Tampereen yliopisto

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LIVING IN A LINE WORLD

How life would be in a world where we could merely perceive edges

Bachelor's thesis
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ABSTRACT

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Vision has been the most researched topic of the human senses throughout history. The human visual system is a complex system consisting of dorsal and ventral streams, the former of which handles information in object recognition and the latter one in motion perception. Although edge detection is part of the primary visual cortex, being able to only perceive edges changes vision drastically from what an average human being is used to.

Edges are resulted by different physical phenomena, such as lighting variations caused by shadows or variances in albedo between objects. They can occur between objects as well as within a single object, and in many situations all these phenomena can occur at the same time. However not all edges are equally informative in the case of edge detection and can sometimes create rather confusing scenes. This thesis explores whether edge detection provides too much complex and unnecessary information, or whether only perceiving edges causes us to lose crucial information necessary to live a normal everyday life.

The experiments were done considering both ventral and dorsal streams as well as the hierarchy of human visual system. This refers to experiments in both object recognition and motion perception as well as hand-eye coordination and navigating in different environments. The goal was to explore the impact of edge detection on everyday life in as many ways as possible.
The results revealed significant effects on both dorsal and ventral streams. Object recognition became significantly more difficult, while on the other hand motion perception and moving around in different environments had a slighter change. Merely being able to detect edges limits the person's ability to perform certain tasks but does not make everyday tasks completely impossible. Humans are very adaptive and with time living in the line world could become more plausible.

Keywords: edge detection, human visual system, object recognition, motion perception, hand-eye coordination

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Näköaisti on ollut ihmisen aisteista eniten tutkittu kohde kautta aikojen. Ihmisen näköjärjestelmä on monimutkainen kokonaisuus, joka koostuu dorsaalisesta sekä ventraalisesta radasta. Ensimmäinen radoista käsittelee kohteiden tunnistamiseen liittyvää tietoa ja jälkimmäinen liikkeen havaitsemiseen liittyvää tietoa. Vaikka reunojen tunnistaminen on osa primaarista näköaivokuorta, kyky havainnoida ainoastaan reunoja muuttaa näkemistä huomattavasti siitä, mihin ihmiset ovat tottuneet.

Reunat ovat seurausta erilaisista fysikaalisista ilmiöistä, kuten varjojen aiheuttamista valaistusvaihteluista tai kohteiden välisistä albedoeroista. Reunoja voi esiintyä sekä useamman kohteen välillä että vain yhdessä kohteessa. Monessa tilanteessa nämä ilmiöt voivat esiintyä samanaikaisesti. Kaikki reunat eivät kuitenkaan ole yhtä informatiivisia reunantunnistuksen kannalta. Tässä kandidaatintyössä tutkitaan, tarjoaako reunantunnistus liikaa monimutkaista ja tarpeetonta informaatiota vai menetetäänkö vain reunojen havaitsemisen seurauksena tavallisen arkielämän kannalta ratkaisevaa tietoa.

Koejärjestelyissä otettiin huomioon sekä ventraalinen ja dorsaalinen rata että ihmisen näköjärjestelmän hierarkia. Kokeet käsittelivät sekä esineiden tunnistamista ja liikkeen havaitsemista, että silmä-käsi-koordinaatiota ja liikkumista erilaisissa ympäristöissä. Tavoitteena oli tutkia reunantunnistuksen vaikutusta jokapäiväiseen elämään mahdollisimman monipuolisesti eri tavoin.

Tulokset osoittivat merkittäviä vaikutuksia sekä dorsaaliseen että ventraaliseen rataan. Esineiden tunnistaminen vaikeutui merkittävästi, kun taas toisaalta liikkeen havaitseminen ja liikkuminen eri ympäristöissä muuttui vähemmän. Näköjärjestelmän rajoittaminen havaitsemaan ainoastaan reunoja heikentää tiettyjen tehtävien suorittamista, mutta ei tee arkielämän askareista täysin mahdottomia. Ihmiset ovat hyvin sopeutumiskykyisiä, ja ajan myötä viivamaailmassa eläminen voisi muuttua mahdollisemmaksi.

Avainsanat: reunantunnistus, näköjärjestelmä, kohteen tunnistus, liikkeen havaitseminen, silmä-käsi-koordinaatio

CONTENTS

1. INTRODUCTION

Throughout the centuries, sight has been considered to be the most important out of the five human senses. As Aristotle declares in *Metaphysics*, “of all the senses sight best helps us to know things and reveals many distinctions [1].” It does not come as a surprise since the human visual system has been the most researched topic of the human senses throughout history. Many studies have estimated that around 80 % of our perception, as well as learning, cognition, and activities, are mediate through vision [2][3]. Vision is represented as both a sensory and motor system. It is a combination of the communication between the eyes and the brain, and the muscles controlling as well as the coordinating the eyes [3]. The complexity and the dominance of this sense makes vision more researched than any other sensory modality [4].

Colors and trichromatic vision add vividness to our lives as well as help us to perceive our surroundings. The world is full of details when we utilize all the different sections of the visual system hierarchy. Although the human visual system has been studied extensively, edge detection in the human visual system is still rather unknown field. In some respects, edge detection in the human visual system can be compared to edge detection in image processing. It uses different mathematical formulas to identify edges. This series of observations was the motivation for this thesis; What would happen if our vision was limited to only perceive edges like edge detectors do in image processing?

The purpose of this thesis was to experiment whether we could live normal everyday life by only being able to detect edges of the surrounding world. Would it be possible to recognize objects, perceive motion or navigate normally in a *line world*?

This thesis is structured in 6 chapters. Chapter 2 briefly explains the human visual system and the visual hierarchy considering the two streams hypothesis. Chapter 3 presents different types of edges. In addition, it talks about the basics of edge detection both in human visual system and in image processing. Chapter 4 discusses the selected method and equipment to approach the study of the thesis. More detailed descriptions of the experiments done to experiment living in the line world are also explained in this chapter. The results and comments related to the experiments are gathered in Chapter 5. The final chapter, Chapter 6, draws conclusions of the results and discusses future work and thoughts of edge detection affecting everyday life.

