The Tactile Depiction of Visual Conventions: The Advantage of Explicit Cues

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The introduction of representational standards for tactile diagrams might improve their use. Two elements central to the design of visual diagrams are the relative positioning and movement of the objects yet no standard convention for representing either of these in tactile form has been established. Consequently, systems representing the movement and relative positioning of objects were developed with the intention of producing design conventions for these elements. The method of depicting the element of movement was based on the concept that an object's movement is defined by changes between its initial and final positions while the method of depicting relative positioning was based on a number of the principals underlying linear perspective, along with an additional texture-based cue. Tactile diagrams making use of these systems of representation were designed and produced for exploration by eight blind participants. They were confident and accurate in their interpretations of diagrams that depicted relative positioning of objects and, on the basis of their comments on the diagrams depicting movement, a convention for the depiction of movement was proposed.

Introduction

Graphical sources of information have become central to the running of modern society. Examples of this are manifold: much early education makes use of pictures not just for the purpose of illustration but as a means by which to enthuse and attract the attention of pupils; signs and maps utilise visual heuristics in communicating information; and business is increasingly dependent upon computer-based technology which in turn is becoming increasingly dependent upon various forms of graphical user interface (GUI). Many of the benefits derived from the use of images at home, in education and in the workplace - indeed, throughout modern society - can be attributed to the reduction in verbal processing demanded of the user by the use of graphical information; an image can be interpreted with greater speed and less effort by more people than its verbal equivalent.

The benefits that the use of images affords are attractive to all but only available to some: as it is of a largely visual nature this 'informational boon' has in general been denied to blind and partially sighted users; and in many situations, perhaps most notably in computing, the introduction of graphical information has significantly worsened the lot of blind people (Petrie & Gill, 1993). It is understandable then that equivalents to graphical information, mediated via audition and touch, should be considered as information sources of considerable potential for blind people.

Approaches taken to the design of tactile equivalents to visual representations (which for the remainder of this Paper will be referred to as "tactile diagrams") can be divided into three strands. The first is based on guidelines developed by experienced tactile designers many of which address, for example, object orientation and the elimination of extraneous detail. Edman (1992) and Levi and Amick (1982) encourage the labelling of objects with explicit texture cues and where necessary the use of multiple diagrams as illustrations of various facets of a single scene. It is to be noted, however, that certain such guidelines may represent an underestimation of conceptual ability of blind people, particularly in the case of two-dimensional (2D) representations of three-dimensional (3D) 'real world' relationships.

A second approach is the scientific examination of the aspects of visual representation that can be represented effectively in tactile form. This has supported many of the guidelines above in presenting, for example, empirical evidence for the many benefits to blind people through the use of verbal context in tactile diagrams in terms of the effective identification and recall of objects (Pring, 1987; Heller, Calcaterra, Burson & Tyler, 1996). Further to this, evidence has been presented that suggests that people with no visual experience can interact quite effectively with 2D diagrams that depict certain aspects of 3D relationships (Heller & Kennedy, 1990; Heller, Calcaterra, Tyler & Burson, 1996).

The final approach is the study of the nature and limitations of the haptic sense. Considerable evidence has been presented to suggest that there exist certain fundamental differences between vision and touch, i.e. the haptic sense is not simply a touch mediated equivalent to vision (Loomis, 1993). These functional disparities are well illustrated by the differences between the senses in the performance of object identification. Each sense is primarily driven by features that are not generally available to the other: vision by the object's colour and apparent shape; haptics by more material, structural, features such as the object's texture, weight and overall contours (Klatzky, Loomis, Lederman, Wake & Fujita, 1993). On the basis of these differences it is argued that the use of tactile equivalents of visual representation is an inefficient method of communicating information to blind people.

The issues addressed by these bodies of research cannot at present be resolved with any degree of confidence. This is because there currently exists very little direct interaction between them. The methods applied in each vary considerably; much research into the haptic identification of objects, for example, uses experimental items that are in clear contradiction of the guidelines presented by experienced diagram designers not only in terms of the concepts presented (which is, on occasion, a necessity) but also in terms of clarity. In addition, much research has employed comparatively inexperienced tactile diagram users because there is no consistent method of teaching people how to interact effectively with tactile diagrams. Another reason is a lack of consistency in diagram design.

