THE FRAMEWORK FOR UNDERSTANDING HOW TO SHAPE ATTENTION

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WHAT'S THE POINT?

This handout:

- ✓ is an excerpt from Chapter 2 of my thesis *(hence why it refers to other parts of the thesis in the text)*;
- ✓ helps you to understand the key drivers that you can apply to shape attention in other people *(Note: the concepts are universal, but this thesis focusses on visual aspects only)*; and
- ✓ provides a foundation for developing key techniques to optimise learning design, and all forms of presenting.

1. Overview of the Attentional Processes

There are typically numerous competing visual inputs within the field of view[(1)] (Mather & Sutherland, 2011). However, 'there are severe limits on our capacity to process visual information' (Carrasco, 2011, p. 1486), and for this reason all of the available visual stimuli typically can't be processed effectively (Jennings, 2012; Wallis & Bex, 2011). The human brain therefore utilises a range of processes to focus attention on the most important visual information, so the most pertinent subset can be used to support cognition[(2)], and appropriate action (Wu, 2011).

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1. The field of view refers to the angle over which visual information can be projected onto photoreceptor cells on the retina *(See Section 1.3.1.2.1 in Appendix 1 for more details)*. This aspect is influenced by the structure of the retina, and the positioning of the eyes *(e.g. looking left or right, up or down)* (Fulton, 2005, 2009a). There is also another conceptual variation to the term field of view. This is referred to as the Functional Field of View (FFOV), which 'is defined as the range of the visual field around the fixation point where recognition is possible' (Nobata, Hakoda, & Ninose, 2009, p. 887). The FFOV is also referred to in other papers as the Useful Field Of View (UFOV) *(e.g. Couperus (2009) and Richards, Bennett, & Sekuler (2006))*. In this thesis the FFOV/UFOV concepts will be utilised, and simply referred to as the field of view.

2. Cognition in the context of this thesis relates to higher level integration and analysis of the information within the human brain, which is collected through the eye, as a part of the

Attention is therefore a selective activity (Carrasco, 2011), which is applied to implement faster and more detailed processing of certain elements within the field of view (Lamme, 2003). These attentional processes can be applied consciously or unconsciously[(3)] (Kanai, Tsuchiya, & Verstraten, 2006; Kramer, Irwin, Theeuwes, & Hanh, 1999), but they are essential in ensuring that the most significant information is processed (Kida, Wasaka, Nakata, Akatsuka, & Kakigi, 2006; Wu, 2011)[(4)]. This importance is exemplified in the following quotation by Mather & Sutherland (2011, p. 114):

The brain's ability to prioritise information allows us to think and take action without being overwhelmed by external stimuli or internal thoughts and feelings. Attending to what is important while ignoring extraneous detail can enhance performance'.

To achieve this attentional selection the brain applies a range of methods, and to understand these methods a variety of different models have been defined by various researchers[(5)]. The framework utilised within this thesis is based on the widely accepted biased competition model (Desimone & Duncan, 1995; Moore, Lanagan-Leitzel, Chen, Halterman, & Fine, 2007; Sinnett, Spence, & Soto-Faraco, 2007). Biased competition is founded on the principle that percepts[(6)] and representations[(7)] generated within the visual system are

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perception process (Logan, 1999). See Section 1.2.3 in Appendix 1 for a more detailed description of cognition.

3. Consciousness can be classified as the level of neural activity, which generates 'awareness of the sensations, thoughts, and feelings being experienced at a given moment. Consciousness is our subjective understanding of both the environment around us and our private internal world' (Feldman, 2005, p. 148). The term unconscious refers 'to those mental processes of which the individual is not aware while they occur' (Borchert, 2006, p. 570). See Section 1.2.3.1.2 in Appendix 1 for a more detailed definition of consciousness and unconsciousness.

4. See Section 1.2.2 in Appendix 1 for a more detailed description of the attentive processes, and how these affect awareness and learning.

5. For example, Cave (2001) identifies attentional gateways, which facilitate selection even without binding *(Binding is the process related to combining the sensory information that belongs to one object (Mcgovern, Hancock, & Peirce, 2011)).* Alternatively Tsotos, et al (1995, p. 507) identified that the brain selectively tunes 'the visual processing network, which is accomplished by a top-down hierarchy of winner-take-all processes embedded within the visual processing pyramid'. The model used in this thesis takes these concepts into account, within the general framework of the biased competition approach.

6. A percept is a blended construct of visual stimuli, which allows the brain to handle congruent or incomplete information (Crick & Koch, 2003; Navarra, Alsius, Soto-Faraco, & Spence, 2010). This concept, and the physiology which is used to develop and process these percepts, is explained in Section 1.3 in Appendix 1. In terms of the original model by Desimone & Duncan (1995) they do not refer to percepts, but talk about 'targets' and 'nontargets' *(nontargets equate to distractors, which are discussed in Section 7).* Both targets and nontargets can become percepts or representations.

7. Representations are higher level (Crick & Koch, 2003; Pugh et al., 2000) mental constructs (Wu, 2011), which are based on feature *(e.g. percept)* conjunctions and these can then be linked to previous knowledge (Becker & Horstmann, 2009; Lewis, Borst, & Kosslyn, 2011). Each representation is developed as required (Kristjánsson & Nakayama, 2003), and they are typically volatile, which means that they are forgotten quickly unless attention is focussed on them (Chua, 2009). See Section 1.2.3 in Appendix 1 for more information on the use of representations in cognition.

analysed within a competitive framework *(e.g. like a knockout competition)* for attention at the higher levels of cognition (Mounts, 2005).

For instance, distinctive aspects of the visual scene will be processed by different neuronal areas within the brain (Serences & Yantis, 2006), as discussed in Appendix 1. Once the neurons handling a percept or representation win this competition and gain neural attention, then there is a bias toward processing the selected visual information in more detail (Boynton, 2005). Alternatively, neurons that are not attended to, do not remain active (Miller, 2000), and the percept or representation will rapidly reach extinction (Ptak, 2012) *(e.g. the unattended visual information will be forgotten quickly).*

Biased competition can be influenced by external factors within the visual field, such as the attractive colouration of objects(8) (Noiwan & Norcio, 2006; Turatto & Galfano, 2001). These types of external stimuli are collectively called exogenous factors (Chua, 2009). Alternately, there are other factors which drive attention from within the human brain (Jennings, 2012), such as consciously focussing on a particular task (Yi & Chun, 2005). These internal influences are known as endogenous factors (Turatto & Galfano, 2001).

The exogenous and endogenous factors interact within a neural network in the brain, to shape human attention(9) (Inukai, Kumada, & Kawahara, 2010; Theeuwes, 2004). For example, the colour of an object may attract the viewer's attention, but this can be modulated or even suppressed by what the viewer is doing (Intraub, Hoffman, Wetherhold, & Stoehs, 2006; Ries, 2007). A good example of this occurs when a person is reading, and they do not pay attention to a brightly coloured diagram, which would normally attract attention.

The exogenous and endogenous factors are managed through processes that are referred to as:

- ***Bottom-up processes.*** These processes handle exogenous stimuli with little recourse to higher-level knowledge (Treiman, 2001). In other words, they tend to be more mechanistic processes (Rusanen & Lappi, 2006), which work at the level of individual neurons (Lehar, 2003) to manage the percepts. Bottom-up processes are also characterised as involuntary reactions to the external stimuli (Fischer & Weber, 1998; Neo & Chua, 2006), and these are predominantly handled unconsciously (Breitmeyer, Ro, Ogmen, & Todd, 2007; Taylor, 2011; Zhaoping, 2008), or they produce only fleeting consciousness (Crick & Koch, 2003).
- ***Top-down processes.*** The endogenous factors are handled through top-down, goal-directed processes (Chua, 2009). This means that the individual's prior knowledge, expectations (Treiman, 2001) and intent (Inukai, et al., 2010) shape the way the percepts or representations are managed. Top-down processes can be applied unconsciously (Kanai, et al., 2006; Shipp, 2006), or consciously (Tapia & Breitmeyer, 2011).

8. For this thesis the term 'object' refers to something that is perceptible by the human visual system, and can be assessed coherently or categorised (Smith, 2003). An object can be categorised by its features *(e.g. shape, colour, orientation, etc.)* (Lachter, Remington, & Ruthruff, 2009), and they can be familiar or unfamiliar to the viewer (Honda, Abe, Matsuka, & Yamagishi, 2011). See Section 3 for more information on familiarity and object recognition.

