data plots that represent models in the dataset with low CPU clock rate, storage, and RAM. By using interactive visualization tools, it can be shown that these models are usually released in the earlier years of the dataset. The points away from the origin are often the models released in the later years, which are clearly differentiated from the other plots and have a higher value in all three features. The distribution and nature of the dataset fits the expectation of our approach towards solving the task.

A. Comparing Vectors Using the Euclidean Distance

Now we have plotted the data plots in 3-dimensional space, there must be a way to compare them. If we regard the line from the origin to model points with direction, then all the models can be considered as vectors [5]. For vectors to be comparable, each vector needs to be converted into scalar values; hence, we decided to use the magnitudes of vectors, which is the distance from the origin to the point [6].

The equation we used to calculate the magnitude, which is the distance for each point containing the three different attributes to the origin in $\mathbf{R}^3$ is:

$$\sqrt{(\mathrm{CPU}^2 + \mathrm{RAM}^2 + \mathrm{Storage}^2)}$$

This equation is based on the Euclidean distance between two points [7]. Because the three values are displayed on each axis as (CPU, 0, 0), (0, RAM, 0), (0, 0, Storage), and the origin is just (0, 0, 0), thus it can be shortened and represented as above. The magnitude calculated can be viewed as a performance score for the model, since all three attributes can now contribute to a single value for comparison [11].

TABLE I. EXAMPLES OF THE CALCULATED EUCLIDEAN DISTANCES AMONG PERFORMANCE FEATURES FOR SOME MODELS

Model Name	Company	Year	Euclidean Distance
Psion Organiser II LZ 64	Zebra Technologies	1989	0
Hewlett-Packard 95LX (HP Jaguar)	Hewlett-Packard	1991	0.00224027916947 6...
Psion Series 3	Zebra Technologies	1991	0.00189713924067 1...
Hewlett-Packard 95LX 1MB RAM (HP Jaguar)	Hewlett-Packard	1992	0.00227657059578 0...
Apple Newton H1000 (Apple OMP)	Apple Inc	1993	0.00955525214640 01...

B. *The Visualisation of the Device Performance Score*

The model performance scores were calculated by the Euclidean distance in 3D space from 1988 to 2012 in the above section. In figure 2, we use a point chart to visualize the processed data, which can display large quantities of items with easily seen correlations among points as well as the clustering effect [8]. The x- and y-axes are the performance score (the K value as the calculated Euclidean distance of CPU, RAM and storage, in 100T-scale for easier reading) and the year from 1989 to 2012, respectively.

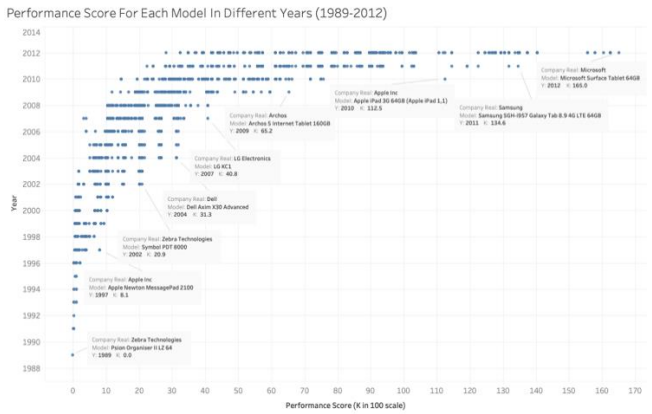

Fig. 2. The Performance Score for Each Model in Different Years

Though the dataset does contain tablets and even laptops, we were told to treat them all as mobile devices. Not all the peak points are highlighted each year, but only the models which have obvious differences with others. For example, after the years where the models have similar performance score, there exists a point that is away from the cluster. There also exist several models having the same performance score, however, it shows only the last model with the same score with draggable annotations by visualizing via Tableau. The visual variable used here is the draggable text label for the top models in each period. According to the figure above, we can find devices that tried to create new markets in different periods and summarized them as the following table.