It is therefore desirable that conventions related to tactile representation be established. Such systems would allow the introduction of consistency to diagram design and, consequently, the development of effective training in their use. With improved training it is probable that people will become considerably more competent and confident in interactions with tactile diagrams.

The Study reported here is an attempt to develop conventions for the tactile representation of two design elements central to visual depiction, the movement and the relative positioning of objects. The representation of movement is common to many forms of diagram, particularly those related to the sciences, but there is no single established method of depicting this element in visual diagrams (Figure 1). While this is perhaps acceptable in a vision-based domain such inconsistency is most impractical in tactile diagrams.

The use of linear perspective in visual representation is extremely common. It is a convention that not only attempts to depict the identity but also the relative positioning of objects. This is achieved through a number of manipulations of the basic appearance of an object, such as varying its apparent size and position dependent on its distance relative to the viewer (Figure 2) or allowing nearer objects to occlude more distant ones (Figure 3). The ultimate aim of perspective is to mimic the visual experience (Dubery & Willats, 1983). Because of its close relationship with vision the use of perspective in tactile diagrams is generally discouraged (Edman, 1992). However, this is to overlook the fact that regardless of its verisimilitude the convention of perspective is just that; a convention, a series of representational rules that can, theoretically, be learned; it is not necessarily the case that visual experience is required to interpret them successfully.

It is proposed that through the introduction of explicit texture-based cues visually impaired people will be able to grasp the relative positioning and size of objects and any movement made by them depicted within a basic perspective system.

Method

Participants

The eight participants in this Study, all volunteers, three female and five male, ranged in age from 27 to 57; four were blind from birth and all had lost most useful vision by the age of three. Loss of sight varied from accident to congenital conditions. All reported considerable experience of braille but somewhat less of tactile diagram use for education, recreation and work; and all reported a lack of training in tactile diagram use.

Materials

The tactile diagrams were designed on a computer art package, printed onto paper and then transferred to swell paper to produce seven sets of diagrams. Each set examined a different aspect of tactile perception or visual representation (Table 1 and Appendix B).

1. The Basic Shapes set was intended to ascertain whether participants would be able to interact effectively with the diagrams that were to follow.
2. The Relative Distance set addressed the depiction of objects at various distances: two standard diagrams depicted objects of the same actual size at various distances; four further diagrams featured depictions of objects of varying actual sizes placed at the same relative distances as the objects represented in the standard diagrams.
   An explicit distance cue was introduced for these trials which graduated from filled shapes, representing foreground objects, to outlines representing objects in the background, and objects of an intermediate relative distance were filled with a dotted texture.
3. The Occlusion diagram set made use of the explicit distance cue featured in the Relative Distance set and introduced the concept that nearer objects may appear to overlap more distant ones.
4. The Movement diagram sets presented various depictions of movement. Each diagram featured two circles representing the start and end points of the object's movement between which there were placed various patterns to represent the nature of the movement in terms of speed, direction and smoothness.

4a. For the 2D Movement set the moving object remained at a constant distance relative to the viewer throughout transit and thus retained its apparent size.

4b. The 3D Movement set presented objects whose relative distance and, consequently, apparent size (and fill texture) changed as they moved, i.e. the object either approached or retreated from the viewer. These diagrams examined the readiness of participants to apply the concepts introduced in one context to another, in this case Relative Distance to Movement.

5. Non-Textured diagrams featured elements that appeared in the perspective and movement trials but all traces of the explicit distance cue (illustrated in Table 1 and used in diagrams 6-18 and 24-28, Appendix B) were removed leaving only outlines of shapes. The inclusion of these texture-free diagrams assessed the contribution made by the explicit distance cue to performance with the textured diagrams.

6. The Alternative Textures diagrams presented three different texture gradations to represent increasing relative distance. These were included to assess whether any texture might be preferred for use in future research.

Pilot Study

A Pilot Study addressed issues related to tactile perception and visual representation.

Participants were presented with tactile diagrams that made use of the same concepts addressed by the main study: shape identification; movement; and relative positioning. Also presented in the Pilot Study diagrams were depictions of foreshortened cubes. None of these stimuli made use of the explicit distance cue.

Participants had difficulty in describing 3D relationships and were unable to decipher diagrams that made use of foreshortening. On the basis of these findings, the selection of items to be presented in the main Study was made.

