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HANDWRITING MODEL ADJUSTABLE TO WRITERS

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ABSTRACT

A new handwriting model is proposed for simulating complex handwriting variation in obedience to individual handwriting tendencies. Individual handwriting tendency is represented as a set of deformation rules each of which deforms one structure of pen movements. Characters are represented as hierarchical descriptions of pen movements, so that deformation rules for various types of pen movements structure can be easily and uniformly applied to characters. Several writers' handwriting of Kanji characters have been simulated using this model and the experimental results demonstrate the capability of this model.

1. INTRODUCTION

Handwritten characters exhibit a great deal of deformation from archetypical characters. The handwriting variability has been investigated in order to improve the recognition methods of handwritten characters [1].

A lot of models of handwriting processes have been proposed from biomechanical and/or neuropsychological points of view [2]. The relations between handwriting variability and, nervous or physical system, have been analyzed using these models [3].

Kuklinski and Ward enumerated the factors having influences on handwriting variability and formulated "dimensions" of handwriting variability, for example, variability of stroke order and variability of corner style [4, 5]. They represented total handwriting variability as a combination of several "dimensions".

Ishii and Kondo et.al. practically generated variations of characters by adding divergences to archetypical pen movements [6, 7].

While all these studies have aimed to totally cover handwriting variability, Naito et.al. gave attention to the individuality of handwriting variability. They verified that variations of individual handwritten characters exhibit particular tendencies and that the tendencies are fairly stable [9]. They also developed a personal recognizer which recognizes handwritten characters using individual handwriting model. Since the individual model is defined respectively for each category, the individual's handwritten characters for each category are required to construct the model.

However, individual handwriting variation is mixture of primitive variations which are common to all characters and relevant to basic pen movements; for example, rounding of corners and slanting to right. The individual handwriting tendency can be efficiently defined independently of each category by using those primitive variations.

This paper proposes a new handwriting model which compactly represents individual handwriting tendency. In this model, individual handwriting variation is represented as a combination of primitive variations. Each primitive variation is represented in terms of a condition-action rule which deforms pen movements satisfying the condition-part by means of the action-part. A character is represented as a hierarchical description of pen movements in order to be easily referred to by the rules. Individual handwriting for a character is simulated by applying the individual rules set to archetypical pen movements in drawing the character. Some experimental results on the simulation demonstrate the capability of this model.

2. PRIMITIVE HANDWRITING VARIATIONS

Individual handwriting variation tends to be the mixture of various kinds of primitive handwriting variations. In this section, we clarify these primitive handwriting variations. They are classified into the following three categories.

2.1 Arbitrary variations

Inaccurate factors of human physical motion cause errors in length and direction of pen movements.

- *arbitrary length of pen movements*

  All pen movements vary their lengths arbitrarily.

- *arbitrary direction of pen movements*

  All pen movements except for sharply turning corners arbitrarily miss the directions relative to the previous pen movement's direction.

- *arbitrary direction after sharply turning corner*

  Pen movements just after sharply turning corners arbitrarily miss the absolute directions.

2.2 Habitual variations

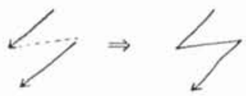
People usually have handwriting habits, for example, someone writes a corner sharply and others roundly. Here, we enumerate seventeen typical habitual variations with illustrations for each. Though these are picked up from handwritten Kanji characters, these are common to all kinds of characters. In the following illustrations, a solid line with an arrow indicating the direction illustrates "a stroke" which is a continuous pen movements keeping pen down on a paper, while a dotted line illustrates "a connective movement" which is a pen movement keeping pen up above a paper between two consecutive strokes. Left-hand figures show basic pen movements and right-hand ones show pen movements after deformation.

- *connecting collinear strokes*

  Several consecutive strokes collinear each other are written as one straight stroke.

- *connecting parallel strokes*

  Several parallel strokes are written as one stroke.

