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Catchpole

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(54) **SPEECH RECOGNITION CIRCUIT USING PARALLEL PROCESSORS**

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(52) **U.S. Cl.** **704/235**; 704/242; 704/243; 704/258

(58) **Field of Classification Search** 704/235, 704/242, 243, 256, 258
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,293,213 A 3/1994 Klein et al.
5,832,428 A * 11/1998 Chow et al. 704/254

(Continued)

FOREIGN PATENT DOCUMENTS

GB 2 112 194 A 7/1983

(Continued)

OTHER PUBLICATIONS

S. Glinski et al., "Spoken Language Recognition on a DSP Array Processor", IEEE Transactions on Parallel and Distributed Systems, Jul. 5, 1994, No. 7, New York, USA, pp. 697-703.

(Continued)

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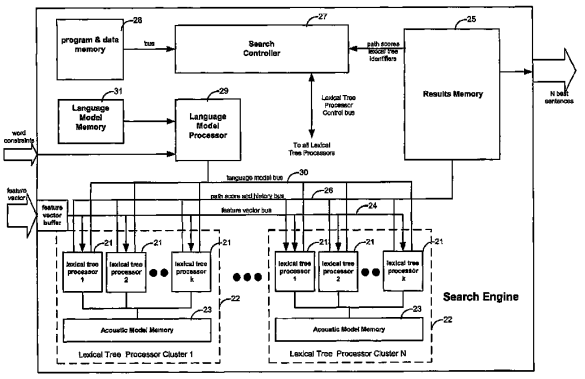
(57) **ABSTRACT**

A speech recognition circuit comprises an input buffer for receiving processed speech parameters. A lexical memory contains lexical data for word recognition. The lexical data comprises a plurality of lexical tree data structures. Each lexical tree data structure comprises a model of words having common prefix components. An initial component of each lexical tree structure is unique. A plurality of lexical tree processors are connected in parallel to the input buffer for processing the speech parameters in parallel to perform parallel lexical tree processing for word recognition by accessing the lexical data in the lexical memory. A results memory is connected to the lexical tree processors for storing processing results from the lexical tree processors and lexical tree identifiers to identify lexical trees to be processed by the lexical tree processors. A controller controls the lexical tree processors to process lexical trees identified in the results memory by performing parallel processing on a plurality of said lexical tree data structures.

69 Claims, 6 Drawing Sheets



U.S. PATENT DOCUMENTS

5,881,312	A	3/1999	Dulong	
5,995,930	A *	11/1999	Hab-Umbach et al.	704/254
6,047,283	A *	4/2000	Braun	707/3
7,035,802	B1 *	4/2006	Rigazio et al.	704/256
7,120,582	B1 *	10/2006	Young et al.	704/255
7,174,037	B2	2/2007	Arnone et al.	
2001/0011218	A1 *	8/2001	Phillips et al.	704/256
2003/0178584	A1	9/2003	Arnone et al.	
2008/0255839	A1	10/2008	Larri et al.	

FOREIGN PATENT DOCUMENTS

GB	2 331 392	A	5/1999
GB	2 347 835	A	9/2000
GB	2 380 920	A	4/2003
WO	WO 00/50859		8/2000
WO	WO 03/067572	A2	8/2003

OTHER PUBLICATIONS

S. Chatterjee et al., "Connected Speech Recognition on a Multiple Processor Pipeline", ICASSP 89, May 23, 1989, Glasgow, UK, pp. 774-777.

S-H. Chung et al., "A Parallel Phoneme Recognition Algorithm Based on Continuous Hidden Markov Model", Proceedings of 13th International Parallel Processing Symposium and 10th Symposium on Parallel and Distributed Processing, 1999, Los Alamitos, CA, USA, pp. 453-457.

S-H. Chung et al., "A Parallel Computational Model for Integrated Speech and Natural Language Understanding", IEEE Transactions on Computers, New York, USA, vol. 42, No. 10, Oct. 1, 1993, pp. 1171-1183.

N. Deshmukh et al., "Hierarchical Search for Large-Vocabulary Conversational Speech Recognition: Working Toward a Solution for the Decoding Problem", IEEE Signal Processing Magazine, vol. 16, No. 5, Sep. 1999, pp. 84-107.

R.M. Woodward et al., "Tissue Classification Using Terahertz Pulsed Imaging", Proceedings of the SPIE—The International Society for Optical Engineering SPIE-INT. Soc. Opt. Eng. USA, vol. 5318, No. 1, 2004, pp. 23-33. Abstract also attached.

V.P. Wallace et al., "Biomedical Applications of THz Imaging", Microwave Symposium Digest, 2004, IEEE MTT-S International Fort Worth, TX, USA, Jun. 6-11, 2004, Piscataway, NJ, USA, IEEE, vol. 3, Jun. 6, 2004, pp. 1579-1581.

V.P. Wallace et al., "Biomedical Applications of Terahertz Pulse Imaging", Second Joint EMBS-BMES Conference 2002. Conference Proceedings. 24th Annual International Conference of the Engineering in Medicinal and Biology Society. Annual Fall Meeting of the Biomedical Engineering Society, Houston, TX, Oct. 23-26, 2002, Annual vol. 1 of 3. Conf. 24, Oct. 23, 2002, pp. 2333-2334.

A.J. Fitzgerald et al., "Terahertz Imaging of Breast Cancer, a Feasibility Study", Conference Digest of the 2004 Joint 29th International Conference on Infrared and Millimeter Waves and 12th International Conference on Terahertz Electronics IEEE Piscataway, NJ, USA, 2004, pp. 823-824.

B.E. Cole et al., "Terahertz Imaging and Spectroscopy of Human Skin, In-vivo", Proceedings of SPIE, vol. 4276, pp. 1-10.

* cited by examiner

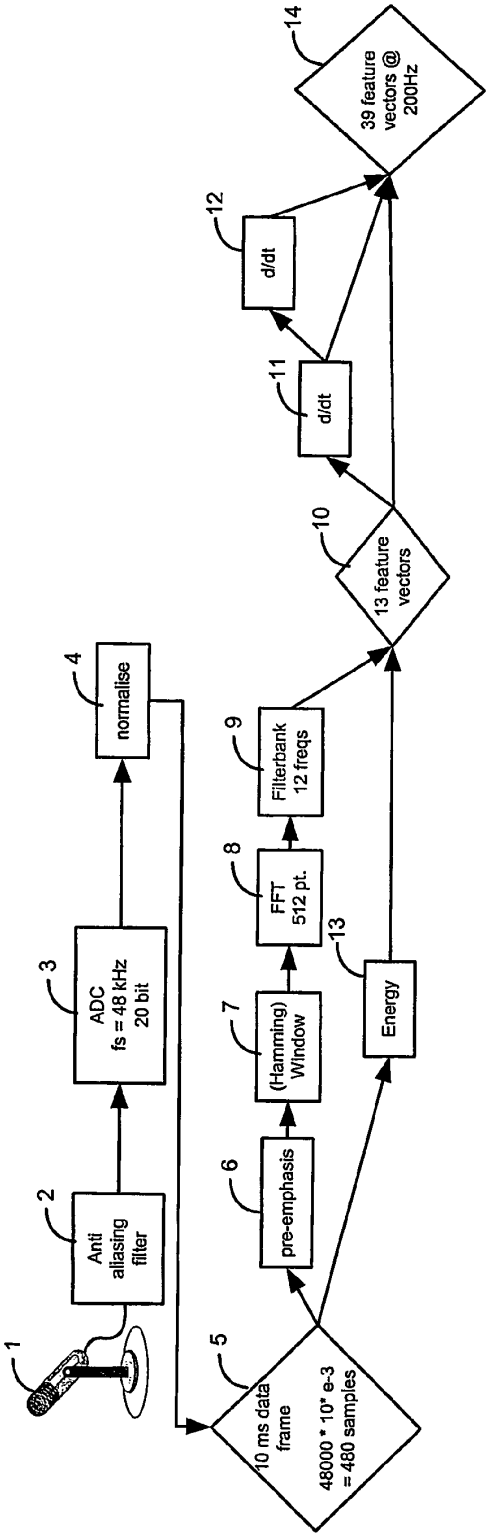

1
2
Anti aliasing filter
3
ADC fs = 48 kHz 20 bit
4
normalise
5
10 ms data frame
48000 * 10* e-3 = 480 samples
6
pre-emphasis
7
(Hamming) Window
8
FFT 512 pt.
9
Filterbank 12 freqs
10
13 feature vectors
11
d/dt
12
d/dt
13
Energy
14
39 feature vectors @ 200Hz

