US007313523B1

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

(10) **Patent No.: US 7,313,523 B1**
(45) **Date of Patent: Dec. 25, 2007**

(54) **METHOD AND APPARATUS FOR ASSIGNING WORD PROMINENCE TO NEW OR PREVIOUS INFORMATION IN SPEECH SYNTHESIS**

(75) Inventors: **Jerome R. Bellegarda**, Los Gatos, CA (US); **Kim E. A. Silverman**, Mountain View, CA (US)

(73) Assignee: **Apple Inc.**, Cupertino, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 856 days.

(21) Appl. No.: **10/439,217**

(22) Filed: **May 14, 2003**

(51) **Int. Cl.**
G10L 13/04 (2006.01)

(52) **U.S. Cl.** **704/268**; 704/9; 704/257

(58) **Field of Classification Search** ..... None
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,704,345 A * 11/1972 Coker et al. 704/266
4,908,867 A * 3/1990 Silverman 704/260
5,212,821 A * 5/1993 Gorin et al. 706/20
5,475,796 A * 12/1995 Iwata 704/260
5,652,828 A * 7/1997 Silverman 704/260
6,970,881 B1 * 11/2005 Mohan et al. 707/102
7,043,420 B2 * 5/2006 Ratnaparkhi 704/9
7,113,943 B2 * 9/2006 Bradford et al. 707/4
2004/0049391 A1 * 3/2004 Polanyi et al. 704/271

OTHER PUBLICATIONS

□□Digital Equipment Corporation, OpenVMS RTL DECtalk (DTK$) Manual, May 1993.*
Digital Equipment Corporation, "OpenVMS Software Overview", Dec. 1995.*
Harry Newton, "Newton's Telecom Dictionary," Flatiron Publishing, Mar. 1998, pp. 62, 155, 610-611, 771.*

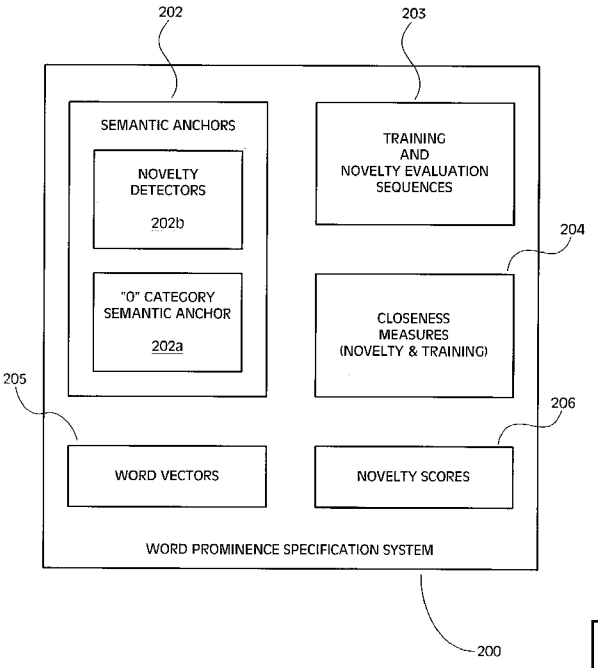
* cited by examiner

Primary Examiner—Donald L. Storm
(74) *Attorney, Agent, or Firm*—Blakely, Sokoloff, Taylor & Zafman LLP

(57) **ABSTRACT**

A method and apparatus is provided for generating speech that sounds more natural. In one embodiment, word prominence and latent semantic analysis are used to generate more natural sounding speech. A method for generating speech that sounds more natural may comprise generating synthesized speech having certain word prominence characteristics and applying a semantically-driven word prominence assignment model to specify word prominence consistent with the way humans assign word prominence. A speech representative of a current sentence is generated. The determination is made whether information in the current sentence is new or previously given in accordance with a semantic relationship between the current sentence and a number of preceding sentences. A word prominence is assigned to a word in the current sentence in accordance with the information determination.

25 Claims, 9 Drawing Sheets



Samsung v. Cerence
IPR2025-00459
Exhibit 1014

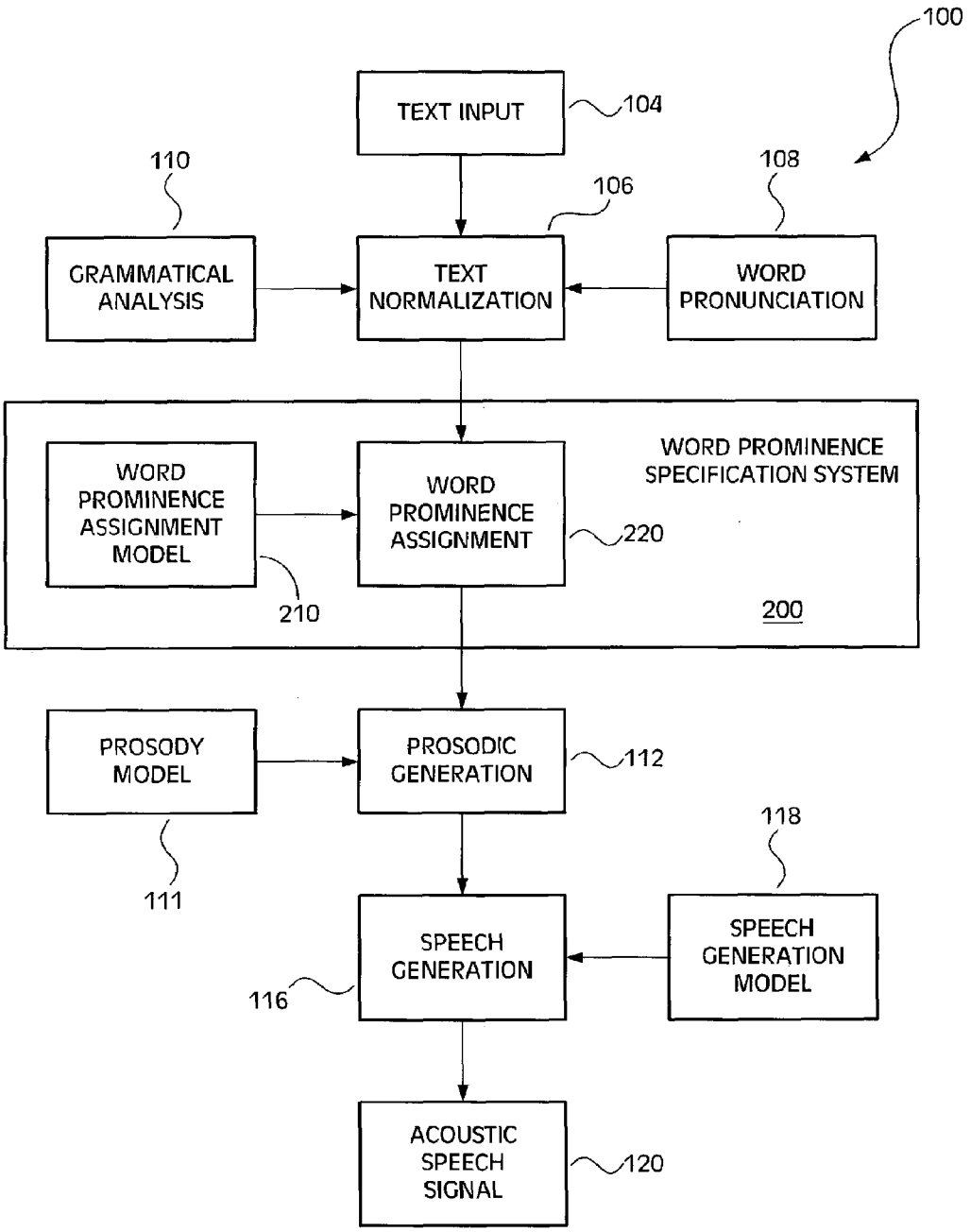

100
TEXT INPUT
104
110
108
106
GRAMMATICAL ANALYSIS
TEXT NORMALIZATION
WORD PRONUNCIATION
WORD PROMINENCE SPECIFICATION SYSTEM
WORD PROMINENCE ASSIGNMENT MODEL
WORD PROMINENCE ASSIGNMENT
220
210
200
PROSODY MODEL
PROSODIC GENERATION
112
118
111
SPEECH GENERATION
SPEECH GENERATION MODEL
116
ACOUSTIC SPEECH SIGNAL
120

