

# An Ecological Perspective of Visual Information Density in Interface Design

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**Abstract** – Interface design often overlooks the problem of visual information density. This problem is concerned with how uniform a set of data is laid out on a display. It tries to avoid both clutter and sparsity of data as those two problems have a negative effect on the efficient use of display space. Since visual density is part of the perception process, it has to be dealt on this basis. This paper tries to lay down the concepts of ecological perception and relate them to the problem of visual information density. A new approach is inspired by this relation. This approach is based on depth layout which provides a more natural interface and introduces more affordances and flexibility than normal interfaces. Those new affordances and flexibility are the basis of maintaining uniform visual density.

**Index Terms**--information, density, visualization, ecological, interface

## I. INTRODUCTION

THE main purpose of visual interface design is to develop an interface that will aid its users to work in the most efficient way by providing them with the information they need in a suitable way. One of the areas of interface design that has to be dealt with when designing an interface is *Information Density*. The problem of visual information density is mainly concerned with the non-uniform distribution of data in visualization, and in particular *clutter* and *sparsity* of data. This problem has a negative effect if not taken care of properly in the process of interface design. Accordingly, the objective here is to make efficient use of the display by avoiding those two problems of non-uniform density, namely: avoiding overplotting of data, and minimizing the waste of display space. Efficient use of display space is becoming more important area of interest, especially now with the emerging technology of hand-held devices which have a very restricted display area. One interesting way to understand the problem of information density is to tackle it from the ecological perspective of visual perception. This paper tries to

help better understand the problem and correlate visual information density to the underlying concepts of human perception from an ecological perspective.

In the following sections a preliminary introduction of ecological visual perception is presented, and then a discussion of the differences between displays and reality is presented, followed by a discussion of visual information density and its metrics. A novel approach for interface design based on depth layout is then presented, followed by some remarks. Future work is discussed, and a conclusion ends the paper.

## II. ECOLOGICAL VISUAL PERCEPTION

According to Gibson [1], visual perception has been always studied from a physiological perspective, paying no attention to the ecological side of perception. Gibson developed a new theory for human perception based on an ecological approach. This theory tries to detach the common belief of physical optics, which is based on retinal images and stimulation of sensory vision organs, from the more robust approach of visual perception based on human-environment interaction and *direct perception*. Gibson suggested the presence of an ambient array of light at any point of observation (or a potential point of observation.) The array has a specific structure of ambient light coming into the point of observation. This structure is the basis of his approach, which he built upon many other findings. He interpreted the environment in terms of the medium, substances and surfaces. He further emphasized on the layout of surfaces, and interpreting the perception of the layout in terms of solid angles with their bases on the layout and their apexes at the center of the array (the eye.) He was able to interpret the perception of the changes that happen in the environment as being disturbances in the ambient array in different ways according to the nature of change. For example, occlusion of objects is interpreted as deletion of ambient structure on one end and accretion of structure on the other end.

One of the powerful aspects of ecological optics is the concept of invariance. The idea behind invariance is the persistence of some properties of objects that do not change when we change our point of observation. For example, a table has a rectangular surface, but when we look at the table from different

points of observations we see the surface as a trapezoid. And despite the fact that we see trapezoidal surfaces, we perceive the table surface as being rectangular. The invariant surface layout (rectangle) is what underlies the change of surface appearance from different points of observation. This is what is called persistence under change. Other properties are considered invariants also such as material and color. This concept of invariance will serve us when we discuss the change of object appearance at different levels of zooming later.

### III. THE DIFFERENCE BETWEEN DISPLAYS AND REALITY

No doubt that there is a difference between perceiving the real world and perceiving displays. The former gives the perceiver endless information and opportunities to discover more about the world. In the latter case, perceiving displays, the opportunities to pick up information from the display are far less than in the case of the real world.

