What is Integrated Across Saccades?

(Irwin, D.E. and Andrews, R.V., "Integration and accumulation of information across saccadic eye movements", **Attention and Performance XVI**, pp 157-177, 1995)

Even though detailed, literal images of successive fixations are not integrated across saccades, several studies have shown that at least some visual information is remembered from one fixation to the next.

One study (Palmer and Ames, 1992) showed that subjects could make precise discriminations between lines of different lengths and shapes of different sizes even when the stimuli where viewed in separate fixations.

Another study (Irwin, Zacks, and Brown, 1990) found that subjects could determine accurately whether two dot patterns presented in successive fixations were the same, even when these patterns were displayed at differing locations.

This result indicates that some visual information is maintained in a location-independent manner.

Other studies have shown that, when the task requires it, precise spatial information about several points can be held in a map-like representation across multiple fixations. For example, (Hayhoe, Lachter, and Feldman 1991) found that subjects could judge precisely whether points viewed in successive fixations formed a right triangle.

(Carlson-Radvansky and Irwin) found that structural descriptions, rather than edge-based representations are retained across eye movements.

Memory Capacity, Accuracy, and Time Course

Irwin's group has determined that the accuracy in a tras-saccadic pattern discrimination task is highly dependent on the pattern complexity - simple patterns were recognized more accurately than complex patterns.

Varying the time interval between patterns between 0 and 5 seconds had little effect on recognition accuracy.

Spatial displacements of the patterns between displays also had little effect on accuracy.

The conclusion is that transaccadic memory is a limited capacity, location independent and long lasting memory, similar to visual short-term memory.

Experiments suggest that attention, which precedes the eye to a saccade target, determines what is stored in the trans-saccadic memory (Shepherd, Findlay, and Hockey 1986).

Object File Theory of Trans-saccadic Integration

Irwin has proposed a theory of trans-saccadic memory, which he calls the *Object File Theory*.

This theory makes a number of predictions:

- Objects are the fundamental organizing units for representing and maintaining information across saccades.
- Attention determines what is stored in memory.
- Only a limited number of object files are created and maintained across a saccade.
- There should be little loss of information in trans-saccadic memory over short time spans (less than 5 seconds).
- Surface characteristics (e.g. color, shape) of the attended objects should be maintained in the memory.
- Spatial locations/relations are coded coarsely.

In this theory relatively little information accumulates across saccades; rather ones mental representation of a scene consists of mental schemata and identity codes activated in long term memory and of a small number of detailed object files in short term memory.

In the Irwin study, subjects appeared to remember items as integral units, i.e. as coloured letters, rather than remember colour and identity separately.

Subjects could remember 4 items at short delays, and 3 items at longer delays.

Subjects remembered objects near the saccade target better than objects further away. This could be due to the enhancing effect of attention near the target.

If more than one fixation was made, the number of objects that could be remembered did not increase very much over the single fixation case.

Accumulation of information across saccades does seem to occur, but only up to the apparent capacity of the memory, which is about 4 to 5 objects.

If trans-saccadic memory consists of only a few object files, and residual activity in feature maps, as well as long term memory, then why does the world appear stable and continuous across eye movements?

It would seem that this would require a detailed memory of the contents of successive fixations.

Irwin suggests that the exact opposite is actually true: the world appears stable because very little is remembered from one fixation to the next!

In this theory, instability would be perceived only if one of the few elements that were remembered changed, otherwise the perceptual system would *assume* that the world is stable.

The Saccade Target Theory of Perceptual Stability

(Currie, C., McConkie, G.W., and Carlson-Radvansky, L.A., Irwin, D.E., "Maintaining visual stability across saccades: Role of the saccade target object", Human Perception and Performance Technical Report UIUC-BI-HPP-95-01, University of Illinois, 1995)

Retinal factors rather than extra-retinal signals may be all that is needed to detect shifts in saccade targets.

It appears that where the eye lands relative to the target of a saccade plays a role in the detection of a target shift, independent of the length of the saccade.

