Depth Cues For Information Design

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Abstract

The desire to create a compelling sense of 3-D space in two-dimensional media such as print and screen has always been a goal of many information designers. But while we have an awareness of how to create 3-D through depth, it has been difficult to judge when it is appropriate and how to do it successfully. The best efforts undertaken towards understanding depth have been by cognitive scientists who have sought to answer the questions: How do we see and interpret depth from our environment and what triggers this reaction? Their collective search has resulted in a depth cue theory that suggests our visual sense of depth originates from at least 19 identifiable cues in our environment. This paper studies depth cue theory in the context of information design, considering how we may link the mechanisms of how we see depth to the effect they have in visual communication. The paper focuses on three groups of depth cues in particular (Perspective, Occlusion-based, and Focus-related cues) that aid in shaping form, organization, and attention. It looks at how each group functions collectively and considers ways that designers may apply them to create richer, more effective communication.

1. Introduction

Our ability to see depth is an amazing feature of our vision. Somehow we automatically translate the images we get from the two-dimensional surface of our eyes into rich 3-dimensional pictures of our environment. The example above of a Japanese railroad map from Edward Tufte's Envisioning Information demonstrates how much richer information can be with depth than without it. As the train's route passes outside the 3-dimensional picture on the right side, the amount of information shrinks to a fractional of what it had been; the relationships between each route is simplified into flat abstraction. Our ability to see depth is functional too. We use it to navigate our world. When we look around us, we know a visual hierarchy of our surrounding space exists. We see that a chair is in front of a table, one page of a book is behind another page, our hand is closer to our eye than our knee, and so on. All these relationships we instantly combine into information we use to find our way. The odd thing is that even though depth perception is an unavoidable, critical part of the natural process of everyday vision, we give it no thought while doing it and have little understanding of how it works. The best efforts undertaken towards understanding depth have been by cognitive scientists who have sought to answer the questions: *How* do we see and interpret depth from our environment and *what* triggers this reaction? Their collective search has resulted in a depth cue theory that suggests our visual sense of depth originates from at least 19 identifiable cues in our environment. This rich body of knowledge concerning how we construct meaning out of what we see has been relatively untapped by designers. Only a few have considered depth, mostly approaching it from the end-effect side, asking this question: *Why* does the effect of 3-D depth appear to be important to communication and how can we use it in design? Tufte, for example, is one information designer who has struggled to reason this through.

> Even though we navigate daily through a perceptual world of three spatial dimensions and reason occasionally about higher dimensional arenas with mathematical ease, the world portrayed on our information displays is caught up in the two-dimensionality of the endless flatlands of paper and video screen…. *Escaping this flatland is the essential task of envisioning information –for all the interesting worlds (physical,*

> *biological, imaginary, human) that we seek to understand are inevitably and happily multivariate in nature. Not flatlands.*[1]

Tufte argues that escapes from flatland through depth are important in bringing communicated information up to the level of other multivariate worlds. To put it in simpler words, he argues that depth is important in making displayed information more "interesting." But is this true? Is depth important to design and if so, how? The problem standing in the way of our ability to answer this question is a fundamental gap between the scientists who study the visual perception mechanisms that create a sense of depth, and the designers who study depth's effect. *No definitive work exists that comprehensively links the mechanisms of how we see depth with the effect they have in the context of communication*. Such work is badly needed, especially now as the use of 3D in communication design expands. The psychologist/artist Colin Ware explains:

> It is inevitable that there is now much ill conceived 3D design, just as the advent of desktop publishing brought much poor use of typography and the advent of cheap color brought much ineffective use of color. Through an understanding of space perception, [we can] reduce the amount of poor 3D design and clarify those instances in which 3D design is really useful.[2]

Work in the communicative function of depth cues would be immeasurably valuable for its practical information regarding how we can specifically apply depth to enhance communication design. As designers, we already have an awareness of how to create 3D through depth, but it at best a partial knowledge of a few visual tricks. As Ware points out, we designers are faced with the proliferation of 3D design tools but not enough information to leverage them effectively. The process of communicating successful 3D is frustrating at best. Testimony to this fact lies in the vast number of badly designed compositions we encounter daily that use 3-dimensional effects poorly or unsuccessfully. There is a clear need for a better, unified understanding that ties the mechanisms and

[1] Edward, Tufte, Envisioning Information (1990; Cheshire: Graphics Press, 1999) 12.

[2] Colin Ware, Information Visualization (London: Academic Press, 2000) 274.

effect of depth together in the context of communication. With such understanding, we could then accurately qualify not only *how* we can design convincing depth but also *when* we should or should not use depth in our designed communications. A degree in depth psychology is not needed, just a broadened understanding of the basic principles behind depth's effect. Collecting scientific and design perspectives together to create a comprehensive understanding is an ongoing and as yet incomplete activity, with people such as Ware and Tufte making small first steps. It is in this way that this paper is also a modest contribution towards our understanding of how we construct depth and what impact it has for communication in design. Depth cues rarely exist alone, but operate interactively to provide depth information. Our sense of depth is strongest when derived from cues communicating in concert. This is why grouping cues is a useful approach when considering their effect in the context of communication. Cues usually appear together and reinforce each other. The paper focuses on three groups of depth cues that I believe to be the most important for communication design in aiding to shape form, organization, and attention. These groups are 1.) Perspective cues, 2.) Occlusion-based cues, and 3.) Focus-related cues. For most of the cues in each group their effect for design is somewhat known, but still needs investigation.

The criteria dividing the three groups relates to their function. Perspective cues create a sense of depth through their ability to communicate an overarching sense of structure and order. In an environment of information they function to build the base framework of relationships between both objects and object parts. Occlusion-based cues establish depth through direct overlap, communicating basic hierarchy and separation of objects. Finally, focus-related cues involve judging differences in the clarity of detail. They function to direct our attention, limiting, organizing, and separating according to significance. The boundaries between these groups' functions are not rigid however. Occlusion and Focus groups for example, have some relation to each other since both involve separation. Also, significance and hierarchy are related conceptually, both addressing differing levels of importance in structuring visual relationships. Since the functional boundaries of depth cues are not always clearly apparent, they require consideration in the context of communication at two levels: their ability to reinforce each other internally within a functional group, and a group's ability to reinforce another group through their different roles in communication.