2. VISUAL SYSTEM

The visual system consists of the sensory organ (eye) and the connections from the retina to the primary visual cortex and to different areas of the brain [5]. The visual system of humans, and mammals in general, is a complex combination of various tasks and it takes into account both sensory and motor systems. The eye and the brain work together to interpret light in order to perceive the world around us. This is what we call sight. A simple representation of the human visual system is presented in Figure 1.

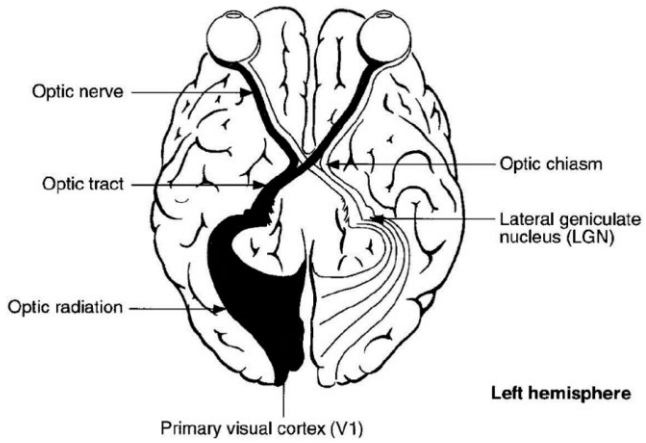

Figure 1. *Human visual system [5]*

The figure shows the connections from the retina to the left and right hemisphere. The hemispheres get sensory input from the opposing sides of the visual field; thus, the right hemisphere receives information from the left side of the visual field and vice versa. Visual information is processed in the visual cortex of the brain. The visual cortex is divided into parts, with the primary visual cortex (also known as the visual area 1, V1) acting as the initial stage of visual processing. Visual areas 2, 3, 4, and 5 (V2, V3, V4, V5) make up the extrastriate cortex. [5]

The visual hierarchy presented in Figure 2 is due to increasing featural complexity that arises over the areas of the visual cortex. Different parts of the visual cortex send feedback and receive feedforward connections from each other providing a complex network [6][7]. It has been suggested that the feedforward process plays an important role in the primary visual cortex and in shape recognition [8][9].

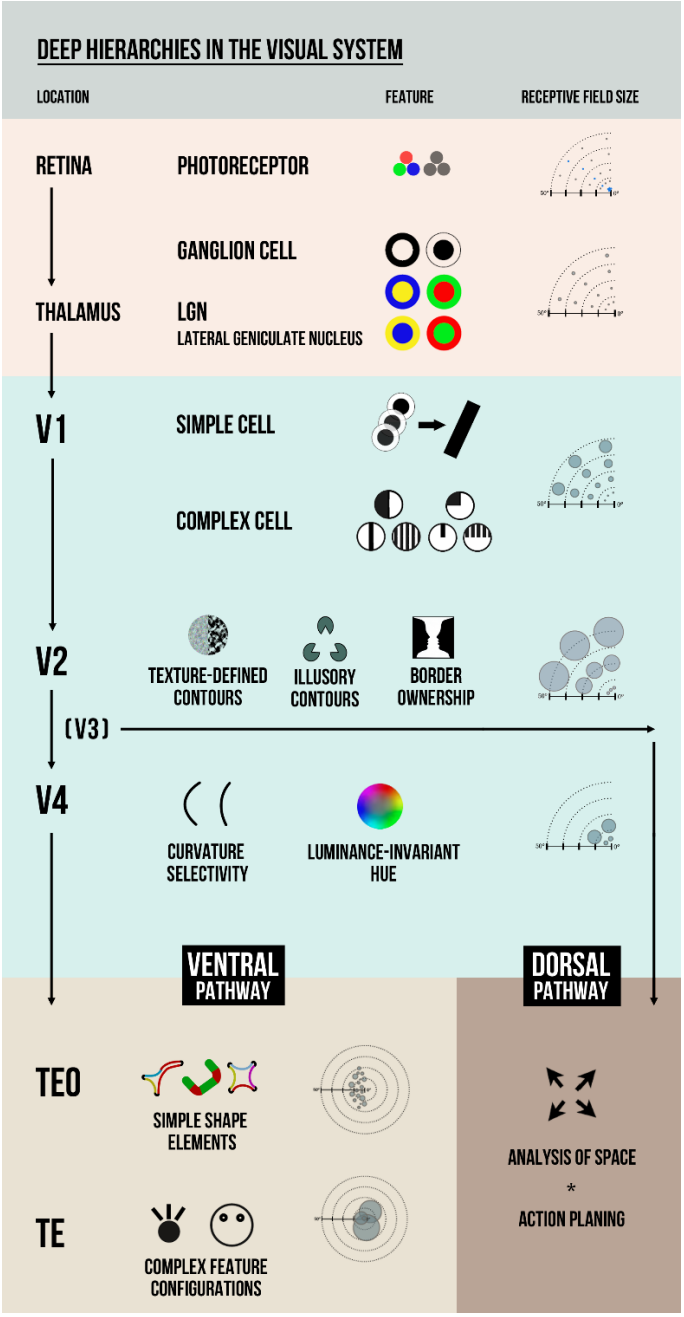

Figure 2. *Hierarchical model of the human visual system [10]*

The size of the receptive fields affects the complexity of the feature of each visual area [11] (Figure 2 and Figure 3). As we can see from the figure below, the primary visual cortex (V1) detects oriented edges and lines which are combined into junctions of lines (shapes). V4 has more complicated visual characteristics, allowing it to perceive objects provided the information from the previous states. The inferior temporal cortex (IT) can be divided into two sections, posterior and anterior. IT-posterior is responsible for recognizing individual faces and IT-anterior contains semantic categories used for action making. [12][13]

