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Role of Visualization in a Knowledge Transfer Process

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Abstract

Background: Efficient management of the knowledge requires implementation of new tools and refinement of the old ones - one of them is visualization. As visualization turns out to be an efficient tool for transfer of acquired knowledge, understanding of the influence of visualization techniques on the process of knowledge sharing is a necessity. **Objectives:** The main objective of the paper is to deepen the understanding of the relation of visualization to other knowledge sharing paths. The supplementary goal is a discussion of constraints on visualization styles in relation to readability and efficiency. **Methods/Approach:** Due to the ambiguous nature of the problem, case analysis was selected as a research method. Two research papers have been selected for that. The first one focused on agrotourism, introduces a general use theoretical tool suitable for various purposes, such as consumer sentiment analysis. The second one evaluates possibilities of revealing an implicit organizational structure of an organization by means of visual analysis using interaction graphs. **Results:** Visualization is an important part of data analysis and knowledge transfer process. Hybrid visualization styles enhance information density but may decrease clarity. **Conclusions:** In order to maximise the role of visualization in a knowledg tranfer process, the special care must be devoted to clarity, the optimal level of details and information density in order to avoid obfuscation.

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Introduction

In the paper relation between two items is discussed: knowledge as a subject and visualization as a tool aimed at knowledge transfer between individuals.

In general, knowledge is being collected by a variety of scientific disciplines: experimental sciences (experimental physics, engineering), theoretical (mathematics, cosmology, computer science) as well as descriptive sciences including business science, in particular knowledge is a key element of the modern economy.

Deepened knowledge allows for better management of biological natural resources, like fishing or agricultural and forest economy as well as services like tourism. Visualization is one of the oldest knowledge transfer methods, dated back to the middle Paleolithic era (Balter, 2011; Wong, 2018). Of course, over the curse of years visualization techniques and technical means of visualization have been greatly improved. However, still there are numerous issues concerning proper graphical display of data, information, and knowledge (Weissgerber et al., 2015).

Acquiring knowledge is a complex, multi-stage process, and its inherent part is the transfer of knowledge between individuals. Without knowledge sharing, collected knowledge would be valuable, though useless, a collection of personal notes. Thus, acquiring and transferring knowledge is a complex and continuous process involving many techniques of expression, including not only written or oral communication but also numerous forms of visualization (Opiła, 2017b, Opiła et al. 2018a). The growing complexity of scientific discoveries requires ever more sophisticated forms of visualization, including not only conventional ("Tufte style") 2D line-art (Tufte, 2001), but also photorealistic, often hybrid, and sometimes true 3D (e.g., augmented reality or holographic) or 4D (interactive/animated) designs. This suggests that knowledge visualization may and should be researched subject on its own.

As the amount of knowledge rapidly grows enterprises must react to the growing number of signals coming a.o. from science, economy (trends), law (legal regulations) and politics (taxes). This huge pile of data must be processed into knowledge and then presented to management in readable form - usually, managerial dashboards are used for that. In education, lecturers must pass more knowledge of the ever-increasing complexity each year. While many years ago it was just reading, writing, and simple counting, nowadays students must learn how to decompose trends in time series or forecast demand. Thus, all known methods of knowledge transfer should be thoroughly analyzed in order to find their best field of implementation and possibly find ways for improvement, in particular, knowledge transfer rate and efficiency.

Paper consists of seven chapters. After general "Introduction," "Methodology" section details the reasons for the selection of employed research method. In the next section, "Knowledge acquiring and transferring," considerations on constraints, methods, and efficiency of selected knowledge gathering ways and knowledge sharing paths are presented. Next two sections present two case studies of visualizations used in published papers and debate their pros and cons. Paper is concluded with condensed "Discussion" and final "Conclusions."

Two papers have been chosen for case studies. The first one introduces a generic method based on the Monte-Carlo technique, used to analyze consumer sentiment as a coefficient in the econometric model of an agrotouristic farm, the second one is devoted to the analysis of the possibility of revealing a hidden or simply implicit organizational structure through visual analysis of the communication graph.

For both cases, selected visualizations are only presented as an example for discussion. For short consistency description of the theoretical background for each work is provided. This main research part of the paper is preceded with in-depth discussion concerning visualization as a subject of the study.

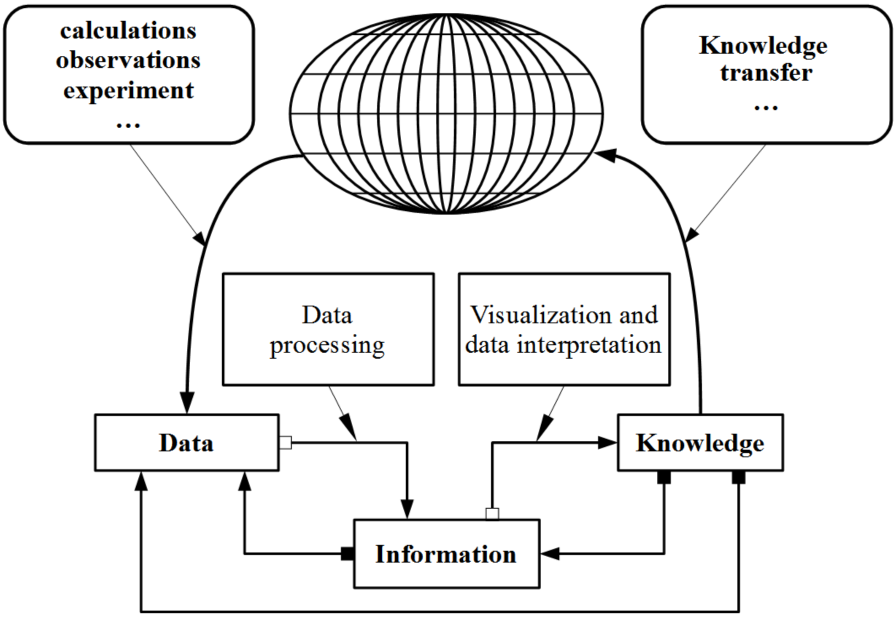
Knowledge acquiring and transferring

Only established knowledge may be transferred. The steps of acquiring the knowledge and ways to pass it to the audience are discussed in the next two subsections.