Procedure

After agreeing to take part in the Study, and to having it audio-recorded, participants were asked some general questions about their age and visual status and then the tactile diagrams were presented. The general procedure followed with all diagram sets was that each diagram was presented successively at the orientations and in the order shown in Appendix B. While exploring each diagram participants were asked appropriate questions (Appendix A).

For Basic Shapes diagrams (1-5, Appendix B) participants were asked to inspect each and then describe the four shapes. With diagram 4, which featured circles and ellipses, participants were expected to mention size; with diagram 3, which featured parallelograms and trapezia, they were expected to consider the extent of the angles used. It should be noted, however, that these expectations were not made explicit; participants were simply asked to identify and describe the presented shapes.

For Relative Distance diagrams (6-11, Appendix B) participants were informed that each was constructed from squares of varying sizes and a reference line. The squares had three possible fill textures: entirely filled, representing close proximity; a dotted pattern, representing intermediate distance; and unfilled, representing greatest distance. Participants had this cue to distance introduced at the same time as certain principles of linear perspective (apparent size and position dependent upon actual position) as they explored two standard diagrams: the first (6) featured only two shapes where participants were informed that these represented two objects of the same actual size at different distances; the second (7) featured three shapes, again representative of objects of the same actual size at different relative distances. For the remaining diagrams (8-12) they were asked to describe the scene depicted in terms of the actual relative sizes and distances of the objects, i.e. 'Object X is further away than object Y but appears to be the same size; therefore, object X must be larger than object Y'. A diagram was considered to have been fully explored once the depicted relationship had been fully described.

For Occlusion diagrams (12-18, Appendix B) participants were informed that each was constructed from two or three shapes that overlapped and were filled and positioned appropriate to the depicted 3D relationship, i.e. if one shape depicting an object overlapped another the overlapping object was defined as nearer and textured appropriately. Participants were asked to describe these diagrams in a similar fashion to the Relative Distance diagrams. In addition to the actual relative size and distance of the depicted objects the issue of object identification was of interest. Participants were therefore asked to identify the presented shapes and then to describe their depicted relationship. Once this had been performed successfully the diagram was considered to be fully explored.

For 2D Movement diagrams (19-23, Appendix B) participants were informed that the two circles featured in each diagram represented the start and end points of an object's movement and the pattern between the circle represented the movement itself. They were asked to describe the movement in terms of direction, speed and quality, or 'smoothness', of the movement and to state how effective a representation of movement each pattern was.

For 3D Movement diagrams (24-28, Appendix B) participants were informed that these were again representations of movement, and again they were asked to describe the type of movement and rate each movement pattern's effectiveness. If they had difficulty with the added 3D information, i.e. that objects could move towards or away from the viewer, they were encouraged to consider what the depth cues on the previous perspective diagrams (6-12, Appendix B) had signified. Particular attention was paid to descriptions of the direction of movement and whether movements towards and away were correctly identified.

For Non-Textured diagrams (29-35, Appendix B) participants were informed that these featured no fill textures but retained all other aspects of perspective and movement applied in previous parts of the experiment. They were then asked to describe the relationships depicted in these diagrams and also whether they had any preference between diagrams that utilised outline only and those that featured textures.

For Alternative Textures diagrams (36-38, Appendix B) participants were asked to inspect three alternative gradations of texture that might represent relative distance and to assess them in terms of clarity.

Results and Discussion

A detailed breakdown of performance can be found in Table 2.

Basic Shapes

Performance with the Basic Shapes diagrams was generally good. Only two errors occurred: where two participants failed to differentiate between circles and ovals. There were also difficulties reported within diagrams that featured polygons with large numbers of sides (seven or more). One participant was unable to differentiate between circles and polygons of this level of detail whereas another described all shapes of six sides or more as hexagons. As the number of sides on a regular polygon increases each side decreases in length and the angles between sides become progressively less acute, thus making differentiation between lines increasingly difficult.

Apart from this, participants identified shapes with a high degree of accuracy, speed and confidence; slight changes in shape dimensions, such as those occurring between a circle and an oval or between parallelograms of slightly different slants, were recognised consistently and without prompting by all participants.

The strategies used when exploring Basic Shapes varied considerably. Most used hand movements and many applied special measuring techniques, one of which identified a shape with an even number of sides by finding parallel lines and counting them in pairs which greatly reduced identification time.

