Dynamic Perceptual Objects

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Abstract. A perceptual object is created when an observer perceives a single "thing" even though it is comprised of separately perceptible components. A perceptual object has permanence across changes in position and, within limits, changes in the arrangement or composition of the constituent parts. The present research is an examination of the emergence of perceptual objects solely from the dynamics of data presentation. Ten participants viewed presentations of dot patterns that varied in persistence, color, and opacity. Half the presentations were set to have parameters optimized to promote object perception. The same data were also presented with other (non-optimized) settings. Participants correctly detected about 95% of the targets presented with optimized settings and less than 5% of the same targets with non-optimized settings. There were very few false alarms. Participants perceived a unitary object that was hopping from place to place on display despite changes in speed, direction, or color.

Keywords: perceptual objects, beta motion, user interface, big data.

1 Introduction

The human visual perception system readily organizes the visual field into objects, and actively constructs missing attributes needed to complete those objects. Early Gestalt theorists noted that people tend to perceive the whole rather than the parts, and readily distinguish a figure from the ground [1]. The perceived object retains its identity across changes in perspective created by motion of the object or the observer, or both. Although the change in perspective may create significant distortion in the image that falls on the retina, the unity of the object is preserved. This perceptual capability emerges in infancy [2], and degradation of the capability may indicate a neurological disorder [3].

Object attributes that are perceived include direction and magnitude of motion. Perception of object identity is retained across changes in motion, spin, or rotation. These tendencies can be readily demonstrated with common everyday objects in the real world (e.g., cups and saucers), and with simple geometrical shapes presented on a display.

Given this robust tendency to organize individual components into higher-order objects, user interfaces may be designed to promote perception of objects even though only the individual components are plotted on a display. There has been considerable

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interest in discovering the principles that govern object perception, to provide guidance to display designers regarding effective graphical displays [4]. Creating a reliable perception of an object requires that the arrangement of the components matches human perceptual tendencies. It is particularly useful if object perception is intuitive for the observer. For example, a circle, two dots, and an arc, arranged within certain constraints, are perceived as the common "smiley face", not as four separate components. Outside those constraints, no face is perceived.

Matching human perceptual tendencies is important for visualization techniques to be effective. Visualization techniques should attempt to amplify cognition – not strain it [5]. One desirable property of a visualization technique (and perhaps a measure of its utility) is whether it promotes a rapid, intuitive understanding of relationships in the data in comparison to a tabular form [6]. The value of intuitive visualization is increased when dealing with large data sets, where inspecting a tabular representation of the data might not be practical. Visualization techniques that promote object perception could greatly increase understanding of relationships and trends in the data while greatly reducing the time required to achieve that understanding.

Dynamic elements in a perceptual object may convey information. For example, a gradual change in the orientation of the arc that comprises the mouth of the smiley face can convey emotion change from happy to neutral to unhappy ("frowny face"). In the present research, we examine perceptual objects that arise solely from the dynamic properties of components.

Presentation of images in rapid succession is the basis for motion pictures. The resulting perception of apparent motion, even though each image is a still frame, is called the phi phenomenon [7]. Motion is reliably perceived as long as the frequency (in frames per second) is sufficiently high, and the continuity of objects across frame is sufficiently consistent. The resulting perceptual experience is quite like the real world. If playback speed is too slow, jerkiness or disjointed movement may be perceived. If slower still, the presentation will be perceived as successive still frames.

A related phenomenon is beta motion [8], which is often created by on/off patterns of points of light (such as on a neon advertisement sign) in which adjacent elements are turned on or off in rapid succession, creating the perception of a moving ripple or wave proceeding across the array of elements. With beta motion, the perceptual object is an anomaly in the visual field that is moving systematically. It does not necessarily have a perceived identity.

In the present research, we demonstrate the emergence of dynamic perceptual objects in the presence of random dots that appear and eventually fade (or disappear completely) from a display. This perception is related to beta motion, but does not match the usual definition of beta motion. During the design of a fast replay capability for a sensor system, we noted the occasional emergence of beta motion (or at least something akin to it) when the replay was set at just the right speed and persistence to just the right level. At substantially slower or faster replay speeds the perception of motion did not occur. With no persistence or with permanent persistence, the perception was unlikely to occur. A given set of playback parameters (speed and persistence) did not create the effect for all data sets, because those sets were collected on different time scales. Clearly, the important parameters were related to the rate at which adjacent areas on the display (and consequently, on the retina) changed states.