Knowledge acquiring

Usually, cognition results from the observation of nature, which is rather passive, in descriptive sciences (economics, finance, geography) or active, in experimental ones (physics, chemistry, biology). With a relatively high level of generality, it can be explained with the help of Fig. 1.

Figure 1
Diagram of the Knowledge Transfer process



Source: Authors' illustration, (Opiła, 2017b; Opiła 2018b) reworked

The very first stage is usually inspection of the observable environment which involves the collection of datasets which contain, amongst others, remarks, notes, photographs, maps, measurements, interviews, queries. At this stage, data have no meaning; thus the next step is data processing. Besides a simple classification of data, advanced data processing techniques might be employed in producing information (Opiła, 2016; Zekić-Sušac et al., 2015; Kozlíková et al., 2017). Collected information is the basis for extension of knowledge, but on the other hand, it can be used for deeper understanding and subsequent re-analysis of the data-set or to obtain additional data, e.g. from the data warehouse. Again, acquired knowledge can be used as a guide to the re-analysis of information or as an impulse to collect additional data this time is focused on testing of research hypotheses or simply observing the dynamics of the evolution of the monitored system. However, the acquired knowledge is still hermetically sealed inside the research team. Thus, one more step is necessary knowledge transfer, at the beginning between specialists, then between research institutions and finally from professors to their students and further to the general public.

In particular, knowledge of the dynamics of tourist traffic at the level of a scientific institute will not help owners of agrotouristic farms or private apartments to react adequately to disturbances caused by, e.g. unfavorable weather until they are properly notified about possible threats and suitable solutions, e.g. price lowering or cooperation between farm owners (Stanovčić et al., 2018).

Data visualization and knowledge transfer

Knowledge transfer is a complex process, prone to distortions and requiring the sender and the recipient to share the same conceptual apparatus. Discussion considering the influence of pollutants such as bisphenols (e.g. BPA, 4,4'-(propane-2,2-diyl) diphenol — (CH3)2C(C6H4OH)2) on neurohormone system, requires that both the sender and the recipient share knowledge of bisphenols chemistry (Gosztyła et al., 2011), biological activity (Erler et al., 2010), their retention in natural environment (Jone et al., 2015), patterns of introduction into the organism, cellular metabolism, and excretory routes.

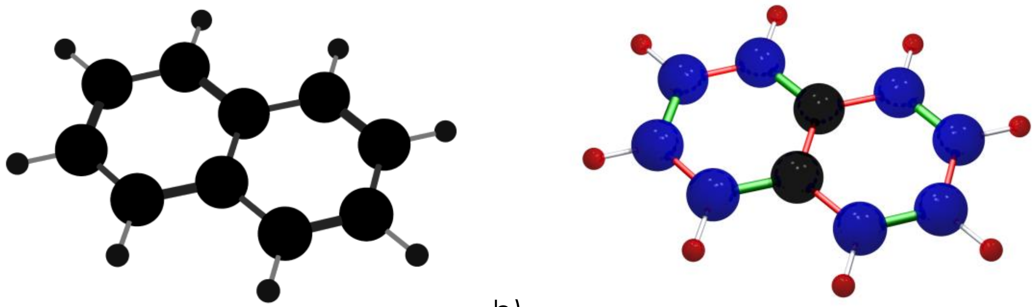
The textual transfer of knowledge is often ineffective because it is very difficult to efficiently present the spatial relationships, e.g. in a chemical molecule or describe the organizational structure of the company. Thus, the limitation of verbal communication may hinder the perception of the obtained research results. The interesting example is determination and following the presentation of the molecular spatial and crystalline structure of an organic compound — naphthalene C10H8, (Robertson, 1933) through X-Ray study. Exact spatial placement of carbon and hydrogen atoms in naphthalene molecule established later is listed in Table 1. This is very precise, but the reader can hardly get any clue about the true shape of the molecule. On the other hand, a brief look at the visualizations shown in the Fig.2 gives instant insight into mutual distances, simplified electron structure, and chemical bonds but no exact values may be read out. So, table and figure are mutually dependent and thus inseparable.

Table 1
Cartesian Coordinates of Atoms in Naphthalene Molecule

Atom	x [Å]	y [Å]	z [Å]
C	2.423247	0.705674	0.000000
C	1.239335	1.396987	0.000000
C	0.000000	0.713185	0.000000
C	0.000000	-0.713185	0.000000
C	1.239335	-1.396987	0.000000
C	2.423247	-0.705674	0.000000
H	-1.237376	2.476742	0.000000
H	3.361100	1.238312	0.000000
H	1.237376	2.476742	0.000000
C	-1.239335	1.396987	0.000000
C	-1.239335	-1.396987	0.000000
H	1.237376	-2.476742	0.000000
H	3.361100	-1.238312	0.000000
C	-2.423247	-0.705674	0.000000
C	-2.423247	0.705674	0.000000
H	-1.237376	-2.476742	0.000000
H	-3.361100	-1.238312	0.000000
H	-3.361100	1.238312	0.000000

Source: Pirali et al., 2013, Table S3

Figure 2
a) – Grayscale Visualization of Spatial Structure of Naphthalene $C_{10}H_8$ only.
b) – Artistic visualization of Spatial and Electronic Structure of Naphthalene $C_{10}H_8$ (Red spheres: hydrogen (electric charge approximately q= +1*e*); blue spheres: carbon, app. q = -1*e*; black spheres carbon, q = 0*e*. Cylinders symbolize chemical bonds: silver **C-H**; red **C-C** and green **C=C**).



a) b)
Source: Authors' work, using the development version of ScPovPlot3D (2019) toolbox

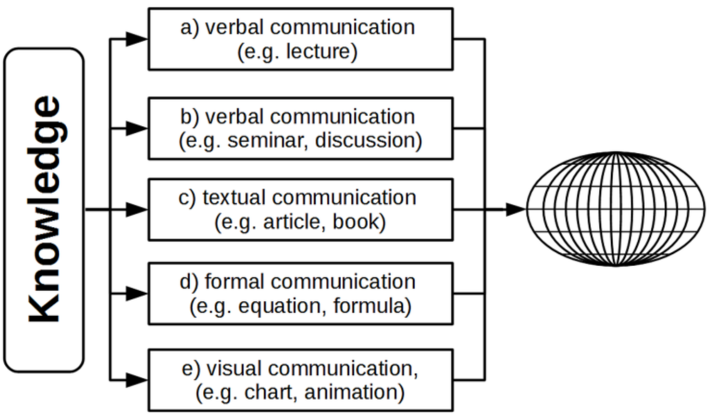
This is the reason why even the most valuable work deprived of visualization may become hermetic even for specialists in related fields, not to mention representatives of other scientific disciplines.