#### A. *Affordances*

In this section this difference will be presented in terms of the powerful concept of *affordances*. According to the Gibson's theory of affordances, "affordances of the environment are what it *offers* the animal, what it *provides* or *furnishes*, either for good or ill." [1]. So perceiving an affordance is perceiving what an object, for example, offers us to use it for (or get away from.) Under this concept, we can differentiate between the two cases of perceiving the real world and perceiving a display. The real world affords locomotion and manipulation. Those two affordances are not present by default in displays. So, for example, in the real world you can get closer to an object, move about it, and scrutinize it. And as you keep getting closer to the object, more details of the object start appearing, and its texture looks less dense. On the other hand if you walk away from an object, you see less details of the object, and its texture looks denser. You can always extract new information from the real world, because information is inexhaustible. This is not the case with displays, where scrutiny of an object is not afforded by the displayed object, simply because it is drawn on a flat surface. This is why the information associated with objects on a

display has to be well laid out, and more important they have to provide something similar to the affordances provided in the real world through special metaphors that imitate those affordances.

### *B. Occlusion*

Having introduced the difference between displays and reality, we need to find out the similarities between them so that we get a full understanding of how to apply real life affordances in the interface design. One important similarity is the fact that objects tend to obscure each other if they get in the way of each other. To get in the way is to make the projected object in the optical array unprojected by filling the solid angle part of the back object with that of the front object, making the back object “unseen” anymore. This is the basic idea of occlusion. This can happen on a display as it happens in the real world. An object on the display can get *occluded* by another object if both objects happen to be at the same place on the display. Occlusion on displays is undesirable most of the time because it tends to hide potential information. In some cases however, occlusion has its advantages, such as displaying layers of information on top of each other to get a new type of information. We are concerned here with the first case where we want to avoid *clutter* of data by avoiding the occlusion of objects by each other on the display.

### *C. Uniformity of Density*

In order to gain insight into the concept of visual information density we must emphasize an important fact of the real world. This fact is concerned with typical layout of surfaces and objects in the real world. The layout of surfaces in our life has some *uniformity* in most cases. When speaking of uniformity we do not mean a specific arrangement of surfaces and objects, but instead a certain degree of uniform distribution of surfaces and objects. We rarely find most of the objects concentrated in one area leaving the rest of the place sparse. It has to be noted that we are speaking on the scale of human vision and not on the scale of large geographic layouts. This is consistent with the fact that we always tend to make efficient use of space. It also helps us avoid having to deal with distant dispersed objects and layouts.

This fact is what motivates the replication of such a property on displays. Avoiding sparsity in displays helps the user to have better perception and control over the interface and avoid inefficient use of display space by keeping a uniform distribution of data.

#### IV. VISUAL INFORMATION DENSITY

When speaking of density, some sort of measurement has to be used to be able to deal with density values, calculate thresholds, comparing densities, and so forth. In the real world, we use some metrics for our density measures. In the case of displays we are going to adopt some of those metrics to be able to deal with density.

##### A. Density Metrics

Before going on adopting those metrics, we have to decide what type of information we are going to deal with so that we can choose the appropriate metrics. In most cases of interface design, we have to deal with graphical layouts, and in some cases we deal with textual layouts. Allison Woodruff, *et al* [2] [4], worked on a system called VIDA (Visual Information Density Adjuster), where she was mainly concerned with cartographic type of applications. Woodruff used custom density functions that return the associated density metric for a given layer. The density metrics she used was the number of objects and number of vertices. Such metrics are very useful for graphical and cartographic application interfaces. An extension of those metrics could include, for example, number of line segments, or a combination of the number of objects and the associated number of vertices per object. However, for textual interfaces, we cannot use such metrics. We need a suitable measurement for text density. Unfortunately for text interfaces the choices are less than their counterpart in graphic interfaces. Suggested metrics could be the number of characters or number of words per unit area. Table 1 shows some metrics for density calculation.

|         |  | Type of interface       |                      |
|---------|--|-------------------------|----------------------|
|         |  | Graphic                 | Text                 |
| Metrics |  | vertices/unit area      | characters/unit area |
|         |  | objects/unit area       | words/unit area      |
|         |  | line segments/unit area |                      |
|         |  | filled pixels/unit area |                      |