Performance on these trials allowed several conclusions to be drawn. Of primary importance was that the diagrams for the remainder of the Study, whose constituent elements were such comparatively simple shapes as squares and circles, were not inherently difficult to recognise. Consequently, any problems arising in the exploration of the tactile diagrams depicting visual concepts would be the result of the concepts depicted within the diagrams rather than any inaccessibility of the depictions themselves.

It seems that there exists some variance in the ability to identify accurately polygons with large numbers of sides. That this variability did not emerge in exploration of any of the other Basic Shapes is possibly indicative of a 'ceiling effect'; the arrays of stars and ellipses were not of a difficulty to elicit effects similar to those found with polygons. The variance itself possibly resulted from differing levels of cutaneous acuity or the variety of exploratory techniques. It is, therefore, desirable that the many techniques used during tactile exploration should be investigated further and recorded. It would also be of benefit to establish currently acceptable levels of diagram design in terms of the detail, size and quantity of elements depicted.

Perspective: Relative Distance and Occlusion

While there was some variance in the readiness with which participants adapted to the explicit distance cue, all trials were successfully performed with increasing confidence and ease. It is significant that in understanding each diagram as the interview progressed they made frequent reference to the explicit distance cue and to the relationships between apparent size, actual size and the relative distance of objects.

Physical relationships between objects depicted in an occlusive relationship were described with little difficulty and considerable accuracy. The introduction of an additional cue to relative distance had little influence on judgments; the factors that were pertinent to relative distance diagrams remained predominant in Occlusion trials.

On the basis of these findings it is reasonable to suggest that blind people can successfully interact with depictions of perspective in spite of the convention's basis in visual experience. It might further be stated that the explicit distance cue was central to these interactions. That the introduction of occlusion failed to enhance performance on these trials is no reason to argue for its exclusion from tactile diagram design; occlusion's importance can only be demonstrated in situations where information associated with the specific positioning of objects is a priority. The ability of participants to name partially obscured shapes such as circles and polygons of various numbers of sides suggests that certain aspects of 'visual imagery' may exist in blind people and that they were employed while exploring Occlusion diagrams. The extent to which this is actually the case is a matter for further research.

There remain some concerns regarding the Relative Distance and Occlusion trials. While the presented physical relationships were verbalised effectively by participants, a practical understanding of perspective was not necessarily demonstrated. It is desirable, therefore, that the extent to which blind people can apply information extracted from tactile diagrams to the physical world is assessed. To that end a study will be carried out which addresses the ability of blind people to reproduce with real objects simple 3D relationships as depicted in tactile diagrams reversing a process described by Heller and Kennedy (1990). Only the successful performance of a task such as this will confirm that the depiction of 3D relationships in tactile diagrams can benefit blind people in a genuine, practical fashion.

Movement

Throughout all Movement trials participants demonstrated a definite understanding of motion; that movement has both a start point and an end point. They also frequently referred to the direction and velocity of object movement.

The 3D Movement trials addressed the application of the explicit distance cue, as introduced in the perspective diagrams, to the novel context of movement. Participants varied in the time they took to interpret this abstraction but, as was the case with the Relative Distance trials themselves, they were all able to give accurate and confident descriptions following the presentation of two diagrams. While describing the direction of movement was ultimately not problematic, it should be noted that responses were often of an over-specified nature. Terms such as "rolling", "bouncing" and "flying" rather than simply moving were frequently used. This could be explained by the fact that the movement diagrams all featured a circular object that might well have been interpreted as a ball. Further research into the representation of movement should utilise shapes that do not lend themselves to similar confusion.

A convention viewed favourably by participants as a representation of movement was a combination of two of the patterns presented in the Movement trials. They repeatedly interpreted arrows (Figure 4) as representing fast movement and curves (Figure 5) as slow movement with the 'points' of the arrows and curves representing the direction of the movement; in Figures 4, 5 and 6 all movement flows from left to right. A cue featuring a gradation between these two extremes might allow effective and accurate depictions to be made of both the changing velocity and direction of an object's motion (Figure 6). Movement diagrams that utilised dotted lines as part of the movement cue (Appendix B) were viewed quite unfavourably. Dotted lines were considered more representative of a physical joining of the start and end point shapes. A further point made by participants was that the movement cue should not change in size as in the 3D Movement diagrams because the start and end point shapes, coupled with the changes in fill texture, were sufficient cues to changes in relative distance.