Selected Knowledge Transfer Paths

The graphical diagram of selected knowledge transfer paths is shown in Fig. 3 (Opiła, 2017b; Opiła, 2018b). In general, it was arbitrarily decided to distinguish five important communication paths:

- verbal — non-interactive (e.g. lecture, presentation),
- verbal — interactive (e.g., seminar, panel),
- textual — printed text (e.g., books, textbooks, e-books),
- formalized — e.g., BPN notation, chemical formulas,
- visual — e.g., graphics 2D or 3D.

Figure 3
Knowledge Transfer - Selected Paths.



Source: Authors' illustration (Opiła, 2017b; 2018b), reworked

Each of the techniques mentioned has advantages and flaws and the field where it can or should be used. Although the lecture (a) allows for an orderly transmission of content, the possibilities of asking a lecturer are limited and losing a thread often causes a misunderstanding of the whole issue. Though the seminar (b) allows for discussion, it is effective only in a small group, and there is always a risk of useless litigation resulting from personal ambitions. The printed text (c) is usually carefully thought out, orderly, available to many recipients and also allows re-analysis of the content to a full understanding of the argument, on the other hand, the rate at which knowledge increases means that the printed text is outdated and its specificity makes it impossible to ask the author for details of his deduction paths. A formalized message (d) is admittedly precise, but its proper interpretation requires training and knowledge of certain conventions specific for the given specialty, e.g., in business process analysis and optimization.

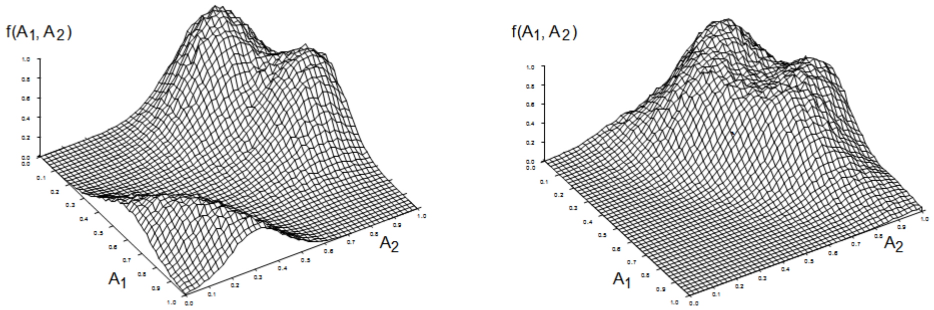
In this context, the visual message (e) seems to be the most attractive and legible especially to a mass audience. However, there are also strong constraints here. The specificity of a scientific discipline may require visualization in compliance with strictly defined rules, understandable only to the educated recipient. The structural formula of the naphthalene molecule (Pirali et al., 2013, op. cit) is fully understandable only to a person familiar with the paradigms of organic chemistry. At the same time, the use of visualization for the transfer of knowledge carries the risk of domination of the form over the content, or reversely, of overloading with content, which inevitably leads to the illegibility of the message. For example, a graph may carry a significant amount of information, but when the number of nodes (vertices) of the graph exceeds a certain threshold value, it easily becomes illegible, for example, due to limited printing resolution or inefficiency of the human eye (Tamassia, 2014). This problem is experienced, for example, by analysts using the technique of classification trees or dealing with social networks. However, finding the optimum, although difficult, is often possible and advanced visualization techniques allow to merge many cognitive layers into one hybrid graphic (Opiła, 2016, Opiła, 2018a).

To sum up this section, it should be noted that Fig.1 and Fig.3 are intended examples of utilization of line-art graphs for the knowledge transfer about the subject hereby investigated.

Case study 1. Visual Sentiment Analysis

Stochastic econometric models enable the analysis of the functioning of an economic entity and testing of various control data combinations. Numerical experiments that can be performed on the model cannot be carried out in the real world due to the risk of irreversible financial damages. In particular, What If sentiment analysis may be easily carried out using numerical Characteristic Surface Model **CSM** (Opiła, 2005; Opiła et al., 2008).

Figure 4
Evolution of the Characteristic Surface due to Change of One of the Components. Left image – before the negative signal, right – thereafter



Source: Authors' illustration, (Opiła, 2008), reworked

In the following description, CSM keywords are italicized. The essence of the model is a manner of choosing one of the "M" available options from the set {O1, O2, …, OM}. Assuming that a given individual may assign a numerical value of attractiveness Ai (from the interval [0,1]) to every option {Oi}, one can mark a point in a unitary M-dimensional hypersquare by assigning coordinates P(A1, A2, …, AM). By repeating this procedure for a certain population one obtains an empirical multi-dimensional probability distribution function f(A1, A2, …, AM). Because the graphical representation of such a function requires an M+1-dimensional space in which it creates an M-dimensional manifold, i.e. M-dimensional hypersurface function f(A1, A2, …, AM) was named the "characteristic surface" of the model. Having characteristic surface established, one may employ Monte Carlo formalism to draw N individuals – i.e., deciders each of them may select only one of M options {Oi}. For each decider criterion function K(A1, A2, …, AM)→{1,..,M} (another key part of the model), determines the index of the particular option to be selected, based on the coordinates of the randomly selected point and the past choices. Nature of the decider is flexible. In social sciences, it is usually a person, e.g., consumer. However, in biology, it may be an animal while in chemistry it may be one of the possible active areas on the molecule to be bonded with. It should be stressed that the Characteristic Surface Model is generic and due to that implementable in many, extremely varied disciplines.

Complete model may be described as a set (1):

$$\{\{O_1, \dots, O_M\}, \boldsymbol{f}(A_1, \dots, A_M), \boldsymbol{K}(A_1, \dots, A_M), \boldsymbol{M}, \boldsymbol{N}\} \quad (1)$$

where N is a number of individuals in the sample, and other items are defined above.