These retinal effects may be confined to the area of the stimulus centered around the landing site of the eye.

It has been reported that when an image is shifted during a saccade, rather than perceiving the entire image as shifting, only the objects the eyes are moving to seem to shift.

The research group of McConkie and Irwin at the University of Illinois have proposed a "localist", retinal signal based theory of visual stability called the *Saccade Target Theory*.

This theory proposes the following sequence:

- the visual system selects a target. This is called the saccade target.
- critical features of the target are encoded and stored in memory.
- a saccade is made to the target.
- the remembered critical features are used to locate the target object in a limited region about the fovea.
- if the target is found we perceive stability.
- if the target is not found, the search region must be broadened and instability is perceived.
- if the target shift is large enough a "corrective" saccade might be generated, or even a new target acquisition cycle might be started.

The strict version of the Saccade Target Theory predicts that only retinal information is used in the target localization process, thus:

- The perception of stability across eye movements depends critically on whether the object to which the eyes are sent maintains its spatial position.
- If the object changes position during a saccade, instability is perceived.
- If the object remains stationary, even if everything else moves, stability is perceived.

A more relaxed version of the theory would suggest that other information about the target might be used, such as the relative spatial relationships of the target with nearby objects.

This would predict that shifts in the target relative to these other objects would be detected and lead to perception of instability.

Currie *et al* performed an experiment aimed at testing the Saccade Target Theory.

In this experiment subjects performed the following sequence of tasks:

- Direct their gaze to a fixation point on an otherwise blank screen.
- A small star appears in the periphery, and the subjects saccade to fixate it.
- During the saccade to the star, it disappears and a full color natural scene appears.
- During the first fixation on this scene, one of the objects in the image is cued by wiggling briefly, drawing the subjects attention to it.
- The subject then makes a saccade to the cue object.

→ (continued on next page)

(continued from previous page)

- During this saccade one of 4 types of changes in the image occurs:
  - CONTROL: no change
  - ALL SHIFT: the entire image is shifted
  - OBJECT SHIFT: the cued object only is shifted
  - BACKGROUND SHIFT: everything but the cued object shifts.
- The subject then reports whether they noticed any change in the picture.

Expected Patterns of Results

- Integrative Buffer Model -
  the more features in the picture are shifted, the more detectable the shift should be. Thus the detection rate should be highest for the ALL condition, next highest would be the BACKGROUND case, and lowest for the OBJECT shift condition.
- Strict Saccade Target Theory -
  the ALL and OBJECT shift conditions should be equally detectable, and the BACKGROUND condition should yield low detection rates.
- Relaxed Saccade Target Theory -
  The OBJECT shift condition should be most detectable, as both image and spatial relationships change, and the ALL and BACKGROUND shift conditions will have lower detection rates. Which of these has higher detectability depends on how image information is traded off against spatial relationships.

Measured Results

It was found that the OBJECT and ALL conditions both yielded very high detection rates, with the OBJECT condition being slightly more detectable than the ALL condition. The BACKGROUND condition was observed to yield significantly lower detection rates.

This results fits in best with the (slightly) Relaxed Saccade Target Theory interpretation, as there appears to be a slight dependence on the information regarding the objects around the saccade target.

Based on response time measurements, it is suggested that configurational and retinal features are used separately to detect target shifts, and that detection using configurational features is slower than using retinal features. Target location may be primarily done by visual features followed by subsequent perception of spatial relations between objects.

Neural Substrate for Saccade Target Location

The question now arises as to where in the brain the saccade target location processing is performed.

The likely candidate is the population of neurons in the LIP cortex that were described by Colby *et al* (c.f. notes for lecture 16). Recall that these were parietal cortex "memory cells" that were active when the *intention* to make an eye movement to a target was formed. These cells appeared to shift their receptive field before an eye movement is made.

These LIP cells could then compute the visual "template" used to locate the target after the eye movement, as their receptive field matches that which will overlay the expected location of the target after the eye movement.