FIG. 1

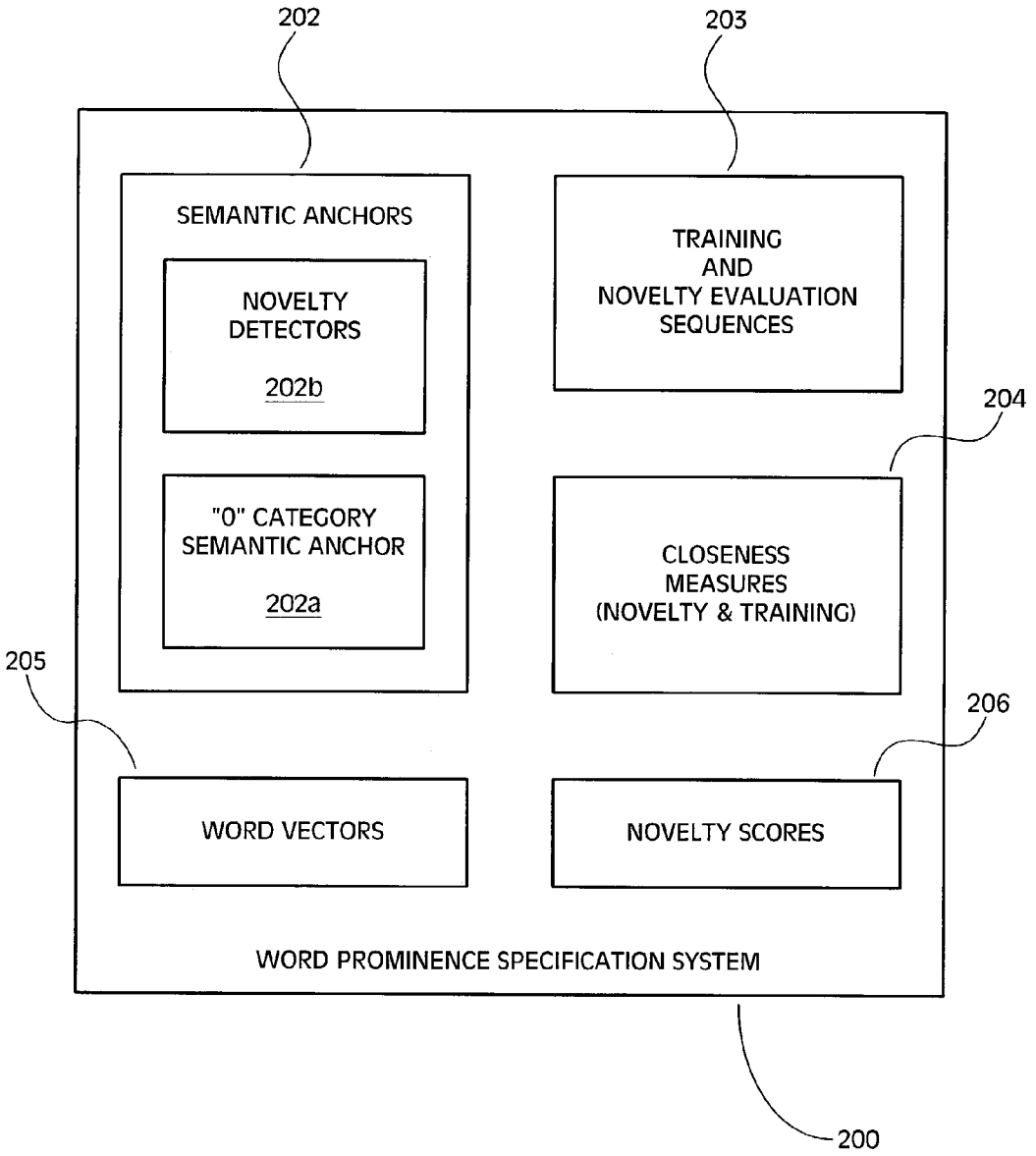

202
203
SEMANTIC ANCHORS
NOVELTY DETECTORS
202b
"0" CATEGORY SEMANTIC ANCHOR
202a
TRAINING AND NOVELTY EVALUATION SEQUENCES
204
CLOSENESS MEASURES (NOVELTY & TRAINING)
205
206
WORD VECTORS
NOVELTY SCORES
WORD PROMINENCE SPECIFICATION SYSTEM
200

FIG. 2

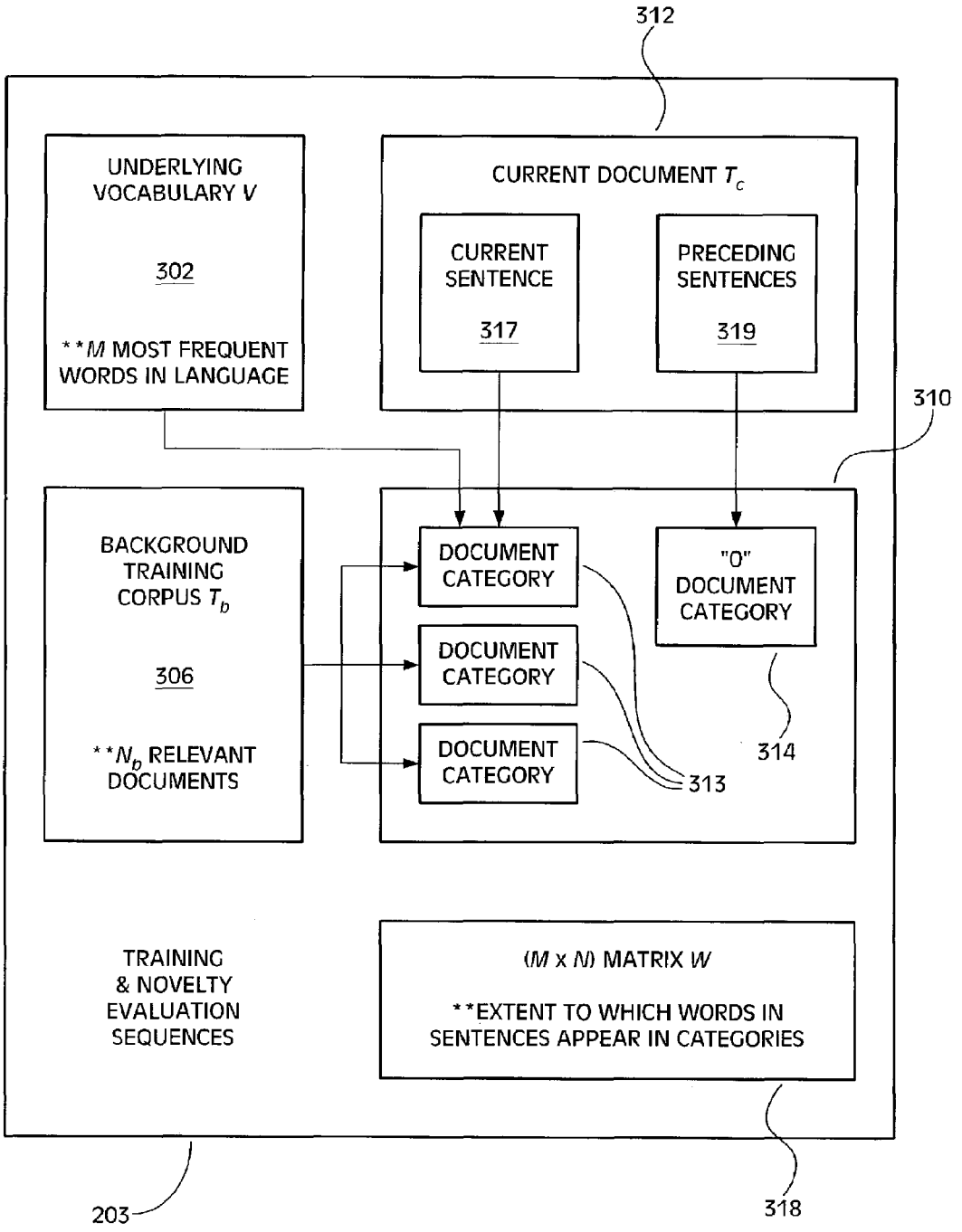

312
UNDERLYING VOCABULARY V
302
**M MOST FREQUENT WORDS IN LANGUAGE
CURRENT DOCUMENT T_c
CURRENT SENTENCE
317
PRECEDING SENTENCES
319
310
BACKGROUND TRAINING CORPUS T_b
306
**N_b RELEVANT DOCUMENTS
DOCUMENT CATEGORY
DOCUMENT CATEGORY
DOCUMENT CATEGORY
"0" DOCUMENT CATEGORY
314
313
TRAINING & NOVELTY EVALUATION SEQUENCES
(M x N) MATRIX W
**EXTENT TO WHICH WORDS IN SENTENCES APPEAR IN CATEGORIES
203
318

FIG. 3

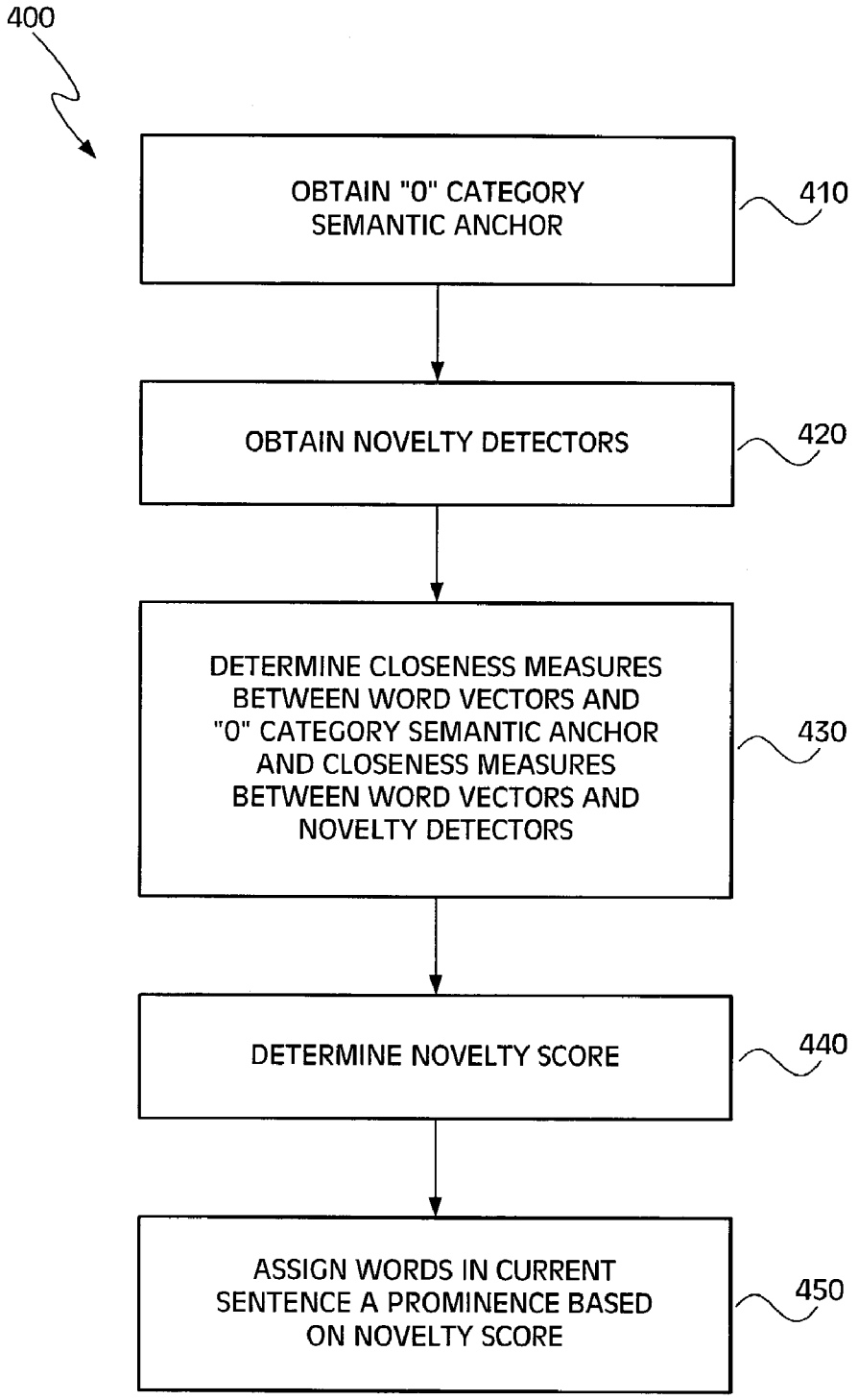

400
OBTAIN "0" CATEGORY SEMANTIC ANCHOR
410
OBTAIN NOVELTY DETECTORS
420
DETERMINE CLOSENESS MEASURES BETWEEN WORD VECTORS AND "0" CATEGORY SEMANTIC ANCHOR AND CLOSENESS MEASURES BETWEEN WORD VECTORS AND NOVELTY DETECTORS
430
DETERMINE NOVELTY SCORE
440
ASSIGN WORDS IN CURRENT SENTENCE A PROMINENCE BASED ON NOVELTY SCORE
450