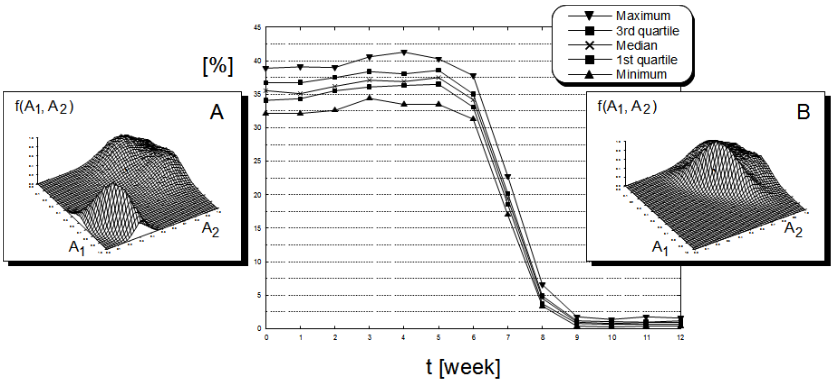
Determination of the characteristic surface is a separate non-trivial problem. Several methods may be used, including computational methods, surveys, business intelligence tools, and machine learning. Fortunately, human preferences are characterized by considerable inertia, so the characteristic surface is evolving slowly rather than undergoing rapid changes, which is why it can be treated as an attribute of the given population at mid-terms.

One of many implementations is an evaluation of the demand on given wares, manufactured by the enterprise under study. For practical reasons the number of competing options may be reduced to just two – i.e., selected firm and its competitors aggregated as a single option. Thus, each individual may select one of the two possible options only.

In the more complex scenario, the entire population can be divided into subgroups uniquely responding to external signals. For example, for windsurfers windy, even cloudy weather is much demanded while regular tourists prefer a lack of wind and a cloudless sky. Therefore, although both will choose the date of their leave in the period of greater probability of the desired weather conditions, these might be quite different periods. The behavior of each of the subgroups will be different in response to the same stimulus but based on historical data, possible to model. Assuming that one of the options is to rent an apartment and the second one is to cancel the trip, you can model the demand for tourist services depending on the expected conditions (weather, exchange rates, fuel prices). In turn, using the estimated demand as a factor in an econometric model for a given tourist facility, its financial outcome for the given period may be modeled. The same applies to tourist organizations, for example, agrotourism clusters described by Stanovčić and others (2018). Due to the number of participants, such a network is more durable to unexpected demand fluctuations.

Figure 5

Estimated Financial Outcome Obtained by Means of Characteristic Surface Model



Source: Authors' illustration, (Opiła, 2008), reworked

Such an analysis was carried out for a hypothetical agritourism farm (Opiła et al., 2008). It was assumed that set of all potential customers consisted of three mutually exclusive subsets – layers (subgroups), one of which steadily evolved from start to final position in response to an external signal (which is an event specifically for given discipline) received at the start (t=0) while two others were kept unchanged. The evolution of only one layer had a visible effect not only on the appearance of the characteristic surface (Fig. 4) but also resulted in a drastic breakdown of the financial result. The process flow can be visualized on one hybrid chart, shown in Fig. 5. The financial result obtained through Monte Carlo simulation is presented in the middle graph. Figure 5 was constructed from three subgraphs prepared using gnuplot, a data plotting program (gnuplot, 2019). The left and right inset contain a visualization of the characteristic surface before and after the signal was detected. Influence of the signal on the characteristic surface of the layer results from the sensitivity of layers. Some may stay unchanged (neutral) while some may be pushed in any direction depending on the signal and some may just flatten or oppositely develop peaks. In the presented case, the signal for the selected layer was emitted at the beginning of the simulated period. It has to be mentioned that from the point of view of the layer no signal is negative nor positive. However, it may be such for observed category, e.g. the total profit of the farm. In this case, the signal was negative for the observed entity.

In the beginning, everything looks good, profit is solid and stable, but unexpectedly falls down several cycles after the negative signal is emitted. This process is visualized as the line-art chart (middle). As usual for the Monte Carlo method, simulation of the profit is performed over a period of time (here 12 weeks, 13 data points) and then repeated many times in order to determine averaged properties of the phenomena. On the data level for every repetition new data vector is created. Thus after, e.g. 100 repetitions researcher has 100 data vectors, each 13 values long. How can that be presented?

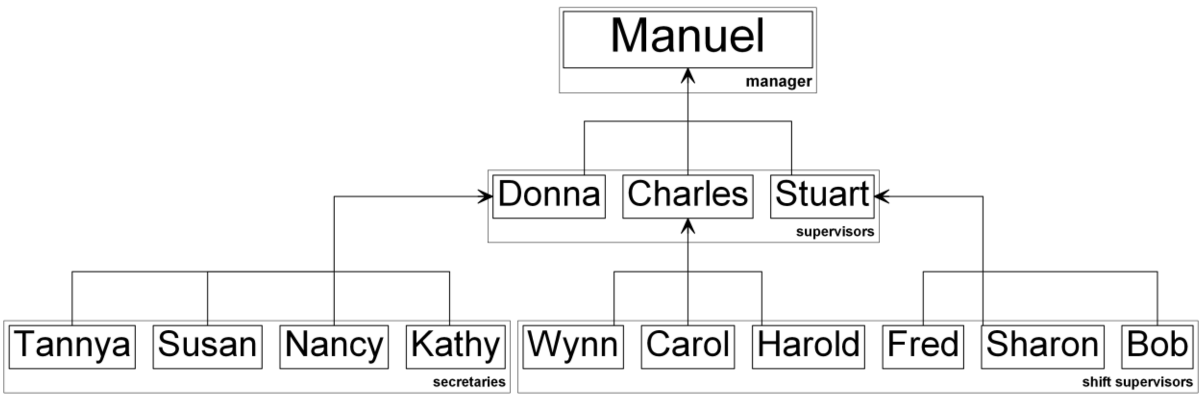
In the selected graph on every time step (100 data points from 100 simulations) five points were computed, namely: minimum, 1st quartile, median, 3rd quartile, and maximum value. Relevant points of all five series have been visually connected using straight sections. Alternatively, instead of quartiles, the mean and standard deviation may be displayed. The line-art keeps pictorial clean and concise according to the rule "the less ink, the better" (Tufte, 2001).