Fig 1

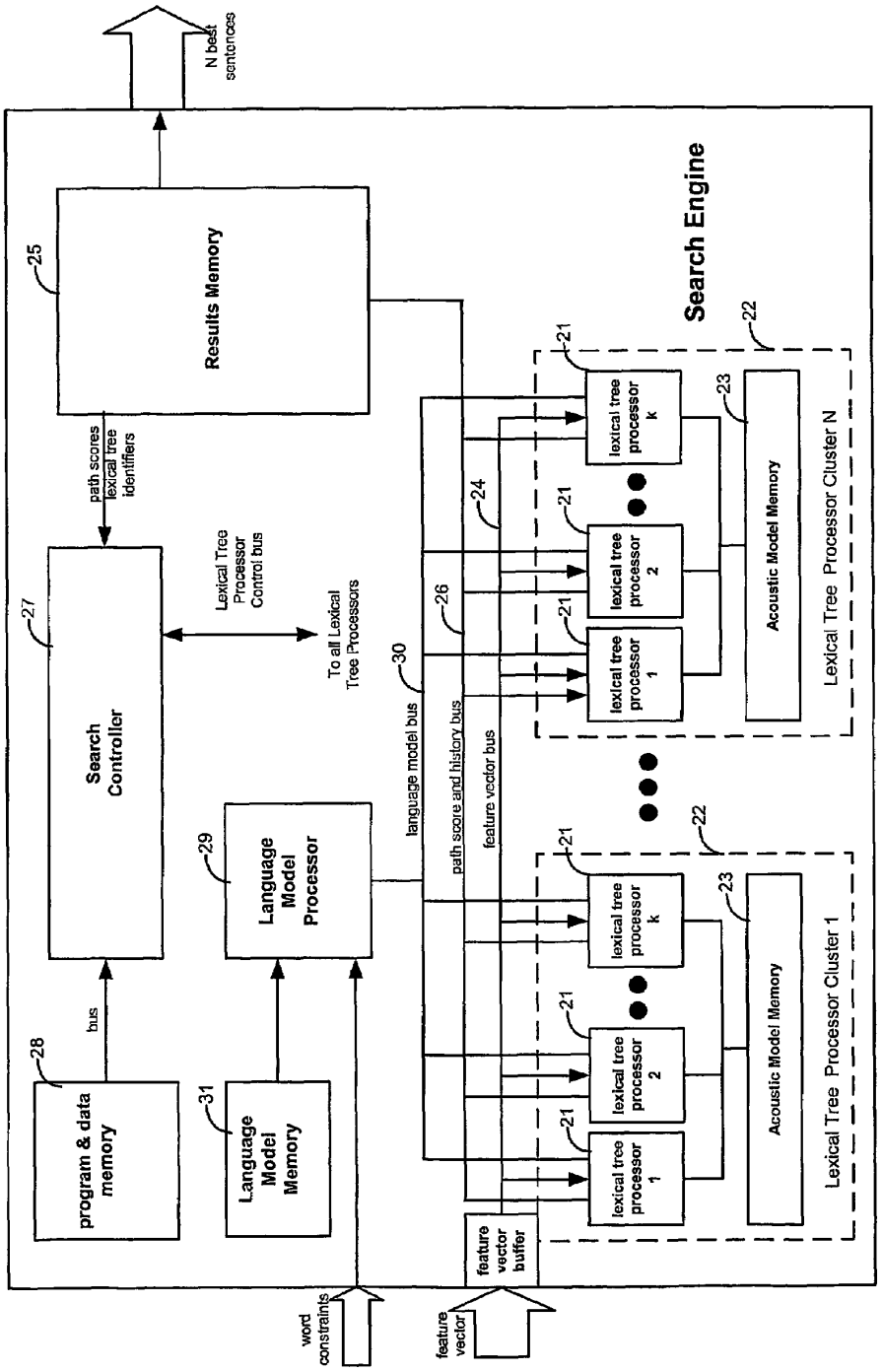

N best sentences
Results Memory
25
path scores
lexical tree identifiers
Search Controller
27
Lexical Tree Processor Control bus
To all Lexical Tree Processors
program & data memory
28
bus
Language Model Memory
31
Language Model Processor
29
word constraints
feature vector
feature vector buffer
language model bus
30
path score and history bus
feature vector bus
24
26
Search Engine
lexical tree processor k
lexical tree processor 2
lexical tree processor 1
21
22
23
Acoustic Model Memory
Lexical Tree Processor Cluster N
Lexical Tree Processor Cluster 1

Fig 2

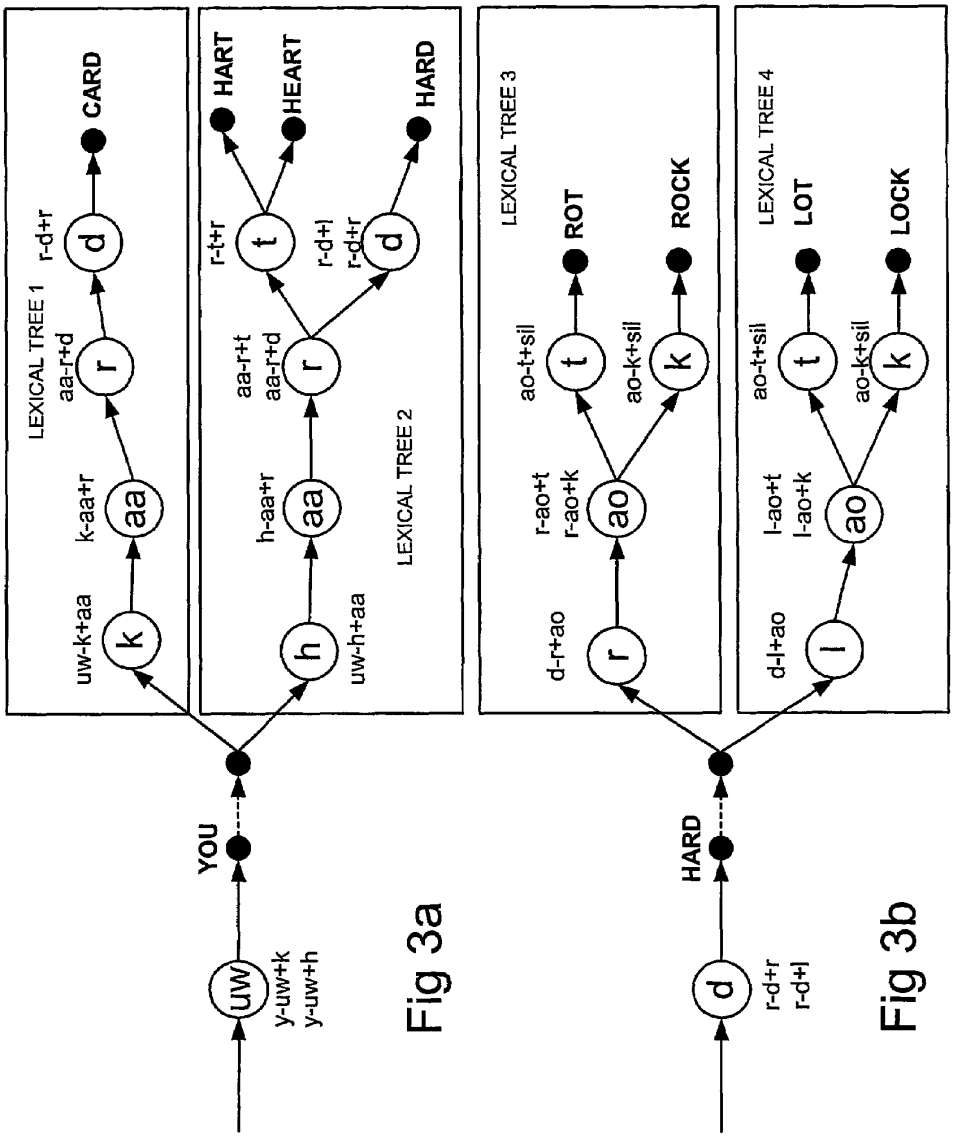

LEXICAL TREE 1
uw-k+aa
k-aa+r
aa-r+d
r-d+r
CARD
LEXICAL TREE 2
h-aa+r
uw-h+aa
aa-r+t
aa-r+d
r-t+r
r-d+l
r-d+r
HART
HEART
HARD
LEXICAL TREE 3
d-r+ao
r-ao+t
r-ao+k
ao-t+sil
ao-k+sil
ROT
ROCK
LEXICAL TREE 4
d-l+ao
l-ao+t
l-ao+k
ao-t+sil
ao-k+sil
LOT
LOCK
YOU
y-uw+k
y-uw+h
HARD
r-d+r
r-d+l

