An Infovis approach to compare ATC comets

A theoretical basis for comparing visual entities

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***Abstract*—Air Traffic Control systems display information with multiple visual entities. The research described in this paper is an initial effort to develop a theory-driven approach to the characterization of visual entities. We enhance the state of the art in data visualization to characterize four "comet" designs. This work helps to understand visualization more precisely and provides a basis to help the designer to formally assess the effectiveness of their work.**

Information Visualization, design, taxonomy, graphical coding.

I. Introduction

In current Air Traffic Control (ATC) environments, air traffic controllers use several visualization systems: radar view, timelines, electronic strips, meteorological views, supervision etc… Each of these visualizations is rich and dynamic: it displays numerous visual entities that move and evolve over time.

The objective of our work is to develop a suitable set of tools based on established theoretical methods, in order to evaluate the effectiveness of visual entities before testing them with users. We will answer the simple question: "what is the displayed information, how is it displayed and how can we compare them?"

Our goal is not to answer the question: "what makes one type of visualization better than another?" This answer is linked to controller activity. First, the user is always able to perceive information that is visually coded, but the cognitive resource varies depending on the nature of this visual information, e.g. the difference of perception between text and color. Second, users' perceptual skills are linked to their activity (tower controllers or en-route controllers do not need the same information although they might be able to work with the same HCIs). We are not trying to answer the following question either: "how can we help designers improve perception?"

Users' perception is nevertheless very important. These kind of issues have already been addressed in the Information Visualization field (IV). These tools will help us to give an accurate description of visual entities.

Because the characterization of a full image may be tedious, the paper focuses on one visual entity through four designs: the radar comet. In the ATC field, a comet represents aircraft position. In order to understand each comet design, we will have a look at each software feature that uses this design. Then, we will detail the design of each comet, find out their design properties and their associated semantic.

A. The design issues

The design process is very tricky. It takes time and intuition. Joahnnes Itten [12] p7, a design teacher and an artist, claims that if you don't know how to create a satisfying painting it means that you are not (yet) an artist. But you can still draw nice paintings with a theoretical approach. You can learn rules and apply them. Most artists know these rules but did not learn them; they just rely on their genius.

It is very difficult to create a new design based on nothing. We identify four different approaches when building a visual entity:

- Empirical approach : design based on trial and error methodology,
- Historical approach: design based on the continuity of previous work with a concern for adaptation to the given context,
- Ecological approach: design based on the respect of both human physical and perceptual characteristics,
- Technological approach: design based on technological opportunities.

Those four approaches shall not be considered as separate spaces; each design process mixes a bit of the other. Of course, there is no clearly defined boundary between the sources of design, and there is a lot of overlap.

The four sources of design inspiration help to understand and justify design choices. By extension, they will give clues on how to perform an exhaustive characterization.

B. The characterisation issues

Characterization is a precise and minimal description that unveils differences and allows comparison. Characterization is a very helpful tool for designers along the design process. To perform this characterization we need tools, and the only one available is the human perception through its eyes and brain. This can't be satisfactory because we can't be certain to perform an exhaustive description of the displayed information. This is the reason why characterization is awkward, and this paper is an initial effort to fill this gap.

II. The Infovis Field

As said in the previous section, human perception is involved in the transmission of information. The design and study of human perception of representations is a subfield of the Human Computer Interaction (HCI) field, called Information Visualization, or Infovis (IV). Information visualization is the visual presentation of abstract information spaces and structures to facilitate their rapid assimilation and understanding.

Text-based interfaces require cognitive effort to understand their information content. Humans have remarkable perceptual abilities of graphical entities; they can rapidly and automatically detect patterns and changes in size, color, shape, movement, or texture. Information visualization seeks to present information visually, to offload cognitive work to the human visual perception system.

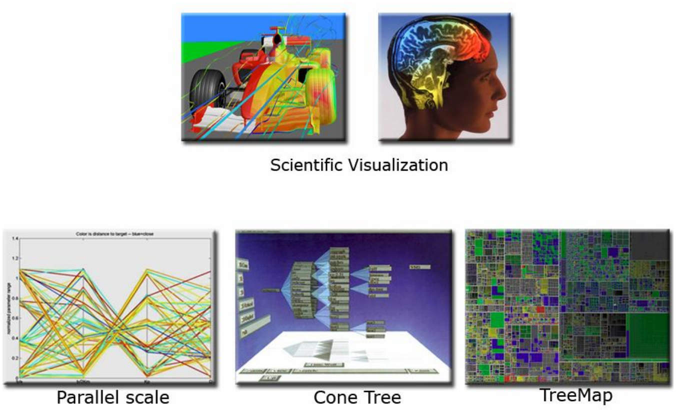


Figure 1 : Scientific and InfoVis

Figure 1, displays the difference between visualizations. Scientific visualization displays canonical representation of real objects and phenomena. InfoVis displays data in an abstract way [11][17][18]. Its goal is to optimize the bandwidth between the displayed data and the perceived data.

