Change Detection

Ronald A. Rensink
University of British Columbia

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Change detection is the noticing of change in the world around us. For example, when driving in traffic, the vehicles around us constantly change their position, and sometimes their speed and direction as well. In order to avoid collisions, we must notice any such changes and respond to them. More generally, the ability to detect change is important for coping with everyday life; humans (and most animals) are consequently very good at it. However, our knowledge of how changes are detected remains incomplete. The progress that has recently been made owes its existence to two related developments: (i) a realization of some of the confusions and assumptions built into our previous ideas about change, and (ii) new methodologies that allow it to be more effectively isolated and studied.

An important step is to clarify the meaning of the terms themselves. As used here, “change detection” is restricted to the noticing of a change (i.e., the observer seeing that a change *exists*) via the use of vision. This can include the related abilities of identifying the change (i.e., seeing *what* it is), as well as localizing it (i.e., seeing *where* it is), although these abilities likely involve somewhat different mechanisms.

An adequate understanding of change detection has been difficult to achieve. Part of this is due to the nature of change itself. Although the concept of change appears simple, attempts to formalize it have shown otherwise. For example, change requires that some aspect of an object remain constant while another aspect does not, a situation that has not been completely resolved by present-day philosophers. Furthermore, our intuitions about change detection are often highly inaccurate. For example, we generally believe that we could easily detect any change in front of us provided that its size is sufficiently large. But we can be amazingly "blind" to such changes, failing to detect them even when they are large, repeatedly made, and are expected. Such *change blindness* is a phenomenon strikingly at odds with our intuitions about how change detection should work. However, such counterintuitive results have taught us much about what change detection is and how it works.

Background

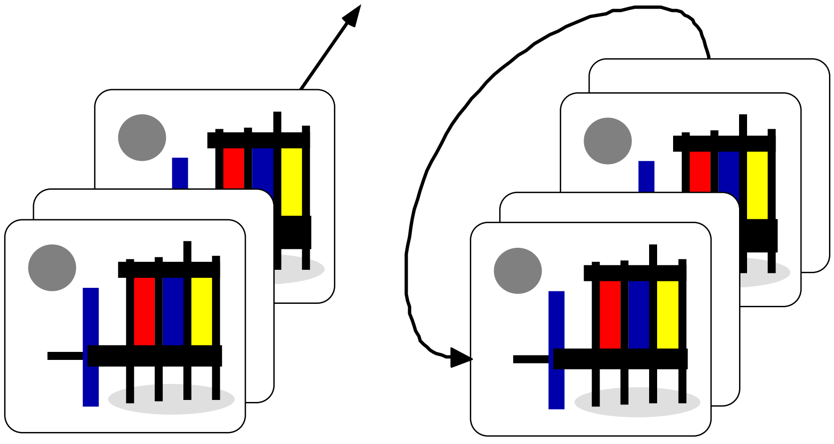
Insight into change detection has been obtained from a variety of sources. Some of the earliest discoveries occurred in Hollywood studios in the 1930s, where filmmakers found that an audience could fail to notice a sudden change (e.g., the appearance of a new character) if this occurred at the moment they made an eye movement (or saccade) from one side of the screen to the other, or when they blinked their eyes in response to a sudden noise. Filmmakers also discovered their own blindness to changes made during a film cut (e.g., the change in length of cigarettes in different shots), with such continuity errors often going unnoticed until long after the film had been released.

Controlled investigations of this phenomenon began in the 1950s. One line of research examined simple displays composed of about a dozen dots with random positions; observers were found to be surprisingly poor at determining if one of these dots had changed in a later presentation of that image. This work ultimately formed the basis for the proposal of a limited-capacity visual short-term memory (vSTM), an important part of current theories of visual perception.

A later wave of studies in the 1990s extended this in several important ways: images were more realistic, repeating changes were often used, and change blindness was also induced in other ways, such as making changes during an eyeblink. These developments allowed change detection to be more deeply investigated, and connections made to other aspects of visual perception. One of the more important findings in this regard was the discovery that *attention is needed to see change.*

Methodologies

All studies of change detection use essentially the same design: an observer is first shown an initial stimulus (e.g., a picture of a harbor with some ships in it), followed by a modified version of this (e.g., the same picture with one of the ships removed). The ability of the observer to detect the change is then measured, usually in terms of speed or accuracy (Figure 1).



(a) one-shot paradigm (b) flicker paradigm

Figure 1. *Example of method used to study change detection*. Here, a gap-contingent technique makes the change at the same time a brief blank appears. Two ways of measuring performance are illustrated. (a) One-shot paradigm. The observer views a single alternation of the stimuli; performance is measured by the accuracy of detection (or identification) of the change; (b) Flicker paradigm. The observer views a continual cycling of stimuli; performance is measured by the time taken until the change is detected (or identified). Both measurement paradigms can also be applied to other techniques, such as changes made during an eye movement or a shift in the image.

In real life, the motion signals produced by a change automatically attract attention, causing it to be easily seen. (For example, waving at your friends usually makes them see you right away.) To study the mechanisms involved in change detection, the process is slowed by eliminating this automatic drawing of attention. This can be done in several ways:

Gap-contingent techniques

In this approach, the initial image is presented for a short time (e.g., a half second), followed by a brief blank field or mask (typically about 100 ms); the modified image is then shown (Figure 1). The change therefore occurs during the gap between the original and modified stimuli. If this gap is longer than about 80 ms, changes can be extremely difficult to see—indeed, some can require over a minute to be seen, even though continually repeated.