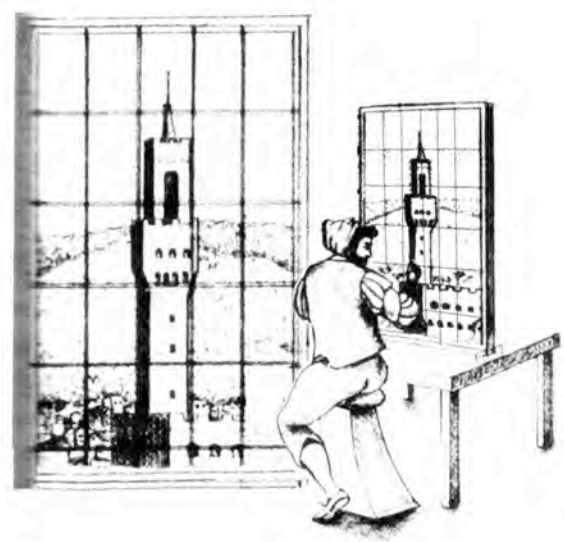
2. Perspective Cues

The most familiar set of depth cues are those of size gradient, texture gradient, and linear perspective. Collectively they are known as the perspective depth cues. It is appropriate to start with them as they are among the oldest quantified cues first observed as a method during the Renaissance.

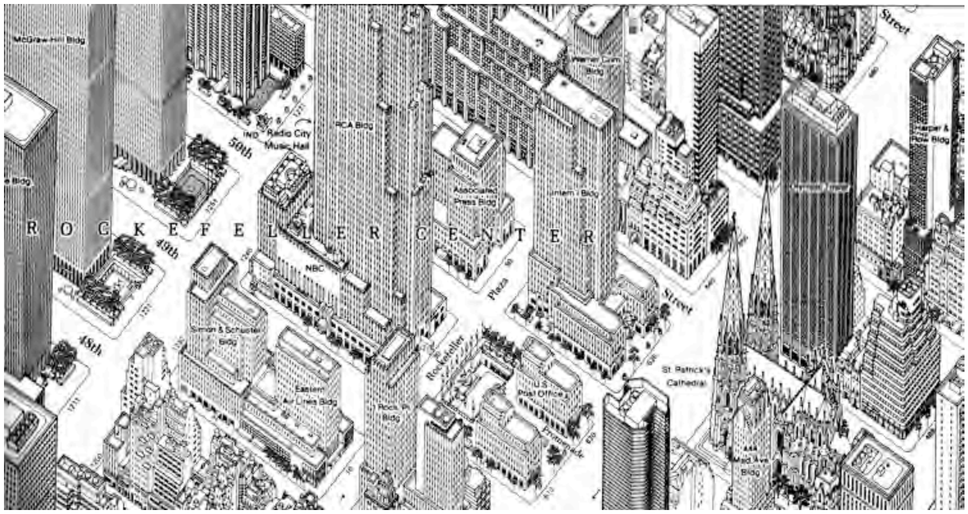
> The simulation of three-dimensional objects in space dates back to the early Renaissance when painters searched for, and eventually formulated a set of rules for constructing realistic spatial settings which became known as perspective. These rules derived from a study of optics and changes which occur in our perception of horizontal and vertical elements over increasing distances.[3]

The function of the perspective cues is to give shape and form to objects in ways that suggest their general yet accurate interrelationship to one another. We can see this notion demonstrated in the context of perspective's first application as a method in 1435 by Leon Battista Alberti with the Alberti window technique.

[3] E. Bruce Goldstein, Sensation & Perception (1980; Pacific Grove: Brooks/Cole Publishing, 1989) 235.



His formulation of this technique along with visual rules to helping artists accurately bring the structure and organization of what they saw in real life to their canvases using overlapping physical grids. The artist in the picture is looking at a tower through a grid on a window and has drawn a corresponding grid on his canvas. He uses this grid on the window to break down the objects he sees into the relationship of abstract shapes in each box. These he can then copy down accurately in the grid on his canvas. The Alberti window is a reverse engineering of our natural structuring process of combining shapes into objects into scenes. Perspective rules therefore communicate the spatial interrelationship of the visual elements we see, giving rise to our perception of form. At some point in our design studies we probably have learned these perspective rules and applied them in our design work. We use them in design as a way of establishing the definition and context of elements in a visual composition. A good example that uses perspective cues together effectively is offered by Tufte's of an isometric map of midtown Manhattan by Herman Bollman.



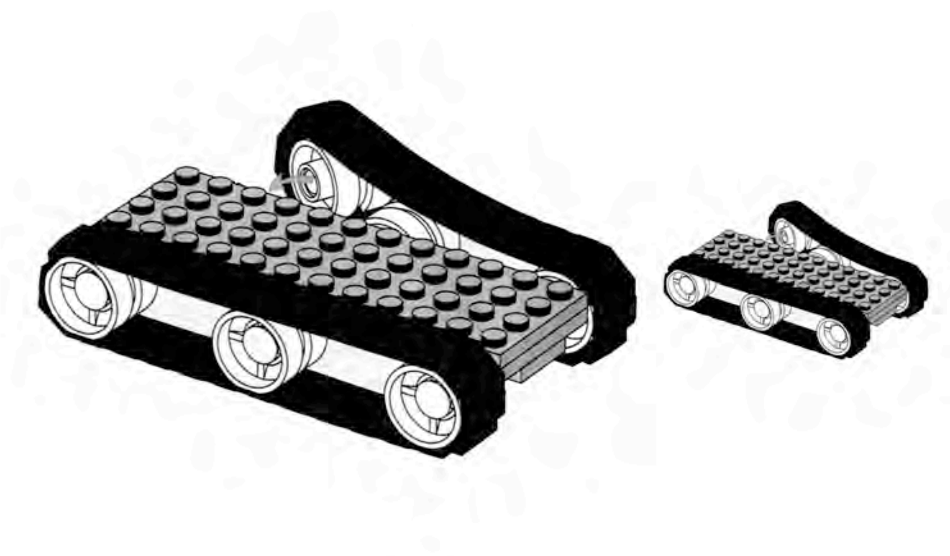
Tufte explains that perspective depth cues here operate in a two-fold manner. Firstly, they communicate the form relationship between each individual mark in the picture, such as the dash-like windows on the RCA building. From these relationships we then derive meaning that these marks group together as a form that we then recognize as a building. Secondly, they communicate the relationship between all the building objects together, from which we then derive meaning that this picture is of a city. Perspective depth cues therefore potentially operate on multiple points of a scalar level of relationships, from individual marks to objects.