FIG. 4

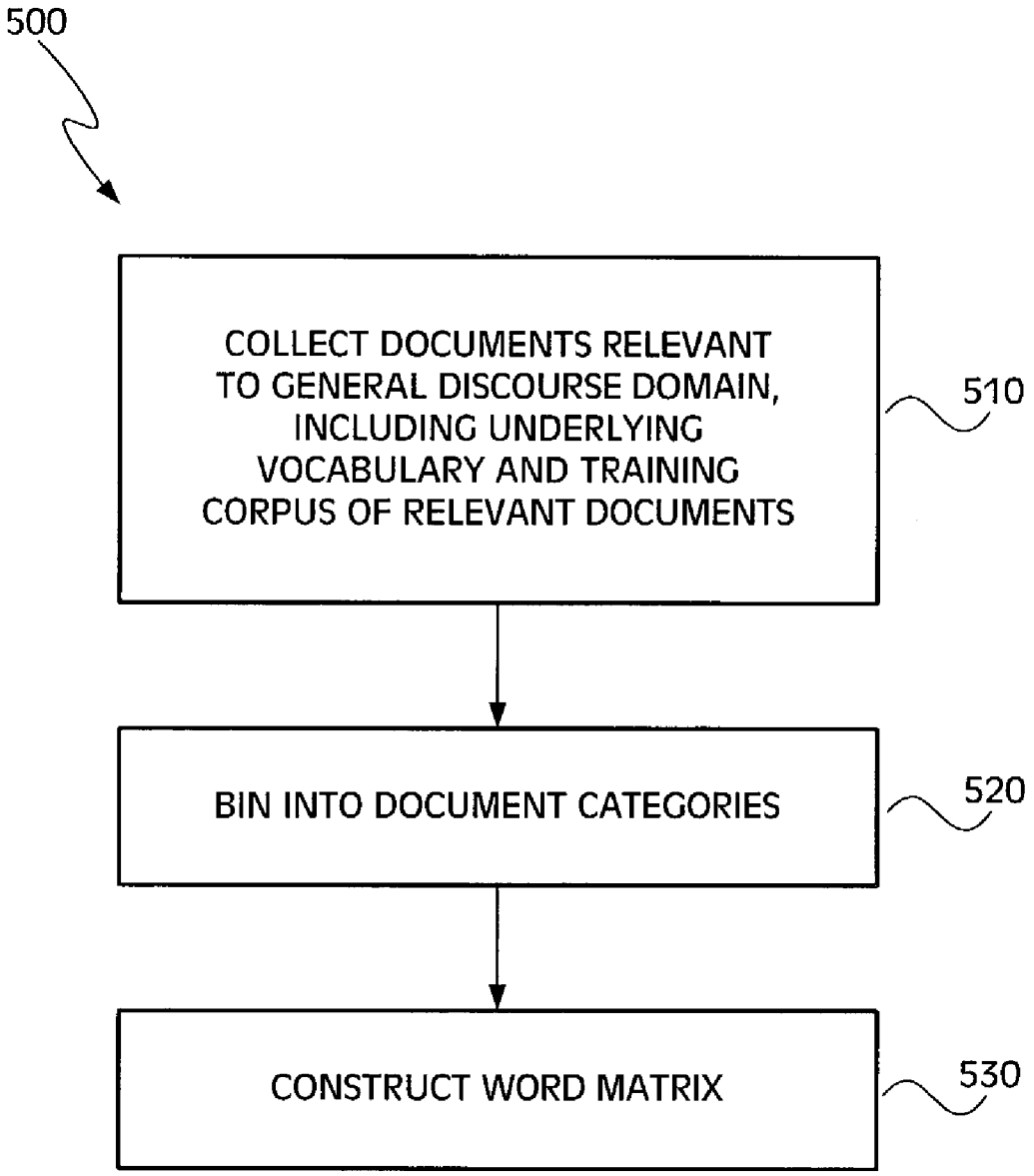

500
COLLECT DOCUMENTS RELEVANT TO GENERAL DISCOURSE DOMAIN, INCLUDING UNDERLYING VOCABULARY AND TRAINING CORPUS OF RELEVANT DOCUMENTS
510
BIN INTO DOCUMENT CATEGORIES
520
CONSTRUCT WORD MATRIX
530

FIG. 5

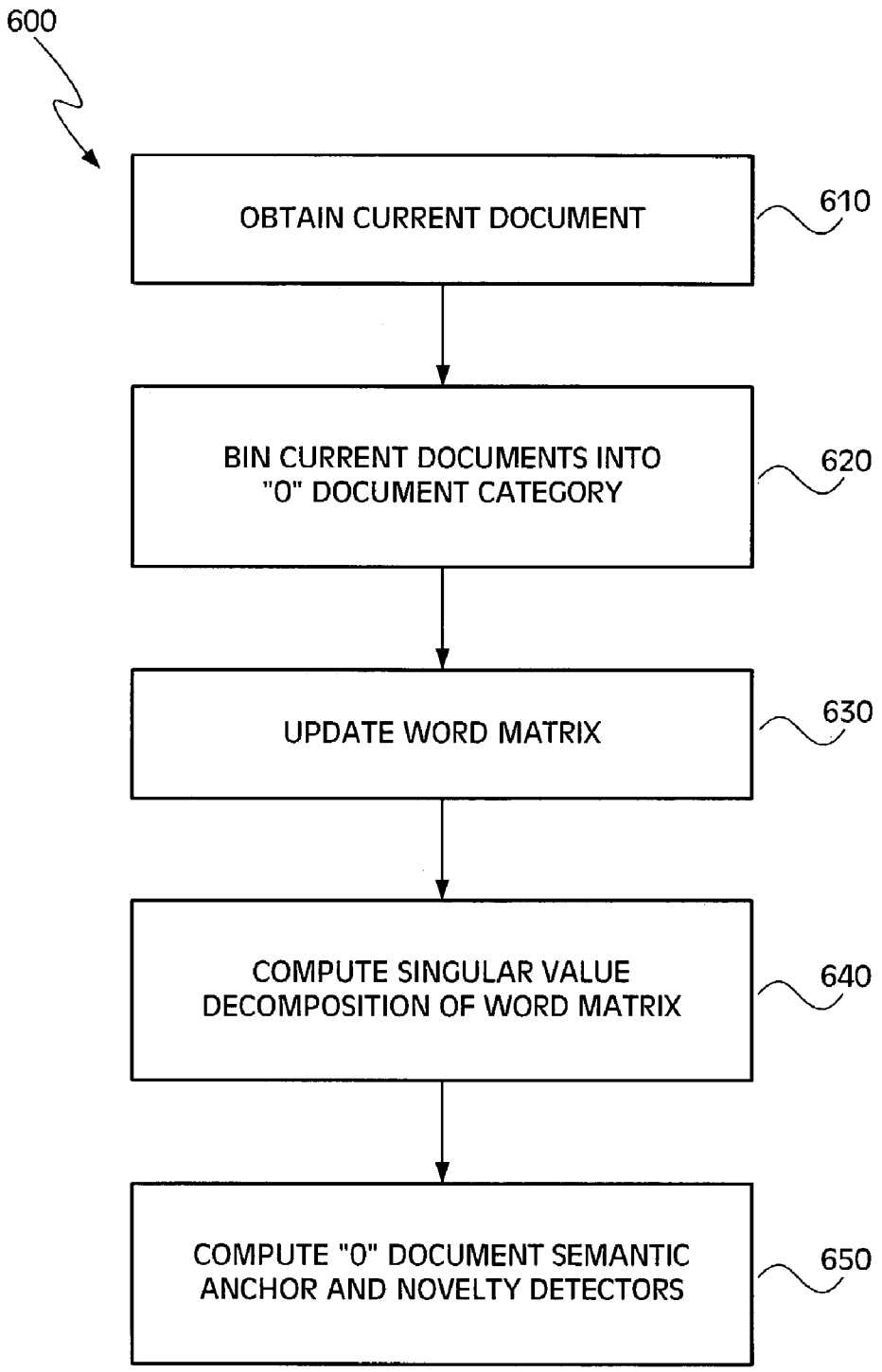

600
OBTAIN CURRENT DOCUMENT
610
BIN CURRENT DOCUMENTS INTO "0" DOCUMENT CATEGORY
620
UPDATE WORD MATRIX
630
COMPUTE SINGULAR VALUE DECOMPOSITION OF WORD MATRIX
640
COMPUTE "0" DOCUMENT SEMANTIC ANCHOR AND NOVELTY DETECTORS
650

