CSC2521/DIGF6B13: Sketching: Interaction, Modeling and Perception
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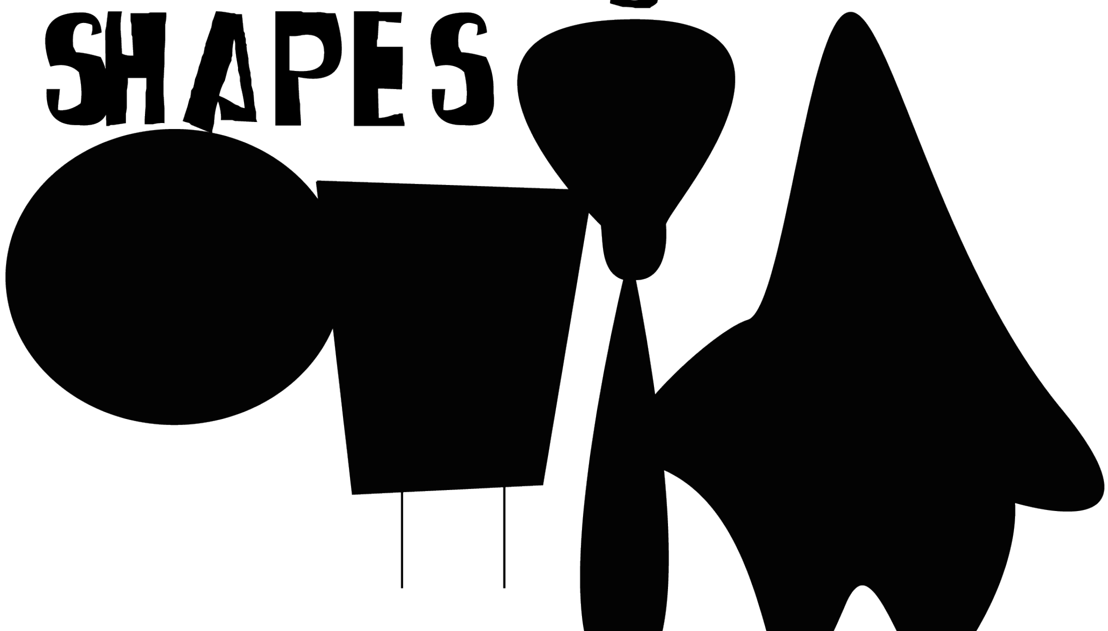
# Minimal Distinguishable SHAPES



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# Introduction

Shapes play an extremely important role in human object recognition. It is amazing that people can recognize different forms of an object even the shape of it is unique. For example, if presented with several silhouette shapes of a horse with varying contours, one can still recognize each of them as long as they match the abstract model of what a horse should look like in one's mental outlines. This abstract model, similar to what Plato called the "theory of forms", is something humans possess while machines lack. It also accounts for the reason why scene understanding and object recognition are still open problems, while these are nothing but simple tasks for human beings.

How can we "install" this knowledge of abstract models to machines? First, we must have quantitative understanding about the main feature of each abstract model; such as horse and cow both have four legs, and a special shaped pair of wings implies a butterfly. Hence, in this project, we originally proposed to study the number of strokes humans need to recognize an object. By studying these essential strokes, we will have a better understanding of what defines an object to a human and what are secondary features.

However, because there are some theoretical and technical difficulties as detailed later, we proceed with another perspective of a related problem. In this project we investigate the question: "to what extent can a shape be simplified so that it can still be distinguishable from other shapes?" Addressing this problem is a different approach that can also help us understand the main feature that defines an object. For example, we humans perceive that both horses and cows have four legs; however, the hair on a horse's neck and the horns of a cow distinguish them from each other. Thus, if we over-simplified these feature, they may no longer be discernible from each other.

# Related work

Fu et al. [Fu 2011] studied how to construct line drawing animations by incorporating principles derived by art and cognitive community into a computational process to decide the order of strokes. The principles used in this paper is mainly proposed by van Sommers [Sommers 1984]. In this work, however, artistic heuristics is introduced, which is different from our cognitive approach.

McCrae et al. [McCrae 2011] proposed an algorithm to derive minimal representation in planar sections after gaining knowledge from their user study.

Cole et al. [Cole 2008] examined the relation between line drawings and geometric parameters. In their later work [Cole 2009], the effectiveness of using line drawings to depict a three-dimensional shapes was also studied.