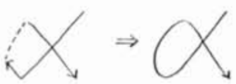


- *connecting adjacent strokes*

  When the end position of a stroke is very close to the start position of the following stroke, the two strokes are written as one stroke.

- *connecting loop strokes*

  A partial pen movements constructing a loop structure is written as one stroke.

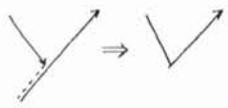


- *omitting retraced part*

  When the latter part of a stroke is retraced by the following connective movement, the retraced part is omitted.

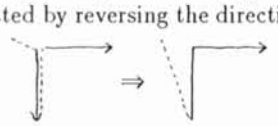
- *omitting retracing part*

  When a connective movement is retraced by the former part of the following stroke, the retracing part is omitted.



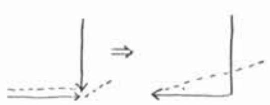
- *omitting following connective movement*

  When a stroke is entirely retraced by the following connective movement, the following connective movement is omitted by reversing the direction of the stroke.



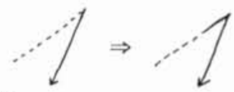
- *omitting previous connective movement*

  When a connective movement is entirely retraced by the following stroke, the connective movement is omitted by reversing the direction of the stroke.



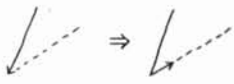
- *earlier pen down*

  A small part of a connective movement just before the following stroke becomes the part of the stroke.



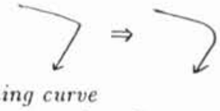
- *later pen up*

  A small part of a connective movement just after the previous stroke becomes the part of the stroke.



- *rounding corner*

  Sharp corners within a stroke are rounded.

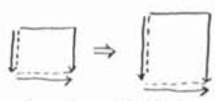


- *straightening curve*

  Curving parts of strokes are written straight.

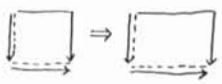
- *vertical extension of whole pen movements*

  Whole pen movements are equally extended in the vertical direction.



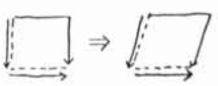
- *horizontal extension of whole pen movements*

  Whole pen movements are equally extended in the horizontal direction.



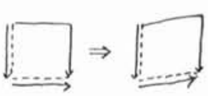
- *vertical slant of whole pen movements*

  Upper side of whole pen movements are shifted to right or left.



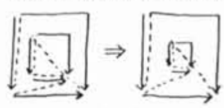
- *horizontal slant of whole pen movements*

  Right side of whole pen movements are shifted up or down.



- *shrinking surrounded part*

  A partial pen movements surrounded with the other pen movements is written in small size.



2.3 Intentional variations

Slight deformations of characters often cause misreading. For example in Kanji characters, if the upper end of the middle vertical stroke of "田" went up through the uppermost horizontal stroke, the character would change into a different character "由". At such a characteristic part, which discriminates the character from the other characters, writer's intention in order to prevent fatal deformations causes variations peculiar to the part. We call the variations "intentional variations".

- *keeping shape*

When a pen movement forms a characteristic shape of the character, arbitrary and/or habitual variations for the pen movement are restricted. For example, the right under stroke of "見" does not undergo the other variations in order to keep the difference from "貝".

- *keeping relation*

When a pen movement forms a characteristic shape of the character in combination with the former pen movements, the current pen movement is intentionally changed as it keeps the characteristic shape by referring to the former trajectory. For example, in the character "田", the middle vertical stroke is deformed so as to its top-end comes to the middle of the uppermost horizontal stroke which has been deformed.

3. HIERARCHICAL DESCRIPTION OF PEN MOVEMENTS

As seen in the previous section, primitive handwriting variations are relevant to various types of pen movements: some variations are concerning to global structures in characters and the others are concerning to local pen movements. For coping with all variations, any types of pen movements in a character should be easily referred to. Therefore, in our system, hierarchical description of pen movements is adopted for representing a character.