9. See Section 1.2.2 in Appendix 1 for more information on this aspect.

These two procedural groups manage numerous processes, which determine the percepts and representations to which an individual pays attention (Schutz, Braun, & Gegenfurtner, 2011). However, these different types of processes should not be seen as separate, because they interact to shape human attention (Awh, Belopolsky, & Theeuwes, 2012)[(10)]. The key aspects managed within this top-down, bottom-up processing continuum appear to be those illustrated in Figure 2.2[(11)].

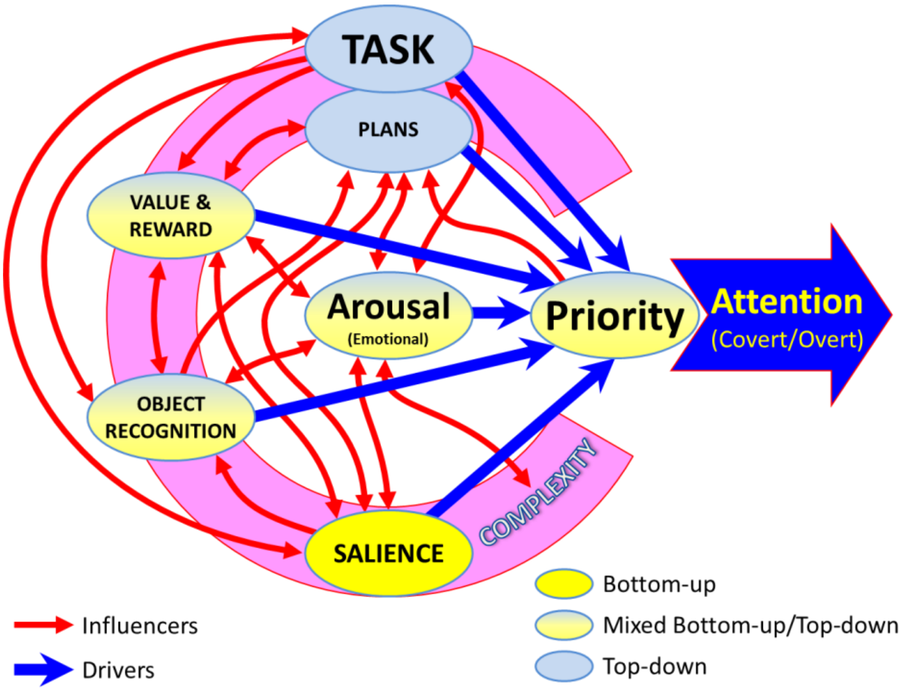

Figure 2.2: Interaction between Top-down and Bottom-up attention drivers

As shown in this diagram, there are a range of bottom-up, top-down and mixed processes, which can be categorised as salience, object recognition, value and reward, complexity, tasks and plans. Each of these processes interacts within the biased competition framework to generate *(and be affected by)* arousal, and create a priority map, which determines the percepts and representations to which attention will be applied. The priority map is then utilised to apply:

- ***Overt Attention.*** In overt attention the area of central vision, which is known as the fovea[(12)], is moved to the point of interest in the field of view (Wu, 2011). These types

10. The integrated continuum of top-down and bottom-up processes is discussed in more detail in Section 1.2.2 in Appendix 1.

11. This model was developed by the author, by rationalising and coalescing information provided in: Schutz, Braun, & Gegenfurtner (2011); Schütz, Trommershäuser, & Gegenfurtner (2012); Ipata, Gee, Bisley, & Goldberg (2009); Awh, Belopolsky, & Theeuwes (2012); Merker (2007); C.M. Moore, Elsinger, & Lleras (2001); C.M. Moore, Hein, Grosjean, & Rinkenauer (2009); C.M. Moore, Lanagan-Leitzel, Chen, Halterman, & Fine (2007); K.S. Moore & Weissman (2010); Tatler, Hayhoe, Land, & Ballard (2011); Lisberger (2010); Pins & ffytche (2003); Cave (2001); Tsotos, et al. (1995); Bishop (2008); Mather & Sutherland (2011); Fecteau & Munoz (2006) and Lee, Itti & Mather (2012).

12. See Section 1.3.1.2 in Appendix 1 for a description of the fovea.

of movements are known as saccades or smooth pursuits[13]. Eye movements like these are important, because they shift the high definition visual areas within the retina[14], so the point of interest is envisioned through the region of the eye that typically has the greatest acuity[15] (Rossi & Roorda, 2010).

- ***Covert Attention.*** This type of attention is achieved without moving the eye, so the fovea does not necessarily focus on the point of interest (Wu, 2011). Covert attention is therefore used to monitor the environment (Carrasco, Eckstein, Verghese, Boynton, & Treue, 2009). Such monitoring can then create triggers, which change the biased competition, and this can then lead to overt attention (Fix, Rougier, & Alexandre, 2011). In fact, overt attention is usually preceded by covert attention (Becker & Horstmann, 2009). For example, Wolfe's (2001) Guided Search model posits that in the first stage the mind creates a guidance map *(priority map)* and then uses this to direct the deployment of attention[16]. The guidance map is created through a weighted sum of the bottom-up and top-down processes (Wolfe, 2001).

The following sections provide a short overview of each of these top-down and bottom-up processes, and explains how they trigger and shape overt and covert attention.

2. Salience

SALIENCE

In this thesis the term salience conforms to the meaning used by Serences & Yantis (2006, p. 39), who defined it as the 'intrinsic property of the stimulus (e.g. local feature contrast), independent of its task relevance'[17]. These intrinsic properties are described later in this section.

Salience is important, because:

- it determines how quickly a visual target will be identified within the field of view *(e.g. more salient objects will typically be perceived first if there are no other top-down processes driving attention)* (Fecteau & Munoz, 2006; Jamet, Gavota, & Quaireau, 2008; Wong, 2010); and
- salience appears to be managed in an unconscious and pre-attentive state (Itti & Koch, 2001), so it then becomes a driver for rapidly focussing attention (Sawaki & Luck, 2010; Schutz, et al., 2011; Theeuwes, Devries, & Godijn, 2003; Turatto & Galfano, 2001).

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13. See Section 1.6 in Appendix 1 for an explanation of saccades and smooth pursuits.
14. See Section 1.3.1.2 in Appendix 1 to this thesis for a description of the retina.
15. The term visual acuity is used to define the clearness of the vision, and it is dependent on the sharpness of the retinal focus and the brain's ability to interpret the visual stimuli (Cline, Hofstetter, & Griffin, 1997).
16. Wolf (2001) refers to pre-attentive features as the constructs that are bound by attention within the guidance map. In terms of this thesis, these are equated to percepts.
17. This definition is utilised to avoid the ambiguity generated in a range of papers, which utilise salience models that include significant top-down aspects. The definition utilised in this thesis therefore helps to ensure that salience is only identified in the context of bottom-up processes.

The key visual factors and features that appear to be involved in the development of bottom-up salience driven attention[18] are illustrated in Figure 2.3[19].

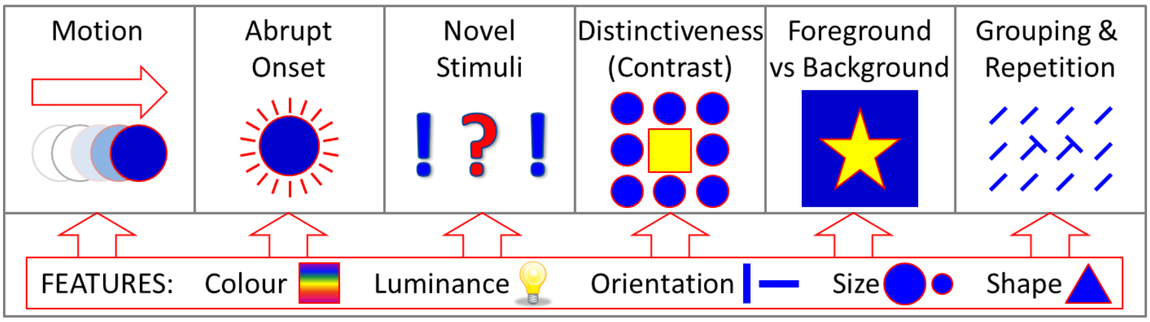


Figure 2.3: Salience Factors and Features

The top row in this diagram lists the key salience factors. They are ordered in terms of their relative salience, which aligns to their likelihood to shape attention. For instance, the first two *(motion and abrupt onset)* are typically considered the most effective at capturing attention, because they generate a sensory transient[20] (Hollingworth, et al., 2010). As an example, moving an object into the scene can create strong bottom-up processes that capture attention (Hollingworth, et al., 2010; Ries, 2007).