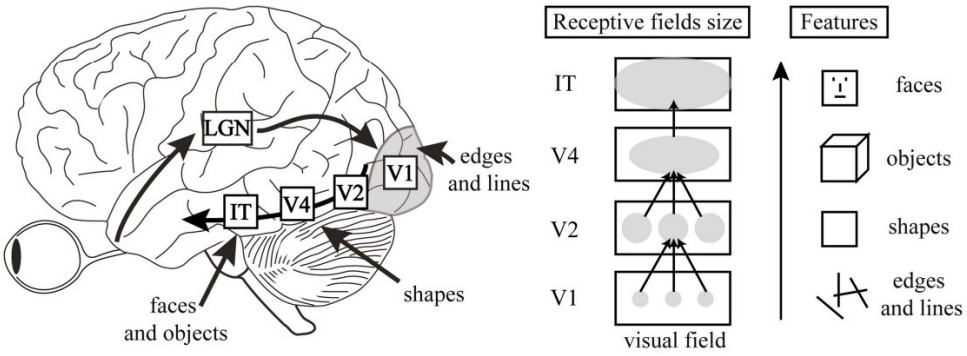

Figure 3. *A typical representation of hierarchical, feedforward model of the visual system [14]*

The visual system can be presented with the two-streams hypothesis [15]. It is a model of the neural processing of vision, where visual information transfers through two main streams: the ventral stream (“what”) and the dorsal stream (“where”). Ventral stream has been said to be very important for visual perception. On the other hand, the visual control of skilled activities is mediated by the dorsal stream. [15][16]

The following chapters will explain in more detail the functionalities of ventral and dorsal streams.

2.1 Ventral streams

The ventral stream is said to travel through the ventral (“the belly”) side of the brain [17]. It transfers information from V1, the primary visual cortex, to the temporal lobe. The information transferred is related to the visual identification and recognition of objects. It takes into account the position, size and pose of the observed object. Due to its nature, it can also be called as the “what” or “vision-for-perception” pathway. [5][11] The higher levels of the stream have the ability to learn to recognize an enormous number of different objects and patterns, just like a computational model would in image processing. In addition to recognition and object representation features, the ventral stream is also associated with storage of long-term memory. [11][16] Since the ventral stream is crucial in identifying what we are looking at, injury to it may result in an inability to recognize faces or understand facial expressions. [5]

2.2 Dorsal stream

The dorsal stream on the other hand carries information from V1 to the parietal lobe. The stream is said to travel through the dorsal (“back”) side of the brain [17]. This “where” or “vision-for-action” pathway also has access to information about the shape and size of

objects, but focuses on motion and the spatial relationship between objects in the visual field [16][18]. It is said to utilize an egocentric (self-to-object) spatial coding system instead of an allocentric (object-to-object) one [16]. This means it represents the location of objects in space relative to the body axes on the self instead of other objects. Furthermore, the dorsal stream plays a role in the control of the eyes and arms, particularly when visual information is used to guide saccades or reaching [19]. Just like in the case of ventral stream, damage to dorsal stream can cause problems related to its functions, such as optic ataxia where the sufferer cannot use visuospatial information to guide arm movements, or motion blindness. [5]

3. EDGE DETECTION

Edges and gradients are important to visual perception since they indicate the location of object boundaries and shadows. They correspond to a variety of physical phenomena such as lighting variations caused by shadows or variances in albedo between objects. Edges can occur between objects as well as within a single object, and in many situations, all these phenomena can occur at the same time. [20]

This chapter concludes which edges are important for perceiving enough information, and the differences between edge detection in the human visual system and in image processing tasks such as image segmentation and texture classification. Although humans process visual information differently than a computer would do, according to Marr [21] and Gibson [22] the perception of shapes and objects as well as depth are crucial to the human visual system.

3.1 The importance of edges

Research from 2013 [20] demonstrates the distinction of different types of edges. As previously stated, edges arise due to variety of physical phenomena. An example of different edge types is presented in Figure 4.

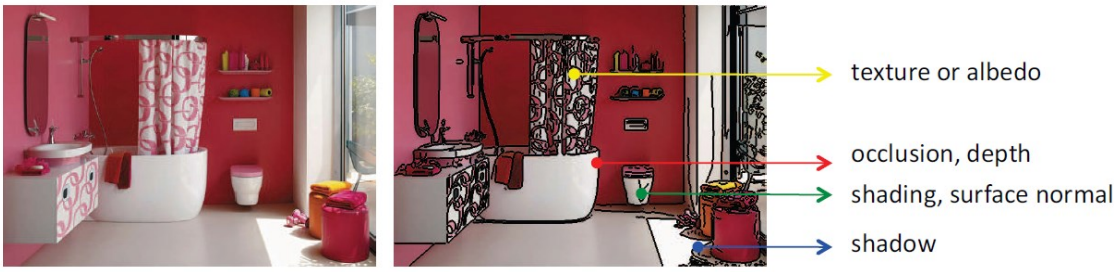

Figure 4. *Typical types of edges occurring in edge detection [20]*

The study was interested in which edge types are found as most informative and important in human visual system. According to the results, surface normal and depth play a more important role in object recognition while on the other hand edges created from shadows and textures are found distracting. Marr [23] has stated one of the primary responsibilities of the human visual system is to extract the most essential information from an image quickly and without any struggle in order to construct a symbolic representation of the scene. On topic of vision, RGB (red, green and blue) and BW (black and white) scenes are natural and thus the most informative and recognizable. The more information we are given in a scene, the better recognition performance is [20].

Object recognition changes drastically when the scene consists only of edges. When more information (e.g., color cues) plays an important role in human vision, an edge scene of the same view may be distracting due to complex textures and shadows as shown in Figure 5. A clearer general view can be received when we ignore these aspects. Although color vision is proven to be important when it comes to recognizing objects, it is not always necessary to execute everyday tasks [24]. Lines and edges themselves are already rich sources of visual information and have been proven to have an essential role in navigating in different environments [24].

