Visualization of Multi Key Performance Indicators by Dynamic Chernoff Faces

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Abstract. Digitalization and Big Data have arrived in almost all areas of daily life. Data are today the new oil (1). But not only the flood of data has increased, the data have become more complex and heterogeneous. Making a fact-based decision is getting much more difficult. A meaningful aggregation of data to information for a better overview and for a better understanding by human beings has become more important. One possible aggregation method of information is a better visualization. The visualization method which is analyzed is Chernof Faces. It is a method of glyph-based visualizations of multi-dimensional space was developed in 70´s by Hermann Chernoff (7). They consist of different facial features to which KPIs are assigned. A KPI is e.g. assigned to the mouth. The larger the value of this KPI is the bigger changes the mouth its shape and vice versa. Each facial feature has a different effect on humans. The result is a human emotion from happy to sad. Chernoff Faces thus combine several key figures into a facial expression, which people can quickly perceive and interpret. One problem of Chernoff faces theie static nature. As the KPIs are statically assigned to the same face parts. What to do, if the importance of the KPIs changes for the company? Instead of maximizing profit, maximizing sales takes center stage. The relative importance of face features remains the same! One possible solution would be dynamic Chernoff Faces, in which software decides company-specific or situation-specific, which KPI are assigned to which facial features and thus provides an overall evaluation.

Keywords: Key Performance Indicators, Data aggregation, Information visualization, Chernoff Faces, dynamic Chernoff Faces

1 Data, Information, Knowledge

The complexity of the modern world can be seen in the dashboards of modern cars. Ford's Model T had only one speedometer. The information provided by the speedometer was enough to operate the car. In current vehicles significantly more sensors are installed, which generate much more raw data while driving. This operational data is summarized into several pieces of information that the driver understands. In addition to the speedometer, the engine temperature, time of arrival, average speed, distance to the destination, etc. are constantly displayed to the driver. These information give him a very good basis to make fact-based decisions for operating the car. The driver can

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speed up if the dashboard informs him that the estimated arrival time is later then planed. The possible questions which arise here:

- Is the driver able to evaluate the large number of information pieces simultaneously?
- Are the drivers not distracted from driving the car by the huge amount of information?
- Will the quality of the car driving be improved by this additional information?

1.1 Information Pyramid

The terms information and data are often falsely equated, though they have fundamentally different meanings. Data (lat. Dare: give) are individual values which are represented by means of characters and appear in numerical, alphabetic, alphanumeric form or just in form of other signs. They are produced and processed by machines. For example, the numbers 500 or D are data coded in the first case with Arabic and in the second case with Roman characters.

Information (lat. Informatio: explanation) are data which people only understand when they are explained semantically. The information is the basis for knowledge because it contains messages or meanings (**Fig. 1**, Industrial Age).

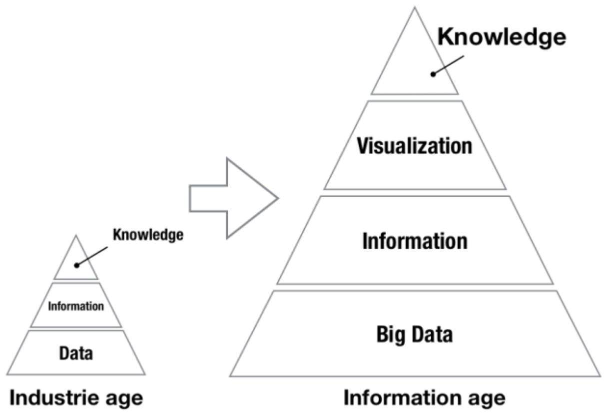

Fig. 1. Changes in information pyramid

For example, the number 500 becomes an information when it is assigned a semantic meaning. This can be 500 contract terminations, 500 EURO basic salary or 500 liters of water consumption. The knowledge is a consequent action based on information. The information 500 contract terminations may e.g. lead to the action of improving the service processes for customers to increase the competitiveness.