Flatla et al. [Flatla 2010] proposed a framework to examine the minimal differences that human can detect in a variety of environment. The basic idea of study design is similar to our approach. However, our study is even more challenging because no computational function has yet been proposed for the quantity of shape differences. Under this condition, we have to design our approach in a more subtle than their method.

Wilder et al. [Wilder 2011] also examined the superordinate statistics by a machine learning approach.

# Study Design

### User Study Introduction

The goal of the survey is to determine what people deem as an object outline's primary features and what features can be exclude. To do so, we present several source images that depict objects (ranging from abstract models to recognizable shape models) to people and task participants to simplify each model in the form of a sketch. The design of the survey took two different approaches; the latter having slightly modified the design requirements to better respond to the goals of the study.

### Various Design Considerations

Participants are asked to observe the source images that the survey provides and draw the most simplified shape that they can imagine, using only one stroke while at the same time, making the shape distinguishable relative to the other shapes on the same page.

The design of the survey took consideration of the tasks participants (the designers) are most prone to. The concept of sketching is what most designers are used to when first encountering a design problem. A sketch is a reflection of the guiding mental image; this instrument allows designers to really put forth intuitively their first reaction in perceiving the visual precepts (Arnheim, 1983). Thus revealing what they deem most important feature of the shape.

Several media to record user input were considered for the study: Digitally, using Adobe Illustrator and/or Adobe Photoshop, and manually, using pencil and paper. The concept of using a digital medium was desirable as it allows for immediate digital transfer; nevertheless, this process takes more time and is less intuitive for the participants if each individual is asked to draw with a mouse or a keypad. The use of a tablet was also an alternative; however, we may have less control of what the participants use and thus challenge the reliability of the data. Hence, the choice of pencil and paper, which provides the flexibility, efficiency and ease of sketching, affords the most intuitive interaction (Saffer, 2010). This way participants use similar devices throughout the survey and mechanically, we have more control over the outcomes.

Aside from the different tools that we consider, we also reflected upon the potential of other factors to accomplish a similar goal for the study. We have considered incorporating a time constraint for the participants so that they have to draw the shape in certain amount of time; for example, thirty seconds for the five objects on each page. This way, participants are forced to instinctively focus on the most important feature of each object and sketch very quickly while concerning other objects' distinctive properties so that each of them is distinguishable from each other.

The idea of revealing an object one stroke at a time in order to understand how many strokes a person needs to see in order to recognize the object was also assessed. This option was chosen as the first prototype as it reflects more on our initial direction, which is to assess what are the essential strokes of an object that reveal its properties to a person without any preconceived notions about what object they are about to perceive.

**First Prototype of User Study**

In the first prototype, participants are asked to specify which object they think it is through the gradual revelation of the strokes. The strokes are not revealed randomly. They are revealed based on the way the designer of the survey drew it. The first prototype mainly focused on the importance of strokes rather than regarding the shape in its general overall form to determine the essence of the object. This very first prototype was devised through Adobe Illustrator's pen tool to draw the object stroke by stroke; however the overall choices of the object were not systematically considered. We placed each object into one of three categories: animals, fruits and human sport figures. As the stroke is revealed, a participant can select which object they believe the stroke is revealing.