For example, an archetypical pen movements in fig.1 is hierarchically described as shown in fig.2. A "root" is a whole pen movements. Unit structures, such as '*hen*' and "*tsukuri*" in Kanji characters, are the next lower layer. We call elements of this layer "components". Each component is divided into three types of "segments"— lines, arcs and corners. Such segments construct the layer under the components layer. Line and arc segments are equally separated into short "vectors" which are elements of the lowest layer.

The description of each element is as shown in fig.3. Segments and vectors have some attributes for geometrical information of pen movements. A line segment has a length attribute, an arc segment has a length attribute and a curvature attribute, a corner segment has a turning angle attribute and a vector has a length attribute and a turning angle attribute. Moreover, all of them have sign values specifying pen up-down state. Only corner segments have the absolute direction values after turning.

When a character has characteristic shapes involving intentional variations, constraints for keeping the shapes

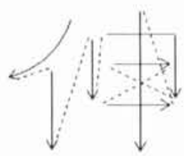


Fig.1. An archetypical pen movements in drawing the character "仲".

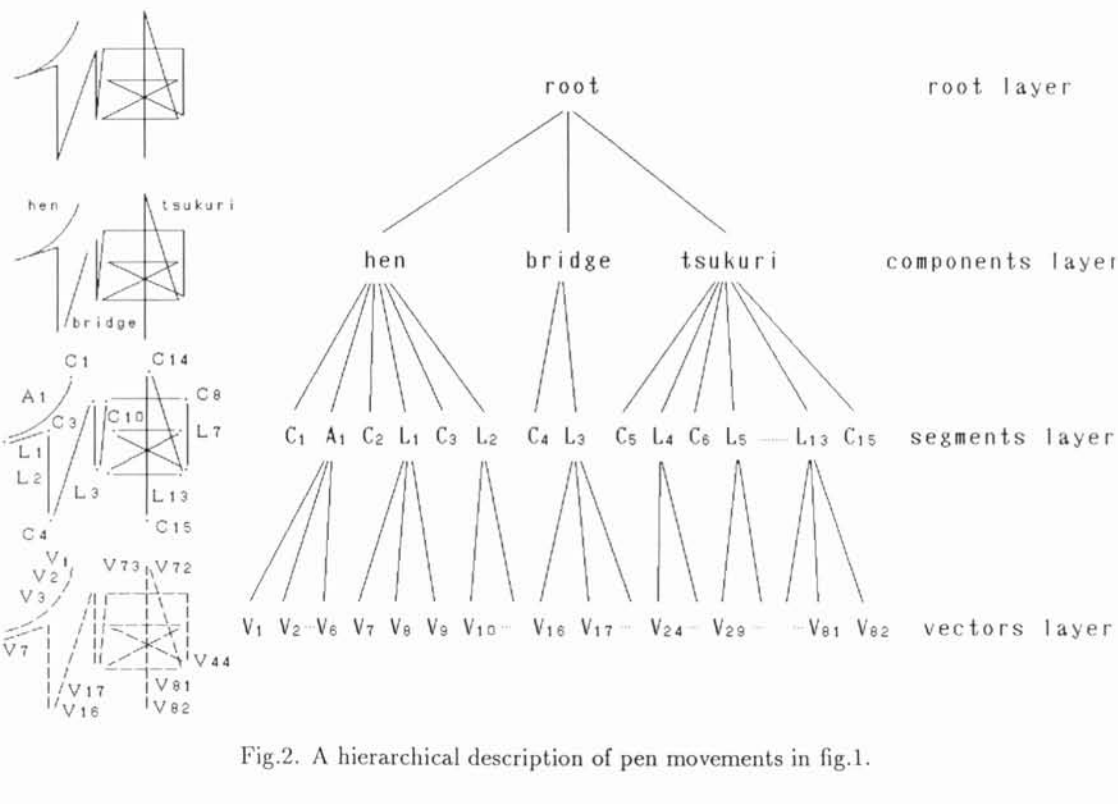


Fig.2. A hierarchical description of pen movements in fig.1.

are added to the relevant segments in terms of constraint attributes, as shown in fig.3. The type of a constraint attribute is *keep-shape* or *keep-relation*. Moreover, a *keep-relation* attribute has an argument specifying the relation which should be kept.