As an analogy, consider the playback of weather radar data. If the playback speed and other parameters are within certain bounds, an observer can readily perceive the movement of a storm cloud or a weather front. For this perception to occur reliably, the playback speed (expressed as a multiple of real time) would be different for slow-moving clouds versus faster moving clouds. Data depicting slower moving clouds would need a faster playback speed, compared to faster moving clouds, to create an accurate perception of the speed and direction of movement of the cloud. Moreover, the playback speed would also vary for different range scales of the map. More zoomed-in range scales could be viewed at a slower playback speed than more zoomed-out range scales. What matters is the rate at which adjacent areas of the display change state. There is a range of values over which accurate perception is likely, but outside those ranges, accurate perception becomes less likely, and potentially unlikely. Optimizing the display presentation to promote accurate perception of object motion requires consideration of the rate of change of position of the object. The purpose of the present research was to demonstrate that optimized settings for presentation of dynamic data promote intuitive perception of moving objects, compared to non-optimized settings.

2 Method

2.1 Participants

Participants were five male and five female volunteers, ranging in age from 18 to 49. All had normal or corrected-to-normal visual acuity. All participants were friends and acquaintances of the investigators.

2.2 Equipment and Simulated Data

Ten synthetic data sets were created from a software simulation. Three were used in engineering development but not in the experiment. Two were used for training and the other five were used in evaluation. In each set, from one to three targets were present, with a random starting position in an arbitrarily defined x-y plane. At each time step in the simulation, one quadrant of the plane was sampled, and approximately 75 to 125 random false contact reports were generated, randomly located in the quadrant. On successive time steps, a different quadrant was sampled. When a target was present in the quadrant, a true contact report was generated at the target location. Thus for every target contact there were about 300 - 500 false contact reports. Each target was scripted to follow a designated path. Across data sets, no path of movement was replicated. Some targets left the plane before the simulation concluded. Some stopped altogether but remained in the plane; others paused and resumed motion. Some targets moved in a straight line, but most changed direction at least once; some changed often. Figure 1 depicts the pattern of motion for the two training and five evaluation trials.

