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Kanda et al.

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(54) **HYPOTHESIS STITCHER FOR SPEECH RECOGNITION OF LONG-FORM AUDIO**

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(63) Continuation of application No. 18/157,070, filed on Jan. 19, 2023, now Pat. No. 11,935,542, which is a (Continued)

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G10L 15/00 (2013.01)
G10L 15/22 (2006.01)
(Continued)

(52) **U.S. Cl.**

CPC ***G10L 17/02*** (2013.01); ***G10L 15/22*** (2013.01); ***G10L 15/26*** (2013.01); ***G10L 19/022*** (2013.01); ***G10L 21/0272*** (2013.01)

(58) **Field of Classification Search**

CPC G10L 15/26; G10L 19/022; G10L 15/16; G10L 21/0272; G10L 15/04; G10L 17/00;
(Continued)

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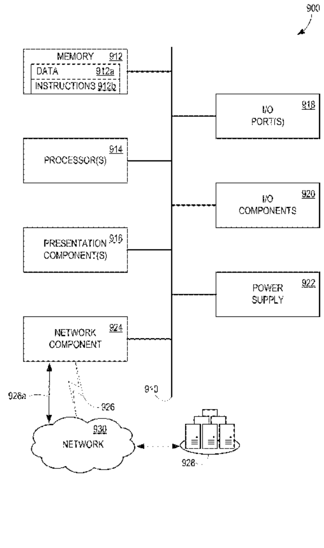
(57) **ABSTRACT**

A hypothesis stitcher for speech recognition of long-form audio provides superior performance, such as higher accuracy and reduced computational cost. An example disclosed operation includes: segmenting the audio stream into a plurality of audio segments; identifying a plurality of speakers within each of the plurality of audio segments; performing automatic speech recognition (ASR) on each of the plurality of audio segments to generate a plurality of short-segment hypotheses; merging at least a portion of the short-segment hypotheses into a first merged hypothesis set; inserting stitching symbols into the first merged hypothesis set, the stitching symbols including a window change (WC) symbol; and consolidating, with a network-based hypothesis stitcher, the first merged hypothesis set into a first consolidated hypothesis. Multiple variations are disclosed, including alignment-based stitchers and serialized stitchers, which

(Continued)



may operate as speaker-specific stitchers or multi-speaker stitchers, and may further support multiple options for differing hypothesis configurations.

20 Claims, 11 Drawing Sheets

Related U.S. Application Data

continuation of application No. 17/127,938, filed on Dec. 18, 2020, now Pat. No. 11,574,639.

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G10L 17/02	(2013.01)
G10L 19/022	(2013.01)
G10L 21/0272	(2013.01)

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CPC G10L 17/02; G10L 15/22; G10L 15/32; G10L 25/45; G10L 25/03; G06F 18/25; G06T 17/05

USPC 704/251

See application file for complete search history.

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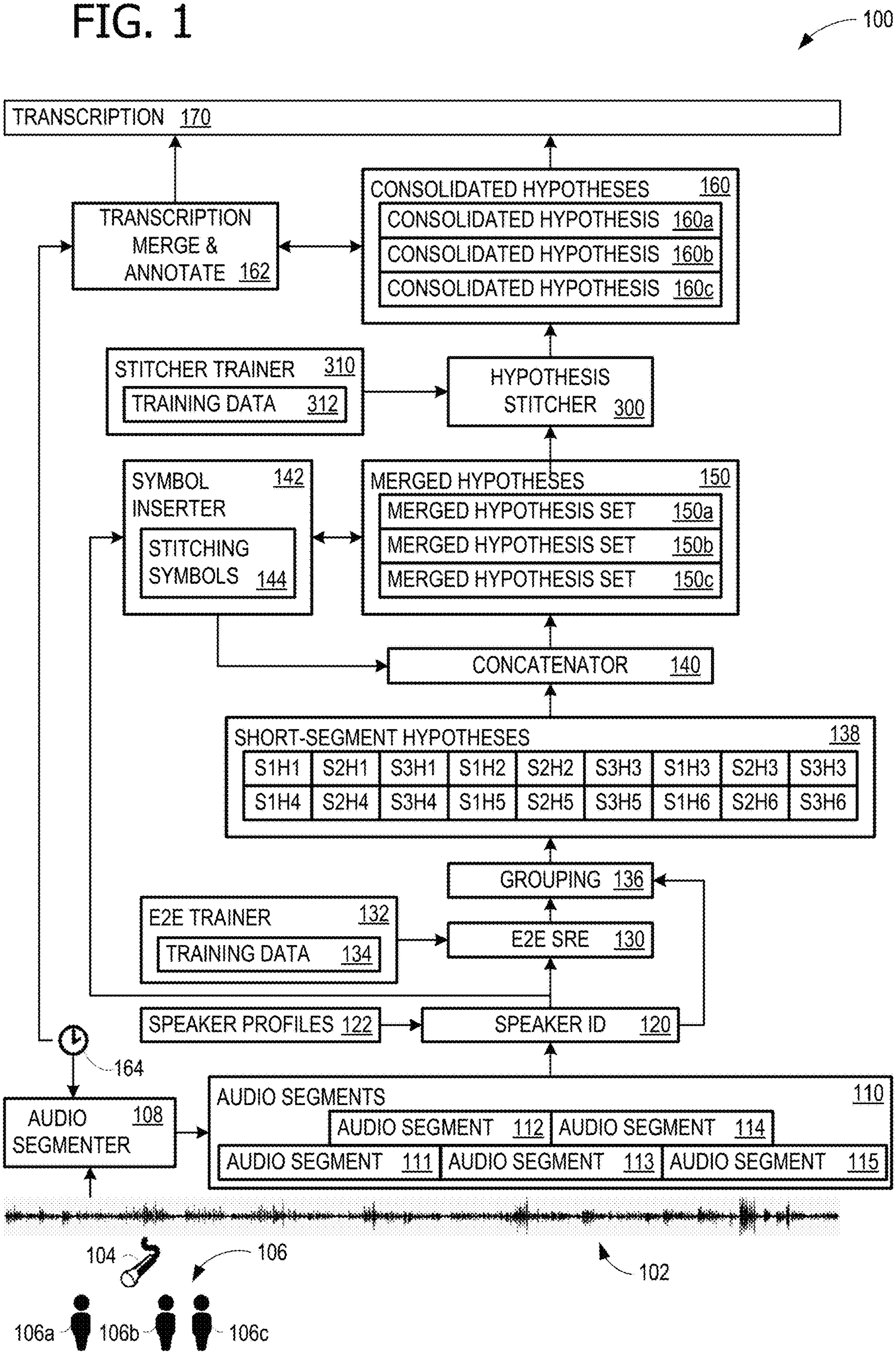
FIG. 1


100
TRANSCRIPTION 170
TRANSCRIPTION MERGE & ANNOTATE 162
CONSOLIDATED HYPOTHESES 160
CONSOLIDATED HYPOTHESIS 160a
CONSOLIDATED HYPOTHESIS 160b
CONSOLIDATED HYPOTHESIS 160c
STITCHER TRAINER 310
TRAINING DATA 312
HYPOTHESIS STITCHER 300
SYMBOL INSERTER 142
STITCHING SYMBOLS 144
MERGED HYPOTHESES 150
MERGED HYPOTHESIS SET 150a
MERGED HYPOTHESIS SET 150b
MERGED HYPOTHESIS SET 150c
CONCATENATOR 140
SHORT-SEGMENT HYPOTHESES 138
S1H1 S2H1 S3H1 S1H2 S2H2 S3H3 S1H3 S2H3 S3H3
S1H4 S2H4 S3H4 S1H5 S2H5 S3H5 S1H6 S2H6 S3H6
GROUPING 136
E2E TRAINER 132
TRAINING DATA 134
E2E SRE 130
SPEAKER PROFILES 122
SPEAKER ID 120
164
AUDIO SEGMENTER 108
AUDIO SEGMENTS 110
AUDIO SEGMENT 112
AUDIO SEGMENT 114
AUDIO SEGMENT 111
AUDIO SEGMENT 113
AUDIO SEGMENT 115
104
106
102
106a
106b
106c