The explanation for this is that the "flicker" created by the gap overwhelms the local motion signals created by the stimulus change, making it impossible for them to automatically draw attention to its location. The observer must then carry out a time-consuming scan of the image until the change is found.

Saccade-contingent techniques

Here, the initial image is again presented to the observer, but the transition to the modified image is made during an eye movement (or *saccade*) to a new location. The stimulus on a retina is smeared during a saccade. Thus, from the point of view of the retina, the pattern encountered here is: initial image—smeared image—modified image. This is similar to that encountered in the gap-contingent techniques, and so induces similar amounts of change blindness.

Shift-contingent techniques

In this approach, the initial image is shown to the observer for a short time, and the modified image then shown immediately afterward, with its location shifted somewhat—e.g., moved right or left a few degrees of visual angle. Changes made under these conditions are again very difficult to detect, even when they are large and expected.

The reason for change blindness here is much like that for the gap-contingent techniques: the shifted image means that there is mismatch at most points in the original and modified image, generating motion signals that swamp those created by the change itself. Note that this is closely related to the blindness found for changes made during film cuts, where the signals created by the mismatch of the images swamp the local signals created by the change, requiring a time-consuming attentional scan of the image.

Gradual-change techniques

These techniques have the initial image gradually fade away, with its place taken by the modified image. If the transition occurs over the course of several seconds, the change will be difficult to see. The reason for change blindness here is essentially the same as that for the other conditions: the ability of the motion detectors to guide attention to the location of the change has been eliminated: in this case, by making the change slowly enough that motion detectors don't fire.

Implications for Perceptual Mechanisms

The failure to see large changes under various experimental conditions can be explained by the proposal that attention is needed to see change. However, the story does not end here. Indeed, new distinctions and new questions arise, many of which have more general implications for how we see. These include:

Change vs. motion

Work on change detection motivates a more careful distinction between change and motion. Here, *motion* is the temporal variation in a property at a given point in space. For example, the flow of muddy water in a stream can be described in terms of its velocity at each point. There is no object here, no sophisticated structure—only unstructured "stuff" extending over part of space. Simple motion detectors in the human visual system respond to exactly such variation.

In contrast, *change* refers to the transformation of a particular object or event over time—for example, the wing movement of a bird overhead. Here, there is a constant structure (the bird) in which a transformation (wing movement) occurs. Attention is important here, being used to form a coherent representation that persists over the course of its transformation.

In this view, any dynamic variation in the world is picked up by two separate perceptual systems: one for *motion* (variation in regards to a particular location) and one for *change* (variation in regards to a particular structure). Both systems will generally be in play. One of the key insights of recent work is the need to separate the contributions of each system, so that their operation can be studied independently.

Mechanisms of change detection

Another set of issues involves the mechanisms of change detection itself, and how attention enters into their operation. An important finding is that only 3-4 items can be seen to change at a time. Indeed, it appears that the items held by attention may be not independent, but may instead be parts of a single structure that corresponds to a single object.

Recent work is beginning to explore the components involved. Contrary to our intuitions, change detection need not be an elementary process. It can be divided—at least conceptually—into a sequence of distinct operations: (i) load the information into a memory store (such as vSTM), (ii) put it into a coherent form, (iii) hold it across a temporal gap, (iv) compare the contents of memory to the new stimulus, (v) unload this memory, and (vi) shift processing to the next candidate item(s). Results indicate that distinct mechanisms for at least some of these do in fact exist.

Scene Perception

Given that our representation of a scene contains no more than a few coherent structures at a time, an important question is why we have the impression that we see everything in coherent form. (Note that much of a scene is represented—at least while our eyes are open—but this is not necessarily in coherent form.)

Recent work supports the view that scene perception is based on a dynamic process, rather than an accumulation of detailed information. More precisely, attention appears to be allocated on a "just-in-time" basis, with the representation of an object formed at the moment it is needed, and dissolved once attention has been withdrawn. Longer-term visual memories are still needed to coordinate this process. But these may contain relatively sparse amounts of information—perhaps just the information from the items currently attended, along with some properties from the locations used in the management process.

Implications for Individual Differences

Change detection can help explore not only the general mechanisms involved in visual perception, but also how particular individuals (and cultures) perceive the world around them. One approach to this is based on the *priority* given to items in a display. Given that attention is first allocated to interesting items, the speed at which a change is detected can indicate if the associated item is considered interesting. For instance, observers addicted to a substance such as alcohol or cannabis are faster and more likely to detect changes to items associated with that substance than are observers who are not.

Individuals also differ in the *way* they encode items, something that depends at least partly on training. Experts at American football are better able to spot meaningful changes to football scenes than novices, indicating that the experts have learned to see aspects of the scene not perceived by others. In addition, some studies suggest that Americans may be less able to detect changes in the surrounding context (e.g., the surrounding elements in a scene) than are Japanese, indicating a difference in the encoding of foreground and background elements.

Finally, individuals can also differ in the *mechanisms* at their disposal. For example, some individuals can have a "gut feeling" that something is changing, even though they do not yet have a "picture" of the change. Although there is still dispute about the basis of this phenomenon, the fact that observers can show differences in the way they experience change may provide an interesting new perspective on how we perceive our world.

See also **Attention; Eye Movements; Motion Perception; Object Perception; Visual Memory**

Further Readings

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—Ronald A. Rensink