2.1 Size Gradient

Size gradient states that when two objects of similar or same size are placed apart in space, one will appear proportionally smaller sized to the other when it is placed further away from the viewer in visual space. This difference communicates a sense of relative distance between the two objects and hence a perception of depth. Most explanations focus on its use on the object-element level of spatial relationships (the level of buildings in the case of the Manhattan map). Ware states this in a generic premise that, “objects at a distance appear smaller on a picture plane than nearby objects.”[4] Another psychologist, Robert S. Feldman explains it as “The phenomenon by which if two objects are the same size, the one that makes a smaller image on the retina [is perceived to be] farther away than the one that provides a larger image.”[5] A perceptual psychologist, Myron Braunstein, gives the best explanation of the effect.

> The relative distance of pictured objects may be judged by comparing their relative sizes in the picture to their relative sizes in three-dimensional space. Even when the objects are not of known size, the sizes of their representations in the picture may be used to judge relative distance.[6]

An example of this effect is this drawing taken from a Lego building toy manual.



[4] Ware 276.
[5] Robert S. Feldman, Understanding Psychology 3rd ed. (New York: McGraw-Hill, 1993) 148-149.
[6] Myron L. Braunstein, Depth Perception Through Motion, (London: Academic Press, 1976) 18.

If we place a reduced version to the right of the original object, we assume that the objects are the same size and interpret that the second version (on the right) must be further back in space since it is visually smaller than its counterpart. Size relationships of this manner are therefore very straightforward. Where they potentially run into design trouble however, is with the issue of what Braunstein refers to as “known size.” The known size of an object can greatly affect our perception of depth. Goldstein offers a culture-based example from an anthropologist who met an African bushman in a dense rainforest (where depth is consistently limited by obstacles) and accompanied him on his first outing into an open plain.

> Kenge looked over the plains and down to where a herd of about a hundred buffalo were grazing some miles away. He asked me what kind of insects they were, and I told him they were buffalo, twice as big as the forest buffalo known to him. He laughed loudly and told me not to tell such stupid stories…. We got into the car and drove down to where the animals were grazing. He watched them getting larger and larger…. and muttered that it was witchcraft…. Finally, when he realized that they were real buffalo he was no longer afraid, but what puzzled him still was why they been so small, and whether they really had been small and suddenly grown larger, or whether it had been some kind of trickery.[7]

Experience therefore appears to have an influence on how we interpret depth in what we see. Ware offers a simplified version of this when he says,

> Objects of a known size may have a very powerful role in determining the perceived size of adjacent unknown objects. Thus if an image of a person is placed in a picture of otherwise abstract objects, this gives a scale to the entire scene.[8]

We can see this phenomenon demonstrated in the example of the Manhattan map. Our perceived amount of depth changes drastically if we state that the buildings are for ants instead of people. Size gradient is therefore an important depth cue for judging the relative relationship of objects to one another, but is heavily influenced by prior knowledge of an object’s expected size.

[7] Feldman 145.
[8] Ware 276.

2.2 Texture gradient

The second of the perspective based cues is Texture gradient. According to psychologists, texture gradient acts like a size gradient in communicating relationships, but it more commonly operates on a smaller level of individual marks rather than objects. Textures are in essence multiple reference points that, when similar enough in size or orientation, group together. Through a size gradient interrelationship they act on a micro-scale to clarify the spatial form of an object. Even objects themselves, if small enough in size and in sufficient quantity as to be indistinguishable from marks, can form texture gradients. Windows such as those on the RCA building in the Manhattan map demonstrate this. We group them through their common vertical orientation and our assumption that they are the same size and conclude that they must therefore recede in space. Goldstein provides a good explanation of the benefits to texture gradients.

> Gradients result in a perception of depth as the spacing of the gradients' elements provides information about the distance at any point on the gradient. [It] provides orientation information for surfaces and remains constant even if the observer changes position.[9]

Texture is therefore a very powerful information design tool where communicating the accuracy of spatial relations is critical. It provides strong feature information of a surface. This also results in another significant effect. Texture has the ability to unify the boundaries of an object, enhancing clarity. According to David Reagan, a perception psychologist, this is called form segregation.

> A difference in texture between the retinal images of a spatial form and its surroundings can cause the form to segregate from its surroundings so that it can be recognized[10]

In addition to providing feature information within a form, texture gradients therefore also can help to clarify communication at an object level. We can see this effect in the Manhattan map with the Olympic Tower and the Harper & Row buildings. The Olympic Tower has a clearly different texture to its sides that sets

[9] Goldstein 265.
[10] David Reagan, Human Perception of Objects (Sunderland: Sinauer Assoc., 2000) 268.

it apart from the other buildings surrounding it. The Harper & Row building to the right of it acts in a similar fashion, but it is interesting to note that its form is clearer because of more pronounced contrast in the texture of its two sides compared to the Olympic Tower. Texture therefore clarifies both form and feature information. The application of texture for clarity is a stunning notion, because it goes against the popular design mantra of "less is more." Tufte marvels at this odd idea.

> Detail cumulates into larger coherent structures; those thousands of tiny windows, when seen at a distance, gray into surfaces to form a whole building…. A most unconventional design strategy is revealed: *to clarify add detail*.[11]

It can be stated then, that texture gradients give rise to clarity in individual form if the degree of detail is sufficient to communicate a unity between the individual feature elements or marks. The important thrust of this for information design is that we should not overlook the communicative effect that detail can have when it gives rise to texture. If the level of detail is sufficient enough for the interrelationship of elements to give rise to visual groupings, then an increased level of clarity is possible.

2.3 Linear perspective

Linear perspective is the third of the perspective-based cues and the one depth cue we are most likely aware of as designers. It involves the tendency for imaginary, inferred, or visible lines to meet in a single "vanishing point" on a horizon. Psychologists differ as to the linear perspective's cause. Goldstein describes it as a form of converging objects.

> Lines that are parallel in a scene converge as they get father away. The greater the distance, the greater the convergence, until at a distance of infinity, these lines meet at vanishing point.[12]

[11] Tufte, Envisioning Information 37.
[12] Goldstein 234.

Braunstein argues that linear perspective is a form of texture gradient of space between objects, or at least related to it.

> Linear perspective is a special case of texture gradient. It occurs "when 2 parallel lines are present in the same plane in the effective array, and this lane is slanted with respect to the line of sight. The systematic decrease in the distance between the two lines on the projection plane, going from the bottom to the top of that plane constitutes a gradient.[13]

Whether or not it is true that the decreasing space between two lines or the lines themselves that communicate a perspective gradient, the effect of linear perspective appears to operate primarily on the macro-scale of objects. It works in concert with size and texture gradients as a framework in which the other two act to reinforce spatial form. The Manhattan map does not demonstrate this effect since we see that it uses isometric perspective,[14] where linear perspective is warped to accommodate a uniform display of all the buildings. This example however, of a Renaissance town drawing taken from Goldstein's work gives an impression of linear perspective's potential.