Table II, which has five columns, summarized our findings. The first column shows different periods of in the market. The second is the name of the model that tried to create new markets. Then the 'Release Year' is the year in which the model was released. The fourth column, 'Highest Score Last year', is the highest score of last year's model, and the last one is the performance score of the model which tried to create new markets during this period. We think the chosen one in different periods should show a huge improvement in performance when compared with last year's best one, e.g., between 1991 and 1997, the best model's score was 8.1 and before its release year (1996), the highest score was only 2.2.

TABLE II. THE SUMMARIZED TABLE

Period	Best Model Name	Release Year	Highest Score of Last year's models	Performance Score
1989-1990	Psion Organiser II LZ 64	1989	none	0
1991-1997	Apple Newton MessagePad 2100	1997	2.2	8.1
1998-2002	Symbol PDT 8000	2002	12	20.9
2003-2004	Dell Axim X30 Advanced (Dell Axim X50v)	2004	20.9	31.3
2005-2007	LG KC1	2007	31.8	40.8
2008-2009	Archos 5 Internet Tablet 160GB	2009	40.8	65.2
2010	Apple iPad 3G 64GB (Apple iPad 1,1)	2010	65.2	112.5
2011	Samsung SGH-i957 Galaxy Tab 8.9 4G LTE 64GB	2011	112.5	134.6
2012	Microsoft Surface Tablet 64GB	2012	134.6	165

There are two specific points to point out: (1) from 1989 to 1990, there was only one model in the market, and we thought it was a milestone that could be regarded as a model which tried to create new markets, and (2) from 2003 to 2004, there were two models that showed the same highest score.

III. NEW TYPES OF DEVICES – FORM FACTOR

In addition to the performance attributes, we also look at the form factor (physical) attributes to identify new types of device in the market. Here, we consider new devices with noticeably different screen sizes and depth than those previously available in the market as the new type of device.

A. *Pocket PCs and Palm devices (1989-1995)*

There are a lot of mobile devices with varying screen sizes in the market and different screen sizes deliver different user experience, i.e., users engage in different interaction modes depending on the size of the screen they are looking at. For example, mobile phones are typically used for short session micro-tasks such as sending and receiving messages, whereas tablets are normally used for content consumption such as watching movies [9]. Observing the different screen sizes can help identify new types of mobile device in the market.

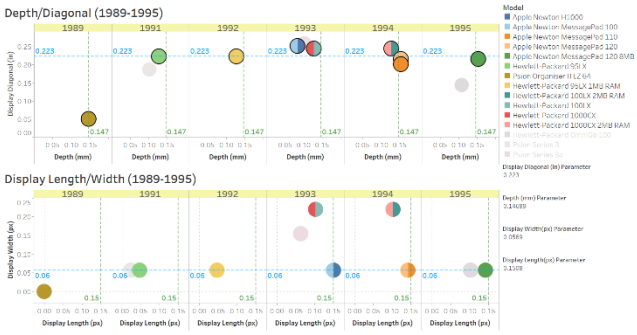

Fig. 3. Mobile devices based on depth and display diagonal (1989-1992)

In figure 3, scatter plots are used to show different screen sizes of mobile devices between 1989-1995. The top charts plot the Depth on the x-axis and the Display Diagonal on the y-axis, whereas the bottom charts use the Display Length against the Display Width on the x- and y-axis, respectively. Instead of overlapping circles, pie charts have been used to display the different devices, which is more effective to give a general sense of the size/number of products in the market. Then, visual variable colour is used to show the different models and the new types of devices are highlighted to distinguish them from the others. The top and bottom charts are linked so the models highlighted at the top would also be highlighted at the bottom. This interaction would help users compare four attributes on the same visualization. Notice that,

whilst the new devices that came since 1991 had similarly large Display Diagonals (top), from 1993 onwards they could be grouped into two new types of devices with different Display Lengths/Widths (bottom): ones with wider screens (Pocket PCs) and those with longer screens (Palm devices).