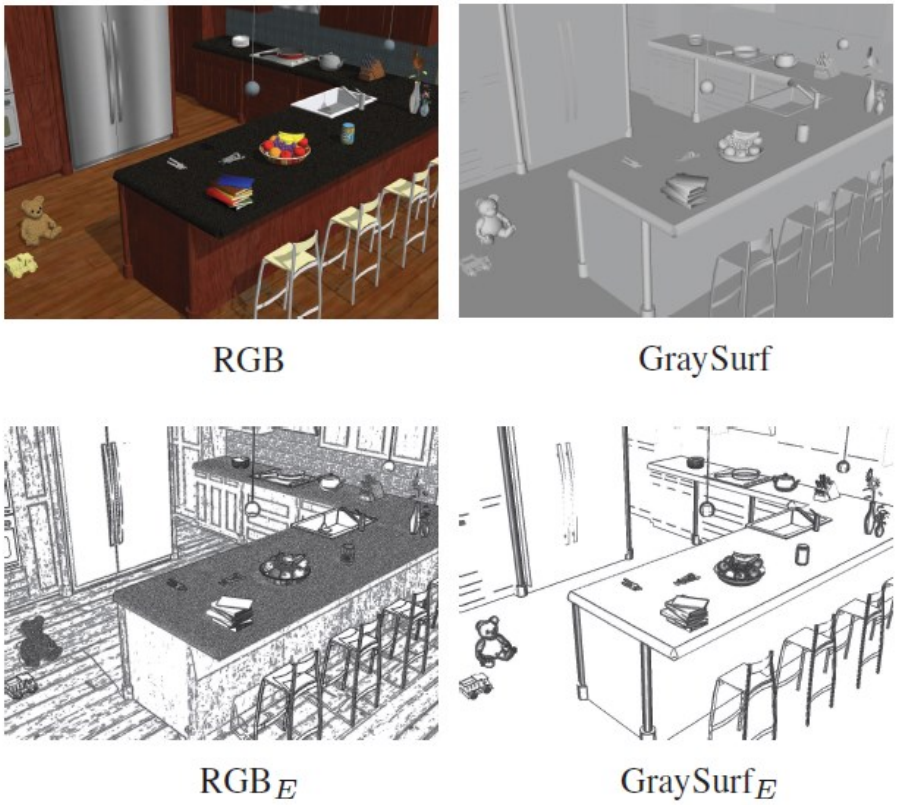

Figure 5. *Example scenes and their corresponding results after edge detection [20]*

It is obvious not all edges are equally informative. In a scene representing everyday life, edges correspond more to uninformative aspects (shadows and albedo) rather than informative ones (surface normal and depth changes) (see Figure 5). Useful edge detectors ignore shadows and textures even if it might mean a loss in detail and sometimes crucial information [20]. For example, shadows play a different role in real life. It gives information such as where the light source is located, the material of an object, its location and the spatial relation to its surroundings [25].

3.2 Edge detection in human visual system and image processing

Edge detection is said to occur in the primary visual cortex (V1). It is the first part receiving visual information before transferring it forward to other visual cortex parts. The primary visual cortex has neurons which react to changes in illumination. Inhibition between bipolar cells is provided by horizontal cells in the retina. This so-called lateral inhibition mechanism is believed to be responsible for contrast enhancement and is crucial for edge detection. [26] An example of a single cortical cell is presented in Figure 6.

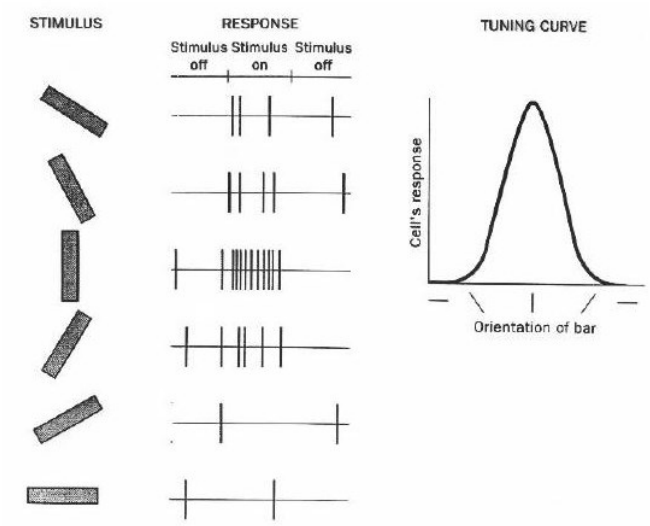

Figure 6. *Oriented edge detectors in primary visual cortex [12]*

The results demonstrate that the single neuron prefers stimuli that are vertically orientated. The tuning curve resembles a bell curve, indicating that the observed neuron responds strongest to vertical orientation. In neuroscience, neurons are often organized topographically, which means that nearby sections of neurons have similar orientation tuning. [12]

Many studies use gradient-based Gabor-like responses to describe the primary visual cortex of the mammalian visual system [27][28]. Gabor function can be defined as a sinusoidal wave with a certain frequency and orientation that is modulated by a Gaussian wave [28]. Due to its nature, Gabor filters are used in image processing to analyze content with high frequency components such as optical character recognition and fingerprint recognition.

Just like in the human visual system, edge detection in image processing tries to identify points with discontinuities (changes in brightness levels). This is usually done by typical

edge detection steps which consist of smoothing, enhancement, detection, and localization. This thesis has utilized an application with a Canny edge detector. It is widely used method of edge detection since it performs well in detection, localization, and response.

The purpose of edge detection in image processing can be compared to how the human visual system utilizes it. A good example of an everyday situation is indoor and outdoor navigation, since that has been proven to be strongly dependent on edge detection. Simply, an edge detection algorithm – such as Canny – can be used for detecting obstacles in a mobile robot environment allowing it to navigate around complex areas [29]. Another, more human-centered approach is an indoor navigation assistant for visually impaired persons [30].

As we can see, edge detection has a wide range of applications and some of its aspects can be compared to how the visual system perceives objects and surroundings. The following chapter, Chapter 4, will put into practice the theoretical knowledge gathered from the previous chapters.

4. METHODOLOGY

This thesis utilizes an Android application represented in Figure 7 paired with Samsung Galaxy S6 and Samsung Gear VR-headset model SM-R321.

