A Multilingual Sketch-based Sudoku Game with Real-time Recognition

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Abstract Sudoku is one of the most popular puzzles of all time. Easy to understand but still very challenging, Sudoku continues to captivate players all over the world through newspapers, puzzle books, and digital devices. The application introduced in this work is a multilingual, sketch-based version of the Sudoku game. Sketch input renders more flexibility to users and increases usability. Multilingual support paired with sketching allows the game to serve as an educational tool for those learning a new language, with the current implementation supporting Chinese and Hindi. The recognition algorithm proposed in this work, based on the Hausdorff metric, easily enables extending the application to support other languages. Preliminary results indicate an overall accuracy of over 93% when recognizing Chinese and Hindi numbers at the same time.

1 Introduction

Sudoku is a very well-known puzzle that appears in papers and magazines. It is a 9 by 9 grid filled with numbers from 1 to 9. The grid is partially filled when the game

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begins. Users have to complete the grid by filling in the missing fields. There can be no repeated number in any row, column or in the 3 by 3 sub-grids. It is naturally played with a pen and pencil. However, there have been many Sudoku applications available to play on the desktop and other mobile devices such as smartphones and tablets. Most of them use the keyboard to input numbers. Some of them have an on-line keypad from which numbers can be chosen, and played with a stylus. However, these designs do not facilitate natural user interaction.

In this paper we propose a sketch-based Sudoku game playable in multiple languages, currently supporting Chinese and Hindi. The game can be played on pen and touch surfaces very much like it is played on pen and paper, while it also can be used as an enjoyable and useful learning tool for beginners of a new language. The sketch-based input also encourages more natural interaction with the user, providing users the ability to modify fields through gestures or make partial strokes that the system will ignore so that they can keep notes without interfering with game play. These features further strengthen the analogy of the sketching surface to the feel of pen and paper.

2 Previous Work

Digital games have been used in education for quite some time, and the benefits have already been demonstrated [13]. One of the challenges faced by the usage of educational games is how to integrate them into more traditional learning schemas, Torrente et al. propose an educational games authoring tool that might ease this problem [12]. We elected to use a sketching interface to facilitate integration with player's current playing methods. The combination of sketch interfaces and educational games has also been discussed in recent years [6].

There have been many systems that recognize Chinese characters. On [11] and [10] a geometric approach to recognize Chinese characters is used. The former performs Chinese radical recognition using LADDER [3] and Sezgin [8] for low-level interpretation. While our system could have used LADDER for Chinese recognition because of the high geometric symmetry of Chinese numerals, our goal was to use one algorithm to support multiple languages.

Hindi numerals are generally drawn using a single stroke and could hence be classified well using a gesture recognition algorithm like Rubine's features [7]. In [1], Al-Omari proposes an Arabic numeral recognition system based on template matching, and [5] performs Hindi numeral recognition using neural networks. Since it deals with printed numbers instead of sketches, the pre-process stage is a little different than what it is commonly used in sketch recognition techniques. So, in order to provide multilingual support, we decided to use a simple template matching algorithm using a Hausdorff measure. Hausdorff is introduced in [4] and [9], and it is used extensively in many domains, including sketch recognition and image processing.

3 Methodology

Our system uses two separate applications, both developed using JAVA. The first application is used to collect templates from a certain number of people, which are used to train the system by assigning appropriate labels. These templates are then compared against user sketches in the recognition stage. The second application is the Sudoku game itself. Sketched user inputs for both applications were performed through a Wacom Bamboo Pen Tablet.

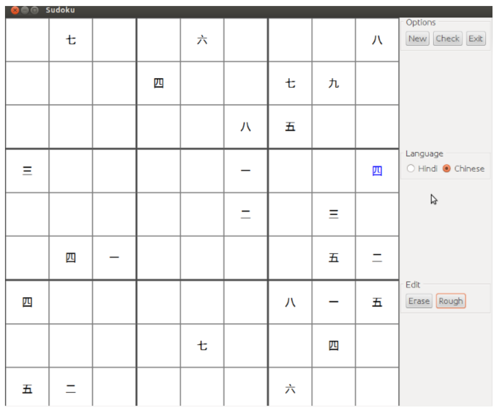

Fig. 1: Sudoku game played in Chinese.

3.1 Training Data

This JAVA application was only created to ease the development and extension of the Sudoku game. It collects sketches from several test users in order to train the system in any new language. We collected data from graduate students at Texas A&M University who were proficient in the languages of Chinese or Hindi. For each user, ten samples for each of the nine digits (1 through 9) were collected. In all, we have collected 270 samples, from three different users, for each language in the current implementation.

The application prints the digit to be written, along with the iteration number of that digit. A clear button is provided for the user to clear the canvas if he/she is not satisfied with the submission. After all the iterations are complete, an XML file is generated, which has coordinate information regarding the sketch drawn. There are tags to identify a number, iteration, the stroke number of that iteration, and the points (X and Y coordinates) for that stroke. This file is read at the start of the Sudoku application to normalize all the templates collected.

