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(54) **SYSTEM AND METHOD FOR UPDATING AN ADAPTIVE SPEECH RECOGNITION MODEL**

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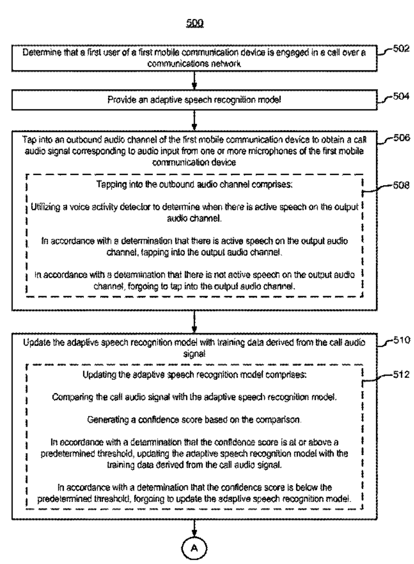
(57) **ABSTRACT**

A method for updating an adaptive speech recognition model is provided. In some implementations, the method is performed at a communications device including one or more processors and memory storing instructions for execution by the one or more processors. The method includes determining that a first user of a first mobile communication device is engaged in a call over a communications network and providing an adaptive speech recognition model The method also includes analyzing an outbound audio channel of the first mobile communication device to obtain a call audio signal corresponding to audio input from one or more microphones of the first mobile communication device and updating the adaptive speech recognition model with training data derived from the call audio signal.

26 Claims, 9 Drawing Sheets



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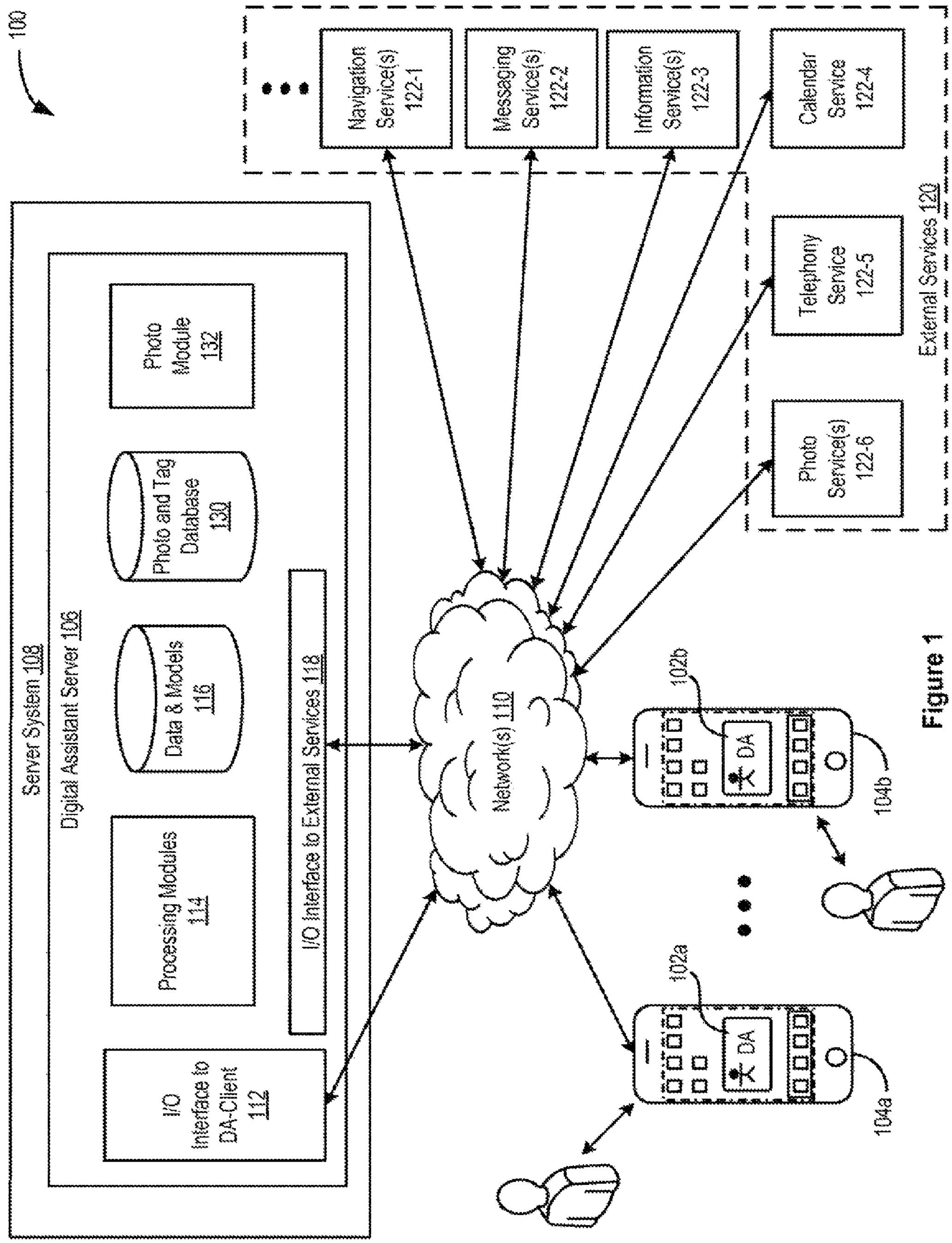
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Digital Assistant Server 106
I/O Interface to DA-Client 112
Processing Modules 114
Data & Models 116
Photo and Tag Database 130
Photo Module 132
I/O Interface to External Services 118
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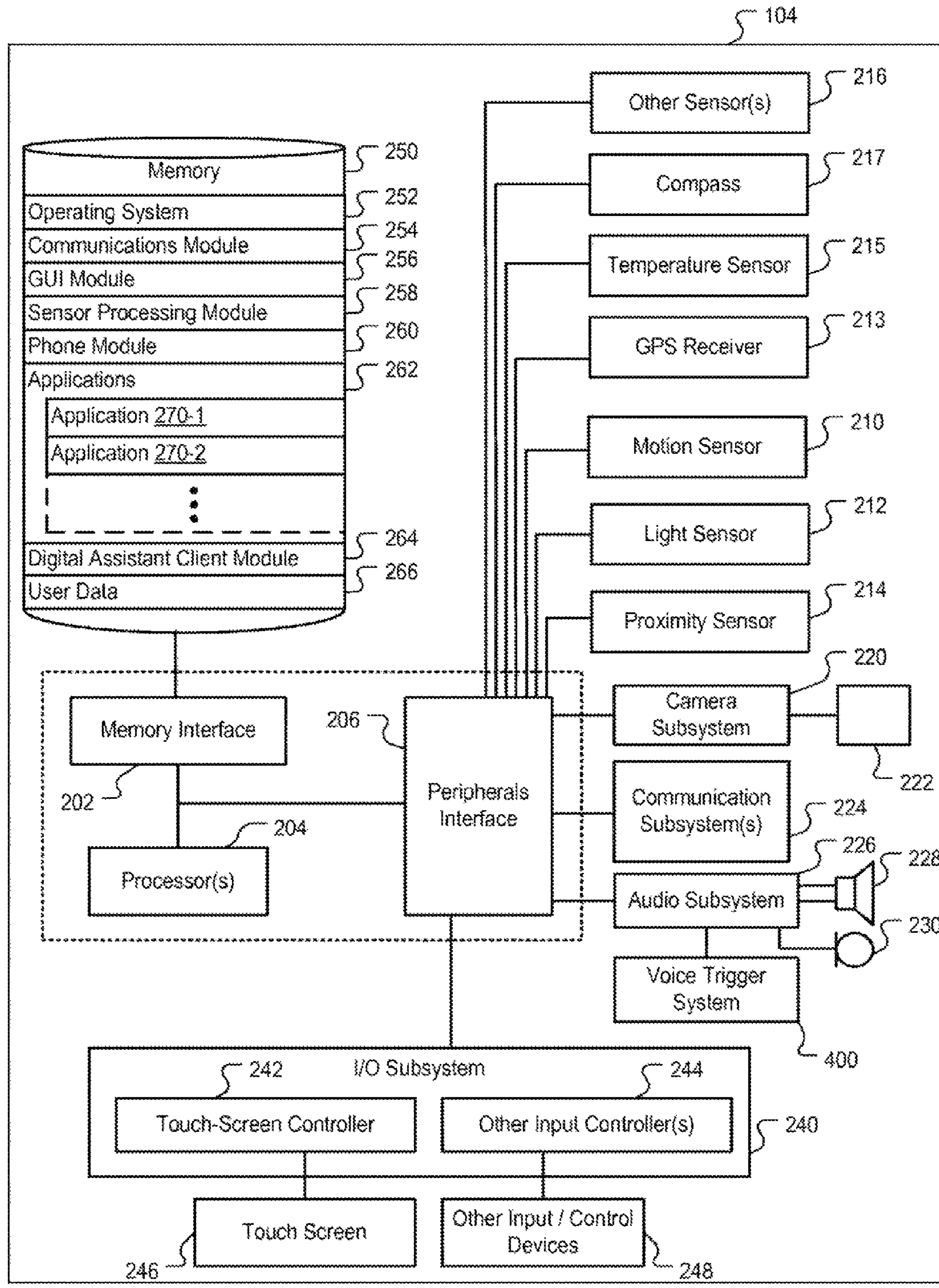
Navigation Service(s) 122-1
Messaging Service(s) 122-2
Information Service(s) 122-3
Calendar Service 122-4
Telephony Service 122-5
Photo Service(s) 122-6
External Services 120
102a
102b
DA
DA
104a
104b

