Chapter 1

Conclusions

1.1 Recapitulation

The goal of this work was the development of an *analytical* handwriting recognition engine for Kanji. A subordinated aim was to study the new possibilities such a system component offers. This has been exemplified for a sample e-learning application that includes exercises for handwritten input. The analytical handwriting recognition provides the e-learning application with the ability to give the learner feedback about an entered character.

This thesis contains a number of topics that do not share a common academic background. The prerequisites for building an analytical handwriting recognition and integrate it into an e-learning environment form a common ground for the topics. The thesis starts with the basics of Japanese handwriting. The Japanese writing system with its three scripts is fairly different from alphabetic writing systems. The structure of the Japanese character system has been introduced in chapter **??**. Chapter **??** contains a literature review of the topic *handwriting recognition systems*. The general techniques and models for handwriting recognition are presented as well as the special techniques for on-line character recognition and the specifics of Japanese and Chinese character recognition. Seemingly unrelated to the previous chapters, but required for building an e-learning application, chapter **??** presents the general methods and techniques for implementing e-learning applications, especially for e-learning of languages. This first part of the thesis builds the foundation of the following chapters.

The next two chapters are concerned with the design of the prototype that has been developed during the course of the thesis. The findings of these chapters are directly geared to the goals of the thesis. Chapter **??** takes an abstract viewpoint and incorporate the conceptual insight of the foundational chapters for the high-level design of the application. The knowledge about the Japanese character structure and the educational methodology of e-learning are used for the conceptual design. Chapter **??** presents the technical design choices that implement the concepts developed in the precedent chapter.

The core of the recognition engine is laid out in chapter **??**. This chapter contains topics that are part of the technical design. However, the viewpoint in this chapter is more detailed and magnifies a specific part of the application. The core recognition engine uses a combination of different pattern matching techniques in order to perform an analytical character recognition, including error recognition.

The evaluation of the analytical handwriting recognition has been presented in chapter **??**. The recognition rates were below the rates of non-analytical systems, but the systems provides additional analytical information that can be used in different contexts.

1.2 Discussion

In this work an analytical handwriting recognition engine has been developed. The motivation behind that was not just to develop another recognition system for Japanese characters, but to create a system that is oriented towards weak artificial intelligence and analysis the structures to a certain degree of *understanding*. Another motivational aspect was to look into a different type of user interface for e-learning applications.

A direct comparison to other efforts in the field of Japanese handwriting recognition is not entirely possible because of the additional analytical steps performed by the prototype. The sheer recognition rates are lower than the recognition rates of systems that perform a pure and optimised handwriting recognition. That seems due to the fact that the detailed analysis increases the recognition options. Partial character recognition of substructures of Japanese characters has similar recognition results compared to state-of-the-art recognition systems.

The attempt to integrate NLP and e-learning was successful. The central part of the e-learning system relies on the analytical handwriting recognition. When a user enters a character, the character is split into sub units, the generated feedback about the input correctness can guide a user precisely to the error. This feature is advantageous compared to the binary statement *correct* or *incorrect* that other recognition systems provide. The success of the learning component could not be evaluated because that would have been outside the scope of the thesis. However, it is plausible that writing Kanji and receiving feedback is an appropriate method to learn writing Kanji. A direct comparison to other e-learning systems was not possible as this is the only e-learning system know to the author that provides feedback to handwritten input.

1.3 Future Directions

1.3.1 General Considerations for Improvement

The performance results shown by the approach presented in this thesis open up further research opportunities. The technical status of the recognition suggests that the problem of analytical OLCCR is not solved yet. In order to reach the recognition performance of non-analytical systems the analytical methods should be improved. In order to improve the recognition performance, one could combine multiple methods of analysis, probably even non-analytical full character recognition. The area of pattern representation leaves room for improvement. The traditional structural representation mirrored in the XML format used has an insufficiency because it does not provide additional information about the characters. The feature-vector representation generated from the original character's stroke sequences could be stored and modified alongside with the actual traces. Inspired by the research efforts of **?** (**?**), the database size could be reduced by storing only parts of characters and their spatial relations instead of full character representations. This has been considered a minor issue because of the ready availability of storage space. However, that improvement could also increase recognition speed because less patterns would need to be held in RAM and compared with the input.

Additionally, hybrid statistical-structural representations could help choosing the best match. Both the stroke and between-strokes relationships can be modelled statistically.

1.3.2 Additional Research Possibilities

The handwriting recognition engine developed in this thesis, can conceptually be applied to other languages and character sets. The same style of handwriting recognition can be applied to Chinese characters, in fact, on an abstract level Chinese and Japanese characters are identical, despite their small language specific differences. A fairly similar concept of analytical character recognition could be applied to Korean characters with a slightly modified database structure. Korean characters bare the potential for an analytical handwriting recognition, due to their structured composition. Yet, the composition for Korean characters works in a different way than for Chinese and Japanese. A research hypothesis for the analysis of Korean characters might be that an analytical recognition system could have a higher accuracy, because there are are less combination possibilities for the substructures of Hangul.

A different field of additional research opportunities opened up by the kind of analytical handwriting recognition engine developed during the course of this thesis lies in the area of e-learning. Because of the loosely coupled design and the SOAP interface to the engine as a web service, the handwriting recognition can easily serve as a service for other applications. Instead of using a GUI on a desktop computer, new devices like tablet PCs or Apple Inc.'s iPad could be deployed. In the e-learning context these different devices could add to the possibilities of the HWR-engine. For example, in a multi-touch environment, the a learner could draw characters and command the e-learning environment with his fingers instead of a stylus. It could be compared if the learning success is significantly higher, lower or stays the same compared to using a stylus. Additionally, a fully-fledged educational study could be conducted, comparing the learning success achieved with an e-learning environment to the learning success using only pen and paper. For a study like that there would have to be at least two considerably sized randomised groups of learners that would be compared with each other.

Another interesting research topic around the analytical handwriting recognition could be pressure intensity. When using a pressure-sensitive device, the pressure-intensity could be used as an additional recognition feature. Pressure-intensity offers to be a completely new feature that has not been exploited. However, a study would need to show if pressure-intensity is a feature at all. It would be plausible to assume that pressure intensity is very individual to the writer. Thus, featuring pressure intensity in a HWR application could add more noise to the data. However, at least the differences in pressure intensity between different characters drawn by the same writer should be analysed. If pressure intensity is more individual to the writer than the shape of the drawn characters it could even lower recognition accuracy, but may be appropriate for writer identification using handwriting recognition.

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