In the presented case, the process can be analyzed not only within the numerical econometric model but also on the basis of just visual analysis of the characteristic surface, which makes it more understandable and useful for the average educated user. The host may state that the characteristic surface starts looking badly thus some additional marketing activity is required

Case study 2. Insight into Hidden Organizational Structure

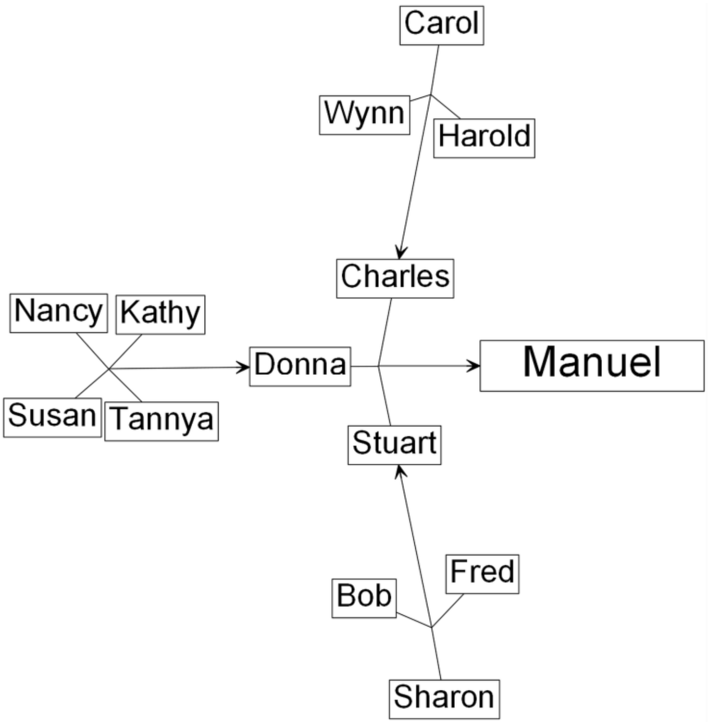
For every organization, including business entities, steady discovery, analysis, verification, and improvement of the organizational structure is an important element of the survival strategy on the increasingly competitive market. This implies searching for better and better tools to achieve this goal including proper graphic representation (Fig.6, Fig.7). In addition to proven surveys or participant observation methods, it is worth looking for methods that are independent of the level of cooperation of the surveyed employees. One of the possible approaches is an attempt to discover the factual, operational structure of the company by examining traffic in its communication network (Opiła, 2017a).

Figure 6
Formal Organizational Structure of Inspected Fictitious Firm



Source: (Opiła, 2017a)

Figure 7
Alternate Diagram of Organizational Structure

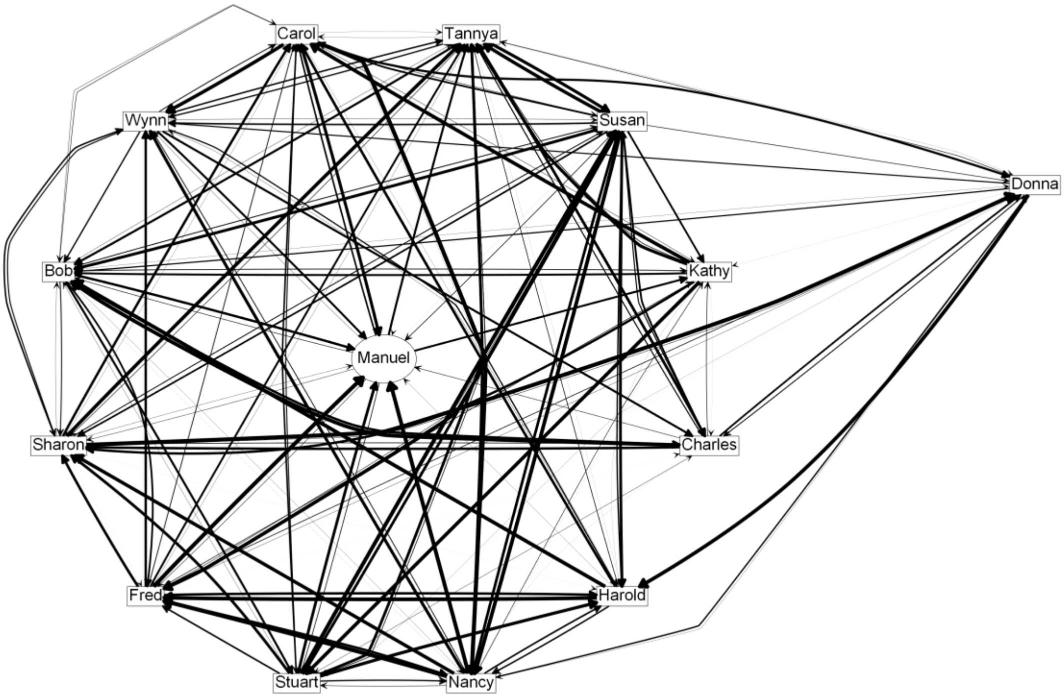


Source: Authors' work

The organizational structure may be defined as:
„*The typically hierarchical arrangement of lines of authority, communications, rights and duties of an organization. Organizational structure determines how the roles, power, and responsibilities are assigned, controlled, and coordinated, and how information flows between the different levels of management*." (Business Dictionary, 2018). This definition emphasizes the role of communication and information transfer paths between individual elements of the organization, in particular between the management levels. The organizational structure of an enterprise, created at foundation time, may undergo, more or less, evolutionary change. This may result from the intended reorganization, or from the spontaneous tendency of human teams to self-organize. Thus, concealed or even secret elements of the organizational structure may emerge. Their existence may solve some ailments of the official organizational structure but sometimes may pose a real threat. This is why analysis of the actual organizational structure and comparing it with the intended theoretical construction is an essential element of supervision over the efficiency, effectiveness, and security of the organization.

Thus, the problem that arises is how to discover the actual organizational structure. One can just survey employee about affiliation with a given department and the strength of this relationship according to a specially designed scale (Brzeziński et al., 2015, p.100). There, the weaknesses of the company's hitherto formal organizational structure were identified, and the concept of a new, favorable to its growth was proposed (Brzeziński et al., 2015, p. 104). In this case, the analysis was carried out by visual analysis based on network visualization using graphs constructed using the Pajek program (PAJEK, 2018). However, the survey method has several disadvantages. First of all, it assumes objective correctness of the answer. Secondly, such a study may arouse the feeling of uncertainty in the company, and thirdly it absorbs the employee's time. It seems that analysis of communication lines and information flow paths between the nodes of the organization allows overcoming these drawbacks. In order to check this assumption, a visual analysis of a hypothetical company (Tamassia, 2014, p. 808) with the structure shown in Fig.6 and Fig.7, was carried out using the graphviz program (graphviz, 2018). The analysis included communication between employees via telephone or e-mail (data obtained by computer simulation in this case).