B. *The arrival of smartphones and tablets (1996-2001)*

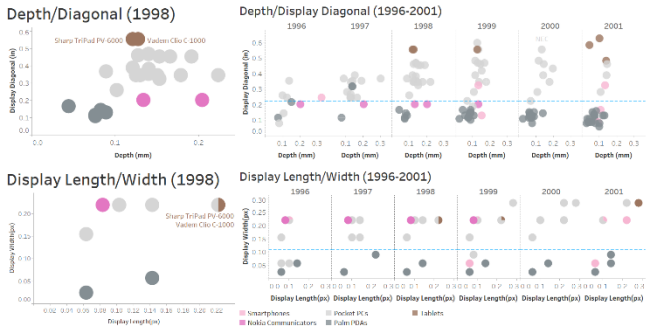

Fig. 4. Mobile devices based on depth and display diagonal (1996-2001)

In figure 4, the same x- and y-axes arrangements are used. On the right-hand side, the different models are grouped into five categories, e.g., tablets, smartphones, etc. (distinguished using variable color) to show the evolution of the groups from 1996-2001. If users are interested in the details, they can select the year on the right chart, then a snapshot of that year will be shown on the left, complete with the name of the new types of devices. From the charts, we can see the arrival of tablets in 1998 (see the snapshot) and smartphones in 1996, though most devices were still Palms and Pocket PCs. Notice also how Nokia Communicators distinguished themselves with the thinnest pocket PC smartphones during this period.

C. *The growth of small/medium-size devices (2002-2006)*

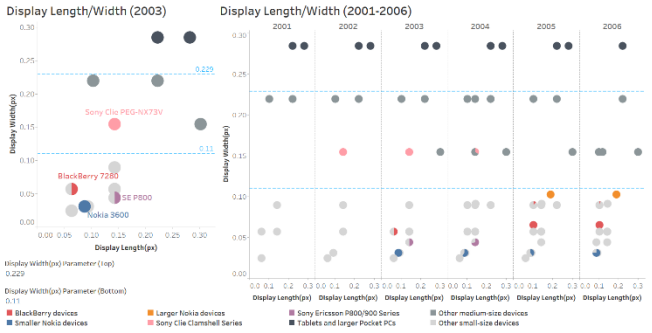

Fig. 5. Mobile devices based on display length and width (2001-2006)

In figure 5, the same axes arrangements using Display Length and Width and user interaction are used. Here, visual variable grey colours distinguish the different groups (small, medium and large devices), and brighter colours and text labels highlight new types of devices within that period. Notice the growth of small devices from 2003-2006 (more crowded). Different companies, including BlackBerry (the reds) and Sony Ericsson (the purples), introduced new small devices with slightly different screen sizes to distinguish themselves, with Nokia took it a step further by extending their product coverage to include smaller (the blues) and larger (oranges) small devices. In the medium-size market, Sony launched a new type of device, the Sony Clie Clamshell Series (the pinks) from 2002. The new medium-size display, which was not available in previous years, allowed Sony to pack in a thumb-sized keyboard, MP3 playback and a speaker into the device, which were uncommon features in handheld devices at the time [10]. The large device market on the other hand (the dark greys), remained quiet with not many new products.

D. *The evolution of large storage devices (2007-2012)*

Many companies try to distinguish themselves from the competition by introducing a thinner device, yet in doing so, they often have to compromise on performance. Apple was one company that was able to do it well, by packing a large storage in a thin device. In figure 6 and 7, scatter plots are used to show different mobile devices based on Storage, Display Diagonal and Depth. By plotting the Storage against the Display Diagonal (on the x- and y-axes) and highlighting the new types of devices (and other models in the background), we were able to show that Apple was the first company to introduce two thin small devices with the largest storage in 2007, the iPhone and iPod Touch. Then in 2012, it followed with a large storage tablet, the iPad 3G. Notice on the charts, how those three products stood out from the competition, which were then followed by other companies in subsequent years. In 2009, Samsung launched the Galaxy phone, followed by the Galaxy S and S II in 2010 and 2011. They also introduced a variant with slightly larger screen, the Galaxy Note in 2011, followed by the Note II in 2012. In the tablet market, Samsung launched the Galaxy Tab line ups in 2010 and 2011, followed by the Microsoft Surface in 2012, with many other large storage products also came out in this period.