1.2 Operational Data

Due to the increasing digitalization of business processes, significantly more process data are generated in companies. For the running the business processes Online Transaction Processing Systems (OLTP) is used. With every business process e.g. every delivered customer order, every paid invoice or every hired employee operational data are automatically generated by OLTP systems. These mass data can also be called **raw data**. They are often difficult for humans to understand. They rarely provide an important insight for the management and therefore they are summarized, aggregated into key performance indicators (KPIs). This process of aggregation can be also described as **data refinement** (2 S. 591). Data must become information, otherwise people will not understand them and they will be not able to initiate knowledge-based actions.

1.3 Key Performance Indicators

Key performance indicators, as aggregated data, have the task to capture quantitatively recorded facts in concentrated form and to serve as a control and steering instrument for managers (3 S. 19-20). Through the key performance indicators operational **raw data** are transformed into **information**. People are the primary users of these information.

In the information age two developments take place. On one side many companies diversificated their business e.g. transition at VW from one Car-Company "Beetle" to many services company. On the other side companies digitalized many different business processes, which previously either did not exist or were handled conventionally. These two developments increased the variance of operational raw data. The result is the inflation of the information which people must use for the operational and strategic decisions.

At this point one phenomenon of information age is revealed. The transition from the Ford T to modern cars, which was accompanied by the enrichment the car dashboard with information happens now to the business. Managers have to analyze a lot more information to make decisions. The first phenomena of this development can be spotted in the late 90`s with the introduction of Kaplan and Norton's Balanced Scorecard as a result of the transition from the industrial to the information age (4). Whereas in the industrial age, financial indicators such as profit, sales, costs, and ROI were enough to control the business activity. In the information age much more indicators are needed to run the company in a balanced way. Kaplan and Norton combined many different and isolated indicators into a multi KPI system, such as the balanced scorecard with perspectives as finances, processes, employees, sustainability, etc. Each perspective can hold several key performance indicators. This leads to inflation of KPIs. At this point the same questions, regarding the driver of a modern car, can be raised. Are managers able to process large number of information pieces simultaneously? Are they distracted by the information amount?

The inflation of the KPIs requires a further aggregation level or meaningful visualization of multi KPIs (**Fig. 1**, Information Age) so that people can understand and process this information. Will the quality of decisions increase? If that does not happen, there is a risk that multi KPI systems will not be understood by humans and will degenerate into data.

Due to the flood of KPIs, methods of data visualization as a further aggregation level have to be analyzed in detail. Data visualization is the systematic, rule-based, external, permanent and graphic representation of information in order to gain insights, to develop understanding and to communicate to people (5 S. 1). Humans are at the forefront of visualization. As a possible visual aggregation of multi KPIs, Chernoff faces are considered below. The central question is: "Is it possible to use Chernoff-faces to aggregate multiple KPIs to make faster and better decisions?"

2 Visualization as an Aggregation of the Key Figures

2.1 Basics of Information Visualization

Seeing is done in different steps. When light falls on the retina, it is transmitted to the visual cortex. Already during the transport, the information is partly processed. This includes edge recognition, orientation recognition, segmentation, motion detection and color processing. Significantly, these processes take place without direct attention, that means that they are pre-conscious. These processes are very fast and parallel (6 S. 13, 21).

Only through attention, information is actively filtered out. The subsequent processes do not use the full information that has come to the retina. So-called feature maps are created for each feature that is detected in the first phase. There are e.g. a map highlighting the red color, a map for movement, a map for horizontally oriented objects, etc. These maps serve as a basis for attention (6 S. 150-153). Looking at the KPI total turnover of € 1,000,000, the retina only picks up the points of light for the first time. Late they are split into the different cards. A map is created which filters out only the edges of each letter and number. Additional cards are created for the color of the paper, for the color of the font and so on.

