Is Drawing Order Important?

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Abstract

The drawing process is crucial to understanding the final result of a drawing. There has been a long history of understanding human drawing; what kinds of strokes people use and where they are placed. An area of interest in Artificial Intelligence is developing systems that simulate human behavior in drawing. However, there has been little work done to understand the order of strokes in the drawing process. Without sufficient understanding of natural drawing order, it is difficult to build models that can generate natural drawing processes. In this paper, we present a study comparing multiple types of stroke orders to confirm findings from previous work and demonstrate that multiple orderings of the same set of strokes can be perceived as human-drawn and different stroke order types achieve different perceived naturalness depending on the type of image prompt.

CCS Concepts

• ***Computing methodologies*** → *Perception; Image processing;* • ***Applied computing*** → *Fine arts;*

1. Introduction

A drawing is incomplete without its drawing process. Results from Tong et al. [TCNW21] demonstrate that people better understand a drawing when they see the process. As drawings are composed of sequences of strokes, the order of strokes is inherent to the drawing process. Researchers have attempted to develop algorithms for realistic stroke ordering. Fu et al. [FZLM11] and Lu et al. [LFT14] rely on cognitive principle-based and entropy-based algorithms for stroke ordering. In this paper we explore the assessment of the naturalness of different stroke orderings.

There is a long history in computer graphics of studying how people draw. Analysis has been done on line drawings to determine where people draw lines to convey 3D shape [CGL*08] and how well those lines depict shape [CSD*09]. Further work was done to compare tracings, freehand drawings, and computer-generated drawing approximations to better understand how well NPR approximates drawing [WQF*21]. Other work was done to discover how well sketches represent object categories [EHA12], as well as how differently experts and novices sketch 3D shapes [XSL*22]. Gryaditskaya et al. [GSH*19] discusses line types used by students and professionals in product design sketches and concludes that the order of line types over time is similar for both groups. The previous analyses mainly focus on the end result of the drawing, whereas we focus on the order in which strokes are drawn.

One goal of Artificial Intelligence research is to mimic human behavior. In the case of creating sketching, the focus is models that output a sequence of strokes to mimic the process of drawing. It is more imperative to understand realistic drawing order to develop accurate loss functions and models.

Sketch-RNN [HE18] and Learning to Sketch [SPS*18] generate sequences of strokes, similar to how humans draw. BezierSketch [DYH*20] and the Virtual Sketching System [MSSG*21] improve on these preliminary generative models by predicting sequences of Bezier parameters representing strokes, allowing for fully vector sketches that are scalable and high-resolution. While these models are good at generating strokes, they do not take into account human drawing patterns in stroke ordering, so there is no guarantee that the predicted sequences are human-like.

We perform a user study to compare multiple types of stroke orderings and observe which ones are likely to be perceived as human-drawn. Our study setup can be used to evaluate naturalness of future drawing algorithms. The results of our study can be applied when determining how to order strokes for AI drawing frameworks and when maintaining continuity for instructional or storytelling demonstrations.

Our paper makes the following contributions:

- A comparison of multiple types of stroke orderings to determine which ones are likely to be perceived as human-drawn.
- A novel imposed ordering algorithm to re-order person A's tracing by person B's strokes of the same prompt.
- Results from the study indicate:
  - Confirmation of findings about natural stroke ordering from previous work.
  - Multiple orderings of the same set of strokes can be perceived as natural.
  - Different stroke order types have different perceived naturalness depending on the type of image prompt.

DOI: 10.2312/egs.20231009

2. User Study

We designed a user study to compare 6 types of stroke orderings. We showed users playbacks of orderings and asked them to select the naturalness of the ordering with two-alternative forced choice.

2.1. Data

We required a dataset with vector information to play back the strokes as if they are drawn in real time. We chose the SpeedTracer dataset [WQF*21] for its vector data and broad variation of strokes, including sillhouette, interior contours, and hatching. The variety of strokes was important to reflect natural drawing tendencies. We used a tracing dataset as a proxy for drawing, as tracing was concluded to be a viable proxy for drawing in [WQF*21].

We present the user with 6 types of stroke orderings: 1) original, 2) random, 3) length (longest to shortest), 4) shuffled time bins, 5) ordered based on cognitive principles from Fu et al. [FZLM11], 6) imposed order.

