US007620245B2

(12) **United States Patent**
Zhang et al.

(10) **Patent No.:** **US 7,620,245 B2**
(45) **Date of Patent:** **Nov. 17, 2009**

(54) **CURSIVE HANDWRITING RECOGNITION WITH HIERARCHICAL PROTOTYPE SEARCH**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 675 days.

(21) Appl. No.: **11/442,799**

(22) Filed: **May 30, 2006**

(65) **Prior Publication Data**

US 2007/0280535 A1 Dec. 6, 2007

(51) **Int. Cl.**
G06K 9/18 (2006.01)
G06K 9/00 (2006.01)

(52) **U.S. Cl.** **382/186**; 382/187

(58) **Field of Classification Search** 382/182–189
See application file for complete search history.

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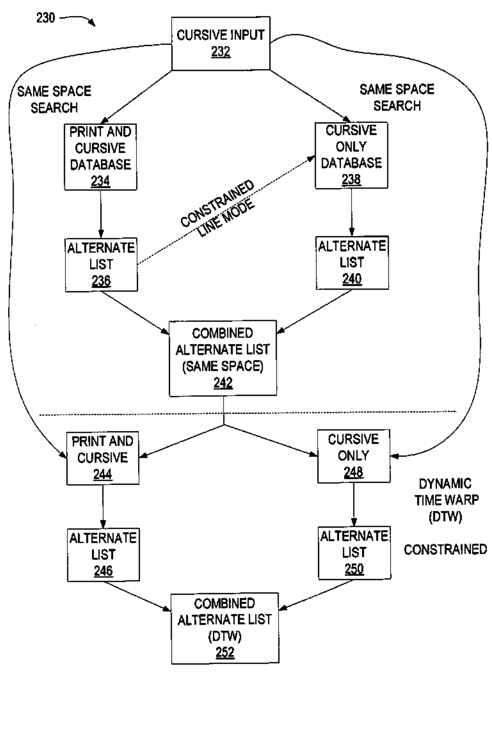
Assistant Examiner—Thomas A Conway

(57) **ABSTRACT**

Various technologies and techniques are disclosed that improve cursive handwriting recognition. Cursive handwriting input is received from a user. The system performs a hierarchical prototype search as part of a recognition operation. A same space search is performed against a mixed database that has both print and cursive samples. A same space search is also performed against a cursive database that has only cursive samples. The results of these two same space searches are merged into a combined alternate list. The combined alternate list is then used as a constraint for the dynamic time warp searches that are performed against the mixed and cursive databases, respectively. The results of the dynamic time warp searches are also merged into a final combined alternate list, and the combined alternate list is used to make a recognition decision regarding the user's handwritten input.