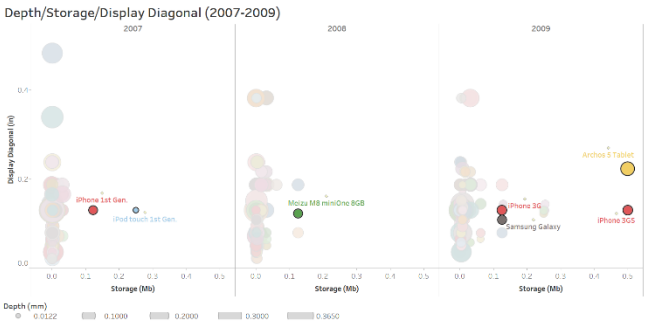

Fig. 6. Devices based on Depth, Storage and Display Diagonal (2007-2009)

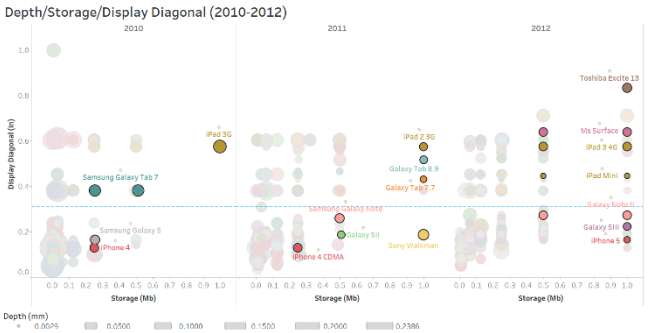

Fig. 7. Devices based on Depth, Storage and Display Diagonal (2007-2012)

IV. MARKET LEADING COMPANIES – PERFORMANCE

In this section, methods that we use to find which companies tried to lead the new markets from the aspect of performance will be discussed. The dataset used in this section is refined from the dataset we used in section II [11].

A. *How to Measure the Leading Companies?*

Measurement of leadership is quite an open-ended question however we decided to approach this question by

using quantitative key performance indicator (KPI). In our case, this means to calculate the number of products released each year by different companies and compare this statistic.

B. Count-based Approach

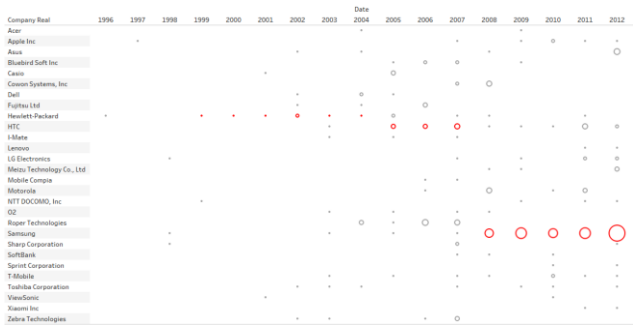

Fig. 8. Product release according to year by each company

By counting the number of products released each year, we are able to plot a simple graph in 2-dimension. As shown in figure 8. The x-axis is the interval variable date, which has been transformed into YYYY format; the y-axis is the company name for different models in this dataset. The bubbles in the graph represents that there is a release in that year for the company, and the size of the bubble determines the number of products released, hence the larger the bubble size the better. Red Color is used to highlight the plots we found that fits our metric discussed in section A. In conclusion, from 1999 to 2004, Hewlett-Packard is leading the performance market, then from 2005 to 2007, HTC became the leader; and from 2008 to 2012, Samsung became the market leader without a doubt.

V. MARKET LEADING COMPANIES – FORM FACTOR

In this section, we discuss which companies tried to lead the new markets from the aspect of form factor. The same KPI (the number of products released by each company each year) is used to measure which companies tried to lead the market in different periods identified in section III earlier.

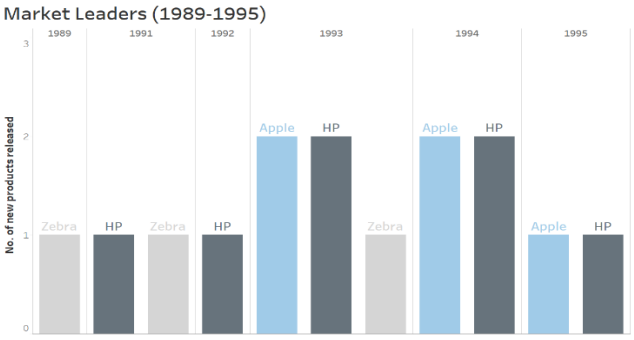

Fig. 9. Market Leaders of mobile devices (1989-1995)

In figure 9, a bar chart is used to display which companies tried to lead the new markets from 1989-1995. The bars, along with the years, on the x-axis represent the different companies that released new products in each different year, and on the y-axis, the height of the bar shows the product count (how many products were released each year). Visual variable colour and text label are then used to highlight the market leader(s) each year in different markets. As seen on the plot, Apple and HP tried to dominate the market in this period with the most products released each year.