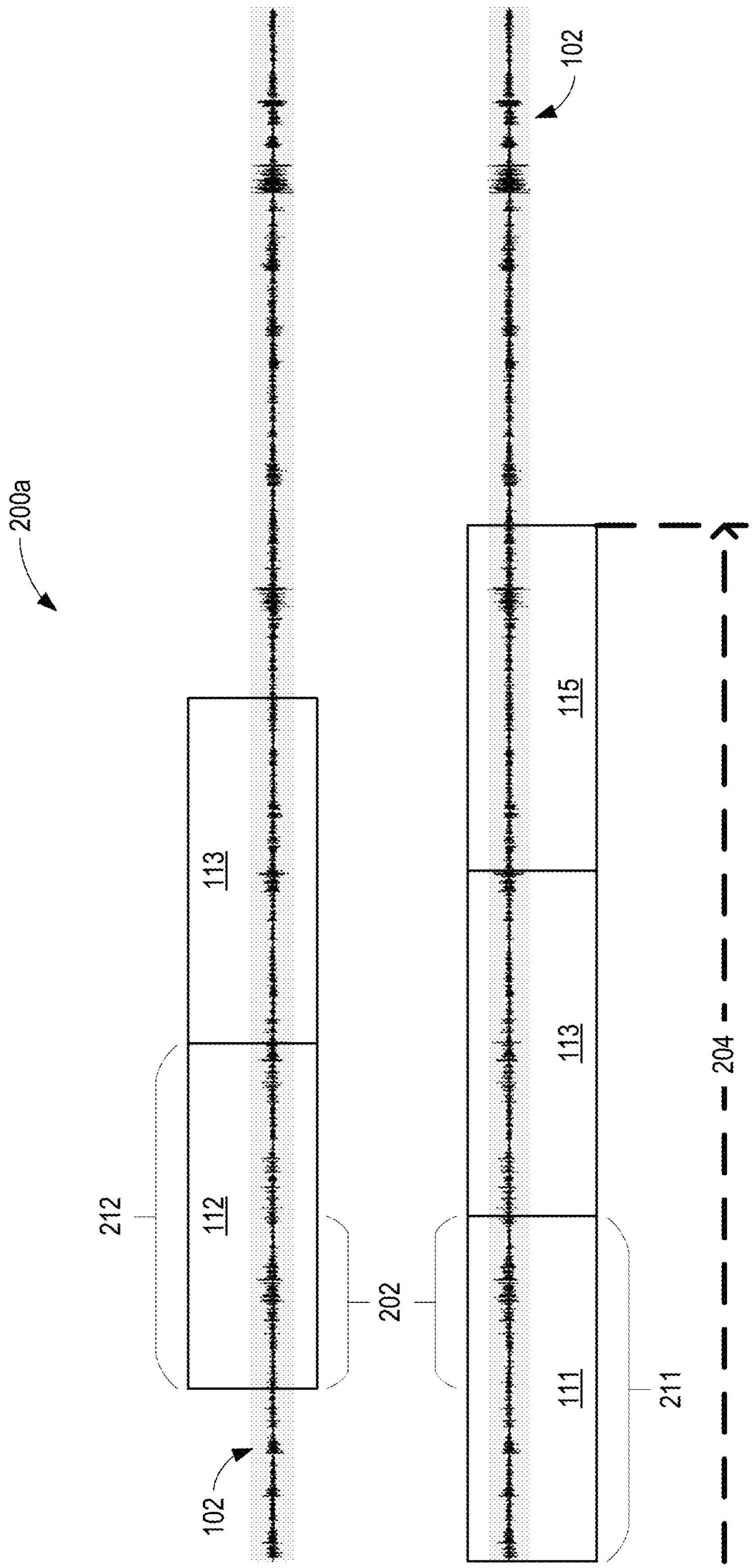


FIG. 2A

FIG. 2B

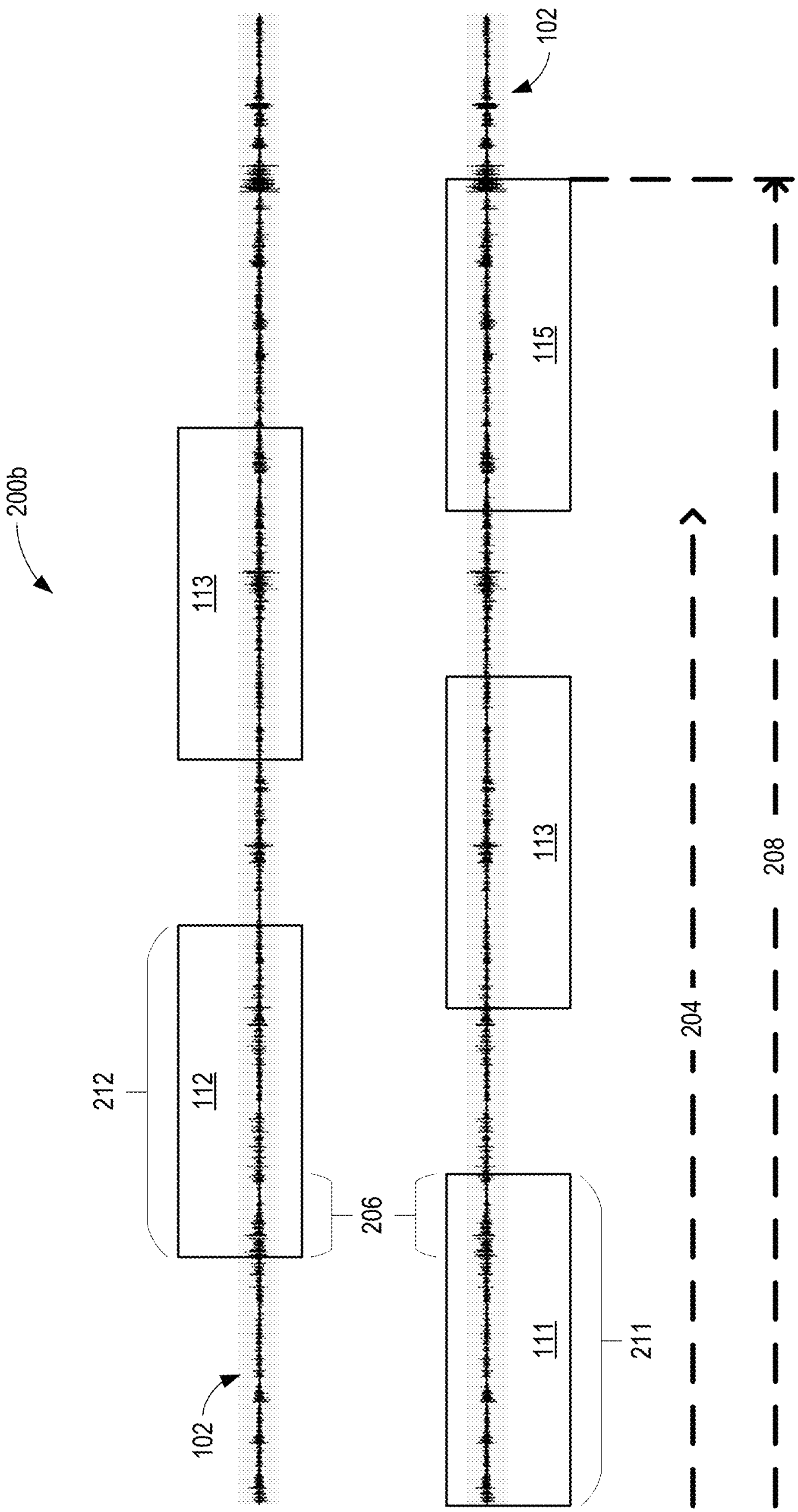


FIG. 3

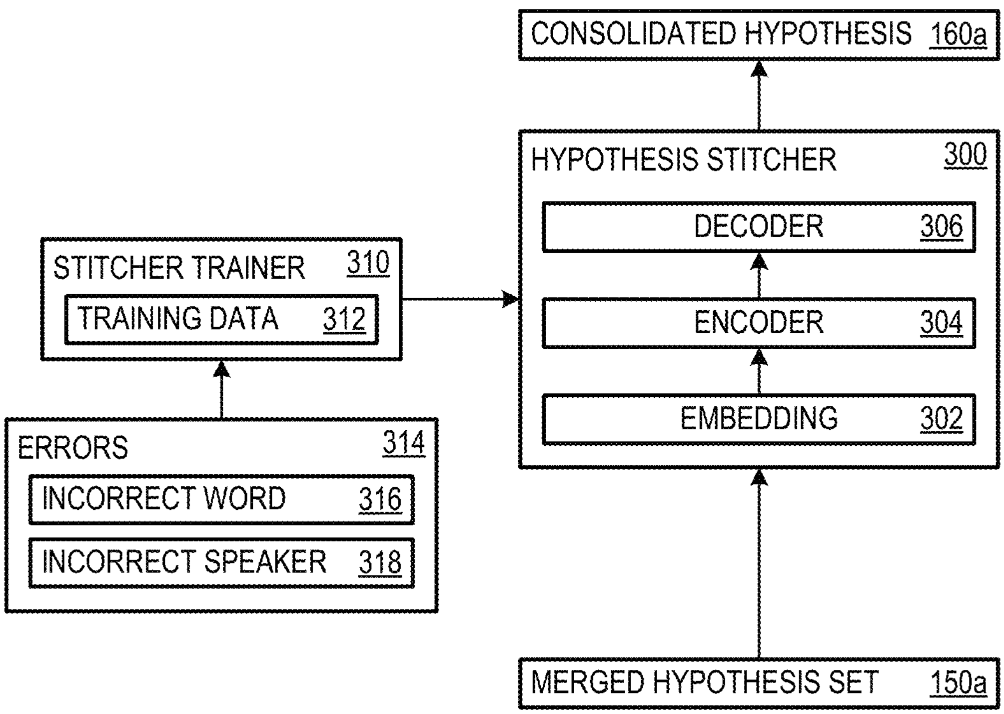

CONSOLIDATED HYPOTHESIS 160a
HYPOTHESIS STITCHER 300
DECODER 306
ENCODER 304
EMBEDDING 302
STITCHER TRAINER 310
TRAINING DATA 312
ERRORS 314
INCORRECT WORD 316
INCORRECT SPEAKER 318
MERGED HYPOTHESIS SET 150a

FIG. 4

401 144a

400o $\hat{Y}^{k}_{o,wc} = \{\hat{Y}^{1,k}, \langle WC \rangle, \hat{Y}^{3,k}, \langle WC \rangle, \ldots, \hat{Y}^{2m-1,k}, \langle WC \rangle, \ldots\}$

400e $\hat{Y}^{k}_{e,wc} = \{\hat{Y}^{2,k}, \langle WC \rangle, \hat{Y}^{4,k}, \langle WC \rangle, \ldots, \hat{Y}^{2m,k}, \langle WC \rangle, \ldots\}$

402

FIG. 5

501 502 144a

510 $\hat{Y}^{k}_{wc} = \{\hat{Y}^{1,k}, \langle WC \rangle, \hat{Y}^{2,k}, \langle WC \rangle, \hat{Y}^{3,k}, \langle WC \rangle, \ldots, \hat{Y}^{M,k}\}$

520 $\hat{Y}^{k}_{wc} = \{\hat{Y}^{1,k}, \langle WCE \rangle, \hat{Y}^{2,k}, \langle WCO \rangle, \hat{Y}^{3,k}, \langle WCE \rangle, \ldots, \hat{Y}^{M,k}\}$

501 502 144c 144b

FIG. 6A

602

W1 W2 W3 W4 <S1> W5 W6 W7 <S2> W8 W9 W10 <S1> <WCO> W11 W12 <S2> W13 W14 W15 <S3> <WCE> ...

604

W1 W2 W3 W4 <S5> W5 W6 W7 <S1> W8 W9 W10 <S5> <WCO> W11 W12 <S1> W13 W14 W15 <S4> <WCE> ...

606

W1' W2' W3' W4' <S1> W5' W6' W7' <S2> W8' W9' W10' <S1> W11' W12' <S2> W13' W14' W15' <S3> ...

FIG. 6B

612

W1 W2 W3 W4 W5 W6 W7 W8 W9 W10 <WCO> W11 W12 W13 W14 W15 <WCE> ...
S1 S1 S1 S1 S2 S2 S2 S1 S1 S1 S0 S2 S2 S3 S3 S3 S0 ...

614

W1' W2' W3' W4' W5' W6' W7' W8' W9' W10' W11' W12' W13' W14' W15' ...
S1 S1 S1 S1 S2 S2 S2 S1 S1 S1 S2 S2 S3 S3 S3 ...

616

W1' W2' W3' W4' <S1> W5' W6' W7' <S2> W8' W9' W10' <S1> W11' W12' <S2> W13' W14' W15' <S3> ...

FIG. 6C

622

W1 W2 W3 W4 W5 W6 W7 W8 W9 W10 <WCO> W11 W12 W13 W14 W15 <WCE> ...
S1 S1 S1 S1 S2 S2 S2 S1 S1 S1 S0 S2 S2 S3 S3 S3 S0 ...
L1 L1 L1 L1 L2 L2 L2 L1 L1 L1 L0 L2 L2 L1 L1 L1 L0 ...

624

W1' W2' W3' W4' W5' W6' W7' W8' W9' W10' W11' W12' W13' W14' W15' ...
S1 S1 S1 S1 S2 S2 S2 S1 S1 S1 S2 S2 S3 S3 S3 ...
L1 L1 L1 L1 L2 L2 L2 L1 L1 L1 L2 L2 L1 L1 L1 ...