Figure 8
Number of Conversations Between 4th and 7th Hour of the Business Day Presented using *twopi* Algorithm



Source: (Opiła, 2017a, Opiła, 2018b) reworked

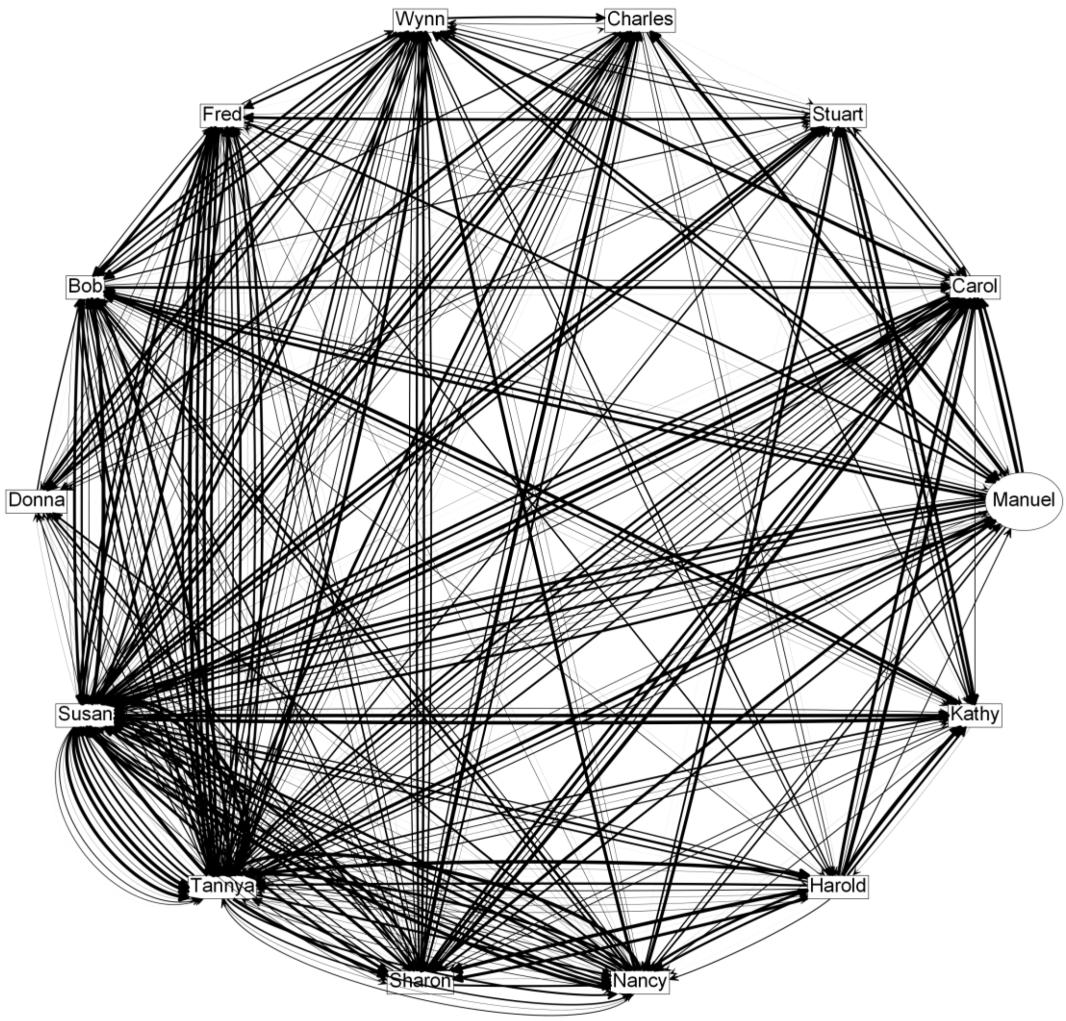
From the billing databases, usually stored on communication servers, one can obtain extracts containing the searched data, e.g., a number of calls during a selected time interval, say between the fourth and seventh hour of a business day. The resulting data structure can be visualized using a directed graph, where the communication partakers are represented as the graph's vertices, and the edge thickness of the graph reflects the examined feature, here the number of conversations or their total duration. The exemplary resulting graph, constructed using the twopi algorithm, (graphviz, 2018), is shown in Fig.8 i.e. the number of communication events from the 4th to the 7th hour of a business day, due to the clue that the peak of productivity falls within this period (Austin, 2017; The Redbooth Team, 2018).

It is clearly visible that while "Manuel" is the manager, "Donna" seems to create a separate decision center of the company, but "Charles" and "Stuart," who are on identical organization position as "Donna" (see Fig.6 and Fig.7) do not distinguish from other workers. Moreover, it can be spotted, that "Stuart" had intense communication with "Susan" (secretary) while "Charles" communicated intensely with "Bob," shift supervisor. Thus, the hypothesis may be put forward and then verified, that "Stuart" and "Susan" are in a personal relationship but "Bob" consulted with "Charles" any production disturbances.

These and other spotted fluctuations may and should be thoroughly investigated in order to improve the efficiency of the management. What is important, relevant diagrams may be created automatically on a regular basis by the computer system of the enterprise and their time evolution may be analyzed by experts or using AI systems. Thus, important modification of the structure may be introduced on time.

The method described above seems to work very well. Unfortunately, interactions graphs may easily be obfuscated by including too many details. Thus, before making a drawing, some aggregation should be done. It is shown in the Fig. 9 that including into analysis all conversations longer than 3 and shorter than 7 minutes (this period is selected as an example) in a whole day creates a graph so dense that cannot be studied. For example, it is not clear who initiated given conversation, as tails and heads of arrows marking directed edges cannot be perceived. In case of large structures with a number of edges, the use of 3D imaging may be necessary in order to distinguish overlapping edges and vertices. Consequently, employing of Virtual Reality systems may help navigate through the extremely complex diagram.