In figure 10, horizontal bar charts are used to show the new market leading companies from 1996-2001 in different product groups, as outlined in section III. Here, the years and the companies are on the y-axis, and the product count on the x-axis. Due to the large number of products in this period, we use variable colour dark grey and text label to highlight only the market leader in each year, and the lighter grey bars were only shown to give a sense of how far the leader was compared to the others. As seen, HP tried to dominate the Pocket PCs market with many new products, whereas 3Com, Casio and Sony excelled in Palm devices. Nokia, Qualcomm and HTC tried to dominate the smartphone market whereas many different companies tried to lead the tablet market.

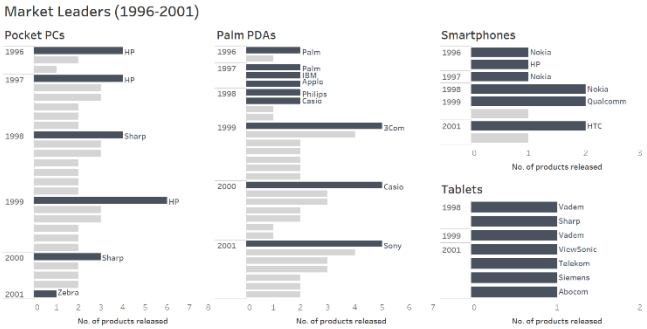

Fig. 10. Market Leaders of mobile devices (1996-2001)

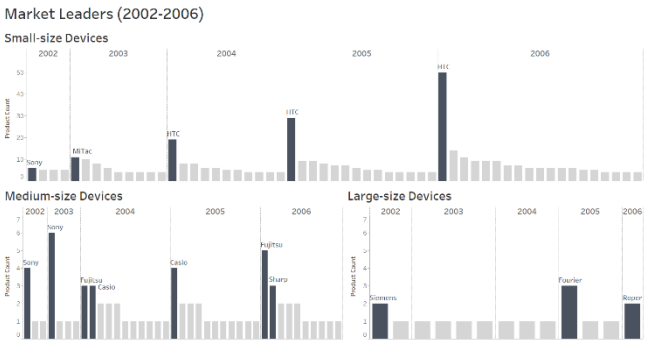

Fig. 11. Market Leaders of mobile devices (2002-2006)

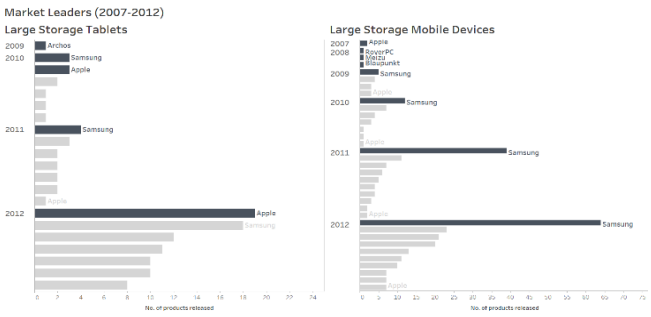

Fig. 12. Market Leaders of mobile devices (2007-2012)

In figure 11, a bar chart is also used to show the leading companies in different groups (small, medium and large-size devices) from 2002-2006, with the same axes arrangements as in figure 10. Similarly, the colour dark grey and text are used to highlight the market leaders, with other companies in lighter grey for comparison only. Notice how Sony, MiTac and later HTC, tried to dominate the small device market, with Siemens, Fourier and Roper tried to do the same in the large-size market. In the medium-size market, whilst Sony was the leader in 2002/2003, it was taken over by others in later years.