This visual information is stored in **iconic memory** for a short notice and is filtered out by the attention, then processed accordingly in the visual and verbal working memory. Here it comes to the usual restrictions of **3 to 5 objects of memory** (6 S. 22, 180, 311, 377, 383). This means that people can simultaneously perceive, interpret and evaluate a maximum of 3 to 5 key performance indicators. As the KPIs become more complex, it becomes more difficult or even impossible to completely utilize the upper limit (5 object of memory). The modern multi KPI systems, such as e.g. the Balanced Scorecard far exceed the biologically limited number of memory items. At this point, the next problem of the information age is revealed. On the one hand, the amount of key performance indicators which are relevant to run the company in a balanced way is increasing permanently. On the other hand, humans are encountering biological limits of information processing that nature has given. The car driver of modern cars and the manager of a up to date companies are reaching biological limits to process multi KPIs simultaneously because there are too many KPIs.

2.2 Information Visualization by Chernoff Faces

The idea of glyph-based visualizations is that single KPIs of a multi KPI system are shown graphically, e.g. represented by dashes, symbols (6 S. 163). Chernoff Faces is a method of glyph-based visualizations of multi-dimensional space was developed in 70´s by Hermann Chernoff (7). They consist of different facial features to which KPIs are assigned. A KPI is e.g. assigned to the mouth. The larger the value of this KPI is the bigger changes the mouth its shape and vice versa (**Fig. 2**).

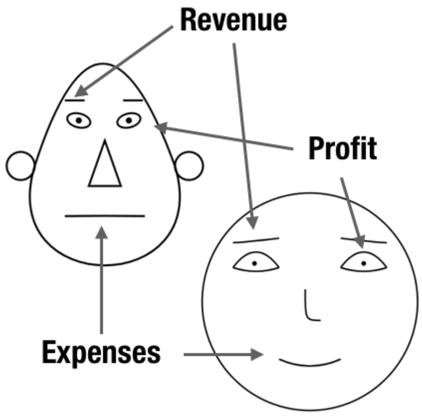

Fig. 2. Chernoff Face

Each facial feature has a different effect on humans. The mouth shape, for example, change the perceived emotion from happy to sad. Chernoff Faces thus combine several key figures into a facial expression, which people can quickly perceive and interpret.

Chernoff claimed that faces are part of everyday's life for people and therefore even small changes are easily recognized. He suggested that cartoon or cartoon faces are sufficient for the recognition of emotions. It was also mentioned that Chernoff Faces are perceived as a whole, as an emotion. (7 S. 363). Thus, individual key figures are perceived as a unit respectively as a system. This goal is also tracked by aggregation of data or by multi KPI systems.

An important task of visualizations is to highlight the important details to draw attention to them. This feature is called salience or relative importance. People focus on different facial features. The importance of the individual parts of the face to transmit an emotion is as follows:

1. Curvature of mouth,
2. Size of the eyes
3. Form of the chin
4. Height of the face,
5. Angle of the eyes,
6. Length of the nose and
7. Length of the eyebrows. (8 S. 210)

The relative importance of facial features means that most important KPIs must be assigned to the most salient face feature (**Table 1**)

Table 1. Assignment of KPI to facial features based on their importance

Rank	Part of the face	KPI	Max
1	Curvature of mouth	Annual Revenue	100.000 €
2	Size of the eyes	Annual cost	25.000 €
3	Form of the chin	Profit	75.000 €
4	Height of the face	ROI	2,50 €
6	Length of the nose	Customer Satisfactory	10,0
7	Length of the eyebrows	employee satisfaction	10,0

Based on the assignments in the **Table 1** following Chernoff Faces are generated (**Fig. 3**).

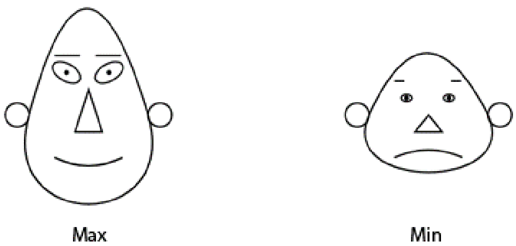

Fig. 3. Best and worst Chernoff faces, if all KPIs are perfect or miserable

Looking at these Chernoff Faces a human can much faster evaluate the overall comparison. The face on the left looks happier than the face on the right. That means that the situation of the company described by the KPIs in the column “Max” is better the situation of the company in the column “Min”. The evaluation speed of multi KPIs is the most important advantage of the Chernoff Faces.