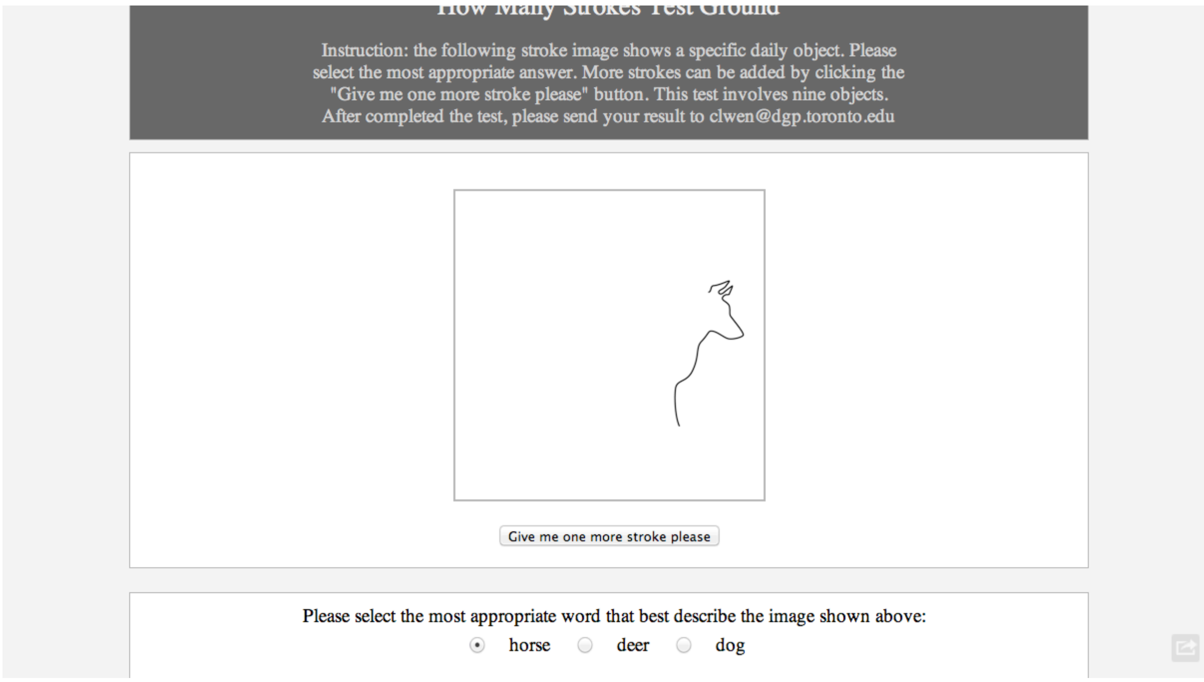

Figure 1. First Prototype

However, this method has several concerns. First of all, images are hardly free of cultural conditioning (Danesi, 2004). With the initial exposed choices that the participants have to choose from, they will already have unconscious mental outlines of the shapes, which can then effect the way they perceive each stroke.

Secondly, the order of strokes can be subjective. For instance, if one is to see the antlers of the deer prior to the tail, he/she may find it easier to recognize that the object is a deer as compared to the person that first sees the tail of the deer, he/she may guess it is either a horse, a deer or a dog, as all three animals have tails. An alternative to this concern is to randomize the exposed strokes. However, the ordered ones and the randomized ones might just provide results that just cancel out each other, in which in the end we might not be able to find generalizable patterns in the data.

## New Direction Toward Second Prototype

To eliminate these problems, we took our study in a new direction where we simplified the source objects and try to find the simplest and fewest stroke that render those objects recognizable in relation to a set of other objects, with the goal of finding the most meaningful strokes and features. We are trying to reduce the objects to these basic characteristics of the object's referred concept. According to Stephen Kosslyn, who is well known for his studies of the brain's imagery system, proposed that subjects can easily form images in their mind to help them carry out tasks, such as arranging furniture in a room or designing a blueprint (Danesi, 2004). In our case, once we stripped down the object to its most basic concept, a user can potentially perform a gesture or a line to express the same characteristics of the object.

The requirement for choosing the objects for five different sets was to consist of both recognizable symbolic objects and abstract objects. The symbolic objects reflect back to the unconscious mental outline that each person perceives in the recognizable objects. Therefore mimetic symbols that represent things in reality are chosen. They are shapes that are pervasive and easier to recognize.

Original

Simplified

Figure 2. Mimetic Objects Choices

Other iconic shapes that people encounter in their lives include Health and Safety Symbols