**Table 1**  
**Information Density Metrics**

### B. Maintaining Uniform Density

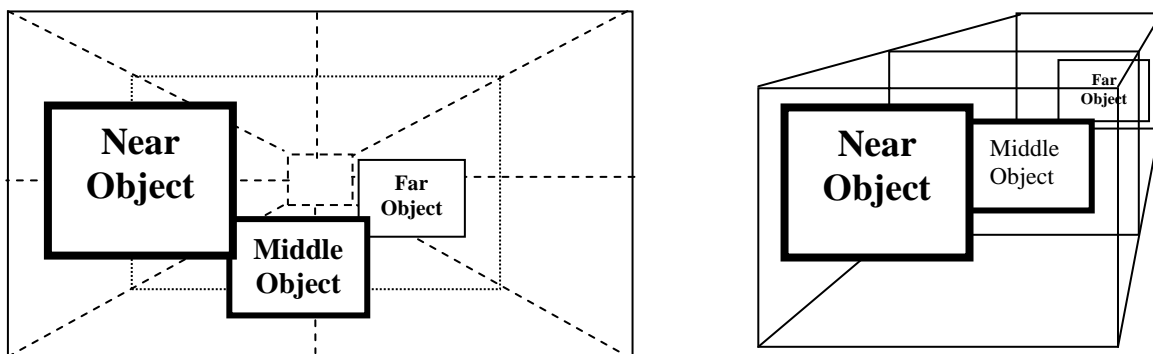
Now that we discussed the metrics of density, our objective is to maintain a *reasonable* density measure for a certain interface design. Woodruff mentioned a principle used in cartography visualization called the Principle of Constant Information Density, which states that the amount of information per unit area should remain constant all the time. According to this principle Woodruff developed the VIDA system, which uses a two dimensional spatial canvas metaphor, with the objects laid out on the canvas, giving the user control over panning and zooming. The distance from the canvas at any time is called the *elevation*, which is the level of zoom. In order to apply the principle of constant information density, she used multiple graphical representations of objects, where each object has different representations to be used at different elevations. For example, an object could have three representations corresponding to three levels of zoom (or elevation.) This way, at low elevations objects can be shown with larger size and more details and complexity, while at high elevations, objects can be shown with smaller size and less details and complexity. However, VIDA allows mixing different representations of different objects at the same level of elevation. This feature solves the problem of maintaining uniformity in the x-y dimensions as it does in the z dimension. It also emphasizes outliers. However, it has a severe impact on the distortion of perception of the actual density of underlying data space. Moreover it cannot be applied to those dimensions in which the user is explicitly studying distribution. Those drawbacks were mentioned by Woodruff. In the next section a novel concept of data layout will be presented. This concept builds upon VIDA's idea, but it is mainly based on the idea of three-dimensional synthesized camera model for visualizing data in depth.

## V. DEPTH LAYOUT

The idea of depth layout was inspired by the *optics of occlusion* developed by Gibson [1; pp. 85.] One of the points Gibson mentioned was that “Any surface of the layout that is hidden at a given fixed point of observation will be unhidden at some other fixed point.” Another point he mentioned was that “Hidden and unhidden surfaces *interchange*. What is revealed by a given movement is concealed by the reverse of that movement. This principle of reversible occlusion holds true for both movements of the point of observation and motions of detached objects.” Those two concepts is what *depth layout* is all about. The discussion of visual density in depth layout will be presented at the end of this section after presenting the depth layout model.

### A. Depth Layout Basics

Instead of laying out objects on a two-dimensional canvas as in VIDA, the depth layout uses three-dimensional structure to layout the objects. It has to be noted that we are not trying to design a three-dimensional modeler; objects are not modeled in 3D. Only a two-dimensional representation of objects are used. However, objects are laid out in a way that gives the feeling of being in front of (or behind) each other through a perspective structure. Multiple imaginary layers are used to lay down objects. Objects on the near layers are larger and have more details and complexity, while objects on the far layers are smaller and have less details and complexity. Figure 1 shows a schematic of the depth layout concept.