[13] Braunstein 46.
[14] Isometric perspective differs from Linear perspective in that imaginary lines drawn from its objects do not converge on the horizon, but continue infinitely in parallel.

If we look at the tile sets on the ground, size gradient explains the depth relationship between the front and back edge of each tile. Linear perspective accounts for how the sides shrink from front to back and (from an overall viewpoint) how objects spatially converge in the scene. It therefore can be utilized in design to communicate the overall framework relationship between objects, giving context through phenomena such as convergence of their position in space.

The three depth cues of size gradient, texture gradient, and linear perspective all define the relationship of objects. This perhaps is what we might best keep in mind when we use them for information design. The way in which linear perspective and size gradient act strongest on the macro-level, while texture gradient operates on the micro level suggests that they can best be employed to reinforce each other. A size gradient of objects operates stronger when coupled with a surface texture; the texture giving more precise information of an object's degree of depth. We see this situation in the Manhattan map, as the texture of the buildings communicates clearer spatial size relationships compared to the featureless streets below them. If we look at the RCA building, the small patios stepped down the side of it have a clear indication of their relative depth to one another because of the building's texture. In comparison, the distance to the eye of the 49th and 50th cross streets is unclear and the depth measurement to the eye less accurate. We therefore may employ the perspective depth cues as a means to reinforce meaningful depth relationships of designed elements, particularly by adding informative detail for clarity. A further, overall communicative effect this has is in the concept of micro/macro reading of features versus objects. Tufte notes this in the context of the Manhattan map.

> This fine texture of exquisite detail leads to personal micro-readings, individual stories about the data: shops visited, hotels stayed at, walks taken, office windows at a floor worked and so on- all in the extended context of an entire building street, and neighborhood.[15]

The three perspective cues can be a means to create structures to designs that can be read in more than one fashion, leading to greater interest and meaning.

[15] Tufte, Envisioning Information 37.

Their ability to organize and communicate relationships on both macro and micro levels make them powerful techniques for design communication. They do have one key drawback that limits their use. All three do not help in differentiating the importance of one element of information from another. They do not give us the tools to sort their depth information in discriminating manner. This is where the Occlusion and Focus-related cues reinforce Perspective cues by helping us establish a visual hierarchy and determine significance to what we see.

3. Occlusion related cues

The second group of cues involves Occlusion (also known as overlap or interposition to psychologists) and cast shadow. The group's function is to denote a direct relationship and hierarchy between two separate elements, and as such is arguably stronger than perspective cues in creating a sense of depth. Designers have focused on their effect on communication in both static or dynamic information displays. Tufte calls their application in design "layering and separation" and argues that their ability to enhance communication can be powerful.

> Among the most powerful devices for reducing noise and enriching the content of displays is the technique of layering and separation, visually stratifying various aspects of the data.[16]

It is important to talk about these two cues together because, as is noted later, while they operate in the same fashion and have a similar stratifying effect, their ability to reinforce each other is vital to their accuracy in communicating depth.

3.1 Occlusion (or overlap, interposition)

The scientific explanation of the occlusion depth cue is that when two objects overlap, the one appearing to be partially obscured by the other is determined to

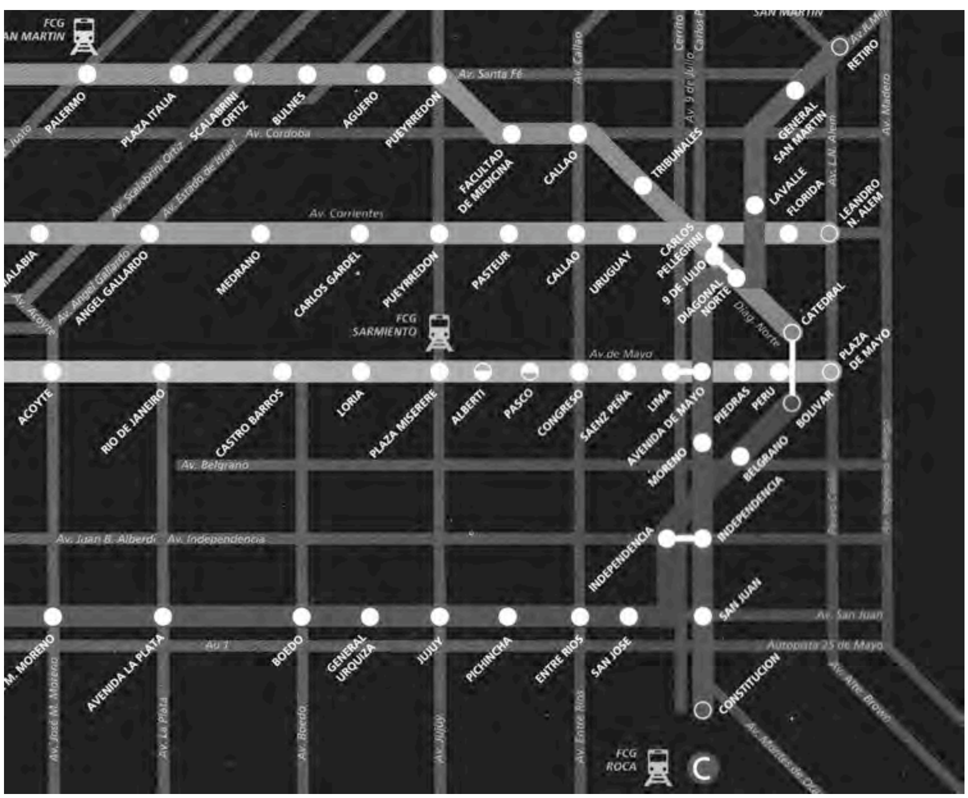
[16] Tufte, Envisioning Information 53.

be further back in visual space. Goldstein and Braunstein offer similar accounts of this circumstance:

> Overlap [is seen] if object A covers part of object B, then object A is seen as being in front of object B. Note that overlap does not provide information about an object's distance from us; instead, it indicates *relative depth*- that one object is closer to us.[17]
>
> (Goldstein)

> When one contour appears complete and appears to interrupt another contour, the completed contour is usually perceived as closer than the interrupted contour. [18]
>
> (Braunstein)

An information design example that demonstrates this well is this map of the Buenos Aires Underground System, a combination of a train and street map.



[17] Goldstein 230.
[18] Braunstein 18.