Lastly, in figure 12, a bar chart with the same axes arrangements as in figure 10 show the top leading companies from 2007-2012. In this chart, we also labelled Apple on the right-hand side to show where they stood in the small device market, compared to Samsung. As seen in this period, for large storage devices, while both Apple and Samsung tried to lead the tablet market, mainly only Samsung in the mobile market.

VI. Most Successful Market-Leading Company

A. *Most Successful Company based on the Performance*

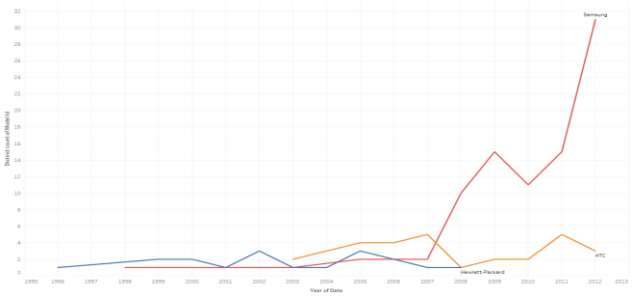

Fig. 13. Product releases according to year by Samsung, HTC and HP

As illustrated in the above figure, Samsung started to release high performance products since 1998, and continued to develop excellent products until the latest year in this dataset. The x-axis is the year that products are released, and y-axis is the number of products released. The line is used to represent the trend and different colors are assigned to three different companies where red represents Samsung, orange represents HTC, and blue represent Hewlett-Packard. Starting from 2008, Samsung had beaten its competitors by far with almost double to triple the number of products each year afterwards, showing that its intention to lead the mobile device could not be unnoticed. The latter years in the dataset made Samsung the standout and we think it is the most successful company in leading the market.

B. *Most Successful Company based on the Form Factor*

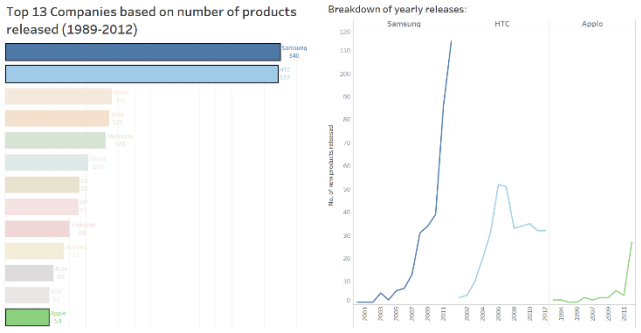

Fig. 14. Top 13 companies based on number of product released (1989-2012)

In figure 14, we used interactive charts to show which company was considered the most successful to lead the market from 1989-2012. On the left-hand side, a horizontal bar chart is used to show the top 13 companies that released the most products during the 23-year period. The product count is on the x-axis and the company name is on the y-axis. Because colour and text label have been used to show the company name and the count next to the bars, we removed the x- and y-axes, and the legend to avoid redundancy. We also allow users to highlight any bar(s) they are interested in to show the yearly trend of the products released by the highlighted companies. On the line charts, the company names and the years are shown on the x-axis, and the product count is shown on the y-axis. For demo, we highlighted three companies: (1) Samsung, the most successful company in the market based on the number of products released, then followed closely by (2) HTC, and (3) Apple, which did reasonably well in 2012. Notice on the line chart that, even though HTC was second overall on the bar chart, the trend shows that they were in decline, whereas both Samsung and Apple showed remarkable growth in later years (and in Samsung case, it was able to lead the market by 2012).

VII. Conclusion

In this paper, we used two approaches to identify new types of mobile device from 1989-2012. In section II, we outlined the new types of devices based on the performance factors (CPU, RAM and Storage) and identified various products that can be considered as new types of devices in the market, as summarised in Table II. Then in section III, we identified other new types of devices based on the form factors (Depth, Display Length/Width/Diagonal) throughout different periods between 1989-2012. Based on these findings, we showed which companies that tried to lead the new markets with the new devices in section IV and V, which then led to our KGI of finding the company that was considered the most successful to lead the market. The most interesting point is that, while our findings in Sections II-V presented different new types of devices with different companies trying to lead the market (and this is normal because different companies always try to distinguish themselves from the competition and lead the market using different strategies, hence we used different attributes when solving this task), both approaches ultimately led to the same conclusion, that Samsung was considered the most successful company within that period.

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