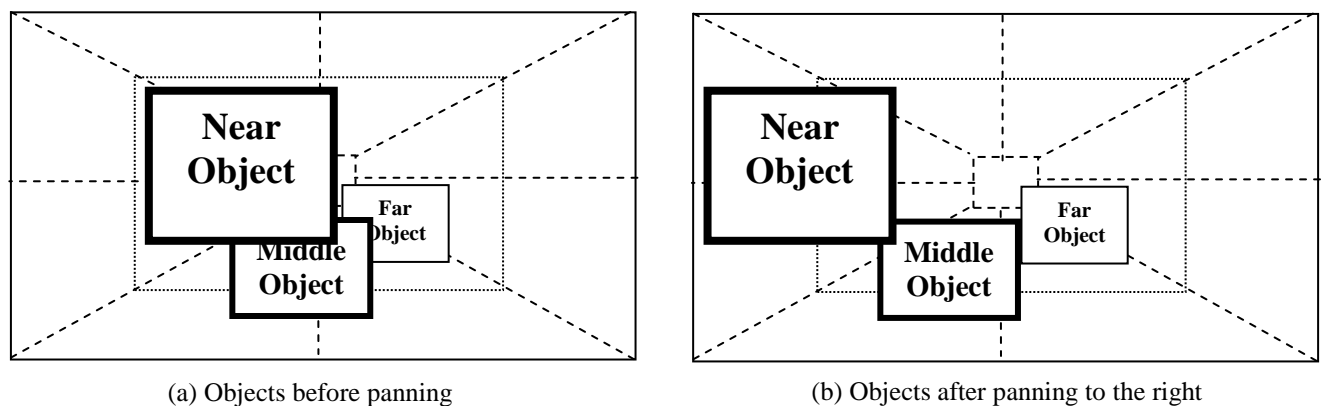


**Figure 1**  
**Depth Layout**

Objects are laid out on imaginary layers. Near objects appear larger and more detailed than far objects.

### B. Dynamics of Depth Layout

The nature of depth layout introduced above dictates that one could *move* in the layout space. We have created the affordance for locomotion inside the layout since it is now a three-dimensional metaphor. Panning and zooming in the layout now have more natural feeling. In regular two-dimensional designs, panning results in all the objects to be moved with equal displacements. On the other hand, in depth layout near objects move larger displacements than far objects. This is similar to the real world where a moving point of observation will notice that near objects seem to move larger displacements than far objects. Moreover, we have satisfied Gibson's concept of optics of occlusion that any object is hidden at some point of observation will be unhidden at another point (Figure 2). Also zooming has become more natural. Zooming in depth layout actually is merely shifting of the hidden layers. Zooming in will shift all the layers in the direction of the user, eliminating the nearest layer, and introducing a new furthest layer; and vice versa. This idea of depth dynamics is consistent with what Gibson said, "the *separation* between hidden and unhidden surfaces at occluding edges is best specified by the *perspective* structure of an array."



**Figure 2**  
**Panning In Depth Layout**

Near objects are displaced more than far objects

The idea of multi-scale representation of objects should be applied in depth layout. Different representations for each object at different zooming levels are used. Each representation is appropriate for a certain layer in the depth layout. When zooming in, for example, the object is shifted from a far layer to a nearer one; and accordingly the corresponding representation for that layer is used for this object.

### C. Layers

A depth layout has  $n$  layers. Layer  $1$  is the nearest layer, and layer  $n$  is the furthest one. Panning the layout does not change the order of layers. Zooming, on the other hand, shifts the layers inward or outward depending on the direction of zoom. Layer numbering stays the same after zooming, however objects that were associated with layer  $i$  before zooming out, for example, will be associated with layer  $i+1$  after the zoom operation. Zooming in has the reverse effect; objects associated with layer  $i$  before zooming in will be associated with layer  $i-1$  after the zoom operation. Objects can disappear from the layout in two cases: (1) if they were on layer  $1$  and a zoom-in operation is performed, and (2) if they were on layer  $n$  and a zoom-out operation is performed. Layer  $1$  and layer  $n$  are two special layers; they act as the near and far boundaries of the viewing volume, respectively. Objects in front of the near boundary are not visible, and objects behind the far boundary are not visible. This idea is consistent with ecological optics, where the point of zero distance specifies the “self”, and any object at zero distance will totally block the field of vision. On the other hand, the point of infinity is at the horizon, where everything disappears, or more accurately diminishes to a very small size. The far boundary acts as the vanishing point for far objects.