Here we see occlusion occurring in the layering of a colorful subway map over a spatially corresponding brown street map. A depth hierarchy is seen where the contours of the subway shapes interrupt those of the streets. Certain subway routes such as the green route are also, in turn interrupted by other subway routes (in this case the red route). From these relationships a hierarchy is formed and depth communicated. As Tufte notes earlier, this is a powerful design method to organize information in a visually uncomplicated fashion. Its directness allows for instant comparison. The impact occlusion has as an information design technique for communication is expressed in this quote from a reporter observing layering use in maps.

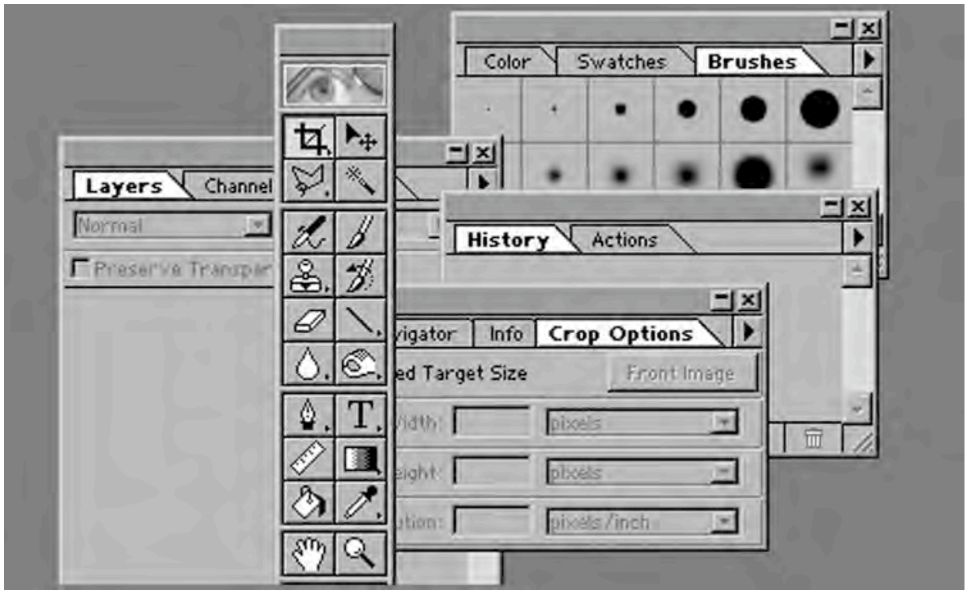
> Information is displayed in layers, with each succeeding layer laid over the preceding ones, like transparent sheets on an overhead projector. The resulting maps often reveal trends or patterns that might be missed if the same information was presented in a spreadsheet. [19]

The Buenos Aires map provides information in this manner, allowing us to directly connect and compare the street and subway maps, making meaningful connection between the two. Each map reinforces the other's information, allowing us to better navigate the space whether we are above or below ground. In the context of dynamic media, where space is an issue, there are similar benefits to occlusion use, as noted by the designer David Small.

> Often, it is desirable to show more information at one time than can reasonably fit onto the display. We can take advantage of the computer's ability to create multiple dynamic layers of information…. to overcome that constraint and to go beyond anything that was possible on the realm of ink on paper.[20]

We see the benefits of this everyday with graphic-based computer interfaces, as in this example on the next page.

[19] Catherine Greenman, "Turning a Map into a Layer Cake of Information," New York Times, 20 Jan. 2000, late ed.: D1.
[20] David Small, "Rethinking the Book, " diss., MIT University, 1999, 47.



The occlusion of one application window element with another compensates for the limited visual real estate available for display. Occlusion through layering is therefore best applied in dynamic situations as a space saving tool; the dynamic ability to reorder the windows compensating for the obscuring of information. Static mediums do not allow for this re-ordering ability and therefore place some limits to the degree occlusion may be used, but this shortcoming can be somewhat compensated by transparency. Ware notes that “a kind of partial occlusion occurs when one object is transparent or translucent.”[21] Hierarchy is still communicated, but the information is not completely lost. The only other limitation of occlusion that should be considered is in respect to the degree of depth it communicates. According to Ware again, “If one object overlaps or occludes another, it appears closer to the observer. This is probably the strongest depth cue, but provides only *binary*[22] information.”[23] Occlusion unfortunately does not communicate the *degree of depth* involved as can be seen in the overlapping windows of the graphic-based user interface, the only information communicated is that one object is clearly in front of another. It is in

[21] Ware 280.
[22] Binary refers to occlusion’s limit of only indicating whether or not one object is before another, not the scalar amount of depth involved.
[23] Ware 280.

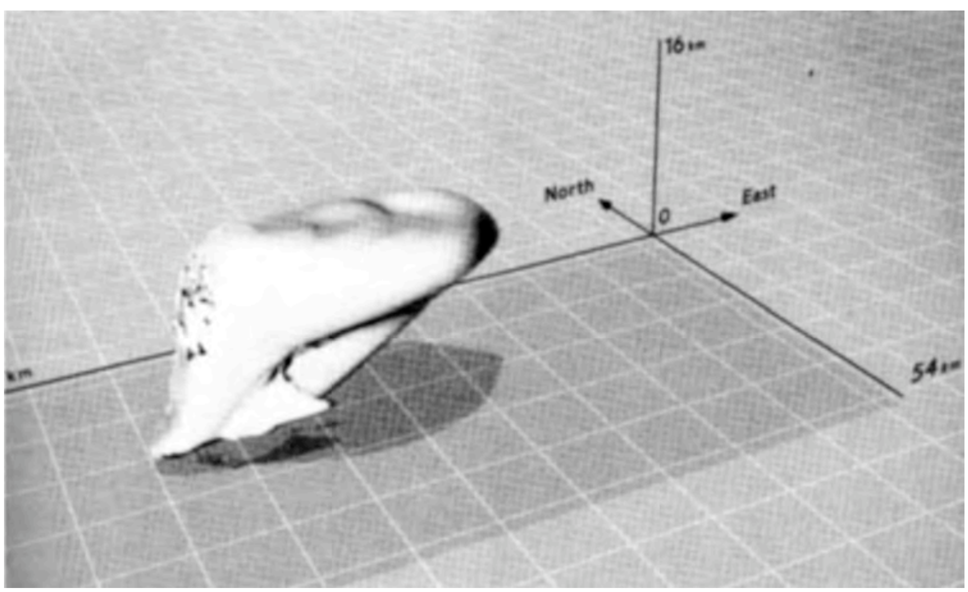
this respect that the depth cue of Cast shadow is important as a reinforcing cue.

3.2 Cast shadows

Many psychologists do not qualify Cast shadow as a depth cue, but Ware counts it as one that acts in an indirect manner.