Figure 1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Compass
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Temperature Sensor
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GPS Receiver
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Light Sensor
212
Proximity Sensor
214
Memory
250
Operating System
252
Communications Module
254
GUI Module
256
Sensor Processing Module
258
Phone Module
260
Applications
262
Application 270-1
Application 270-2
Digital Assistant Client Module
264
User Data
266
Memory Interface
202
206
Peripherals Interface
204
Processor(s)
Camera Subsystem
220
222
Communication Subsystem(s)
224
226
228
Audio Subsystem
230
Voice Trigger System
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I/O Subsystem
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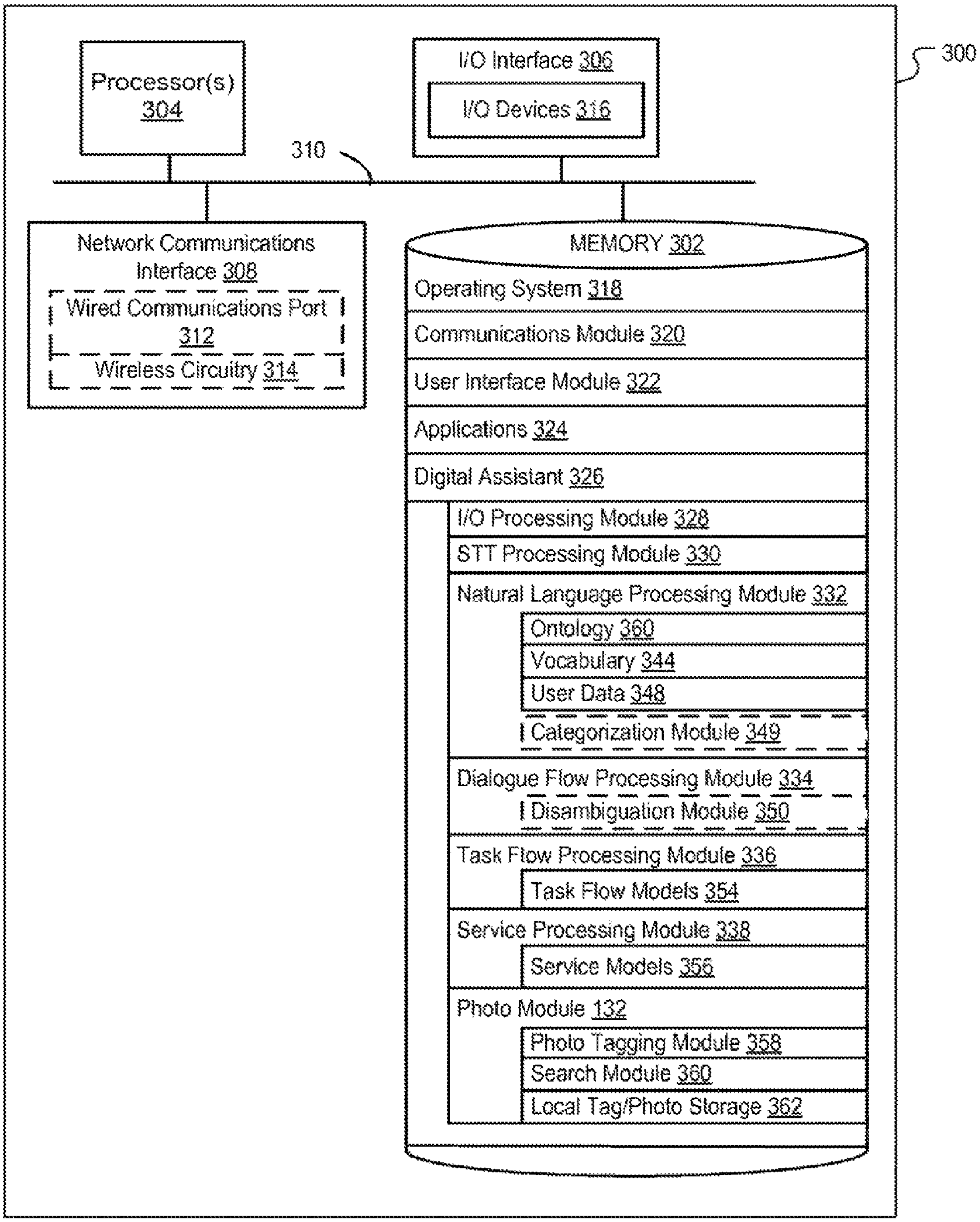
Touch-Screen Controller
Other Input Controller(s)
240
Touch Screen
Other Input / Control Devices
246
248

Figure 2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I/O Interface 306
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310
Network Communications Interface 308
Wired Communications Port 312
Wireless Circuitry 314
MEMORY 302
Operating System 318
Communications Module 320
User Interface Module 322
Applications 324
Digital Assistant 326
I/O Processing Module 328
STT Processing Module 330
Natural Language Processing Module 332
Ontology 360
Vocabulary 344
User Data 348
Categorization Module 349
Dialogue Flow Processing Module 334
Disambiguation Module 350
Task Flow Processing Module 336
Task Flow Models 354
Service Processing Module 338
Service Models 356
Photo Module 132
Photo Tagging Module 358
Search Module 360
Local Tag/Photo Storage 362

Figure 3A

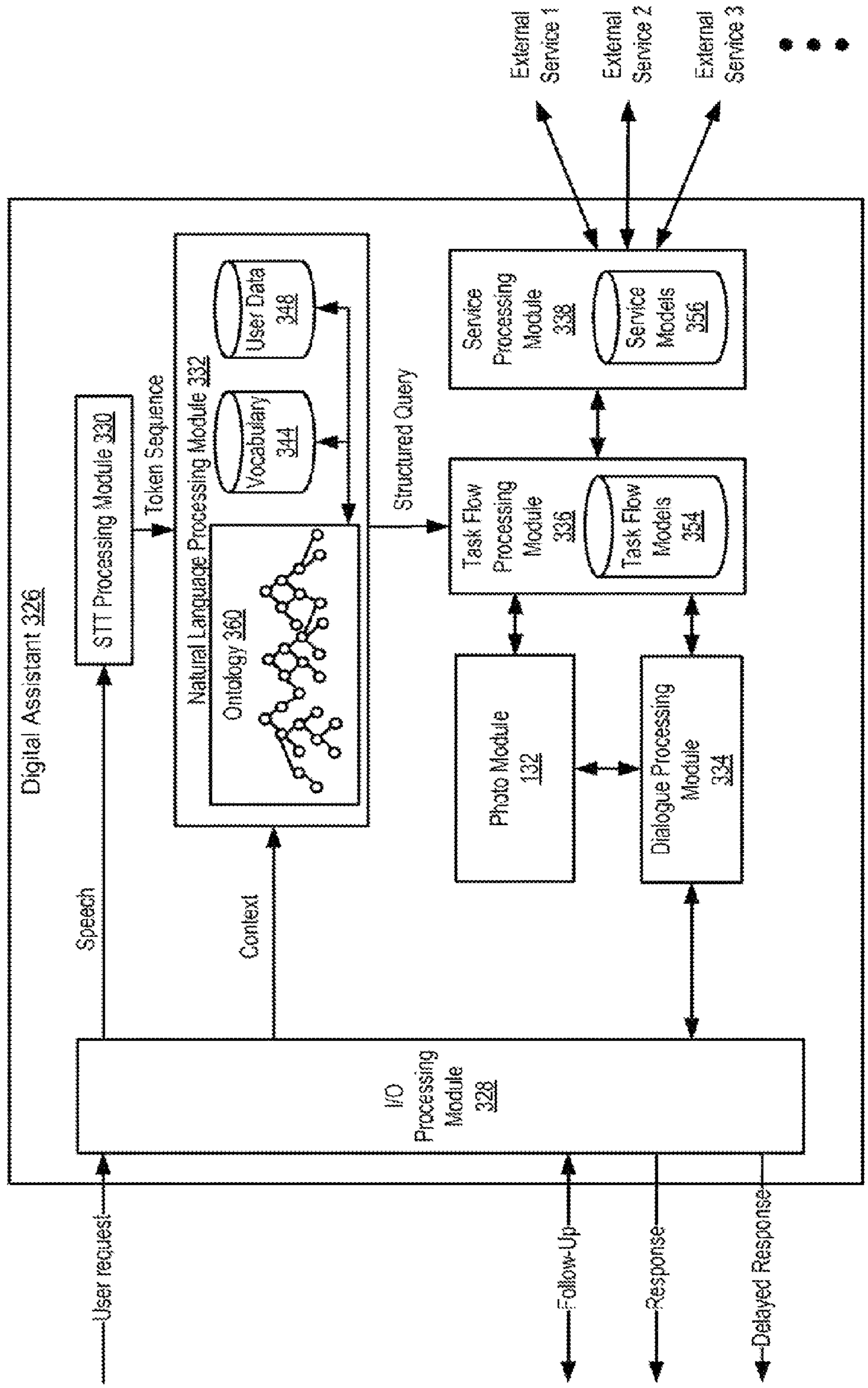

Digital Assistant 326
I/O Processing Module 328
STT Processing Module 330
Natural Language Processing Module 332
Ontology 360
Vocabulary 344
User Data 348
Task Flow Processing Module 336
Task Flow Models 354
Service Processing Module 338
Service Models 356
Photo Module 132
Dialogue Processing Module 334
Speech
Context
Token Sequence
Structured Query
User request
Follow-Up
Response
Delayed Response
External Service 1
External Service 2
External Service 3

Figure 3B

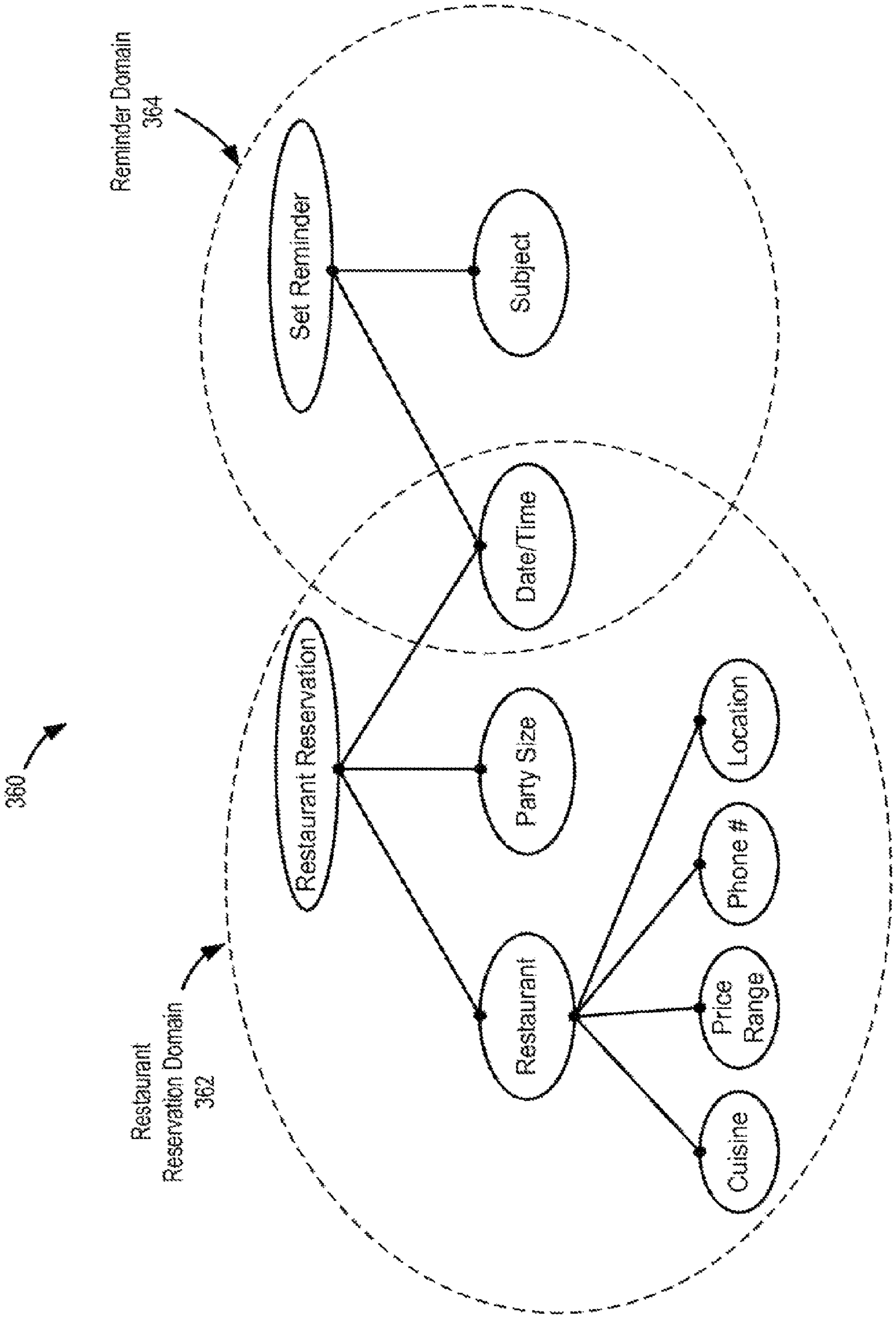

360
Reminder Domain
364
Set Reminder
Subject
Date/Time
Restaurant Reservation
Party Size
Restaurant
Location
Phone #
Price
Range
Cuisine
Restaurant
Reservation Domain
362