The correct perception of visualization has nothing to do with artistic design. There are tools for the IV that can help us to answer the following questions:

- What kind of data is being displayed?
- How is the data processed or updated?
- How can we characterize the suggested visualization?

In the next chapter, we present some of the Infovis Tools which are suitable for the analysis of ATC images.

A. Data type

The major distinction we can make for data type is whether their values are:

- Nominal: are only equal or different to other values (e.g. aircraft call sign),
- Ordered: obey a < rule (e.g. an aircraft's number in the landing sequence),
- Quantitative: can be manipulated by arithmetic (e.g. the aircraft speed).

The quantitative type can be split into two parts: Interval and Ratio. Interval can be the gap between values but cannot be null, e.g. the time lapse between 7.00am and 8.00am is the same as 14.00am to 15.00am but we cannot say that 15.00am is twice 7.00am.

The ratio type is the full expressive power of real numbers. The Table 1 summarizes the different terms used in the literature.

Bertin [4]	Stevens [19]	Ware [21]
Nominal	Nominal	Category
Ordinal	Ordinal	Integer
Quantitative	Interval	Real number
	Ratio	

Table 1 *:* data types

1) Design and Data type

Bertin[4] was the first one to study representation rules. He identified three distinct levels for a visualization analysis: elementary (for a single item), intermediate (for a group of items), and overall (for all the items). He finds out rules to code information in a monosemic way: there can't be any ambiguity in the perception of displayed information.

Afterward, Cleveland[8], McGill[9] and then Mackinlay[15] built scales of expressivity and effectiveness (dependant on the human perceptual capabilities) to assess alternative designs (Figure 2). This scale depends on the data type. The visual property ranked higher in the chart is perceived more accurately than those that are ranked lower in the chart. In the Figure 2 Gray items are not relevant to the concerned type of data.

The quantitative data type ranking has been experimentally verified by Cleveland [9]. Independently of the data type, the best way to represent the data is to code it with a position on a scale. To represent the speed of an aircraft (quantitative data), we can use the length of a line (speed vector). The aircraft position number in the landing sequence (Ordinal) is better coded using the color saturation than length.

Despite the fact that the text involves perceptual and cognitive processing that helps one to decode a graphic in the same way that perceiving color or pattern does, the text entity isn't listed in Mackinlay's perception ranking. "Images are better for spatial structures, location, and detail, whereas words are better for representing procedural information, logical conditions, and abstract verbal concepts." Ware [21]p301-307. Graphical perception is highly parallel which works on visual properties such as position and color, but has limited accuracy.

Text representation is accurate but is limited in capacity. The cognitive workload is very high when we are reading a text. This is the reasons why text is not integrated in Mackinlay's perception ranking.

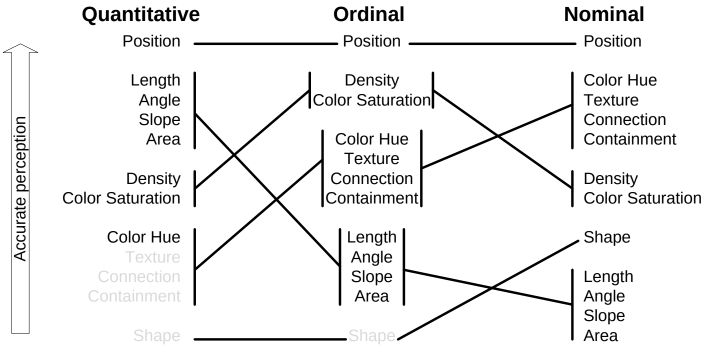


Figure 2 : Mackinlay ranking of perceptual task [15]

This ranking was built for statistical graphs. Air traffic control displays, and other iconic representations of data addressed quite different tasks. Still this approach remains a promising starting point of research to answer the question: "What is the most suitable visual property I can use?"