Figure 9
Graph Including All Conversations 3-7 minutes long, in the One Day. The width of Edges is Proportional to the Duration of the Talk. *circo* scheme was used.



Source: (Opita, 2017a) reworked

Discussion

Because visualization seems to play important however underestimated role in knowledge transfer it was necessary to study that problem in details. In both cases discussed, visualization plays a significant but different role. The first one illustrates the results of the numerical analysis and its conceptual basis. In the second case, it is essentially an independent tool of inference, while maintaining an illustrating role. Thus, visualization plays a supporting as well as a dominant role in the process of acquiring and transferring the knowledge. In each case, the proper balance of visual effects (which improves attractiveness) and clarity (which enables understanding) is required.

Another concern arises about visualization presented in Figure 2b. Due to the popular paradigm that scientific illustration must be black&white and as simple as possible, preferably in line-art style, this figure is unacceptable because it not only intensively utilizes color but also advanced, polished textures. However, usage of additional attributes allows for the introduction of supplementary cognition layers, namely approximated electric charge distribution — that way several properties are presented in a single pictorial making it a hybrid visualization. As a result, information density encoded into the graph is enhanced but not by the cost of obfuscation. Thus, the value of given visualization should be determined based not only on purely formal principles but on its goal and intended recipient too. The same pictorial may be useless in some circumstances and useful in another. Unfortunately, there is another constraint, namely printing technology. It is well known that the printing process of full color picture is much more expensive than black&white one. On the other hand, the growing number of articles is published in an electronic form which not only allows for usage of full color but interactive animations as well (NASA, 2019a).

Visualization must obey strict rules in order to become a scientific, academic or managerial tool. Thus, several aspects of visualization must always be inspected, especially those which impact most information density (known as "data-to-ink ratio," Tufte, 2001) and expressiveness of the given pictorial mostly in the form of a chart. It must be stressed that poorly designed visualization may hide important attributes of the dataset or even suggest wrong conclusions which are consistent with literature remarks (e.g., Weissgerber et al., 2015). Another form of visualization is managerial dashboards. In order to achieve maximum knowledge transfer rate, efficiency and legibility they must include important data only, i.e. carefully selected KPI's, shown using graphics stripped of unnecessary effects like fake 3D, glowing textures, fancy gauges, etc. If in doubt it is safer to keep knowledge to ink ratio of visualization at a suboptimal level, as above critical threshold visualization becomes obfuscated and ambiguous.

Artistic visualization is a separate and special form of visualization – Fig.2b is described to be of that type. This form is also useful in the process of transfer of the knowledge but is usually addressed to a mass audience or treated as an artistic vision in case of lack of sufficient data on the subject. It may be often noticed, e.g. in articles concerning the search for exoplanets (NASA, 2019b). Another field of application is the case when the eye-catching look is more important than knowledge contained within. Usually, this is applicable to opening slide or cover graphics.

Another aspect of visualization in knowledge sharing and management is the preservation of human values. This postulate may be achieved a.o. by employing more human-oriented, suitable for cognitive abilities of average recipient techniques. Visualization treated as some special form of the Graphical Art definitely introduces human ingredient into the knowledge. On the other hand, Graphic Arts may be recognized as a form of visualization — visualization of unseeable, e.g., feelings or emotions like sadness, fear, joy or euphory.

Full understanding of the impact of visualization on knowledge transfer requires quantitative studies involving extensive experiments with a number of participants. This is because the quantitative assessment of the impact of visualization on the understanding is a rather complex task and as such necessitates cooperation in a multidisciplinary research group. It depends amongst others on specific scientific discipline but also on characteristics of the given recipient, including their skills and prior education level. Such a study would require a broad spectrum of research methods including such diverse methods as queries or functional NMR. However, some preliminary conclusions may be drawn based on discussion and critical analysis of visualizations employed in scientific papers. It is planned to investigate this subject further in future projects.

Conclusion

Well-designed visualization may greatly improve the efficiency and accuracy of the knowledge transfer. However, badly constructed charts may negatively affect the understanding of presented concepts. New phenomena require innovative forms of graphical expression.

Most often usual black&white visualization is sufficient. However, in some cases utilization of modern graphics tools like photorealistic rendering is justifiable and allows for a safe increase of information density. Additional attributes create supplementary cognition layers usually encoded as color or texture.

There is an optimum level of knowledge to ink density contained within single pictorial. Below that level resources are just wasted but above charts become obfuscated and thus useless. This suggests that it is safer to plan knowledge to ink density factor just below estimated optimum.

Artistic visualization under some circumstances may be useful for presentation of ideas and knowledge in case of insufficient data even in scientific, academic or managerial context.

Graphics used for managerial dashboards must be kept as simple as possible in order to achieve maximum legibility and knowledge transfer rate.

Full understanding of the impact of visualization on knowledge transfer requires quantitative studies involving extensive experimentation. It is planned to investigate this subject further in future multidisciplinary projects.

References

1. Austin, P. L. (2017), "Work During Your Hours of Peak Productivity," available at: https://lifehacker.com/work-during-your-hours-of-peak-productivity-1822000501 (21 February 2019).
2. Balter, M. (2011), "Was the Spotted Horse an Imaginary Creature?", available at: https://www.sciencemag.org/news/2011/11/was-spotted-horse-imaginary-creature (18 March 2019).
3. Brzeziński, Ł., Wyrwicka, M. (2015), "Wykorzystanie wizualizacji sieciowej do stymulacji wzrostu przedsiębiorstwa" (The use of network visualization to stimulate enterprise growth), in Kiełtyka, L., Niedbał, R. (Eds.), Wybrane zastosowania technologii informacyjnych wspomagających zarządzanie w organizacjach, wyd. P.Cz., Częstochowa, p. 93-106.
4. Business Dictionary (2018), WebFinance, Inc., available at: https://goo.gl/hWHDdw (20 March 2018).
5. Erler, C., Novak, J. (2010), "Bisphenol A exposure: human risk and health policy", Journal of pediatric nursing, Vol. 25, No. 5, pp. 400-407.