17 Claims, 6 Drawing Sheets



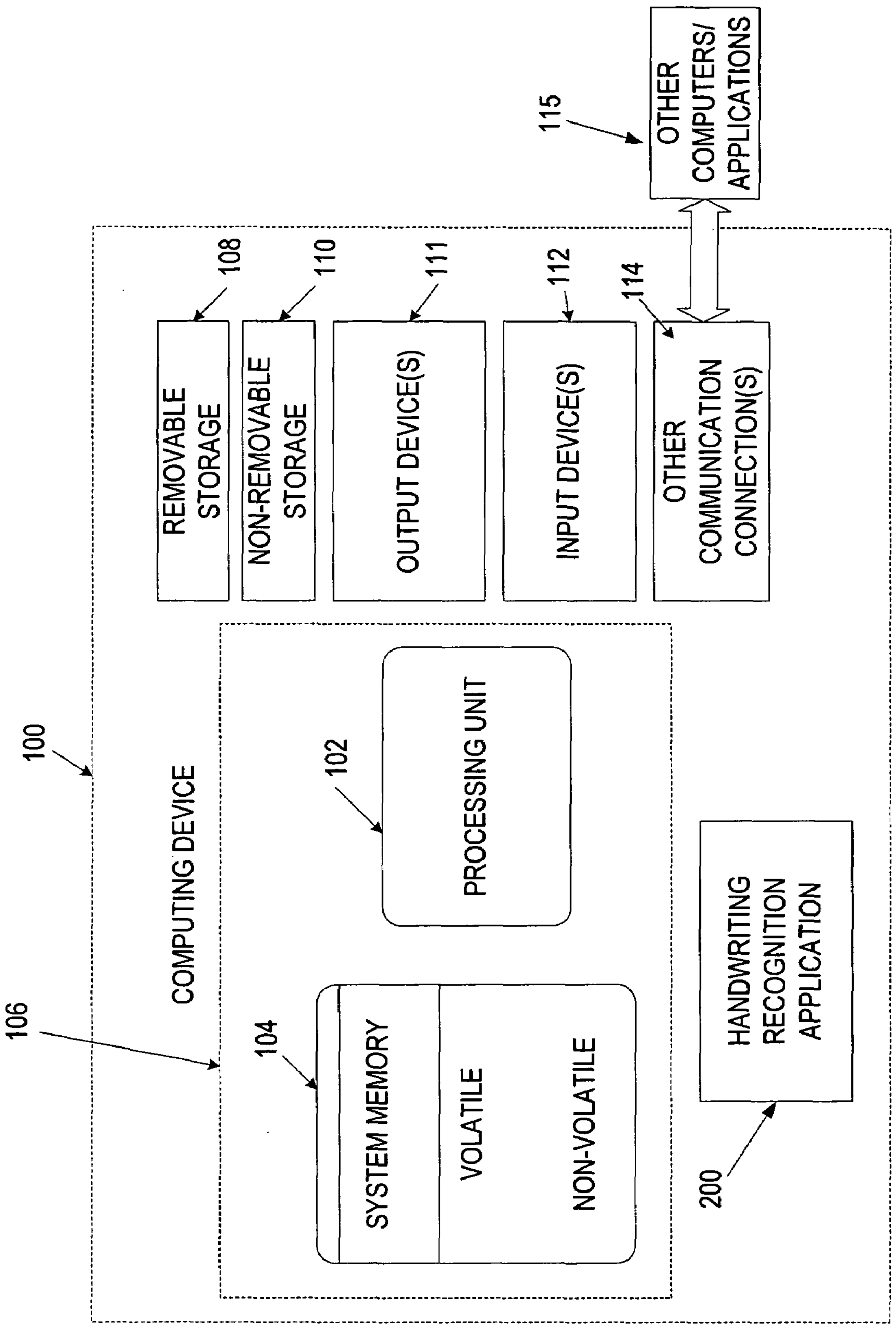

100
COMPUTING DEVICE
106
104
SYSTEM MEMORY
VOLATILE
NON-VOLATILE
102
PROCESSING UNIT
REMOVABLE STORAGE
108
NON-REMOVABLE STORAGE
110
OUTPUT DEVICE(S)
111
INPUT DEVICE(S)
112
OTHER COMMUNICATION CONNECTION(S)
114
OTHER COMPUTERS/ APPLICATIONS
115
HANDWRITING RECOGNITION APPLICATION
200