The bottom layer in Figure 2.3 refers to the features, which also affect each of the factors. These five salience features, and the six factors, are discussed in the following subsections.

2.1. Features

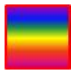
There are key features which combine to make an object or element in the visual field more salient and conspicuous (Tatler, et al., 2011), which means that it is more likely to be attended (Fecteau & Munoz, 2006). The primary salience features can be categorised as explained in the following subsections.

18. In terms of the neural mechanisms utilised to support salience mapping, it appears that this aspect is handled within a network that utilises the Frontal Eye Fields (FEF) *(see Section 1.4.3.2.1 in Appendix 1)*, Lateral Intraparietal area (LIP) *(see Section 1.4.2.3 in Appendix 1)*, Pulvinar *(see Section 1.3.3.1.3 in Appendix 1)*, Superior Colliculus *(see Section 1.3.4.1 in Appendix 1)*, and the Reticular Formation *(see Section 1.3.4.3 in Appendix 1)* (Fecteau & Munoz, 2006). Additionally, areas V1 (Li, 2002; Zhaoping, 2008) and V4 (Mazer & Gallant, 2003) also appear to play a facilitating role in managing salience *(see Section 1.3.5 in Appendix 1 for information on V1 and V4)*.

19. This model was developed by the author, by merging and rationalising information provided in Wong (2010); Dorr, Martinetz, Gegenfurtner, & Barth (2010); Hancock & Phillips (2004); Johnston, Hawley, Plewe, Elliott, & DeWitt (1990); Rensink (2002); Fecteau & Munoz (2006); Tatler, et al. (2011); Schutz, et al. (2011) and Butcher & Cavanagh (2008).

20. A sensory transient is created when an object or scene undergoes a highly visible salient change (Hollingworth, et al., 2010). Such transients can trigger attention spikes, which facilitate the application of attention (Krahe & Gabbiani, 2004).

2.1.1. Feature 1 - Colour

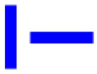


Different colours can specifically attract attention (Chen, 2003; Turatto & Galfano, 2001). See Sections 3.4.1 and 3.4.2 for a detailed description of colour issues and their salience.

2.1.2. Feature 2 - Luminance

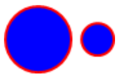
Luminance is perceived in direct relationship to other aspects of colour(21), and elements of the human perceptive systems are highly sensitive to even subtle changes in luminance levels (Ries, 2007). For example, the greatest salience is typically achieved for items that have the highest levels of luminance over the largest area (Tsotsos, et al., 1995). Additionally, abrupt changes in the level of luminance can be highly attracting, and can even disrupt top-down processing, to directly shape attention (Maclean et al., 2009)(22).

2.1.3. Feature 3 - Orientation



Orientation of objects and other visual elements is determined as a part of the pre-attentive processes(23) (Bisley & Goldberg, 2010). Orientation is important, because it plays a part in object recognition *(see Section 3)*. Additionally, when assessing distinctiveness as a salience factor *(see Section 2.2.4)*, orientation appears to play an important role in shaping attention (Fuchs, Ansorge, Redies, & Leder, 2011).

2.1.4. Feature 4 - Size



The size of objects (Doré-Mazars, Pouget, & Beauvillain, 2004; Wong, 2010), or parts of objects (Hoffman & Singh, 1997) have a direct influence on their salience. For example, in static scenes the most salient edges will typically be those that comprise the longest and highest contrast straight line (Tsotsos, et al., 1995). Size is also important, because small objects typically need to be fixated by the fovea or parafovea(24) (Larson & Loschky, 2009), which means that small items normally need to be assessed using overt attention. In practical terms, this means that smaller objects are typically less salient, because active attention(25) often needs to be applied first, to perceive them adequately. Small objects are therefore often not strong salient bottom-up drivers (Hoffman & Singh, 1997), because they

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21. See Section 1.3.1.2 in Appendix 1 for background information on colour and luminance.

22. This sensitivity to changes in luminance is particularly important in lower light levels, where the rods become more active *(see Section 1.3.1.2.1 in Appendix 1)*. The salience delivered in these circumstances may be due to the fact that the rod cells predominantly feed into the fast tracked magnocellular pathway *(see Section 1.3.2.2 in Appendix 1)*, which then rapidly feeds into the dorsal stream to facilitate early cognition *(see Sections 1.2.3.2 and 1.4.2 in Appendix 1)*.

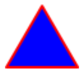
23. The initial perception of orientation appears to take place predominantly within the striate visual cortex (V1) (Li, 2002) *(see Section 1.3.5 in Appendix 1)*, so it becomes an important part of the low level percepts.

24. See Section 1.3.1.2.1 in Appendix 1 for a description of the fovea and parafovea.

25. Active attention refers to the volitional application of attentive processes to a specific object (Bradley, 1902). See Section 1.2.1.3.8 in Appendix 1 for more information on active attention.

may not be elevated to representations until overt attention has already been applied to them[26] (Mounts, 2005).

2.1.5. Feature 5 - Shape

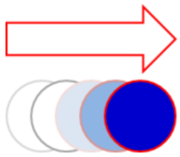


Shapes are defined through the integration of edges and bounding contours (Bravo & Farid, 2006). Interestingly, changing shape information may take attentional precedence over previous shape information, so it appears that new shape salience re-competes with previous shape percepts or representations (Watson, Braithwaite, & Humphreys, 2008). This effect appears to be linked to the object recognition issues discussed in Section 3. However, on its own, shape may not be strongly salient, because it can be readily suppressed by other factors and features (Suzuki, 2003). Shape does play another important role, however, because similarity judgements between shapes are integral to cognition (Briscoe, 2008). Therefore the distinctiveness of varying shapes can create salience, as discussed in Section 2.2.4.

2.2. Factors

Whereas the preceding section addressed the salience features, the following subsections address the six key salience factors.

2.2.1. Factor 1 - Motion



Motion within the visual field is highly attracting, and provides a strong predictor for the focussing of attention (Dorr, et al., 2010; Jamet, et al., 2008)[27]. For instance, motion can be so powerful in attracting attention that it can actually suppress the perception[28] of other types of salience (Libedinsky & Livingstone, 2011).

However, not all motion is strongly attracting. As an example, simulated looming objects *(e.g. where an object gets larger rapidly, simulating that it is getting closer)* capture attention, whereas apparently receding objects *(e.g. objects that rapidly get smaller)* may not (Franconeri & Simons, 2003, 2005)[29]. Additionally, continuously moving elements may act as a distraction (Wong, 2011).

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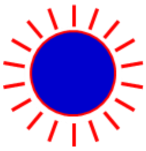
26. This concept is discussed in more detail in Section 1.2 in Appendix 1.

27. This appears to be facilitated by the processing of motion through the magnocellular and koniocellular pathways *(see Section 1.3.2.2 and 1.3.2.3 in Appendix 1)*, and then the rapid processing through area V5 *(see Section 1.3.5 in Appendix 1)* and the dorsal stream *(see Section 1.4.2 in Appendix 1)*. The swift processing through this path can pass the visual information to the frontal cortex *(see Section 1.4.3 in Appendix 1)* very quickly *(see Section 1.4.2.1 in Appendix 1)*, so it is more likely to capture attention *(see Section 1.2.3.2 in Appendix 1)*.

28. See Section 1.2.1 in Appendix 1 for an explanation of the term perception, as it is used in this thesis.

29. This rapid application of attention may be invoked through an alarm mode reaction (Fulton, 2003). In alarm mode, neural constructs in the interbrain region *(see Section 1.3.3 in Appendix 1)* and midbrain area *(see Section 1.3.4 in Appendix 1)*, and possibly areas within the dorsal stream *(see Section 1.4.2 in Appendix 1)* are activated to rapidly facilitate the allocation of attention and efferent commands (Fulton, 2003, 2009b). Efferent systems are sensory loops

2.2.2. Factor 2 - Abrupt Visual Onsets

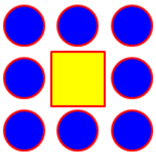


The term abrupt visual onset relates to the sudden appearance of a stimuli within the visual field (Jonides & Yantis, 1988). As identified by Hancock & Phillips (2004, p. 2285) ‘abrupt visual onsets are highly salient’ and can directly initiate bottom-up processes, even when top-down attentional drivers are being applied (Boot, Kramer, & Peterson, 2005; Schreij, Owens, & Theeuwes, 2008) [30].