Original

Simplified

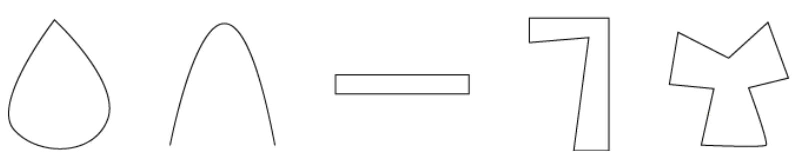

Figure 3. Health and Safety Symbols

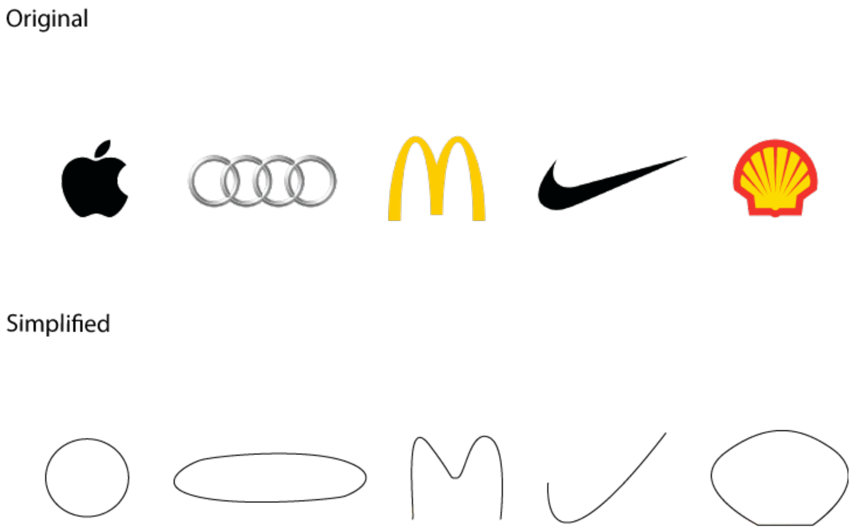


Figure 4. Iconic Logos

Logos are interesting due to their minimalistic features that allow people to recognize the symbol immediately. However, these symbols are conceptual images that can impact our findings as people may associate their pre-existing mental images with the presented image and use different codes of interpretation. Therefore abstract shapes are included in the study. Abstract shapes help us get away from the meanings we impose on the images and allow users to freely associate the simplest strokes to the shapes.

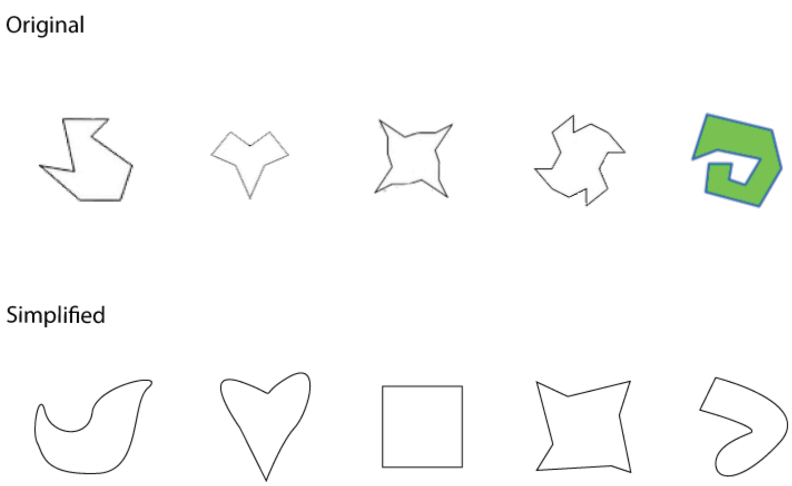


Figure 5. Abstract Shapes

## Second Prototype Requirements

This approach brings us to our second prototype. Several elements are needed when organizing and arranging shapes to make the ensure the shapes have consistency. First, the shapes should have similar contours so as to not be very distinct from one another. In this way, the artists have to really consider how to create quality simplifications that are distinguishable relative to the other presented shapes. To make the object contours similar, artists and designers can really reveal the essential stroke of the objects. Secondly, all presented source images should be closed shapes, which means users can draw an outline of the shape in one stroke without lifting the pen. Thirdly, we stripped away all the colours of the objects to avoid possible colour influence on artist's perception of the objects. Also, we would like more variety of objects, other than the five that we discussed above, to further improve on the breadth of the survey. Most importantly, the inclusion of various types of abstract shapes allow for diverse observations on the simplification of each stroke.

The abstract shapes are especially interesting due to its cues that are perceived by participants. "Cues" according to Rosche et al (in Logothetis, 1976), are perceivable characteristics of natural groupings of stimuli where they can be used for valid category predictors. However, when vastly different, yet clearly identifiable shapes are presented alongside one another, these atypical exemplars are then recognized as individual entities rather than specific categories, and they become the entry point of recognition (Logothetis & Sheinberg, 1996). In this case they are the abstracted random shapes. With these new simplified 'cues' derived from abstracted shapes, simplified relationships between objects can be observed and generalized.