Figure 3C

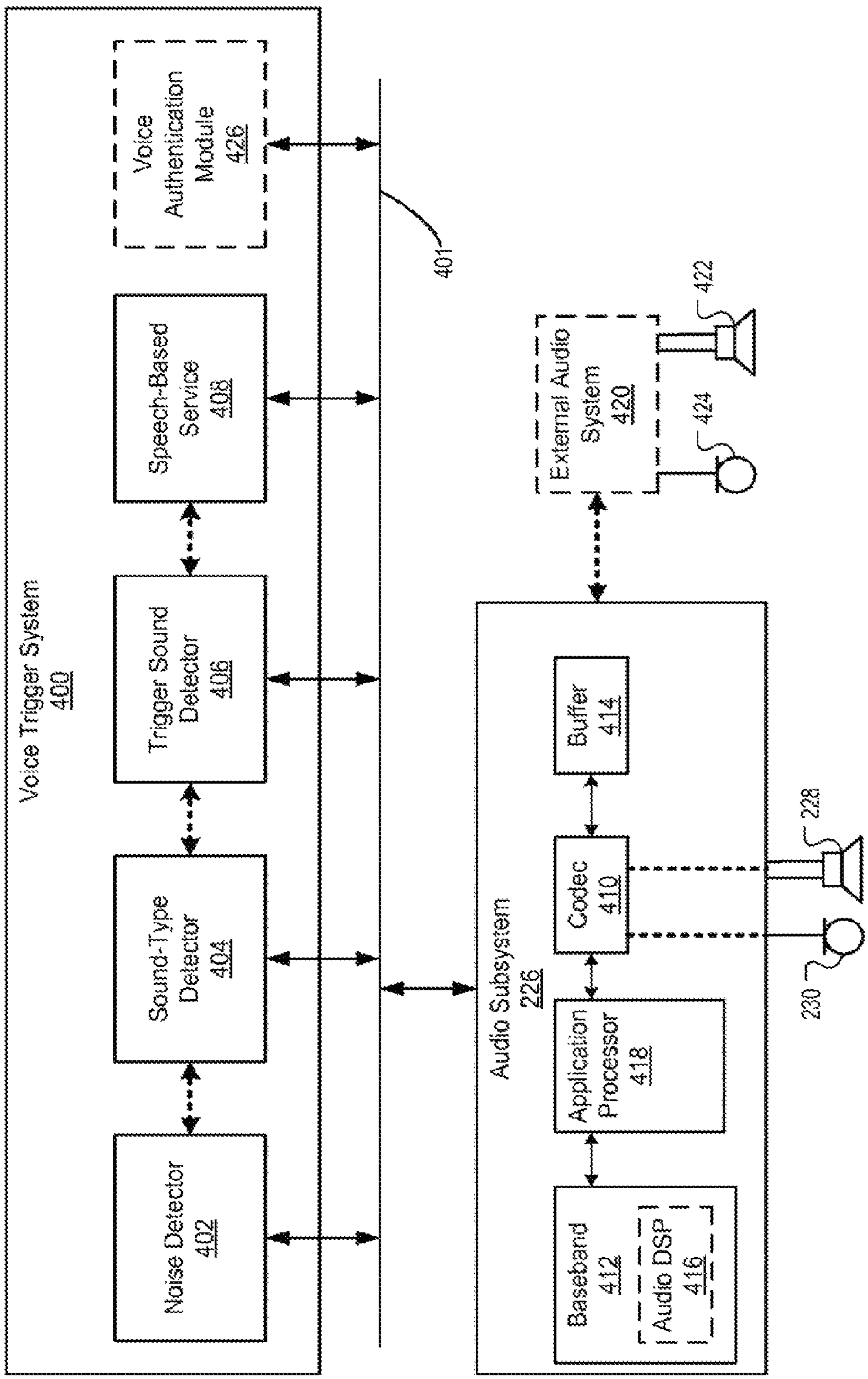

Voice Trigger System
400
Noise Detector
402
Sound-Type Detector
404
Trigger Sound Detector
406
Speech-Based Service
408
Voice Authentication Module
426
401
External Audio System
420
422
424
Audio Subsystem
226
Baseband
412
Audio DSP
416
Application Processor
418
Codec
410
Buffer
414
228
230

Figure 4

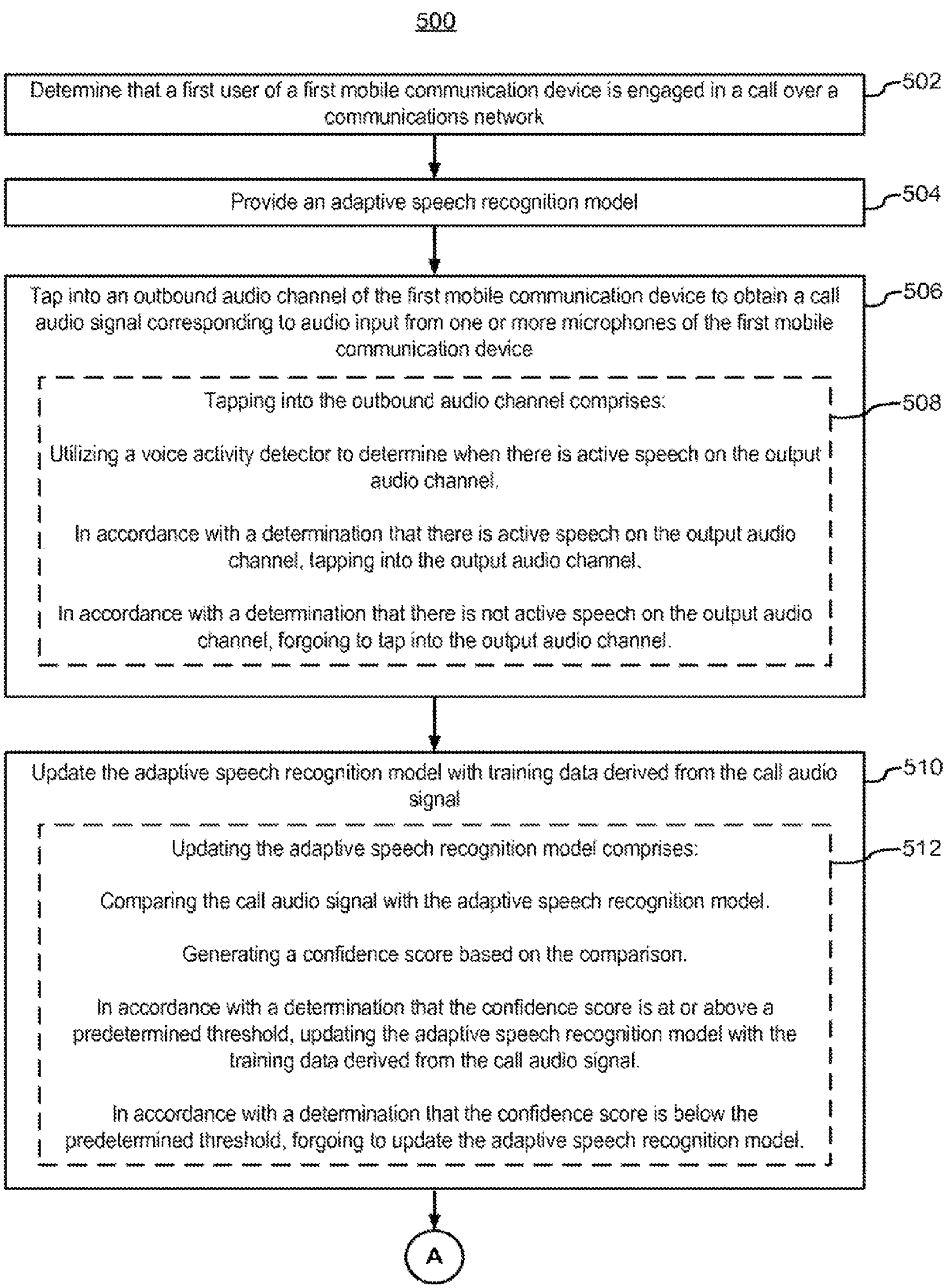

500
Determine that a first user of a first mobile communication device is engaged in a call over a communications network
502
Provide an adaptive speech recognition model
504
Tap into an outbound audio channel of the first mobile communication device to obtain a call audio signal corresponding to audio input from one or more microphones of the first mobile communication device
506
Tapping into the outbound audio channel comprises:
Utilizing a voice activity detector to determine when there is active speech on the output audio channel.
In accordance with a determination that there is active speech on the output audio channel, tapping into the output audio channel.
In accordance with a determination that there is not active speech on the output audio channel, forgoing to tap into the output audio channel.
508
Update the adaptive speech recognition model with training data derived from the call audio signal
510
Updating the adaptive speech recognition model comprises:
Comparing the call audio signal with the adaptive speech recognition model.
Generating a confidence score based on the comparison.
In accordance with a determination that the confidence score is at or above a predetermined threshold, updating the adaptive speech recognition model with the training data derived from the call audio signal.
In accordance with a determination that the confidence score is below the predetermined threshold, forgoing to update the adaptive speech recognition model.
512
A