We include original orderings of tracings as well as purely random orders of strokes. If order of strokes is important to the naturalness of a drawing process, original ordering should be noticeably more natural than random ordering.

From [WQF*21], the authors concluded that the length of strokes trends from longest to shortest across the duration of a drawing. We include this ordering to verify its naturalness.

We include shuffled time bins to test the importance of relative ordering to the perceived naturalness of a drawing. We split the strokes of a tracing into 5 time bins, and shuffle the bins. Within each bin, the stroke order of the original tracing is preserved. By shuffling the bins, we randomize global ordering.

We include previous work done in stroke ordering in the study for comparison. We used a re-implementation of Fu et al.'s algorithm [FZLM11] to order strokes using the SpeedTracer data. The algorithm creates a coarse-to-fine hierarchy of unordered vectors through drawing simplification. In the coarse representation each stroke corresponds to a group of lines in the input drawing. Within each group, strokes are divided into two types: significant (skeleton of the drawing) vs. detail (fill in the shape). Ordering significant lines involves minimizing an energy function composed of individual stroke cost and transition cost between strokes. Detail lines are ordered mainly by proximity to each other and to lines within other groups of strokes. Fu et al. compared their algorithm with random order and longest-first ordering in evaluation, and showed their algorithm outperformed the other two orderings in naturalness.

Finally, we include a new type of ordering called *imposed order*. Multiple users tracing the same prompt may produce similar strokes, but in different orders. All of the original orderings are natural, so is it possible for person A's ordering imposed on person B's strokes to also look natural? To test this theory, we developed an imposed ordering algorithm, to order person A's strokes based on person B's ordering.

2.2. Imposed Ordering

Since the SpeedTracer data is registered to the image prompt by default, tracings of the same prompt were correlated based on pixel position. For each stroke in person A's tracing, we found a corresponding stroke in person B's tracing based on pixel overlap. Each stroke was split into smaller segments and for each pair of segments between two different strokes, we determined whether they overlap based on pixel intersection and the directions in which they were drawn. Two segments overlapped if the angle between was less than 30° and their intersection-over-union ratio was greater than 0.15. Person A's stroke matched person B's stroke if the majority of the segments in person A's stroke overlapped with person B's stroke. Strokes in person A's tracing that correlated to a stroke in person B's tracing were assigned the corresponding order from person B's tracing. Remaining strokes from person A's tracing that didn't map to any strokes in person B's tracing were appended to the new imposed drawing order in their original order by person A.

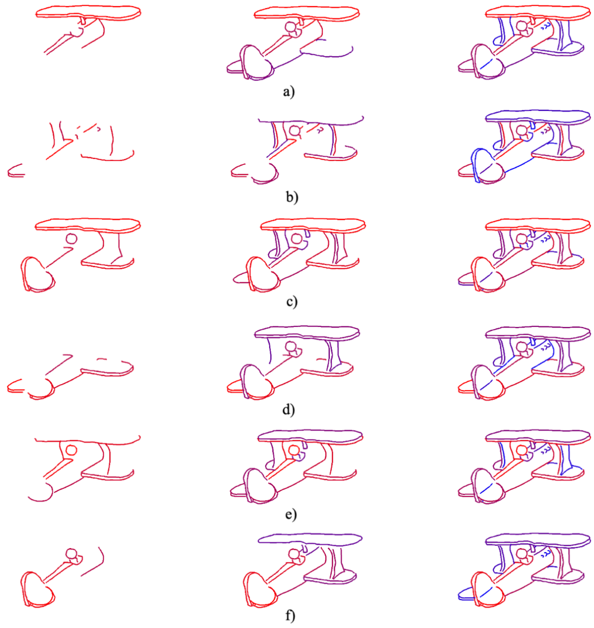

Figure 1: *Order types: a) original b) random c) descending stroke length d) shuffled time bins e) ordered by Fu et al.'s algorithm, f) imposed. Red strokes drawn early, blue strokes late.*

Artists may use different speeds to draw during different times of the tracing process. After reordering the strokes, the speeds of consecutive strokes may be inconsistent and seem unnatural. We resampled all strokes to play at the same speed, as to not let stroke speed be an indicator of natural or computer-generated ordering.

2.3. Interface

More complex and nuanced tasks have been used to study stroke ordering, however these tasks are best conducted in-person when researchers can explain and demonstrate the task to participants. As we conducted our study remotely via Mechanical Turk, we designed a simpler task with two-alternative forced choice (2AF) more readily communicated on the Turk platform.