Chernoff Faces have a side effect of non-linearity. This can also lead to the fact that desired effects are not observed clearly enough, even distracted from it (7 S. 363). For example, an important metric may be on the nose, but the observer is distracted by the variety of other facial features and instead focuses on the mouth and eye areas. This reduces the information of the nose and instead looks for salient facial features.

The next problem is that Chernoff faces are static. What is to do, if the importance of the KPIs changes for the company? Instead of maximizing profit, maximizing sales takes center stage. The relative importance of face features remains the same!

Non-linearity, the statics of the Chernoff Faces and the lack of standard software to implement the method probably have prevented the spread of this method in practice, despite very good research results. One possible solution would be dynamic Chernoff Faces, in which software decides company-specific or situation-specific, which KPI are assigned to which facial features and thus provides an overall evaluation.

2.3 Information Visualization by Dynamic Chernoff Faces

Dynamic Chernoff Faces use the idea that the most important KPIs should be assigned to the most salient facial features (8 S. 210). The salience order of facial features is determined bilocally and was defined in the previous chapter. But how can the rating of the KPIs be determined?

A very simple key figure system consisting of three KPIs with actual and target values is displayed in **Table 2**.

Table 2. Multi Key Performance Indicator System

KPI	Weighting factor	Actual	Target	Target achieve-ment	Relative Im-portance	Rank
Revenue	40%	160.000	220.000	-27%	0,109	2
Cost	20%	110.000	150.000	27%	0,053	3
Profit	40%	50.000	70.000	-29%	0,114	1

Weighting factors are defined individually by the managers. They can be derived from the corporate strategy. For a company that wants to penetrate the market quickly, sales are more important than profits and costs. A company that would like to consolidate itself would define profit as the most important measure. In this case the company pursues revenue/profit maximizing strategy. Cost reduction is inferior.

According to the actual data the company did not hit the target for revenue and profit, but exceeded the target for the cost by 27%. How to assess the particular performance based on this KPI system? Which indicator is more important for the total performance of the company? A possible algorithm for evaluating individual measures in the multi-measure system can be defined as follows:

$$\text{Revaltive Importance of KPI} = \left|\frac{Target-Actual}{Target} * Weight\right|$$

The most important KPI is the one with the highest absolute value. As a result, key figures that deviated significantly from the target value and have higher weight are perceived as more important key figures. So here is the order of KPIs: profit, revenue and costs. The next step is to assign the KPIs to the face features according their salience: Profit to the mouth, revenue to the eyes and cost to the chin. The face emotion based on single face features will deliver the assessment of the total performance of the company.

2.4 Empirical Test

The question "Do dynamic Chernoff faces lead to faster and more correct evaluation of multi KPIs systems?" can be answered with an empirical test. The test was conducted with 168 subjects by Tim Stahringer at the University of Applied Sciences in Coburg (9). Subjects had to compare companies based on KPI systems. The test subjects were presented several fictitious companies. There was always an objective ranking between companies, such as **Table 3**: Company 1 is better than company 2.

Table 3. KPI systems of two different companies presented as grid

Company 1

KPI	Weighting factor	Actual	Target
Revenue	40%	160.000	220.000
Cost	20%	110.000	150.000
Profit	40%	50.000	70.000

Company 2

KPI	Weighting factor	Actual	Target
Revenue	20%	190.000	200.000
Cost	40%	180.000	185.000
Profit	40%	10.000	15.000

A group of subjects is presented the company's KPIs in form of grid as in **Table 3**, the other group in the form of bullet graphs (**Fig. 4**), while another group was presented the same key figures in the form of dynamic Chernoff Faces (**Fig. 4Fig. 5**). The subjects had to evaluate the individual performance of many different companies and to rank the companies.