Figure 5A

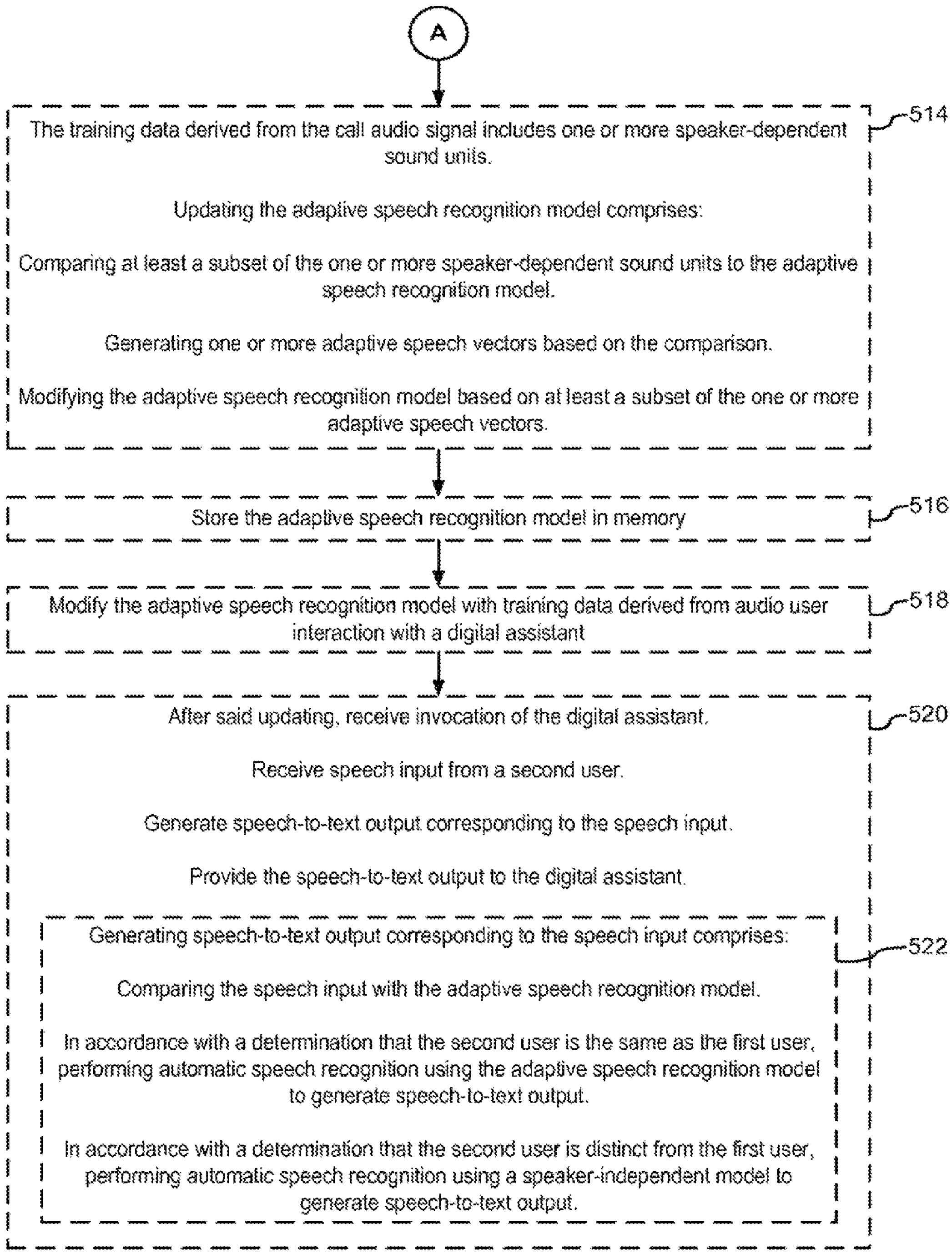
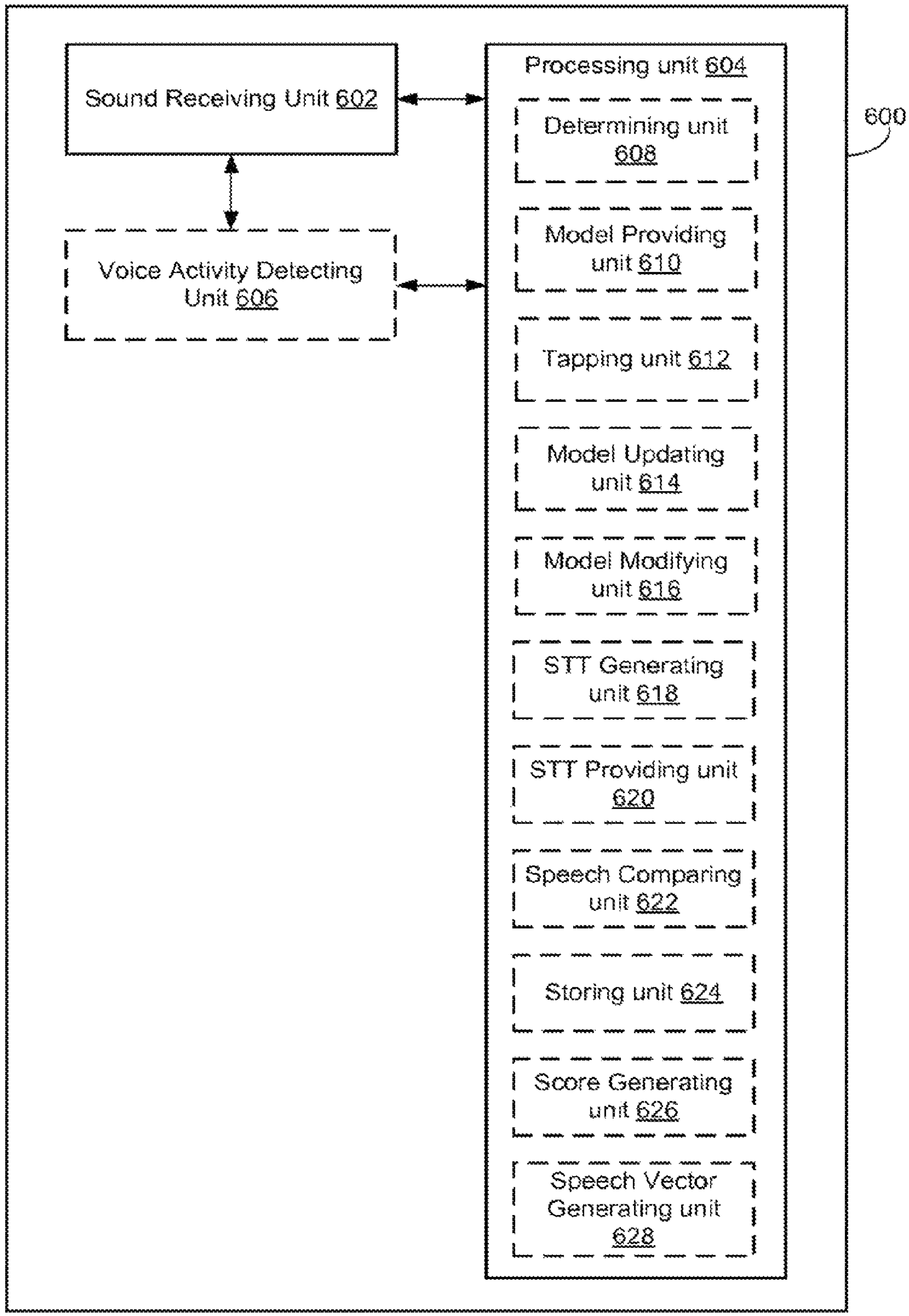

A
The training data derived from the call audio signal includes one or more speaker-dependent sound units.
Updating the adaptive speech recognition model comprises:
Comparing at least a subset of the one or more speaker-dependent sound units to the adaptive speech recognition model.
Generating one or more adaptive speech vectors based on the comparison.
Modifying the adaptive speech recognition model based on at least a subset of the one or more adaptive speech vectors.
514
Store the adaptive speech recognition model in memory
516
Modify the adaptive speech recognition model with training data derived from audio user interaction with a digital assistant
518
After said updating, receive invocation of the digital assistant.
Receive speech input from a second user.
Generate speech-to-text output corresponding to the speech input.
Provide the speech-to-text output to the digital assistant.
520
Generating speech-to-text output corresponding to the speech input comprises:
Comparing the speech input with the adaptive speech recognition model.
In accordance with a determination that the second user is the same as the first user, performing automatic speech recognition using the adaptive speech recognition model to generate speech-to-text output.
In accordance with a determination that the second user is distinct from the first user, performing automatic speech recognition using a speaker-independent model to generate speech-to-text output.
522

Figure 5B



Sound Receiving Unit 602
Voice Activity Detecting Unit 606
Processing unit 604
Determining unit 608
Model Providing unit 610
Tapping unit 612
Model Updating unit 614
Model Modifying unit 616
STT Generating unit 618
STT Providing unit 620
Speech Comparing unit 622
Storing unit 624
Score Generating unit 626
Speech Vector Generating unit 628
600

Figure 6

SYSTEM AND METHOD FOR UPDATING AN ADAPTIVE SPEECH RECOGNITION MODEL

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a Continuation Application of U.S. Utility application Ser. No. 14/213,781 filed on Mar. 14, 2014, entitled SYSTEM AND METHOD FOR UPDATING AN ADAPTIVE SPEECH RECOGNITION MODEL, which claims the benefit of U.S. Provisional Application No. 61/799,479, filed on Mar. 15, 2013, entitled SYSTEM AND METHOD FOR UPDATING AN ADAPTIVE SPEECH RECOGNITION MODEL, both of which are hereby incorporated by reference in their entity and for all purposes.

TECHNICAL FIELD

The disclosed implementations relate generally to digital assistants. More specifically, to a method and system for obtaining training data to update an adaptive speech recognition model for use when interacting with a digital assistant.

BACKGROUND

Recently, voice-based digital assistants, such as Apple's SIRI, have been introduced into the marketplace to handle various tasks such as web searching and navigation. Currently, voice-based digital assistant systems utilize either speaker-independent models or speaker-dependent models in order to generate speech-to-text (STT) input to the digital assistant. The speaker-dependent model increases accuracy in generating the STT input, and therefore, enables the digital assistant to provide better results to the user. However, speaker-dependent models require significant training data in order to function with increased accuracy. Reciting many lines of predefined text in order to train a speaker-dependent model has several drawbacks. Many users would prefer not to expend the time and effort in providing training data for a model. In addition, a user's speech is markedly different when reading as opposed to ordinary conversation, therefore the accuracy of a speech model trained with data obtained from a user reading is worse than one trained with data obtained from a user's ordinary conversation. Finally, a user's speech changes with time and environment.

SUMMARY

The implementations described below provide systems and methods for obtaining training data to update an adaptive speech recognition model for use when interacting with a digital assistant. The systems and methods obtain training data to update a speaker-dependent speech recognition model using a user's ordinary conversations.

Interactions with a voice-based digital assistant (or other speech-based services, such as a speech-to-text transcription service) often utilize a speaker-dependent speech recognition model (e.g., an adaptive speech recognition model). However, the accuracy of speaker-dependent speech recognition models depends on the volume and quality of training data. As described herein, an adaptive speech recognition model is updated by deriving training data from analyzing an outbound audio channel of a mobile communication device to obtain a call audio signal.

Some implementations provide a method for obtaining training data to update an adaptive speech recognition model. The method is performed at a first mobile communication device including one or more processors and memory storing instructions for execution by the one or more processors. The method includes determining that a first user of a first mobile communication device is engaged in a call over a communications network and providing an adaptive speech recognition model. The method further includes analyzing an outbound audio channel of the first mobile communication device to obtain a call audio signal corresponding to audio input from one or more microphones of the first mobile communication device, and updating the adaptive speech recognition model with training data derived from the call audio signal.

Some implementations provide a method for obtaining training data to update an adaptive speech recognition model. In these implementations, the method is performed at a server system distinct from a first mobile communication device. The method includes determining that a first user of the first mobile communication device is engaged in a call over a communications network and providing an adaptive speech recognition model. The method further includes analyzing an outbound audio channel of the first mobile communication device to obtain a call audio signal corresponding to audio input from one or more microphones of the first mobile communication device, and updating the adaptive speech recognition model with training data derived from the call audio signal (e.g., sending parameters derived from the call audio signal at the device to a server to update the adaptive speech recognition model).

In some implementations, the first mobile communication device is a mobile telephone. In some implementations, the first mobile communication device is a laptop computer. In some implementations, the first mobile communication device is a tablet computer.

In some implementations, the call is a mobile telephone call. In some implementations, the call is a multimedia communication. In some implementations, the call is a VoIP communication. In some implementations, the call comprises an interaction between the first user of the first mobile communication device and a second mobile device. In some implementations, the call comprises a conversation between the first user of the first mobile communication device and a user of a second device.

In some implementations, providing an adaptive speech recognition model comprises providing a speaker-independent model. In some implementations, providing an adaptive speech recognition model comprises providing a speaker-dependent model associated with a user of the first mobile communication device.

In some implementations, the method further includes, prior to analyzing the outbound audio channel, converting the call audio signal from an analog audio signal to a digital audio signal. In some implementations the method further comprises, prior to analyzing the outbound audio channel, determining that the first mobile communication device is in an adaptive-speaker-training mode.

In some implementations, analyzing the outbound audio channel comprises analyzing the baseband unit. In some implementations, analyzing includes analyzing the digital signal processor (DSP). In some implementations, analyzing includes analyzing the application processor.

In some implementations, the method further includes, prior to updating the adaptive speech recognition model, determining that the call has ended.

In some implementations, training data comprises one or more speaker-dependent sound units. In some implementations, updating the adaptive speech recognition model comprises replacing the adaptive speech recognition model with

a new adaptive speech recognition model generated from the training data. In some implementations, updating the adaptive speech recognition model comprises generating a speaker-dependent model from the data, comparing the speaker-dependent model to the adaptive speech recognition model, and updating the adaptive speech recognition model based on the comparison.

In some implementations, the method further includes modifying the adaptive speech recognition model with training data derived from audio user interaction with a digital assistant. In some implementations, the method further comprises, after said updating, receiving invocation of the digital assistant, receiving speech input from a second user, generating speech-to-text output corresponding to the speech input, and providing the speech-to-text output to the digital assistant. In some implementations, generating speech-to-text output corresponding to the speech input comprises comparing the speech input with the adaptive speech recognition model; in accordance with a determination that the second user is the same as the first user, performing automatic speech recognition using the adaptive speech recognition model to generate speech-to-text output; and in accordance with a determination that the second user is distinct from the first user, performing automatic speech recognition using a speaker-independent model to generate speech-to-text output.