B. The data flow model

Card, Mackinlay and Shneiderman[6] created a model (Figure 3) which describes visualizations as a data processing sequence from the raw data to the views. The processing is based on structures of intermediate data which is easy to handle by the user. Chi [7] detailed the various stages of this model. This data flow model is still widely used.

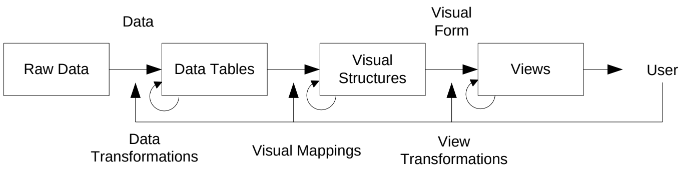


Figure 3: Schematic Dataflow of Information Visualization [6]

This model is based on the management of a data flow. It is used in many toolkits (InfoViz[10], prefuse, VTK, Tulip, Pajek…) and visualization software (SpotFire[1] , ILOG Discovery[2] , nVizN[22]…).
This model formalizes the transformation process from raw data to a screen and is the foundation of a compact and precise characterization.

C. Characterization model

Card and Mackinlay[5] attempted to establish comparison criteria of the images with their work. They propose a table for each function of transformation (Table 2).

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

Table 2: C&M representation model

The lines correspond to the input data. The column D and D' indicate the type of data (Nominal, Ordered, and 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[4].
The image has four dimensions: X, Y, Z plus time T. R corresponds to the retinal perception which describes the method employed to represent information visually (color, form, size…). 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. The C&M table is filled with the notations in the Table 3.

L	Line
S	Size
Sh	Shape
f	Function
N, O, Q	Nominal , Ordered, Quantitative
Lon, Lat	Longitude, Latitude
Pt	Point
Orien	Orientation
T	Text

Table 3: C&M Model notations

The previous chapter described the state of the art of the InfoVis tools. The next chapter deals with the historical design of the comet and its initial use in a non ATC environment.

III. COMETS

The comet visual properties have been used for the first time in the early seventh century by Edmond Halley[16] who coded the trade wind direction on a map [20] p23[21] p 203 . He coded the flow with a stroke.
The comet has accurate design properties; it displays the direction of the shape and its tendency. The comet is composed of a bigger part, its head, and a smaller, its tail. Its head indicates the comet heading. The tendency indicates the future position of the aircraft. The curvature of this shape indicates if it is turning right or left and the amount of steering.

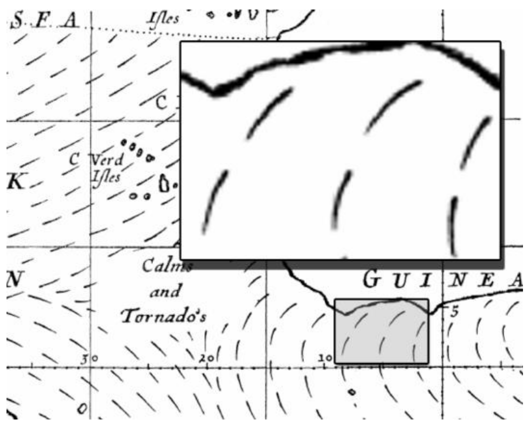


Figure 4 : Detail of Halley's chart of the Trade Winds 1686.

ATC visualization derives some benefit of this comet. To do so, designers use different design options to display the aircraft position with a comet. In the next chapter, we will detail different ATC systems which use the comet.

A. The ODS comet

ODS is the main French radar view for the air traffic controllers. Its main goal is to display aircraft positions and to help controllers space aircrafts beyond the security minima.

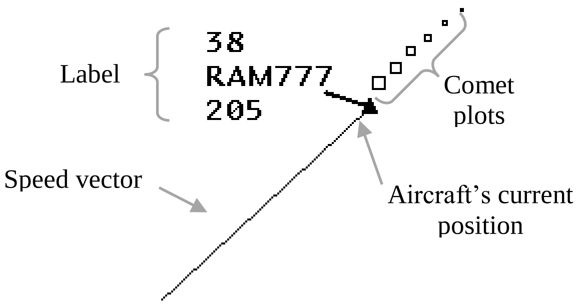


Figure 5 : radar track

Figure 5 displays the terms used to depict a radar track. The radar track presents the aircraft position, its speed, its name, altitude and speed as text. The design of the comet is built with squares, whose size varies with the recentness of the aircraft position: the biggest square displays the last position of the aircraft, whereas the smallest square displays the oldest aircraft position.