FIG. 1

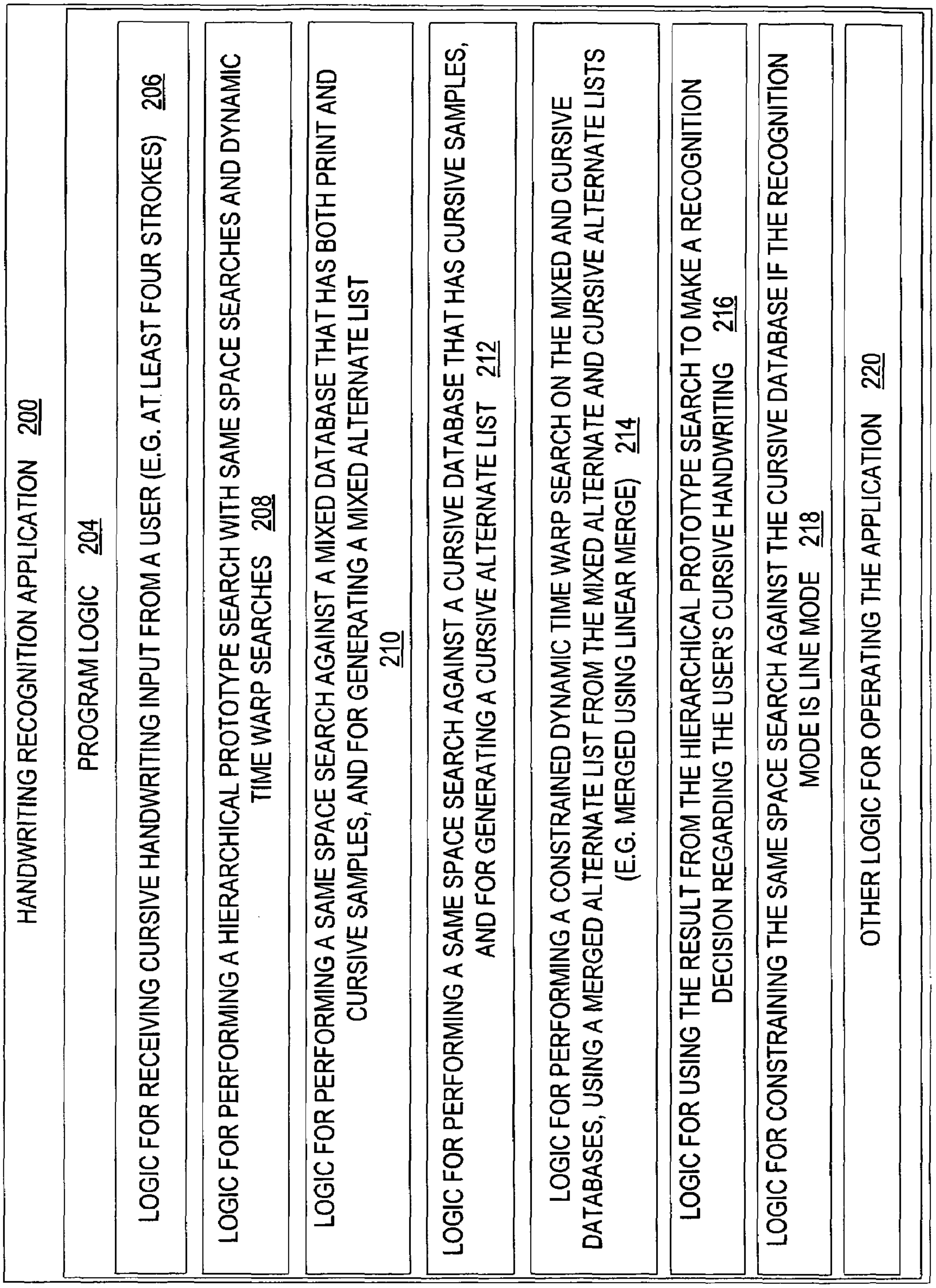

HANDWRITING RECOGNITION APPLICATION 200
PROGRAM LOGIC 204
LOGIC FOR RECEIVING CURSIVE HANDWRITING INPUT FROM A USER (E.G. AT LEAST FOUR STROKES) 206
LOGIC FOR PERFORMING A HIERARCHICAL PROTOTYPE SEARCH WITH SAME SPACE SEARCHES AND DYNAMIC TIME WARP SEARCHES 208
LOGIC FOR PERFORMING A SAME SPACE SEARCH AGAINST A MIXED DATABASE THAT HAS BOTH PRINT AND CURSIVE SAMPLES, AND FOR GENERATING A MIXED ALTERNATE LIST 210
LOGIC FOR PERFORMING A SAME SPACE SEARCH AGAINST A CURSIVE DATABASE THAT HAS CURSIVE SAMPLES, AND FOR GENERATING A CURSIVE ALTERNATE LIST 212
LOGIC FOR PERFORMING A CONSTRAINED DYNAMIC TIME WARP SEARCH ON THE MIXED AND CURSIVE DATABASES, USING A MERGED ALTERNATE LIST FROM THE MIXED ALTERNATE AND CURSIVE ALTERNATE LISTS (E.G. MERGED USING LINEAR MERGE) 214
LOGIC FOR USING THE RESULT FROM THE HIERARCHICAL PROTOTYPE SEARCH TO MAKE A RECOGNITION DECISION REGARDING THE USER'S CURSIVE HANDWRITING 216
LOGIC FOR CONSTRAINING THE SAME SPACE SEARCH AGAINST THE CURSIVE DATABASE IF THE RECOGNITION MODE IS LINE MODE 218
OTHER LOGIC FOR OPERATING THE APPLICATION 220

FIG. 2

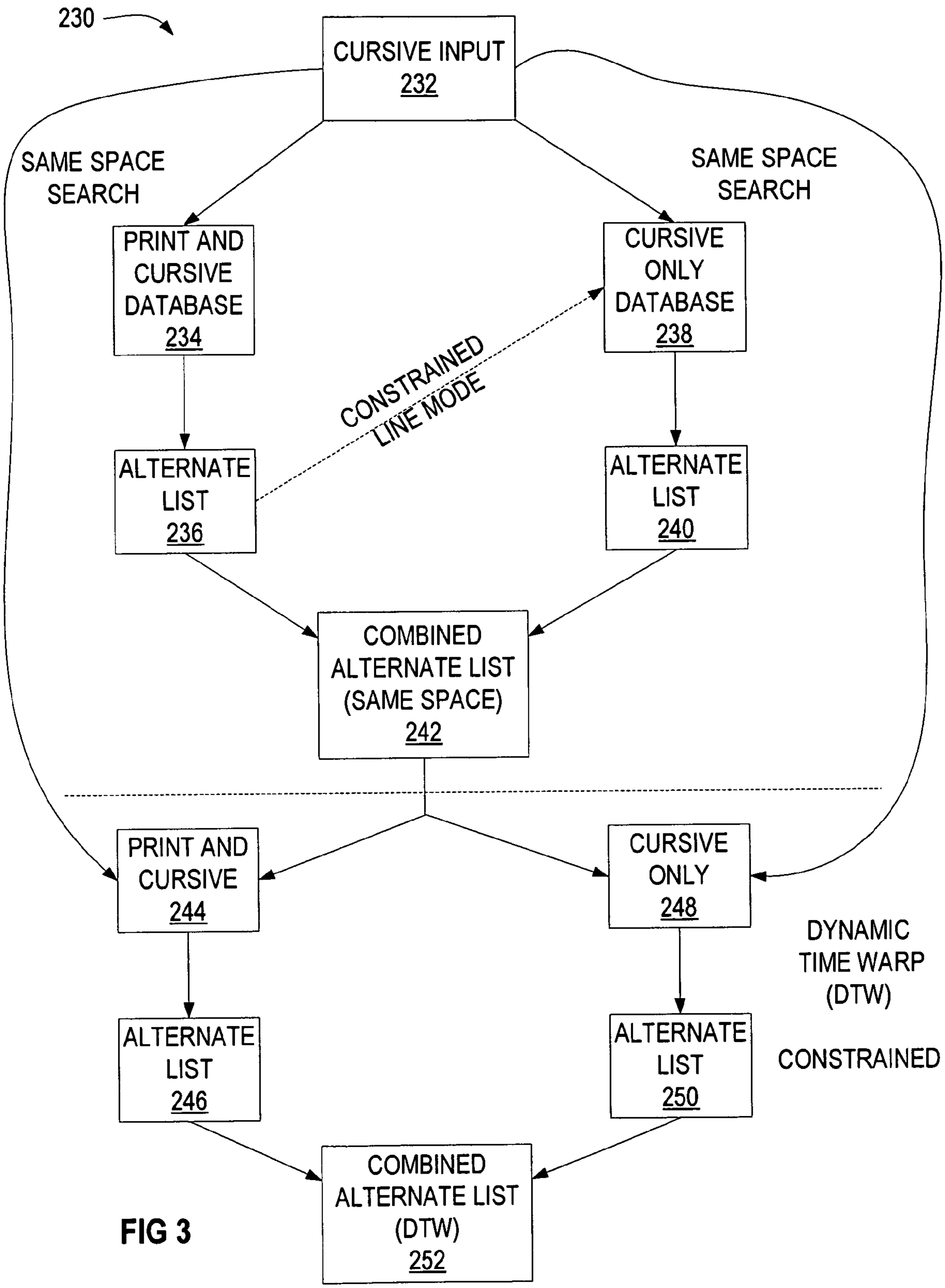

230
CURSIVE INPUT
232
SAME SPACE
SEARCH
SAME SPACE
SEARCH
PRINT AND
CURSIVE
DATABASE
234
CURSIVE
ONLY
DATABASE
238
CONSTRAINED
LINE MODE
ALTERNATE
LIST
236
ALTERNATE
LIST
240
COMBINED
ALTERNATE LIST
(SAME SPACE)
242
PRINT AND
CURSIVE
244
CURSIVE
ONLY
248
DYNAMIC
TIME WARP
(DTW)
CONSTRAINED
ALTERNATE
LIST
246
ALTERNATE
LIST
250
COMBINED
ALTERNATE LIST
(DTW)
252