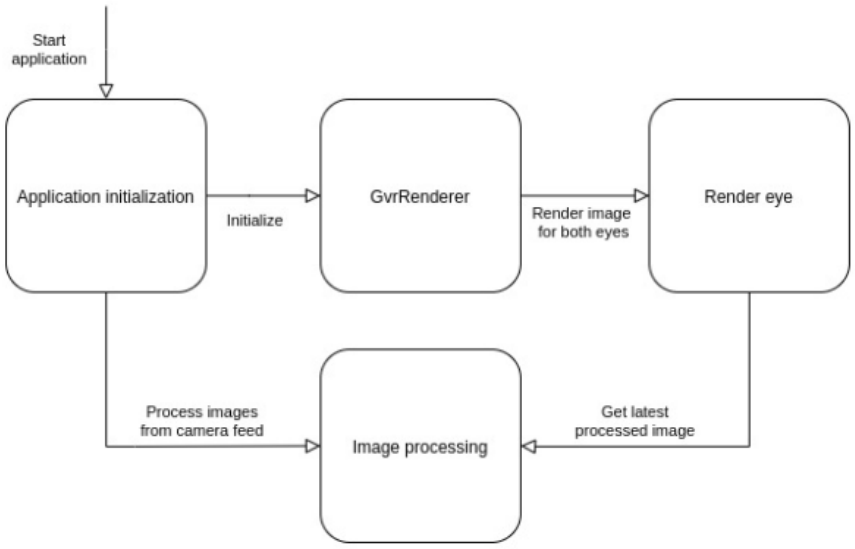

Figure 7. *Overview of the utilized application [31]*

The application works as a real time feature camera which can be used along with a VR headset. Application initialization works as the spine for the whole program. GvrRenderer displays an image on the surface created in the initialization stage. Render eye works as the function which prepares the rest of the functions to create the application. The most notable part of the application functions, considering this thesis, is image processing, which serves as the edge detector. [31] Since the goal is to experiment on how everyday life would be if we could only detect edges, we want to preserve all the information possible – such as colors. Preserving colors in edge detection has been done as follows [31]:

- apply blur filter
- apply Canny edge algorithm
- conversion of extracted edges to RGBA color space
- conversion of original colored image to COLOR_YUV2RGBA_I420 color space
- apply RGBA lines as mask to colored image

The blur filter has a kernel size of 3x3, and hysteresis thresholds set to 70 and 170 to receive a balanced output. It has been said, these parameters are not the most optimal

for every situation [31], but this will be discussed furthermore in the results chapter, Chapter 5.

4.1 Overview of the experiments

The goal of this thesis was to examine how well everyday tasks would be executed in a line world, one where all we can perceive from the real world are its edges in RGB colors. Living in the line world was simulated by doing regular daily tasks, from walking around, cooking, shopping to enjoying hobbies. In addition, a few specific experiments are going to be highlighted to evaluate this study. The experiments were chosen considering the visual hierarchy and the two-streams hypothesis; object recognition, motor skills (guiding reaching and grabbing), motion perception, coordination, and perceiving details. The specific experiments are explained in detail in the following chapters 4.2, 4.3, 4.4 and 4.5.

4.2 Object recognition

Object recognition, as stated in the previous chapters, is more reliable when the colors are present. To provide variety in object recognition required in everyday tasks, the experiments were divided into two types starting from easier tasks and moving on to more difficult experiments. The experiments consisted of object recognition in general from a group of objects and organizing same type of objects in a desired way. The following experiment was still directed towards object recognition but focused more on the importance of color when objects share the same shape.

The simplest object recognition test was done representing a situation that may occur in an everyday scenario. This meant classifying objects from a clustered group of similar objects. For this experiment, the objects were related to stationery items, consisting of different types of pens, rulers and markers as well as other typical objects that can be found in a pencil case. The content of a pencil case was emptied on a table. The goal was to identify the objects in a desired order, such as find scissors from the cluster, and group them up according to their type, such as highlighters and pens.

More complex experiments were done working around citrus fruits. This experiment was chosen considering the similarities the fruits share, making color perception play more important role in segmentation of the fruits. The chosen fruits for this experiment were orange, grapefruit, lime and lemon. The fruits were placed along with different types of berries and fruits. The goal of this experiment was to identify the citrus fruits for further experiment.

After being able to find the citrus fruits, the more challenging experiment was to observe the cross sections of the fruits. Since the cross sections are almost identical, and mostly can be told apart only by color, this experiment was considered the most challenging one of the classifying tasks. The citrus fruits were cut in half and the goal was to identify each which fruit was which.

4.3 Hand-eye coordination

Hand-eye coordination is an essential skill in everyday life. It is a process through which the visual system coordinates what is being perceived in order to guide hands in a certain task. Since lots of tasks, even ones as simple as writing, require hand-eye coordination it is an interesting aspect to test how the line world would affect it.

Hand-eye coordination was tested on basic everyday tasks, such as reaching for different shaped and sized objects and moving them from place A to place B. Other chores that occur in everyday life were related to making and serving food. These tasks consisted of preparing ingredients such as cutting vegetables as well as pouring water in a transparent glass and a nontransparent mug. The last specified experiment related to hand-eye coordination was writing on a paper.

4.4 Navigating in different environments and motion perception

Navigation was tested in different types of environments one can face in everyday life, changing from indoors to outdoors as well as from familiar environments to new, more unfamiliar environments. Most of the moving around experiments were done during daylight or in indoors lighting due to safety, but an example of poor lighting is also represented to show how poorly edge detection works in dark environments.

Outdoor environments consisted both of rural and urban scenes. These scenes were chosen considering the differences the scenes had. Urban scenes have more precise shapes and straight lines compared to rural outdoors, such as forest paths.

In addition to motion perception in real life, motion perception and navigation was also experimented on a computer screen to test the extreme cases of motion perception. The tests were done on two different types of video games played on a computer; fast reaction based first person shooter game and more laid-back open world game, which scenery almost represents the real world.

4.5 Perceiving details and precise work

Chapter 3.1 talked about which edges are important and what may cause unwanted complexity. However, the world is full of bigger and smaller details and doing meticulous work is extremely dependent on those details. The purpose of these experiments is to test how much details are perceived. The question is whether information will be lost or whether complex and overly detailed content would become too messy preventing us from having a clear image. The experiments consisted of more artistic hobbies such as reading piano sheet music and drawing.

