Data-Driven Handwriting Synthesis in a Conjoined Manner

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“The grown-ups are certainly very, very old”, he said to himself, as he continued on his journey

Times New Roman

“The grown-ups are certainly very, very old”, he said to himself, as he continued on his journey

Lucida Handwriting

“The grown-ups are certainly very, very odd,” he said to himself, as he continued on his journey.

Human Handwriting
chapter 12

The next planet was inhabited by a tippler. This was a very short visit, but it plunged the little prince into deep dejection.

“what are you doing here?” he said to the tippler, whom he found settled down in silence before a collection of empty bottles and also a collection of full bottles.

“I am drinking,” replied the tippler, with a lugubrious air.

“why are you drinking?” demanded the little prince.

“So that I may forget,” replied the tippler.
Chapter 1

The next planet was inhabited by a tippler. This was a very short visit, but it plunged the little prince into deep dejection.

"What are you doing there?" he said to the tippler, whom he found seated down in silence before a collection of empty bottles and also a collection of full bottles.

"I am drinking," replied the tippler.

"Why are you drinking?" demanded the little prince.

"So that I may forget," replied the tippler.

"Forget what?" inquired the little prince, who already was sorry for him.

"Forget that I am ashamed," the tippler confessed, hanging his head.

"Ashamed of what?" insisted the little prince, who wanted to help him.

"Ashamed of drinking!" The tippler brought his speech to an end, and shut himself up in an impregnable silence.

And the little prince went away, perturbed.

"The grown-ups are certainly very, very odd," he said to himself, as he continued on his journey.
Handwriting Style

Importance factors of handwriting style

- Elements of styles
- Elements of execution
- Natural variance between each writing

Other effects

- Alcohol, emotion, ...

We want to model all possible factors
Previous work - Handwriting Synthesis

Handwritten

Initial velocity in order to determine the final velocity on acceleration time curve before, even gives only the velocity

Synthesized

Initial velocity in order to determine the final velocity on acceleration time curve before, even gives only the velocity

Handwriting

Wang et al., IJDAR 2005

what work good home asked people little should around

Synthesized results

Training set

Synthesized

Chang and Shin, IJDAR 2012

what work good home asked people little should around

Lin and Wang, PR07
Data-driven Synthesis

how to boxes

Lu et al., SIGGRAPH 2012

Search

ball
ball
ball

Ma et al., EG 2014

Average

ball

Zitnick, SIGGRAPH 2013
Multidimensional Morphable Model

Jones and T. Poggio, ICCV 98

Ezzat et al., SIGGRAPH 2002
Contribution

A data-driven optimization approach to synthesize non-existent paragraph

- We find neighborhood characters’ interaction
- We determine cursive probability for synthesis
Approach pipeline

Data Collection

Parameterization

Shape Model

Paragraph Synthesis

Word Synthesis

Character Synthesis

“The grown-ups as he continued

grown-ups

grown-ups

“The grown-ups as he continued

grown-ups

grown-ups

Paragraph Synthesis

Word Synthesis

Character Synthesis
Approach pipeline

Data Collection

"The grown-ups as he continued"

Parameterization

"g"

Shape Model

\(a\) \(k\)  \(k\)

Paragraph Synthesis

"The grown-ups as he continued"

Word Synthesis

grown-ups

Character Synthesis

grown-ups
We want to find a smallest dataset that capture enough information to imitate one’s handwriting style.
Observation - Word

Non-conjoining letters

Conjoining letters
"I am drinking," replied the tippler, with a lugubrious air.

"Why are you drinking?" demanded the little prince.

"So that I may forget," replied the tippler.
Data Collection

- We should collect at least two instances for each letter.

```
+---+---+---+---+
|   | A  | B  | C  |
+   +---+---+---+
| A | A  | I  | J  |
+   +---+---+---+
| B | H  | I  | J  |
+   +---+---+---+
| C | I  | P  | Q  |
+   +---+---+---+

(a) Individual sample.
```

- We should cover more commonly used letter pairs ("aa", "ab", "ac", ...).
- The collection sheet should not over constraint.
Project Gutenberg

- Project Gutenberg collected as many as possible eBooks in the world
- We find most common pairs according to its frequency list

![Bar chart showing the percentage of uncovered and covered pairs in top 78, 109, and 159 pairs.](image-url)
Data Collection

(a) Individual sample.

(b) Integral sample - Word

(c) Integral sample - Paragraph
Approach pipeline – Parameterization

Data collection → Parameterization → Shape Model

Paragraph Synthesis → Word Synthesis → Character Synthesis
Character Parameterization

- We assume each letter has only topology
- For each letter $C_i = \{c_i^k\}_{k=1}^{S_i}$, we build B-spline fitting

Handwritten | Reconstruction

Control points
Approach pipeline – Shape Model

Data collection

"The grown-ups as he continued"

Parameterization

9

Shape Model

[Diagram of a, k, k]

Paragraph Synthesis

"The grown-ups as he continued"

Word Synthesis

grown-ups

Character Synthesis

grown-ups
Shape Model

- We build shape model from displacement:

\[
d_i^k = \{d_i^k(p_1), d_i^k(p_2), \ldots, d_i^k(p_N)\}
\]

- Shape model:

\[
\text{Var}(D_i) = \frac{1}{S_i - 1} \sum_{k=1}^{S_i} (d_i^k - \mu_i)(d_i^k - \mu_i)^T
\]

\[
d_i^k = \mu_i + \Phi_r \alpha_i + \Phi \epsilon
\]
Approach pipeline – Character Synthesis

Data collection

"The grown-ups as he continued"