2.2.3. Factor 3 - Novel Stimuli

Novel stimuli are objects or visual elements which are unexpected or unfamiliar within a particular context (Johnston, et al., 1990). These novel stimuli can capture attention (Carretié, Hinojosa, Martín-Loeches, Mercado, & Tapia, 2004; Johnston, et al., 1990; Tarbi, Sun, Holcomb, & Daffner, 2011), and can also affect emotional arousal (Carretié, et al., 2004) *(see Section 8 for more information on arousal).*

2.2.4. Factor 4 - Distinctiveness (Contrast)



Readily identifiable differences between an object and its surroundings, or surrounding objects, can create salience (Rensink, 2002). Differences of this nature can be categorised as illustrated in Figure 2.4[31].

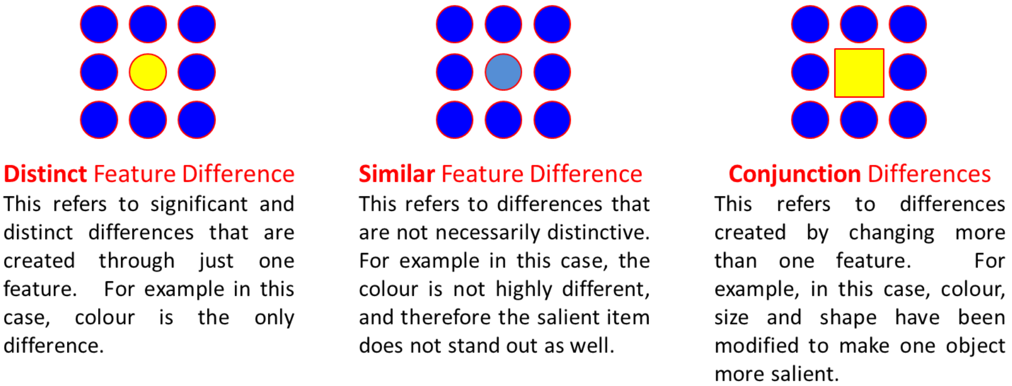


Figure 2.4: Distinct, Similar and Conjunctional Differences

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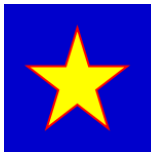
which are directed away from the central processing systems to an effector. For example, efferent systems initiate a saccade, so that overt attention can be applied rapidly. See Section 1.1.2 in Appendix 1 for more information on the efferent systems.

30. Deubel, Wesenick, & Schneider (2001) identified that the human visual system is specifically biased toward identifying and attending to changes within the visual field. This predilection toward processing changes is handled in a variety of different parts of the visual processing system. For example, the amacrine and ganglion cells within the retina are optimised to fire on perceiving change *(see Sections 1.3.1.2.2, and 1.3.1.2.3 in Appendix 1).* Additionally, the Parrahippocampal Place Area (PPA) *(see Section 1.4.1.3.1 in Appendix 1),* limbic system *(see Section 1.4.1.3.4 in Appendix 1),* and the processing within the dorsal stream *(see Section 1.4.2.2 in Appendix 1)* are also focussed on responding rapidly to changes within the environment. For this reason, top-down processes can be inhibited when significant changes are perceived.

31. This diagram was created by the author from information provided in Fecteau & Munoz (2006).

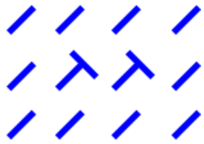
If the differences are sufficiently significant, the salient object will pop-out of the scene (Itti & Koch, 2001), and 'attract attention through their inherent physical properties with little influence from top-down mechanisms' (Ries, 2007, p. 2). These types of differential factors can therefore create bottom-up stimulus-driven attention capture, and the greater the number of differences *(e.g. conjunction differences)* the more likely it becomes that the bottom-up processes may drive attention (Horstmann & Beckerm, 2008).

2.2.5. Factor 5 - Foreground versus Background



Many people focus their attention on foreground objects, with relatively little overt attention allocated to the background in many situations (Tatler, et al., 2011)[32]. This lack of attention to the background can create change blindness for background elements (Mazza, Turatto, & Umiltà, 2005). However, aspects such as red colouration within the background can still affect attention, as identified in the experiments conducted by Bedwell, Brown, & Orem (2008)[33].

2.2.6. Factor 6 - Grouping & Repetition



Salient groups can be defined as collections or clusters of adjacent items, which can be linked by common salient features and factors (Mcmains & Kastner, 2009). The salient features are detected rapidly through low level processes (Butcher & Cavanagh, 2008; Feldman, 2007), and then resolved through 'context-dependent grouping mechanisms and competitive interactions', which provide bottom-up bias 'toward candidate objects in cluttered scenes' (Mcmains & Kastner, 2009, p. 2417). In other words, the low level development of perceptual groups *(by linking objects)* is designed to simplify complexity[34] within the field of view, so attention can be applied to a smaller number of object groupings (Murray, Schrater, & Kersten, 2004).

In practical terms, grouping involves the aggregation of perceived objects into more complex structures (Feldman, 2007). For instance, in the diagram to the left of Figure 2.5 a salient square shape may stand out from the aggregation of the dots. Therefore, grouping can affect contextual understanding, and can also capture attention for the whole collection (Conci & Von Mühlenen, 2009).

32. It should be noted that there are cultural variations in terms of this bias, as discussed in Section 2.3.1.2.4.

33. According to Bedwell, et al., (2008) changes in perception appear to be induced by red backgrounds. They postulated that the changes were induced through suppression of the magnocellular pathway *(see Section 1.3.2.2 in Appendix 1)*. This factor is discussed in more detail in Section 3.4.2.

34. See Section 7 for more information on complexity.

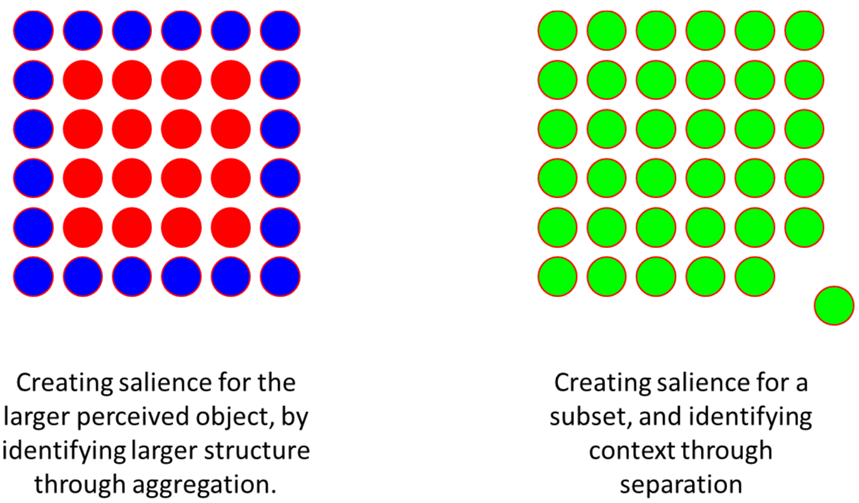


Figure 2.5: Grouping and Separation Salience

Alternately, salience can be created through separation from the group (Wong, 2010). This concept is illustrated by the single green circle in the diagram to the right of Figure 2.5. Separation salience of this nature appears to work as long as the singleton is not detached by enough distance to become cognitively separable from the rest of the group (Murray, et al., 2004). This concept is discussed in more detail in Section 3.4.3.

Repeated objects also stand out within a grouping, because 'low-level processes group physically identical items more efficiently (Butcher & Cavanagh, 2008, p. 714). The development of salience in this way is particularly true when the repeated objects are within close proximity (Butcher & Cavanagh, 2008; Kramer & Jacobson, 1991), as illustrated in Figure 2.6.

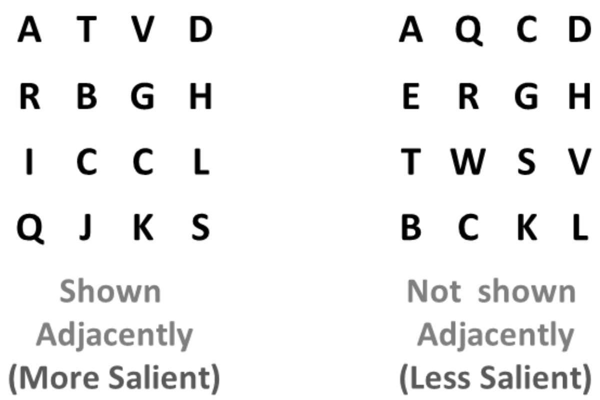


Figure 2.6: Salience through repeating objects

2.2.7. Salience within the Overall Processing Model

Each of the preceding features and factors can definitively drive attention through bottom-up processing (Zhaoping, 2008). Additionally, salience can also influence top-down processes, such as:

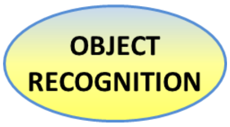
- ***Tasks and Plans.*** Salience can influence the implementation of tasks and plans, by either dominating top-down processing (Boot, et al., 2005; Schreij, Theeuwes, &

Olivers, 2010), or actually enhancing covert attention and memory (Fine & Minnery, 2009). The application of effective and appropriate salience techniques is therefore important.