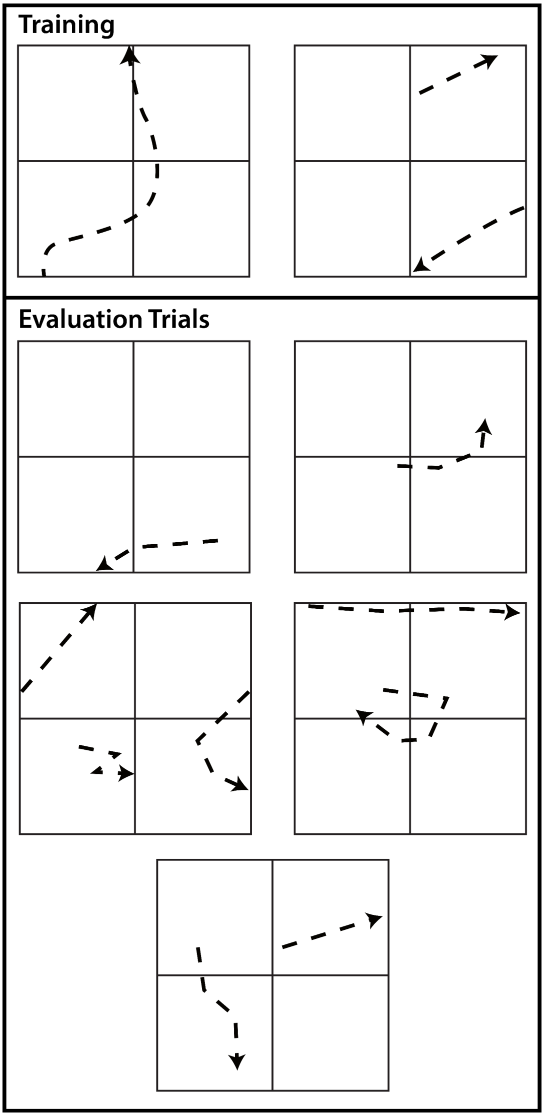

Fig. 1. Target motion in two training and five test trials

The playback software was configured with a designated set of playback parameters as shown in Table 1. Each of the five data sets was played back with two different parameter sets, one intended to promote object perception (optimized, or "good" parameters), or not to do so (non-optimized, or "bad" parameters). The notation in Table 1 shows the data set (4, 5, 8, 9, or 10) and the good (G) and bad (B) parameters. The playback software was allowed to loop (repeat) the playback three times, and the computer screen video was captured and stored, to provide a uniform playback for presentation to participants. All contacts were plotted as small colored dots on the display. The target color was always either magenta (for the entire trial) or red and blue (switching color one or more times during the trial). Distractors (false contacts) were always the same color(s) as the target, and on some trials, there were also green distractors. The target was never green. Persistence was set to control how long a given contact dot remained on the screen independent of the playback speed. For the experiment, playback speed was held constant at approximately 6 Hz, which resulted in an update of target position at a rate of about 1.5 Hz, given the quadrant stepping procedure employed. At this playback rate, each playback loop was approximately 15 s in duration. The captured video files, with three loops, were about 45 s in duration.

Table 1. Playback parameters for evaluation trials

Trial ID	Target Color	Distractor Color	Persistence
4G	Red & Blue	Red, Blue, Green	3 cycles
4B	Red & Blue	Red, Blue, Green	10 cycles
5G	Magenta	Magenta, Green	4 cycles
5B	Magenta	Magenta, Green	12 cycles
8G	Red & Blue	Red, Blue	4 cycles
8B	Red & Blue	Red, Blue, Green	1 cycle
9G	Magenta	Magenta	4 cycles
9B	Magenta	Magenta, Green	10 cycles
10G	Magenta	Magenta, Green	3 cycles
10B	Red & Blue	Red, Blue, Green	12 cycles

The key distinction between the good and bad parameter sets was the persistence setting. The optimized values were to persist the contact for either three or four cycles, whereas the non-optimized values were one, ten, or twelve cycles. With three or four cycles of persistence, the target contacts formed a train of three or four dots, and as a new dot was plotted, a previous plot from three or four cycles ago was removed. With just one cycle of persistence, each new plot of a target contact was coincident with the removal of the previous plot, thus no train of dots ever formed. With ten or twelve cycles, target contacts remained on the display longer and the resulting train was ten or twelve dots in length.

During the experiment, the captured screen video was played back on a laboratory computer under experimenter control. The display resolution for the captured video was 760 x 760, both when captured and when played back.

2.3 Procedure

Each participant reviewed and signed the informed consent form prior to participation. The experimenter provided a brief overview and explanation of the experiment, and demonstrated the software, pointing out the appearance of a target-like object hopping across the screen. Participants were instructed to verbally report they spotted a moving object and to point to it on the display. Training was provided, initially featuring targets whose motion was relatively straightforward to spot. A second training trial was provided, featuring target motion that was more complex. Participants were allowed to ask questions until they were confident they understood the task.

Each participant then viewed ten evaluation trials, consisting of five data sets presented twice each (once with good parameters and once with bad, as summarized in Table 1). The presentation order was randomized for each participant, constrained to ensure that each participant received a unique presentation order, and that presentation of a given data set with good versus bad parameters first was balanced across participants.

During a given trial, the experimenter confirmed that the participant was ready, and then initiated the video playback. The participant watched the video and verbally announced when he or she spotted a moving object. The experimenter recorded responses on a coded sheet that depicted the actual target location and movement for that trial. If the participant did not detect the object during the first replay (i.e., the first three loops), the presentation was repeated for an additional iteration of three loops. For each trial, the experimenter recorded which of the targets were detected (hits), which were missed, and any false alarms reported by the participants. The experimenter also noted if a correct detection was made immediately at the onset of data playback (i.e., before the playback restarted for the second loop.)

3 Results and Discussion

Performance across the five good and five bad trials is summarized in Table 2. Participants readily perceived the target in motion on nearly 95% of the good trials, and on less than 5% of the bad trials. In fact, only one of the ten participants correctly detected target motion on any bad trial. All but one participant correctly identified at least one target on all good trials; the one exception missed detecting a lone target on just one trial. All the correct detections occurred on the first iteration of the video playback.

Table 2. Summary of overall performance across evaluation trials

Trial ID	Positive ID	False Alarm	Miss	Immediate
4G	90%	0	10%	70%
5G	100%	3	0%	30%
8G	90%	0	10%	70%
9G	95%	0	5%	60%
10G	100%	1	0%	30%
4B	10%	1	90%	0%
5B	10%	0	90%	0%
8B	0%	0	100%	0%
9B	5%	3	95%	0%
10B	0%	0	100%	0%

There were only eight false alarms across all participants. Seven of the ten participants made no false alarm reports. One participant reported four of the eight false alarms.