FIG. 6

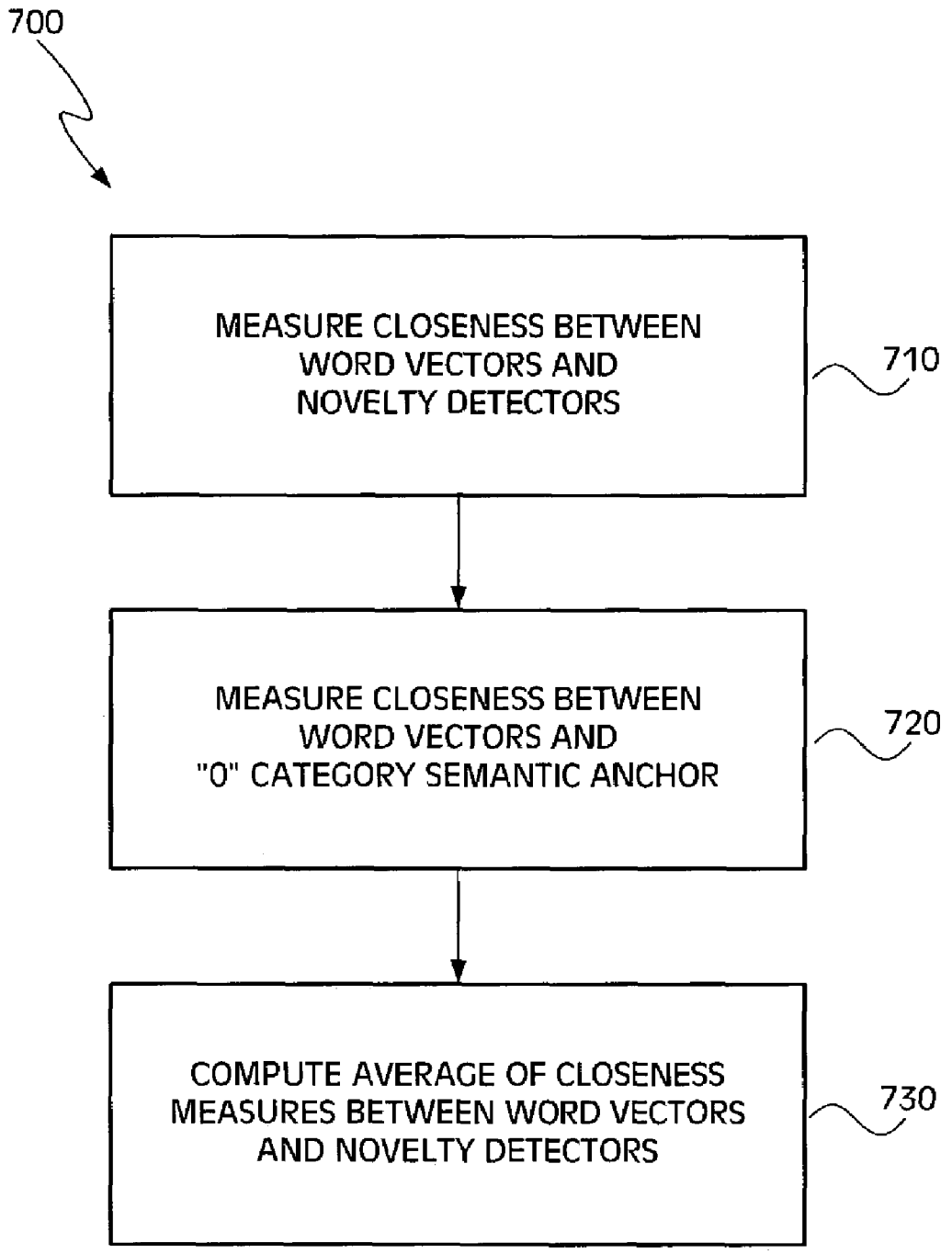

700
MEASURE CLOSENESS BETWEEN WORD VECTORS AND NOVELTY DETECTORS
710
MEASURE CLOSENESS BETWEEN WORD VECTORS AND "0" CATEGORY SEMANTIC ANCHOR
720
COMPUTE AVERAGE OF CLOSENESS MEASURES BETWEEN WORD VECTORS AND NOVELTY DETECTORS
730

FIG. 7

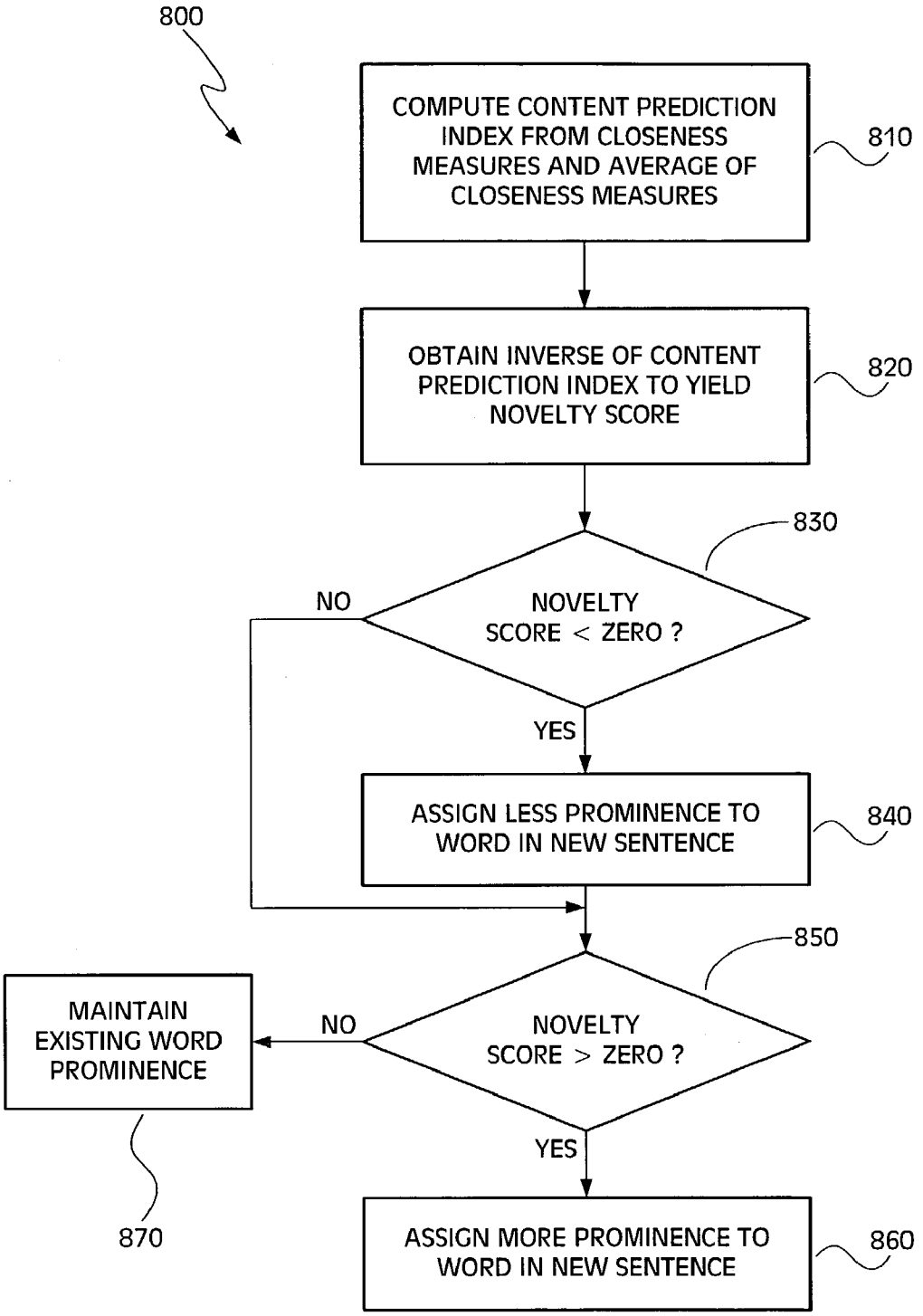

800
COMPUTE CONTENT PREDICTION INDEX FROM CLOSENESS MEASURES AND AVERAGE OF CLOSENESS MEASURES
810
OBTAIN INVERSE OF CONTENT PREDICTION INDEX TO YIELD NOVELTY SCORE
820
830
NOVELTY SCORE < ZERO ?
NO
YES
ASSIGN LESS PROMINENCE TO WORD IN NEW SENTENCE
840
850
NOVELTY SCORE > ZERO ?
NO
MAINTAIN EXISTING WORD PROMINENCE
870
YES
ASSIGN MORE PROMINENCE TO WORD IN NEW SENTENCE
860

FIG. 8

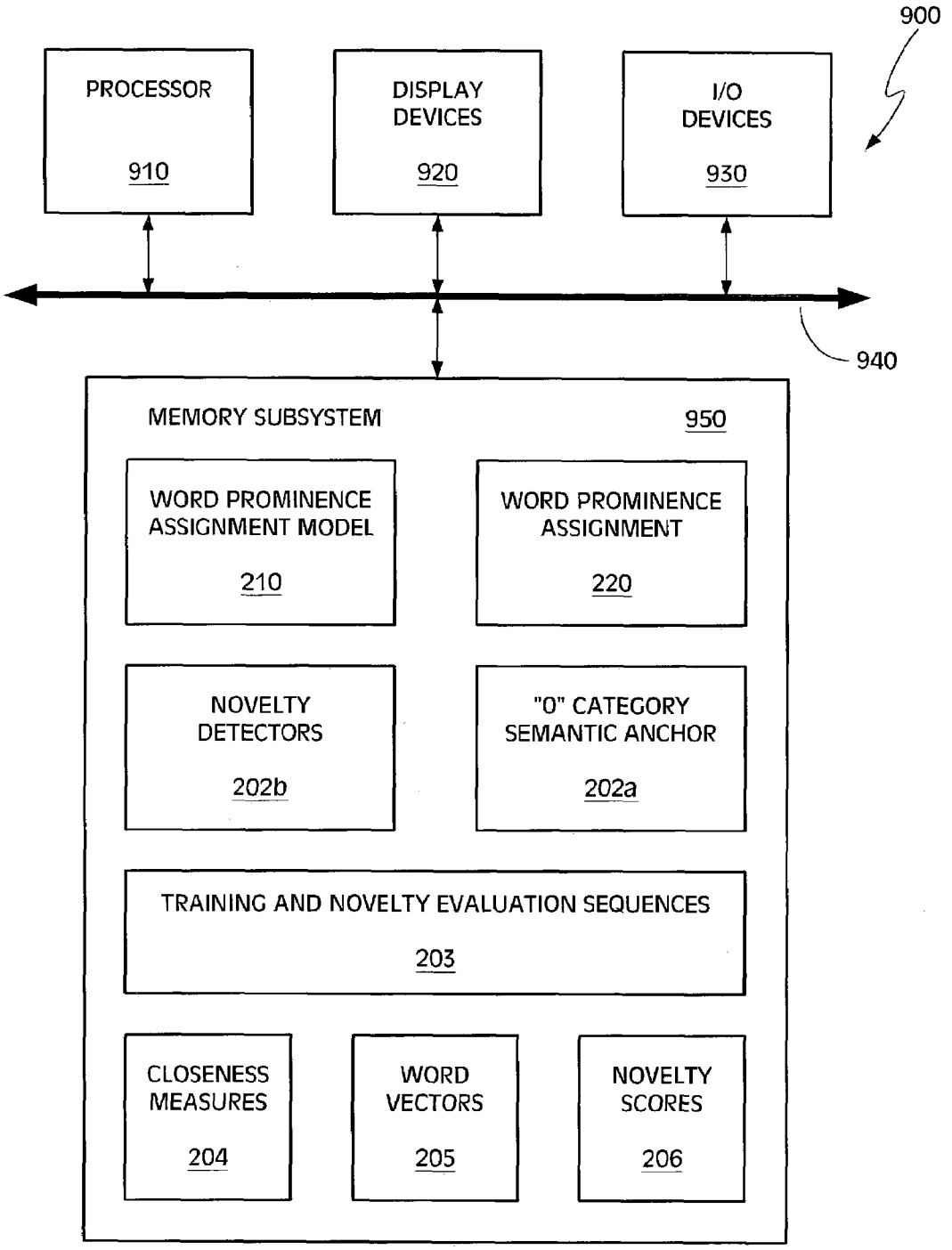

900
PROCESSOR
910
DISPLAY DEVICES
920
I/O DEVICES
930
940
MEMORY SUBSYSTEM
950
WORD PROMINENCE ASSIGNMENT MODEL
210
WORD PROMINENCE ASSIGNMENT
220
NOVELTY DETECTORS
202b
"0" CATEGORY SEMANTIC ANCHOR
202a
TRAINING AND NOVELTY EVALUATION SEQUENCES
203
CLOSENESS MEASURES
204
WORD VECTORS
205
NOVELTY SCORES
206

FIG. 9

METHOD AND APPARATUS FOR ASSIGNING WORD PROMINENCE TO NEW OR PREVIOUS INFORMATION IN SPEECH SYNTHESIS

FIELD OF THE INVENTION

The present invention relates generally to speech synthesis systems. More particularly, this invention relates to generating variations in synthesized speech to produce speech that sounds more natural.