In some implementations, the method further includes storing the adaptive speech recognition model in memory. In some implementations, the memory is a component of the first mobile communication device. In some implementations, the memory is a component of a server distinct from the first mobile communication device.

In some implementations, analyzing the outbound audio channel comprises utilizing a voice activity detector to determine when there is active speech on the outbound audio channel; in accordance with a determination that there is active speech on the outbound audio channel, analyzing the outbound audio channel; and in accordance with a determination that there is not active speech on the outbound audio channel, forgoing analyzing the outbound audio channel.

In some implementations, updating the adaptive speech recognition model comprises comparing the call audio signal with the adaptive speech recognition model, generating a confidence score based on the comparison; in accordance with a determination that the confidence score is at or above a predetermined threshold, updating the adaptive speech recognition model with the training data derived from the call audio signal; and in accordance with a determination that the confidence score is below the predetermined threshold, forgoing to update the adaptive speech recognition model.

In some implementations, the training data derived from the call audio signal includes one or more speaker-dependent sound units, and updating the adaptive speech recognition model comprises comparing at least a subset of the one or more speaker-dependent sound units to the adaptive speech recognition model, generating one or more adaptive speech vectors based on the comparison, and modifying the adaptive speech recognition model based on at least a subset of the one or more adaptive speech vectors.

In accordance with some implementations, a system includes one or more processors, memory, and one or more programs stored in the memory. The one or more programs comprising instructions to determine that a first user of a first mobile communication device is engaged in a call over a communications network and provide an adaptive speech recognition model. The one or more programs further comprising instructions to analyze an outbound audio channel of the first mobile communication device to obtain a call audio signal corresponding to audio input from one or more microphones of the first mobile communication device and update the adaptive speech recognition model with training data derived from the call audio signal.

In accordance with some implementations, the system comprises the first mobile communication device having the one or more microphones. In accordance with some implementations, the system comprises a server system distinct from the first mobile communication device.

In accordance with some implementations, a computer-readable storage medium (e.g., a non-transitory computer readable storage medium) is provided, the computer-readable storage medium storing one or more programs for execution by one or more processors of an electronic device, the one or more programs including instructions for performing any of the methods described herein.

In accordance with some implementations, an electronic device (e.g., a portable electronic device) is provided that comprises means for performing any of the methods described herein.

In accordance with some implementations, an electronic device (e.g., a portable electronic device) is provided that comprises a processing unit configured to perform any of the methods described herein.

In accordance with some implementations, an electronic device (e.g., a portable electronic device) is provided that comprises one or more processors and memory storing one or more programs for execution by the one or more processors, the one or more programs including instructions for performing any of the methods described herein.

In accordance with some implementations, an information processing apparatus for use in an electronic device is provided, the information processing apparatus comprising means for performing any of the methods described herein.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram illustrating an environment in which a digital assistant operates in accordance with some implementations.

FIG. **2** is a block diagram illustrating a digital assistant client system in accordance with some implementations.

FIG. **3**A is a block diagram illustrating a standalone digital assistant system or a digital assistant server system in accordance with some implementations.

FIG. **3**B is a block diagram illustrating functions of the digital assistant shown in FIG. **3**A in accordance with some implementations.

FIG. **3**C is a network diagram illustrating a portion of an ontology in accordance with some implementations.

FIG. **4** is a block diagram illustrating components of an audio system, in accordance with some implementations.

FIGS. **5**A-**5**B are flow charts illustrating methods for updating an adaptive speech recognition model, in accordance with some implementations.

FIG. **6** is a functional block diagram of an electronic device in accordance with some embodiments.

Like reference numerals refer to corresponding parts throughout the drawings.

DESCRIPTION OF IMPLEMENTATIONS

FIG. **1** is a block diagram of an operating environment **100** of a digital assistant according to some implementations. The terms "digital assistant," "virtual assistant," "intelligent automated assistant," "voice-based digital assistant," or "automatic digital assistant," refer to any information processing system that interprets natural language input in spoken and/or textual form to deduce user intent (e.g., identify a task type that corresponds to the natural language input), and performs actions based on the deduced user intent (e.g., perform a task corresponding to the identified task type). For example, to act on a deduced user intent, the system can perform one or more of the following: identifying a task flow with steps and parameters designed to accomplish the deduced user intent (e.g., identifying a task type), inputting specific requirements from the deduced user intent into the task flow, executing the task flow by invoking programs, methods, services, APIs, or the like (e.g., sending a request to a service provider); and generating output responses to the user in an audible (e.g., speech) and/or visual form.

Specifically, once initiated, a digital assistant system is capable of accepting a user request at least partially in the form of a natural language command, request, statement, narrative, and/or inquiry. Typically, the user request seeks either an informational answer or performance of a task by the digital assistant system. A satisfactory response to the user request is generally either provision of the requested informational answer, performance of the requested task, or a combination of the two. For example, a user may ask the digital assistant system a question, such as "Where am I right now?" Based on the user's current location, the digital assistant may answer, "you are in Central Park near the west gate." The user may also request the performance of a task, for example, by stating "Please invite my friends to my girlfriend's birthday party next week." In response, the digital assistant may acknowledge the request by generating a voice output, "Yes, right away," and then send a suitable calendar invite from the user's email address to each of the user's friends listed in the user's electronic address book or contact list. There are numerous other ways of interacting with a digital assistant to request information or performance of various tasks. In addition to providing verbal responses and taking programmed actions, the digital assistant can also provide responses in other visual or audio forms (e.g., as text, alerts, music, videos, animations, etc.).

As shown in FIG. **1**, in some implementations, a digital assistant system is implemented according to a client-server model. The digital assistant system includes a client-side portion (e.g., **102***a* and **102***b*) (hereafter "digital assistant (DA) client **102**") executed on a user device (e.g., **104***a* and **104***b*), and a server-side portion **106** (hereafter "digital assistant (DA) server **106**") executed on a server system **108**. The DA client **102** communicates with the DA server **106** through one or more networks **110**. The DA client **102** provides client-side functionalities such as user-facing input and output processing and communications with the DA server **106**. The DA server **106** provides server-side functionalities for any number of DA clients **102** each residing on a respective user device **104** (also called a client device or electronic device).

In some implementations, the DA server **106** includes a client-facing I/O interface **112**, one or more processing modules **114**, data and models **116**, an I/O interface to external services **118**, a photo and tag database **130**, and a photo-tag module **132**. The client-facing I/O interface facilitates the client-facing input and output processing for the digital assistant server **106**. The one or more processing modules **114** utilize the data and models **116** to determine the user's intent based on natural language input and perform task execution based on the deduced user intent. Photo and tag database **130** stores fingerprints of digital photographs, and, optionally digital photographs themselves, as well as tags associated with the digital photographs. Photo-tag module **132** creates tags, stores tags in association with photographs and/or fingerprints, automatically tags photographs, and links tags to locations within photographs.

In some implementations, the DA server **106** communicates with external services **120** (e.g., navigation service(s) **122-1**, messaging service(s) **122-2**, information service(s) **122-3**, calendar service **122-4**, telephony service **122-5**, photo service(s) **122-6**, etc.) through the network(s) **110** for task completion or information acquisition. The I/O interface to the external services **118** facilitates such communications.

Examples of the user device **104** include, but are not limited to, a handheld computer, a personal digital assistant (PDA), a tablet computer, a laptop computer, a desktop computer, a cellular telephone, a smartphone, an enhanced general packet radio service (EGPRS) mobile phone, a media player, a navigation device, a game console, a television, a remote control, or a combination of any two or more of these data processing devices or any other suitable data processing devices. More details on the user device **104** are provided in reference to an exemplary user device **104** shown in FIG. **2**.

Examples of the communication network(s) **110** include local area networks (LAN) and wide area networks (WAN), e.g., the Internet. The communication network(s) **110** may be implemented using any known network protocol, including various wired or wireless protocols, such as Ethernet, Universal Serial Bus (USB), FIREWIRE, Global System for Mobile Communications (GSM), Enhanced Data GSM Environment (EDGE), code division multiple access (CDMA), time division multiple access (TDMA), Bluetooth, Wi-Fi, voice over Internet Protocol (VoIP), Wi-MAX, or any other suitable communication protocol.

The server system **108** can be implemented on at least one data processing apparatus and/or a distributed network of computers. In some implementations, the server system **108** also employs various virtual devices and/or services of third party service providers (e.g., third-party cloud service providers) to provide the underlying computing resources and/or infrastructure resources of the server system **108**.

Although the digital assistant system shown in FIG. **1** includes both a client-side portion (e.g., the DA client **102**) and a server-side portion (e.g., the DA server **106**), in some implementations, a digital assistant system refers only to the server-side portion (e.g., the DA server **106**). In some implementations, the functions of a digital assistant can be implemented as a standalone application installed on a user device. In addition, the divisions of functionalities between the client and server portions of the digital assistant can vary in different implementations. For example, in some implementations, the DA client **102** is a thin-client that provides only user-facing input and output processing functions, and delegates all other functionalities of the digital assistant to the DA server **106**. In some other implementations, the DA client **102** is configured to perform or assist one or more functions of the DA server **106**.

FIG. **2** is a block diagram of a user device **104** in accordance with some implementations. The user device **104** includes a memory interface **202**, one or more processors **204**, and a peripherals interface **206**. The various components in the user device **104** are coupled by one or more communication buses or signal lines. The user device **104** includes various sensors, subsystems, and peripheral devices that are coupled to the peripherals interface **206**. The sensors, subsystems, and peripheral devices gather information and/or facilitate various functionalities of the user device **104**.

For example, in some implementations, a motion sensor **210** (e.g., an accelerometer), a light sensor **212**, a GPS receiver **213**, a temperature sensor, and a proximity sensor **214** are coupled to the peripherals interface **206** to facilitate orientation, light, and proximity sensing functions. In some implementations, other sensors **216**, such as a biometric sensor, barometer, and the like, are connected to the peripherals interface **206**, to facilitate related functionalities.

In some implementations, the user device **104** includes a camera subsystem **220** coupled to the peripherals interface **206**. In some implementations, an optical sensor **222** of the camera subsystem **220** facilitates camera functions, such as taking photographs and recording video clips. In some implementations, the user device **104** includes one or more wired and/or wireless communication subsystems **224** provide communication functions. The communication subsystems **224** typically includes various communication ports, radio frequency receivers and transmitters, and/or optical (e.g., infrared) receivers and transmitters. In some implementations, the user device **104** includes an audio subsystem **226** coupled to one or more speakers **228** and one or more microphones **230** to facilitate voice-enabled functions, such as voice recognition, voice replication, digital recording, and telephony functions. In some implementations, the audio subsystem **226** is coupled to a voice trigger system **400**. In some implementations, the voice trigger system **400** and/or the audio subsystem **226** includes low-power audio circuitry and/or programs (i.e., including hardware and/or software) for receiving and/or analyzing sound inputs, including, for example, one or more analog-to-digital converters, digital signal processors (DSPs), sound detectors, memory buffers, codecs, and the like. In some implementations, the low-power audio circuitry (alone or in addition to other components of the user device **104**) provides voice (or sound) trigger functionality for one or more aspects of the user device **104**, such as a voice-based digital assistant or other speech-based service. In some implementations, the low-power audio circuitry provides voice trigger functionality even when other components of the user device **104** are shut down and/or in a standby mode, such as the processor(s) **204**, I/O subsystem **240**, memory **250**, and the like. The voice trigger system **400** and the audio subsystem **226** are described in further detail with respect to FIG. **4**.