5. RESULTS

Experiments based on everyday chores were mostly executed successfully. Chapter 3.1 stated edges provide lots of information and color cues are not necessary for all tasks. The results of the experiments support this claim. In general, being only able to perceive edges seems to be affecting both dorsal and ventral streams. According to the results of the experiments, object recognition became significantly more difficult, in some cases even impossible, while on the other hand motion perception and navigation in different environments had a slighter change. Merely being able to detect edges limits the user's ability to perform certain tasks. It is obvious that the execution time of the chores was extended simply due to the fact our brain needs time to adjust in new type of visual cues, but in the end everyday living in the edge world is plausible. However, to get more reliable answers, the experiments should have been done in a longer timeframe with multiple different people. Adaptation to a new visual view takes time and everyday tasks in the line world would become easier after getting used to it.

The following chapters will explain in more detail the results of the specified experiments and comment the results as well as present furthermore ideas.

5.1 Effects on object recognition

Object recognition is based on comparing seen object to a memory representation of the object [32]. The objects are coded in the brain giving a clear image of what something is supposed to look like. However, the results of the experiments reveal that even familiar objects can become unrecognizable when only the edges are perceived. This happens particularly when the objects are clustered together not to mention when the objects have similar shapes.

The first specialized experiment was segmenting objects from a cluster of objects of a similar type. Edge presentation and the set of the first experiment is shown in Figure 8. The brain can segment most of the items to be stationery items with the cues of a few specific objects, such as scissors and a harp. However, some of the objects remain rather confusing especially if the brain does not already know what items the pencil case held inside of it. Object recognition in both the normal visual world and the line world is easier when the context of the objects is known beforehand.

Figure 8. *Edge representation and the original scene of stationery items in a cluster*

Figure 8 shows, that detecting clearly different shapes, such as a pair of scissors, a pencil sharpener and a harp is relatively easy to do. The shapes differ significantly from the rest of the objects. Although the brain can tell that the scene contains different types of pens, a specific segmentation for them is harder to do due to the complexity of the edge representation. In addition to more familiar objects, the scene contains a few items which are hard to recognize, the first of these objects being transparent rulers. The edge detector works better, when the object has bright and clear colors, meaning transparent objects blend in and become difficult to see. The second type of objects which were difficult to classify in this experiment were mechanical pencil lead packs due to their unfamiliar shape.

5.2 Importance of colors

In general, it is obvious that only being able to perceive edges from the surrounding world will make living in it very different from what we are used to. Lots of information is lost in edge detection. When object detection might still work most of the time for different shaped objects, situations where color is a prominent factor need other senses to be able to process the information. As expected, the experiments about object recognition show us that recognizing different fruits from each other becomes almost impossible when the object cannot be seen fully in color. An edge representation of the fruit scene and the cross sections of citrus fruits are shown in Figure 9. The shapes are similar to each other, making color to be the only visual cue to separate the objects. However, the colors were not vivid enough for the edge detector to provide proper information.

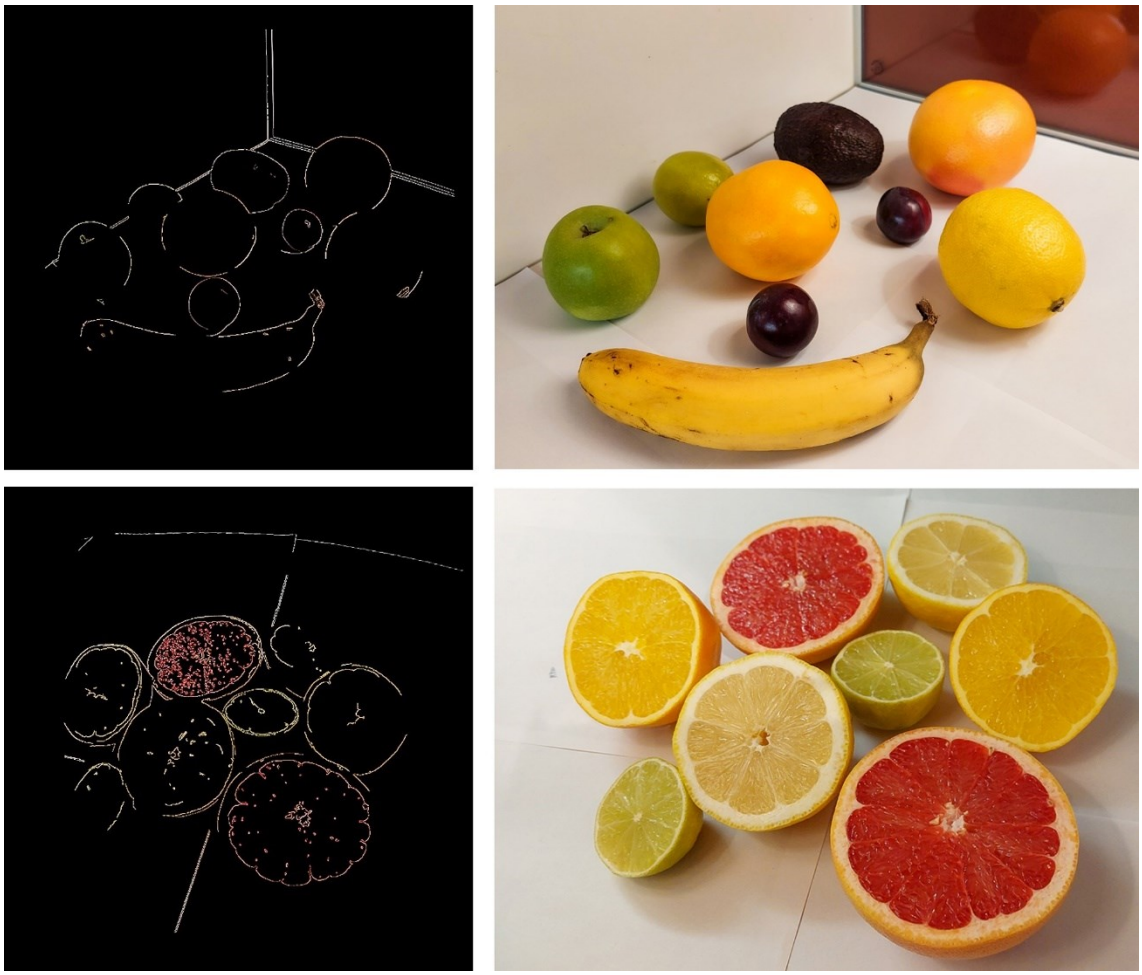

Figure 9. *Edge presentation and the original scene of fruits grouped together. The lower image pair shows the cross sections of different citrus fruits.*