The thirteen pages of image sets are given to each individual. Each set consists of five to seven images of the same category. Users are requested to simplify each object on the page as much as possible yet still make them recognizable relative to the other objects on the same page. They are also asked to use closed shapes for all their simplifications.

In a later session, we import the user-generated images into a web system and randomize the display order of the simplified images from each set and ask participants to match the simplified ones to the original ones in a system. The system also asked the participants to provide feedback on the simplifications to better understand whether the success of the match is due to good simplification or due to detailed replication of the source image, an issue we will discuss later in the evaluation and result section.

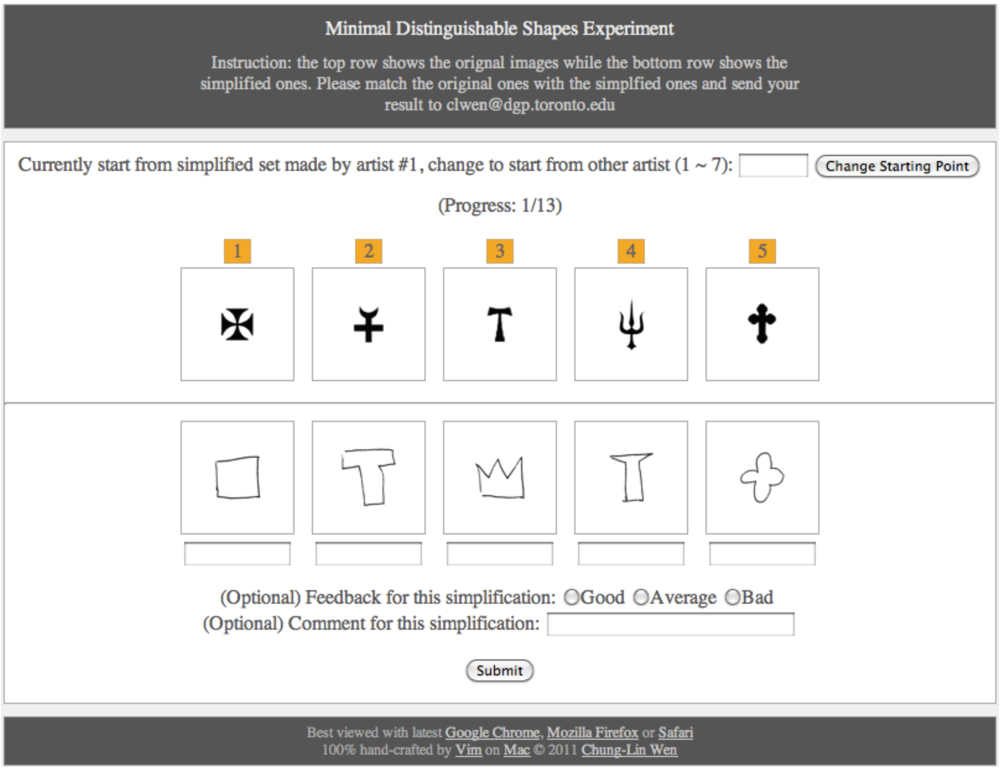

Figure 6. Interface of Part 2 of Second Prototype

## Survey Participants

By conducting a user study that asks users to match the simplified images with original ones, we verified that the simplifications are indeed distinguishable to users. We built a web interface for users to participate as shown in the above figure.

Seven participants were asked to participate in simplifying the shapes; four artists/ designers, an architect, a system analyst and a computer engineer participated. The main participants are students of CSC2521 and CSC490 Fall 2011 from the University of Toronto with about 40% female and 60% male, age ranging from 20 to 30, and design experience ranging from expert to little. In order to balance the experience, ability and other variables in the experiment, we conducted the experiment in a Latin Square fashion.

Each participant was instructed to “Simplify each object on the page as much as possible yet still recognizable relative to the other objects on the same page. Use closed shape which means one can draw an outline other shape in one stroke without lifting the pen” For all of them, further verbal explanations were also given to clarify any misunderstandings of the directions given. Nevertheless, an interesting pattern exists between artists/designers and others. For artists and designers, they tend to draw more elaborated simplified shapes no matter how much we stress on the importance of making the objects as simplified as possible. On the other hand, the concept of quantification and elimination of details are more apparent to the other professions, architect, engineer, system analyst, even with few verbal explanations.