Fig 3a

Fig 3b

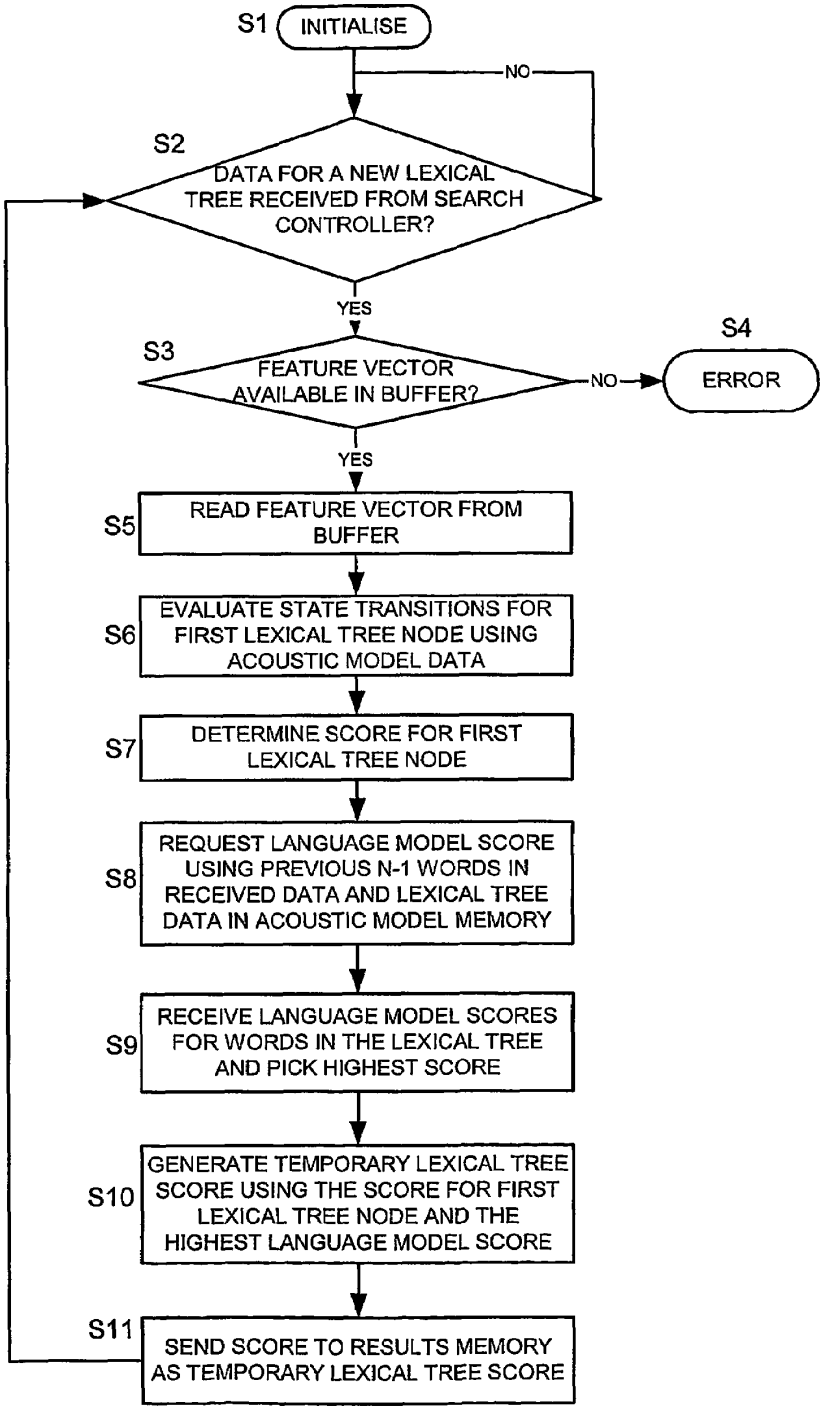

S1
INITIALISE
NO
S2
DATA FOR A NEW LEXICAL TREE RECEIVED FROM SEARCH CONTROLLER?
YES
S3
FEATURE VECTOR AVAILABLE IN BUFFER?
NO
S4
ERROR
YES
S5
READ FEATURE VECTOR FROM BUFFER
S6
EVALUATE STATE TRANSITIONS FOR FIRST LEXICAL TREE NODE USING ACOUSTIC MODEL DATA
S7
DETERMINE SCORE FOR FIRST LEXICAL TREE NODE
S8
REQUEST LANGUAGE MODEL SCORE USING PREVIOUS N-1 WORDS IN RECEIVED DATA AND LEXICAL TREE DATA IN ACOUSTIC MODEL MEMORY
S9
RECEIVE LANGUAGE MODEL SCORES FOR WORDS IN THE LEXICAL TREE AND PICK HIGHEST SCORE
S10
GENERATE TEMPORARY LEXICAL TREE SCORE USING THE SCORE FOR FIRST LEXICAL TREE NODE AND THE HIGHEST LANGUAGE MODEL SCORE
S11
SEND SCORE TO RESULTS MEMORY AS TEMPORARY LEXICAL TREE SCORE

Fig 4

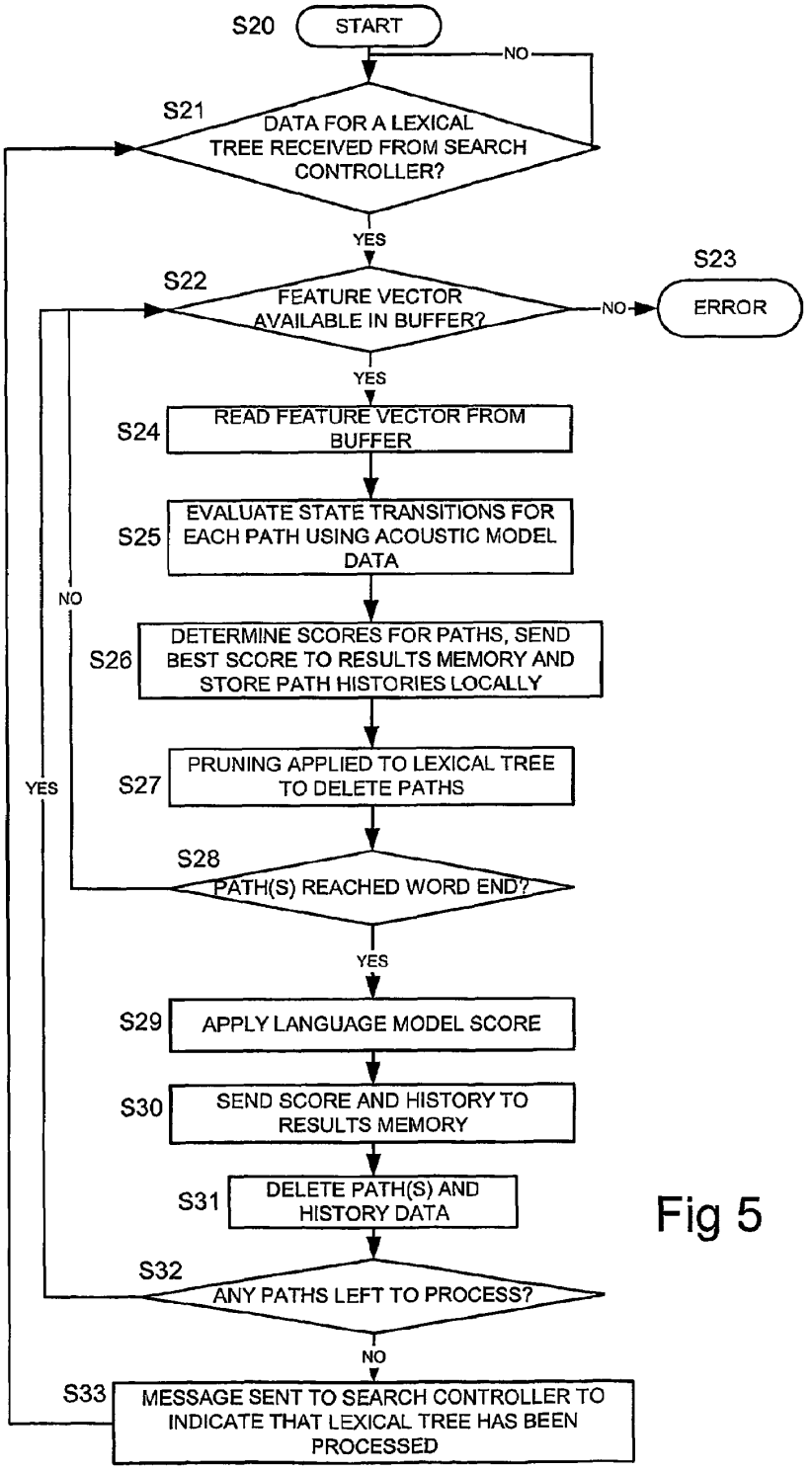

S20
START
NO
S21
DATA FOR A LEXICAL TREE RECEIVED FROM SEARCH CONTROLLER?
YES
S22
FEATURE VECTOR AVAILABLE IN BUFFER?
NO
S23
ERROR
YES
S24
READ FEATURE VECTOR FROM BUFFER
S25
EVALUATE STATE TRANSITIONS FOR EACH PATH USING ACOUSTIC MODEL DATA
NO
S26
DETERMINE SCORES FOR PATHS, SEND BEST SCORE TO RESULTS MEMORY AND STORE PATH HISTORIES LOCALLY
YES
S27
PRUNING APPLIED TO LEXICAL TREE TO DELETE PATHS
S28
PATH(S) REACHED WORD END?
YES
S29
APPLY LANGUAGE MODEL SCORE
S30
SEND SCORE AND HISTORY TO RESULTS MEMORY
S31
DELETE PATH(S) AND HISTORY DATA
S32
ANY PATHS LEFT TO PROCESS?
NO
S33
MESSAGE SENT TO SEARCH CONTROLLER TO INDICATE THAT LEXICAL TREE HAS BEEN PROCESSED