L_{12}	A_1
length : 22.5	length : 26.8
pen-state : up	curvature : +67.9
constraint : (keep-relation	pen-state : down
((y end) > (y (middle L_6))))	constraint : nil
C_2	V_1
turning angle : +138.3	length : 4.5
direction after turning : 304.2	turning angle : +11.3
constraint : nil	pen-state : down

Fig.3. The examples of internal descriptions of elements constituting the hierarchical description in fig.2.

4. DEFORMATION RULES

In the description of a primitive handwriting variation in section 2, the partial pen movements before a variation can be regarded as conditions under which the variation arises. Then, the procedure which performs the changes corresponding to the variation under the conditions can realize the primitive variation. Such procedure is concisely described in terms of a condition-action rule. A condition part is a description of partial pen movements before the variation, and an action part is a simple procedure changing the pen movements to the situation after the variation. Once the rules operate to an archetypical pen movements, the changed pen movements reveal the trajectory having been deformed.

For instance, the rule for "*omitting retraced part*" variation belonging to habitual variations is as follows.

IF object is belonging to segment layer
& object is line segment
& sign of object indicates pen-down state
& absolute value of following corner angle is about 180°
& object is longer than following line segment
THEN shorten object by length of following line segment
and delete following corner and line segment
and add deleted corner angle to following angle

Condition parts of all rules are matched to all elements of the hierarchical description and "object" means the element which is now matched to the rule. The first condition is always concerning to the choice of a layer, so that the rests of the conditions are described using the suitable layer of pen movements description. In this case, the condition is that the object is a line part of a stroke partly retraced by the following connective segment. Though actions are concisely described as the action to the chosen layer, the changes caused by the action in the layer actually lead the changes in the lower layers. For example, "Shorten a line segment" appearing in the action of this case not only changes the description of the segment but also leads deletions of some vectors constituting the shorten part.

For an example of the rules for arbitrary variation, the rule for "*arbitrary length of pen movements*" variation is given as follows.

IF object is belonging to vector layer
THEN arbitrarily change length of object

This action locally operates every vectors.

The rules for intentional variations are different from ones for the other variations in the point that these condition parts refer to not the structure of the pen movements but the constraint attribute of them. The rule for "*keeping relation*" variation is as follows.

IF object is belonging to segment layer
& object has a *keep-relation* constraint attribute
THEN change object as keeping relation
indicated by constraint's argument

When the object is the segment L_{12} in fig.2., which has the constraint attribute — "(*keep-relation* ((y end) > (y (middle L_6))))", "keeping relation rule" changes the description of the segment L_{12} as its end comes to upper than the segment L_6.

Such deforming procedures of all rules have some parameters for adjusting the deformation to a writer's handwriting tendency; the probability that the deformation occurs under the satisfied condition, the quantity of the deformation and so on. For example, the rule for "*vertical slant of whole pen movements*" has a parameter θ specifying the slanting angle as follows.

IF object is a root
THEN vertically slant object $\theta°$

5. SIMULATION OF INDIVIDUAL HANDWRITING

An individual handwriting of a character is simulated by applying the individual deformation rules set to an archetypical pen movements of the character. An individual rules set is obtained by selecting deformation rules and adjusting the parameters in the rules for the individual. The deformation rules are applied to each element in the depth-first order at the hierarchical tree of pen movements description; it means that the deformation proceeds in the stroke order and the global deformations precede local ones. Considering priority among primitive handwriting variations, deformation rules are applied to each element in the following order: the rules for intentional variations, the rules for habitual variations and the rules for arbitrary variations.