COPYRIGHT NOTICE/PERMISSION

A portion of the disclosure of this patent document contains material that is subject to copyright protection. The copyright owner has no objection to the facsimile reproduction by anyone of the patent document or the patent disclosure as it appears in the Patent and Trademark Office patent file or records, but otherwise reserves all copyright rights whatsoever. The following notice applies to the software and data as described below and in the drawings hereto: Copyright© 2002, Apple Computer, Inc., All Rights Reserved.

BACKGROUND

Speech is used to communicate information from a speaker to a listener. In a computer-user interface, the computer generates synthesized speech to convey an audible message to the user rather than just displaying the message as text with an accompanying "beep." There are several advantages to conveying audible messages to the computer user in the form of synthesized speech. In addition to liberating the user from having to look at the computer's display screen, the spoken message conveys more information than the simple "beep" and, for certain types of information, speech is a more natural communication medium. Speech synthesis may also be useful in bulk output applications (e.g., reading aloud a document).

Generating natural sounding synthesized speech has long been the ultimate challenge for text-to-speech (TTS) systems. Not only is naturalness more aesthetically pleasant, but it affects intelligibility as well. The more closely synthetic speech models natural speech, the more richly and redundantly the content and structure of the information will be represented in the acoustic signal. This in turn means that it will be easier for the listener to recover the intended meaning from the signal—i.e., the cognitive load associated with this task will be lower. Consequently, the task of understanding the speech will interfere less with other tasks the user is performing when using the computer system. More natural TTS will thereby support a wider range of applications.

One important component of naturalness in synthesized speech is generating the correct prominence contour for each spoken sentence. As used herein, the phrase "prominence contour" refers to the relative perceptual salience or emphasis of each of the words in each spoken sentence. This is sometimes described as some words being intentionally spoken in such a way as to stand out to the listener more than other words in the same sentence. In natural speech, more or less prominence is assigned to the different words of a sentence depending on a variety of factors, including word type (e.g., function word or content word), syntactic category (e.g., noun or verb), and the semantic role (e.g., the difference between "French teachers" meaning people who teach the French language, regardless of where they come

from—versus "French teachers"—meaning teachers of any subject who happen to come from France). These factors are lexical properties of the words or noun compounds, and can usually be found in a dictionary. However, a more important function of the relative prominence of words in a sentence is to convey how the overall information is structured, and how the concepts that are conveyed by the individual words relate to each other and to the overall contextual meaning of the message as a whole. One particularly important role of relative prominence is to convey whether a word is introducing a new concept to the current discourse, or whether it is merely referring to a concept that has already been introduced earlier in the discourse. This role is often referred to as "given versus new" information. In synthesized speech (or, for that matter, natural speech), if any word is assigned the wrong prominence, the spoken sentence becomes distorted, resulting in anything from a mildly misleading change in emphasis, to the distraction of a complete shift in meaning, to the perception of a foreign accent, to an unnatural delivery affecting understandability, and thereby interfering with usability of the technology. For this reason the perceived quality of text-to-speech (TTS) systems is heavily dependent on word prominence assignment.

Most existing TTS systems use simple rules to carry out word prominence assignment. For example, function words (such as "the," "for," or "in") are not, ordinarily, emphasized; all other things being equal, nouns are assigned more prominence than verbs; and, in some recent and more sophisticated systems, new information is accentuated more than information that was previously given. In the vast majority of cases, the first two rules are easily implemented, as it is straightforward to devise a list of function words, and only slightly more challenging to maintain a list of possible parts of speech for each word. It is, however, considerably more difficult in practice to determine what constitutes "new" versus "given" information.

Some of the most recent state-of-the-art TTS systems use a simple rule for prominence assignment: give less prominence to those words that have already been seen in previous sentences (within some well-defined domain such as a paragraph, discourse segment, or document), because they refer to "given" information. However, even words that have not already been seen in previous sentences may refer to given information. What constitutes given information is more accurately measured in terms of the underlying concepts to which the words refer, rather than merely whether the words have already been seen. Since many different words can be used to express the same concept, once a concept has been introduced, all words referring to the concept should be assigned less prominence, and not just the previously used word. Determining which words express the same concept involves not only words that are synonyms, but more generally, words that are semantically related to one another. To better understand the distinction between synonyms and semantically related words, consider the following question "Has John read Lord of the Rings?" and the accompanying answer "John doesn't read books." The word "books" has little or no prominence in this context because it is semantically related to (although not a synonym for) "Lord of the Rings." If this answer were not preceded by the above question, then "books" would have greater prominence. Determining which words are semantically related is, however, very complex due to the multi-faceted nature of semantic relationships.

For example, recited below are two versions of a simple dialog with the same answer:

Why did you decide to spend your vacation in Tennessee?

(1)

My mama lives in Memphis.

(2)

and

You're gonna visit your mother when you're in Nashville?

(3)

My mama lives in Memphis.

(4)

Using the simple rules of word prominence, a prior art TTS system would generate the words mama and Memphis in both sentences (2) and (4) with about the same prominence, since neither mama nor Memphis are present in the previous sentences (1) and (3). In natural speech, however, mama and Memphis are spoken with about the same prominence only in sentence (2), while in sentence (4) mama is spoken with markedly less prominence than Memphis. This phenomenon is explained in terms of which words represent "new" information and which do not. In both sentences (2) and (4), Memphis is not only semantically related to a word in the preceding question, Tennessee or Nashville, but also adds new information (the exact location in the first answer, and the correct location in the second answer). In contrast, mama in sentence (4) is semantically related to the word mother in (3), but adds no new information since mama is a strict synonym for mother. Thus, in natural speech, the word mama is treated as a representative of a previously given concept and, accordingly, is spoken with comparatively less prominence.

The challenge, therefore, is to provide a principled way to obtain a semantically-driven prominence assignment that is consistent with the way humans assign word prominence in natural speech, in order to more redundantly convey meanings and, therefore, to generate synthesized text that is more easily understood. Doing so should result in a more natural-sounding synthetic speech with a perceptively better quality than provided by prior art TTS systems.

SUMMARY

A method and apparatus for generating speech that sounds more natural are described. According to one aspect of the present invention, a method for generating speech that sounds more natural comprises generating synthesized speech having certain word prominence characteristics and applying a semantically-driven word prominence assignment model to assign word prominence characteristics consistent with the way humans assign word prominence. In one embodiment, the word prominence assignment model employs latent semantic analysis.

According to one aspect of the invention, as each new sentence in a text to speech generator is generated, a word prominence specification system develops a word prominence assignment model by determining semantic anchors representing the preceding sentences and semantic anchors representing the general discourse domain. The word prominence specification system classifies each word in the current sentence against the semantic anchors, and obtains an appropriate score to characterize the "novelty" of the words in the current and preceding sentences in view of the general discourse domain, i.e., to characterize which information in the current sentence is new.

According to one aspect of the present invention, a machine-accessible medium has stored thereon a plurality of instructions that, when executed by a processor, cause the processor to generate synthesized speech having certain word prominence characteristics and apply a semantically-driven word prominence assignment model to assign word prominence characteristics consistent with the way humans assign word prominence. The instructions, when executed, may cause the processor to create synthesized speech by developing a word prominence assignment model including semantic anchors associated with the current and preceding sentences and the general discourse domain. The instructions may further cause the processor to determine whether a word in the current sentence represents new information by applying the model to a current sentence to classify each word against the semantic anchors.

According to one aspect of the present invention, an apparatus to generate speech that sounds more natural includes a speech synthesizer to generate synthesized speech and a semantically-driven word prominence assignment model to assign word prominence characteristics consistent with the way humans assign work prominence. The word prominence assignment model may include semantic anchors associated with the current and preceding sentences and the general discourse domain. The model may then be applied to a current sentence to classify each word of the sentence against the semantic anchors.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram illustrating one embodiment of a speech synthesis system having a word prominence specification system.

FIG. **2** is a block diagram illustrating one embodiment of the word prominence specification system of FIG. **1**.

FIG. **3** is a block diagram illustrating one embodiment of the training and evaluation sequences of FIG. **2**.

FIG. **4** is a flow diagram illustrating an embodiment of a method for word prominence assignment, as may be performed by the word prominence specification system illustrated in FIGS. **1-3**.

FIG. **5** is a flow diagram illustrating an embodiment of a method for semantic anchor training, as may be performed by the word prominence specification system illustrated in FIGS. **1-3**.

FIG. **6** is a flow diagram illustrating an embodiment of a method for determining semantic anchors, as may be performed by the word prominence specification system illustrated in FIGS. **1-3**.

FIG. **7** is a flow diagram illustrating an embodiment of a method for closeness measurement processing, as may be performed by the word prominence specification system illustrated in FIGS. **1-3**.

FIG. **8** is a flow diagram illustrating an embodiment of a method for novelty score processing, as may be performed by the word prominence specification system illustrated in FIGS. **1-3**.

FIG. **9** is a block diagram of one embodiment of a computer system in which the word prominence specification system of FIGS. **1-3** may be implemented.