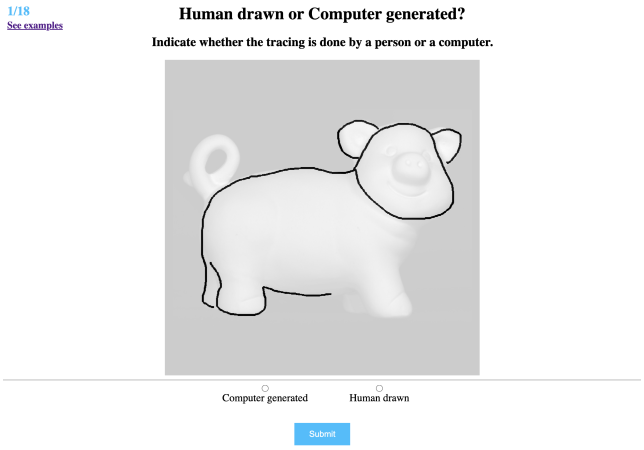

Figure 2: *Example of task in the user study. The user is presented with a playback of a set of strokes, over the image prompt. The user must identify whether the ordering is natural ("Human drawn") or unnatural ("Computer generated").*

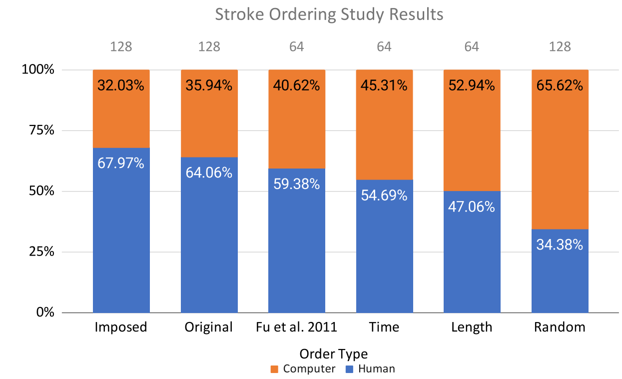

Figure 3: *User study results. 6 different order types with percentage of responses identifying each type as human-drawn or computer-generated. Top values above bars indicate how many total responses were received for that order type. χ^2 = 36.111, p-value < 0.05 indicating significant relation between order type and its perceived naturalness.*

Each user is shown 18 orderings of 17 unique tracings of 9 unique image prompts, with the distribution: 4 original, 4 imposed, 4 random, 2 descending length, 2 time bins, 2 heuristic algorithm. One tracing of random order is repeated in the study as an attention check. The strokes are played back over the prompt, as if drawn in real time. The user is asked to select whether the ordering is Human drawn or Computer generated. Nine distinct image prompts are shown, with 6 prompts of a single object and 3 of a scene.

We included filtering mechanisms before and during the study to encourage robust results. Before the study begins, we present 8 test questions of 4 unique tracings: 2 random and 2 original. Each tracing is shown twice. If the user is paying attention, they should give the same response to the same tracing both times. If the user's pre-selection results do not meet this criterion, s/he is not paying attention and is not allowed to proceed to the study. During the study, we insert two attention checks of simple questions ("What animal is shown in this image?"). If the user fails the attention checks, s/he is not allowed to continue the study. When processing the final results, we apply our third filtering mechanism. The one tracing of random stroke order that is repeated during the study is used as an attention check. We discard a user's results if s/he gives a different response each time this specific tracing is shown.

3. Results

3.1. General Analysis

Results were collected from 40 Turkers, then 8 sets of responses were discarded after the selection process discussed in the study design.

Of the 32 participants, 17 identified as male, 15 female, 0 non-binary, and 0 declined to respond. The age range was 22-54 years, with a median age of 29. 31 participants completed the study on a computer and 1 completed it on a tablet. 2 participants claimed expert knowledge of computer graphics, 5 advanced, 7 intermediate, 13 beginner, and 5 none. 1 participant claimed expert artistic knowledge, 5 advanced, 8 intermediate, 15 beginner, and 3 none.

The results of the study can be found in Fig. 3. A χ^2 test gives χ^2 = 36.111, corresponding to p-value < 0.05 indicating significant relation between order type and its perceived naturalness.