The design of this comet is historical. It is not based on the Halley design but on early radar equipment which relied on scope persistency (**Figure 6**). Old radar scopes retained the previous plot position with the fading of the screen phosphor. This kind of design has the same remarkable properties as the Halley comet: it displays the aircraft trajectory's curvature tendencies and shows if an aircraft is turning and the amount of steering.

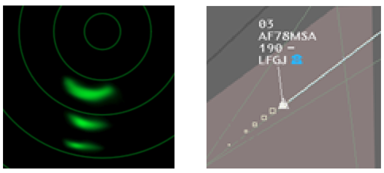


Figure 6 : Spot decreases in intensity over time on a scope (left picture). ODS comet metaphor (right picture).

B. RadarGL

The goal of the RadarGL project is to develop a prospective visualization of the aircraft's position using the latest technologies. This project uses the latest rendering techniques (animation, alpha blending…) and some of the HCI (Human Computer Interaction) techniques for the interaction and the control of the image. RadarGL displays a top view of the aircraft position. The Xscreen is the latitude and the Yscreen the longitude of each aircraft.

C. ASTER

The ASTER [3] tool was initially designed to assist Air Traffic Controllers in their task on terminal sectors, notably by providing controllers with an efficient way to feed the system with clearance data. In a few words, controllers' activity in this context is characterized by the construction of a proper sequencing of arrival flights towards a geographical point called the Initial Approach Fix (IAF, sector exit point) respecting airport capabilities.

The vertical view constitutes one of its specific tools. It allows a better monitoring of the vertical profile. Former studies have proved that controllers tend even to be blind in the vertical profile in the current environment.

Figure 7 : ASTER comet 1 (left), ASTER comet 2 (right)

In the Figure 7, the aircraft comets show the position of the aircraft in the vertical view, among a lot of other information.

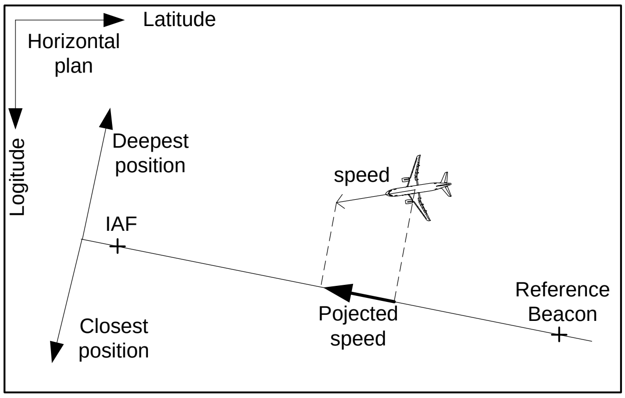


Figure 8 : Aster projection plan

The displayed information in the ASTER project is based on a projection along an axis. The IAF is the first point of this axis and a reference beacon is the second. This axis splits the sector into two parts. The aircraft behind this axis are deeper than the aircraft in front. Actually, the aircraft speed representation is the result of the projection of the current speed on this axis, whereas the aircraft position is the distance between the aircraft projected position and the IAF. All the information is summarised in Figure 8 and in the C&M characterisation (Table 5).

IV. Comet Characterisation

This section deals with the comet characterisation. Firstly, we will apply the C&M model; secondly we will discover that this model is a partial characterisation. Finally we will characterise comets with a table inspired from the IV tools.

A. Applying C&M characterization

Figure 9 : the comet of an evolving aircraft, the image exhibits direction and acceleration changes

The last positions of the aircraft merge by effect of Gestalt continuity [14], from which a line does emerge with its particular characteristics (curve, regularity of the texture formed by the points, etc). In this case, it is not possible to characterize the radar comet directly using the C&M transformation model. But we can characterize individually the shapes that build the comet (Table 4). 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 its age.

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

Table 4 : C&M Radar Comet

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 : ASTER Comet characterization

The characterization cannot integrate controllers' analysis of the evolution of aircraft latest positions (speed, evolution of speed and direction). Thus, in **Figure 9**, the shape of the comet indicates that the plane has turned 90° to the right and that it has accelerated. These data are emergent from the comet design. In other words, they were not directly used to generate the image.

1) ASTER and the Speed Vector

The characterization of the radar speed vector (Table 6) shows that its size (in Bertin's notation, but as it is a line, we can also use the term length), changes with the aircraft's speed.

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

Table 6 : C&M Speed vector characterisation

In addition, the same information is coded by the length of ASTER comet and by the speed vector of the radar's comet. The ASTER comet is thus equivalent to the modulus translation of the radar's speed vector. It is the characterization and its comparison which allows us to link two visualizations, and thus to give to the designer elements of analysis. This result shows the importance of the work carried out.