# Evaluation/Results

### Choice of Image vs. Simplifications

The goal of the survey is to render the most essential and meaningful stroke of various shapes in relation to other shapes. The mixtures of objects presented in this study however may affect simplifications differently. For certain sets of images, such as Set 3, Set 4, Set 8 and Set 9, not many simplifications can be done due to their original already simplified shapes. Several sets, such as Set 1 and Set 3 may direct people to simplify those shapes through lines instead of closed shapes.

With recognizable figures, participants tend to present 'distinct feature' of the object, for example, rabbits with its two long ears and elephants with its long trunk. One participant even placed eyes on the simplified figures. However, this issue did not occur with abstracted shapes. Several participants still had issues grasping the concept of closed shape where it's most apparent with the necklace object on Set 9. Few of them sketched the simplified objects without closed shapes; this may be due to the tendency of line drawing that the object affords.

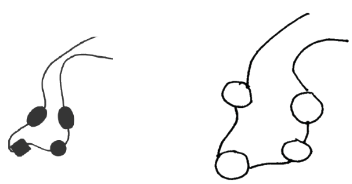

Figure 7. Result Example 1: Tendency to Draw Lines

### General Observations on Simplifications

As we expected, when simplifying the objects, many participants discarded details of the source objects and made a generalized stroke. However, several participants, rather than discarding the details, simply converted curvilinear to angular shapes

Figure 8. Result Example 2: Curvilinear to Angular

Regarding objects with repeating features, such as leaves, participants either drew a circle to represent the leaf or they draw very few repetitions of a feature to represent the object as a simplification. This latter notion exemplifies Gestalt psychology where the grouping of similar percepts can be perceived as sufficient to distinguish a shape (Graham, 2008).

Figure 9. Result Example 3: Repetition

Some other participants also when simplifying the curve, they flatten the curve and convert it straight lines.

Figure 10. Result Example 4: Curve to Straight Lines

However, the opposite was also observed. For shapes with several sharp corners, such as a star, participants either curved the shape to represent the overall size of the star, or they draw only one sharp corner to represent the whole.

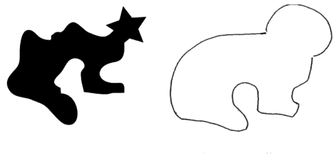

Figure 11. Result Example 5: Curved of Sharp Corners

**Issue: detailed drawing vs. good simplification**

One main concern for the study is that when subjects correctly match the simplified shapes with the source images, is the success of matching due to good and distinguishable simplifications or a detailed replication of the image itself? Several sketches that we assessed bear out this concern, as participants, rather than making simplifications of the source image, make a rather detailed drawing of the images we presented.

**Verification**

11 participants replied in total, with 143 units of testing conducted. In these 143 units of testing, 125 (87.4%) of them responded correctly, (artists correctly match the source objects with the randomly positioned corresponding simplifications), while 18 (12.6%) responded incorrectly. The correctness ratio for specific artists and sets of images are summarized in the following tables.

| artist | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| precision (%) | 88.5 | 88.9 | 76.9 | 84.6 | 96 | 96.2 | 80.8 |

Table 1: Artists' Precision in Percentage

| set | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| precision (%) | 92.9 | 71.4 | 85.7 | 100 | 100 | 78.6 | 85.7 | 78.6 | 100 | 78.6 | 85.7 | 92.9 | 86 |

Table 2: Sets' Precision in Percentage

As we can see from the above tables, although an extreme outlier is not visible, there is a significant difference in precision between artists and sets. For instance, artist #3 and sets #2 have apparently lower accuracies relative to others. For sets, this might be due to the already quite simplified source images which are difficult to make further simplifications. For artist, this could be caused by the artists' ability of understanding what it means to simplify. However, it is difficult to claim that artists who produce images with a higher recall rate create truer simplifications than the others who have lower rate of accuracy, since this depends on the extent of simplifications that one has made. How to define and balance recognizability and the extent of simplification is one of our future works.