In the upper image pair of Figure 9, the bottom object, a banana, became the only one that is clearly recognizable due to its different shape, as for the rest one could only guess what they could have been. A more drastic result was received comparing the intersections of the citrus fruits on the bottom image pair of Figure 9. However, the red color pops out a lot making grapefruit the easiest to detect. The uncertainty of classifying the fruits leads to importance of other senses. Since classifying objects with only vision becomes less accurate, other senses such as smell and taste must be used to ensure correct classification. These results could be compared to the neuroscientific point of view, where damage that causes the inability to recognize objects is frequently associated with an impairment of color perception [5].

The importance of color is seen in everyday life situations as simple as predicting weather and temperature via sight. It is natural for humans to check how the weather looks like before going outdoors. With a glance it is possible to tell what season it is and whether the day is going to look cloudy, rainy, or rather sunny. As Figure 10 shows, missing color cues makes predicting weather rather impossible. If the same figure was

shown to someone who does not know the context it would even be difficult to identify the season.

Figure 10. *Edge presentation and original scene to demonstrate perceiving weather and seasons visually.*

During the experiments there were few extreme/rare cases that clearly show the presence of sunlight. For example, in Figure 11, the edges of the shadows provide information of the position of the light source. Also, the vivid colors of the buildings on the left in Figure 11 and blue tint on the tree branches indicate a sunny, probably cloudless day.

Figure 11. *Edge presentation and original scene of shadows and vivid colors caused by bright sunlight.*

The results indicate that color deprivation drastically complicates everyday life.

5.3 Effects on hand-eye coordination and navigation in real world

Although some problems were faced due to technology and equipment, the results reveal that hand-eye coordination remains nearly the same in the line world. The problems will be later explained in Chapter 5.6. Still objects are easy to grasp, handle and move around. Also, for example, using cutlery for eating could be done as normal as possible, the only problems were related to detecting the actual food on the plate rather than with fine motoric skills. The same results were received when working with knifes for cutting and preparing meals, and scissors making handicrafts.

Like in the case of detecting transparent objects, working around with water turned out to be difficult. Pouring water into a glass or a mug turned out to be difficult and had to be done very carefully to avoid overpouring. The edge detector faced a challenge in detecting the surface of the water making it difficult to tell at what point the glass or the mug would be filled. However, this only affected the speed of the process rather than the hand-eye coordination.

The most difficult hand-eye coordination activity turned out to be a task as simple as writing on a piece of paper. It is possible to execute in very good lighting, but it requires more coordination than with normal vision. The brain takes more time to process the visual information of text due to its more complex visual look. This problem faced will be explained more in Chapter 5.5.

Like hand-eye coordination, navigation is said to be less dependent on color vision, keeping it relatively the same in the line world as compared to the real world. Clear, geometric paths are easier to navigate through to a destination. It takes less effort to scan the ground and plan the next position for a foot compared to a walk in the forest. This same idea of the real world can be transferred to the line world. An urban scene provides clear paths due to the architectural landscaping. Pedestrian streets and roads are distinctly defined with curbs or plantation. Buildings and structures give strong visual cues of depth making it easy to navigate in urban scenes. Examples of the scenes are shown in Figure 12.

Figure 12. *Edge presentations and original scenes of urban structures.*

Unlike in urban scenes, rural scenes with less geometric shapes become more difficult to navigate through. For example, the forest path shown in Figure 13 provides too much unnecessary information making the path almost impossible to detect. Without the support of buildings helping to perceive depth, it is hard to estimate the distance from the location to the end of the pathway.

Figure 13. *Edge presentation and original scene of a forest path.*

5.4 Effects on motion and detail perception on a screen

The results show that playing videogames which are fast-paced and require quick reaction time became difficult while taking away from the enjoyment. The refresh rate of the edge detector used for the experiments is relatively slow (30 FPS). What was perceived via the VR glasses did not match what was happening on the actual screen, the perceived visuals were more like a slideshow than a smooth video. This could be referred to on the neuroscientific side as something called motion blindness mentioned in Chapter 2.2.

The importance of colors also emerged during the video game experiments. Opponents in video games are usually outlined as red whereas blue is used to indicate teammates. This is demonstrated in Figure 14.

Figure 14. *Edge presentation and original scene of fast-paced shooter game. Opponents are seen further away with red outlines and teammates close by with blue names above the robots. Explosion of the right-side robot is included in the edge representation to demonstrate the nature of the visual effects.*

Although it is possible to distinguish opponents and teammates from a still image, due to the fast changes and large volume of information on the screen, the gameplay became rather challenging and hard to follow. In addition, it was difficult to adapt to the new visual cues which resulted in a headache and nausea.

A more story-driven game on the other hand contained real-world elements and what was perceived on the screen could be compared to real life moments. For example, moving around was easier to do in the city-scenes than in rural pastures. Nevertheless, the game was full of details as the example figure, Figure 15, shows making the gaming experience hectic from time to time.

Figure 15. *Very detailed edge presentations and original scenes of an open world game. The upper image pair shows more rural scene and the lower image pair more urban scene.*

Although the second experiment had the same problems as during the fast-paced game, it was easier for the brain to process. The same result was received from watching news and less action-based shows from the TV. Audiovisual and multimedia entertainment becomes easier to follow provided it has fewer visual changes and less quick movements.

5.5 Effects on details and precise work

The edge detector faces many challenges in perceiving details. Since too many edges means too many unnecessary and distracting information, we will lose details and fine lines. This becomes a problem in creating visual art. It is impossible to draw a sketch with very light pencil because we would simply perceive nothing. Lines and colors must be very clear and saturated in order to see a complete image as represented in Figure 16. The same problem occurs when trying to do precise work such as sewing badges on your overalls or painting your nails. You are more likely to have a messy result than a good one.