Non-Textured Diagrams

Participants successfully identified the relationships in the non-texture diagrams but stressed that this was because of their familiarity. It was repeatedly stated that these diagrams would have been considerably more difficult, if not impossible, to interpret accurately had their textured equivalents not directly preceded them. This was particularly the case with occlusion diagrams. Statements such as these are supported by comparisons between performance in this Study and in the Pilot Study where all participants had considerable difficulty describing depictions of 3D relationships and most were unable to do so at all. The comparative ease with which all of them managed to interpret the textured diagrams in this Study suggests that the presence of the explicit distance cue substantially improves the interpretation of perspective in tactile diagrams.

Alternative Textures

Feedback on the three alternative textures was consistent but failed to provide any single preference. All were of the opinion that the gradations in the striped texture cue were more difficult to differentiate than those in either of the dotted textures. In retrospect, the explanation for this is obvious; stripes vary in only the one dimension of breadth whereas dotted textures vary in length and breadth.

Participants had difficulty in deciding on a preference between the dotted textures where both sets of gradations were considered equally acceptable. They were in agreement nonetheless that the 'litmus test' for these textures is the depiction of the small shape which might not provide the necessary space to allow an assessment of texture concentration, while a texture cue, whose elements vary only in size, may unintentionally fill an object entirely and be indistinguishable from an intentionally filled object. Before this issue can be realistically solved acceptable stimulus size must be determined.

Conclusions and Recommendations

Performance in interpreting the tactile diagrams presented over the course of this Study was very promising in terms of its implications for tactile diagram design. Identification of basic polygons was generally effective as was differentiation between ellipses of varying size and extent (although this aspect of the research must be extended before any definite conclusions may be drawn).

It is clear that blind people can successfully interpret tactile diagrams that utilise linear perspective in depicting the relative position of objects. The introduction of an explicit distance cue improved both the accuracy of interpretations and the confidence with which participants made these interpretations. Further research is necessary to establish whether certain aspects of perspective are more a hindrance than an aid to tactile diagram exploration by blind people. However, certain aspects of the system applied in this Study, particularly the explicit distance cue, appear to lend themselves strongly to the development of a convention for depicting the relative position of objects.

On the subject of movement, the consistency of comments on the nature of the movement cue suggests that the overall method of depicting movement - the concept of movement as a process between a start and end point - was consistently understood. Furthermore, there exists clear potential for consensus on the specific nature of a convention for the depiction of movement.

The idiosyncratic nature of the strategies used by participants while exploring the tactile diagrams in this Study may be a symptom of the lack of standardised training methods in tactile diagram use. Strategies that prove beneficial to performance should be identified and recorded, reducing the currently dramatic heterogeneity of tactile identification techniques and, hopefully, effecting a general improvement in tactile acuity.

It is evident that limits exist to the level of detail that even basic shapes may possess before becoming difficult to interpret. Although these limits are likely to change for the better once a training system becomes established and general tactile expertise improves, the acquisition of knowledge related to currently acceptable levels of stimulus presentation - size, quantity and detail - should be of prime importance to designers of tactile diagrams.

The introduction of an explicit distance cue has made the depiction of 3D relationships a realistic possibility and, furthermore, has suggested the possible existence of certain aspects of 'visual imagery' in congenitally blind people. The ability to transpose verbal responses to 'real world' applications is yet to be assessed.

A further cue representative of movement has been proposed and is to be investigated further. The combination of these two cues, perspective and movement, was easily described by participants. On the basis of their comments, which were extremely consistent, a number of guidelines and conclusions emerged:

- Diagrams making use of an explicit distance cue appear to be understood with greater ease, confidence and accuracy than those based purely upon outlines.
- The explicit distance cue, and its contribution to the understanding of perspective, should be assessed further in terms of its applicability to 'real world' interactions.
- Any movement cue should contain an element associated with the direction of movement.
- The movement cue should remain at a constant size to facilitate its identification.
- Certain patterns, such as dotted lines, are to be avoided in the depiction of movement because they are perceived as representing a physical connection between two separate objects rather than as the movement of a single object.