> Cast shadows are a very potent cue to the height of an object above a plane. This then can function as a kind of indirect depth cue – the shadow locates the object with respect to some surface in the environment, and cues from the surface, such as perspective or texture gradients, give the actual distance. Since shadows are most effective when cast onto a nearby surface, they can be very useful in distinguishing information that is layered a small distance above a planar surface.[24]

This image from an animation of severe storm cloud formation model demonstrates the powerful affect that cast shadow can have in communicating depth.



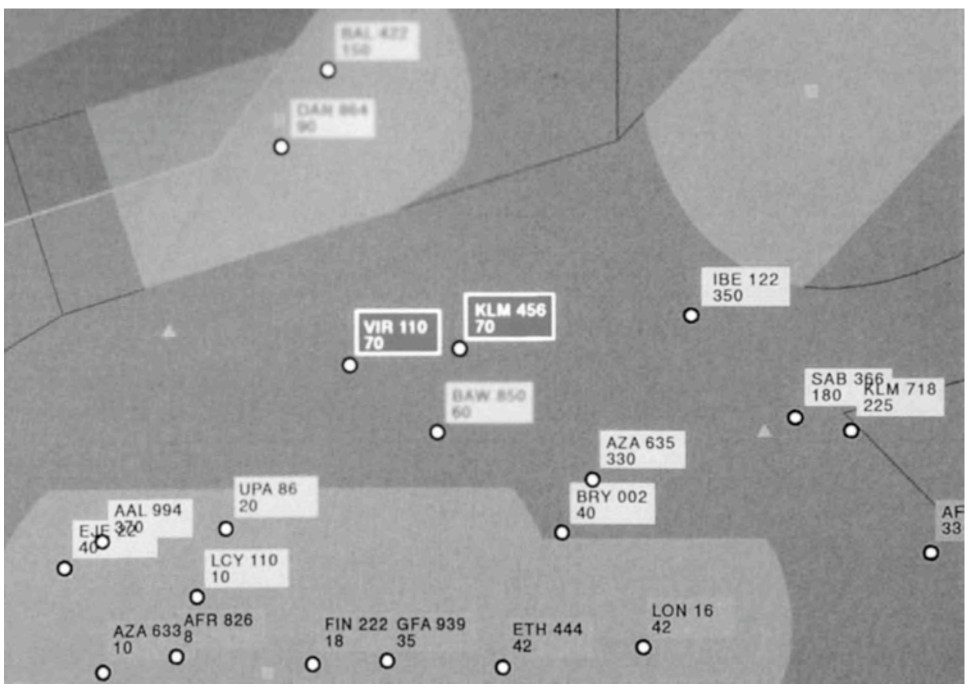
[24] Ware 281.

Here, the white cloud's cast shadow on the beige plane below provides information of the clouds relative depth to the surface. The right end of the cloud is far away from the surface, as indicated by the distance between the shadow and object. The left end, with a shorter distance between cloud and surface is closer. This information combined with the shape of the shadow and its partial occlusion of the grid in linear perspective underneath even gives us an understanding of the cloud's relative volume (further depth information). Occlusion's communication of depth is therefore greatly enhanced by the further addition of Cast shadow.

What is clear from our understanding of Occlusion and Cast shadow depth cues is that they operate powerfully where there are direct or close relationships of information elements. As a visual mechanism, their communicative effect of depth is binary unless other cues come into play. It is possible from this to form a basis for determining whether or not to use occlusion with or without other depth cues. If the information goal is direct comparison of the two elements alone then occlusion by itself is sufficient. The benefit to limiting a design to this cue is that it allows a clear depth hierarchy to be determined without the visual complication of other cues like linear perspective. If communication needs to extend beyond this binary fashion and the relative degree of depth is important information, then cast shadow (and the other depth cues it often brings with it) is required. But it is important to note that both Occlusion and Cast shadow are limited in their effect by distance. The greater the distance between the two objects, the more imprecise shadow is in communicating the relationship. We see this in the severe storm cloud formation example, where the closer part of cloud-to-texture-plane has depth that is easier to measure. It is in this respect that the Focus-related group of cues helps to over come this shortcoming at communicating greater depth, for they act in the opposite manner, being more effective where there is greater distance disparity between two objects.

4. Focus related cues

The third group of depth cues for information design include Focus (or depth of focus), Atmospheric perspective, and Relative intensity. They can be considered related to occlusion as their function and application in design is the same layering and separation effect. Where these depth cues differ from Occlusion however is in the conditions that they are effective; all three focus-related cues communicate depth best where there is a great distance between objects seen from the viewer's vantage point. They also provide more than a binary level information, giving a rough approximation of the amount of depth involved. This redesign of a British air traffic control screen display is a good example of all three focus-related cues operating together.



The goal driving this redesign was a desire for a clearer presentation of complex spatial information than older displays that used uniform color, size, and weighting of its visual elements. There is a deliberate and clear hierarchy to what our eyes are drawn to. Our attention is immediately drawn to the two red boxes in the center of the screen. They pop up in our vision, differentiated from the blue or white boxes (both fuzzy and sharp) that surround them. The design context in this case is significant as each box is a label that represents a plane with its corresponding importance to the air traffic controller at the time. If we look at the white labels we are also quickly aware of some more than others, a factor corresponding to their sharpness. In the image the fuzziness of the two white labels above the red labels is emphasized to show also how the hierarchy can be pushed beyond the color difference. Finally there is an overall, immediate sense of the difference between the labels and the background, which delineates sections of airspace. This involves the comparison of muted and bright colors between background and labels.

4.1 Atmospheric perspective (or atmospheric attenuation)

Psychologists state that the further back an object is in real space, the less distinct and hazier its features are. Goldstein attributes this to airborne particles in the air between the viewer and the object.

> Atmospheric [or ariel] perspective causes us to see distant object as less sharp because we must look through the air and the particles suspended in the air between us and the object. The farther away... the less sharp than close objects. Increased pollution, fog, or mist can increase atmospheric perspective.[25]

The amount of clear detail is therefore associated with the degree of depth involved. In the air traffic control screen display, the difference in the clarity of the labels is a designed construction of atmospheric depth. Lower plane labels are hazier to suggest their further distance from the overhead point of view than the sharper, closer plane labels. If we compare the sharp and hazy labels together, particularly where they occur close together such as at the top of the picture, a relative difference in distance becomes apparent. Similarly, the difference in the amount of detail on the labels (and their text) compared to the plain background also provides an overall sense of separation that brings the labels forward in our attention. Since this depth cue is an effect created and influenced by physical atmospheric phenomena (weather conditions), it is important to note that our judgment of depth is subject to the same cultural bias as size gradient. If an area

[25] Goldstein 232.

has air quality that is persistently very good or bad, then it can lead to a cultural difference in the perception of depth. Goldstein proposes an example of Montana vs. Pittsburgh.