An interesting feature of the depth layout is that some layers can be “turned off” selectively. This enables the user to *hide* some information on purpose so that he/she can focus on the rest of the layout. Turning off all the layers except one layer only reduces the depth layout to a two-dimensional canvas metaphor such as VIDA.

The use of layers to manage graphical objects is not a new idea. However, depth layout may not be restricted to mapping a depth relationship between objects only. The layers can act as “information filters”, where the near layers display more relevant information, while far layers display less relevant information. Another use for the layers may be to associate certain type of information to certain layers. And in a dynamic information system, for example, objects (pieces of information) can jump from one layer to another depending on the relevance of information to a specific layer. For example, we can use the depth layout to plot information in time, where each layer represents a certain instant in time; the first layer

represents the current instant, while further layers represent older instants, which creates a trend tunnel of temporal data.

Thus the depth layout gives the flexibility of displaying different types of information, not necessarily three-dimensional layouts, but can accommodate other types of information that can be represented in depth as mentioned above.

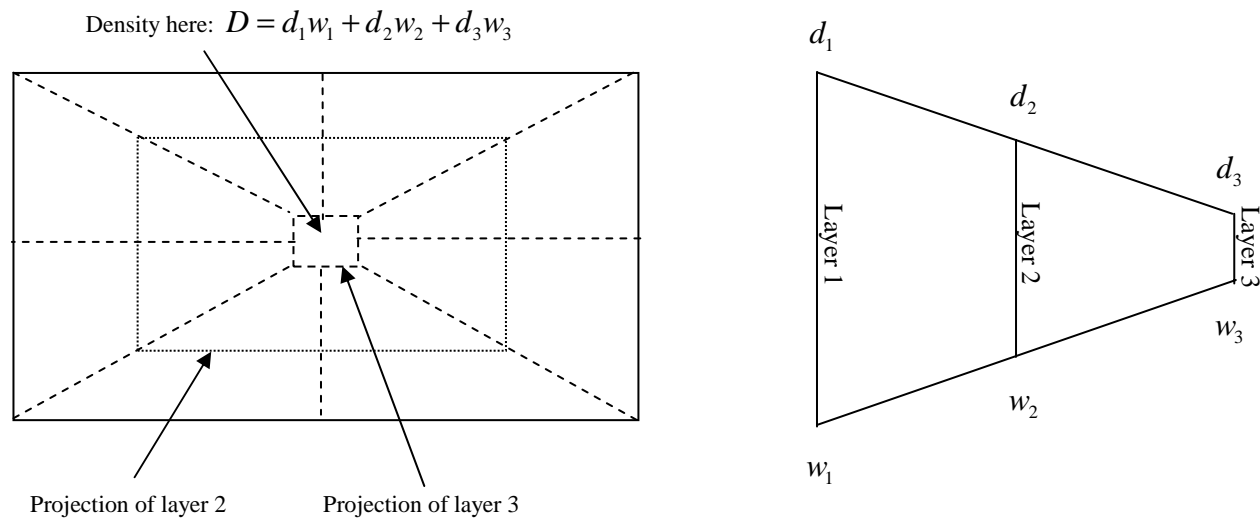
#### *D. Density in Depth Layout*

Our objective from the beginning was to have uniform visual density for an interface, now we turn to the discussion of how depth layout can help us maintain such a uniform visual data distribution.