- ***Value and Reward.*** Aspects of salience *(e.g. showing reward related shapes)* also affect the perception of value and reward (Awh, et al., 2012).
- ***Arousal (Emotional).*** There also appears to be significant interaction between emotional aspects of arousal and salience, when shaping attention in some situations (Humphrey, Underwood, & Lambert, 2012; Niu, Todd, Kyan, & Anderson, 2012).
- ***Object Recognition.*** Salient features *(e.g. orientation)* also influence other processes, such as object recognition (Vickery & Jiang, 2009).

However, in many circumstances salience may only have a modest effect on the focussing of attention (Schutz, et al., 2011; Tatler, et al., 2011), and the following processes may be more important in many situations.

3. Object Recognition



Object recognition relates to the brain's ability to associate salient features into a recognisable whole (Humphreys & Forde, 2001), and then use semantic memory[35] to distinguish and apply perceptual and cognitive constructs (Daskagianni, 2011; Zannino, Perri, Caltagirone, & Carlesimo, 2011). These constructs appear to:

- ***Drive Attention.*** Object recognition facilitates faster and more effective application of attentional focus (Anaki & Bentin, 2009; Nelson & Palmer, 2007).
- ***Generate Cognitive Inferences.*** Object recognition can also shape the impressions of the viewer, in relation to the information being perceived (Honda, et al., 2011). For example, certain objects may create positive or negative emotional arousal, as discussed in Section 8.
- ***Shape perception of objects.*** Recognition can also shape the perception of visual information, by enhancing or inhibiting the processing of percepts (Anaki & Bentin, 2009). For example, early recognition *(prior to fully perceiving the object)* creates the situation where a person sees what they want, or expect to see, and not necessarily what is really there (Mcdonald, 1998). These types of top-down influences on perception can have a profound effect on the viewer's understanding of the provided information (Balcetis, 2006).

However, recognition, or the lack of recognition, is not a binary all-or-none gateway. As explained by Honda, et al. (2011) recognition takes place within a continuum of familiarity. In this continuum, the object may be more or less familiar to different people (Honda, et al., 2011). In terms of the levels of familiarity used in this thesis, an object may be considered

35. 'Semantic memory is the subcomponent of memory that is responsible for the acquisition, representation, and processing of conceptual information. This critically important system of brain function is implicated in a wide range of cognitive functions, including the ability to assign meaningful interpretations to words and sentences, recognize objects, recall specific information from previously learned concepts, and acquire new information from reasoning and perceptual experience' (Saumier & Chertkow, 2002, p. 516).

unrecognisable, or it may be within a range covering vaguely familiar to immediately recognisable.

The familiarity of an object will be dependent on the semantic memories held by the viewer (Silveri & Ciccarelli, 2009). In practical terms, this stems from the fact that different people have learnt different things, and individual characteristics of semantic memory may therefore be dissimilar for different people (Binder & Desai, 2011)[36].

There are a range of theories postulated for the development of object recognition[37]. In essence they reflect the general principle that the human brain:

- ***Develops Percepts.*** As a part of the perception process, the brain binds or segregates[38] visual elements *(e.g. salient features)* (Cheadle et al., 2008). Grouping in this way is achieved by linking image properties *(e.g. low level percepts)* in terms of their location (Cave, 2001), proximity, similarity, orientation, context, and other visual relationships (Vickery & Jiang, 2009). The more coherent these aspects are, the more rapidly the object will be recognised (Sanocki, Michelet, Sellers, & Reynolds, 2006)[39]. Therefore, bottom-up processes such as salience can directly influence object recognition, but salience is not essential for identification (Schutz, et al., 2011).
- ***Links Percepts to Memory.*** In conjunction with this process, familiar objects are assessed in relation to representations held in semantic memory (Silveri & Ciccarelli, 2009). Through this interaction with semantic memory a '"candidate set" of similar perceptual objects is activated, and the selection that results in recognition is made by a

36. However, as discussed in Section 3.4.6, there appears to be enough commonality within demographic groupings to make use of familiarity to optimise comprehension and impressions. See Section 2.3.2.1 for more information on the demographic variables that have been applied to determine if there is significant variation induced by demographic differences.

37. This includes Feature Integration Theory (FIT) developed by Treisman & Gelade (1980), which is widely cited. For this thesis, not all of the aspects of the FIT have been identified as valid. In particular, the concept that perception and attention can only be guided through primitive features prior to binding is not considered validated, as specified by Becker & Horstmann (2009). Becker and Horstmann's (2009) research identified that object conjunctions can also affect recognition and attention. Additionally, as pointed out by Quinlan (2003), the concept of independent feature processes within the FIT model are not supported by experimentation. However, the FIT approach to concentration of visual attention once an object has been recognised is appropriate for this thesis, as it is supported by other research (Quinlan, 2003). Other theories include the Hierarchical Interactive Theory (HIT), which posits that humans identify objects by utilising percepts *(low-level object perceptions)* and matching these to stored representations (Humphreys & Forde, 2001) within semantic memory (Desmarais, Dixon, & Roy, 2007). Alternatively, the Dual-Process Theory states that recognition decisions are based on recollection *(this is a slow process that entails retrieving specific details of an object),* and familiarity *(this is a fast process, which involves appreciating that an object has been encountered previously, without having to recall context)* (Wixted, 2007).

38. Binding is the process related to combining the sensory information that belongs to one object, whereas segregation is the process of disassociating information between objects (Mcgovern, et al., 2011).

39. It is noteworthy that the research conducted by Sanocki, et al. (2006) identified that the benefits inherent in coherence for object recognition were not necessarily applicable for overall scene recognition.

top-down contextual module' (Allen, Smith, Lien, Kaut, & Canfield, 2009, p. 282). For example, the neural systems[40] draw on learnt features and shapes from memory (Eric Maillot & Thonnat, 2008). Therefore, once an object has been learnt, it appears to be perceived very quickly (Allen, et al., 2009)[41], because the brain relates new objects within common perceptual groups (Vickery & Jiang, 2009).

Once an object has been recognised this can significantly increase the speed at which attentional focus is applied (Becker & Horstmann, 2009), 'and can bias the next attentional shift through top-down control' (Itti & Koch, 2001, p. 195). For example, the human brain appears to be very quick to pick recognisable animal shapes and outlines within a scene (Drewes, Trommershäuser, & Gegenfurtner, 2011; Wichmann, Drewes, Rosas, & Gegenfurtner, 2010). However, it is not just animal shapes that create this effect, and recognition of many types of object can induce top-down processes for focussing attention (Lee, Kim, Kim, Kim, & Yoo, 2010).

Object recognition:

- can also influence the level of arousal if there is emotional relevance associated with the object (Mather & Sutherland, 2011), and in turn object recognition can be influenced by the emotional gist of an object (Humphrey, et al., 2012);
- assists in binding salient associations *(e.g. colour associations)* with distinctive shapes, which can assist in remembering content in working memory[42] (Delvenne & Dent, 2008)[43];

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40. It appears that object recognition is predominantly managed within the temporal lobe *(see Section 1.4.1.1 in Appendix 1)*, including the inferotemporal cortex (Bartolomeo & Chokron, 2002; Mather & Sutherland, 2011), and perirhinal cortex (Davies, Graham, Xuereb, Williams, & Hodges, 2004), as well as other areas within the ventral stream (Brogaard, 2011; Chan & Newell, 2008) *(see Section 1.4.1 in Appendix 1)*. As the percepts progress along the ventral stream the size of the receptive fields becomes smaller, which mirrors the application of attention to specific areas (Deco & Rolls, 2004). Additionally spatial information handled within the dorsal stream *(see Section 1.4.2 in Appendix 1)* appears to trigger aspects of object-recognition within the ventral stream (Farivar, 2009; Singh-Curry & Husain, 2009).

41. According to Allen, et al. (2009) it appears that the magnocellular pathway *(see Section 1.3.2.2 in Appendix 1)* provides rapid transfer of low acuity percept information, so that global objects and context can be developed. Where more detailed information is required to identify or perceive an object, the initial percepts can be reinforced by the transfer of slower, but higher resolution information through the parvocellular pathway (Allen, et al., 2009; Bar, 2004).