Fig 5

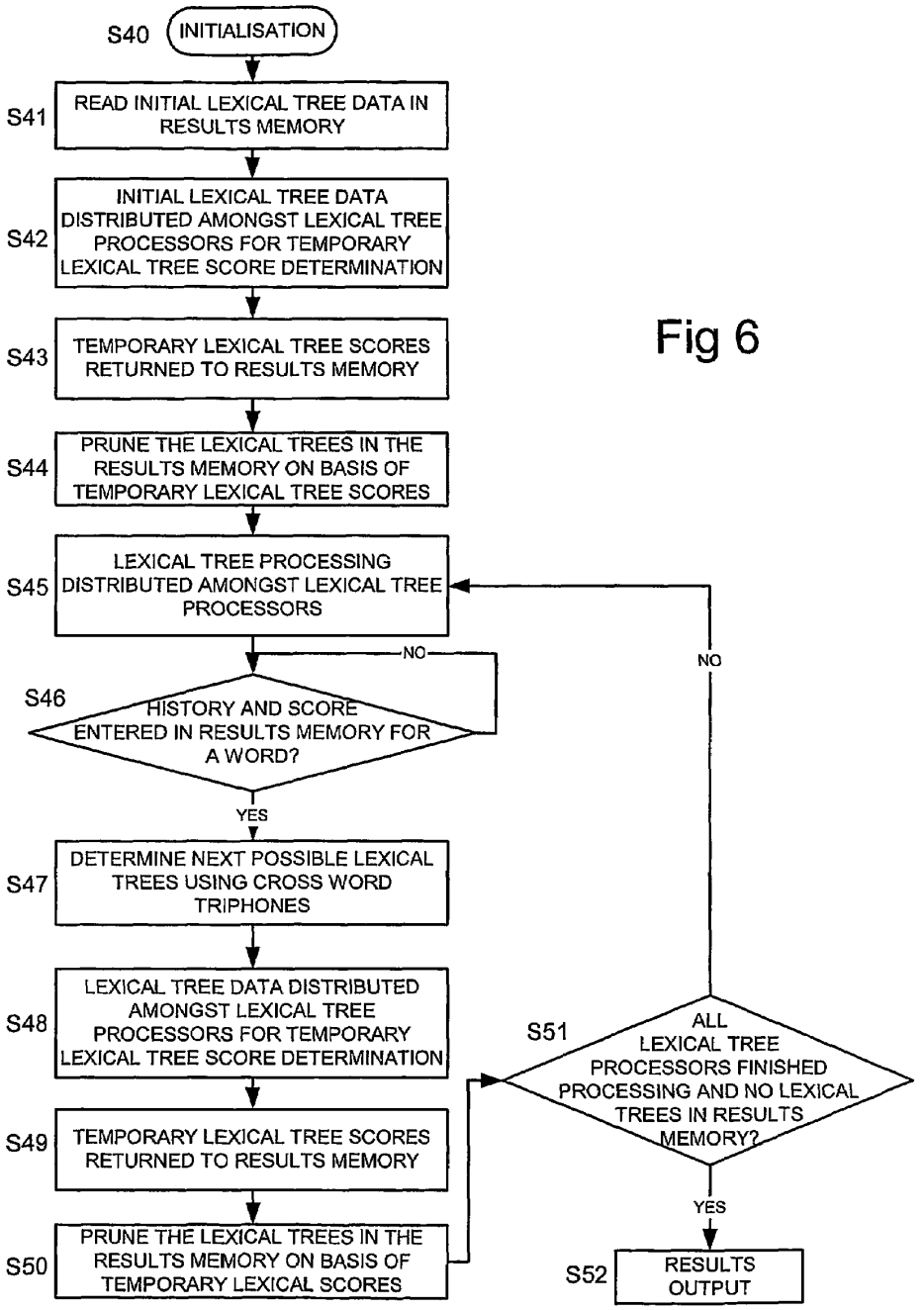

S40
INITIALISATION
S41
READ INITIAL LEXICAL TREE DATA IN RESULTS MEMORY
S42
INITIAL LEXICAL TREE DATA DISTRIBUTED AMONGST LEXICAL TREE PROCESSORS FOR TEMPORARY LEXICAL TREE SCORE DETERMINATION
S43
TEMPORARY LEXICAL TREE SCORES RETURNED TO RESULTS MEMORY
S44
PRUNE THE LEXICAL TREES IN THE RESULTS MEMORY ON BASIS OF TEMPORARY LEXICAL TREE SCORES
S45
LEXICAL TREE PROCESSING DISTRIBUTED AMONGST LEXICAL TREE PROCESSORS
S46
HISTORY AND SCORE ENTERED IN RESULTS MEMORY FOR A WORD?
NO
YES
S47
DETERMINE NEXT POSSIBLE LEXICAL TREES USING CROSS WORD TRIPHONES
S48
LEXICAL TREE DATA DISTRIBUTED AMONGST LEXICAL TREE PROCESSORS FOR TEMPORARY LEXICAL TREE SCORE DETERMINATION
S49
TEMPORARY LEXICAL TREE SCORES RETURNED TO RESULTS MEMORY
S50
PRUNE THE LEXICAL TREES IN THE RESULTS MEMORY ON BASIS OF TEMPORARY LEXICAL SCORES
S51
ALL LEXICAL TREE PROCESSORS FINISHED PROCESSING AND NO LEXICAL TREES IN RESULTS MEMORY?
NO
YES
S52
RESULTS OUTPUT

Fig 6

SPEECH RECOGNITION CIRCUIT USING PARALLEL PROCESSORS

The present invention generally relates to a speech recognition circuit which uses parallel processors for processing the input speech data in parallel.

Conventional large vocabulary speech recognition can be divided into two processes: front end processing to generate processed speech parameters such as feature vectors, followed by a search process which attempts to find the most likely set of words spoken from a given vocabulary (lexicon).

The front end processing generally represents no problem for current processing systems. However, for large vocabulary, speaker independent speech recognition, it is the search process that presents the biggest challenge. An article by Deshmukh et al entitled "Hierarchical Search for Large-Vocabulary Conversational Speech Recognition" (IEEE Signal Processing Magazine, September 1999, pages 84 to 107), the content of which is hereby incorporated by reference, discusses the general concepts of large vocabulary speech recognition. As discussed in this paper, one algorithm for performing the search is the Viterbi algorithm. The Viterbi algorithm is a parallel or breadth first search through a transition network of states of Hidden Markov Models. An acoustic model for words in a lexicon are represented as states of Hidden Markov Models. These states represent phones or n phones in a phone model of the words. The search requires the evaluation of possible word matches. It is known that such a search is computationally intensive.

In order to speed up the processing performed during such a search in a speech recognition system, parallel processing has been explored. In an article by M K Ravishankar entitled "Parallel Implementation of Fast Beam Search for Speaker-Independent Continuous Speech Recognition" (Indian Institute of Science, Bangalor, India, Jul. 16, 1993) a multi-threaded implementation of a fast beam search algorithm is disclosed. The multi-threading implementation requires a significant amount of communication and synchronization among threads. In an MSC project report by R Dujari entitled "Parallel Viterbi Search Algorithm for Speech Recognition" (MIT, February 1992) the parallel processing of input speech parameters is disclosed in which a lexical network is split statically among processors.

It is an object of the present invention to provide an improved circuit which can perform parallel processing of speech parameters.

In accordance with a first embodiment of the present invention, a speech recognition circuit comprises an input port such as input buffer for receiving parameterized speech data such as feature vectors. A lexical memory arrangement is provided which contains lexicon data for word recognition. The lexical data comprises a plurality of lexical tree data structures representing a plurality of lexical trees. Each lexical tree data structure comprises a model of words having common prefix components and an initial component which is unique as an initial component for lexical trees. A plurality of lexical tree processors are connected in parallel to the input port and perform parallel lexical tree processing for word recognition by accessing the lexical data in the lexical memory arrangement. A results memory arrangement is connected to the lexical tree processors for storing processing results from the lexical tree processors and lexical tree identifiers to identify lexical trees to be processed by the lexical tree processors. A controller controls the lexical tree processors to process lexical trees identified in the results memory arrangement by performing parallel processing of a plurality of lexical tree data structures.

Thus in accordance with this embodiment of the present invention, the processing in order to perform word recognition is distributed across the processors by controlling the processors to perform processing on different lexical trees. The controller controls the processor by the processes to provide for efficient process management by distributing lexical processing to appropriate processors.

The lexical tree data structure can comprise a phone model of words, wherein the components comprise phones. For reduced storage, the lexical tree data structure can comprise a mono phone lexical tree. The mono phone lexical tree can be used to generate context dependent phone models dynamically. This enables the use of context dependent phone models for matching and hence increased accuracy whilst not increasing memory requirements. Alternatively, the lexical tree data structure can comprise context dependent phone models.

The processing performed by each processor in one embodiment comprises the comparison of the speech parameters with the lexical data, e.g. phone models or data derived from the lexical data (e.g. dynamically generated context dependent phone models) to identify words as a word recognition event and to send information identifying the identified words to the results memory as the processing results. In this embodiment a language model processor arrangement can be provided for providing a language model output for modifying the processing results at a word recognition event by a lexical tree processor. The modification can either take place at each lexical tree processor, or at the language model processing arrangement.

In one embodiment each lexical tree processor determines an output score for words in the processing results at word recognition events. Thus in this embodiment the language model processing arrangement can modify the score using a score for a language model for n preceding words, where n is an integer.

In one embodiment the controller instructs a lexical tree processor to process a lexical tree by passing a lexical tree identifier for the lexical tree and history data for a recognition path associated with the lexical tree from the results memory. The history data preferably includes an accumulated score for the recognition path. This enables a score to be determined based on the score for the recognition path to accumulate a new score during recognition carried out using the lexical tree data structure. The scores can be output in the processing results to the results memory during the processing of the speech parameters so that the scores can be used for pruning.

In one embodiment of the present invention, each lexical tree processor operates on more than one lexical tree at the same time, e.g. two lexical trees represented by two different lexical tree data structures, or two lexical trees represented by the same data structure but displaced in time (which can be termed to instances of the same lexical tree).

At word recognition events, the controller determines new lexical tree identifiers for storing in the results memory for words identified in the results memory for respective word events. In order to reduce the processing, the controller can prune the new lexical tree identifiers to reduce the number of lexical trees which are required to be processed. This pruning can be achieved using context dependant n phones to reduce the number of possible next phones. The number can be further reduced by using a language model look ahead technique.

In one embodiment of the present invention, the lexical tree processors are arranged in groups or clusters. The lexical memory arrangement comprises a plurality of partial lexical memories. Each partial lexical memory is connected to one of

the groups of lexical tree processors and contains part of the lexical data. Thus a group of lexical tree processors and a partial lexical memory form a cluster. Each lexical tree processor is operative to process the speech parameters using a partial lexical memory and the controller controls each lexical tree processor to process a lexical tree corresponding to partial lexical data in a corresponding partial lexical memory.

In another embodiment of the present invention the lexical memory arrangement comprises a plurality of partial lexical memories. Each partial lexical memory being connected to one of the lexical tree processors and containing part of the lexical data. Each lexical tree processor processes the speech parameters using a corresponding partial lexical memory and the controller is operative to control each lexical tree processor to process a lexical tree corresponding to partial lexical data in a corresponding partial lexical memory.

In one embodiment of the present invention the lexical memory arrangement stores the lexical tree data structures as Hidden Markov Models and the lexical tree processors are operative to perform the Viterbi search algorithm using each respective lexical tree data structure. Thus in this way, this embodiment of the present invention provides a parallel Viterbi lexical tree search process for speech recognition.

The first aspect of the present invention is a special purpose circuit built for performing the speech recognition search process in which there are a plurality of processors for performing parallel lexical tree processing on individual lexical tree processors.