We have introduced some of the metrics used in density measurement earlier; any of those metrics will be appropriate for analyzing the density in depth layout. To be able to calculate the density of a certain display area, we are faced with two alternatives. One alternative is what Woodruff [2] used in the VIDA system, which is a grid-based model. The two-dimensional layout was divided into grid cells, and each cell's density was calculated separately. If the density crossed a certain threshold, VIDA adjusts the representation of all the objects in that cell to a certain level of elevation which has a reasonable density value. This had the negative effect of mixing different representations in the whole layout, because different cells are treated separately. Mixing representations destroys the underlying data distribution and distorts perception of the layout. Woodruff's justification was that most of us are used to reading maps that has the same feature; some dense areas are missing details that would be present in sparse areas, besides it helps detect outliers instantly. Another alternative for the grid-based model is an object-based model, where the density is a function of the distance between objects (or whatever the metric is using.) The object-based model has the same negative effect of mixing representations; however, it has the advantage of avoiding the grid effect which can result in separate treatment of close objects if they happen to be in adjacent cells.

Any of the two alternatives mentioned above can be used when analyzing the depth layout density. However, we must note that we are measuring the density of the two-dimensional display interface; measuring the density of each layer independently and summing them up will not help. What has to be

measured is the cumulative density of the projection of all the layers onto the display. To avoid such an awkward mathematical manipulation, we will treat each layer separately and similarly. However, each layer will be assigned a *weight* value according to its distance from the nearest layer. For example, layer 1 could be assigned a weight of 1; layer 2 could be assigned a weight of 0.8, and so on. Then each layer is projected onto the first layer and its area of projection is specified. The total density of a certain area is specified by the summation of the weighted densities of all the intersecting projections at this area (Fig. 3.)



**Figure 3**  
**Density calculation in depth layout**

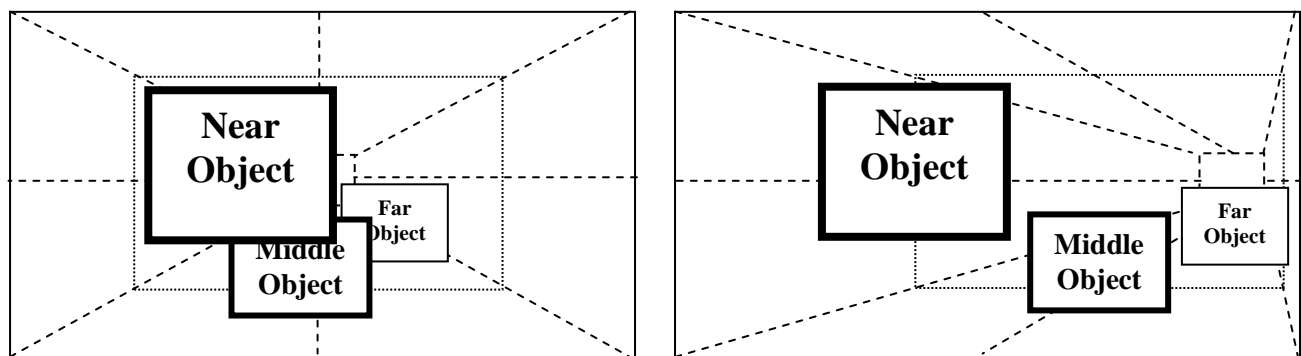
Density of a certain area is calculated as the summation of weighted densities of all the intersecting projections at this area.

If the weights of the layers are specified as  $w_1$  to  $w_n$ , and their densities at the projected area under consideration are  $d_1$  to  $d_k$ ; where  $k$  is the number of intersecting projections, then the total density at the area under consideration is given by:

$$D = \sum_{i=1}^k d_i w_i$$

This measure of density will be the guide to how good or bad the density is uniformly distributed. A comparison between different display areas densities can be a measure of how cluttered or how sparse the interface is. The usefulness of the depth layout interface is that we do not have to stick with the current