626

W1' W2' W3' W4' <S1><L1> W5' W6' W7' <S2><L2> W8' W9' W10' <S1><L1> W11' W12' <S2><L2> W13' W14' W15' <S3><L1> ...

FIG. 6D

632 W1 W2 W3 W4 <N1> W1* W2* W3* W4* <N2> W1** W2** W3** W4** <N3> <WCO> ...

634 W1 W2 W3 W4 <N*> W1* W2* W3* W4* <N*> W1** W2** W3** W4** <N*> <WCO> ...

636 W1' W2' W3' W4' ...

638 W1 W2 W3 W4 <N1> W1* W2* W3* W4* <N2> W1** W2** W3** W4** <N3> <S1>

→ W5 W6 W7 <N1> W5* W6* W7* <N2> W5** W6** W7** <N3> <S2>

→ W8 W9 W10 <N1> W8* W9* W10* <N2> W8** W9** W10** <N3> <S1> <WCO> ...

640 W1' W2' W3' W4' <S1> W5' W6' W7' <S2> W8' W9' W10' <S1> ...

FIG. 7

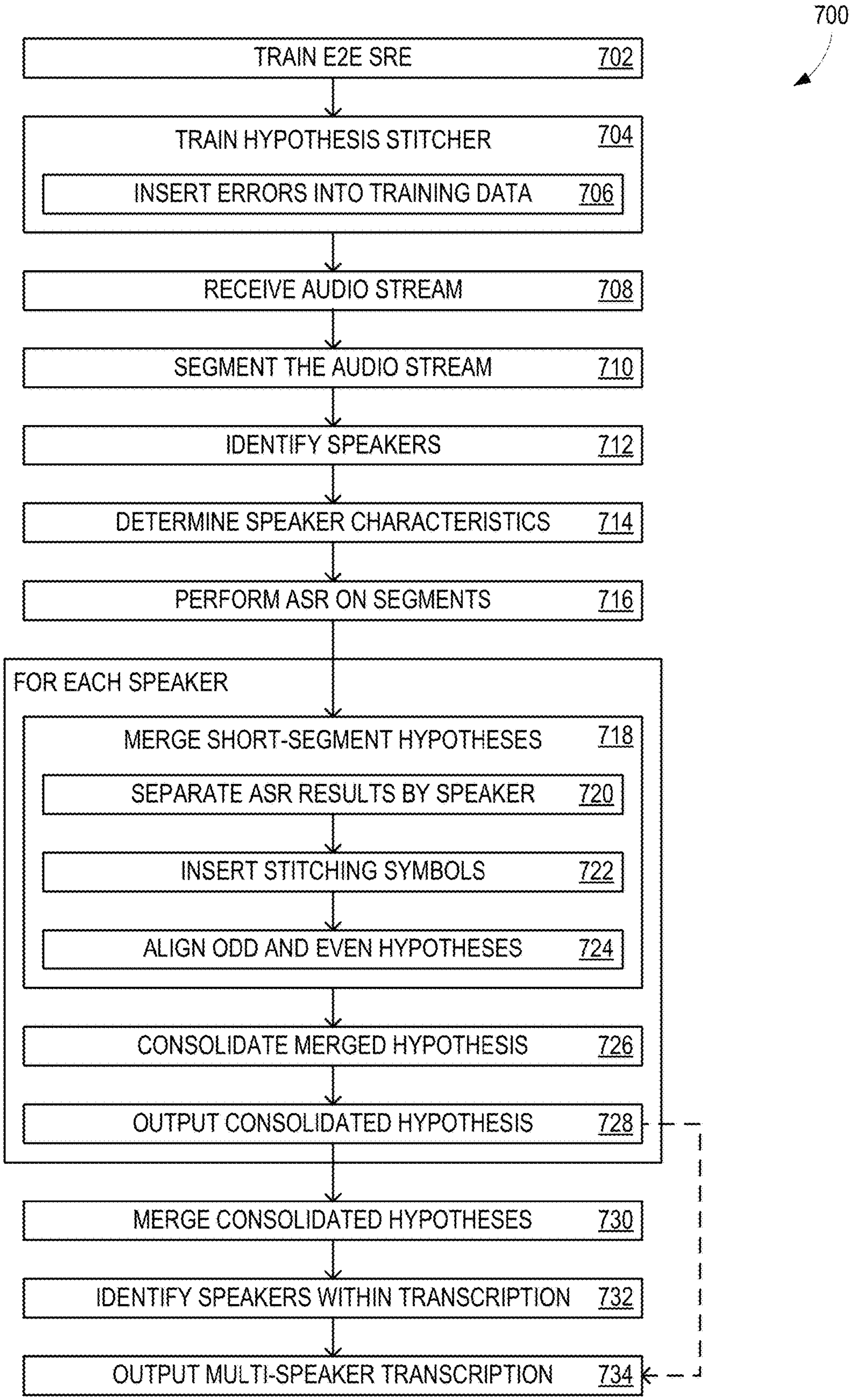

700
TRAIN E2E SRE 702
TRAIN HYPOTHESIS STITCHER 704
INSERT ERRORS INTO TRAINING DATA 706
RECEIVE AUDIO STREAM 708
SEGMENT THE AUDIO STREAM 710
IDENTIFY SPEAKERS 712
DETERMINE SPEAKER CHARACTERISTICS 714
PERFORM ASR ON SEGMENTS 716
FOR EACH SPEAKER
MERGE SHORT-SEGMENT HYPOTHESES 718
SEPARATE ASR RESULTS BY SPEAKER 720
INSERT STITCHING SYMBOLS 722
ALIGN ODD AND EVEN HYPOTHESES 724
CONSOLIDATE MERGED HYPOTHESIS 726
OUTPUT CONSOLIDATED HYPOTHESIS 728
MERGE CONSOLIDATED HYPOTHESES 730
IDENTIFY SPEAKERS WITHIN TRANSCRIPTION 732
OUTPUT MULTI-SPEAKER TRANSCRIPTION 734

FIG. 8

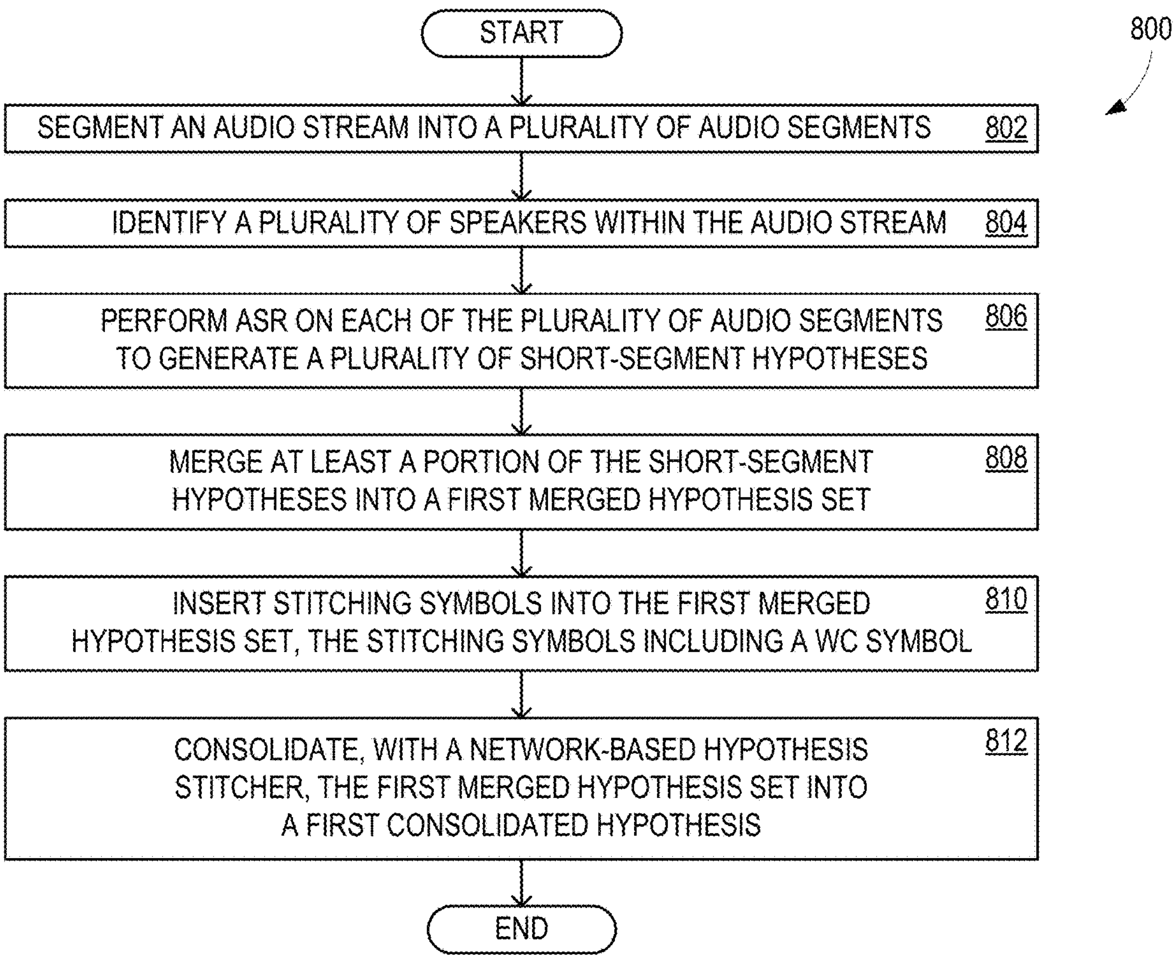
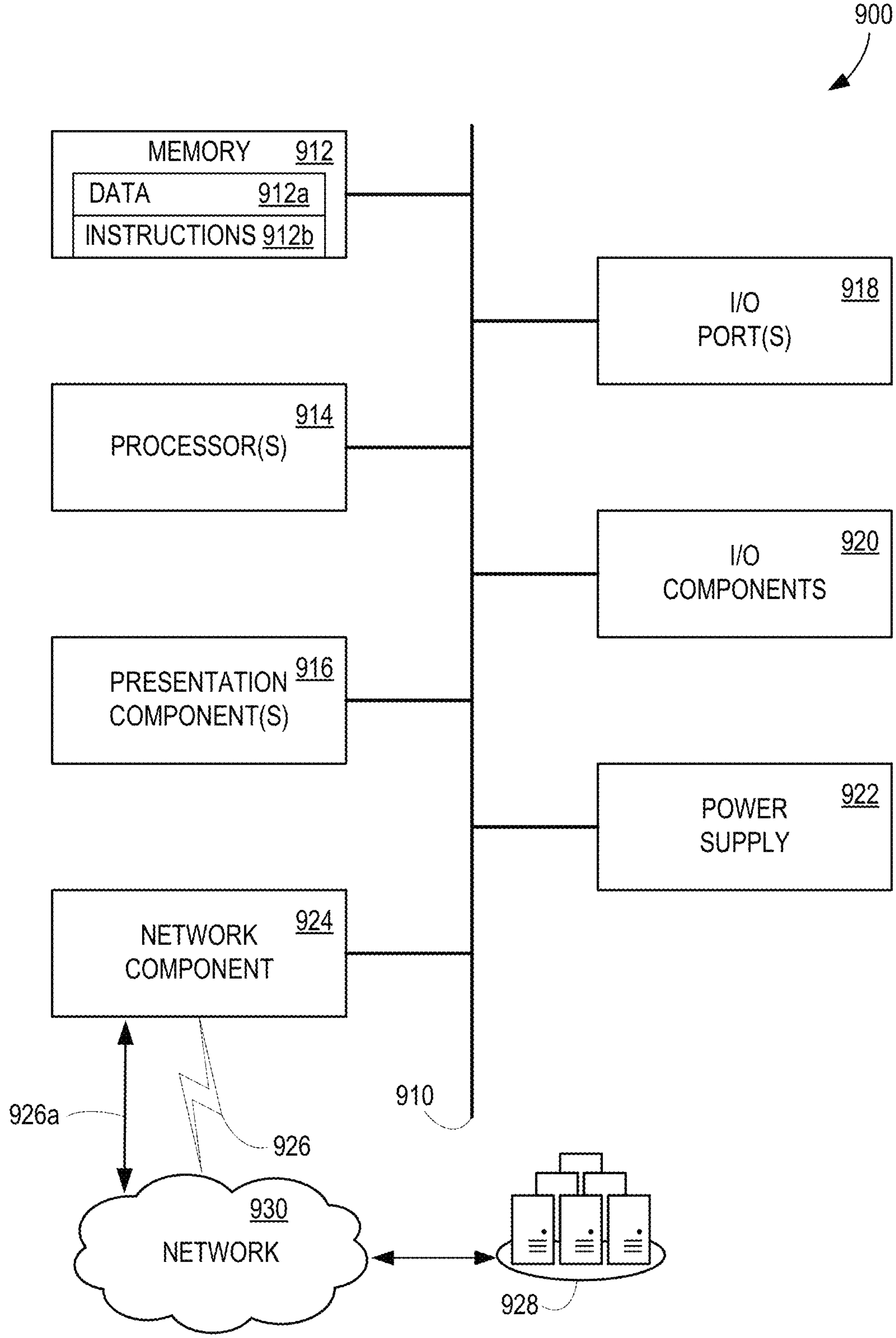