Random ordering was unlikely to be perceived as natural, at 34.38%, indicating that stroke order is important to the naturalness of the drawing process and that humans are unlikely to place strokes in random locations of the drawing.

Users identified imposed ordering as human-drawn most often, at 67.97%, with original ordering a close second, at 64.06%. The close gap of perceived naturalness between original and imposed ordering indicates order types apart from original ordering can be perceived as human-drawn. Imposed ordering voted human-drawn the most often indicates there can be multiple orderings of the same set of strokes that can be perceived as natural.

Fu et al.'s algorithm [FZLM11] was voted human-drawn over half the time, at 59.38%. This indicates the cognitive principles used are viable assumptions about drawing. Ordering by shuffled time bins was also voted human-drawn over half the time, at 54.69%, which means preserving relative stroke orders, even while randomizing global ordering, is important to perceived naturalness.

Finally, ordering by descending length was voted human-drawn less than half the time, at 47.06%. While it was previously concluded in [WQF*21] that people draw long strokes at the beginning and short strokes at the end, this sole piece of information is insufficient to provide natural stroke ordering.

Post hoc analysis comparing pairs of order types using χ^2 tests of independence and a Bonferroni correction reveals pairs that differ significantly in perceived naturalness. The pairs (original, random), (imposed, random), and (Fu et al. 2011, random) have p-value <

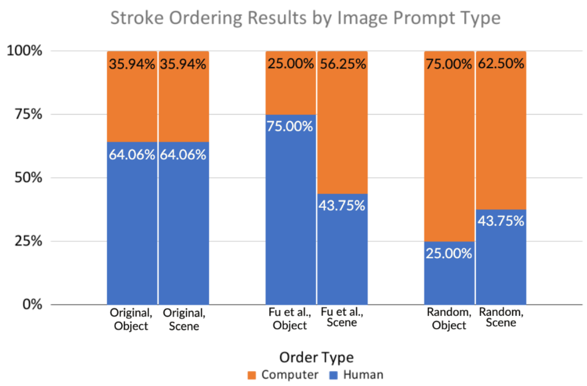

Figure 4: *Responses per prompt category. Fu et al. 2011 achieves similar naturalness to original ordering for object prompts, but for scene prompts its naturalness is similar to random ordering.*

0.05, indicating random order achieves significantly different naturalness than original order, imposed order, and Fu et al.'s algorithm.

3.2. Analysis by Image Prompt

We explore whether the image prompt affects perceived naturalness of the drawing process. We display these results in Fig. 4.

Performing the χ^2 test on responses for prompts of objects gives $\chi^2 = 26.269$, corresponding to p-value < 0.05. For prompts of scenes, $\chi^2 = 11.0717$, corresponding to p-value < 0.05. We conclude that regardless of image prompt, there is significant relation between stroke order type and its perceived naturalness.

Post hoc analysis within each category of prompts comparing each pair of order types using χ^2 tests of independence and a Bonferroni correction reveals pairs of stroke ordering types that have similar perceived naturalness. For object prompts, the pair (original, Fu et al. 2011) has p-value > 0.05, indicating no significant difference between original ordering and Fu et al. 2011 in perceived naturalness. Conversely, the pairs (original, random) and (Fu et al. 2011, random) both have p-value < 0.05, indicating that choosing one order type over the other in a pair will result in significantly different perceived naturalness. Interestingly, for scene prompts, the pairs (original, Fu et al. 2011) and (Fu et al. 2011, random) both have p-value > 0.05, while (original, random) has p-value < 0.05.

We observe Fu et al.'s algorithm achieves similar naturalness to original ordering for object prompts, but for scene prompts its naturalness is similar to random ordering. More work is needed to understand how different image prompts affect the perceived naturalness of the stroke order type used in the associated drawing.

4. Conclusion & Future Work

In this paper we present a study on the drawing order of strokes. We describe imposed ordering, a novel stroke ordering method. The results showed that stroke ordering is important to the perceived naturalness of a drawing process. The study confirmed conclusions from previous work on the drawing process, however more work is needed to understand how image prompts affect naturalness of various order types. Our results on naturalness of ordering methods can be used for loss functions in AI drawing applications and communication through drawing in tutorials and storytelling.

5. Acknowledgments

This work was supported by National Science Foundation award #1942257. We thank Inyoung Shin for feedback on the analysis.

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