Towards Characterizing Visualizations

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Abstract. The ability to characterize visualizations would bring several benefits to the design process. It would help designers to assess their designs, reuse existing designs in new contexts, communicate with other designers and write compact and unambiguous specifications. The research described in this paper is an initial effort to develop a theory-driven approach to the characterization of visualizations. We examine the Card and Mackinlay characterization tool and we show its limitations when it comes to performing a complete characterization.

Keywords: Information Visualization, Evaluation Tools, Design, Graphical Coding.

Topics: Development Processes, Verification and Validation, Specification of Interactive Systems.

1 Introduction

Research in HCI has led to the design of methods and tools to evaluate the effectiveness of interfaces. *A posteriori* methods rely on user tests to check if an interface is usable. They involve developing parts of the interfaces, which are costly. *A priori* (or *heuristic*) methods use models of the system and the user to predict effectiveness before the development of the interface. *A priori* methods are less expensive, and they enable designers to design and compare a large set of solutions and help them produce better interfaces. *A priori* methods include the keystroke-level model, to help compute the time needed to perform an interaction [5], or the CIS [1] model, which extends keystroke by taking into account the context in which the interaction takes place. Both keystroke and CIS are *predictive* models, i.e. they can help compute a measurement of expected effectiveness, and enable quantitative comparison between interaction techniques. These tools have proved to be accurate and efficient when designing new interfaces. *Descriptive* models only help describe phenomena. They are less powerful than predictive models, but are nonetheless very valuable, since they help designers organize their thinking along relevant dimensions. Even if not supported with quantitative data, designers are able to make better design decisions since they use relevant dimensions of analysis. For example, the cognitive dimension framework [6] is an analysis tool that helps designers to recognize patterns of important interaction dimensions, discuss them with other designers using the same vocabulary, and help them find the right solutions during the design process.

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Although methods do exist for *a priori* evaluation of interaction effectiveness, very few exist for *a priori* evaluation of visualizations. The lack of efficient models to describe visualization hinders the design process. For example, designers sometimes inappropriately transpose the existing features of a particular visualization to another one, because they have no means of analyzing visualizations in detail, so as to really understand them, and they have no way of comparing visualizations. In addition, the lack of description tools makes specification writing tasks very difficult. Many specifications use prose to describe a visualization, which is cumbersome to read, subjective and error-prone: we observed during our engineering projects that there were a lot of differences between an expected system that we designed and a delivered system coded by a third party.

This paper describes the first steps towards building a method to describe visualization systematically. In particular, we try to characterize visualizations, i.e. to find a precise and compact description that unveils similarities and differences, and allows for comparison. We seek to answer the following questions: what information is displayed on the screen? How many information are displayed? How is information displayed? At first sight, it seems that the answer is trivial: the information on the screen is exactly what the designer wanted to put there when he designed the visualization. However, we will see that the answer is more complex, as it does not take into account information built up from our perception system. We want to insist on the fact that we do not try to assess the effectiveness of different representation. We only identify what is displayed and not how well a user perceives it.

To bridge the characterization gap, we use the Card and Mackinlay model from the Information Visualization field (InfoVis). We apply this tool to particular visualization, and show the usefulness of the result. Finally, we show why this tool is not satisfactory, especially when characterizing emerging information.

2 Characterization Model: Card and Mackinlay

Card and Mackinlay [4] (C&M) attempted to establish comparison criteria of visualizations. They proposed a table for each transformation function (Table 1). The C&M table is completed with the notations in Table 2.

Table 1. C&M representation model

				automatic perception						Controled perception	
Name	D	F	D'	X	Y	Z	T	R	-	[]	CP

Table 2. C&M Model notations

S	Size	Lon, Lat	Longitude, Latitude
Sh	Shape	P	Point
f	Function	O	Orientation
N, O, Q	Nominal , Ordered, Quantitative		

The horizontal rows correspond to the input data. The column D and D' indicate the type of data (Nominal, Ordered or Quantitative). F is a function or a filter which transforms or creates a subset of D. Columns X, Y, Z, T, R, -, [] are derived from the visual variables of Bertin [3]. The image has four dimensions: X, Y, Z and time, T. R corresponds to the retinal perception which describes the method employed to represent information visually (color, form, size,etc.). The bonds between the graphic entities are noted with '-', and the concept of encapsulation is symbolized by '[]'. Finally, a distinction is made if the representation of the data is treated by our perceptive system in an automatic or controlled way. Card and Mackinlay depicted some well-known InfoVis visualizations. However, they did not explicitly demonstrate how to use their model, nor its usefulness. We applied this model to visualization from Air Traffic Control (ATC), which we describe in the next section.