> One of my friends took a trip from Pittsburgh to Montana. He started walking towards a mountain that appeared to be perhaps a two or three hour hike away, but found after three hours of hiking that he was still very far from the mountain. Since my friend's perceptions were "calibrated for Pittsburgh, he found it difficult to accurately estimate distances in the clearer air of Montana.[26]

We may not encounter circumstances in information design where this potential cultural bias will affect perception so severely, but it is an important consideration in application. Atmospheric perspective is therefore not a cue for accurate measurements of depth, only relative measurements. A further limitation of atmospheric perspective in light of our air traffic control design example shows also that elements must be laterally close together for a good sense of comparative depth. Design circumstances where the lateral proximity of elements are unreliable would make atmospheric cues bad to use their own without other cues to reinforce depth. Atmospheric perspective is therefore a mechanism that communicates depth powerfully only when there is a sufficient degree of disparity in sharpness between laterally close objects to show separation.

4.2 Focus (Depth of focus)

Focus (or depth of focus) is a dynamic equivalent of atmospheric perspective that is based on the physical constraints of our eyes. Ware explains the basis of this effect.

> As we look around in our world, our eyes change focus to bring the images of fixated objects into sharp focus on the fovea [of the eye]. Focus effects are important in separating foreground objects from background objects. In normal vision, our attention shifts and our eyes refocus dynamically depending on the distance of the object fixated.[27]

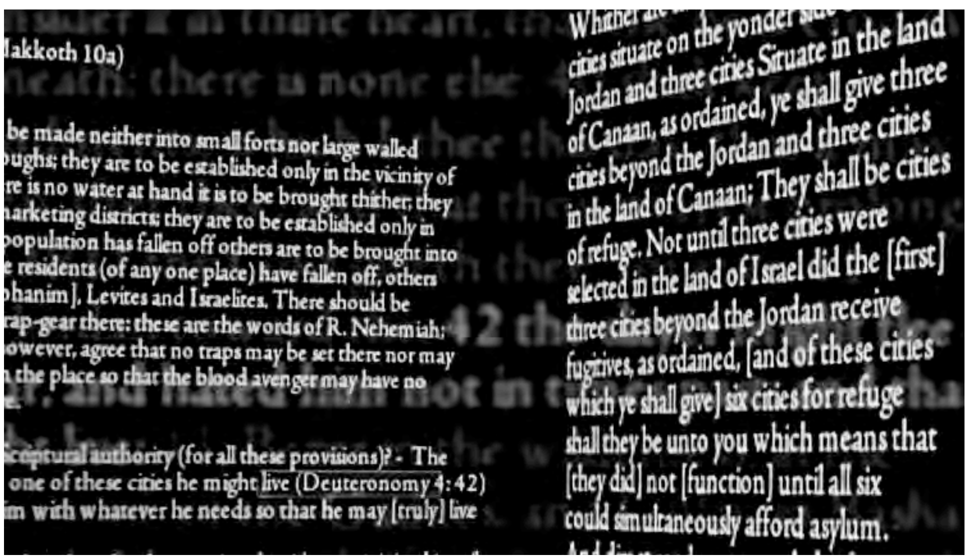
Our eyes are limited to focusing at one level of depth at a time, resulting in a differentiation in clarity between levels in z-space. We are also limited to focus on only one area at a time as well. If we look straight ahead at an object, placing its

[26] Goldstein 232.
[27] Ware 280.

image directly in our fovea[28], other objects surrounding it in the periphery of our vision appear blurred with less detail. As the phrase “focus of our attention” would suggest, the focus depth cue is therefore directly tied to attention level because it requires conscious action to perform. Depth is inferred from the shifting of attention (and focus) from one object to another as elements beyond and before our focus of attention become blurred. This separation created between what our attention is and isn’t focused on has a very practical application for information design in dynamic displays. David Small has used this mechanism to great effect in his work.

> If we know which layer is of interest at the moment, we can adjust the display such that the various layers appear to either “pop” out to the front or recede into the background. This is accomplished through a combination of focus or transparency controls.[29]

Small’s Talmud project demonstrates this application in his use of the focus cue to dynamically shift attention between multiple texts.

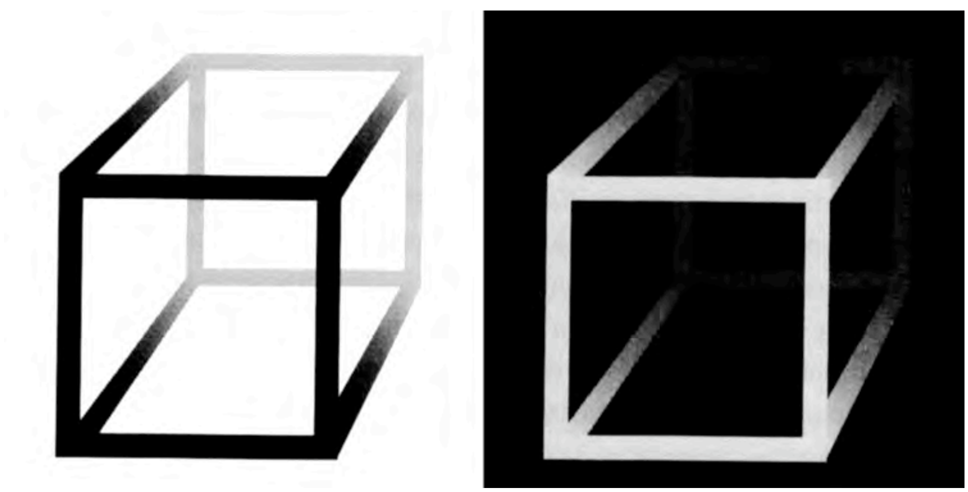


[28] The fovea is a physical feature of our eye where there is a significant concentration of cells that sense small details. This spot we use to detect edges and feature information of what we see.
[29] Small 53.