In some implementations, an I/O subsystem **240** is also coupled to the peripheral interface **206**. In some implementations, the user device **104** includes a touch screen **246**, and the I/O subsystem **240** includes a touch screen controller **242** coupled to the touch screen **246**. When the user device **104** includes the touch screen **246** and the touch screen controller **242**, the touch screen **246** and the touch screen controller **242** are typically configured to, for example, detect contact and movement or break thereof using any of a plurality of touch sensitivity technologies, such as capacitive, resistive, infrared, surface acoustic wave technologies, proximity sensor arrays, and the like. In some implementations, the user device **104** includes a display that does not include a touch-sensitive surface. In some implementations, the user device **104** includes a separate touch-sensitive surface. In some implementations, the user device **104** includes other input controller(s) **244**. When the user device **104** includes the other input controller(s) **244**, the other input controller(s) **244** are typically coupled to other input/control devices **248**, such as one or more buttons, rocker switches, thumb-wheel, infrared port, USB port, and/or a pointer device such as a stylus.

The memory interface **202** is coupled to memory **250**. In some implementations, memory **250** includes a non-transitory computer readable medium, such as high-speed random access memory and/or non-volatile memory (e.g., one or more magnetic disk storage devices, one or more flash memory devices, one or more optical storage devices, and/or other non-volatile solid-state memory devices).

In some implementations, memory **250** stores an operating system **252**, a communications module **254**, a graphical user interface module **256**, a sensor processing module **258**, a phone module **260**, and applications **262**, and a subset or superset thereof. The operating system **252** includes instructions for handling basic system services and for performing hardware dependent tasks. The communications module **254** facilitates communicating with one or more additional devices, one or more computers and/or one or more servers. The graphical user interface module **256** facilitates graphic user interface processing. The sensor processing module **258** facilitates sensor-related processing and functions (e.g., processing voice input received with the one or more microphones **228**). The phone module **260** facilitates phone-related processes and functions. The application module **262** facilitates various functionalities of user applications, such as electronic-messaging, web browsing, media processing, navigation, imaging and/or other processes and functions. In some implementations, the user device **104** stores in memory **250** one or more software applications **270-1** and **270-2** each associated with at least one of the external service providers.

As described above, in some implementations, memory **250** also stores client-side digital assistant instructions (e.g., in a digital assistant client module **264**) and various user data **266** (e.g., user-specific vocabulary data, preference data, and/or other data such as the user's electronic address book or contact list, to-do lists, shopping lists, etc.) to provide the client-side functionalities of the digital assistant.

In various implementations, the digital assistant client module **264** is capable of accepting voice input, text input, touch input, and/or gestural input through various user interfaces (e.g., the I/O subsystem **244**) of the user device **104**. The digital assistant client module **264** is also capable of providing output in audio, visual, and/or tactile forms. For example, output can be provided as voice, sound, alerts, text messages, menus, graphics, videos, animations, vibrations, and/or combinations of two or more of the above. During operation, the digital assistant client module **264** communicates with the digital assistant server (e.g., the digital assistant server **106**, FIG. **1**) using the communication subsystems **224**.

In some implementations, the digital assistant client module **264** utilizes various sensors, subsystems and peripheral devices to gather additional information from the surrounding environment of the user device **104** to establish a context associated with a user input. In some implementations, the digital assistant client module **264** provides the context information or a subset thereof with the user input to the digital assistant server (e.g., the digital assistant server **106**, FIG. **1**) to help deduce the user's intent.

In some implementations, the context information that can accompany the user input includes sensor information, e.g., lighting, ambient noise, ambient temperature, images or videos of the surrounding environment, etc. In some implementations, the context information also includes the physical state of the device, e.g., device orientation, device location, device temperature, power level, speed, acceleration, motion patterns, cellular signals strength, etc. In some implementations, information related to the software state of the user device **106**, e.g., running processes, installed programs, past and present network activities, background services, error logs, resources usage, etc., of the user device **104** is also provided to the digital assistant server (e.g., the digital assistant server **106**, FIG. **1**) as context information associated with a user input.

In some implementations, the DA client module **264** selectively provides information (e.g., at least a portion of the user data **266**) stored on the user device **104** in response to requests from the digital assistant server. In some implementations, the digital assistant client module **264** also elicits additional input from the user via a natural language dialogue or other user interfaces upon request by the digital assistant server **106** (FIG. **1**). The digital assistant client module **264** passes the additional input to the digital assistant server **106** to help the digital assistant server **106** in intent deduction and/or fulfillment of the user's intent expressed in the user request.

In some implementations, memory **250** may include additional instructions or fewer instructions. Furthermore, various functions of the user device **104** may be implemented in hardware and/or in firmware, including in one or more signal processing and/or application specific integrated circuits, and the user device **104**, thus, need not include all modules and applications illustrated in FIG. **2**.

FIG. **3**A is a block diagram of an exemplary digital assistant system **300** (also referred to as the digital assistant) in accordance with some implementations. In some implementations, the digital assistant system **300** is implemented on a standalone computer system. In some implementations, the digital assistant system **300** is distributed across multiple computers. In some implementations, some of the modules and functions of the digital assistant are divided into a server portion and a client portion, where the client portion resides on a user device (e.g., the user device **104**) and communicates with the server portion (e.g., the server system **108**) through one or more networks, e.g., as shown in FIG. **1**. In some implementations, the digital assistant system **300** is an embodiment of the server system **108** (and/or the digital assistant server **106**) shown in FIG. **1**. In some implementations, the digital assistant system **300** is implemented in a user device (e.g., the user device **104**, FIG. **1**), thereby eliminating the need for a client-server system. It should be noted that the digital assistant system **300** is only one example of a digital assistant system, and that the digital assistant system **300** may have more or fewer components than shown, may combine two or more components, or may have a different configuration or arrangement of the components. The various components shown in FIG. **3**A may be implemented in hardware, software, firmware, including one or more signal processing and/or application specific integrated circuits, or a combination thereof.

The digital assistant system **300** includes memory **302**, one or more processors **304**, an input/output (I/O) interface **306**, and a network communications interface **308**. These components communicate with one another over one or more communication buses or signal lines **310**.

In some implementations, memory **302** includes a non-transitory computer readable medium, such as high-speed random access memory and/or a non-volatile computer readable storage medium (e.g., one or more magnetic disk storage devices, one or more flash memory devices, one or more optical storage devices, and/or other non-volatile solid-state memory devices).

The I/O interface **306** couples input/output devices **316** of the digital assistant system **300**, such as displays, keyboards, touch screens, and microphones, to the user interface module **322**. The I/O interface **306**, in conjunction with the user interface module **322**, receives user inputs (e.g., voice input, keyboard inputs, touch inputs, etc.) and process them accordingly. In some implementations, when the digital assistant is implemented on a standalone user device, the digital assistant system **300** includes any of the components and I/O and communication interfaces described with respect to the user device **104** in FIG. **2** (e.g., one or more microphones **230**). In some implementations, the digital assistant system **300** represents the server portion of a digital assistant implementation, and interacts with the user through a client-side portion residing on a user device (e.g., the user device **104** shown in FIG. **2**).

In some implementations, the network communications interface **308** includes wired communication port(s) **312** and/or wireless transmission and reception circuitry **314**. The wired communication port(s) receive and send communication signals via one or more wired interfaces, e.g., Ethernet, Universal Serial Bus (USB), FIREWIRE, etc. The wireless circuitry **314** typically receives and sends RF signals and/or optical signals from/to communications networks and other communications devices. The wireless communications may use any of a plurality of communications standards, protocols and technologies, such as GSM, EDGE, CDMA, TDMA, Bluetooth, Wi-Fi, VoIP, Wi-MAX, or any other suitable communication protocol. The network communications interface **308** enables communication between the digital assistant system **300** with networks, such as the Internet, an intranet and/or a wireless network, such as a cellular telephone network, a wireless local area network (LAN) and/or a metropolitan area network (MAN), and other devices.

In some implementations, the non-transitory computer readable storage medium of memory **302** stores programs, modules, instructions, and data structures including all or a subset of: an operating system **318**, a communications module **320**, a user interface module **322**, one or more applications **324**, and a digital assistant module **326**. The one or more processors **304** execute these programs, modules, and instructions, and reads/writes from/to the data structures.

The operating system **318** (e.g., Darwin, RTXC, LINUX, UNIX, OS X, iOS, WINDOWS, or an embedded operating system such as VxWorks) includes various software components and/or drivers for controlling and managing general system tasks (e.g., memory management, storage device control, power management, etc.) and facilitates communications between various hardware, firmware, and software components.

The communications module **320** facilitates communications between the digital assistant system **300** with other devices over the network communications interface **308**. For example, the communication module **320** may communicate with the communications module **254** of the device **104** shown in FIG. **2**. The communications module **320** also includes various software components for handling data received by the wireless circuitry **314** and/or wired communications port **312**.

In some implementations, the user interface module **322** receives commands and/or inputs from a user via the I/O interface **306** (e.g., from a keyboard, touch screen, and/or microphone), and provides user interface objects on a display.

The applications **324** include programs and/or modules that are configured to be executed by the one or more processors **304**. For example, if the digital assistant system is implemented on a standalone user device, the applications **324** may include user applications, such as games, a calendar application, a navigation application, or an email application. If the digital assistant system **300** is implemented on a server farm, the applications **324** may include resource management applications, diagnostic applications, or scheduling applications, for example.

Memory **302** also stores the digital assistant module (or the server portion of a digital assistant) **326**. In some implementations, the digital assistant module **326** includes the following sub-modules, or a subset or superset thereof: an input/output processing module **328**, a speech-to-text (STT) processing module **330**, a natural language processing module **332**, a dialogue flow processing module **334**, a task flow processing module **336**, a service processing module **338**, and a photo module **132**. Each of these processing modules has access to one or more of the following data and models of the digital assistant **326**, or a subset or superset thereof: ontology **360**, vocabulary index **344**, user data **348**, categorization module **349**, disambiguation module **350**, task flow models **354**, service models **356**, photo tagging module **358**, search module **360**, and local tag/photo storage **362**.

In some implementations, using the processing modules (e.g., the input/output processing module **328**, the STT processing module **330**, the natural language processing module **332**, the dialogue flow processing module **334**, the task flow processing module **336**, and/or the service processing module **338**), data, and models implemented in the digital assistant module **326**, the digital assistant system **300** performs at least some of the following: identifying a user's intent expressed in a natural language input received from the user; actively eliciting and obtaining information needed to fully deduce the user's intent (e.g., by disambiguating words, names, intentions, etc.); determining the task flow for fulfilling the deduced intent; and executing the task flow to fulfill the deduced intent. In some implementations, the digital assistant also takes appropriate actions when a satisfactory response was not or could not be provided to the user for various reasons.

In some implementations, as discussed below, the digital assistant system **300** identifies, from a natural language input, a user's intent to tag a digital photograph, and processes the natural language input so as to tag the digital photograph with appropriate information. In some implementations, the digital assistant system **300** performs other tasks related to photographs as well, such as searching for digital photographs using natural language input, auto-tagging photographs, and the like.

As shown in FIG. 3B, in some implementations, the I/O processing module **328** interacts with the user through the I/O devices **316** in FIG. **3**A or with a user device (e.g., a user device **104** in FIG. **1**) through the network communications interface **308** in FIG. **3**A to obtain user input (e.g., a speech input) and to provide responses to the user input. The I/O processing module **328** optionally obtains context information associated with the user input from the user device, along with or shortly after the receipt of the user input. The context information includes user-specific data, vocabulary, and/or preferences relevant to the user input. In some implementations, the context information also includes software and hardware states of the device (e.g., the user device **104** in FIG. **1**) at the time the user request is received, and/or information related to the surrounding environment of the user at the time that the user request was received. In some implementations, the I/O processing module **328** also sends follow-up questions to, and receives answers from, the user regarding the user request. In some implementations, when a user request is received by the I/O processing module **328** and the user request contains a speech input, the I/O processing module **328** forwards the speech input to the speech-to-text (STT) processing module **330** for speech-to-text conversions.