FIG 3

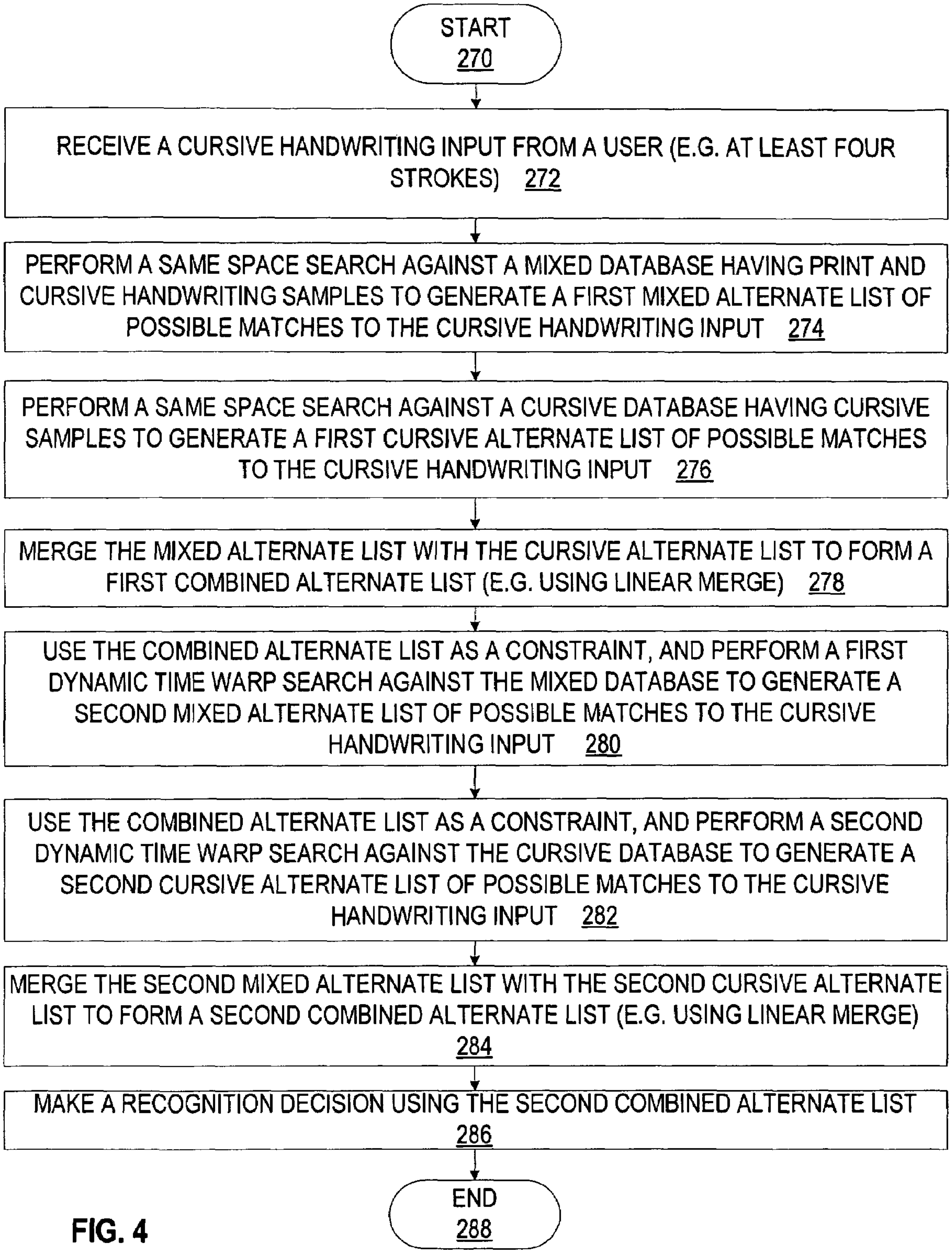

START 270
RECEIVE A CURSIVE HANDWRITING INPUT FROM A USER (E.G. AT LEAST FOUR STROKES) 272
PERFORM A SAME SPACE SEARCH AGAINST A MIXED DATABASE HAVING PRINT AND CURSIVE HANDWRITING SAMPLES TO GENERATE A FIRST MIXED ALTERNATE LIST OF POSSIBLE MATCHES TO THE CURSIVE HANDWRITING INPUT 274
PERFORM A SAME SPACE SEARCH AGAINST A CURSIVE DATABASE HAVING CURSIVE SAMPLES TO GENERATE A FIRST CURSIVE ALTERNATE LIST OF POSSIBLE MATCHES TO THE CURSIVE HANDWRITING INPUT 276
MERGE THE MIXED ALTERNATE LIST WITH THE CURSIVE ALTERNATE LIST TO FORM A FIRST COMBINED ALTERNATE LIST (E.G. USING LINEAR MERGE) 278
USE THE COMBINED ALTERNATE LIST AS A CONSTRAINT, AND PERFORM A FIRST DYNAMIC TIME WARP SEARCH AGAINST THE MIXED DATABASE TO GENERATE A SECOND MIXED ALTERNATE LIST OF POSSIBLE MATCHES TO THE CURSIVE HANDWRITING INPUT 280
USE THE COMBINED ALTERNATE LIST AS A CONSTRAINT, AND PERFORM A SECOND DYNAMIC TIME WARP SEARCH AGAINST THE CURSIVE DATABASE TO GENERATE A SECOND CURSIVE ALTERNATE LIST OF POSSIBLE MATCHES TO THE CURSIVE HANDWRITING INPUT 282
MERGE THE SECOND MIXED ALTERNATE LIST WITH THE SECOND CURSIVE ALTERNATE LIST TO FORM A SECOND COMBINED ALTERNATE LIST (E.G. USING LINEAR MERGE) 284
MAKE A RECOGNITION DECISION USING THE SECOND COMBINED ALTERNATE LIST 286
END 288