In another aspect of the present invention a speech recognition circuit comprises an input port such as an input buffer for receiving parameterized speech data such as feature vectors. A plurality of lexical memories are provided which contain in combination complete lexical data for word recognition. Each lexical memory contains part of the complete lexical data. A plurality of processors are provided connected in parallel to the input port for processing the speech parameters in parallel. The processors are arranged in groups in which each group is connected to a corresponding lexical memory to form a cluster. A controller controls each processor to process the speech parameters using partial lexical data read from a corresponding lexical memory. The results of processing the speech parameters are output from the processors as recognition data.

Thus this aspect of the present invention provides a circuit in which speech recognition processing is performed in parallel by groups of processors operating in parallel in which each group accesses a common memory of lexical data. This aspect of the present invention provides the advantage of parallel processing of speech parameters and benefits from a limited segmentation of the lexical data. By providing a plurality of processors in a group with a common memory, flexibility in the processing is provided without being bandwidth limited by the interface to the memory that would occur if only a single memory were used for all processors. The arrangement is more flexible than the parallel processing arrangement in which each,processor only has access to its own local memory and requires fewer memory interfaces (i.e. chip pins). Each processor within a group can access the same lexical data as any other processor in the group. The controller can thus control the parallel processing of input speech parameters in a more flexible manner. For example, it allows more than one processor to process input speech parameters using the same lexical data in a lexical memory. This is because the lexical data is segmented into domains which are accessible by multiple processors.

In a preferred embodiment this aspect of the present invention is used in combination with the first aspect of the present invention. In such an arrangement each processor performs lexical tree processing and the lexical data stored in each lexical memory comprises lexical tree data structures which each comprise a model of words having common prefix components and an initial component that is unique.

In preferred embodiments of the second aspect of the present invention, the preferred embodiments of the first aspect of the present invention are incorporated.

Embodiments of the present invention will now be described with reference to the accompanying drawings in which:

FIG. **1** is a diagram of a speech data processing circuit for generating parameterized speech data (feature vectors);

FIG. **2** is a diagram of a speech recognition circuit in accordance with an embodiment of the present invention;

FIGS. **3***a* and **3***b* are schematic diagrams illustrating lexical tree structures;

FIG. **4** is a flow diagram illustrating the process performed by a lexical tree processor to determine a temporary lexical tree score in accordance with an embodiment of the present invention;

FIG. **5** is a flow diagram illustrating the process performed by the lexical tree processor for processing the input feature vectors in accordance with an embodiment of the present invention; and

FIG. **6** is a flow diagram illustrating the process performed by the controller in accordance with an embodiment of the present invention.

FIG. **1** illustrates a typical circuit for the parameterization of input speech data. In this embodiment the parameters generated are speech vectors.

A microphone **1** records speech in an analogue form and this is input through an anti-aliasing filter **2** to an analogue-to-digital converter **3** which samples the speech at 48 kHz at 20 bits per sample. The digitized output signal is normalized (**4**) to generated a 10 millisecond data frame every 5 milliseconds with 5 milliseconds overlap (**5**). A pre-emphasis operation **6** is applied to the data followed by a hamming window **7**. The data is then fast Fourier transformed (FFT) using a 512 point fast Fourier transform (**8**) before being filtered by filter bank **9** into 12 frequencies. The energy in the data frame **5** is also recorded (**13**) as an additional feature and together with the 12 frequency outputs of the filter bank **9**, 13 feature vectors (**10**) are thus produced and these are output as part of the 39 feature vectors **14**. First and second derivatives (**11** and **12**) are taken of the 13 feature vectors **10** to complete the generation of the 39 feature vectors **14**.

The arrangement illustrated in FIG. **1** is purely given for illustration. The present invention encompasses any means by which speech and data can be parameterized to a suitable form for input to the search process as will be described in more detail hereinafter.

FIG. **2** is a schematic diagram of a speech recognition circuit in accordance with an embodiment of the present invention for performing the search process. The parameterized speech data, which in this embodiment comprise feature vectors are input to a feature vector buffer **20**. The feature vector buffer **20** is provided to buffer the incoming feature vectors to allow lexical tree processors **21** to read and process the feature vectors in the buffer **20** via a feature vector bus **24**. A plurality k of lexical tree processors **21** are arranged in a respective lexical tree processor cluster **22**. Each lexical tree processor cluster **22** has an acoustic model memory **23** in which is stored lexical data for use by the lexical tree processors **21** within the lexical tree processor cluster **22**. Each lexical tree processor **21** in the lexical tree processor cluster **22** are connected to the acoustic model memory **23** within the

lexical tree processor **22**. There are N lexical tree processor clusters and thus there are Nk lexical tree processors **21** connected by the feature vector bus **24** to the feature vector buffer **20**. Each lexical tree processor **21** is capable of processing a different lexical tree and thus Nk lexical trees can be processed in parallel. The acoustic model memories **23** store as a whole a complete set of lexical data, i.e. lexical tree data structures for use in the lexical tree processing by the lexical tree processors **21**. Each acoustic model memory **23** contains part or a segment of the lexical tree data. Since lexical tree processors **21** in a lexical tree processor cluster **22** access the same acoustic model memory **23**, it is possible for more than one lexical tree processor **21** to process the same lexical data. This provides for some degree of flexibility in the controlling of the processing by the lexical tree processors **21**. Further, the acoustic model memories **23** need not contain only one copy of the lexical data. It is possible to build in a redundancy in the data to further enhance the flexibility. This avoids any bottleneck in the processing due to the search processing focusing on a small number of lexical trees.

A results memory **25** is provided for storing processing results from the lexical tree processors **21** which are received over the path score and history bus **26**. The results memory **25** also stores information on lexical trees to identify which lexical trees are to be processed. A search controller **27** is provided to control the processing performed by the lexical tree processors **21** in dependence upon a program and data stored in program and data memory **28**. The search controller reads the path scores and lexical tree identifiers from the results memory and controls the lexical tree processors accordingly. A language model processor **29** is provided which is connected to each lexical tree processor **21** by a language model bus **30**. The language model processor **29** accesses a language model memory **31** to read language model data for provision to lexical tree processors **21** in response to language model data requests. External control of the language model memory **31** is provided by a word constrains input. The language model processor **29** determines a score for a word occurring following N previous words using N grams. When a lexical tree processor requires a language model score a request is sent to the language model processor **29** over the language model bus **30** identifying the current word and the N−1 previous words. A language model score for the N gram can be returned to the lexical tree processor **21** for the modification of the score at the end of a branch of lexical tree processing. The lexical tree processor can modify the score in accordance with the language model and output a score to the results memory **25** for a word at the end of a branch of the lexical tree processing. Thus the results memory stores the results as an ordered list of scores for words together with their histories.

The results memory **25** stores the following data:

1. initial lexical tree data. This comprises pointers to an initial set of lexical trees. No history data is associated with the initial set of lexical trees. The initial set of lexical trees is predetermined and stored in the results memory **25** based on the most likely initial phones of an utterance. This initial lexical tree data is required to initialize the search process.
2. History data for search results. This comprises a record of a recognition path through the lexical tree recognition process performed by the lexical tree processors **21**. The history data includes the current word, the previous N−1 words, the current accumulated score, the phone history (for use in the determination of likely next lexical trees using cross word context dependent tri-phones), and an identifier or pointer to the lexical tree used for identifying the word.
3. Best scores for best paths being processed by each lexical tree processor **21**. This information enables the search controller **27** to monitor the processing being performed by lexical tree processors **21** to determine whether a global pruning strategy should be applied in order to reassign processing performed by a lexical tree processor if its best score for its best path is below a threshold or well below the best scores for the paths being processed by other lexical tree processors **21**.
4. Temporary lexical tree scores. These comprise tree scores which are determined as temporary scores to prune the next lexical trees to be processed at word ends. The temporary lexical tree scores include lexical tree identifiers or pointers to identify the next lexical trees to be processed. The scores enable the pruning of this list.
5. Pruning threshold. This can be a global threshold value for use in the pruning of the lexical trees globally, or a local threshold value for use by a lexical processor for locally pruning the processing performed by the lexical processor **21**.

The acoustic model memory **23** stores a Hidden Markov Model for acoustically modelling words as lexical trees. The acoustic model memory **23** stores a plurality of lexical tree data structures. Each lexical tree data structure comprises an n phone model of a number of words having common prefix phones. The first node of the lexical tree (the root) comprises a common n phone to all words in the lexical tree and uniquely identifies the lexical tree.

Each lexical tree processor **21** includes on-board memory (or local memory) to be used during the lexical tree processing. This working memory has to store all of the parameters currently working on including current scores for all paths being processed within the lexical tree, and previous N−1 words for the lexical tree. The local storage of the previous N−1 words enables the lexical tree processor **21**, when a word end is reached along a branch of the lexical tree, to send a request for the language model score for an N gram by sending the identity of the N−1 previous words together with the word identified at the end of the branch.

FIG. **3***a* and **3***b* schematically illustrate lexical trees which can be processed by the lexical tree processor **21** during the recognition of the two words HARD ROCK. In FIG. **3***a* a previous lexical tree terminated at a branch recognizing the word YOU and terminating with the mono phone uw which is associated with two context dependent tri-phones y−uw+k and y−uw+h. Thus the context dependent tri-phone associated with the last phone in the lexical tree word model for YOU indicates two possible next lexical trees, i.e. the lexical trees beginning with the mono phone k and h and having a left context phone of uw. As can be see in FIG. **3***a* this word end YOU therefore leads to two possible next lexical trees. These two lexical trees are traversed in parallel by two different lexical tree processors accumulating scores for matching of input feature vectors into Hidden Markov Models of the context dependent tri-phones associated with each node in the tree. When the end of the branch is reached, a word end event is reached and a word is recognized. As can be seen in FIG. **3***a*, in this example since four words are of similar phone length, it is possible for the search strategy based on inputting feature vectors in parallel to simultaneously reach a number of possible word ends. These possible word ends are sent as processing results to the results memory. The results memory stores the accumulated score at the word end together with phone history to identify the last phone and its associated context dependent tri-phones. In this example, considering the branch where the word HARD is recognized, the last phone is d which has associated with it two context dependent

tri-phones r−d+1 and r−d+r. Thus the search controller **27** can identify next possible lexical trees using the next phone in the context dependent tri-phone. In this case, as can be seen in FIG. **3***b*, the next possible lexical trees begin with the phones r and **1** and have associated with them context dependent tri-phones d−r+ao and d−1+ao respectively. Thus these are the next lexical trees that require processing following the end node or word event detected in the processing lexical tree **2**. FIG. **3***b* thus represents the processing that is required at the end of FIG. **3***a* at the word node for HARD in processing the second lexical tree.