42. Working memory contains information that was just experienced *(e.g. percepts)* or just retrieved from long-term memory *(e.g. representations)*. These percepts or representations are 'short-lived, but can be maintained for longer periods of time through active rehearsal strategies, and can be subjected to various operations that manipulate the information in such a way that makes it useful for goal directed behaviour. Most definitions of working memory include both storage and (executive) control components.' (Curtis & D'esposito, 2003, p. 415). Additionally, the duration of working memory can be extended through reverberation, which is described in Section 1.4.4.3 in Appendix 1. The general purpose definition of working memory, which is used in this thesis, has been applied to alleviate confusion, which could arise through the operational differentiation between working memory and short term memory, and in particular visual Short Term Memory (vSTM). This approach also conforms to the recognition that working memory is a more suitable term, noting that this type of memory is not so much a 'holding store' *(which better aligns to the Short Term Memory (STM) or vSTM concepts)*, but

- shapes or influences perceptual plans *(e.g. saccade, motor, or action plans)* by capturing attention once the object has been recognised (Wong & Peterson, 2011); and
- interacts with the value and reward processes to shape cognition *(e.g. the perceived value of the object can affect the perception of size)* (Veling & Aarts, 2009).

4. Value and Reward

The term reward refers to the application of some exogenous stimuli or benefit, which can include the provision of a positive advantage, or the avoidance of a negative outcome *(e.g. avoiding punishment)* (Shadlen & Roskies, 2012). Value relates to the perceived worth that a viewer places on specific objects and elements within the field of view (Navalpakkam, Koch, Rangel, & Perona, 2010). The perceived value, and the provision of rewards, affect human cognition at a very fundamental biological level[44], and these aspects play an important role in shaping attention (Navalpakkam, et al., 2010; Shadlen & Roskies, 2012). For example, value and reward (V&R) can affect the selection of objects for saccade targets (Schutz, et al., 2011).

Much of the value and reward system can therefore be considered a top-down process (Schütz & Gegenfurtner, 2010). However, salience and V&R also interact to shape attentional focus (Awh, et al., 2012; Schütz, et al., 2012), so there are aspects of bottom-up processing that also affect this aspect. Additionally, value and reward directly influences the application of salience based attention (Hickey, Chelazzi, & Theeuwes, 2010), and also impacts on the level of arousal (Mather & Sutherland, 2011). The perceived value of a task will also influence the level of effort that the individual plans to apply to cognitive functions (Bandura, 1989; Moreno, 2010), so V&R also shapes other types of top-down attention processes.

5. Task

Tasks being conducted by an individual drive top-down processes, which can have a direct effect on the preceding factors that influence attention (Betz, Kietzmann, Wilming, & König, 2010; Schutz, et al., 2011). For instance, a person's perception of salience can be enhanced (Edelman, Kristjánsson, & Nakayama, 2007; Schreij, et al., 2010), or suppressed (Droll, Hayhoe, Triesch, & Sullivan, 2005; Einhäuser, Rutishauser, & Koch, 2008; Sawaki & Luck, 2010) by the task being conducted. Such enhancement or suppression can then directly influence which percepts and representations

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'the cognitive system's processing engine' (Sweller, 2002, p. 1502). See Section 1.4.4.2 in Appendix 1 for more information on working memory.

43. This is likely to be due to the interaction of the ventral stream with the hippocampi, as explained in Section 1.4.1.3.2 in Appendix 1.

44. As specified by Kable & Glimcher (2009) value and reward issues are handled within the orbitofrontal cortex *(see Section 1.4.3.3 in Appendix 1)*, the ventromedial prefrontal cortex *(see Section 1.4.3.2.3 in Appendix 1)*, supplementary eye fields *(see Section 1.4.3.1 in Appendix 1)*, the striatum *(see Section 1.4.1.3.3 in Appendix 1)*, areas within the parietal lobe, such as the Lateral Intraparietal (LIP) area *(see Section 1.4.3.2 in Appendix 1)*, and regions within the midbrain, such as the superior colliculus *(see Section 1.3.4 in Appendix 1)*.

are utilised for cognition[45] (Tatler & Land, 2011). Alternatively, the task being conducted can directly influence object recognition tasks *(e.g. ignoring some objects and focussing on others that are more relevant)* (Chan & Newell, 2008).

An important task related top-down control factor stems from the use of attention focused eye movements, so the required information is provided just before it is needed for cognition (Ballard, Hayhoe, & Pelz, 1995). These just-in-time saccades *(or smooth pursuits)* allow percepts and representations to be collected as they are needed, which helps to overcome the limited capacity and duration of working memory[46] (Hayhoe, Shrivastava, Mruczek, & Pelz, 2003). In other words, the brain uses the world as a form of external memory, which it utilises to access the required information as needed (Schutz, et al., 2011). The eyes will therefore saccade to the point which needs to be attended to, as it is required to meet the task (Rensink, 2002), and this will inhibit other attentional drivers (Schutz, et al., 2011). Additionally, observers will learn where to look, and are likely to spend more time attending to areas where they believe that an object of interest *(in relation to the task being conducted)* is more likely to appear (Droll, Gigone, & Hayhoe, 2007).

6. Plans

As discussed in the preceding section, the task being undertaken can directly affect the application of attention. To facilitate the required tasks, the human brain often develops an appropriate plan to optimise the application of overt (Bisley & Goldberg, 2010), or covert attention (Ignashchenkova, Dicke, Haarmeier, & Thier, 2004; Moore, Armstrong, & Fallah, 2003).

Additionally, plans can be created to specifically manage the perception of recognised objects (Sheinberg, Peissig, Kawasaki, & Mruczek, 2006), cope with salience issues (Brockman, 1991; Mazer & Gallant, 2003; Serences & Yantis, 2006), or directly respond to new priorities

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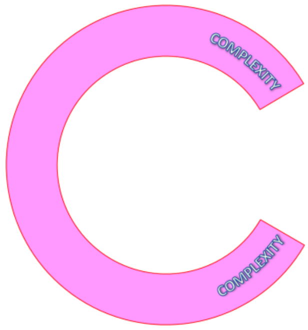
45. Gibson (1966, 1979) postulated that human perception and cognition is directly influenced by ‘affordances’. The concept of affordances relates to the objects and things that the environment ‘offers’, ‘provides or furnishes’, and how people and other animals will interact with those things (Gibson, 1979, p. 127). This aspect is considered an ecological development, because the brain has evolved to focus on the objects and things that afford benefit in the organism’s circumstances (Gibson, 2000). In practical terms, this means that affordances can be directly related to a task being undertaken (Fajen, Diaz, & Cramer, 2011; Sumner & Ahmed, 2006; Waller & Richardson, 2008). For instance, people will focus on important landmarks, whilst navigating through an area *(e.g. affordances for a navigation task)* (Gibson, 2000), or individuals will focus on information that will help them to learn *(e.g. affordances for a learning task)* (Chu, Lin, Liu, & Tan, 2012; Mayer, Hegarty, Mayer, & Campbell, 2005). Although, some aspects of Gibson’s (1979) ecological affordance related theories have not been supported by later researchers *(e.g., Costall & Still (1989), Creem & Proffitt (2001), Scarantino (2003))*, the concept still appears to have a significant role to play in perception (J. Norman, 2002), and shaping attention in relation to the task being performed (Reppa, Schmidt, & Ward, 2012). Norman (2002) also linked the initial processing of affordances to the dorsal stream *(see Section 1.4.2 in Appendix 1)*, and the actual perception of the affordance to the ventral *stream (see Section 1.4.1 in Appendix 1)*. As discussed in Section 1.4.4 in Appendix 1, both streams and the frontal cortex interact to process affordance related percepts and representations.

46. See Section 7 for more information on the limited capacity of working memory.

(Bisley & Goldberg, 2010). The resultant plans[47] can generate attention for specific percepts or representations, or they can actively inhibit attention being paid to other objects in the field of view (Jennings, 2012).

7. Complexity



Attention is directly affected by the complexity of the information perceived in the field of view (Bradley, Houbova, Miccoli, Costa, & Lang, 2011; Schutz, et al., 2011). For example, increasing complexity:

- tends to shorten fixation periods (Bradley, et al., 2011); and
- slows attentional focus, and makes it less reliable (Tatler, et al., 2011).

Visual complexity can be created by:

- ***The number of objects to be attended.*** Although working memory is distributed across a range of neural elements *(see Appendix 1)*, it is limited in its capacity (Cowan, 2005; Fukuda, Awh, & Vogel, 2010; Paas, Renkl, & Sweller, 2003). For example, for most people it appears to be limited to handling about four unique objects or chunks[48] at a time (Cowan, 2005; Rensink, 2002). If the number of percepts and representations that need to be attended exceeds this limit[49], then pertinent visual information may not be processed.