START
800
SEGMENT AN AUDIO STREAM INTO A PLURALITY OF AUDIO SEGMENTS 802
IDENTIFY A PLURALITY OF SPEAKERS WITHIN THE AUDIO STREAM 804
PERFORM ASR ON EACH OF THE PLURALITY OF AUDIO SEGMENTS TO GENERATE A PLURALITY OF SHORT-SEGMENT HYPOTHESES 806
MERGE AT LEAST A PORTION OF THE SHORT-SEGMENT HYPOTHESES INTO A FIRST MERGED HYPOTHESIS SET 808
INSERT STITCHING SYMBOLS INTO THE FIRST MERGED HYPOTHESIS SET, THE STITCHING SYMBOLS INCLUDING A WC SYMBOL 810
CONSOLIDATE, WITH A NETWORK-BASED HYPOTHESIS STITCHER, THE FIRST MERGED HYPOTHESIS SET INTO A FIRST CONSOLIDATED HYPOTHESIS 812
END

FIG. 9


900
MEMORY 912
DATA 912a
INSTRUCTIONS 912b
PROCESSOR(S) 914
PRESENTATION COMPONENT(S) 916
NETWORK COMPONENT 924
I/O PORT(S) 918
I/O COMPONENTS 920
POWER SUPPLY 922
910
926a
926
930
NETWORK
928

HYPOTHESIS STITCHER FOR SPEECH RECOGNITION OF LONG-FORM AUDIO

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation application of and claims priority to U.S. patent application Ser. No. 18/157,070, entitled "HYPOTHESIS STITCHER FOR SPEECH RECOGNITION OF LONG-FORM AUDIO," filed on Jan. 19, 2023, which is a continuation application of and claims priority to U.S. patent application Ser. No. 17/127,938 (now U.S. Pat. No. 11,574,639), entitled "HYPOTHESIS STITCHER FOR SPEECH RECOGNITION OF LONG-FORM AUDIO," filed on Dec. 18, 2020, the disclosures of which are incorporated herein by reference in their entireties.

BACKGROUND

End-to-end (E2E) automatic speech recognition (ASR) systems use a single neural network (NN) to transduce audio to word sequences, and are thus typically simpler than earlier ASR systems. E2E ASR solutions typically intake short audio segments to process a full utterance prior to producing a hypothesis. Unfortunately, models trained on short utterances generally underperform when applied to speech that exceeds the training data length. Such scenarios may occur with long-form speech (e.g., speech lasting 10 minutes or more), which may be encountered when transcribing streaming audio and in other ASR tasks.

SUMMARY

The disclosed examples are described in detail below with reference to the accompanying drawing figures listed below. The following summary is provided to illustrate some examples disclosed herein. It is not meant, however, to limit all examples to any particular configuration or sequence of operations.

A hypothesis stitcher for speech recognition of long-form audio provides superior performance, such as higher accuracy and reduced computational cost. An example disclosed operation includes: segmenting the audio stream into a plurality of audio segments; identifying a plurality of speakers within each of the plurality of audio segments; performing automatic speech recognition (ASR) on each of the plurality of audio segments to generate a plurality of short-segment hypotheses; merging at least a portion of the short-segment hypotheses into a first merged hypothesis set; inserting stitching symbols into the first merged hypothesis set, the stitching symbols including a window change (WC) symbol; and consolidating, with a network-based hypothesis stitcher, the first merged hypothesis set into a first consolidated hypothesis. Multiple variations are disclosed, including alignment-based stitchers and serialized stitchers, which may operate as speaker-specific stitchers or multi-speaker stitchers, and may further support multiple options for differing hypothesis configurations.

BRIEF DESCRIPTION OF THE DRAWINGS

The disclosed examples are described in detail below with reference to the accompanying drawing figures listed below:

FIG. **1** illustrates an arrangement for speech recognition that advantageously employs a hypothesis stitcher for speech recognition of long-form audio;

FIGS. **2**A and **2**B illustrates examples of window overlap, as may be used with the arrangement of FIG. **1**;

FIG. **3** illustrates further details for examples of the hypothesis stitcher of FIG. **1**;

FIG. **4** illustrates example hypothesis sets for an alignment-based stitcher, as may be used in the arrangement of FIG. **1**;

FIG. **5** illustrates examples of merged hypothesis sets for a serialized stitcher, as may be used in the arrangement of FIG. **1**;

FIGS. **6**A, **6**B, **6**C, and **6**D illustrate examples of merged hypothesis sets for multi-speaker serialized stitcher variations, as may be used in the arrangement of FIG. **1**;

FIG. **7** is a flowchart illustrating exemplary operations associated with the arrangement of FIG. **1**;

FIG. **8** is another flowchart illustrating exemplary operations associated with the arrangement of FIG. **1**; and

FIG. **9** is a block diagram of an example computing environment suitable for implementing some of the various examples disclosed herein.

Corresponding reference characters indicate corresponding parts throughout the drawings.

DETAILED DESCRIPTION

The various examples will be described in detail with reference to the accompanying drawings. Wherever possible, the same reference numbers will be used throughout the drawings to refer to the same or like parts. References made throughout this disclosure relating to specific examples and implementations are provided solely for illustrative purposes but, unless indicated to the contrary, are not meant to limit all examples.

A hypothesis stitcher for speech recognition of long-form audio provides superior performance, such as higher accuracy and reduced computational cost. An example disclosed operation includes: segmenting the audio stream into a plurality of audio segments; identifying a plurality of speakers within each of the plurality of audio segments; performing automatic speech recognition (ASR) on each of the plurality of audio segments to generate a plurality of short-segment hypotheses; merging at least a portion of the short-segment hypotheses into a first merged hypothesis set; inserting stitching symbols into the first merged hypothesis set, the stitching symbols including a window change (WC) symbol; and consolidating, with a network-based hypothesis stitcher, the first merged hypothesis set into a first consolidated hypothesis. Multiple variations are disclosed, including alignment-based stitchers and serialized stitchers, which may operate as speaker-specific stitchers or multi-speaker stitchers, and may further support multiple options for differing hypothesis configurations.

Aspects of the disclosure improve the speed and accuracy of speech recognition by merging short-segment hypotheses into a merged hypothesis set and consolidating, with a network-based hypothesis stitcher, a merged hypothesis set into a consolidated hypothesis. The network-based hypothesis stitcher provides superior accuracy. Some examples employ a serialized stitcher that does not require alignment of odd and even hypothesis sequences (e.g., word alignment), reducing the required degree of overlap, and thus cutting computational cost.

The hypothesis stitcher intakes multiple hypotheses from short-segmented audio and outputs a fused single hypothesis, significantly improving speaker-attributed word error rate (SA-WER) for long-form multi-speaker audio. As used herein, a hypothesis is an estimated content of audio, and may include a sequence of estimated words or tokens representing words. A hypothesis may further contain other estimated content such as speaker identification, language identification, and other speaker characterizations, along with other tags or symbols. Multiple variants of model architectures are disclosed, including some that have reduced computational cost, due to the relaxation of overlap requirements.

Examples segment long audio using sliding window with overlaps among the segments, end-to-end (E2E) ASR is applied to each window to generate hypotheses. The hypotheses from each window are fused into a single hypothesis using a sequence-to-sequence model that has been trained to fuse multiple hypotheses from overlapping windows. By using a machine learning (ML) module, the hypotheses fusion can be executed with a significantly high accuracy.

FIG. **1** illustrates an arrangement **100** for speech recognition that advantageously employs a hypothesis stitcher for speech recognition of long-form audio. An audio stream **102** is received (captured) by a microphone **104** from a plurality of speakers **106** that includes a speaker **106***a*, a speaker **106***b*, and a speaker **106***c*. Audio stream **102** is received and segmented by audio segmenter **108** into a plurality of audio segments **110**. As shown, plurality of audio segments **110** includes an audio segment **111**, an audio segment **112**, an audio segment **113**, an audio segment **114**, and an audio segment **115**, although it should be understood that a different number of audio segments may be used.