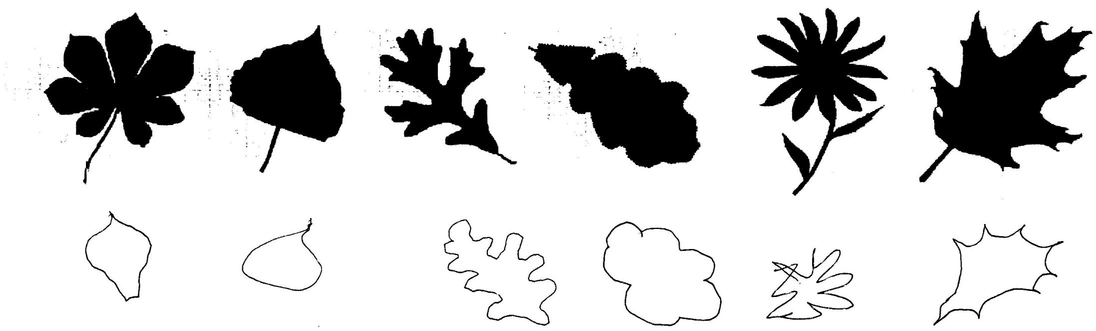

Figure 12. Set 2 of Participant 3

# Future Work and Conclusion

In this project, we examined possible principles for simplification of shapes. We achieved at finding some descriptive principles, as described in the previous section. However, in order to examine the minimal representations of shapes, we still need a quantitative benchmark. In the future, we would like to create an algorithm based on the principles we observed in this project.

For the simplifications artists provided, we noticed that the quality of some sets are poor, as indicated by our verifications. In the future, we would like to provide better principles and closer collaboration with artists to produce improved simplifications. One other possible source of good quality simplifications is crowd sourcing. That is, to incorporate the simplification process into a game (e.g. Luis von Ahn's work). This is to encourage players to try their best to provide better quality simplifications.

Regarding a verification interface, there are some technical details we can improve upon. First, the matching process can be more intuitive if we implement a natural drag and drop interface. Secondly, we can find a clever way to incorporate simplifications and verifications process into a game-like system. Finally, we would like to find more participants so to increase the generalizability of our findings. To accomplish this, some technical modifications have to be completed: 1) automatic Latin Square without the need of a manually inputted starting point; 2) setup a MySQL server.

There are several other valuable directions worth pursuing. This study has been an entry point for our broader goal of quantitatively understanding the abstract model of human object recognition. After gaining more knowledge on the topic, we would like to revisit the original problem by studying the essential features of the abstract model.

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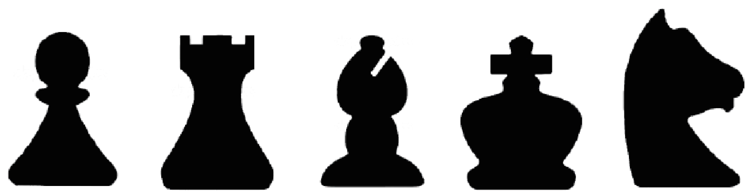
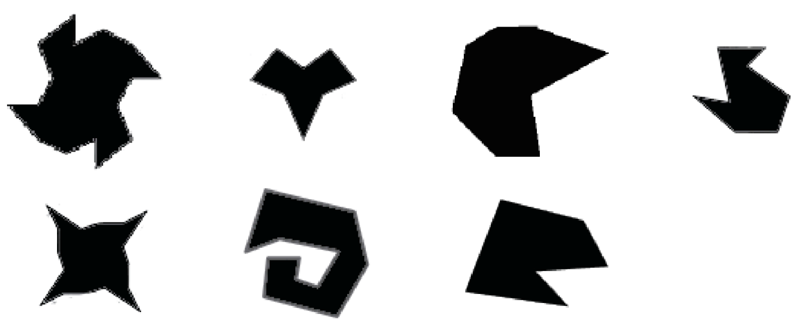
## Appendix

SET 6

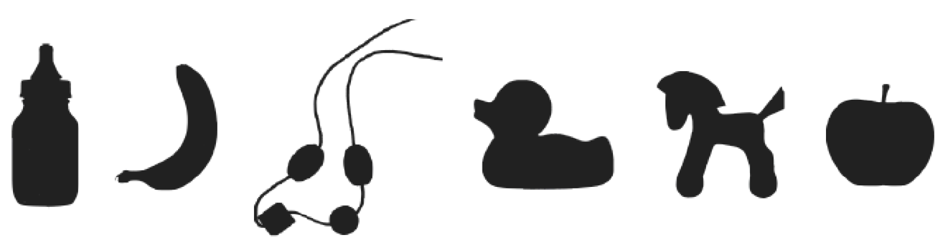


SET 7

SET 8



SET 9



SET 10

SET 11

SET 12

SET 13