3 Rich and Dynamic Visualizations from ATC

Air traffic controllers aim to maintain a safe distance between flights. In current ATC environments, air traffic controllers use several visualization systems: radar view, timelines, electronic strips, meteorological views, supervision, etc. Each visualization is rich and dynamic: it displays numerous visual entities that evolve over time. These visualizations are complex and each visual detail is important. The following section details the design of two Radar visualizations.

3.1 ODS: The French Radar Screen

ODS is the main French radar view for air traffic controllers. It is a top view of the current flying aircrafts. Its main goal is to display aircraft positions and to help controllers to space aircraft beyond the safety minima.

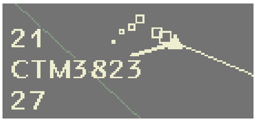


Fig. 1. The ODS comet of an evolving aircraft, the image exhibits direction and acceleration changes

The radar track presents aircraft positions, speed (speed vector), name, altitude and speed as text (Fig. 1). The design of the comet is built with squares, whose size varies with the recentness of the aircraft's position: the biggest square displays the last position of the aircraft, whereas the smallest square displays the least recent aircraft position. The Speed Vector (SV) is a line which starts from the current aircraft position and ends at its future position (3 minutes later). The X axis of the screen codes the latitude of each aircraft; the Y axis of the screen codes the longitude of each aircraft. We applied the C&M characterization of the comet in Table 4 and of the speed vector in Table 3.

3.2 ASTER: A Vertical Visualization

ASTER [2] is a vertical view of the current position of an aircraft. The X axis of the screen codes the current aircraft distance from a reference point (IAF) and the Y axis of the screen codes the Flight Level (FL or altitude) of each aircraft.

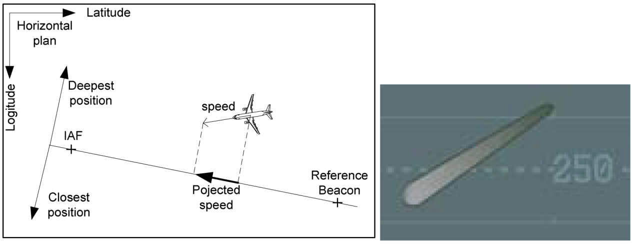


Fig. 2. Aster projection plan (left) and comet (right)

The head of the comet shows the position of the aircraft in the vertical view. Its orientation codes the aircraft vertical speed (or its incidence) and its length codes the projected aircraft speed (Fig. 2). We applied the C&M characterization of the ASTER comet in Table 4.

4 Applying C&M Model

This section deals with the use of the C&M model. First, we show how the C&M characterization enables to compare the ASTER comet and the Speed Vector. Second, we explain why this model is a partial characterization, especially because it lacks characterization of emerging data. Third, we define the notion of 'emerging data'. Finally, we explain why the transformation function alone is not sufficient to fully perform a characterization of static visualization.

4.1 Unveiling Similarities: Success

The characterization of the radar speed vector (Table 3.) shows that its size or length changes with the aircraft's speed.

As we can see by comparing Table 4 and Table 3. , the same information is coded by the length of the ASTER comet and by the speed vector of the radar's comet. The ASTER comet is thus equivalent to the radar's speed vector, modulo a translation.

Designers and users use the term comet to describe the aircraft position in ASTER visualization, but the ASTER comet has not the same semantic as the ODS comet.

Table 3. C&M Speed vector characterisation

Name	D	F	D'	X	Y	Z	T	R	-	[]	CP
speed	Q	f	Q					S			
direction	Q	f	Q					O			

Table 4. C&M ASTER Comet characterization

Name	D	F	D'	X	Y	Z	T	R	-	[]	CP
Plot	Lat Lon (QxQ)	f	Q	P				Shape			
Afl	Q	f	Q		P						
Vert. speed	Q	f	Q					O			
speed	Q	f	Q					S			

Table 5. C&M Radar Comet characterization

Name	D	F	D'	X	Y	Z	T	R	-	[]	CP
X	QLon	f	Q Lon	P				Emerging Shape			
Y	QLat	f	Q Lat		P						
T	Q	f(Tcur)	Q								

This mistake can lead to false information being perceived: for instance, the tail of the ASTER comet is not a previous aircraft position. As a first result, we show the usefulness of characterizing visualizations: it is the characterization and the comparison which allows us to link two visualizations, and thus to give elements of analysis to the designer. This result highlights the importance of carefully analyzing what is displayed in order to make perceivable the right information when building and justifying a design.