Parameterization

"The grown-ups as he continued"

Shape Model

"The grown-ups as he continued"

Paragraph Synthesis

Word Synthesis

Character Synthesis
Character Synthesis

\[ \hat{C}_i = \mu_i + \Phi_r \hat{\alpha}_i + c^1_i \]

Collected data

Shape model with varying \( \alpha \)

Synthesized data
Approach pipeline – Word Synthesis

Data collection

“"The grown-ups as he continued"

Parameterization

Shape Model

Something like "g"

Paragraph Synthesis

Word Synthesis

Character Synthesis

"grown-ups"

"grown-ups"

"grown-ups"
Character Grouping

- We group letters to obtain more conjoining information
- Example:

Criteria

very tippler
The probability we connect two neighboring letters:

\[ P(i, j) = \begin{cases} P_{\text{data}}(i, j), & \text{if character pair } (i, j) \text{ forms a conjoined compound in dataset} \\ P_{\text{group}}(i, j), & \text{otherwise} \end{cases} \]
Word Synthesis

- **Structure similarity constraint**
  - Simplicity: unary term
  - : Smoothness term

\[ \hat{\alpha}_i = \arg\min_{\alpha_i, \beta_i^k} \left\{ \sum_i \| \alpha_i - \beta_i^k \|_2 + \gamma \left( g_{p_N, p_{N-1}}^i \right) \right\} \]

- **Data term**
- **Smoothness term**
- **Boundary constraint**
Approach pipeline – Paragraph synthesis

Data collection

"The grown-ups as he continued"

Parameterization

9

grown-ups

Shape Model

Shape Model

"a" "k"

Paragraph Synthesis

Word Synthesis

Character Synthesis

Paragraph Synthesis

Word Synthesis

Character Synthesis
Paragraph Synthesis

- Line angle, word height and word angle

settled down in silence before a collection of empty bottles and also a collection of full bottles.
User Study: Visual discrimination

65 Subjects

 Participant Scores

<table>
<thead>
<tr>
<th>Number of correct answers</th>
<th>Number of participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>6</td>
<td>13</td>
</tr>
<tr>
<td>7</td>
<td>10</td>
</tr>
<tr>
<td>8</td>
<td>5</td>
</tr>
</tbody>
</table>

Per Synthesized Paragraph Accuracy

<table>
<thead>
<tr>
<th>Paragraph</th>
<th>答 as handwritten</th>
<th>答 as synthesized</th>
</tr>
</thead>
<tbody>
<tr>
<td>synthesized paragraph 1</td>
<td>52%</td>
<td>48%</td>
</tr>
<tr>
<td>synthesized paragraph 2</td>
<td>40%</td>
<td>60%</td>
</tr>
<tr>
<td>synthesized paragraph 3</td>
<td>51%</td>
<td>49%</td>
</tr>
<tr>
<td>synthesized paragraph 4</td>
<td>45%</td>
<td>55%</td>
</tr>
</tbody>
</table>
"Why are you drinking?" demanded the little prince.

"So that I may forget," replied the tippler.
User Study: Similarity test

The next planet was inhabited by a tippler. This was a very short visit, but it plunged the little prince into deep dejection.

Handwritten paragraph

The next planet was inhabited by a tippler. This was a very short visit, but it plunged the little prince into deep dejection.

Synthesized paragraph without layout info

The next planet was inhabited by a tippler. This was a very short visit, but it plunged the little prince into deep dejection.

Synthesized paragraph with layout info
The next planet was inhabited by a tippler. This was a very short visit, but it plunged the little prince into deep dejection.
This was a merchant who sold pills that had been invented to quench thirst. You need only swallow one pill a week, and you would feel no need of anything to drink.

“What are you doing there?” he said to the tippler, whom he found settled down in silence before a collection of empty bottles and also a collection of full bottles.

Just so. Everybody knows that when it is noon in the United States the sun is setting over France.
Comparison II

Captured handwritten samples

Synthesized result by [LW07]

Our result
<table>
<thead>
<tr>
<th>Original writing</th>
<th>[WWXS05]</th>
<th>Ours</th>
</tr>
</thead>
<tbody>
<tr>
<td>down</td>
<td>down</td>
<td>down</td>
</tr>
<tr>
<td>before</td>
<td>before</td>
<td>before</td>
</tr>
<tr>
<td>bottles</td>
<td>bottles</td>
<td>bottles</td>
</tr>
</tbody>
</table>
We present a data-driven optimization approach to synthesized non-exist paragraph.

- We find neighbor characters’ interaction
- We determine cursive probability for synthesis
- The user studies and comparison results show that our approach successfully imitate one’s handwriting style
The End

Thank you

A person’s handwriting appears differently within a typical range of variations, and the shapes of handwriting characters also show complex interaction with their nearby neighbors. This makes automatic synthesis of handwriting characters and paragraphs very challenging. In this paper, we propose a method for synthesizing handwriting texts according to a writer’s handwriting style. The synthesis algorithm is composed by two phases. First, we create the multidimensional morphable models for different characters based on one writer’s data. Then, we compute the cursive probability to decide whether each pair of neighboring characters are conjoined together or not. By jointly modeling the handwriting style and conjoined property through a novel trajectory optimization, final handwriting words can be synthesized from a set of collected samples. Furthermore, the paragraphs’ layouts are also automatically generated and adjusted according to the writer’s style obtained from the same dataset. We demonstrate that our method can successfully synthesize an entire paragraph that mimic a writer’s handwriting based handwriting samples.

http://graphics.csie.ntu.edu.tw/~fensi/research