As can be seen in FIG. **3***b*, the two lexical trees are processed in parallel by traversing through the branches to reach word ends by sequentially entering in feature vectors in parallel to lexical tree processors processing the respective lexical trees. When the word end is reached, the accumulated score is output to the results memory as described before. In this case since it is the last word, the important context dependent tri-phone associated with the final phone has silence (sil) as the following phone. The final phone can in fact have 50 context dependent tri-phones associated with it if there are 50 possible next phones (including silence). FIG. **3***b* only illustrates the relevant one for the end of the utterance.

FIG. **4** is a flow diagram illustrating the processing performed by a lexical tree processor **21** in order to determine a temporary lexical tree score for a lexical tree.

When a word end is identified by a lexical tree processor, the processing results are sent to the results memory **25**. The results memory identifies the last phone of the recognized words and thus enables the search controller **27** to identify possible next lexical trees using context dependent tri-phones as illustrated in FIG. **3***b*. Although in theory if there are 50 phones there are 50^2 possible lexical trees, due to the use of the context dependant triphones, only 100-200 lexical trees are likely to be identified as possible lexical trees. The search controller needs to further prune out the lexical trees which are unlikely to generate likely paths with high scores. In order to do this, instructions are sent to the lexical tree processors to determine a temporary lexical tree score which can be used to prune out lexical trees from the processing which have a low score.

The processing by the lexical tree processor to generate the temporary lexical tree score is shown in FIG. **4** and for this process, following initialization, a lexical tree processor **21** awaits receipt of data for a new lexical tree from the search controller **27** (step S**2**). The data comprises a lexical tree pointer on an identifier to lexical tree data stored in the acoustic model memory **23**, i.e. the lexical tree data structure, previous N−1 words (for use in language model score determination by the language model processor **29**), and the current path score. The previous N−1 words includes the previously recognized word for which a score has been accumulated.

The lexical tree processor **21** then attempts to read the next feature vector from the feature vector buffer **20** (step S**3**) and if this is not available, an error occurs (step S**4**). If the feature vector is available in the feature vector buffer **20**, the lexical tree processor **21** reads the feature vector from the buffer **20** (step S**5**) and evaluates the state transitions for the first lexical tree node using the acoustic model data in the acoustic model memory **23** (step S**6**). Since the state transitions for the first node will require several feature vectors to complete, a score is determined for a state transition of the first node in the lexical tree (step S**7**). The lexical tree processor **21** then sends a request to the language model processor **29** for a language model score. The request includes the previous N−1 words and all of the possible words represented by the lexical tree data structure in the acoustic model memory **23** (step S**8**). The language model processor returns scores for each of the N grams ending in the words represented by the lexical tree. The lexical tree processor thus receives language model scores for the words in the lexical tree and picks the highest score (step S**9**). Alternatively, the language model processor **29** can select the highest n gram score and return this to the lexical tree processor for the determination of the temporary lexical tree score. The temporary lexical tree score for the lexical tree is then generated using the score determined for the first state transition of the first lexical tree node and the highest language model score (step S**10**). The temporary lexical tree score is then sent by the lexical tree processor **21** to the results memory **25** over the bus **26** (step S**11**). In this mode of processing, the processor then awaits the next data of the new lexical tree from the search controller (step S**2**).

This process is just one of the processes performed by the lexical tree processor. The main processing performed by the lexical tree processor is the lexical tree evaluation. This process will now be described with reference to the flow diagram of FIG. **5**.

After the start of the process (step S**20**) a lexical tree processor awaits receipt of data for a lexical tree from the search controller (step S**21**). The data comprises a lexical tree pointer to a lexical tree data structure stored in the acoustic model memory **23**, the previous N−1 words in the recognition path, and the current accumulated score.

The lexical tree processor then attempts to read the next feature vector from the feature vector buffer **20** (step S**22**). If this is not available, an error occurs (step s**23**). If the feature vector is available in the feature vector buffer **20**, the feature vector is read from the feature vector buffer **20** by the lexical tree processor **21** (step S**24**) and the lexical tree processor **21** evaluates the state transitions for each path using the acoustic model data in the acoustic model memory **23** (step S**25**). Scores for the paths are determined in accordance with the conventional Viterbi search technique and the best score for the best path is sent to the results memory **25** while the path histories are stored locally in the on-board memory of the lexical tree processor **21** (step S**26**). Pruning is applied to the lexical tree by the lexical tree processor to delete paths in order to keep the breadth of the search manageable (step S**27**). The pruning applied locally by the lexical tree processor can be purely on the basis of a local threshold, which can be provided by the search controller **27**, or it can be determined on a relative basis dependent upon the range of scores for paths being processed within the lexical tree processor **21**. If the path has not reached a word end (step S**28**) the lexical tree processor **21** attempts to read the next feature vector from the feature vector buffer **20** (step S**22**). If the path reaches a word end (step S**28**) the score must be modified by the language model score (step S**29**). There are two ways in which this can be done, in this embodiment the lexical tree processor **21** sends a request to the language model processor **29** for a language model score. The request includes the current word and the N−1 previous words. The language model processor thus returns the language model score and the language model score is used to modify the current accumulated score at the word end. Alternatively, the lexical tree processor can send the language model processor **29** not just the current word and the N−1 previous words, but also the current accumulated score. The language model processor then determines the language model score using the language model memory **31** and modifies the accumulated score using the language model score. The language model processor **29** can then return the modified score to the lexical tree processor **21** which can then pass it to the results memory **25**, or a connec-

tion between the language model processor **29** and the results memory **25** (not shown) can enable the language model processor **29** to send the score directly to the results memory **25** for the lexical tree processor **21**. In this latter case, the language model processor **29** must also receive a lexical tree pointer to identify the lexical tree for which the score applies.

Assuming in this embodiment that the lexical tree processor calculates the modified score (step S**29**), the score and history is then sent by the lexical tree processor **21** to the results memory **25** (step S**30**). The history data sent to the results memory **25** comprises the lexical tree pointer identifying the lexical tree, the modified score at the word end, the phone history identifying at least the last phone to allow for context dependent tri-phone determination of next lexical trees, and the identity of the word identified in the evaluation process.

The lexical tree processor then deletes the path and history data in its on-board memory (step S**31**) and determines if there are any paths still left to be processed (step S**32**). If so, the lexical tree processor **21** tries to access the next feature vector available in the feature vector buffer **20** (step S**22**). If there are no paths left to be processed, a message is sent by the lexical tree processor to the search controller **27** to indicate that the lexical tree has been processed (step S**33**). In this level of processing the lexical tree processor will then await the next data for a lexical tree from the search controller **27**.

The flow diagram of FIG. **5** illustrates the processing of a single instance of a lexical tree. The single point in time a lexical tree can start to be processed from a feature vector, i.e. lexical tree processing starts at a time frame. However, due to a word end returned from lexical tree processing in another lexical tree processor, the lexical tree processor may also be asked during a subsequent time frame to start processing another instance of the lexical tree with a different path history. Thus a lexical tree processor **21** can be processing multiple instances of the lexical tree with different paths having different path histories. In this instance, the pruning applied in step S**27** needs to take into account all paths currently being processed in all instances of lexical tree processing by the lexical tree processor **21**. Thus although pruning is applied locally, it is applied over more than one instance of the lexical tree.

The operation of the search controller **27** will now be described with reference to the flow diagram of FIG. **6**.

After initialization (step S**40**) initial lexical tree data in the results memory **25** is read (step S**41**). The search controller distributes the initial lexical tree data amongst the lexical tree processors for temporary lexical tree score determination (step S**42**) as described with reference to FIG. **4**. Temporary lexical tree scores are returned by the lexical tree processors **21** to the results memory **25** (step S**43**) and the search controller reads the temporary lexical tree scores in the results memory **25** and prunes the lexical trees in the results memory **25** on the basis of the read temporary lexical scores (step S**44**). Thus the set of initial lexical trees can be quite large and this requires a large number of temporary lexical tree score determinations to be performed by the lexical tree processors **21**. However, since the lexical tree processors only need to determine a score for a single feature vector, this can be performed quite quickly. Thus the number of lexical trees for which full evaluation by the lexical tree processors **21** is required can thus be reduced by the selection of the lexical trees with the highest temporary lexical tree score. The search controller than distributes the lexical tree processing among the lexical tree processors **21** by sending each lexical tree processor data including a lexical tree pointer to a lexical tree data structure in the acoustic model memory **23** in the cluster **22**. The search controller **27** then awaits the entry of processing results, i.e. history and scores in the results memory **25** for words (step S**46**). When history and scores for words are entered in the results memory, the search controller **27** determines next possible lexical trees using cross-word tri-phones (step S**47**). For example, as illustrated in FIGS. **3***a* and **3***b*, when the word HARD is entered in the results memory, the search controller identifies the final phone of the word as being d and thus next possible tri-phones can comprise any tri-phones having the left phone d. If there are 50 possible phones, this results in 50^2 possible tri-phones. In practice, only 1 to 200 are likely. However, this may still represent too many for full evaluation and thus the lexical tree data for the next possible lexical trees are distributed amongst the lexical tree processors for temporary lexical tree score determination (step S**48**). Temporary lexical tree scores are returned to the results memory **25** by the lexical tree processors **21** which execute the process as described with reference to FIG. **4** (step S**49**).