As mentioned, the experimenter also recorded if a correct detection was reported immediately, that is, during the initial playback rather than after it had begun the second loop of playback. Over half the correct detections were made immediately. This finding indicates the participants intuitively perceived target identity and motion.

Across the range of non-optimized parameters that were tested, it was virtually impossible for participants to detect the target. Within the range of optimized parameters, though, the target became quite conspicuous – virtually impossible to miss, even for naïve observers. The persistence setting was the key parameter. With persistence set to three or four iterations, the resulting train of dots appears to hop across the screen, and preserved its identity as a moving object even when it changed direction or its color. With persistence set to just one cycle, each target contact plot disappeared as its successor appeared, and thus no train of dots was ever formed. For the longer persistence settings (ten or twelve cycles), a train of dots would form, but the high number of false contacts that were also appearing in close proximity interfered with object perception. With the optimized parameters, the target was perceived as a train of dots marching across the display. Participants readily perceived it as a single object that was moving across the display – not as a pattern of successive dots from which the presence of a target could be inferred. These perceptual objects emerged purely from the dynamic properties of the succession of dots, and were not dependent on color or any other attribute to reinforce the object permanence.

The playback speed was held constant in this experiment. In engineering development, it was clear that the combination of playback speed and persistence was a key combination. In particular, much slower playback speeds made it more difficult to perceive target motion. The playback speed chosen for the current experiment produced a target update rate of about 1.5 Hz. Our informal observations were that update rates of about 1.0 Hz still produced the effect reliably; below about 0.5 Hz, though, the effect was unreliable, even with optimized persistence settings. We plan to systematically vary this parameter in future experiments to get a better estimate of the range of effective combinations of update rates and persistence settings.

We also did not systematically vary the distance between the successive contact reports. We did allow targets to momentarily stop and then resume motion, but in general the moving targets moved at about the same speed while in motion. This parameter – the distance between the successive dots – is undoubtedly also important, and will need to be parsed in future experiments.

4 Conclusions and Recommendations

We were able to create dynamic perceptual objects by controlling the parameters of data presentation to produce an update rate of about 1.5 Hz for contacts of interest. This rate of presentation did not produce dynamic perceptual objects unless the persistence was set to preserve only two or three previous contacts. The result was the perception of an object, consisting of three or four dots, which appeared to hop across the screen, perhaps changing color or direction. The apparent motion produced by this technique is likely related to beta motion, but the perception was of discrete jumps, not smooth motion. The perception was immediate and intuitive. This phenomenon can be used to help design displays that replay data with a large number of distractors in such a way as to allow the observer to readily detect a moving object in the presence of those distractors.

An obvious application is in presentation of data sets that involve geographic-based plots of potential contacts of interest over time. These data sets could be related to security threats, hard-to-detect contacts such as members of endangered species, or any other object of interest that is at least occasionally in motion and might be detected at a specific location at a specific time.

There is no particular reason why the x-y plane used for this technique must be geographic-based. It could be used for any coordinate system where systematic trends over time are of interest. For example, it could be applied to changes in economic data over time, or changes in opinion over time. For coordinate systems that are not geographic-based, the chosen axes should be continuous (for all practical purposes), and have meaningful ordinal properties.

Color can be used to help reinforce the identity of an object of interest, but color changes do not necessarily disrupt object perception. It is likely beneficial to use color to code attributes that change less frequently than the x-y coordinates used to plot the data – although we have not studied that assertion.

The focus of the display technique is to control data presentation rate so that an object of interest will change states at a rate in the range of 1.0 – 2.0 Hz. The presentation rate must be linked to a persistence parameter that promotes removal of stale data after three or four samples. When data already exist and are being presented, the appropriate playback speed and persistence setting may be calculable (or at least estimable) within the presentation software, by analyzing near neighbor state changes in the data set over time. When this technique is used to present real-time data, such calculations would necessarily be restricted to recent near neighbors.

The primary value of dynamic perceptual objects is that they make use of pre-attentive processing, that is, the observer does not have to concentrate and make deliberate inferences about the relationships depicted in the presentation. The natural, intuitive perception of motion allows cognitive resources to be devoted to other issues, such as the significance or impact of the depicted relationships. Dynamic perceptual objects can help observers quickly perceive attributes of interest in large data sets, and therefore can be a powerful visualization technique when presenting those data sets to interested observers.

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