2) C&M characterisation conclusion

The characterization of C&M does not allow to highlight essential information for end users, and does not allow any exhaustive comparison of different designs. The ODS comet is richer than the Aster comet; 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: the model of C&M is therefore not fully adapted.

The next part of this paper will take into account the knowledge of the InfoVis field and apply it to characterize four design of the comet.

B. Alternative characterization

In this part, we present all the available information on each comet. This information is classified into three categories:

- The design process: how to draw the comet?
- The design properties: what are the design characteristics?
- The semantic: what is the displayed information?

Tableau 8 lists all the terms used to characterize the comet design (Tableau 7).

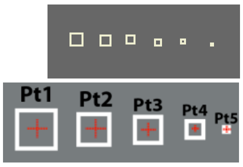
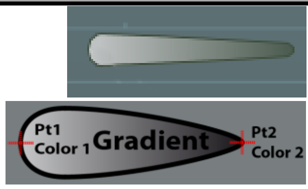
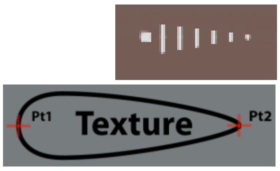
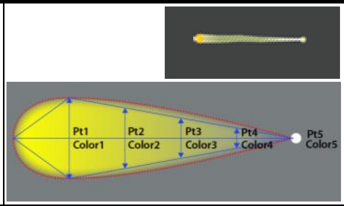
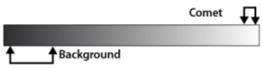
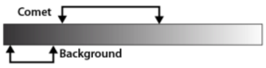
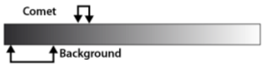
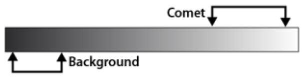
Comet	ODS	ASTER Design 1	ASTER Design 2	RadarGL
				
Design				
Refresh rate	steps	steps	steps	continuous
Enclosure	Same shape and progressive change in the squares size	shape	texture	shape
Design properties				
Zoom invariants	squares size	gradient	texture, color, thickness	gradient, thickness
Background occlusion	partial: holes in the "texture"	full opacity	partial : holes in the texture	partial : (transparency)
Screen depth	yes : priority comet	fake (automatic toolkit Z sorting)	no : texture blending	no : alpha blending
Overlapping resistant	Yes +	Yes ++	Yes +	Yes ++
Background and comet contrast				
Fixed shape	no	yes	yes	no
Semantic				
Acceleration	reflected in the varying distance between the squares	no	no	gradient and dynamic stretching
Depth	not implemented	thickness	no	not implemented
Radar track death	progressive dot fading	fade	fade	lock up and fade
Direction	horizontal plan : the direction given by the tangent at the first point	in the vertical plan : orientation	in the vertical plan : orientation	horizontal plan : orientation curvature
Tendency	curvature	No : unless you perceive the screen refresh	no: unless you perceive the screen refresh	curvature tendency
Speed	horizontal speed : length of the comet	horizontal projected speed : length	horizontal projected speed : length	horizontal speed : length of the comet
Highlight comet head	yes	no	yes	yes
Highlight comet tail	no	no	no	yes
display old positions	yes	no	no	yes

Tableau 7 : description of four comet designs

Refresh rate	Continuous: The aircraft positions are interpolated between two data updates (or frames). Steps: no interpolation, no transition between two frames.
Enclosure	Explains how the comet is perceived as a whole.
Zoom invariants	The visual properties not affected by the zoom variation.
Background occlusion	Is the background still visible through the comet design?
Screen depth	In case of comet overlapping, can we perceive an ordering along the Z axis (screen depth) and how? (Painter Algorithm)
Overlapping resistant	When comets overlap, can we distinguish between comets?
Background and comet contrast	Display the range of luminosity of the background and the comet. Displays if there is a risk of confusion between the background and the comet.
Fixed shape	Does the design always display the same shape?
Acceleration	The aircraft acceleration.
Depth	The depth in altitude (RadarGL and ODS). The depth (ASTRER) with respect to the projection axis (Figure 8).
Radar track death	How does the comet show the loss of data?
Direction	The aircraft direction.
Tendency	The evolution of the aircraft direction.
Speed	The aircraft speed.
Highlight comet head	Does the design highlight the current aircraft position?
Highlight comet tail	Does the design highlight the oldest aircraft position?
Display old positions	Does the design display more than the current aircraft position?