In some implementations, the speech-to-text processing module **330** receives speech input (e.g., a user utterance captured in a voice recording) through the I/O processing module **328**. In some implementations, the speech-to-text processing module **330** uses various acoustic and language models to recognize the speech input as a sequence of sound units (e.g., phonemes), and ultimately, a sequence of words or tokens written in one or more languages. The speech-to-text processing module **330** is implemented using any suitable speech recognition techniques (e.g., an adaptive speech recognition model), acoustic models, and language models, such as Hidden Markov Models, Dynamic Time Warping (DTW)-based speech recognition, maximum a posteriori (MAP) model adaptation (e.g., structural MAP approach), maximum likelihood linear regression (MLLR) model adaptation (e.g., constrained MLLR, mean-only MLLR), and other statistical and/or analytical techniques. In some implementations, the speech-to-text processing can be performed at least partially by a third party service or on the user's device. Once the speech-to-text processing module **330** obtains the result of the speech-to-text processing (e.g., a sequence of words or tokens), it passes the result to the natural language processing module **332** for intent deduction.

The natural language processing module **332** ("natural language processor") of the digital assistant **326** takes the sequence of words or tokens ("token sequence") generated by the speech-to-text processing module **330**, and attempts to associate the token sequence with one or more "actionable intents" recognized by the digital assistant. As used herein, an "actionable intent" represents a task that can be performed by the digital assistant **326** and/or the digital assistant system **300** (FIG. **3**A), and has an associated task flow implemented in the task flow models **354**. The associated task flow is a series of programmed actions and steps that the digital assistant system **300** takes in order to perform the task. The scope of a digital assistant system's capabilities is dependent on the number and variety of task flows that have been implemented and stored in the task flow models **354**, or in other words, on the number and variety of "actionable intents" that the digital assistant system **300** recognizes. The effectiveness of the digital assistant system **300**, however, is also dependent on the digital assistant system's ability to deduce the correct "actionable intent(s)" from the user request expressed in natural language.

In some implementations, in addition to the sequence of words or tokens obtained from the speech-to-text processing module **330**, the natural language processor **332** also receives context information associated with the user request (e.g., from the I/O processing module **328**). The natural language processor **332** optionally uses the context information to clarify, supplement, and/or further define the information contained in the token sequence received from the speech-to-text processing module **330**. The context information includes, for example, user preferences, hardware and/or software states of the user device, sensor information collected before, during, or shortly after the user request, prior interactions (e.g., dialogue) between the digital assistant and the user, and the like.

In some implementations, the natural language processing is based on an ontology **360**. The ontology **360** is a hierarchical structure containing a plurality of nodes, each node representing either an "actionable intent" or a "property" relevant to one or more of the "actionable intents" or other "properties." As noted above, an "actionable intent" represents a task that the digital assistant system **300** is capable of performing (e.g., a task that is "actionable" or can be acted on). A "property" represents a parameter associated with an actionable intent or a sub-aspect of another property. A linkage between an actionable intent node and a property node in the ontology **360** defines how a parameter represented by the property node pertains to the task represented by the actionable intent node.

In some implementations, the ontology **360** is made up of actionable intent nodes and property nodes. Within the ontology **360**, each actionable intent node is linked to one or more property nodes either directly or through one or more intermediate property nodes. Similarly, each property node is linked to one or more actionable intent nodes either directly or through one or more intermediate property nodes. For example, the ontology **360** shown in FIG. **3**C includes a "restaurant reservation" node, which is an actionable intent node. Property nodes "restaurant," "date/time" (for the reservation), and "party size" are each directly linked to the "restaurant reservation" node (i.e., the actionable intent node). In addition, property nodes "cuisine," "price range," "phone number," and "location" are sub-nodes of the property node "restaurant," and are each linked to the "restaurant reservation" node (i.e., the actionable intent node) through the intermediate property node "restaurant." For another example, the ontology **360** shown in FIG. **3**C also includes a "set reminder" node, which is another actionable intent node. Property nodes "date/time" (for setting the reminder) and "subject" (for the reminder) are each linked to the "set reminder" node. Since the property "date/time" is relevant to both the task of making a restaurant reservation and the task of setting a reminder, the property node "date/time" is linked to both the "restaurant reservation" node and the "set reminder" node in the ontology **360**.

An actionable intent node, along with its linked concept nodes, may be described as a "domain." In the present discussion, each domain is associated with a respective actionable intent, and refers to the group of nodes (and the relationships therebetween) associated with the particular actionable intent. For example, the ontology **360** shown in FIG. **3**C includes an example of a restaurant reservation domain **362** and an example of a reminder domain **364** within the ontology **360**. The restaurant reservation domain includes the actionable intent node "restaurant reservation," property nodes "restaurant," "date/time," and "party size," and sub-property nodes "cuisine," "price range," "phone number," and "location." The reminder domain **364** includes the actionable intent node "set reminder," and property nodes "subject" and "date/time." In some implementations, the ontology **360** is made up of many domains. Each domain may share one or more property nodes with one or more other domains. For example, the "date/time" property node may be associated with many other domains (e.g., a scheduling domain, a travel reservation domain, a movie ticket domain, etc.), in addition to the restaurant reservation domain **362** and the reminder domain **364**.

While FIG. **3**C illustrates two exemplary domains within the ontology **360**, the ontology **360** may include other domains (or actionable intents), such as "initiate a phone call," "find directions," "schedule a meeting," "send a message," "provide an answer to a question," "tag a photo," and so on. For example, a "send a message" domain is associated with a "send a message" actionable intent node, and may further include property nodes such as "recipient(s)," "message type," and "message body." The property node "recipient" may be further defined, for example, by the sub-property nodes such as "recipient name" and "message address."

In some implementations, the ontology **360** includes all the domains (and hence actionable intents) that the digital assistant is capable of understanding and acting upon. In some implementations, the ontology **360** may be modified, such as by adding or removing domains or nodes, or by modifying relationship between the nodes within the ontology **360**.

In some implementations, nodes associated with multiple related actionable intents may be clustered under a "super domain" in the ontology **360**. For example, a "travel" super-domain may include a cluster of property nodes and actionable intent nodes related to travels. The actionable intent nodes related to travels may include "airline reservation," "hotel reservation," "car rental," "get directions," "find points of interest," and so on. The actionable intent nodes under the same super domain (e.g., the "travels" super domain) may have many property nodes in common. For example, the actionable intent nodes for "airline reservation," "hotel reservation," "car rental," "get directions," and "find points of interest" may share one or more of the property nodes "start location," "destination," "departure date/time," "arrival date/time," and "party size."

In some implementations, each node in the ontology **360** is associated with a set of words and/or phrases that are relevant to the property or actionable intent represented by the node. The respective set of words and/or phrases associated with each node is the so-called "vocabulary" associated with the node. The respective set of words and/or phrases associated with each node can be stored in the vocabulary index **344** (FIG. **3**B) in association with the property or actionable intent represented by the node. For example, returning to FIG. **3**B, the vocabulary associated with the node for the property of restaurant" may include words such as "food," "drinks," "cuisine," "hungry," "eat," "pizza," "fast food," "meal," and so on. For another example, the vocabulary associated with the node for the actionable intent of "initiate a phone call" may include words and phrases such as "call," "phone," "dial," "ring," "call this number," "make a call to," and so on. The vocabulary index **344** optionally includes words and phrases in different languages.

In some implementations, the natural language processor **332** shown in FIG. **3**B receives the token sequence (e.g., a text string) from the speech-to-text processing module **330**, and determines what nodes are implicated by the words in the token sequence. In some implementations, if a word or phrase in the token sequence is found to be associated with one or more nodes in the ontology **360** (via the vocabulary index **344**), the word or phrase will "trigger" or "activate" those nodes. When multiple nodes are "triggered," based on the quantity and/or relative importance of the activated nodes, the natural language processor **332** will select one of the actionable intents as the task (or task type) that the user intended the digital assistant to perform. In some implementations, the domain that has the most "triggered" nodes is selected. In some implementations, the domain having the highest confidence value (e.g., based on the relative importance of its various triggered nodes) is selected. In some implementations, the domain is selected based on a combination of the number and the importance of the triggered nodes. In some implementations, additional factors are considered in selecting the node as well, such as whether the digital assistant system **300** has previously correctly interpreted a similar request from a user.

In some implementations, the digital assistant system **300** also stores names of specific entities in the vocabulary index **344**, so that when one of these names is detected in the user request, the natural language processor **332** will be able to recognize that the name refers to a specific instance of a property or sub-property in the ontology. In some implementations, the names of specific entities are names of businesses, restaurants, people, movies, and the like. In some implementations, the digital assistant system **300** can search and identify specific entity names from other data sources, such as the user's address book or contact list, a movies database, a musicians database, and/or a restaurant database. In some implementations, when the natural language processor **332** identifies that a word in the token sequence is a name of a specific entity (such as a name in the user's address book or contact list), that word is given additional significance in selecting the actionable intent within the ontology for the user request.

For example, when the words "Mr. Santo" are recognized from the user request, and the last name "Santo" is found in the vocabulary index **344** as one of the contacts in the user's contact list, then it is likely that the user request corresponds to a "send a message" or "initiate a phone call" domain. For another example, when the words "ABC Café" are found in the user request, and the term "ABC Café" is found in the vocabulary index **344** as the name of a particular restaurant in the user's city, then it is likely that the user request corresponds to a "restaurant reservation" domain.

User data **348** includes user-specific information, such as user-specific vocabulary, user preferences, user address, user's default and secondary languages, user's contact list, and other short-term or long-term information for each user. The natural language processor **332** can use the user-specific information to supplement the information contained in the user input to further define the user intent. For example, for a user request "invite my friends to my birthday party," the natural language processor **332** is able to access user data **348** to determine who the "friends" are and when and where the "birthday party" would be held, rather than requiring the user to provide such information explicitly in his/her request.

In some implementations, natural language processor **332** includes categorization module **349**. In some implementations, the categorization module **349** determines whether each of the one or more terms in a text string (e.g., corresponding to a speech input associated with a digital photograph) is one of an entity, an activity, or a location, as discussed in greater detail below. In some implementations, the categorization module **349** classifies each term of the one or more terms as one of an entity, an activity, or a location.

Once the natural language processor **332** identifies an actionable intent (or domain) based on the user request, the natural language processor **332** generates a structured query to represent the identified actionable intent. In some implementations, the structured query includes parameters for one or more nodes within the domain for the actionable intent, and at least some of the parameters are populated with the specific information and requirements specified in the user request. For example, the user may say "Make me a dinner reservation at a sushi place at 7." In this case, the natural language processor **332** may be able to correctly identify the actionable intent to be "restaurant reservation" based on the user input. According to the ontology, a structured query for a "restaurant reservation" domain may include parameters such as {Cuisine}, {Time}, {Date}, {Party Size}, and the like. Based on the information contained in the user's utterance, the natural language processor **332** may generate a partial structured query for the restaurant reservation domain, where the partial structured query includes the parameters {Cuisine="Sushi"} and {Time="7 pm"}. However, in this example, the user's utterance contains insufficient information to complete the structured query associated with the domain. Therefore, other necessary parameters such as {Party Size} and {Date} are not specified in the structured query based on the information currently available. In some implementations, the natural language processor **332** populates some parameters of the structured query with received context information. For example, if the user requested a sushi restaurant "near me," the natural language processor **332** may populate a {location} parameter in the structured query with GPS coordinates from the user device **104**.

In some implementations, the natural language processor **332** passes the structured query (including any completed parameters) to the task flow processing module **336** ("task flow processor"). The task flow processor **336** is configured to perform one or more of: receiving the structured query from the natural language processor **332**, completing the structured query, and performing the actions required to "complete" the user's ultimate request. In some implementations, the various procedures necessary to complete these tasks are provided in task flow models **354**. In some implementations, the task flow models **354** include procedures for obtaining additional information from the user, and task flows for performing actions associated with the actionable intent.