Turning briefly to FIGS. **2**A and **2**B, overlap of audio segments will be described. FIG. **2**A illustrates 50% window overlap in overlap scenario **200***a*, in which each of the odd-numbered audio segments stop and start back-to-back (e.g., without gaps), and the even-numbered audio segments similarly stop and start back-to-back (e.g., without gaps). The changes between odd-numbered windows occur within the even-numbered windows, and the changes between even-numbered windows similarly occur within the odd-numbered windows, producing parallel, staggered sequences. Audio stream **102** is shown twice, once annotated with odd-numbered audio segments (e.g., audio segments **111**, **113**, and **115**) and also annotated with even-numbered audio segments (e.g., audio segments **112** and **112**). Window length **211** for audio segment **111** is consistent for other audio segments **112-115**, for example, matching the window length **212** for audio segment **112**. An overlap duration **202** is half (50%) of each window length **211** and window length **212**. Together, the five audio segments **111-115** cover a time period **204**. In some examples, window length **211** is 16 seconds, or 30 seconds, or some other time period having a duration of less than a minute, whereas the length of audio stream may be in excess of 10 minutes or even in excess of an hour.

FIG. **2**B illustrates 25% window overlap in overlap scenario **200***b*. The changes between odd-numbered windows occur within the even-numbered windows, and the changes between even-numbered windows similarly occur within the odd-numbered windows, producing parallel, staggered sequences—but allowing for gaps within each of the odd and even sequences. Audio stream **102** is shown twice, once annotated with odd-numbered audio segments (e.g., audio segments **111**, **113**, and **115**) and also annotated with even-numbered audio segments (e.g., audio segments **112** and **112**). Window length **211** for audio segment **111** is consistent for other audio segments **112-115**, for example, matching the window length **212** for audio segment **112**. An overlap duration **206** is one-fourth (25%) of each window length **211** and window length **212**. Together, the five audio segments **111-115** cover a time period **208**, which is longer than time period **204** for overlap scenario **200***a* (having 50% window overlap).

Thus, for the same length of time as time period **204**, fewer audio segments are processed for 25% overlap than for 50% overlay, reducing computational cost. The overlap of hypotheses follows the overlap of audio segments. It should be understood that aspects of the disclosure may use differing amounts of overlap, including overlap as low as 10% or lower.

Returning to FIG. **1**, plurality of audio segments **110** is provided to speaker identification **120**, which uses speaker profiles **122** (e.g., information regarding speaker characteristics of speakers **106***a*-**106***c*) to associate each of speakers **106***a*-**106***c* with utterances within plurality of audio segments **110**. Plurality of audio segments **110** is also provided to E2E speech recognition engine (SRE) **130** to perform speech recognition and output hypotheses. In some examples, a different form of SRE, rather than E2E, may be employed. E2E SRE **130** is trained by E2E trainer **132**, which uses speech recognition training data **134**. Hypotheses output by E2E SRE **130** are grouped according to speaker, by speaker grouping **136**, into speaker-specific short-segment hypotheses **138**. ASR is performed on each of audio segments **111-115** to produce $\{\hat{Y}^{m,1}\ \hat{Y}^{m,K}\}$, where K is the number of speakers **106***a*-**106***c* (and is also the number of profiles within speaker profiles **122** for this example).

Short-segment hypotheses **138** is illustrated with an example set of fifteen hypotheses, six for each of speakers **106***a*-**106***c*. S1H1, S1H2, S1H3, S1H4, S1H5, and S1H6 are six hypotheses for speaker **106***a*, in order of occurrence. S2H1, S2H2, S2H3, S2H4, S2H5, and S2H6 are six hypotheses for speaker **106***b*, in order of occurrence. S3H1, S3H2, S3H3, S3H4, S3H5, and S3H6 are six hypotheses for speaker **106***c*, in order of occurrence. It should be understood that three speakers with six utterances each (producing the six hypotheses each) is only an example.

A concatenator **140** merges at least a portion of (e.g., at least some of) short-segment hypotheses **138** into merged hypotheses **150**, which includes at least merged hypothesis set **150***a*. In general, the hypotheses of short-segment hypotheses **138** may be merged into sets and take on the form shown in Equation 1:

$$\hat{Y}^{k}+\{\hat{Y}^{1,k}, \ldots \hat{Y}^{M,k}\} \tag{Eq. 1}$$

where $\hat{Y}^{m,k}$ represents the hypothesis for speaker k in audio segment m, k ranges from 1 to the number of speakers K, and m ranges from 1 to the number of audio segments M. For example, audio stream **102** is segmented into M segments (with overlaps). Ŷk is the merged hypothesis set (e.g., merged hypothesis set **150***a*) for speaker k. In some examples, if a speaker k is not detected in an audio segment m, the hypothesis $\hat{Y}^{m,k}$ is set to an empty sequence.

Multiple options are disclosed in the following figures for the operation of concatenator **140** and the format of merged hypotheses **150**. Variations include whether merged hypotheses **150** includes speaker-specific merged hypothesis sets (e.g., each of merged hypothesis set **150***a*, merged hypothesis set **150***b*, and merged hypothesis set **150***a* is for only a single one if speakers **106***a*-**106***c*) or whether merged hypotheses **150** includes a multi-speaker version of merged hypothesis set **150***a*.

A symbol inserter **142** inserts stitching symbols **144** into merged hypotheses **150**, for example, into merged hypothesis set **150***a* and also merged hypothesis sets **150***b* and **150***c*, if they are used. Stitching symbols **144** include a generic window change (WC) symbol **144***a*, and in some examples, include an even window change (WCE) symbol **144***b* (indicating a change from an odd-numbered window to an even-numbered window) and an odd window change (WCO) symbol **144***c* (changing from an even-numbered window to an odd-numbered window). Window changes correspond to the end of a word or token sequence recognized from one audio segment to the start of a word or token sequence recognized from the next audio segment. In some examples, stitching symbols **144** may further include: a speaker identification (SPKR_k, where k is an index number for the speaker), speaker characteristics (e.g., language (LANG_k), speaker age (AGE_k), and accent (ACCENT_k)), and hypotheses ranks. Multiple options are disclosed for using stitching symbols **144**, as shown in FIGS. **4**-**6**D.

A hypothesis stitcher **300** consolidates merged hypotheses **150** into consolidated hypotheses **160**. In some examples, this may be accomplished by merging speaker-specific merged hypothesis sets **150***a*-**150***c* into speaker-specific consolidated hypotheses (e.g., consolidated hypothesis **160***a*, consolidated hypothesis **160***b*, and consolidated hypothesis **160***c*), whereas in some other examples, merged hypothesis set **150***a* is a multi-speaker merged hypothesis set that is merged into a multi-speaker version of consolidated hypothesis **160***a*. Hypothesis stitcher **300** may be network-based, and in some examples may comprise a neural network (NN). Various configurations are disclosed, for example, an alignment-based stitcher and a serialized stitcher that does not use an alignment of odd and even hypothesis sequences, and thus may have a relaxed overlap requirement. Further detail regarding hypothesis stitcher **300**, a stitcher trainer **310**, and hypothesis stitcher training data **312** is provided in relation to FIG. **3**.

Consolidated hypothesis **160***a* is output as a transcription **170**, which may be used for various tasks for which ASR results are useful, including live transcription of a conversation (e.g., a video call or speech) or streaming video, and voice commands. In some examples, consolidated hypothesis **160***a* is a multi-speaker consolidated hypothesis, and includes the multiple speakers (e.g., speakers **106***a*-**106***c*). In some examples, each of consolidated hypothesis **160***a*-**160***c* is a speaker-specific consolidated hypothesis and transcription **170** will then be a speaker-specific transcription, unless consolidated hypothesis **160***a*-**160***c* are merged into a multi-speaker version of transcription **170** by a transcription merger and annotator **162**. In some examples, transcription merger and annotator **162** intakes each of consolidated hypothesis **160***a*-**160** and outputs a multi-speaker version of transcription **170**. In some examples, transcription merger and annotator **162** annotates transcription **170** with timestamps, obtained by a timer **164**, which may be used for defining time windows used by audio segmenter **108** (so that the timestamps are properly synchronized with audio stream **102**).

FIG. **3** illustrates further details for hypothesis stitcher **300**. Hypothesis stitcher **300** comprises an encoder **304**, a decoder **306**, and an embedding function **302**. Embedding function **302** intakes a symbol (e.g., a word, a token, or a stitching symbol) and outputs a vector (called an embedding) corresponding to the symbol. In some examples, hypothesis stitcher **300** comprises a transformer-based attention encoder decoder architecture. In some examples, hypothesis stitcher **300** comprises a sequence-to-sequence model (e.g., a trained NN) that merges multiple hypotheses from short-segmented audio into a single hypothesis. In some examples, hypothesis stitcher **300** is trained using conversations that have been segmented according to the overlap that will be used during operations, tagged with stitching symbols **144** (so that hypothesis stitcher **300** learns stitching symbols **144**), and labeled for training. That is, hypothesis stitcher training data **312** includes stitching symbols **144** and has overlaps similar to overlaps in merged hypothesis set **150***a*.

In some examples, errors **314** are inserted into hypothesis stitcher training data **312** so that hypothesis stitcher **300** learns to correct errors, such as incorrect word **316** (e.g., mistakenly-recognized words in hypotheses) and incorrect speaker **318** (e.g., a mis-identified speaker). Variations such as an alignment-based stitcher and serialized stitcher are described in further detail in relation to FIGS. **4** and **5**.

FIG. **4** illustrates example hypothesis sequences, sequence **400***o* (o for "odd") and sequence **400***e* (e for "even"), which are combined into hypothesis set **150***a* for an alignment-based stitcher version of hypothesis stitcher **300**. In the scenario depicted, 50% overlap is used, in which the odd-numbered audio segments stop and start, and overlap with the even-numbered audio segments as indicated in FIG. **2**A. The hypotheses from odd-numbered (e.g., **401**) and even-numbered (e.g., **402**) hypotheses sets are jointed into two sequences **400***o* and **400***e*, as indicated in FIG. **4**.

Sequence **4000** ($\hat{Y}_{o,wc}{}^{k}$) has an odd numbered (1 is odd) hypothesis **401**, and other odd numbered hypotheses, for speaker k. Sequence **400***e* ($\hat{Y}_{e,wc}{}^{k}$) has an even numbered (2 is even) hypothesis **40**, and other even numbered hypotheses, also for speaker k. WC symbol **144***a* is inserted between the hypotheses to indicate a change of windows corresponding to changing from one audio segment to the next. Sequences **400***o* and **400***e* are word-aligned as a sequence of word pairs $<o_1, e_1>$, $<o_2, e_2>$, . . . $<o_L, e_L>$ for L pairs, where WC may be o_1 or e_1 for some pair l. Sequences **400***o* and **400***e* are then fused into merged hypothesis set **150***a* (or another merged hypothesis set) for consolidation by hypothesis stitcher **300**.