FIG. 4

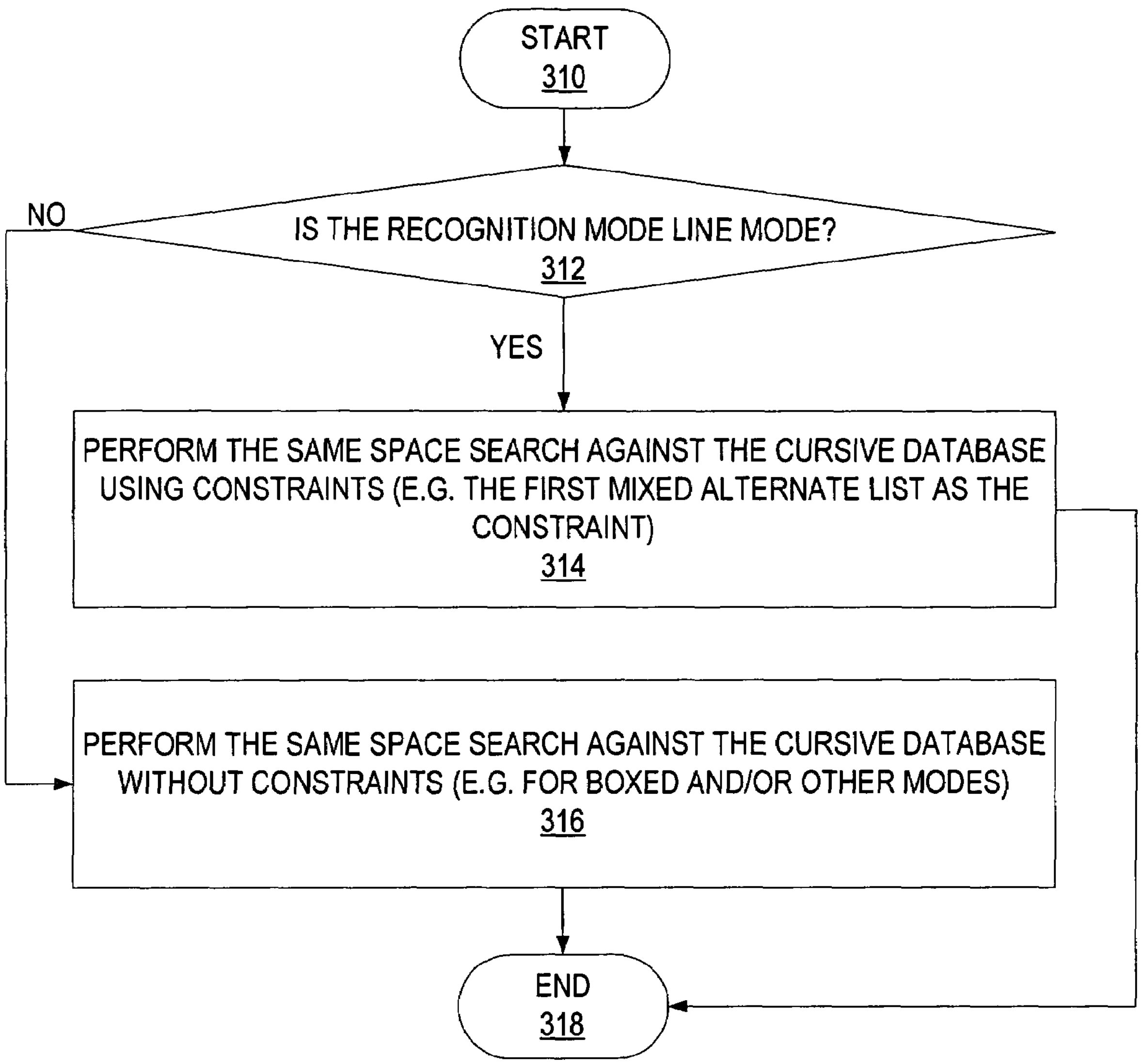

START
310
IS THE RECOGNITION MODE LINE MODE?
312
NO
YES
PERFORM THE SAME SPACE SEARCH AGAINST THE CURSIVE DATABASE USING CONSTRAINTS (E.G. THE FIRST MIXED ALTERNATE LIST AS THE CONSTRAINT)
314
PERFORM THE SAME SPACE SEARCH AGAINST THE CURSIVE DATABASE WITHOUT CONSTRAINTS (E.G. FOR BOXED AND/OR OTHER MODES)
316
END
318