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47. Plans of this nature appear to be predominantly generated within the frontal lobes of the human brain (Itti & Koch, 2001) *(see Section 1.4.3 in Appendix 1 for a discussion of the frontal lobes)*. The frontal lobes then generates feedback messages, which drive the focussing of attention (Dehaene, Changeux, Naccache, Sackur, & Sergent, 2006), as discussed in Section 1.2.3.2 in Appendix 1.

48. The concept of chunks was raised by Miller (1956) to represent the mental aggregation of bits of information. In Miller's (1956, p. 83) model a 'bit of information is the amount of information that we need to make a decision between two equally likely alternatives. If we must decide whether a man is less than six feet tall or more than six feet tall and if we know that the chances are 50-50, then we need one bit of information.' A bit is therefore not necessarily a single aspect *(e.g. a visual feature)*, but a conceptual linking of information for binary analysis, which in itself is an aggregation of discriminable variables *(e.g. points, colours, tones, etc.)* (Miller, 1956). Miller's (1956) chunk concept is therefore not a definitive measure, but a construct for understanding how information is organised or grouped, to allow it to be managed more effectively within working memory. This concept is important, because it explains how the mental aggregation of information through chunking can assist the brain to handle more information than would be possible for individual items or bits (Miller, 1956). Such aggregation may be influenced by aspects like relational pattern matching (Kirsch, Sebald, & Hoffmann, 2010) within representations.

49. The limit of four objects/chunks replaces the commonly cited 'magical number seven, plus or minus two', as the capacity for working memory that was postulated by Miller (1956, p. 81) *(Miller refers to this as the span of attention within immediate memory, which is the same concept as working memory capacity)*. However, close examination of Miller's (1956) text indicates that he was not convinced that the capacity of seven *(plus or minus two)* objects/chunks was the definitive limit. Later research by Cowan (Cowan, 2000, 2005) indicated that the capacity of working memory was closer to about four objects or chunks.

- ***The presence of visual distractors.*** Visual distractors[(50)] can make it more difficult for the viewer to attend to the important information (Inukai, et al., 2010). This is particularly true if the distractors are related to the target information in some way (Balani, Soto, & Humphreys, 2010). This concept is illustrated in Figure 2.7, which shows that a target object with similar *(related)* features to the distractors is harder to separate for the allocation of attention, as the number of distractors increases.

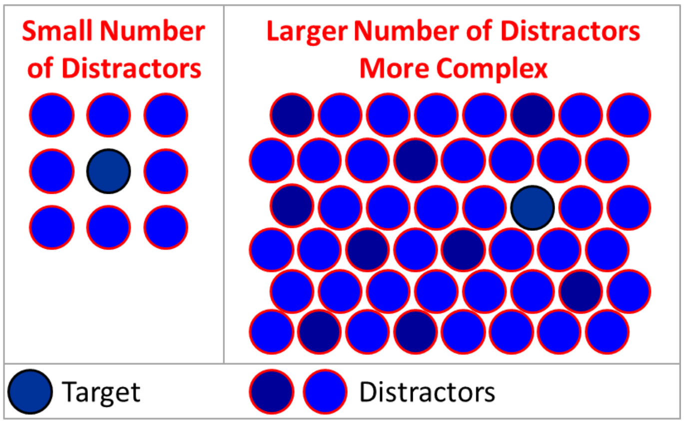

Figure 2.7: Complexity Created Through Distractors

- ***The complexity of the content.*** The complexity of the information being received by the viewer can also affect the demands on working memory (Turner & Engle, 1989). Therefore, highly complex content can make the task of understanding the information more difficult, and this has implications for plans and value judgements *(e.g. is the effort of trying to understand worth the reward?)* (Moreno, 2010).

Interestingly, when the complexity is moderate, the viewer's attention span appears to increase and cognitive aspects such as comprehension improve, in relation to very simple or

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This relatively fixed limit of four objects/chunks is now widely accepted *(e.g. Awh, Barton, & Vogel (2007), Zimmer (2008), Baddeley (2010)).* There is, however, another theory related to working memory capacity, which is predicated on the flexible allocation of working memory resources across objects/chunks (Bays & Husain, 2008). In other words, the number of objects/chunks is not the limit on capacity, but the overall amount of working memory available is the limiting factor (Wilken & Ma, 2004). As more objects/chunks need to be processed, less memory can be allocated to each of them, which leads to the memory related errors that have been cited as the reasoning behind the fixed capacity theory (Bays & Husain, 2008; Wilken & Ma, 2004). Recent research appears to support the fixed *(e.g. about four objects/chunks)* model (Cowan & Rouder, 2009; Fukuda, et al., 2010). This may be due to the limitation of the episodic buffer within working memory, as described in Section 1.4.4.2 in Appendix 1. For the purposes of this thesis, the fixed capacity model has therefore been utilised, but this approach should not jeopardise the findings should the flexible allocation concept be identified as the viable model in future. This robustness stems from the fact that both the fixed and flexible models are predicated on the limited capacity of working memory. The experiments designed for this thesis take this into account and only utilise the fixed limit capacity *(e.g. four objects/chunks)* as an easy-to-apply design benchmark. More information on working memory is provided in Section 1.4.4.2 in Appendix 1.

50. Visual distractors are objects, or other visual content, that are perceivable within the visible field, but are not important for attendance (Eckstein, 2011). Visual content that needs to be attended is typically referred to as a target (Eckstein, 2011).

highly complex situations (Turner & Engle, 1989). Initially, the identified lower level of attention and comprehension for very simple tasks appears to be counter-intuitive. However, the likely causation and implications from these findings is discussed in more detail in Section 3.2.

Finally, as illustrated in the research by Raymond, Tavasoli, & Fenske (2002), the presence of distractors can also adversely affect the impressions of the viewer, so complexity can also have an impact on emotional arousal.

8. Arousal (Emotional)

Arousal relates to the level of physiological activity *(e.g. heart rate, etc.)*, and it is closely linked to emotions(51) (Baumeister & Vohs, 2007). 'A wide range of cognitive and emotional challenges increase autonomic(52) arousal, affecting heart rate, galvanic skin response(53), and pupil dilation(54)' (Mather & Sutherland, 2011, p. 114). For this thesis, arousal has been assessed in terms of its effect on cognition (Blair et al., 2007; Dolan, 2002), comprehension (Havas, 2011) and learning (Feldman, 2005), because the research demonstrates that these effects are significant.

Arousal can be produced by viewing emotive content (Niu, et al., 2012). For example, Bradley, Miccoli, Escrig, & Lang (2008) identified that emotional arousal can be generated whilst viewing an emotive picture for only a few seconds. The generation of this type of emotional arousal is important, because:

- emotional stimuli can directly enhance or suppress attention(55) (Ferneyhough, Stanley, Phelps, & Carrasco, 2010; Schupp et al., 2007);

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51. 'Emotions can be defined as a complex set of interactions among subjective and objective factors, mediated by neural/hormonal systems. These interactions can (a) give rise to affective experiences, (b) generate cognitive processes, (c) activate widespread physiological adjustments, and (d) lead to behaviour that is often expressive, goal directed and adaptive' (Um, 2008, p. 1).

52. The term autonomic refers to the automated regulation of general activities in the body *(e.g. heart rate, metabolic rate, etc.)* (Garrett, 2003). These are controlled through the autonomic nervous system, and emotional responses have a direct influence on arousal generated through this system (Feldman, 2005).

53. Galvanic Skin Response (GSR) 'is a physiological indicator of psychological events that involves measuring the drop in resistance to an electrical current passed through the skin' (Darren & Simon, 2010, p. 2). GSR is a good indicator of emotional arousal (Darren & Simon, 2010).

54. See Section 1.3.1 in Appendix 1 for more information on the ramifications of pupil dilation.

55. Emotions are managed in a range of areas within the human brain. In particular, areas within the limbic system, such as the amygdala and septal area *(see Section 1.4.1.3.4 in Appendix 1)*, and the frontal/fusiform gyri (Kawasaki et al., 2011; Mier et al., 2010), are directly linked to emotion. Additionally, the dorsolateral prefrontal cortex *(see Section 1.4.3.2.2 in Appendix 1)*, the ventromedial prefrontal cortex *(see Section 1.4.3.2.3 in Appendix 1)*, the obritofrontal cortex *(see Section 1.4.3.3 in Appendix 1)*, and the insula *(see Section 1.4.1.3.5 in Appendix 1)* modulate cognition with emotional content. This application of emotion is also facilitated through connections with the hippocampi *(see Section 1.4.1.3.2 in Appendix 1)* within the limbic system *(see Section 1.4.1.3.4 in Appendix 1)*.