This Study has demonstrated that tactile diagrams may communicate a great deal more 'visual' information to blind people than is generally permitted or encouraged in tactile diagram design at present. Standard representational 'codes', of which two were introduced in this Study, act to reduce the level of processing of tactile information necessary to allow an effective understanding of complex physical relationships. Should they be numerous enough and prove as effective as those reported in this study, such reductions may remove many of the limitations currently imposed upon tactile diagram design.

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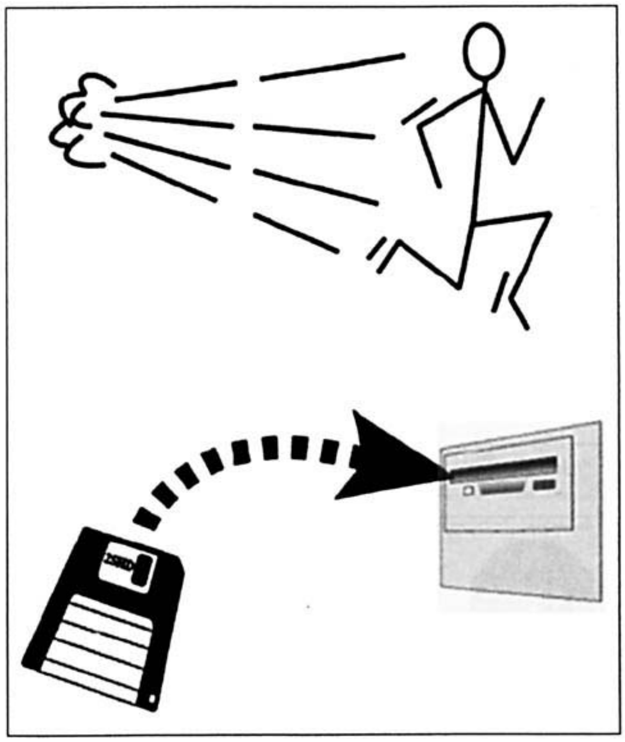

Figure 1: Graphical methods of representing movement.

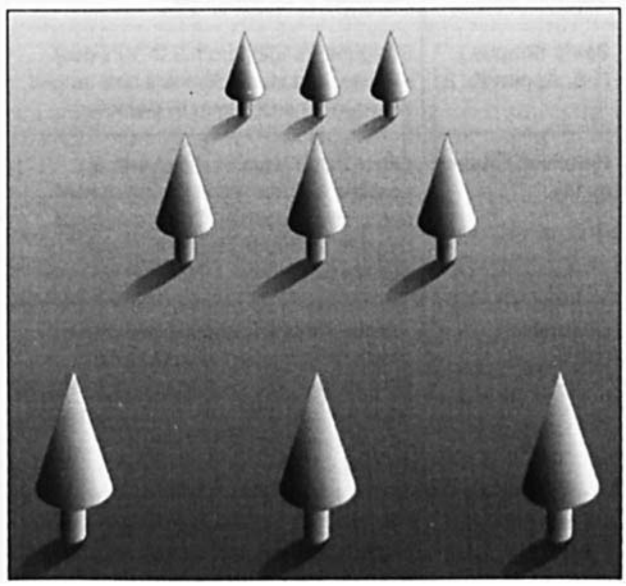

Figure 2: Nearer objects are depicted as larger; their separation appears greater.

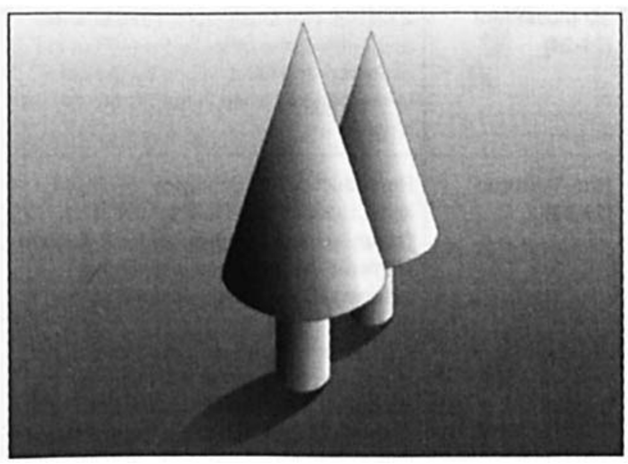

Figure 3: A closer object is shown to occlude a more distant one.