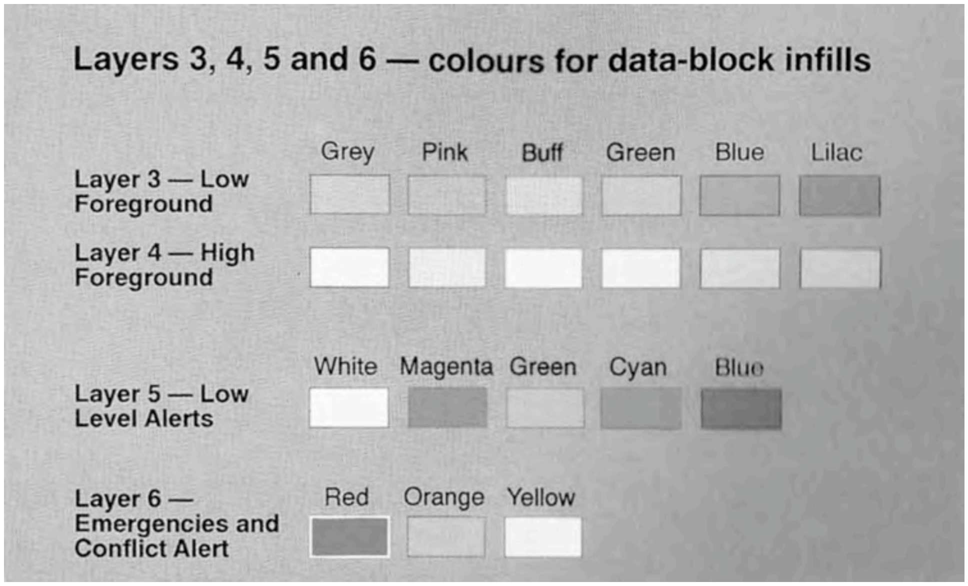
We are able to shift the physical focus of the three texts to bring the one we wish to study to the front, while the others recede, de-focused and darker in the background.

4.3 Relative brightness (or Intensity)

There is some confusion regarding the terminology of this brightness-related depth cue. Some psychologists do not refer to it at all. Those that do, however, tend to differ. Braunstein vaguely describes it as a phenomenon where objects that are brighter tend to be perceived as being closer to the viewer. Ware provides a deeper explanation in what he calls “Proximity luminance.” He describes it as a variation of atmospheric depth, but more extreme than what occurs naturally in the environment. His example demonstrates that this cue, at least in abstract form, can be reversed.



It may therefore be best to define this as Relative luminance or intensity. Objects or parts of objects that are more intense are seen as closer than those that are similar in intensity to the overall background. We can see this depth mechanism and its potential information design application in the air traffic control screen display example. The two red rectangles visually advance in our eye compared to their more subdued companions. Similarly, if we look at the information key on the next page for the display this visual organization is also apparent.



Here, the degree of intensity of color corresponds to the level of alert (collision potential) involved with the corresponding aircraft. The red, orange, and yellow labels are the most intense, and correspond to imminent collision. Linda Reynolds, the project's designer explains her group's thinking behind this intensity range.

> The Colour Group felt that a clearer difference between background and foreground could reduce the controller's information processing load, so it was suggested that the display should be thought of a s series of conceptual "layers" differing in importance, and that colour should be used primarily to represent these as a series of visual layers, with the foreground data having the greatest visual emphasis and the background map the least.[30]

Relative intensity can act as the mechanism for what Tufte describes as information layering and separation. It communicates depth based on the comparative level of attention between objects. This is not without weakness though. One cautionary note is that close to 10% of the population is either fully or partially colorblind. The air traffic control screen display therefore is vulnerable

[30]Linda Reynolds "Air Traffic Control Screens," Information Graphics ed. Peter Wildbur, Michael Burke, (Hong Kong: Thames & Hudson, 1998) 93.

to misinterpretation if a user suffers from visual color impairment. This is why intensity is perhaps better for designers to use in application.

The connection between focus and attention suggests that Atmospheric perspective, Focus, and Relative intensity are best applied in design circumstances where the designer wishes to direct the viewer's attention. While all are subject to the environmentally induced bias inherent to cues related to atmospheric perspective, it is a relatively minor issue provided that these cues are reinforced by other cues. The air traffic control screen display demonstrates how the cues can collectively communicate visual depth. Intensity of the labels (such as the two red ones) along with the blur effect generated by the mechanisms of atmospheric perspective helps to manage the information space by calling attention to important information while de-emphasizing other less-important surround visual data. Atmospheric perspective, depth of focus, and relative intensity therefore make excellent organizational design tools for communicating spatial relationships on an object (macro) level

5. Conclusion

The potential for cognitive sciences such as visual perception to inform design is mostly an unrealized possibility in the design community. Research such as that of visual perception and cognitive scientists is useful to information designers because both disciplines address issues of visual organization, hierarchy, attention, and the recognition of relationships between forms. Scientists have sought to understand these issues from a detection basis, seeking to understand how we naturally process the visual information of our environment. Designers have approached the problem from the other side of implementation and have looked for ways to use visual elements such as depth to construct opportunities that lead to greater understanding. This is in keeping with information design's communication goal to make the complex understandable and navigable. Through better understanding of the base mechanisms behind how we see and interpret information we should be able to more effectively apply visual structure for clarity. Each depth cue group offers potential to realize this. Perspective cues can be used by designers to spatially organize information on multiple levels. As revealed by Tufte, the potential for reading at both micro and macro levels affords a more powerful understanding of information spaces. Perspective cues therefore can assist in giving rise to form relationships that unify elements of information our design compositions. The occlusion-based cue group involves establishing direct comparisons of information sets through layering. A better understanding of this phenomenon can enhance clarity in our communication work through the design of affordances for making connections between information sets. Finally, the focus-related cue group involves our inherent skill at prioritizing what we see. The understanding of such mechanisms for attention can inform the task-oriented element to our active processing of visual information. These cues can be invaluable where design problems require directing or limiting attention to create clarity. Perhaps most important of all, the best application of depth cue theory lies in its potential as an evaluative design tool. It is a way of looking. We can apply them as one possible way to *look at and evaluate* visual information so as to understand how a composition's form is read and the way we go about perceiving the visual relationships involved. Depth cues may therefore be employed in the context of information design to create richer, more effective communication, as understanding how our audience sees can lead to designs that better meet their visual information needs.

A final thought open to further investigation concerns the interplay of depth cues. The community of visual perception scientists has found a significant degree of overlap between the organizational effects of cues, which raises the question of how depth cues act collectively. Are there *combinations* that are more effective for one particular design circumstance or another? Can the designer predict and use such a combination to make clearer designs? This paper has considered a few small groups of cues, but it does not focus on any systematic organization of depth cue combination. What is still needed (and is likely still far off) is a comprehensive survey and mapping of the relationship between all cues. Such a broader understanding could prove valuable in respect for a greater knowledge of which cues best act in concert with one another at a macro level to reinforce the communicative effect of depth for information design.

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