DETAILED DESCRIPTION

A method and an apparatus for assigning word prominence in a speech synthesis system to produce more natural sounding speech are provided. In the following description, for purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of the present invention. It will be evident, however, to one skilled

in the art that the present invention may be practiced without these specific details. In other instances, well-known structures and devices are shown in block diagram form in order to avoid unnecessarily obscuring the present invention.

FIG. **1** is a block diagram illustrating one embodiment of a speech synthesis system **100** incorporating the invention, and the operating environment in which certain aspects of the illustrated invention may be practiced. The speech synthesis system **100** receives a text input **104** and performs a text normalization on the text input **104** using grammatical analysis **110** and word pronunciation **108** processes. For example if the text input **104** is the phrase "½," the text is normalized to the phrase "one half," pronounced as "wUHn hAHf." In one embodiment, the speech synthesis system **100** performs prosodic generation **112** for the normalized text using a prosody model **111**. A speech generator **116** generates an acoustic speech signal **120** for the normalized text that embodies the prosodic features representative of the received text **104** in accordance with a speech generation model **118**.

The TTS **100** incorporates a word prominence specification system **200** in accordance with one embodiment of the present invention. The word prominence specification system **200** applies word prominence assignment **220** to the normalized text using a word prominence assignment model **210**. During operation of the TTS **100**, the word prominence specification system **200** assigns word prominence characteristics to the normalized text to enable the generation of a more naturalized acoustic speech signal **120**.

The two versions of the simple dialog discussed earlier underscores what is of concern in TTS synthesis: not just whether the same words appear again and again, but how "close" new words are to concepts already introduced in the preceding sentences. Sentence (1) introduced the two concepts "vacation" and "Tennessee," and sentence (3) introduced the two concepts "mother" and "Nashville." In terms of concepts, the word "mama" is much farther from sentence (1) than from sentence (3), while the word "Memphis" is about equally far from (1) and from (3). Thus, there appears to be a tight correlation between word prominence and distance from existing concepts. The closer a word is to a concept that has already been introduced earlier into the dialogue, the less prominence that word should receive.

The disclosed embodiments include apparatus and methods for quantifying this distance from existing concepts, such that an appropriate prominence can be assigned to each word of synthesized speech. When a sentence is generated—i.e., a "current sentence"—a semantic relationship between this sentence and a number of preceding sentences may be used to determine whether information in the current sentence is new or was previously given. Based on this determination of "new" versus "given" information, a word prominence may be assigned to one or more words in the current sentence. In one embodiment, as described in more detail below, latent semantic analysis (LSA) is employed to quantify this distance from existing concepts in order to determine whether information is new or previously given. However, it should be understood that a variety of other techniques besides LSA may be employed to assess whether information is "new" or "given." For example, in one alternative embodiment, each new word is considered a candidate for prominence, and a list of previously spoken words is maintained in a FIFO (first-in-first-out) buffer having a specified depth. If a current word is already in the FIFO buffer, no accent is applied to the word when spoken, but if the word is not in the buffer (i.e., the current word is a "new" word), prominence is applied to the word. In either event, the current word is placed at the "top" of the FIFO buffer, as the word is the most recent spoken word. Because the FIFO buffer has a set depth, words that are "old" are pushed out of the buffer. In a further alternative embodiment, in addition to the list of recently spoken words stored in the FIFO buffer, each word is also compared against synonyms of the words contained in the FIFO buffer. In yet another alternative embodiment, the comparison is based on word roots (e.g., word roots are stored in the FIFO buffer in addition to, or in lieu of, the recently spoken words).

In one embodiment, as noted above, the word prominence specification system **200** carries out latent semantic analysis (LSA) of the current sentence in view of the preceding sentences. LSA is known in the art, and has already proven effective in a variety of other fields, including query-based information retrieval, word clustering, document/topic clustering, large vocabulary language modeling, and semantic inference for voice command and control. In the present invention, LSA may be used to characterize what constitutes "new" versus "given" information in a document, where a document is defined as a collection of words and sentences.

FIG. **2** is a block diagram illustrating a generalized embodiment of selected components of the word prominence specification system **200** that may be used in the TTS **100** of FIG. **1**. The selected components include semantic anchors **202**, training and novelty evaluation sequences **203**, a closeness measure **204**, word vectors **205**, and a novelty score **206**. The word prominence specification system **200** employs a plurality of semantic anchors **202**, including one semantic anchor that represents the centroid of all preceding sentences in the current document of interest, also referred to herein as the "0" category semantic anchor **202***a*, and numerous other semantic anchors representing centroids relevant to the general discourse domain, which are referred to herein as the novelty detectors **202***b*.

In one embodiment, the "0" category semantic anchor **202***a* and novelty detectors **202***b* are determined automatically after the addition of the current sentence to the preceding sentences in the current document of interest. Using the closeness measures **204**, a plurality of word vectors **205**, one for each word in the current sentence, is classified against the "0" category semantic anchor **202***a* and the novelty detectors **202***b*, and an appropriate novelty score **206** is obtained to characterize the "novelty" of each word to the current document so far, in view of the general discourse domain, i.e., whether the word represents new information or previously given information (or is neutral).

When the novelty score **206** is high enough, then the word prominence specification system **200** assigns a corresponding word prominence, such that the word represented by the word vector **205** is suitably emphasized when generating the acoustic speech signal **120**. Otherwise, the word prominence specification system **200** assigns a word prominence so that the word represented by the word vector **205** is suitably de-emphasized. The word prominence specification system **200** may be configured so that it operates completely automatically and requires no input from the user.

It should be noted that the emphasis or de-emphasis of the words represented by the word vectors **205** could be accomplished in a number of ways, some of which may be known in the art, without departing from the scope of the present invention. For example, in one embodiment, the TTS **100** may emphasize (or de-emphasize) words by altering the prosodic generation **112** in accordance with the prosody model **111**, including altering the pitch, volume, and phoneme duration of the resulting acoustic speech signal **120**, as is known in the art.

FIG. **3** is a block diagram illustrating an embodiment of training and novelty evaluation sequences **203**. The training and novelty evaluation sequences **203** are used, according to one embodiment, to determine the semantic anchors **202** and to evaluate novelty **206**. Components of training and novelty evaluation sequences **203** includes underlying vocabulary V **302**, background training corpus T_b **306**, document categories **310**, current document T_c **312**, and a matrix W **318**, all of which are explained in greater detail below. The document categories **310** includes a number N_1 of document categories **313** and an additional document category, which is referred to herein as the "0" document category **314**.

The underlying vocabulary V **302** comprises the M most frequent words in the language. The background training corpus T_b **306** comprises a collection of N_b documents relevant to the general discourse domain, binned into the document categories **313** during training the word prominence specification system **200**. In one embodiment, the collection of N_b documents may be binned randomly into the number N_1 of document categories **313**. In a typical embodiment, the number M of the most frequent words in the language and the number of relevant documents N_b are on the order of several thousands, while the number N_1 of the document categories **313** is typically less than 10.

In one embodiment, the current document so far T_c **312** comprises the current sentence **317** and the preceding sentences **319** to the current sentence **317**. The current sentence **317**, which is first evaluated word by word against all existing categories **310** (**313** and **314**), is binned into the "0" document category **314** prior to processing of the next sentence. The preceding sentences **319** are binned into "0" document category **314**. The total number N of document categories **310** in T is denoted as $N=N_1+1\leqq 10$, where T is the union of the background training corpus T_b **306** and the current document so far T_c **312**, which is denoted as $T=T_b\cup T_c$.

The (M×N) matrix W **318** comprises entries w_{ij} that suitably reflect the extent to which each word $w_i\epsilon V$ appears in each document category **313/314**. A reasonable expression for w_{ij} is:

$$w_{ij} = (1-\varepsilon_i)\frac{c_{ij}}{n_j}, \tag{5}$$

where c_{ij} is the number of times w occurs in category j, n_j is the total number of words present in this category, and ϵ_i is the normalized entropy of w_i in the corpus T.

For each word w_i, defining t_i as the sum of c_{ij} over all possible document categories, which is represented by:

$$t_i = \sum_{j=1}^{N} c_{ij} \tag{6}$$

where t_i represents the total number of times the word wi occurs in the entire corpus. The normalized entropy ϵ_i may then be determined as follows:

$$\varepsilon_i = \frac{-1}{\log N}\sum_{j=1}^{N}\frac{c_{ij}}{t_i}\log\left(\frac{c_{ij}}{t_i}\right) \tag{7}$$

where

$$0\leqq\epsilon_i\leqq 1 \tag{8}$$

with equality occurring when $c_{ij}=t_i$ and $c_{ij}=t_i/N$, respectively. A value of ϵ_i close to 1 indicates that a word is distributed across many documents throughout the corpus, whereas a value of ϵ_i close to 0 indicates that the word is present in just a few documents.

Thus, the term $(1-\epsilon_i)$, which may be referred to as a "global weight," can be viewed as a measure of the indexing power of the word w_i. This global weighting implied by $(1-\epsilon_i)$, reflects the fact that two words appearing with the same count in a particular category **313/314** do not necessarily convey the same amount of information; this is subordinated to the distribution of the words in the entire collection T.

To obtain the "0" category semantic anchor **202***a* and novelty detectors **202***b* from the above-described components in FIG. **3**, the word prominence specification system **200** performs a singular value decomposition (SVD) of matrix W **318** as follows:

$$W=USV^T, \tag{9}$$

where U is the (M×N) left singular matrix with row vectors $u_i(1\leqq i\leqq M)$, S is the (N×N) diagonal matrix of N singular values $s_1\geqq s_2\geqq \ldots \geqq s_N\geqq 0$, V is the (N×N) right singular matrix with row vectors $v_j(1\leqq j\leqq N)$, and superscript ^{T} denotes matrix transposition. This (rank−N) decomposition defines a mapping between:

(i) the set of words in the underlying vocabulary V **302** and, after appropriate scaling by the singular values, the N-dimensional vector $\bar{u}_i=u_iS^{1/2}$ $(1\leqq i\leqq M)$, and

(ii) the set of words in the current document so far T_c **312**, including the preceding sentences **319** and the current sentence **317**, and, again after appropriate scaling by the singular values, the N-dimensional vectors

$$\bar{v}_j=v_jS^{1/2}(1\leqq j\leqq N).$$

The former vectors $\bar{u}_i$ **205** each represent a particular word in the underlying vocabulary V **302**. The latter vectors $v_j(j\neq 0)$ are the "novelty" detectors **202***b* (i.e., the semantic anchors **202** associated with the N_1 document categories **313** after binning the current sentence **317** of the current document so far T_c **312**). By convention, the vector representing the "0" category semantic anchor **202***a* (of the current document so far T_c **312**) associated with all of the words in the preceding sentences **319**, is referred to as $\bar{v}_o$.