FIG. 5

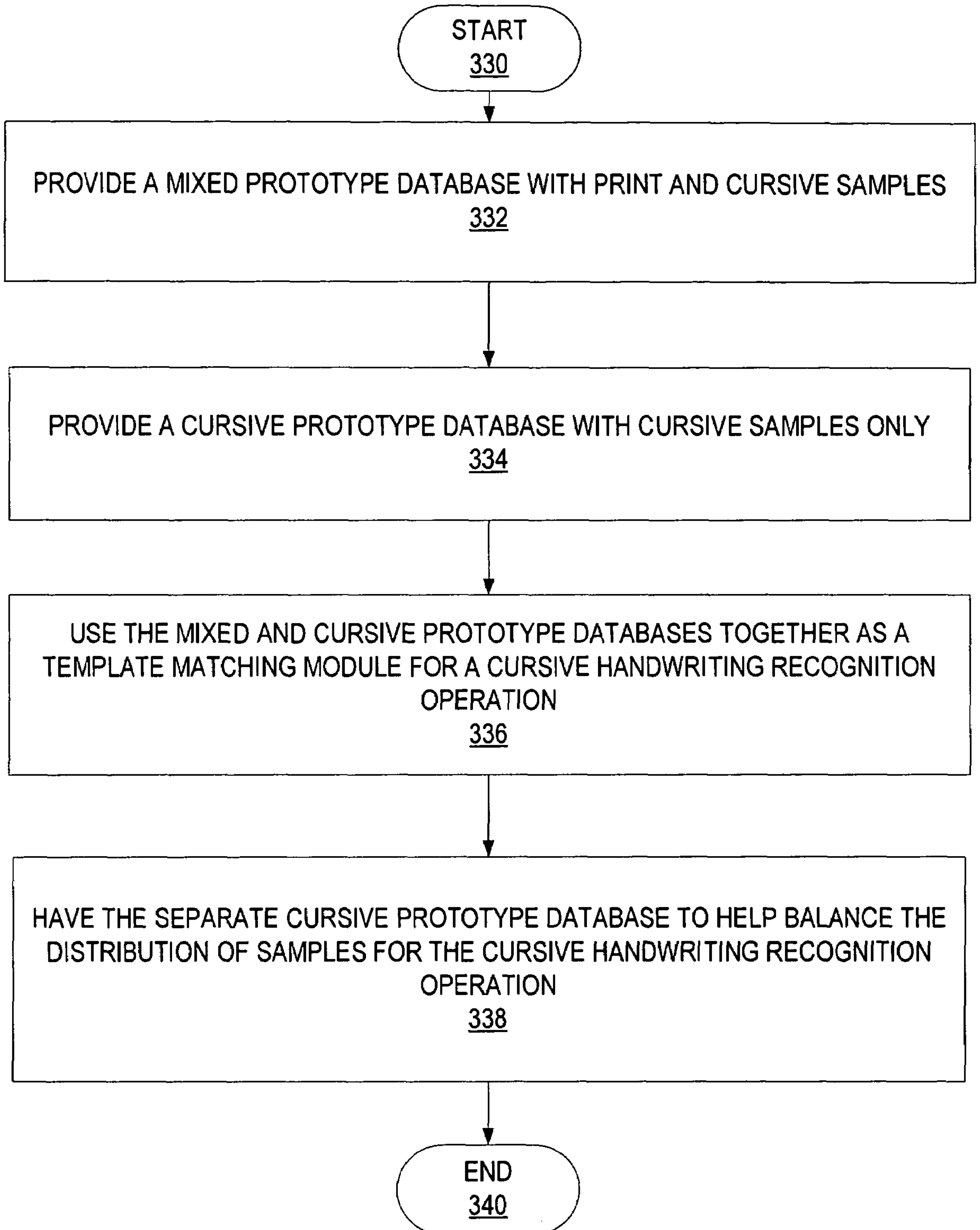

START
330
PROVIDE A MIXED PROTOTYPE DATABASE WITH PRINT AND CURSIVE SAMPLES
332
PROVIDE A CURSIVE PROTOTYPE DATABASE WITH CURSIVE SAMPLES ONLY
334
USE THE MIXED AND CURSIVE PROTOTYPE DATABASES TOGETHER AS A TEMPLATE MATCHING MODULE FOR A CURSIVE HANDWRITING RECOGNITION OPERATION
336
HAVE THE SEPARATE CURSIVE PROTOTYPE DATABASE TO HELP BALANCE THE DISTRIBUTION OF SAMPLES FOR THE CURSIVE HANDWRITING RECOGNITION OPERATION
338
END
340

FIG. 6

CURSIVE HANDWRITING RECOGNITION WITH HIERARCHICAL PROTOTYPE SEARCH

BACKGROUND

Pen-enabled devices such as tablet pc's and personal digital assistants often use one or more types of handwriting recognizers to allow users to enter data using the pen. Handwriting recognizers analyze the user's handwriting according to a series of classifiers to determine the most likely match. With prototype/template based matching recognition techniques, the ink segments are compared to ink samples in a database to determine a list of the most likely results. It is often difficult to achieve good handwriting recognition results for cursive handwriting due to the large number of inter and intra person variations (or writing styles) to write the same character. For example, a N stroke character can be written in 1–N strokes (potentially yielding 2^N writings). Furthermore, the way strokes are connected can vary drastically from person to person and from character to character. In addition, East Asian languages usually have the order of 10,000 characters (codepoints, or classes), which further complicates the problem. Difficulty also arises in instances where there is uneven data distribution (e.g. much more print training samples than cursive samples), which results in a limited number of cursive samples typically present in prototype databases as compared to the number of print samples.

SUMMARY

Various technologies and techniques are disclosed that improve cursive handwriting recognition. Cursive handwriting input is received from a user. The system performs a hierarchical prototype search as part of a recognition operation that includes same space searches and dynamic time warp searches. A same space search is performed against a mixed database that has both print and cursive samples. A same space search is also performed against a cursive database that has only cursive samples. The results of these two same space searches are merged into a combined alternate list. The combined alternate list is then used as a constraint for the dynamic time warp searches that are performed against the mixed and cursive databases, respectively. The results of the dynamic time warp searches are also merged into a final combined alternate list, and the combined alternate list is used to make a recognition decision regarding the user's handwritten input.

In one implementation, by providing the cursive prototype database trained with cursive samples only, in addition to the mixed database that has both print and cursive samples, the distribution of samples is better balanced for the cursive handwriting recognition operation.

This Summary was provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used as an aid in determining the scope of the claimed subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagrammatic view of a computer system of one implementation.

FIG. **2** is a diagrammatic view of a handwriting recognition application of one implementation operating on the computer system of FIG. **1**.

FIG. **3** is a logical diagram for one implementation of the system of FIG. **1**.

FIG. **4** is a process flow diagram for one implementation of the system of FIG. **1** illustrating the stages involved in improving a cursive handwriting recognition operation.

FIG. **5** is a process flow diagram for one implementation of the system of FIG. **1** illustrating the stages involved in performing the second same space search with constraints if the recognition mode is line mode.

FIG. **6** is a process flow diagram for one implementation of the system of FIG. **1** illustrating the stages involved in using a cursive-only database in addition to a mixed database to improve cursive recognition operations.

DETAILED DESCRIPTION

For the purposes of promoting an understanding of the principles of the invention, reference will now be made to the embodiments illustrated in the drawings and specific language will be used to describe the same. It will nevertheless be understood that no limitation of the scope is thereby intended. Any alterations and further modifications in the described embodiments, and any further applications of the principles as described herein are contemplated as would normally occur to one skilled in the art.