Tableau 8 : Comet characterization legend

1) *ODS : historical design*

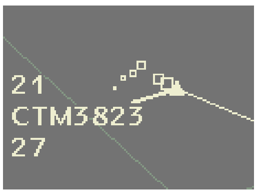


Figure 10 : ODS comet

The design of this comet has already been depicted. The unity of the resulting shape comes from the Gestalt[14] properties. The progressive change in the square size and the squares spacing glue together the squares. This is helpful when comets overlap: although plots may interfere, we are still able to distinguish between two comets.

2) *ASTER design 1 : ecological design*

ASTER comet thickness codes the position (or depth) of the aircraft compared to the IAF-reference axis (Figure 8). If the aircraft is deeper than this axis, the comet is darker and thicker. This is an ecological design because far objects are small and dark. But this design can lead to perception issues with the background.

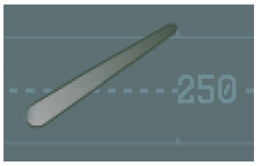


Figure 11 : Aster design 1 comet

The size of the comet is a function of the ground speed. The vertical speed is coded by the orientation of the comet.
The comet length corresponds to one minute flight. The background has an altitude scale. Thus, if we compare the altitude of the comet's end with the altitude of the beginning of the comet we read the vertical speed in Fts/Min (Figure 11).

3) *ASTER design 2 : technical design*

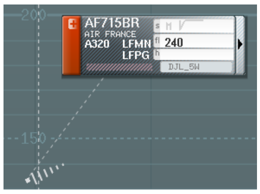


Figure 12 : ASTER comet

The designer wanted a slightly different comet, because ASTER will be used with an ODS screen, and the controller must not confuse the two screens (one code a vertical view, the other a top view).
Due to technological constraints, the first version of ASTER could not code old aircraft positions. Thus the designer used a texture to display the current aircraft position, the length to code the speed and the orientation to code the vertical direction.

4) *GLANCE: empirical, prospective design*

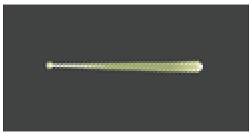


Figure 13 : RadarGL comet

This comet is a shape created with the previous aircraft positions. To draw this comet, five points are needed. Each point has the same color but not the same transparency (alpha). A two pixel width border is added around the shape to smooth the edges. The color choices are empirical, and because the end of the comet blends with the background, the last point of the comet is highlighted with a white dot.
The refresh rate is continuous, the animation is smooth. The acceleration is code with the stretching speed of the comet.

5) *Comet Comparison*

RadarGl and ASTER first design (ASTER design 1 in the table) have a better occlusion resistance. It means that if they are many overlapping comets you can still figure out each comet. With the ODS and the ASTER second design, the comet is created with several entities (texture with holes and squares). The texture of the Aster first design is misleading; by analogy with the ODS design, we may think that each line is an old aircraft position.

The comet tendency (direction evolution) in the ASTER design can be seen only if we see the transition between two comets states, which is unlikely. With the ODS design, the old positions are always visible and then the tendency.

The ASTER depth of an aircraft (to the projection line) is Quantitative information, but it is coded with the Ordinal luminosity which means you may lose some efficiency.

The comet thickness is not invariant with the zoom, and the thickness code the aircraft deep. This is a software mistake which doesn't interfere with the Air traffic controller activity. In a nominal use of ASTER, the zoom ratio remains the same.

V. CONCLUSION

In this article, we have explored the characterization tools available in the InfoVis field, and applied them to rich and dynamic visualizations. Whereas Card and Makinley depicted some InfoVis visualizations without explicitly demonstrating how to use their model, we have shown the practical effectiveness of the C&M model in our comparison of the ASTER comet and the ODS speed vector. Although existing characterization tools are evidently valuable, they are not sufficient to characterize emerging data and image dynamics.

In addition, we have built an exhaustive description of four comet designs with the exception of user activity and perception. With this strong constraint, we can still make comparisons, find design justifications and even detect design errors.

This paper describes the first steps toward building a method to describe visual entities systematically. In particular, we try to characterize them, i.e. to find a precise and compact description that unveils differences and allows comparison. We seek to answer the following questions: what information is displayed on the screen? How much information is displayed? How is it 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 saw that the answer is more complex, as it does not take into account information built up from our perception system, or from the dynamic aspect of the image. 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. 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.

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