6. EXPERIMENTAL RESULTS

Simulation of handwriting using the proposed model has been experimented on for some writers. Fig.4 shows real handwritten characters extracted from a report written by a writer "*X*". Individual deformation rules set are manually determined from the observation of the characters. For example, since large slant to the right-upper direction characterizes the handwriting of "*X*", "vertical slant rule" is selected for his rules set and a large value is set for the parameter of the slanting angle. The archetypical characters and the generated characters using our model are shown in fig.5. The generated characters mostly look like real handwritten characters written by himself. Especially the connection of middle vertical lines in the right-hand unit of the character "情" well reflects one of his handwriting tendencies. There are a few differences from the real handwritten characters, for example a difference is observed in the most right stroke "ろ" of the character "報". This is because only general deformation rules are now adopted. Fig.6 shows the results obtained by applying the same individual rules set for the other characters shown in fig.7. The generated characters also look like real handwritten characters. This is demonstrating that individual deformation rules set represents individual handwriting tendencies in common with all characters.

We show the simulation results for another writer "*Y*" in fig.8. While his handwriting mostly reveals large deformations in lengths and directions of pen movements, characteristic parts of the characters are maintained. The combination of arbitrary variations and intentional variations can represent this handwriting tendencies.

The generated characters for each writer have fairly different shapes among themselves, but they are easily categorized according to writers. This demonstrates that our model can keep individual tendencies while simulating fairly large deformation.

7. CONCLUSION

This paper proposed a new handwriting model which easily simulates individual handwriting. The handwriting variation of a character are analyzed into primitive handwriting variations which arise in basic pen movements. Then, individual handwriting tendencies are described by the mixture of individualized primitive handwriting variations. This description of individual handwriting tendencies is concise and independent on the character categories. Pen movements in drawing characters were hierarchically described in order to be easily matched to various kinds of primitive variations.

The experimental results demonstrated that the proposed model can easily generate the handwritten characters reflecting individual tendencies. This model can generate a great number of templates of the individual handwritten characters without the individual's burden, which are useful to recognize handwritings. By comparing the simulated characters to real handwritten characters, unknown primitive handwriting variations can be inferred. That helps analysis of handwriting variability.

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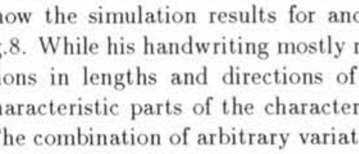

Fig.4. "*X*" 's real handwritten characters used for rules selection.

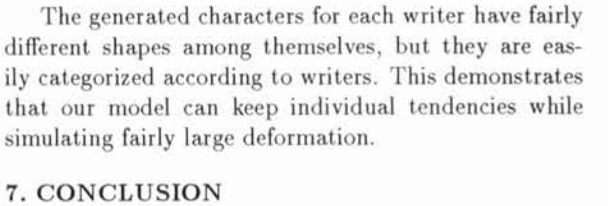

Fig.5. (a) The archetypes of the characters used for rules selection and (b) the characters generated using *X*'s deformation rules set.

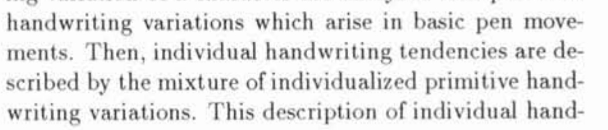

Fig.6. (a) The archetypes of the other characters and (b) the characters generated using the same rules set as used in fig.5.

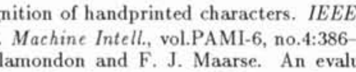

Fig.7. "*X*" 's other real handwritten characters.

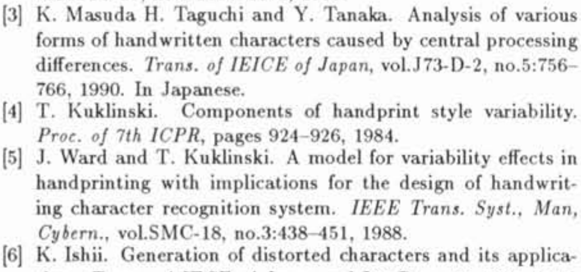

Fig.8. (a) "*Y*" 's real handwritten characters, (b) the archetypes of the characters and (c) the characters generated using *Y*'s deformation rules set.