The system may be described in the general context as an application that improves cursive handwriting recognition, but the system also serves other purposes in addition to these. In one implementation, one or more of the techniques described herein can be implemented as features within a handwriting recognition application, or from any other type of program or service that includes a handwriting recognition feature.

As shown in FIG. **1**, an exemplary computer system to use for implementing one or more parts of the system includes a computing device, such as computing device **100**. In its most basic configuration, computing device **100** typically includes at least one processing unit **102** and memory **104**. Depending on the exact configuration and type of computing device, memory **104** may be volatile (such as RAM), non-volatile (such as ROM, flash memory, etc.) or some combination of the two. This most basic configuration is illustrated in FIG. **1** by dashed line **106**.

Additionally, device **100** may also have additional features/functionality. For example, device **100** may also include additional storage (removable and/or non-removable) including, but not limited to, magnetic or optical disks or tape. Such additional storage is illustrated in FIG. **1** by removable storage **108** and non-removable storage **110**. Computer storage media includes volatile and nonvolatile, removable and non-removable media implemented in any method or technology for storage of information such as computer readable instructions, data structures, program modules or other data. Memory **104**, removable storage **108** and non-removable storage **110** are all examples of computer storage media. Computer storage media includes, but is not limited to, RAM, ROM, EEPROM, flash memory or other memory technology, CD-ROM, digital versatile disks (DVD) or other optical storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices, or any other medium which can be used to store the desired information and which can accessed by device **100**. Any such computer storage media may be part of device **100**.

Computing device **100** includes one or more communication connections **114** that allow computing device **100** to communicate with other computers/applications **115**. Device **100** may also have input device(s) **112** such as keyboard, mouse, pen, voice input device, touch input device, etc. Output device(s) **111** such as a display, speakers, printer, etc. may also be included. These devices are well known in the art and need not be discussed at length here. In one implementation, computing device **100** includes handwriting recognition application **200**. Handwriting recognition application **200** will be described in further detail in FIG. **2**.

Turning now to FIG. **2** with continued reference to FIG. **1**, a handwriting recognition application **200** operating on computing device **100** is illustrated. Handwriting recognition application **200** is one of the application programs that reside on computing device **100**. However, it will be understood that handwriting recognition application **200** can alternatively or additionally be embodied as computer-executable instructions on one or more computers and/or in different variations than shown on FIG. **1**. Alternatively or additionally, one or more parts of handwriting recognition application **200** can be part of system memory **104**, on other computers and/or applications **115**, or other such variations as would occur to one in the computer software art.

Handwriting recognition application **200** includes program logic **204**, which is responsible for carrying out some or all of the techniques described herein. Program logic **204** includes logic for receiving cursive handwriting input from a user (e.g. at least four strokes) **206**; logic for performing a hierarchical prototype search with same space searches and dynamic time warp searches **208**; logic for performing a same space search against a mixed database that has both print and cursive samples, and for generating a mixed alternate list **210**; logic for performing a same space search against a cursive database that has cursive samples, and for generating a cursive alternate list **212**; logic for performing a constrained dynamic time warp search on the mixed and cursive databases, using a merged alternate list from the mixed alternate lists and cursive alternate list (e.g. merged using linear merge) **214**; logic for using the results from the hierarchical prototype search to make a recognition decision regarding the user's cursive handwriting **216**; logic for constraining the same space search against the cursive database if the recognition mode is line mode **218**; and other logic for operating the application **220**. In one implementation, program logic **204** is operable to be called programmatically from another program, such as using a single call to a procedure in program logic **204**.

Turning now to FIGS. **3**-**6** with continued reference to FIGS. **1**-**2**, the stages for implementing one or more implementations of handwriting recognition application **200** are described in further detail. FIG. **3** is a logical diagram **230** for one implementation handwriting recognition application **200**. In one form, the process of FIG. **3** is at least partially implemented in the operating logic of computing device **100**. Cursive input is received from a user (stage **232**). A same space search is performed against the print and cursive database—e.g. the mixed database (stage **234**)—to produce an alternate list of possible matches from the mixed database (stage **236**). A same space search is also performed against a cursive only database (stage **238**) to produce an alternate list of possible matches from the cursive only database (stage **240**). In one implementation, the same space searches are performed against approximately fifty thousand prototypes. In other implementations, more or fewer prototypes are used in the same space searches. The mixed alternate list and the cursive only alternate list are then combined to form a revised alternate list (stage **242**).

In one implementation, when the recognition mode is line mode, the second same space search that is run against the cursive only database is run in a constrained mode. In one implementation, the constraint is the alternate list from the mixed database generated in stage **236**. This is optional step that only occurs in line mode is represented by the dotted line arrow on FIG. **3**. In other modes, such as boxed mode, the full same space search is performed as described previously.

The combined alternate list is used as input to the dynamic time warp searches. In one implementation, there are approximately 10 times N prototypes (e.g. 10×20=200) used in the dynamic time warp searches, with N representing the number of items in the combined alternate list from the same space searches. In other implementations, more or fewer prototypes are used. A constrained dynamic time warp search is performed against the print and cursive (mixed) database (stage **244**) to produce a mixed alternate list (stage **246**). A constrained dynamic time warp search is also performed against the cursive only database (stage **248**) to produce a cursive alternate list (stage **250**). The mixed alternate list and the cursive alternate list are merged, forming a combined dynamic time warp alternate list (stage **252**). The merged alternate list that results after the same space searches and the dynamic time warp searches is then used to make a handwriting recognition decision.

FIG. **4** illustrates one implementation of the stages involved in improving a cursive handwriting recognition operation. In one form, the process of FIG. **4** is at least partially implemented in the operating logic of computing device **100**. The procedure begins at start point **270** with receiving a cursive handwriting input from a user (stage **272**). In one implementation, the process works with four or more handwritten strokes. In other implementations, more or fewer strokes can be used. A same space search is performed against a mixed database having print and cursive handwriting samples to generate a first mixed alternate list of possible matches to the cursive handwriting input (stage **274**). A same space search is performed against a cursive database having cursive samples to generate a first cursive alternate list of possible matches to the cursive handwriting input (stage **276**). The mixed alternate list is merged with the cursive alternate list to form a first combined alternate list (e.g. using linear merge) (stage **278**).