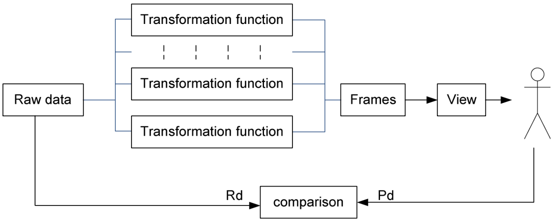
4.2 Unveiling Differences: Failure

In the ODS comet, the last positions of the aircraft merge by Gestalt continuity effect (alignment and progressive size increase of squares). A line does appear with its particular characteristics (curve, regularity of size increasing of the past positions, etc). In this case, it is not possible to characterize the radar comet as a single graphic entity using the C&M transformation model. But we can characterize the shapes that build the comet. With this intention, we introduce the concept of current time (Tcur: the time when the image is displayed). The size of the square is linearly proportional to current time with respect to its aging. The grey row and column are two additional items from the original C&M model (Table 5).

However, the characterization cannot take into account the controllers' analysis of the evolution of aircraft latest positions (speed, evolution of speed and direction). For instance, in Fig. 1, the shape of the comet indicates that the plane has turned 90° to the right and that it has accelerated (dots spacing variation). These data are important to the air traffic controller. The comet curvature and the aircraft acceleration can not be characterized with the C&M model because they constitute emerging information (there is no raw data called 'curvature' to design a curving comet). A precise definition of 'emerging' will be given in the next section.

4.3 Emerging Data

In Fig. 3, raw data are transformed with many Transformation Functions to the view. They are displayed and then perceived by the user as visual entities. In an efficient design, the perceived data and the raw data are the same. If there are more Raw Data (RD) than Perceivable Data (PD), the non-perceived data are useless. As we said earlier, the emerging data are perceived data which are not transformed from raw data, which means that there are more perceived data than raw data. The ODS comet curvature is an example of emerging data; there is no item of raw data named 'curvature' that needs to be transformed to the view, even if we can perceive the aircraft rotation tendency. Pd-Rd is a characterizing dimension (we call it the level of integration) which helps us to characterize a design (Fig. 3).



If PD – RD < 0 => reduce RD
If PD – RD = 0 => balanced design
If PD – RD > 0 => emerging data

Fig. 3. Emerging Data

4.4 Characterizing with Emerging Data

If we consider the amount of coded information as a design efficiency dimension, the C&M model rates the ASTER comet higher than the ODS comet (Table 6). Therefore, we may think that the ASTER comet codes more information than the ODS comet. However, we have already explained that emerging data are not listed with the C&M model. Even with emerging data, this characterization is still incomplete, as the dynamic of the image codes additional information. When the visualization is updated, the ASTER comet evolves. The information about change is visually coded; the user can perceive the movement and thus perceive the aircraft's tendency. Hence, ODS and ASTER comet code the same amount of information (Table 7).

Table 6. ASTER and ODS coded information with C&M model

ASTER coded information	ODS coded information
Aircraft position	Aircraft position
Flight Level	Time of each position
Vertical speed	
Horizontal speed	

Table 7. ASTER and ODS information with C&M model and emerging data

ASTER coded information	ODS coded information
Aircraft position	Aircraft position
Flight Level	Time of each position
Vertical speed	*Aircraft speed*
Horizontal speed	*Aircraft tendency (left, right)*
Tendency (animation)	*Aircraft acceleration*

5 Conclusion

Whereas Card and Mackinley depicted some InfoVis visualizations without explicitly demonstrating how to use their model, we have shown the practical effectiveness of the C&M model when performing the ASTER comet and the ODS speed vector comparison. Although the C&M tables make visualizations amenable to analysis as well as to comparison, this model does not allow essential information to be highlighted for designers, and does not allow any exhaustive comparison of different designs. In this article, we managed to apply the C&M model. We extended this model with the characterization of emerging data. The ODS comet is richer than the Aster comet (when comparing the amount of coded information), although the characterization of C&M seems to indicate the opposite. The wealth of information transmitted by each representation is thus not directly interpretable in the characterizations.

Designers need to be able to evaluate and reuse their work, as well as to communicate effectively. This work is an initial attempt to meet these needs by giving them the supporting tools to measure their design. A tool that is descriptive, predictive and prescriptive would be a valuable aid to designers. As a descriptive tool, visualization characterization and issues related to it form the core of the present paper. Predictive tools may forecast the visual coded information with a given visualization, while prescriptive tools have the ability to find a solution to a specific problem. There are currently no such tools in existence, and our goal is to converge on such a solution.

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