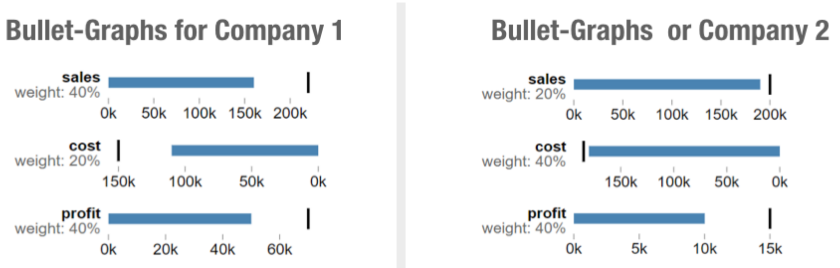

Fig. 4. KPI systems of two different companies presented as Bullet-Graph

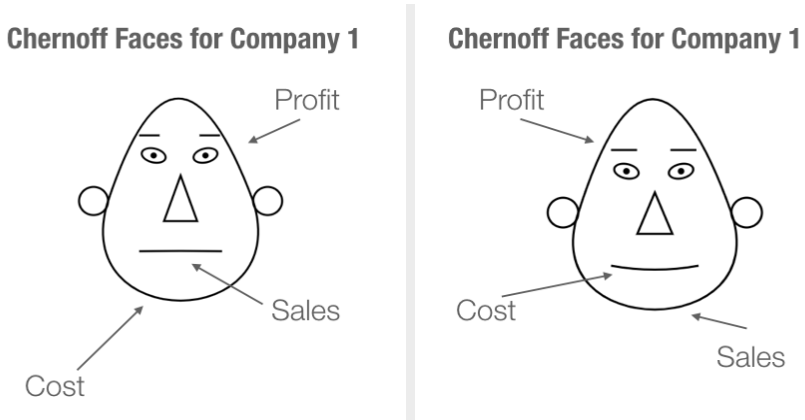

Fig. 5. KPI systems of two different companies presented as dynamic Chernoff Faces

The results of the survey were evaluated by means of Kendall Tau. The Tau = 1 means that the subject has ranked in a pairwise comparison correctly and the Tau = -1 means the rating was wrong. Per subject an average Tau was calculated. The **Table 4** demonstrates that the subject S6 has made the evaluation of all three company pairs correctly and that the subject S5 evaluated everything wrong.

Table 4. Calculation of average tau by subject

Subject	Tau for pair-wise com-parison 1	Tau for pair-wise com-parison 2	Tau for pair-wise com-parison 3	Average tau
S1	+1	-1	+1	+1/3
S2	+1	+1	-1	+1/3
S3	+1	-1	-1	-1/3
S4	-1	+1	-1	-1/3
S5	-1	-1	-1	-1
S6	+1	+1	+1	+1
S7	+1	-1	-1	-1/3
			Total average tau	-0,05

Kendall's Tau has a value range of [-1,1]. The value 1 corresponds to the perfect truth, the value -1means the exact opposite of the truth and 0 equal to coincidence (10 S. 81-85). In the example of **Table 4** is the total average tau equal to -0.05, which is approximately coincidental.

The results of the survey at the University of Applied Sciences in Coburg can be summarized as followed. Grids and Bullet Graphs were compared with dynamic Chernoff Faces. All versions were based on the same KPI system with the same values.

For Bullet Graphs, the average tau was 0,28 and the average response time was 34 seconds. For the dynamic Chernoff Faces, the average tau was 0,71 and the average response time was 9 seconds. For the most common method to present KPIs the grid was the average tau 0,33 and the average response time was 27 seconds. All results were significant. The study has confirmed that the visualization of multichannel systems with Chernoff Faces has resulted in faster and more accurate scores than bullet graphs and grids. That means the transformation of single values of KPIs into a face expression with a specific emotion helps humans to proceed multi KPIs simultaneously. This could be an answer to information inflation.

2.5 Conclusion

The Chernoff Faces reflect a multi KPI system as a unit! The survey also showed if the differences between compared company are very small, the Chernoff Faces could look almost identical, which can be a problem. Restricting the Chernoff Faces to seven metrics because of the most salient face features can be remedied by incorporating less salient facial features. The biological restriction of humans up to 3- to 5 KPIs in the iconic memory can be bypassed by presenting the KPIs in form of Chernoff Faces. Thus, dynamic Chernoff-Faces provide a big added value, as more information can be perceived by humans at the same time.

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