- emotions can influence memory and cognition (Sokol-Hessner, 2010)[56];and
- as stipulated in preceding sections, emotions and arousal interact directly with each of the other processes, to shape attentional focus within the priority map.

9. Priority Map

The priority map integrates bottom-up and top-down process outcomes by assimilating various signals (Bisley & Goldberg, 2010; Ipata, et al., 2009), such as those generated through the processes cited in the preceding sections. The priority map therefore appears to integrate these types of low-level and high-level cues to shape attentional focus (Tatler, et al., 2011).

For example, the priority map[57] integrates combinations of input, such as:

- salience and value/reward, to determine the most important object for attention (Schütz, et al., 2012);
- top-down processes related to the task being undertaken, which then modulate object selection within the priority map (Keech & Resca, 2010); and
- arousal based on shape *(salience)* or object recognition, which can also directly drive selection within the priority map (Ipata, et al., 2009).

Competing inputs such as these appear to be managed within 'a dynamic and additive model' (Schütz, et al., 2012, p. 7551), which then shapes attention. In other words, this provides the mechanism to implement the biased competition for attention, because properties within this integrated model, which have a high activation weight, will become the focus for attention (Franconeri & Simons, 2003).

10. The Variables

To investigate the three dimensions identified in the primary unifying model, a framework of assessable variables was developed. These variables were designed to allow the effects of specific visual changes in tools like PowerPoint® to be analysed, in terms of their ability to optimise comprehension, shape impressions, and generate attention.

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56. This effect appears to be facilitated by structures within the frontal lobe and hippocampi, as specified in the preceding note. In particular, as detailed percepts and representations are processed through the ventral and dorsal stream, emotional links are generated.

57. There is still some debate on whether priority is handled as a singular map, or separate maps which are managed within a network (Schutz, et al., 2011). The likely areas of neural physiology which have been identified as managing the priority map are the Lateral Intraparietal (LIP) area *(see Section 1.4.2.3 in Appendix 1)* (Berman & Colby, 2009; Bisley & Goldberg, 2010; Ipata, et al., 2009), and/or the Frontal Eye Fields *(see Section 1.4.3.2.1 in Appendix 1)* (Ptak, 2012; Schutz, et al., 2011). Additionally, neural structures such as the superior colliculus *(see Section 1.3.4.1 in Appendix 1)*, pulvinar *(see Section 1.3.3.1.3 in Appendix 1)* and V1 *(see Section 1.3.5 in Appendix 1)* are also implicated in supporting the development of a priority map (Tatler, et al., 2011).

This framework forms the second unifying model, which utilises the variables illustrated in the model to the right of Figure 2.8.

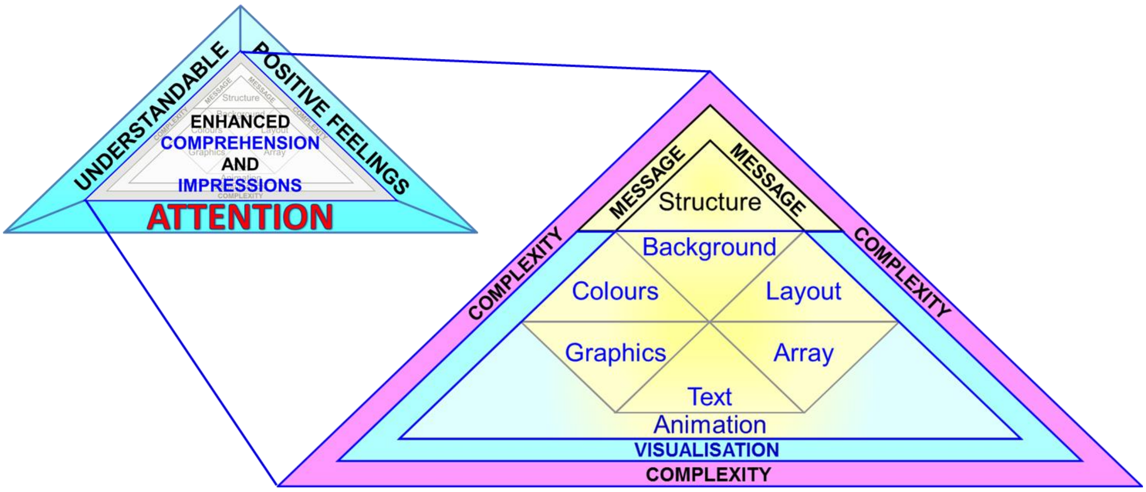

Figure 2.8: Unifying Model 2 - The Framework of Assessment Variables

Within this framework there are three key groupings of variables, which are defined as follows:

- ***Complexity.*** The control of complexity can drive the ability to make the information understandable, create positive feelings and shape attention *(as discussed in Section 7)*. As shown in Figure 2.8, complexity therefore encapsulates each of the following groups of variables. Complexity issues and their implications are explained in more detail in Section 3.2.
- ***Message Structure.*** The message structure has consequences in relation to shaping attention and enhancing comprehension and impressions (Tennyson, 1980; Ziemkiewicz, 2010). This aspect of the framework is discussed in Section 3.3.
- ***Visualisation.*** The visualisation elements form the key focus for this research. There are seven identified visualisation variables, which have been utilised to scope the research. These variables are:
    - ***Colours.*** The colours applied in visual representations can affect salience, object recognition, and complexity, as discussed earlier in this Chapter. The optimal colour combinations can therefore be important in shaping attention, optimising comprehension and creating positive impressions. Matters related to colour are discussed in Section 3.4.1.
    - ***Background.*** Background clutter (Bravo & Farid, 2006), background content and context *(e.g. gist information)* (Epstein, 2005; Larson & Loschky, 2009; Otsuka & Kawaguchi, 2007), as well as background contrast, luminance (Engmann et al., 2009) and colour (Bedwell, et al., 2008) can all affect perception and cognition. These background features and their effects on comprehension, attention, and impressions are covered in Section 3.4.2.
    - ***Layout.*** In the context of this thesis, the term layout refers to the general arrangement of objects and other content over the expanse of the screen. The layout of visual information can have a significant effect on viewer impressions (Altaboli & Lin, 2011) and comprehensibility (Wästlund, Norlander, & Archer,

2008). Additionally, good layout can shape attention, so the viewer processes the most important aspects of the information (Pralle, 2007). Layout issues are explained in Section 3.4.3.

- ***Array.*** The term array(58) refers to the conjoining of objects and other content within the overall layout of the screen. In other words, whereas layout addresses the entire screen arrangement, array addresses the grouping of sub elements within the layout. For example, array issues are generated through grouping and repetition *(see Section 2.2.6).* The design of arrays can therefore have repercussions in terms of salience, emotional arousal, object recognition, and complexity (Donderi, 2006). An explanation of important array variables is provided in Section 3.4.4.
- ***Text.*** In this thesis, text refers to the words and sentences *(verbiage)* that are used to explain the information to the viewer, and the way in which it is represented *(typography).* The verbiage that is used can directly impact on comprehension (Salazar, 2009), and impressions (Havas, 2011; Poonpon & Castello, 2010). Likewise, the typography *(e.g. fonts used, etc.)* can influence emotions (Koch, 2011), comprehension (Sanocki & Dyson, 2012), and attention (Fondren, 2009). Text issues are covered in Section 3.4.5.
- ***Graphics.*** The term graphics covers pictures, graphs, and any form of graphical element used within the display *(e.g. anything that is not text).* Graphical elements can shape attention through salience, object recognition, value and reward, and emotional arousal, as discussed earlier in this Chapter. Additionally, the use of appropriate graphics can enhance comprehension (Mayer, 2001). The influence of optimised graphical elements is explained in Section 3.4.6.
- ***Animation.*** As explained in Section 2.2.1, motion within the visual field can be highly salient, and therefore attract attention. Additionally, appropriate animations can assist in generating comprehension and positive impressions (Kim, Yoon, Whang, Tversky, & Morrison, 2007; Rebetez, Bétrancourt, Sangin, & Dillenbourg, 2010). The most appropriate animation techniques are discussed in Section 3.4.7.

11. Conclusion

By applying these variables, significant benefits can be generated in all forms of presenting. For example, the empirical data collected in this project has demonstrated that the utilisation of the correct combination of visual factors can produce significant benefits in learning outcomes.

58. This definition is developed from information provided in Donderi (2006).

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