The search controller **27** prunes the list of next lexical trees in the results memory **25** on the basis of the temporary lexical scores (step S**50**). The search controller then determines if the words in the results memory have been processed and there are no lexical trees left to be processed and whether or not lexical tree processes are finished (step S**51**). If not, the lexical tree processing is distributed amongst the lexical tree processors (step S**45**). When the end of the utterance is reached, next possible lexical trees will all have been processed and the results can be output from the results memory **25** (step S**52**).

It can be seen from the foregoing description that the embodiment of the invention provides for an efficient parallel processing system incorporating a parallel lexical tree processing architecture and a segmented lexicon storage architecture. Each lexical tree processor performs lexical tree evaluation and language model look ahead for evaluation of company scores for lexical trees to assist in pruning of the number of potential lexical trees that require processing. The architecture is ideally suited to synchronous breadth first searching e.g. a Viterbi search (i.e. real time recognition). The breadth first search is performed synchronously by the parallel processors on the input search parameters when the language model look ahead takes place, it is possible for the feature vector buffer **20** to store a small number, e.g. one or two, feature vectors whilst the language model look ahead is performed on the feature vector so that synchronous breadth first searching can be carried out by re-reading the feature vector out of the buffer **20** when it is determined which lexical trees are to be evaluated by the lexical trees processors **21** after a word end. Thus, the feature vector buffer **20** provides a method of decoupling the search parameterisation circuitry from the search circuit.

If the buffer causes processing to get too far behind, e.g. there are a lot of word end language model look ahead operations to be performed, it is possible for the lexical tree processors to be controlled to temporarily halve their local beamwidths (i.e. more vigorously prune) and thus complete their processing more quickly. This would allow the content of the buffer to be decreased as the processors catch up.

Although the present invention has been described hereinabove with reference to a specific embodiment, it will be apparent to a skilled person in the art that modifications lie within the spirit and scope of the present invention. Although in the embodiment described hereinabove, the acoustic model memories **23** were described as storing parts of the lexical data, it is also possible for more than one copy of the lexical data to be stored in different acoustic model memories **23**. Thus, more than one lexical tree processor cluster **22** can have

access to the same lexical data. This increases the flexibility and allows the controller to avoid any bottlenecks in processing which, for example, can occur if the highest pass scores all require processing by one or a number of lexical tree data structures residing in one of the acoustic model memories **23**.

Although in the embodiments described hereinabove, the memory is partitioned in to a plurality of acoustic model memories **23**, the present invention is not limited to the partitioning of the lexical data and a plurality of lexical tree processors can access a single memory containing lexical data.

The lexical data stored can comprise mono phone models of words. When the lexical data is partitioned, these can be distributed evenly across the memories. If there are 50 mono phones, there will be 50 lexical tree data structures having a unique initial model phone data node. Alternatively, the lexical tree data structures can comprise a context dependent n phone word models. If there are 50 mono phones, there are potentially 50^n lexical tree data structures. For tri-phones, this comprises 50^3 (i.e. 125,000). These are distributed so that trees with the same left context tri-phone, are eventually spread across memories when the lexical data is partitioned. Thus in this way the word end where the left context tri-phone is fixed i.e. the same, the next possible lexical trees will inherently be distributed across the memories, thus ensuring efficient parallel processing of the next lexical trees.

Although the embodiment described hereinabove uses a single results memory accessible by all processors, the present invention encompasses a plurality of results memories. For example, a results memory can be associated with each processor to store the processing results and the controller can read the results in the plurality of results memories in order to control the processors.

Although in the embodiment described above the input speech parameters are described as being feature vectors, the present invention encompasses any type of parameterization of speech data as an input to the circuit. Such parameterization methods are well known in the art.

Although in the embodiment described above there is only one language model processor, more than one can be used and these can be used to operate in parallel for processing scores at word boundaries.

The invention claimed is:

1. A speech recognition circuit comprising:

input means for receiving processed speech parameters;

lexical memory means containing lexical data for word recognition, said lexical data comprising a plurality of lexical tree data structures, each lexical tree data structure comprising a model of words having common prefix components, an initial component of each lexical tree data structure being unique;

a plurality of lexical tree processors connected in parallel to said input means for processing the speech parameters in parallel to perform parallel lexical tree processing for word recognition by accessing said lexical data in said lexical memory means;

results memory means connected to said lexical tree processors for storing processing results from said lexical tree processors and lexical tree identifiers to identify lexical trees to be processed by said lexical tree processors; and

control processor means for controlling said lexical tree processors to process lexical trees identified in said results memory means by performing parallel processing on a plurality of said lexical tree data structures.

2. A speech recognition circuit according to claim **1**, wherein said lexical memory means stores said lexical tree data structure as an n phone model of words, where n is an integer, and said components comprise n phones.

3. A speech recognition circuit according to claim **2**, wherein said lexical memory means stores each lexical tree data structure as mono phone models of words, and said lexical tree processors are arranged to use said mono phone models to generate context dependant phone models of words dynamically for use in processing the speech parameters.

4. A speech recognition circuit according to claim **1**, wherein each lexical tree processor is operative to compare the processed speech parameters with said lexical data or data derived from said lexical data to identify words as a word recognition event and to send information identifying the identified words to said results memory means as the processing results.

5. A speech recognition circuit according to claim **4**, including language model means for providing a language model output for modifying the processing results at a word recognition event by a said lexical tree processor.

6. A speech recognition circuit according to claim **5**, wherein each lexical tree processor is operative to receive said language model output to modify the processing result at a word recognition event determined by said lexical tree processor and to output the modified processing result to said results memory means.

7. A speech recognition circuit according to claim **4**, wherein each lexical tree processor is operative to determine and output scores for words in the processing results at word recognition events.

8. A speech recognition circuit according to claim **1**, wherein said lexical tree processors are operative to process said speech parameters by comparing said speech parameters with said lexical data or data derived from said lexical data in said lexical memory means.

9. A speech recognition circuit according to claim **1**, wherein said control processor means is operative to instruct a said lexical tree processor to process a lexical tree by passing a lexical tree identifier for the lexical tree and history data for a recognition path associated with the lexical tree from said results memory means.

10. A speech recognition circuit according to claim **9**, wherein said history data includes an accumulated score for the recognition path.

11. A speech recognition circuit according to claim **1**, wherein said control processor means is operative to pass a lexical tree identifier to a said lexical tree processor, said lexical tree processor is operative to read lexical data for the identified lexical tree from said lexical memory means and to process said speech parameters using said read lexical data.

12. A speech recognition circuit according to claim **1**, wherein said lexical tree processors are operative to determine and output scores in the processing results during the processing of said speech parameters.

13. A speech recognition circuit according to claim **12**, wherein said lexical tree processors are operative to prune the processing of the lexical tree in dependence upon the determined scores.

14. A speech recognition circuit according to claim **1**, wherein said lexical tree processors are operative to process more than one lexical tree at the same time.

15. A speech recognition circuit according to claim **4**, wherein said control processor means is operative to determine new lexical tree identifiers for storing in said results memory means for words identified in said results memory means.

16. A speech recognition circuit according to claim **15**, wherein said control processor means is operative to prune the new lexical tree identifiers.

17. A speech recognition circuit according to claim **16**, wherein each lexical tree processor is operative to determine and output scores for words in the processing results at word recognition events, and said control processor means is operative to prune said new lexical tree identifiers on the basis of the scores for the words stored in said results memory means.

18. A speech recognition circuit according to claim **1**, wherein said input means is arranged to receive said speech parameters as feature vectors.

19. A speech recognition circuit according to claim **1**, wherein said input means is arranged to receive said speech parameters as n phones, where n is an integer.

20. A speech recognition circuit according to claim **1**, wherein said lexical tree processors are arranged in groups, said lexical memory means comprises a plurality of partial lexical memory means, each partial lexical memory means being connected to one of said groups of lexical tree processors and containing part of the lexical data, each lexical tree processor is operative to process said speech parameters using a said partial lexical memory means, and said control processor means is operative to control each lexical tree processor to process a lexical tree corresponding to partial lexical data in a corresponding partial lexical memory means.

21. A speech recognition circuit according to claim **1**, wherein said lexical memory means comprises a plurality of partial lexical memory means, each partial lexical memory means being connected to one of said lexical tree processors and containing part of the lexical data, each lexical tree processor is operative to process said speech parameters using a said partial lexical memory means, and said control processor means is operative to control each lexical tree processor to process a lexical tree corresponding to partial lexical data in a corresponding partial lexical memory means.

22. A speech recognition circuit according to claim **1**, wherein said lexical memory means stores said lexical tree data structures as Hidden Markov Models, and said lexical tree processors are operative to perform the Viterbi search algorithm using each lexical tree data structure.

23. A speech recognition circuit comprising:

an input buffer for receiving processed speech parameters;

lexical memory containing lexical data for word recognition, said lexical data comprising a plurality of lexical tree data structures, each lexical tree data structure comprising a model of words having common prefix components, the initial component of each lexical tree data structure being unique;

a plurality of lexical tree processors connected in parallel to said input buffer for processing the speech parameters in parallel to perform parallel lexical tree processing for word recognition by accessing said lexical data in said lexical memory;

results memory connected to said lexical tree processors for storing processing results from said lexical tree processors and lexical tree identifiers to identify lexical trees to be processed by said lexical tree processors; and

a control processor for controlling said lexical tree processors to process lexical trees identified in said results memory by performing parallel processing on a plurality of said lexical tree data structures.

24. A speech recognition circuit according to claim **23**, wherein said lexical memory stores said lexical tree data structure as an n phone model of words, where n is an integer, and said components comprise n phones.