FIG. **5** illustrates two examples of hypothesis set **150***a* for a serialized stitcher version of hypothesis stitcher **300** are shown alternatively as hypothesis set **510** or hypothesis set **520**. In this scenario, overlap may be less than 50% because word alignment is not used. In some examples, the hypotheses for speaker k are joined as shown for hypothesis set **510**, which has both odd and even numbered hypotheses, for example odd-numbered hypothesis **501** ($\hat{Y}^{1,k}$), even-numbered hypothesis **502** ($\hat{Y}^{2,k}$), and WC symbol **144***a* inserted between hypotheses. Hypothesis set **520** is similar, although using WC symbols designated as even and odd, for example WCE symbol **144***b* and WCO symbol **144***c*. Hypothesis set **510** or **520** is provided as merged hypothesis set **150***a* (or another merged hypothesis set) for consolidation by hypothesis stitcher **300**.

FIGS. **6**A-**6**D illustrate multi-speaker data sets, in which all speakers' hypotheses are concatenated into a single sequence, and using a SPKR symbol as one of stitching symbols **144**. In some examples, the SPRK symbol indicates a speaker number k, as SPKR_k. To enable the relatively long sequences to be easily shown in FIGS. **6**A-**6**D, sequences uses W1, W2, . . . to indicate hypotheses for words in merged hypotheses **150** (e.g., ($\hat{Y}^{m,k}$) and SPKR_k is abbreviated as S1, S2, S3, S4, and S5, for k=1, 2, 3, 4, 5, respectively. That is, S1 is the abbreviated SPKR_k symbol for the first speaker (k=1).

Two variations for ordering SPKR symbols are shown in FIG. **6**A. Sequence **602** is ordered according to the order of a speaker's first-time appearance in audio stream **102** (and transcription **170**). Sequence **604** shows another possible variation, ordered according to the order of a speaker's profile in speaker profiles **122**. It should be noted that, because of overlap in the windows (e.g., audio segments **111-115**) some of the hypotheses in subsequent windows (e.g., words preceding a WC, WCE, or WCO symbol) correspond. That is, W11 and W12 may correspond to W9 and W10, for example. The output of hypothesis stitcher **300** is shown as sequence **606**, in which W1', W2', . . . indicate the words selected by hypothesis stitcher **300** for consolidated hypothesis **160**_a_ (or another consolidated hypothesis). In some examples, speaker symbols are assigned for along with other stitching symbols (e.g., <WCO > and <WCE>), and may take the form of a special identification, such as <Sn>, where n indicated the speaker number (according to an index in speaker profiles **122**).

FIG. **6**B shows variations for using SPKR symbols in the output of hypothesis stitcher **300** (e.g., consolidated hypothesis **160**_a_, or another consolidated hypothesis) as stitching symbols. Sequence **612** shows the same sequence of words (or tokens) as sequence **602** of FIG. **6**A, but with each word annotated. A special SPKR symbol<S0> may be assigned to each stitching symbol. The output of hypothesis stitcher **300** may alternatively be in the format of sequence **614**, in which each word (or token) is annotated with a SPKR symbol, or in the format of sequence **616**, in which the SPKR symbol is used at the end of a sequence of words attributed to a particular speaker (when the following word is attributed to a different speaker. In the illustrated example, sequences **606** and **616** are similar.

FIG. **6**C shows variations for using LANG symbols in the output of hypothesis stitcher **300** (e.g., consolidated hypothesis **160**_a_, or another consolidated hypothesis) as stitching symbols. Sequence **622** is similar to sequence **612** of FIG. **6**B, but adds a language annotation after each word. The output of hypothesis stitcher **300** may alternatively be in the format of sequence **624**, in which each word (or token) is annotated with a LANG symbol, or in the format of sequence **626**, in which the LANG symbol is used at the end of a sequence of words attributed to a particular speaker or a change in the detected language. In the format of sequence **622**, a special LANG symbol<LO> may be assigned to each stitching symbol. Other speaker attributes (speaker age, accent, and others) may also be embedded. When age annotation is included with stitching symbols, the annotation may take the form of a symbol that incorporates the actual numerical value estimated for a speaker.

FIG. **6**D shows the use of multiple ranked hypotheses, for example the N-best hypotheses, as estimated by E2E SRE **130**. In some examples, E2E SRE **130** is able to output more than a single hypothesis per detected word, and outputs multiple ranked hypotheses (ranked by probability of being correct). Sequence **632** shows a single speaker scenario in which a set of four words is identified as a best guess (N1) as W1, W2, W3, and W4, a second best guess (N2) as W1*, W2*, W3*, and W4*, and a third best guess (N3) as W1**, W2**, W3**, and W4**. An alternative sequence **634** shows the use of a best guess symbol N*in place of specific guess rank values, in which rank is inferred by the order. N1, N2, N3, and/or N*are used as stitching symbols in the input to hypothesis stitcher **300**. The output of hypothesis stitcher **300** is shown as sequence **636**, with selected words W1', W2', W3', and W4'. A multi-speaker version uses sequence **638**, in which the speaker is annotated after each set of N-best guesses. The output of hypothesis stitcher **300** is shown as sequence **640** with selected words W1', W2', W3', W4', W5', W6', W7', W8', W9', and W10'.

FIG. **7** is a flowchart **700** illustrating exemplary operations involved in performing speech recognition. In some examples, operations described for flowchart **700** are performed by computing device **900** of FIG. **9**. Flowchart **700** commences with operation **702**, which includes training E2E SRE **130**. In some examples, a joint model SRE (e.g., an end-to-end speaker-attributed ASR model) and speaker identification is trained in operation **702**, and operations **712**, **714**, **716** below use this joint model. Operation **704** includes training hypothesis stitcher **300** with hypothesis stitcher training data **312** comprising stitching symbols. In some examples, hypothesis stitcher training data **312** has overlaps similar to overlaps in merged hypothesis set **150**_a_. Operation **706**, which is included in operation **704**, includes inserting errors **314** into hypothesis stitcher training data **312**. In some examples, inserted errors **314** include an incorrectly identified word (in an overlapped region of a segment) or an incorrect speaker identification. In some examples, hypothesis stitcher **300** comprises an encoder and a decoder. In some examples, hypothesis stitcher **300** comprises a neural network. In some examples, hypothesis stitcher **300** comprises a transformer-based attention encoder decoder architecture. In some examples, hypothesis stitcher **300** comprises an alignment-based stitcher. In some examples, hypothesis stitcher **300** comprises a serialized stitcher that does not use an alignment of odd and even hypothesis sequences. In some examples, hypothesis stitcher **300** uses 25% overlap or less

Operation **708** includes receiving audio stream **102**. Operation **710** includes segmenting audio stream **102** into plurality of audio segments **110**. In some examples, each of the audio segments have a duration of less than a minute. Operation **712** includes identifying plurality of speakers **106** (e.g., identifying each of speakers **106**_a_-**106**_c_) within each of the plurality of audio segments **110** (e.g., within audio stream **102**). Operation **714** includes determining speaker characteristics. In some examples, the speaker characteristics are selected from a list consisting of: language, speaker age, and accent. Operation **716** includes performing ASR on each of plurality of audio segments **110** (e.g., audio segments **111-115**) to generate plurality of short-segment hypotheses **138**. In some examples, performing ASR comprises performing E2E ASR. In some example, operations **712-716** are performed as a single operation, using a common joint model (e.g., the end-to-end speaker-attributed ASR model described above). In some examples, short-segment hypotheses **138** comprise tokens representing words.

In some examples, short-segment hypotheses **138** are specific to a speaker, and so following operations **718-728** are performed for each speaker, using speaker-specific data sets (e.g., short-segment hypotheses **138**, merged hypotheses **156**, and consolidated hypotheses **160**). In some examples, short-segment hypotheses **138** are for multiple speakers, and so following operations **718-728** are performed using multi-speaker data sets (e.g., multi-speaker versions of short-segment hypothesis **138**, merged hypothesis set **156**_a_, and consolidated hypothesis **160**_a_).

Operation **718** includes merging at least a portion of short-segment hypotheses **138** into merged hypothesis set **150**_a_, and is performed using operations **720-724**. In some examples, merging at least a portion of short-segment hypotheses **138** into merged hypothesis set **150**_a_ comprises concatenated tokenized hypotheses. In some examples, merged hypothesis set **150**_a_ comprises a multi-speaker merged hypothesis set. In some examples, merged hypothesis set **150**_a_ comprises hypotheses ranks. In some examples, merged hypothesis set **150**_a_ is specific to a first speaker of plurality of speakers **106**, and so operation **718** further includes merging at least a portion of short-segment hypotheses **138** into merged hypothesis set **150***b* specific to a second speaker of plurality of speakers **106**. Operation **720** includes grouping separate ASR results by speaker.

Operation **722** includes inserting stitching symbols **144** into merged hypothesis set **150***a*, stitching symbols **144** including a WC symbol (e.g., WC symbol **144***a*, WCE symbol **144***b*, and/or WCO symbol **144***c*). In some examples, operation **722** further includes, based on at least the determined speaker characteristics inserting speaker characteristic tags as stitching symbols **144** into merged hypothesis set **150***a*. In some examples, stitching symbols **144** including at least one symbol selected from the list consisting of: a WC symbol, a WCE symbol, a WCO symbol, an SPKR symbol, an SPKR_k symbol, and a speaker characteristic symbol or value.

In speaker-specific scenarios, operation **722** further includes inserting stitching symbols into merged hypothesis set **150***b*. In some examples, stitching symbols **144** further include a speaker identification (e.g., SPKR_k). In examples using an alignment-based stitcher (see FIG. **4**), merged hypothesis set **150***a* comprises an odd hypothesis sequence and an even hypothesis sequence, and operation **724** includes aligning the odd hypothesis sequence with the even hypothesis sequence. In some examples, aligning the odd hypothesis sequence with the even hypothesis sequence comprises pairing words or tokens in the odd sequence with words or tokens in the even sequence.

Operation **726** includes **726** consolidating, with (network-based) hypothesis stitcher **300**, merged hypothesis set **150***a* into consolidated hypothesis **160***a*. In some examples, consolidated hypothesis **160***a* comprise tokens representing words. In some examples, consolidated hypothesis **160***a* is specific to a speaker (e.g., one of speakers **106***a*-**106***c*. In the situation of speaker-specific consolidated hypotheses **160**, operation **726** also includes consolidating, with hypothesis stitcher **300**, merged hypothesis set **150***b* into consolidated hypothesis **160***b*, specific to a second speaker.