layout if the density measure is not appropriate. The layout can be automatically panned or zoomed to a new state where the density measure will be hopefully more uniform. So, for example, if a certain area is found to be over cluttered by some layers, a panning or zooming operation could be performed in a direction that will make the area less cluttered. On the other hand, instead of panning or zooming, the whole direction of the depth layout could be adjusted (Figure 4.) This automatic panning, zooming, or change of layout direction is subject to intelligent operation where the interface design has to allow for intelligent decisions based on certain state of the interface. An intelligent component (such as a fuzzy system or a neural network) could be included in the interface that can handle such decisions. If such an intelligent decision cannot be provided by the interface, a manual operation should be available for the user to adjust the interface while giving him/her feedback on the current density measure. Another way to reduce the density if the interface is cluttered can be achieved by turning off one or more layers. However turning off layers cannot be done automatically since the interface might hide potential information from the user. This decision has to be taken by the user, while the interface might provide some hints on which potential layers can be turned off to improve the overall density measure.



**Figure 4**  
An automatic change in the direction of the depth layout

### *E. Limitations*

To provide a balanced discussion of the proposed method, some limitations have to be pointed out. As much as the depth layout interface provides flexibility by distributing the information between

successive layers based on depth, some applications may not lend themselves to this arrangement because of their inherent nature. Those applications rely mostly on presenting the data in two-dimensional space only. However the depth layout interface can still be used in those applications through some adjustment to the layers functionality. This can be done by turning off all the layers except the first one. Zooming will have to work with one layer only; where the objects will not be shifted to other layers as in the normal case, instead, the objects will stay on the first layer but their representations will be changed according to the direction of zoom. This is the case of the VIDA system.

A second limitation as mentioned in the previous section is that the interface has to automatically pan and zoom in an appropriate way so that the overall density measure is uniform, which requires as mentioned an intelligent component for this automatic adjustment. Besides, such an automatic adjustment needs to consider a number of alternatives, which might be time consuming and not suitable for real time applications.

Third, since the interface now has multiple layers, a decision has to be made on how the information is to be distributed among layers. Such a decision might not be a straightforward task, and may require some analysis of the problem under consideration. However, once the relation between the data and the layers are established, the interface provides a multitude of flexibility to accommodate for new data and new relationships.

#### *F. Summary*

A new method of interface design was proposed based on ecological perception for the purpose of maintaining uniform visual density distribution. The new method, depth layout, provides a way to arrange data in a depth related manner through a perspective structure. The layout consists of layers with which objects are associated based on their depth relativity. The dynamics of the interface were introduced where operations like zooming and panning were explained. A discussion of visual information density was presented for the interface with a method for calculating the density and how to adjust the interface to maintain the required uniform density distribution. Some limitations of the interface were also discussed.

The approach was inspired by ecological optics, and maintained consistency with the theory of ecological perception.

## VI. FUTURE WORK

The area of visual information density has not been given full attention till now. Hopefully this area will get more attention with the emerging technology of small display devices such as hand-held computers and Personal Digital Assistants (PDA's); these devices have a very restricted display space, so a method for making efficient use of display space has to be developed. The work presented here is one way to aid in making efficient use of display space by maintaining uniform distribution of data. However, this work is still in an early stage, a system implementing the depth layout method has to be implemented and tested for appropriateness. The system has to be intelligent enough to make decisions on how to adjust the interface to maintain the required uniformity. Finally, the depth layout interface has to be efficient enough to accommodate real time applications.

## VII. CONCLUSION

The problem of visual information density is closely related to ecological optics. Visual density is part of the perception process, and we have to deal with it on this basis. The approach taken here started off the ecological approach to perception, laying down the concepts and relating them to the problem in a way to better understand it. Concepts of ecological optics such as the ambient array, optical occlusion, invariance, and affordances helped in developing the basis for inspiring the approach taken in this paper. The approach was based on depth layout which is a more natural metaphor than normal two-dimensional layouts. It introduced new affordances into the interface, while keeping the invariants of the perspective structure. Those affordances introduced flexibility into the interface and made it possible to maintain the required uniform distribution of data. This approach is believed to be a better way to tackle many areas in interface design where other methods might fail.

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