25. A speech recognition circuit according to claim **24**, wherein said lexical memory stores said lexical tree data structure as a mono phone model of words, and each lexical tree processor generates context dependant phone models of words dynamically for use in processing the speech parameters.

26. A speech recognition circuit according to claim **23**, wherein each lexical tree processor compares the processed speech parameters with the lexical data or data derived from the lexical data to identify words as a word recognition event and sends information identifying the identified words to said results memory as the processing results.

27. A speech recognition circuit according to claim **26**, including a language model processor for providing a language model output for modifying the processing results at a word recognition event by a said lexical tree processor.

28. A speech recognition circuit according to claim **27**, wherein each lexical tree processor receives said language model output to modify the processing result at a word recognition event determined by said lexical tree processor and outputs the modified processing result to said results memory.

29. A speech recognition circuit according to claim **26**, wherein each lexical tree processor determines and outputs scores for words in the processing results at word recognition events.

30. A speech recognition circuit according to claim **23**, wherein said lexical tree processors process said speech parameters by comparing said speech parameters with said lexical data in said lexical memory.

31. A speech recognition circuit according to claim **23**, wherein said control processor instructs a said lexical tree processor to process a lexical tree by passing a lexical tree identifier for the lexical tree and history data for a recognition path associated with the lexical tree from said results memory.

32. A speech recognition circuit according to claim **31**, wherein said history data includes an accumulated score for the recognition path.

33. A speech recognition circuit according to claim **23**, wherein said control processor passes a lexical tree identifier to a said lexical tree processor, said lexical tree processor reads lexical data for the identified lexical tree from said lexical memory and processes said speech parameters using said read lexical data.

34. A speech recognition circuit according to claim **23**, wherein said lexical tree processors determine and output scores in the processing results during the processing of said speech parameters.

35. A speech recognition circuit according to claim **34**, wherein said lexical tree processors prune the processing of the lexical trees in dependence upon the determined scores.

36. A speech recognition circuit according to claim **23**, wherein said lexical tree processors process more than one lexical tree at the same time.

37. A speech recognition circuit according to claim **26**, wherein said control processor determines new lexical tree identifiers for storing in said results memory for words identified in said results memory.

38. A speech recognition circuit according to claim **37**, wherein said control processor means is operative to prune the new lexical tree identifiers.

39. A speech recognition circuit according to claim **38**, wherein each lexical tree processor determines and outputs scores for words in the processing results at word recognition events, and said control processor prunes said new lexical tree identifiers on the basis of the scores for the words stored in said results memory means.

40. A speech recognition circuit according to claim **23**, wherein said input buffer receives said speech parameters as feature vectors.

41. A speech recognition circuit according to claim **23**, wherein said input buffer receives said speech parameters as n phones, where n is an integer.

42. A speech recognition circuit according to claim **23**, wherein said lexical tree processors are arranged in groups, said lexical memory comprises a plurality of partial lexical memories, each partial lexical memory being connected to one of said lexical tree processors and containing part of the lexical data, each lexical tree processor processes said speech parameters using a said partial lexical memory, and said control processor controls each lexical tree processor to process a lexical tree corresponding to partial lexical data in a corresponding partial lexical memory.

43. A speech recognition circuit according to claim **23**, wherein said lexical memory comprises a plurality of partial lexical memories, each partial lexical memory is connected to one of said lexical tree processors and containing part of the lexical data, each lexical tree processor processes said speech parameters using a said partial lexical memory, and said control processor controls each lexical tree processor to process a lexical tree corresponding to partial lexical data in a corresponding partial lexical memory.

44. A speech recognition circuit according to claim **23**, wherein said lexical memory stores said lexical tree data structures as Hidden Markov Models, and each lexical tree processor performs the Viterbi search algorithm using a respective said lexical tree data structure.

45. A speech recognition circuit comprising:

input means for receiving processed speech parameters;

a plurality of lexical memory means containing in combination complete lexical data for word recognition, each lexical memory means containing part of said complete lexical data;

a plurality of processors connected in parallel to said input means for processing the speech parameters in parallel, said processors being arranged in groups of processors, each group of processors being connected to a lexical memory means;

control processor means for controlling each processor to process said speech parameters using partial lexical data read from a said lexical memory means; and

receiving means for receiving the results of the processing of the speech parameters from said processors, wherein

each lexical memory means stores lexical data as at least one lexical tree data structure, each lexical tree data structure comprises a model of words having common prefix components, and an initial component of each lexical tree data structure is unique, and

wherein said processors are operative to use lexical data corresponding to more than one lexical tree at the same time.

46. A speech recognition circuit comprising:

an input buffer receiving processed speech parameters;

a plurality of lexical memories containing in combination complete lexical data for word recognition, each lexical memory containing part of said complete lexical data;

a plurality of processors connected in parallel to said input buffer for processing the speech parameters in parallel, said processors being arranged in groups of processors, each group of processors being connected to a lexical memory;

a control processor controlling each processor to process said speech parameters using partial lexical data read from a respective said lexical memory; and

a results memory storing the results of the processing of the speech parameters from said processors.

47. A speech recognition circuit according to claim **46**, wherein each lexical memory stores lexical data as at least one lexical tree data structure, each lexical tree data structure comprises a model of words having common prefix components, and an initial component of each lexical tree data structure is unique.

48. A speech recognition circuit according to claim **47**, wherein each lexical memory stores said lexical tree data structure as an n phone model of words, where n is an integer, and said components comprise n phones.

49. A speech recognition circuit according to claim **48**, wherein each lexical memory stores said lexical tree data structure as a mono phone model of words, and said lexical tree processors use said mono phone models to generate context dependant phone models of words dynamically for use in processing the speech parameters.

50. A speech recognition circuit according to claim **46**, wherein each processor compares the processed speech parameters with the lexical data in a corresponding lexical memory to identify words as a word recognition event and sends information identifying the identified words to said results memory as the processing results.

51. A speech recognition circuit according to claim **50**, a including language model processor providing a language model output for modifying the processing results at a word recognition event by a said processor.

52. A speech recognition circuit according to claim **51**, wherein each processor receives said language model output to modify the processing result at a word recognition event determined by said processor and outputs the modified processing result to said results memory.

53. A speech recognition circuit according to claim **51**, wherein each processor determines and outputs scores for words in the processing results at word recognition events.

54. A speech recognition circuit according to claim **46**, wherein said processors process said speech parameters by comparing said speech parameters with said lexical data or data derived from lexical data in respective said lexical memories.

55. A speech recognition circuit according to claim **47**, wherein said control processor instructs a said processor to process a lexical tree by passing a lexical tree identifier for the lexical tree and history data for a recognition path associated with the lexical tree to said processor.

56. A speech recognition circuit according to claim **55**, wherein said history data includes an accumulated score for the recognition path.

57. A speech recognition circuit according to claim **47**, wherein said control processor passes a lexical tree identifier to a said processor, said processor reads lexical data for the identified lexical tree from a corresponding said lexical memory and processes said speech parameters using said read lexical data.

58. A speech recognition circuit according to claim **46**, wherein said processors determine and output scores in the processing results during the processing of said speech parameters.

59. A speech recognition circuit according to claim **58**, wherein said processors prune the processing of the speech parameters in dependence upon the determined scores.

60. A speech recognition circuit according to claim **47**, wherein said processors use lexical data corresponding to more than one lexical tree at the same time.

61. A speech recognition circuit according to claim **50**, wherein said control processor identifies lexical data in said

lexical memories required for processing next words at word recognition events, and controls said processors to process the speech parameters using the identified lexical data.

62. A speech recognition circuit according to claim **61**, wherein said control processor prunes the identified lexical data.

63. A speech recognition circuit according to claims **62**, wherein each processor determines and outputs scores for words in the processing results at word recognition events, and said control processor prunes the identified lexical data on the basis of the scores for the words.

64. A speech recognition circuit according to claim **46**, wherein said input buffer is arranged to receive said speech parameters as feature vectors.

65. A speech recognition circuit according to claim **46**, wherein said input buffer is arranged to receive said speech parameters as n phones, where n is an integer.

66. A speech recognition circuit according to claim **46**, wherein said control processor controls each processor to process a lexical tree corresponding to partial lexical data in a corresponding said lexical memory.

67. A speech recognition circuit according to claim **46**, wherein said lexical memories store said lexical data as Hidden Markov Models, and each processor performs the Viterbi search algorithm using a respective part of said lexical data.

68. A speech recognition method comprising:

receiving processed speech parameters;

storing lexical data for word recognition, said lexical data comprising a plurality of lexical tree data structures, each lexical tree data structure comprising a model of words having common prefix components, an initial component of each lexical tree data structure being unique;

passing the speech parameters in parallel to a plurality of lexical tree processors to perform parallel lexical tree processing for word recognition by accessing said lexical data;

storing processing results from said lexical tree processors and lexical tree identifiers to identify lexical trees to be processed by said lexical tree processors; and

controlling said lexical tree processors to process lexical trees identified by the stored identifiers by performing parallel processing on a plurality of said lexical tree data structures.

69. A speech recognition method comprising:

receiving processed speech parameters;

storing complete lexical data for word recognition in a plurality of lexical memory means, each lexical memory means containing part of said complete lexical data;

processing the speech parameters in parallel using a plurality of processors connected in parallel, said processors being arranged in groups of processors, each group of processors being connected to a said lexical memory means;

controlling each processor to process said speech parameters using partial lexical data read from a said lexical memory means; and

storing the results of the processing of the speech parameters from said processors.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 7,587,319 B2
APPLICATION NO. : 10/503463
DATED : September 8, 2009
INVENTOR(S) : Mark Catchpole

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the Title Page:

The first or sole Notice should read --

Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 1137 days.

Signed and Sealed this

Twenty-first Day of September, 2010

David J. Kappos

David J. Kappos
Director of the United States Patent and Trademark Office