Operation **728** includes outputting consolidated hypothesis **160***a* as transcription **170**. If consolidated hypothesis **160***a* had been a speaker-specific consolidated hypothesis, operations **730**-**734** are used to produce a multi-speaker version of transcription **170**. However, if operation **728** had output multi-speaker version of transcription **170**, operation **730**-**734** may be unnecessary. Operation **730** includes merging consolidated hypothesis **160***a* with consolidated hypothesis **160***b* to generate a multi-speaker version of transcription **170**. Operation **732** includes identifying speakers **106***a*-**106***c* within the multi-speaker version of transcription **170**. Operation **734** includes outputting the multi-speaker version of transcription **170**, if operation **728** had only output a speaker-specific version of transcription **170**.

FIG. **8** is a flowchart **800** that illustrates exemplary operations involved in performing speech recognition. In some examples, operations described for flowchart **800** are performed by computing device **900** of FIG. **9**. Flowchart **800** commences with operation **802**, which includes segmenting the audio stream into a plurality of audio segments. Operation **804** includes identifying a plurality of speakers within the audio stream (e.g., within the plurality of audio segments). Operation **806** includes performing ASR on each of the plurality of audio segments to generate a plurality of short-segment hypotheses. Operation **808** includes merging at least a portion of the short-segment hypotheses into a first merged hypothesis set. Operation **810** includes inserting stitching symbols into the first merged hypothesis set, the stitching symbols including a WC symbol. Operation **812** includes consolidating, with a network-based hypothesis stitcher, the first merged hypothesis set into a first consolidated hypothesis.

Additional Examples

An example method of speech recognition comprises: segmenting the audio stream into a plurality of audio segments; identifying a plurality of speakers within the audio stream; performing ASR on each of the plurality of audio segments to generate a plurality of short-segment hypotheses; merging at least a portion of the short-segment hypotheses into a first merged hypothesis set; inserting stitching symbols into the first merged hypothesis set, the stitching symbols including a WC symbol; and consolidating, with a network-based hypothesis stitcher, the first merged hypothesis set into a first consolidated hypothesis.

An example system for speech recognition comprises: a processor; and a computer-readable medium storing instructions that are operative upon execution by the processor to: segmenting the audio stream into a plurality of audio segments; identifying a plurality of speakers within the audio stream; perform ASR on each of the plurality of audio segments to generate a plurality of short-segment hypotheses; merge at least a portion of the short-segment hypotheses into a first merged hypothesis set; insert stitching symbols into the first merged hypothesis set, the stitching symbols including a WC symbol; and consolidate, with a network-based hypothesis stitcher, the first merged hypothesis set into a first consolidated hypothesis.

One or more example computer storage devices has computer-executable instructions stored thereon, which, on execution by a computer, cause the computer to perform operations comprising: segmenting the audio stream into a plurality of audio segments; identifying a plurality of speakers within the audio stream; performing ASR on each of the plurality of audio segments to generate a plurality of short-segment hypotheses; merging at least a portion of the short-segment hypotheses into a first merged hypothesis set; inserting stitching symbols into the first merged hypothesis set, the stitching symbols including a window change (WC) symbol; and consolidating, with a network-based hypothesis stitcher, the first merged hypothesis set into a first consolidated hypothesis.

Alternatively, or in addition to the other examples described herein, examples may include any combination of the following:

- outputting the first consolidated hypothesis as a transcription;
- the first merged hypothesis set is specific to a first speaker of the plurality of speakers;
- the first consolidated hypothesis is specific to the first speaker;
- merging at least a portion of the short-segment hypotheses into a second merged hypothesis set specific to a second speaker of the plurality of speakers;
- inserting stitching symbols into the second merged hypothesis;
- consolidating, with the hypothesis stitcher, the second merged hypothesis set into a second consolidated hypothesis specific to the second speaker;
- the first merged hypothesis set comprises a multi-speaker merged hypothesis set;
- the stitching symbols further include a speaker identification;
- the hypothesis stitcher comprises an alignment-based stitcher;

the first merged hypothesis set comprises an odd hypothesis sequence and an even hypothesis sequence;
aligning the odd hypothesis sequence with the even hypothesis sequence;
the hypothesis stitcher comprises a serialized stitcher that does not use an alignment of odd and even hypothesis sequences;
the hypothesis stitcher uses 25% overlap or less;
the first merged hypothesis set comprises hypotheses ranks;
performing ASR comprises performing E2E ASR;
the short-segment hypotheses and the first consolidated hypothesis comprise tokens representing words;
aligning the odd hypothesis sequence with the even hypothesis sequence comprises pairing words or tokens in the odd sequence with words or tokens in the even sequence;
the hypothesis stitcher comprises an encoder and a decoder;
the hypothesis stitcher comprises a neural network;
the hypothesis stitcher comprises a transformer-based attention encoder decoder architecture.
determining speaker characteristics;
the speaker characteristics are selected from a list consisting of: language, speaker age, and accent;
based on at least the determined speaker characteristics inserting speaker characteristic tags as stitching symbols into the first merged hypothesis set;
the stitching symbols further including at least one symbol selected from the list consisting of: a WCE symbol, a WCO symbol, a SPKR symbol, a numbered speaker symbol, and a speaker characteristic symbol or value;
training the hypothesis stitcher with hypothesis stitcher training data comprising stitching symbols;
inserting errors into the hypothesis stitcher training data;
the inserted errors include an incorrectly identified word in an overlapped region of a segment or an incorrect speaker identification;
the hypothesis stitcher training data has overlaps similar to overlaps in the first merged hypothesis set;
merging at least a portion of the short-segment hypotheses into the first merged hypothesis set comprises concatenated tokenized hypotheses;
merging the first consolidated hypothesis with the second consolidated hypothesis to generate a multi-speaker transcription;
identifying speakers within the multi-speaker transcription;
outputting the multi-speaker transcription;
receiving the audio stream;
the audio segments have a duration of less than a minute; and
training the E2E SRE.

While the aspects of the disclosure have been described in terms of various examples with their associated operations, a person skilled in the art would appreciate that a combination of operations from any number of different examples is also within scope of the aspects of the disclosure.

Example Operating Environment

FIG. **9** is a block diagram of an example computing device **900** for implementing aspects disclosed herein, and is designated generally as computing device **900**. Computing device **900** is but one example of a suitable computing environment and is not intended to suggest any limitation as to the scope of use or functionality of the examples disclosed herein. Neither should computing device **900** be interpreted as having any dependency or requirement relating to any one or combination of components/modules illustrated. The examples disclosed herein may be described in the general context of computer code or machine-useable instructions, including computer-executable instructions such as program components, being executed by a computer or other machine, such as a personal data assistant or other handheld device. Generally, program components including routines, programs, objects, components, data structures, and the like, refer to code that performs particular tasks, or implement particular abstract data types. The disclosed examples may be practiced in a variety of system configurations, including personal computers, laptops, smart phones, mobile tablets, hand-held devices, consumer electronics, specialty computing devices, etc. The disclosed examples may also be practiced in distributed computing environments when tasks are performed by remote-processing devices that are linked through a communications network.

Computing device **900** includes a bus **910** that directly or indirectly couples the following devices: computer-storage memory **912**, one or more processors **914**, one or more presentation components **916**, I/O ports **918**, I/O components **920**, a power supply **922**, and a network component **924**. While computing device **900** is depicted as a seemingly single device, multiple computing devices **900** may work together and share the depicted device resources. In one example embodiment, memory **912** is distributed across multiple devices, and processor(s) **914** is housed with different devices.

Bus **910** represents what may be one or more busses (such as an address bus, data bus, or a combination thereof). Although the various blocks of FIG. **9** are shown with lines for the sake of clarity, delineating various components may be accomplished with alternative representations. For example, a presentation component such as a display device is an I/O component in some examples, and some examples of processors have their own memory. Distinction is not made between such categories as "workstation," "server," "laptop," "hand-held device," etc., as all are contemplated within the scope of FIG. **9** and the references herein to a "computing device." Memory **912** may take the form of the computer-storage media references below and operatively provide storage of computer-readable instructions, data structures, program modules and other data for the computing device **900**. In some examples, memory **912** stores one or more of an operating system, a universal application platform, or other program modules and program data. Memory **912** is thus able to store and access data **912***a* and instructions **912***b* that are executable by processor **914** and configured to carry out the various operations disclosed herein.

In some examples, memory **912** includes computer-storage media in the form of volatile and/or nonvolatile memory, removable or non-removable memory, data disks in virtual environments, or a combination thereof. Memory **912** may include any quantity of memory associated with or accessible by the computing device **900**. Memory **912** may be internal to the computing device **900** (as shown in FIG. **9**), external to the computing device **900** (not shown), or both (not shown). Examples of memory **912** in include, without limitation, random access memory (RAM); read only memory (ROM); electronically erasable programmable read only memory (EEPROM); flash memory or other memory technologies; CD-ROM, digital versatile disks (DVDs) or other optical or holographic media; magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices; memory wired into an analog computing device; or any other medium for encoding desired information and for access by the computing device **900**. Additionally, or alternatively, the memory **912** may be distributed across multiple computing devices **900**, for example, in a virtualized environment in which instruction processing is carried out on multiple devices **900**. For the purposes of this disclosure, "computer storage media," "computer-storage memory," "memory," and "memory devices" are synonymous terms for the computer-storage memory **912**, and none of these terms include carrier waves or propagating signaling.

Processor(s) **914** may include any quantity of processing units that read data from various entities, such as memory **912** or I/O components **920**. Specifically, processor(s) **914** are programmed to execute computer-executable instructions for implementing aspects of the disclosure. The instructions may be performed by the processor, by multiple processors within the computing device **900**, or by a processor external to the client computing device **900**. In some examples, the processor(s) **914** are programmed to execute instructions such as those illustrated in the flow charts discussed below and depicted in the accompanying drawings. Moreover, in some examples, the processor(s) **914** represent an implementation of analog techniques to perform the operations described herein. In one example embodiment, the operations are performed by an analog client computing device **900** and/or a digital client computing device **900**. Presentation component(s) **916** present data indications to a user or other device. Exemplary presentation components include a display device, speaker, printing component, vibrating component, etc. One skilled in the art will understand and appreciate that computer data may be presented in a number of ways, such as visually in a graphical user interface (GUI), audibly through speakers, wirelessly between computing devices **900**, across a wired connection, or in other ways. I/O ports **918** allow computing device **900** to be logically coupled to other devices including I/O components **920**, some of which may be built in. Example I/O components **920** include, for example but without limitation, a microphone, joystick, game pad, satellite dish, scanner, printer, wireless device, etc.

The computing device **900** may operate in a networked environment via the network component **924** using logical connections to one or more remote computers. In some examples, the network component **924** includes a network interface card and/or computer-executable instructions (e.g., a driver) for operating the network interface card. Communication between the computing device **900** and other devices may occur using any protocol or mechanism over any wired or wireless connection. In some examples, network component **924** is operable to communicate data over public, private, or hybrid (public and private) using a transfer protocol, between devices wirelessly using short range communication technologies (e.g., near-field communication (NFC), Bluetooth™ branded communications, or the like), or a combination thereof. Network component **924** communicates over wireless communication link **926** and/or a wired communication link **926***a* to a cloud resource **928** across network **930**. Various different examples of communication links **926** and **926***a* include a wireless connection, a wired connection, and/or a dedicated link, and in some examples, at least a portion is routed through the internet.