3.2 Sketch-based Sudoku Application

The Sudoku game provides multilingual options in the form of radio buttons. Regardless of user selected language, sketches can be made in any of the languages supported by the system. So, if a Hindi user is playing in Chinese but forgot how a particular number is written, he can simply write it in Hindi and the system will display the recognized number in Chinese. Users interact with the game much as they would a pen and paper version of Sudoku, filling numbers in the grid according to the the rules of the game. Users can erase sketches using a scribble gesture, or an erase button that clears a cell on click. The system also has a rough sketching mode that allows users to draw sketches without being recognized. Recognition begins after a certain timeout or as soon as the user starts drawing in another cell. Once a number is recognized, the user's sketch is replaced with the recognized digit in blue ink, differentiating it from the original numbers displayed in the puzzle. The Check button can be pressed whenever the user is done filling the grids or just want to assess the correctness of his current assignments, upon button press, all the user inputs are highlighted in green, if the number assigned to the cell is correct, or red, if the number assignment is incorrect. The game ends when there are no empty cells on the board and all the user inputs are highlighted in green. Figure 1 shows a game played in Chinese.

Before running recognition, two conditions are checked. First, if the input sketch is smaller than a fixed threshold, then it is discarded. Second, if the sketch is composed by a single stroke, a horizontal line test is performed to check if the input represents the Chinese numeral one. The second check was necessary because of the simplicity of the numeral concerned, since the system could confuse it with some other interface action. If neither condition is true then the system performs preprocessing and recognition.

Preprocessing is performed on the input sketch by resampling, scaling, and translating. These steps ensure input sketches can be matched to the normalized templates. Next, the one-sided Hausdorff distance is calculated according to $h(A,B) = \max_{a \in A} \min_{b \in B} |a-b|$. Hausdorff distance is a technique for comparing a sets of points; for each point of a model set, it measures how near they are from any point of another sketch set. We always compare the input sketch (A) to the template (B). After obtaining the distances to the template sketches, we use a k-NN classifier with a neighborhood size of 5 to improve selection accuracy. The label with the majority of votes when considering the 5 smallest Hausdorff distances is the recognized number.

4 Evaluation

We use k-fold cross validation to evaluate our recognizer, with k=10 [2]. We consider all-or-nothing accuracy, since that is all that concerns the user in this application, so accuracy is calculated as the number of correct recognitions divided by the total training set size. Each fold contained 54 sketches from our data set, 3 samples for each of the 18 different numbers, 9 Chinese and 9 Hindi. Each time, one of the 10 folds is used for testing and the other nine for training. This process is repeated until all the folds have been used for testing once. Figure 2 shows the confusion matrix for the system. As shown, the majority of the numbers were classified with an accuracy of over 90%, and 4 of the numbers were perfectly classified. The overall classifier accuracy is 93%.

		Chinese									Hindi								
		1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
Chinese	1	0.93	0	0	0	0	0	0	0	0	0	0	0	0	0	0.03	0.03	0	0
	2	0	0.93	0.03	0	0	0	0	0	0	0	0	0	0	0	0	0	0.03	0
	3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5	0	0	0	0.03	0.97	0	0	0	0	0	0	0	0	0	0	0	0	0
	6	0	0	0	0	0	0.97	0	0	0.03	0	0	0	0	0	0	0	0	0
	7	0	0	0	0	0	0	0.97	0	0	0	0	0	0	0	0	0.03	0	0
	8	0.03	0	0	0	0	0	0	0.97	0	0	0	0	0	0	0	0	0	0
	9	0	0	0	0	0	0.07	0	0	0.9	0	0	0	0	0	0	0.03	0	0
Hindi	1	0	0	0	0	0	0.03	0	0	0	0.93	0	0.03	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0	0.03	0.93	0	0	0	0.03	0	0	0
	3	0.03	0	0	0	0	0.07	0	0	0	0.03	0.1	0.73	0	0	0.03	0	0	0
	4	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0.83	0.07	0.03	0.07	0
	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.93	0	0.03	0.03
	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	8	0	0	0	0	0	0.03	0.07	0	0	0	0	0	0	0	0	0.07	0.83	0
	9	0	0	0	0	0	0	0	0	0	0.03	0	0.03	0	0	0	0	0	0.93

Fig. 2: Confusion matrix for the 10-fold cross validation.

5 Discussion

While the results found on the confusion matrix are mostly positive, there is still room for improvement. In general, Hindi numbers seems to be harder to classify using our current template matching technique. These numbers are very curvy and share many similarities with one another, making template matching sensitive to noise. Template matching is still a desirable approach since we wanted a flexible system that could easily support enrolling new languages, but some additional language-specific rules may need to be added as in the case of the Chinese numeral one.

In regards to the user interface of the application, there are also improvements to be considered. For the application to run successfully in smaller mobile devices, it should allow the user to expand the cell size to draw the sketch comfortably. Too small cell sizes can restrict the user from drawing with ease. However, any cell expansion should not hinder the view of the rest of the Sudoku grid.

As mentioned before, the application can be extended to support more languages, but it should be possible to come up with on-the-fly language recognition. In this mode, the game board numbers would change between the available languages according to the user-sketched language. This adds another layer of learning and difficulty, which could be integrated with further optimizations to include different difficulty levels.

6 Conclusion

In this work, we presented a multilingual, sketch-based Sudoku game. Sudoku is a puzzle that is famous all over the globe. Our application can provide a nice variation to those already familiar with the game by providing them with the option of playing in other languages through a natural sketch interface. Multilingual support also allows players to use it as a learning tool to familiarize themselves with writing other languages.

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