The mapping defined above by equation (9) and the accompanying text has a semantic nature since the relative positions of the word vectors **205** and the semantic anchors **202***a-b* is determined by the overall pattern of the language used in all of the documents represented in T, as opposed to the specific words or constructs. Hence, a word vector $\bar{u}_i$ **205** that is "close" (in some suitable metric) to the "0" category semantic anchor **202***a* $\bar{v}_o$ is likely to represent a word that is semantically related to the words in the "0" document category **314** (i.e., the words in the current document so far T_c **312**), while a word vector **205** that is "close" to one or more of the novelty detectors **202***b* $\bar{v}_j(j\neq 0)$, is likely to represent a word that is semantically related to words in one of the other N_1 document categories **313**. When semantically related to the words in the current document so far T_c **312**, the word likely represents given information, whereas when semantically related to the words in the other N_1 document categories **313**, the word likely represents new information. Thus, the "0" category semantic anchor **202***a*, novelty detectors **202***b*, and word vectors **205**, operating together, offer a basis for determining the "novelty" of a word in the current sentence **317**, given the current document so far T_c **312**.

To determine the "novelty" of a word, the word prominence specification system **200** defines an appropriate "closeness measure" 204 to compare the word vectors $\overline{u}_i$ **205** to the semantic anchors **202** (i.e., "0" category semantic anchor **202***a* $\overline{v}_o$ and novelty detectors **202***b* $\overline{v}_j$). In one embodiment, a natural metric to consider for the closeness measure **204** is the cosine of the angle between word vectors **205** and the semantic anchors **202***a-b*, as follows:

$$K(\overline{u_i}, \overline{v_j}) = \cos(u_i S^{1/2}, v_j S^{1/2}) = \frac{u_i S v_i^T}{\|u_i S^{1/2}\| \|v_j S^{1/2}\|}, \tag{10}$$

for $1 \leqq i \leqq M$ and $1 \leqq j \leqq N$.

Using the equation in (10), it would be possible to classify each word in the current sentence by assigning it to the category **313**/**314** associated with the maximum similarity. However, the closest category does not reveal the closeness of a word in a current sentence **317** to the current document so far T_c **312**. The closeness of the words in the current sentence **317** to the current document so far T_c **312** is represented by the closeness measures **204** of the word vectors $\overline{u}_i$ to the "0" category semantic anchor **202***a* $\overline{v}_o$ associated with the "0" category **314**. This can be determined through the use of a novelty score **206**.

The word prominence specification system **200** compares the closeness measure **204** associated with the "0" document category **314** of the current document so far T_c **312** with the average closeness measure **204** associated with the other N_1 categories **313**. In one embodiment, the word prominence specification system **200** accomplishes the comparison by defining a content prediction index $P(\overline{u}_i)$ **208** for the word vector $\overline{u}_i$ as follows:

$$P(\overline{u_i}) = \frac{K(\overline{u_i}, \overline{v_o})}{\frac{1}{N}\sum_{j=1}^{N} K(\overline{u_i}, \overline{v_j})} \tag{11}$$

The higher the content prediction index $P(\overline{u}_i)$ **208**, the more predictable the word represented by word vector $\overline{u}_i$ is, given the current document so far T_c **312**. In one embodiment, the word prominence specification system **200** defines the novelty score $N(\overline{u}_i)$ **206** as inversely proportional to the content prediction index $P(\overline{u}_i)$ **208**, as follows:

$$N(\overline{u_i}) \approx \frac{1}{P(\overline{u_i})} \tag{12}$$

When C denotes the set of all content words (as opposed to the words of the underlying vocabulary V **302**) in the sentence, then the following equation defines the novelty score $N(\overline{u}_i)$ **206**:

$$N(\overline{u_i}) = \frac{1}{1 - \frac{P(\overline{u_1})}{\frac{1}{|C|}\sum_{k \in C} P(\overline{u_k})}} \tag{13}$$

Generally, as used herein, a "content word" is any word which is not a function word (again, function words include words such as "the," "for," and "in," as noted above).

The novelty score $N(\overline{u}_i)$ **206** is interpreted as follows. If $N(\overline{u}_i)<0$, the word associated with word vector $\overline{u}_i$ should be assigned less prominence than would have otherwise been the case. On the other hand, if $N(\overline{u}_i)>0$, the word should be assigned more prominence.

Turning now to FIGS. **4-8**, the particular methods of the invention are described in terms of computer software with reference to a series of flowcharts. The methods to be performed by a computer constitute computer programs made up of computer-executable instructions. Describing the methods by reference to a flowchart enables one skilled in the art to develop such programs including such instructions to carry out the methods on suitably configured computers (the processor of the computer executing the instructions from computer-accessible media). The computer-executable instructions may be written in a computer programming language or may be embodied in firmware logic. If written in a programming language conforming to a recognized standard, such instructions can be executed on a variety of hardware platforms and for interface to a variety of operating systems. In addition, the present invention is not described with reference to any particular programming language. It will be appreciated that a variety of programming languages may be used to implement the teachings of the invention as described herein. Furthermore, it is common in the art to speak of software, in one form or another (e.g., program, procedure, process, application . . .), as taking an action or causing a result. Such expressions are merely a shorthand way of saying that execution of the software by a computer causes the processor of the computer to perform an action or a produce a result.

FIG. **4** is a flow diagram illustrating an embodiment of a method **400** for word prominence assignment, as may be performed by a TTS **100** incorporating a word prominence specification system **200**. At processing block **410**, the word prominence specification system **200** obtains the "0" category semantic anchor **202***a* associated with the "0" category **314** of the current document so far T_c **312**, i.e., the preceding sentences **319**. At processing block **420**, the word prominence specification system **200** obtains the novelty detectors **202***b*.

In one embodiment, at processing block **430**, the word prominence specification system **200** computes two different types of closeness measures **204**: the closeness measures **204** between the word vectors $\overline{u}_i$ and the "0" category vector $\overline{v}_o$ and the closeness measures **204** between the word vectors $\overline{u}_i$ and the "novelty" detectors $\overline{v}_i(j \neq 0)$ **202***a*.

In one embodiment, at processing block **440**, the word prominence specification system **200** uses the closeness measures **204** to determine a novelty score **206** for the words in the current sentence **317**. At processing block **450**, once the novelty score **206** is determined, the word prominence specification system **200** may assign the words of the current sentence **317** an appropriate prominence as indicated by the novelty score **206**. Further details of obtaining the "0" category semantic anchor **202***a*, novelty detectors **202***b*, word vectors **205**, and determining the closeness measures **204** and novelty score **206** are described in FIGS. **5-8**.

FIG. **5** is a flow diagram illustrating an embodiment of a method **500** for semantic anchor training, as may be performed by a TTS **100** incorporating a word prominence specification system **200**. During training of the word prominence specification system **200**, the method **500** for semantic anchor training proceeds as follows. At processing block **510**, the word prominence specification system **200** collects documents relevant to the general discourse domain, including an underlying vocabulary and a training corpus of

relevant documents. At processing block **520**, the word prominence specification system **200** bins the documents into the N_1 document categories **313**, and at processing block **530**, further constructs a word matrix W **318** that represents the extent to which the words appear in the N_1 document categories **313**.

FIG. **6** is a flow diagram illustrating an embodiment of a method **600** for determining semantic anchors, as may be performed by a TTS **100** incorporating a word prominence specification system **200**. During operation of the word prominence specification system **200**, the method **600** for determining semantic anchors proceeds as follows. At processing block **610**, the word prominence specification system **200** obtains the current document so far T_c **312** (including current sentence **317** and preceding sentences **319**). At processing block **620**, the word prominence specification system **200** bins the current document so far T_c **312** into the "0" document category **314**.

In one embodiment, at processing block **630**, the word prominence specification system **200** updates the word matrix W **318**, so that the word matrix W **318** now represents the extent to which the words appear in the N_1 document categories **313**, as well as the extent to which the words appear in the "0" document category **314** representing the preceding sentences **319**.

In one embodiment, at processing block **640**, the word prominence specification system **200** computes a singular value decomposition of the word matrix W **318** as previously described. At processing block **650**, the method **600** for determining semantic anchors concludes by computing the "0" category semantic anchor **202***b* associated with the "0" category **314**, which represents the semantic relationships of the words in the preceding sentences **319**, and the novelty detectors **202***a* associated with other N_1 categories **313**.

FIG. **7** is a flow diagram illustrating an embodiment of a method **700** for closeness measurement processing, as may be performed by a TTS **100** incorporating a word prominence specification system **200**. During operation of the word prominence specification system **200**, the method **700** for closeness measurement processing proceeds as follows. At processing block **710**, the word prominence specification system **200** measures the closeness between the word vectors **205** and the novelty detectors **202***b* for the N_1 document categories **313** to generate a set of closeness measures **204**. At processing block **720**, the word prominence specification system **200** measures the closeness between the word vectors **205** and the "0" category semantic anchor **202***a* for the "0" category **314** to generate another set of closeness measures **204**. In preparation for determining a novelty score **206**, at processing block **730** the word prominence specification system **200** computes the average of the closeness measures **204** associated with the novelty detectors **202***b*.

FIG. **8** is a flow diagram illustrating an embodiment of a method **800** for novelty score processing, as may be performed by a TTS **100** incorporating a word prominence specification system **200**. During operation of the word prominence specification system **200**, the method **800** for novelty score processing proceeds as follows. At processing block **810**, the word prominence specification system **200** computes a content prediction index **208** from the closeness measures **204** associated with the "0" category semantic anchor **202***a* (see FIG. **7**, block **720**) and the average of the closeness measures **204** associated with the novelty detectors **202***b* (see FIG. **7**, block **730**).

In one embodiment, at processing block **820**, the word prominence specification system **200** obtains the inverse of the content prediction index **208** to yield a novelty score **206**. At decision block **830**, when the novelty score **206** for a word vector **205** is less than zero, the word prominence specification system **200** at processing block **840** assigns less prominence to the word in the current sentence **317** represented by the word vector **205**. Conversely, at decision block **850**, when the novelty score **206** for a word vector **205** is greater than zero, at processing block **860**, the word prominence specification system **200** assigns more prominence to the word in the current sentence **317** represented by the word vector **205**. When the novelty score **206** is zero or close to zero, then the word prominence specification system **200** maintains the existing prominence assigned by the TTS **100**, as illustrated at block **870**.