Although described in connection with an example computing device **900**, examples of the disclosure are capable of implementation with numerous other general-purpose or special-purpose computing system environments, configurations, or devices. Examples of well-known computing systems, environments, and/or configurations that may be suitable for use with aspects of the disclosure include, but are not limited to, smart phones, mobile tablets, mobile computing devices, personal computers, server computers, hand-held or laptop devices, multiprocessor systems, gaming consoles, microprocessor-based systems, set top boxes, programmable consumer electronics, mobile telephones, mobile computing and/or communication devices in wearable or accessory form factors (e.g., watches, glasses, headsets, or earphones), network PCs, minicomputers, mainframe computers, distributed computing environments that include any of the above systems or devices, virtual reality (VR) devices, augmented reality (AR) devices, mixed reality (MR) devices, holographic device, and the like. Such systems or devices may accept input from the user in any way, including from input devices such as a keyboard or pointing device, via gesture input, proximity input (such as by hovering), and/or via voice input.

Examples of the disclosure may be described in the general context of computer-executable instructions, such as program modules, executed by one or more computers or other devices in software, firmware, hardware, or a combination thereof. The computer-executable instructions may be organized into one or more computer-executable components or modules. Generally, program modules include, but are not limited to, routines, programs, objects, components, and data structures that perform particular tasks or implement particular abstract data types. Aspects of the disclosure may be implemented with any number and organization of such components or modules. For example, aspects of the disclosure are not limited to the specific computer-executable instructions or the specific components or modules illustrated in the figures and described herein. Other examples of the disclosure may include different computer-executable instructions or components having more or less functionality than illustrated and described herein. In examples involving a general-purpose computer, aspects of the disclosure transform the general-purpose computer into a special-purpose computing device when configured to execute the instructions described herein.

By way of example and not limitation, computer readable media comprise computer storage media and communication media. Computer storage media include volatile and nonvolatile, removable and non-removable memory implemented in any method or technology for storage of information such as computer readable instructions, data structures, program modules, or the like. Computer storage media are tangible and mutually exclusive to communication media. Computer storage media are implemented in hardware and exclude carrier waves and propagated signals. Computer storage media for purposes of this disclosure are not signals per se. Exemplary computer storage media include hard disks, flash drives, solid-state memory, phase change random-access memory (PRAM), static random-access memory (SRAM), dynamic random-access memory (DRAM), other types of random-access memory (RAM), read-only memory (ROM), electrically erasable programmable read-only memory (EEPROM), flash memory or other memory technology, compact disk read-only memory (CD-ROM), digital versatile disks (DVD) or other optical storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices, or any other non-transmission medium that may be used to store information for access by a computing device. In contrast, communication media typically embody computer readable instructions, data structures, program modules, or the like in a modulated data signal such as a carrier wave or other transport mechanism and include any information delivery media.

The order of execution or performance of the operations in examples of the disclosure illustrated and described herein is not essential, and may be performed in different sequential manners in various examples. For example, it is contemplated that executing or performing a particular operation before, contemporaneously with, or after another operation is within the scope of aspects of the disclosure. When introducing elements of aspects of the disclosure or the examples thereof, the articles "a," "an," "the," and "said" are intended to mean that there are one or more of the elements. The terms "comprising," "including," and "having" are intended to be inclusive and mean that there may be additional elements other than the listed elements. The term "exemplary" is intended to mean "an example of" The phrase "one or more of the following: A, B, and C" means "at least one of A and/or at least one of B and/or at least one of C."

Having described aspects of the disclosure in detail, it will be apparent that modifications and variations are possible without departing from the scope of aspects of the disclosure as defined in the appended claims. As various changes could be made in the above constructions, products, and methods without departing from the scope of aspects of the disclosure, it is intended that all matter contained in the above description and shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. A computer-implemented method, comprising:

segmenting an audio stream into a plurality of audio segments using a sliding window with overlaps among the plurality of audio segments, wherein a segment length of each audio segment in the plurality of audio segments is equal to a window length of the sliding window, the window length of the sliding window being consistent for the plurality of audio segments, and wherein each overlap comprises an overlap duration of a fraction of a length of the sliding window;

identifying a plurality of speakers within the audio stream;

determining speaker characteristics for each speaker of the plurality of speakers;

performing automatic speech recognition (ASR) on each of the plurality of audio segments to generate a plurality of short-segment hypotheses;

merging a first portion of the plurality of short-segment hypotheses into a first merged hypothesis set;

based on the determined speaker characteristics, inserting stitching symbols, the stitching symbols comprising speaker characteristic tags, into the first merged hypothesis set;

consolidating, with a hypothesis stitcher, the first merged hypothesis set into a first consolidated hypothesis; and

outputting the first consolidated hypothesis as a transcription.

2. The computer-implemented method of claim **1**, wherein the speaker characteristics are selected from a list consisting of: language, speaker age, and accent.

3. The computer-implemented method of claim **1**, wherein the first merged hypothesis set is specific to a first speaker of the plurality of speakers, and wherein the method further comprises:

merging a second portion of the plurality of short-segment hypotheses into a second merged hypothesis set specific to a second speaker of the plurality of speakers;

inserting the stitching symbols into the second merged hypothesis set;

consolidating, with the hypothesis stitcher, the second merged hypothesis set into a second consolidated hypothesis specific to the second speaker; and

merging the first consolidated hypothesis with the second consolidated hypothesis to generate a multi-speaker transcription.

4. The computer-implemented method of claim **3**, further comprising:

identifying the plurality of speakers within the multi-speaker transcription; and

outputting the multi-speaker transcription.

5. The computer-implemented method of claim **1**, wherein the first consolidated hypothesis is a multi-speaker consolidated hypothesis, and wherein a speaker identification is used as one of the stitching symbols.

6. The computer-implemented method of claim **1**, wherein each audio segment of the plurality of audio segments has an overlap.

7. The computer-implemented method of claim **6**, wherein training data for the hypothesis stitcher comprises overlaps similar to overlaps in the first merged hypothesis set.

8. A system for speech recognition, the system comprising:

a processor; and

a computer-readable non-transitory medium storing instructions that are operative upon execution by the processor to:

segment an audio stream into a plurality of audio segments using a sliding window with overlaps among the plurality of audio segments, wherein a segment length of each audio segment in the plurality of audio segments is equal to a window length of the sliding window, the window length of the sliding window being consistent for the plurality of audio segments, and wherein each overlap comprises an overlap duration of a fraction of a length of the sliding window;

identify a plurality of speakers within the audio stream;

determine speaker characteristics for each speaker of the plurality of speakers;

perform automatic speech recognition (ASR) on each of the plurality of audio segments to generate a plurality of short-segment hypotheses;

merge a first portion of the plurality of short-segment hypotheses into a first merged hypothesis set;

based on the determined speaker characteristics, insert stitching symbols, the stitching symbols comprising speaker characteristic tags, into the first merged hypothesis set;

consolidate, with a hypothesis stitcher, the first merged hypothesis set into a first consolidated hypothesis; and

output the first consolidated hypothesis as a transcription.

9. The system of claim **8**, wherein the speaker characteristics are selected from a list consisting of: language, speaker age, and accent.

10. The system of claim **8**, wherein the first merged hypothesis set is specific to a first speaker of the plurality of speakers, and wherein the instructions are further operative to:

merge a second portion of the plurality of short-segment hypotheses into a second merged hypothesis set specific to a second speaker of the plurality of speakers;

insert the stitching symbols into the second merged hypothesis set;

consolidate, with the hypothesis stitcher, the second merged hypothesis set into a second consolidated hypothesis specific to the second speaker; and

merge the first consolidated hypothesis with the second consolidated hypothesis to generate a multi-speaker transcription.

11. The system of claim **10**, wherein the instructions are further operative to:

identify the plurality of speakers within the multi-speaker transcription; and

output the multi-speaker transcription.

12. The system of claim **8**, wherein the first consolidated hypothesis is a multi-speaker consolidated hypothesis, and wherein a speaker identification is used as one of the stitching symbols.

13. The system of claim **8**, wherein each audio segment of the plurality of audio segments has an overlap.

14. The system of claim **13**, wherein training data for the hypothesis stitcher comprises overlaps similar to overlaps in the first merged hypothesis set.

15. One or more computer storage devices having computer-executable instructions stored thereon, which, on execution by a computer, cause the computer to perform operations comprising:

segmenting an audio stream into a plurality of audio segments using a sliding window with overlaps among the plurality of audio segments, wherein a segment length of each audio segment in the plurality of audio segments is equal to a window length of the sliding window, the window length of the sliding window being consistent for the plurality of audio segments, and wherein each overlap comprises an overlap duration of a fraction of a length of the sliding window;

identifying a plurality of speakers within the audio stream;

determining speaker characteristics for each speaker of the plurality of speakers;

performing automatic speech recognition (ASR) on each of the plurality of audio segments to generate a plurality of short-segment hypotheses;

merging a first portion of the plurality of short-segment hypotheses into a first merged hypothesis set;

based on the determined speaker characteristics, inserting stitching symbols, the stitching symbols comprising speaker characteristic tags, into the first merged hypothesis set;

consolidating, with a hypothesis stitcher, the first merged hypothesis set into a first consolidated hypothesis; and

outputting the first consolidated hypothesis as a transcription.

16. The one or more computer storage device of claim **15**, wherein the speaker characteristics are selected from a list consisting of: language, speaker age, and accent.

17. The one or more computer storage device of claim **15**, wherein the first merged hypothesis set is specific to a first speaker of the plurality of speakers, and wherein the operations further comprise:

merging a second portion of the plurality of short-segment hypotheses into a second merged hypothesis set specific to a second speaker of the plurality of speakers;

inserting the stitching symbols into the second merged hypothesis set;

consolidating the second merged hypothesis set into a second consolidated hypothesis specific to the second speaker; and

merging the first consolidated hypothesis with the second consolidated hypothesis to generate a multi-speaker transcription.

18. The one or more computer storage device of claim **17**, further comprising:

identifying the plurality of speakers within the multi-speaker transcription; and

outputting the multi-speaker transcription.

19. The one or more computer storage device of claim **15**, wherein the first consolidated hypothesis is a multi-speaker consolidated hypothesis, and wherein a speaker identification is used as one of the stitching symbols.

20. The one or more computer storage device of claim **15**, wherein each audio segment of the plurality of audio segments has an overlap, and wherein training data for the hypothesis stitcher comprises overlaps similar to overlaps in the first merged hypothesis set.

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