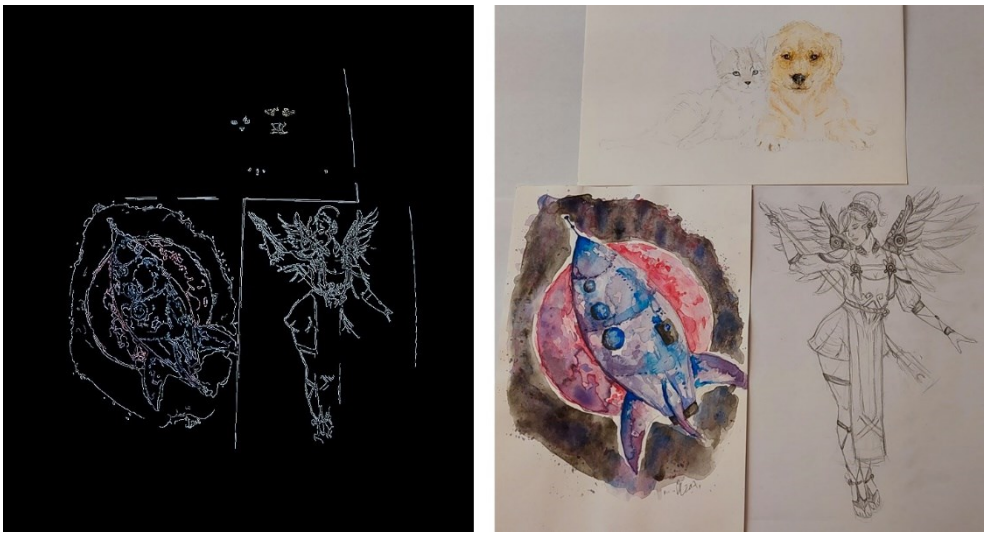

Figure 16. *Edge presentation and original scene of different drawings. The fainter the art is the worse the edge detection works.*

One of the essential problems related to edge detection was whether it provides too much information or too little information. In the line world, letters and written symbols become hollow, which increases the information to be processed. In order to perceive written information properly, the font has to be large and isolated from other information. An example of this case is shown in Figure 17, where “Tietotalo” is easy to read when on the other hand piano sheet becomes a complete mess and impossible to read.

Figure 17. *Edge presentation and the original scenes of a big fontal text and a detailed piano sheet.*

Since preserving details is very situation dependent, optimizing the edge detector cannot be done for every situation. If the human visual system was changed to correspond to the edge detector used in the experiments, some choices would have to be made. This could mean either sacrificing the clarity of a bigger image for a more detailed view or vice versa.

5.6 Typical technology related problems

To begin with, it is important to note that the experiments are done using a VR headset and an edge detection application, which utilizes a phone camera to see the environment. This means the visual scene received using technological equipment does not fully correspond to a real visual scene perceived through only eyes. Human perception, for example, has approximately 180° forward-facing horizontal field of view and around 150° vertical field of view [33].

The focal length of an eye is approximately 17 mm [34], although the eye can alternate it. As a comparison, the camera used for these experiments has a focal length of 28 mm and a field of view of 120° [35]. The field of view in cameras determines how much of the scene fits into the frame. The whole scene would not fit into the frame since the parameters in the camera system differ from the natural parameters of the eyes. This forces further head movement to see more of the surroundings.

Another problem faced with the technical equipment was the scaling of the world. If your Inter-pupillary distance (IPD) is lower than that of the camera, everything looks smaller in VR. On the other hand, your IPD being higher than that of the camera, it will make everything look bigger. [36] In the case of these experiments, everything tended to look bigger and closer than they would appear in real world.

The combination of a different field of view and inter-pupillary distance problems resulted in a slight depth distortion. This resulted in a difficulty of determining distances in motoric arm movements, such as guiding reaching and grabbing. Navigating around in tight places also became hard due to the fear of bumping into something.

To be mentioned last, the code variables cause the edge detector to ignore some edges. The chosen values are not the most optimal in all cases. Lighting is affecting a lot on the performance of the edge detector. Sometimes it works great but sometimes it is unable to detect edges completely especially when the illumination changes are too subtle and when it is very dark.

5.7 The past and future

It is impossible to tell, how far we as humans would have got if our vision was able to see the world only via edges. For example, trichromatic vision has played an important role in foraging and surviving [37]. Another example more relevant to the development of science, is shadows. Shadows have provided early evidence that light travels in straight lines. Presuming the edge detectors would not respond to shadows, it is possible that the information of how light travels would have not been received so early.

In a scenario where every human lost the ability to see normally and started to only perceive edges life would still go on. Humans are very adaptive and adjust to many different situations easily. Although it takes time to change the routines in which humans rely on vision, with enough of time many things would become possible.

In further work it would be interesting to experiment how line world would affect those with visual impairment or spatial learning disabilities, for example. Would edge detection complicate living or ease perceiving surroundings.

6. CONCLUSIONS

This thesis undertook performing experiments on whether we could live in a world where our visual system was limited only to detect edges. This was tested by doing everyday tasks wearing a VR-headset connected to a phone running an edge detection application. In addition to tasks considering everyday living, few experiments were specified considering the ventral and dorsal streams; object recognition, motion perception, hand-eye coordination, and precise work.

There is no question about the importance of vision. It provides so much information that a sudden change or an injury to the visual system complicates daily life. Although the neurons in the primary cortex have characteristics that are comparable to mathematical edge detection algorithms, humans are not machines. Edge detection does not provide enough information in certain cases, such as visually predicting the weather or identifying fruits which have similar features. Other senses would be required in these cases in order be able to live a fairly normal life. Another option would be improving the reliability of edge detecting vision. This becomes a challenge since a large amount of details presented via only lines causes the visual scene to become difficult to comprehend. A compromise between the number of details and clarity should be made.

While everyday tasks needed to survive life are still possible to do by merely perceiving edges, entertainment and hobbies suffer in the line world. However, humans are very capable to adapt to changes and different situations quickly. With enough of time, we would be able to live a normal but visually boring and unappealing life.

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