FIG. **9** is a block diagram of one embodiment of a computer system on which the TTS **100** and word prominence specification system **200** may be implemented. Computer system **900** includes a processor (or processors) **910**, display device **920**, and input/output (I/O) devices **930**, coupled to each other via a bus **940**. Additionally, a memory subsystem **950**, which can include one or more of cache memories, system memory (RAM), and nonvolatile storage devices (e.g., magnetic or optical disks), is also coupled to bus **940** for storage of instructions and data for use by processor **910**. I/O devices **930** represent a broad range of input and output devices, including keyboards, cursor control devices (e.g., a trackpad or mouse), microphones to capture the voice data, speakers, network or telephone communication interfaces, printers, etc. Computer system **900** may also include well-known audio processing hardware and/or software to transform digital voice data to analog form, which can be processed by the TTS **100** implemented in computer system **900**. In addition to personal computers, laptop computers, and workstations, in some embodiments, computer system **900** may be incorporated in a mobile computing device such as a personal digital assistant (PDA) or mobile telephone without departing from the scope of the invention.

Components **910** through **950** of computer system **900** perform their conventional functions known in the art. Collectively, these components are intended to represent a broad category of hardware systems, including but not limited to general purpose computer systems based on the PowerPC® processor family of processors available from Motorola, Inc. of Schaumburg, Ill., or the Pentium® processor family of processors available from Intel Corporation of Santa Clara, Calif.

It is to be appreciated that various components of computer system **900** may be re-arranged, and that certain implementations of the present invention may not require nor include all of the above components. For example, a display device may not be included in system **900**. Additionally, multiple buses (e.g., a standard I/O bus and a high performance I/O bus) may be included in system **900**. Furthermore, additional components may be included in system **900**, such as additional processors (e.g., a digital signal processor), storage devices, memories, network/communication interfaces, etc.

In the illustrated embodiment of FIG. **9**, the method and apparatus for speech recognition using latent semantic adaptation with word and document updates according to the present invention as discussed above is implemented as a series of software routines run by computer system **900** of

FIG. **9**. These software routines comprise a plurality or series of instructions to be executed by a processing system in a hardware system, such as processor **910**. Initially, the series of instructions are stored on a storage device of memory subsystem **950**. It is to be appreciated that the series of instructions can be stored using any conventional computer-readable or machine-accessible storage medium, such as a diskette, CD-ROM, magnetic tape, DVD, ROM, Flash memory, etc. It is also to be appreciated that the series of instructions need not be stored locally, and could be stored on a propagated data signal received from a remote storage device, such as a server on a network, via a network/communication interface. The instructions are copied from the storage device, such as mass storage, or from the propagated data signal into a memory subsystem **950** and then accessed and executed by processor **910**. In one implementation, these software routines are written in the C++ programming language. It is to be appreciated, however, that these routines may be implemented in any of a wide variety of programming languages.

These software routines are illustrated in memory subsystem **950** as word prominence assignment model instructions **210** and word prominence assignment instructions **220**. In the illustrated embodiment, the memory subsystem **950** of FIG. **9** also includes the "0" category semantic anchor **202***a*, the novelty detectors **202***b*, the closeness measures **204**, the word vectors **205**, and the novelty scores **206** that support the word prominence specification system **200**.

In alternate embodiments, the present invention is implemented in discrete hardware or firmware. For example, one or more application specific integrated circuits (ASICs) could be programmed with the above-described functions of the present invention. By way of another example, TTS **100** and the word prominence specification system **200** of FIG. **1**, or selected components thereof could be implemented in one or more ASICs of an additional circuit board for insertion into hardware system **900** of FIG. **9**.

It is to be appreciated that the method and apparatus for predicting word prominence in speech synthesis may be employed in any of a wide variety of manners. By way of example, a TTS **100** employing word prominence assignment could be used in conventional personal computers, security systems, home entertainment or automation systems, etc.

Preliminary experiments were conducted using an underlying vocabulary of approximately 19,000 most frequent words in the language and background training documents extracted from the Wall Street Journal database, to which was appended either example query sentence (1) or (3). The background documents were chosen to reflect general financial news information related to either "Tennessee" or "mother" (approximately 100 documents on each topic). They were then binned into randomly selected document categories **313**, to come up with four different renditions of the general discourse domain. This multiplicity better rendered the weak indexing power of function words, which otherwise might be accorded too much semantic weight. With the addition of the current sentence **317**, i.e. either (1) or (3), to the current document so far **312** resulted in a total number of five categories, or N=5.

For each word in the sentences (2) and (4), the above approach was followed to obtain closeness measures **204** across all five categories, and then compute novelty scores **206** for the three content words, "mama," "lives" and "Memphis." The results are listed below in Table I, normalized to the (neutral) score of the word "lives" in each case for ease of comparison.

TABLE I

Content Word	Sentence (2)	Sentence (4)
mama	117.4	109.2
lives	0.0	0.0
Memphis	158.5	159.1

As can be seen from the results listed in Table I, for sentence (**2**), the proposed approach assigns "mama" about 7% less prominence than in sentence (**4**), which is consistent with the above discussion. On the other hand, "Memphis" is assigned approximately the same level of prominence in both cases: the difference is less than 0.5%. This illustrates that the novelty detectors **202***b* work as expected, by causing the TTS **100** to emphasize "mama" more in sentence (2) than in sentence (4), despite the fact that in either case the word "mama" had never been seen before in the current document.

Thus, a method and apparatus for a TTS **100** using a word prominence specification system **200** has been described. Whereas many alterations and modifications of the present invention will be comprehended by a person skilled in the art after having read the foregoing description, it is to be understood that the particular embodiments shown and described by way of illustration are in no way intended to be considered limiting. References to details of particular embodiments are not intended to limit the scope of the claims.

We claim:

1. An apparatus for assigning word prominence in synthetic speech comprising:

a memory having stored thereon a set of instructions; and

a processing device coupled with the memory, the processing device, when executing the set of instructions, to

generate a speech representative of a current sentence,

determine whether an information in the current sentence is new or previously given based on a semantic relationship between the current sentence and a number of preceding sentences, and

assign a word prominence to a word in the current sentence in accordance with the information determination.

2. The apparatus of claim **1**, the processing device, when executing the set of instructions, to determine the semantic relationship between the current sentence and the number of preceding sentences using latent semantic analysis (LSA).

3. The apparatus of claim **2**, the processing device, when determining the semantic relationship using LSA, to:

generate a word prominence assignment model comprising semantic anchors associated with the current sentence and the number of preceding sentences; and

classify each word in the current sentence against the semantic anchors to determine whether the word represents the new or previously given information.

4. The apparatus of claim **3**, the processing device, when classifying each word in the current sentence against the semantic anchors, to:

measure a closeness between a vector representing the word and the semantic anchors to determine closeness measures; and

determine a novelty score from the closeness measures, wherein the novelty score has a first value when the information is new and a second value when the information is previously given.

5. The apparatus of claim **4**, wherein the first value is a positive value and the second value is a negative value.

6. The apparatus of claim **4**, wherein the first value is a negative value and the second value is a positive value.

7. The apparatus of claim **4**, the processing device, when determining the novelty score from the closeness measures, to:

compute a content prediction index from a first closeness measure of the closeness measures of the semantic anchor associated with the number of preceding sentences and a second closeness measure of the closeness measures of the semantic anchors associated with the current sentence; and

invert the content prediction index.

8. The apparatus of claim **1**, the processing device, when assigning a word prominence to a word in the current sentence, to:

emphasize the word in the current sentence when the word represents the new information; and

de-emphasize the word in the current sentence when the word represents the previously given information.

9. The apparatus of claim **8**, wherein to achieve emphasizing and de-emphasizing, the processing device alters a prosodic feature of the word.

10. The apparatus of claim **9**, wherein altering the prosodic feature includes altering at least one of volume, pitch, and phoneme duration.

11. The apparatus of claim **1**, wherein the memory comprises a random access memory device.

12. The apparatus of claim **1**, wherein the memory comprises a nonvolatile storage device.

13. The apparatus of claim **1**, wherein the memory comprises a remote memory device coupled with the processing device by a network.

14. The apparatus of claim **1**, wherein the processing device comprises a microprocessor.

15. The apparatus of claim **1**, wherein the processing device comprises an application specific integrated circuit (ASIC).

16. An apparatus for assigning word prominence in synthetic speech comprising:

means for storing a set of instructions; and

means for processing coupled with the means for storing, the means for processing, when executing the set of instructions, to

generate a speech representative of a current sentence,

determine whether an information in the current sentence is new or previously given based on a semantic relationship between the current sentence and a number of preceding sentences, and

assign a word prominence to a word in the current sentence in accordance with the information determination.

17. The apparatus of claim **16**, the means for processing, when executing the set of instructions, to determine the semantic relationship between the current sentence and the number of preceding sentences using latent semantic analysis (LSA).

18. The apparatus of claim **17**, the means for processing, when determining the semantic relationship using LSA, to:

generate a word prominence assignment model comprising semantic anchors associated with the current sentence and the number of preceding sentences; and

classify each word in the current sentence against the semantic anchors to determine whether the word represents the new or previously given information.

19. The apparatus of claim **18**, the means for processing, when classifying each word in the current sentence against the semantic anchors, to:

measure a closeness between a vector representing the word and the semantic anchors to determine closeness measures; and

determine a novelty score from the closeness measures, wherein the novelty score has a first value when the information is new and a second value when the information is previously given.

20. The apparatus of claim **19**, wherein the first value is a positive value and the second value is a negative value.

21. The apparatus of claim **19**, wherein the first value is a negative value and the second value is a positive value.

22. The apparatus of claim **19**, the means for processing, when determining the novelty score from the closeness measures, to:

compute a content prediction index from a first closeness measure of the closeness measures of the semantic anchor associated with the number of preceding sentences and a second closeness measure of the closeness measures of the semantic anchors associated with the current sentence; and

invert the content prediction index.

23. The apparatus of claim **16**, the means for processing, when assigning a word prominence to a word in the current sentence, to:

emphasize the word in the current sentence when the word represents the new information; and

de-emphasize the word in the current sentence when the word represents the previously given information.

24. The apparatus of claim **23**, wherein to achieve emphasizing and de-emphasizing, the means for processing alters a prosodic feature of the word.

25. The apparatus of claim **24**, wherein altering the prosodic feature includes altering at least one of volume, pitch, and phoneme duration.

* * * * *