Using the combined alternate list as a constraint, the system performs a first dynamic time warp search against the mixed database to generate a second mixed alternate list of possible matches to the cursive handwriting input (stage **280**). Using the combined alternate list as a constraint, the system performs a second dynamic time warp search against the cursive database to generate a second cursive alternate list of possible matches to the cursive handwriting input (stage **282**). The second mixed alternate list is merged with the second cursive alternate list to form a second combined alternate list (e.g. using linear merge) (stage **284**). The system makes a recognition decision using the second combined alternate list (stage **286**). The process ends at end point **288**.

FIG. **5** illustrates one implementation of the stages involved in performing the second same space search with constraints if the recognition mode is line mode. In one form, the process of FIG. **5** is at least partially implemented in the operating logic of computing device **100**. The procedure begins at start point **310** with the system determining whether the recognition mode is line mode (decision point **312**). If the recognition mode is line mode (decision point **312**), then the same space search (as described in stage **276** in FIG. **4**) is performed against the cursive database using constraints (e.g. the first mixed alternate list as the constraint) (stage **314**). If the recognition mode is not line mode, then the same space search is performed against the cursive database without constraints (e.g. for boxed and/or other non-line modes) (stage **316**). The process ends at end point **318**.

FIG. **6** illustrates one implementation of the stages involved in using a cursive-only database in addition to a mixed database to improve cursive handwriting recognition operations. In one form, the process of FIG. **6** is at least partially implemented in the operating logic of computing device **100**. The procedure begins at start point **330** with providing a mixed prototype database with print and cursive samples (stage **332**). A cursive prototype database with cursive samples only is also provided (stage **334**). The system uses the mixed and cursive prototype databases together as a template matching modules for a cursive handwriting recognition operation (stage **336**). By having the separate cursive prototype database, the distribution of samples for the cursive handwriting recognition operation is better balanced (stage **338**). The process ends at end point **340**.

Although the subject matter has been described in language specific to structural features and/or methodological acts, it is to be understood that the subject matter defined in the appended claims is not necessarily limited to the specific features or acts described above. Rather, the specific features and acts described above are disclosed as example forms of implementing the claims. All equivalents, changes, and modifications that come within the spirit of the implementations as described herein and/or by the following claims are desired to be protected.

For example, a person of ordinary skill in the computer software art will recognize that the client and/or server arrangements, and/or data layouts as described in the examples discussed herein could be organized differently on one or more computers to include fewer or additional options or features than as portrayed in the examples.

What is claimed is:

1. A method for improving cursive handwriting recognition comprising the steps of:

receiving a cursive handwriting input from a user;

performing a first same space search against a mixed database having print and cursive handwriting samples to generate a first mixed alternate list of possible matches to the cursive handwriting input;

performing a second same space search against a cursive database having cursive samples to generate a first cursive alternate list of possible matches to the cursive handwriting input;

merging the first mixed alternate list with the first cursive alternate list to form a first combined alternate list;

using the first combined alternate list as a constraint, performing a first dynamic time warp search against the mixed database to generate a second mixed alternate list of possible matches to the cursive handwriting input;

using the first combined alternate list as a constraint, performing a second dynamic time warp search against the cursive database to generate a second cursive alternate list of possible matches to the cursive handwriting input; and

merging the second mixed alternate list with the second cursive alternate list to form a second combined alternate list.

2. The method of claim **1**, further comprising:

making a recognition decision using the second combined alternate list.

3. The method of claim **1**, wherein a recognition mode for the cursive handwriting input is boxed mode.

4. The method of claim **1**, wherein a recognition mode for the cursive handwriting input is a line mode.

5. The method of claim **4**, wherein the second same space search against the cursive database is constrained.

6. The method of claim **1**, wherein the first mixed alternate list is merged with the first cursive alternate list using a linear merge.

7. The method of claim **1**, wherein the second mixed alternate list is merged with the second cursive alternate list using a linear merge.

8. The method of claim **1**, wherein the cursive handwriting input from the user was written in at least four strokes.

9. A computer-readable medium having computer-executable instructions for causing a computer to perform the steps recited in claim **1**.

10. A computer-readable medium having computer-executable instructions for causing a computer to perform steps comprising:

receive a cursive handwriting input from a user;

perform a hierarchical prototype search comprising:

perform a first same space search against a mixed database having print and cursive samples;

perform a second same space search against a cursive database having cursive samples; and

perform a constrained dynamic time warp search on the mixed and cursive databases, using the results returned from the first same space search and the second same space search as the constraint; and

use a result from the hierarchical prototype search to make a recognition decision regarding the cursive handwriting input from the user.

11. The computer-readable medium of claim **10**, wherein the first same space search is further operable to generate a first mixed alternate list of possible matches to the cursive handwriting input from the mixed database.

12. The computer-readable medium of claim **11**, wherein the second same space search is further operable to generate a first cursive alternate list of possible matches to the cursive handwriting input from the cursive database.

13. The computer-readable medium of claim **12**, further having computer-executable instructions for causing a computer to perform the step of:

merge the first mixed alternate list with the first cursive alternate list to form a first combined alternate list.

14. The computer-readable medium of claim **13**, wherein the first mixed alternate list is merged with the first cursive alternate list using a linear merge.

15. The computer-readable medium of claim **13**, further having computer-executable instructions for causing a computer to perform the step of:

use the first combined alternate list as the constraint for the dynamic time warp search.

16. The computer-readable medium of claim **10**, wherein when a recognition mode is line mode, the second same space search is constrained.

17. The computer-readable medium of claim **10**, wherein the hierarchical prototype search is operable to work with cursive handwriting input from the user that was written in at least four strokes.

* * * * *