6. Gosztyła, K., Pulka, M., Milewicz, T., Lurzyńska, M., Opiła, J., Stochmal, E., Hubalewska-Dydejczyk, A., Galicka-Latała, D., Krzysiek, J. (2011), "The impact of polychlorinated biphenyls on placental and ovarian steroidogenesis", Przegląd Lekarski, Vol. 68, No. 2, pp. 118-122.
7. gnuplot (2019), computer program, available at: http://www.gnuplot.info/ (25 February 2019).
8. graphviz (2018), computer program, available at: http://www.graphviz.org/ (22 March 2018).
9. Kozlíková, B., Krone, M., Falk, M., Lindow, N., Baaden, M., Baum, D., Viola, I., Parulek, J., Hege, H.-C. (2017), "Visualization of Biomolecular Structures: State of the Art Revisited" Computer Graphics Forum, Vol. 36, No. 8, pp. 178-204.
10. Jone, C., Kristofco, L. A., Steele, W. B., Yates, B. S., Breed, C. S., William,s S. E., Brooks, B. W., (2015), "Global Assessment of Bisphenol A in the Environment. Review and Analysis of Its Occurrence and Bioaccumulation", Dose-Response. Vol. 13, No. 3.
11. NASA (2019a), Interactive chart "Kepler-7b. A giant planet composed mainly of gas", available at: https://exoplanets.nasa.gov/alien-worlds/strange-new-worlds/ (25 February 2019).
12. NASA (2019b), "Out of the Dust, A Planet is Born", available at: https://exoplanets.nasa.gov/resources/20/out-of-the-dust-a-planet-is-born/ (25 February 2019).
13. Opiła, J. (2005), "Analiza ewolucji nastrojów konsumenckich z wykorzystaniem metody powierzchni charakterystycznej" (An analysis of the evolution of consumer sentiment using the characteristic surface method), in Duda, J. T. (Ed.), Systemy informatyczne i metody obliczeniowe w zarządzaniu, AGH Uczelniane Wydawnictwa Naukowo-Dydaktyczne, Kraków, pp. 141-148.
14. Opiła, J., Opiła, C., Cichowska, J. (2008), "Prognozowanie ostrzegawcze w mikroprzedsiębiorczości z zastosowaniem rozszerzonej metody powierzchni charakterystycznej na przykładzie gospodarstwa agroturystycznego" (Emergency forecasting in microenterprise with the use of the extended surface method on the example of an agritourism farm) in „Zarządzanie przedsiębiorstwem – teoria i praktyka", XI międzynarodowa konferencja naukowa, Kraków, WZ AGH, pp. 1-10.
15. Opila, J. (2016), "Prototyping of visualization designs of 3D vector fields using POVRay rendering engine", in Proceedings of 39th International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO), Opatija, Croatia, pp. 343-348.
16. Opiła, J. (2017a), "Wizualna analiza struktury organizacyjnej z wykorzystaniem narzędzi Open Source" (Visual analysis of the organizational structure with the use of Open Source tools), in Kiełtyka, L., Sokołowski, A. (Eds.), Techniki i technologie wspomagające funkcjonowanie przedsiębiorstw, Wydawnictwo P.Cz., Częstochowa, pp. 191-203.
17. Opiła, J. (2017b), "Wizualizacja jako narzędzie transferu wiedzy" (Visualization as a Knowledge Transfer Tool), in Garbacz, J. (Ed.), Diagnozowanie stanu środowiska: metody badawcze prognozy: kompleksowe badania i ochrona środowiska naturalnego: zbiór rozpraw, BTN, Bydgoszcz 2017, pp. 169-182.
18. Opiła, J., Opiła, G. (2018a), "Visualization of computable scalar 3D field using cubic interpolation or kernel density estimation function", in Proceedings of 41st International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO), Opatija, Croatia, pp. 189-194.
19. Opiła, J. (2018b), "Visualization in a Knowledge Transfer Process", in Proceedings of the ENTRENOVA-ENTerprise REsearch InNOVAtion Conference, Split, Croatia, pp. 485-493.
20. PAJEK (2018), computer program, available at: http://mrvar.fdv.uni-lj.si/pajek/ (22 March 2018).
21. Pirali, O., Goubet, M., Huet, T. R., Georges, R., Soulard, P., Asselin, P., Courbe, J., Roy, P., Vervloet, M. (2013) "The far infrared spectrum of naphthalene characterized by high resolution synchrotron FTIR spectroscopy and anharmonic DFT calculations", Physical Chemistry Chemical Physics, Vol. 15, No. 25, pp. 10141-10150, available at: http://www.rsc.org/suppdata/cp/c3/c3cp44305a/c3cp44305a_2.pdf (22 February 2019).

22. Robertson, J. M. (1933), "The crystalline structure of naphthalene. A quantitative X-ray investigation", in Proceedings of the Royal Society of London, Series A, Containing Papers of Mathematical and Physical Character, Vol. 142, No. 847, pp. 674-688.

23. ScPovPlot3D (2019), "scPovPlot3D POVRay templates, version 4", computer program, https://github.com/JustJanush/Plot3Dv4 (25 February 2019).
24. Stanovčić, T., Peković, S., Vukčević, J., Perović, D. (2018), "Going Entrepreneurial: Agro-tourism and Rural Development in Northern Montenegro", Business Systems Research Journal, Vol. 9, No. 1, pp. 107-117.
25. Tamassia, R. (2014), Handbook of Graph Drawing and Visualization, Boca Raton FL, CRC Press.
26. The Redbooth Team (2018) "Everybody's Working for the Weekend, But When Do You Actually Get Work Done?", available at: https://redbooth.com/blog/your-most-productive-time (21 February 2019).
27. Tufte, E. (2001), The Visual Display of Quantitative Information, Graphics Press, 2nd edition.
28. Weissgerber, T. L., Milic, N. M., Winham, S. J., Garovic, V. D. (2015), "Beyond Bar and Line Graphs: Time for a New Data Presentation Paradigm", PLOS Biology, Vol. 13, No. 4.
29. Wong, K. (2018), "Ancient Cave Paintings Clinch the Case for Neandertal Symbolism", Scientific American, available at: https://www.scientificamerican.com/article/ancient-cave-paintings-clinch-the-case-for-neandertal-symbolism1/ (18 March 2019).
30. Zekić-Sušac, M., Has, A. (2015), "Data Mining as Support to Knowledge Management in Marketing", Business Systems Research Journal, Vol. 6, No. 2, pp. 18-30.

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