As described above, in order to complete a structured query, the task flow processor **336** may need to initiate additional dialogue with the user in order to obtain additional information, and/or disambiguate potentially ambiguous utterances. When such interactions are necessary, the task flow processor **336** invokes the dialogue processing module **334** ("dialogue processor") to engage in a dialogue with the user. In some implementations, the dialogue processing module **334** determines how (and/or when) to ask the user for the additional information, and receives and processes the user responses. In some implementations, the questions are provided to and answers are received from the users through the I/O processing module **328**. For example, the dialogue processing module **334** presents dialogue output to the user via audio and/or visual output, and receives input from the user via spoken or physical (e.g., touch gesture) responses. Continuing with the example above, when the task flow processor **336** invokes the dialogue processor **334** to determine the "party size" and "date" information for the structured query associated with the domain "restaurant reservation," the dialogue processor **334** generates questions such as "For how many people?" and "On which day?" to pass to the user. Once answers are received from the user, the dialogue processing module **334** populates the structured query with the missing information, or passes the information to the task flow processor **336** to complete the missing information from the structured query.

In some cases, the task flow processor **336** may receive a structured query that has one or more ambiguous properties. For example, a structured query for the "send a message" domain may indicate that the intended recipient is "Bob," and the user may have multiple contacts named "Bob." The task flow processor **336** will request that the dialogue processor **334** disambiguate this property of the structured query. In turn, the dialogue processor **334** may ask the user "Which Bob?", and display (or read) a list of contacts named "Bob" from which the user may choose.

In some implementations, dialogue processor **334** includes disambiguation module **350**. In some implementations, disambiguation module **350** disambiguates one or more ambiguous terms (e.g., one or more ambiguous terms in a text string corresponding to a speech input associated with a digital photograph). In some implementations, disambiguation module **350** identifies that a first term of the one or more terms has multiple candidate meanings, prompts a user for additional information about the first term, receives the additional information from the user in response to the prompt and identifies the entity, activity, or location associated with the first term in accordance with the additional information.

In some implementations, disambiguation module **350** disambiguates pronouns. In such implementations, disambiguation module **350** identifies one of the one or more terms as a pronoun and determines a noun to which the pronoun refers. In some implementations, disambiguation module **350** determines a noun to which the pronoun refers by using a contact list associated with a user of the electronic device. Alternatively, or in addition, disambiguation module **350** determines a noun to which the pronoun refers as a name of an entity, an activity, or a location identified in a previous speech input associated with a previously tagged digital photograph. Alternatively, or in addition, disambiguation module **350** determines a noun to which the pronoun refers as a name of a person identified based on a previous speech input associated with a previously tagged digital photograph.

In some implementations, disambiguation module **350** accesses information obtained from one or more sensors (e.g., proximity sensor **214**, light sensor **212**, GPS receiver **213**, temperature sensor **215**, and motion sensor **210**) of a handheld electronic device (e.g., user device **104**) for determining a meaning of one or more of the terms. In some implementations, disambiguation module **350** identifies two terms each associated with one of an entity, an activity, or a location. For example, a first of the two terms refers to a person, and a second of the two terms refers to a location. In some implementations, disambiguation module **350** identifies three terms each associated with one of an entity, an activity, or a location.

Once the task flow processor **336** has completed the structured query for an actionable intent, the task flow processor **336** proceeds to perform the ultimate task associated with the actionable intent. Accordingly, the task flow processor **336** executes the steps and instructions in the task flow model according to the specific parameters contained in the structured query. For example, the task flow model for the actionable intent of "restaurant reservation" may include steps and instructions for contacting a restaurant and actually requesting a reservation for a particular party size at a particular time. For example, using a structured query such as: {restaurant reservation, restaurant=ABC Café, date=3/12/2012, time=7 pm, party size=5}, the task flow processor **336** may perform the steps of: (I) logging onto a server of the ABC Café or a restaurant reservation system that is configured to accept reservations for multiple restaurants, such as the ABC Café, (2) entering the date, time, and party size information in a form on the website, (3) submitting the form, and (4) making a calendar entry for the reservation in the user's calendar. In another example, described in greater detail below, the task flow processor **336** executes steps and instructions associated with tagging or searching for digital photographs in response to a voice input, e.g., in conjunction with photo module **132**.

In some implementations, the task flow processor **336** employs the assistance of a service processing module **338** ("service processor") to complete a task requested in the user input or to provide an informational answer requested in the user input. For example, the service processor **338** can act on behalf of the task flow processor **336** to make a phone call, set a calendar entry, invoke a map search, invoke or interact with other user applications installed on the user device, and invoke or interact with third party services (e.g. a restaurant reservation portal, a social networking website or service, a banking portal, etc.). In some implementations, the protocols and application programming interfaces (API) required by each service can be specified by a respective service model among the service models **356**. The service processor **338** accesses the appropriate service model for a service and generates requests for the service in accordance with the protocols and APIs required by the service according to the service model.

For example, if a restaurant has enabled an online reservation service, the restaurant can submit a service model specifying the necessary parameters for making a reservation and the APIs for communicating the values of the necessary parameters to the online reservation service. When requested by the task flow processor **336**, the service processor **338** can establish a network connection with the online reservation service using the web address stored in the service models **356**, and send the necessary parameters of the reservation (e.g., time, date, party size) to the online reservation interface in a format according to the API of the online reservation service.

In some implementations, the natural language processor **332**, dialogue processor **334**, and task flow processor **336** are used collectively and iteratively to deduce and define the user's intent, obtain information to further clarify and refine the user intent, and finally generate a response (e.g., provide an output to the user, or complete a task) to fulfill the user's intent.

In some implementations, after all of the tasks needed to fulfill the user's request have been performed, the digital assistant **326** formulates a confirmation response, and sends the response back to the user through the I/O processing module **328**. If the user request seeks an informational answer, the confirmation response presents the requested information to the user. In some implementations, the digital assistant also requests the user to indicate whether the user is satisfied with the response produced by the digital assistant **326**.

Attention is now directed to FIG. **4**, which is a block diagram illustrating components of an audio subsystem **226** and a voice trigger system **400**, in accordance with some implementations. (The voice trigger system **400** is not limited to voice, and implementations described herein apply equally to non-voice sounds.) The audio subsystem **226** and the voice trigger system **400** are composed of various components, modules, and/or software programs within the electronic device **104**.

In some implementations, the audio subsystem **226** includes a baseband subsystem **412**, an application processor **418**, a codec **410**, and a buffer **414**. In some implementations, more or fewer of these modules are used. The baseband subsystem **412**, application processor **418**, codec **410**, and buffer **414** may be referred to as modules, and may include hardware (e.g., circuitry, memory, processors, etc.), software (e.g., programs, software-on-a-chip, firmware, etc.), and/or any combinations thereof for performing the functionality described herein. In some implementations, the codec **410** includes an analog to digital converter (ADC) and a digital to analog converter (DAC). In some implementations, the audio subsystem **226** is coupled to one or more microphones **230** (FIG. **2**) and one or more speakers **228** (FIG. **2**). In some implementations, the baseband subsystem **412**, application processor **418**, codec **410**, and buffer **414** are connected using an Integrated Interchip Sound (I^2S) interface. In some implementations, the baseband subsystem **412**, application processor **418**, codec **410**, and buffer **414** are connected using a high-speed interchip (HSIC) interface. In some implementations, the audio subsystem **226** is coupled to an external audio system **416** that includes at least one microphone **418** and at least one speaker **420**. The audio subsystem **226** provides sound inputs to the voice trigger system **400** (as well as other components or modules, such as a phone and/or communication(s) subsystem of a phone) for processing and/or analysis. In some implementations, the baseband subsystem is not a component of audio subsystem **226**. In some implementations, the baseband subsystem is a component of communications subsystem **220**.

Privacy is a concern for many users. Therefore, in some implementations, the baseband unit (e.g., baseband subsystem **412** in FIG. **4**) has a per-device privacy key and analyzing the baseband unit to obtain a call audio signal does not introduce any vulnerability into the system. In some implementations, the adaptive speech recognition model is also encrypted to preserve privacy. In some implementations, the outbound audio channel of the first mobile communication device is encrypted and only authorized systems can analyze the outbound audio channel. Thus, unauthorized persons cannot analyze the outbound audio channel in a similar/analogous manner. Also, in some implementations, the adaptive speech recognition model does not include data which could be used to reconstruct a user's call audio. In other words, in these implementations, obtaining training data from a user's calls does not compromise the user's privacy during the calls. Thus, in some implementations, the data yielded from phone conversations need not be saved or transmitted to a server, thereby avoiding privacy issues.

In some implementations, baseband subsystem **412** includes an audio digital signal processor (DSP) **416**. In some implementations, the audio digital signal processor **416** is included within the application processor **418**. In some implementations, the audio digital signal processor (DSP) **416** is included within the codec **410**. In some implementations, the audio digital signal processor (DSP) **416** is a standalone module within the audio subsystem **226**. In some implementations, application processor **418** includes an embedded recognition engine. In some of these implementations, the embedded recognition engine is used to align sound units for updating the adaptive speech recognition model. In some implementations, application processor **418** corresponds to one or more processor(s) **204**.

In some implementations, the voice trigger system **400** includes a noise detector **402**, a sound-type detector **404**, a trigger sound detector **406**, and a speech-based service **408**, and an audio subsystem **226**, each coupled to an audio bus **401**. In some implementations, more or fewer of these modules are used. The sound detectors **402**, **404**, and **406** may be referred to as modules, and may include hardware (e.g., circuitry, memory, processors, etc.), software (e.g., programs, software-on-a-chip, firmware, etc.), and/or any combinations thereof for performing the functionality described herein. In some implementations, the sound detectors are communicatively, programmatically, physically, and/or operationally coupled to one another (e.g., via a communications bus), as illustrated in FIG. **4** by the broken lines. (For ease of illustration, FIG. **4** shows each sound detector coupled only to adjacent sound detectors. It will be understood that each sound detector can be coupled to any of the other sound detectors as well.)

In some implementations, the speech-based service **408** is a voice-based digital assistant, and corresponds to one or more components or functionalities of the digital assistant system described above with reference to FIGS. **1**-**3**C. In some implementations, the speech-based service is a speech-to-text service, a dictation service, or the like.

In some implementations, the noise detector **402** monitors an audio channel to determine whether a sound input from the audio subsystem **226** satisfies a predetermined condition, such as an amplitude threshold. The audio channel corresponds to a stream of audio information received by one or more sound pickup devices, such as the one or more microphones **230** (FIG. **2**). The audio channel refers to the audio information regardless of its state of processing or the particular hardware that is processing and/or transmitting the audio information. For example, the audio channel may refer to analog electrical impulses (and/or the circuits on which they are propagated) from the microphone **230**, as well as a digitally encoded audio stream resulting from processing of the analog electrical impulses (e.g., by the audio subsystem **226** and/or any other audio processing system of the electronic device **104**).

In some implementations, the predetermined condition is whether the sound input is above a certain volume for a predetermined amount of time. In some implementations, the noise detector uses time-domain analysis of the sound input, which requires relatively little computational and battery resources as compared to other types of analysis (e.g., as performed by the sound-type detector **404**, the trigger word detector **406**, and/or the speech-based service **408**). In some implementations, other types of signal processing and/or audio analysis are used, including, for example, frequency-domain analysis. If the noise detector **402** determines that the sound input satisfies the predetermined condition, it initiates an upstream sound detector, such as the sound-type detector **404** (e.g., by providing a control signal to initiate one or more processing routines, and/or by providing power to the upstream sound detector). In some implementations, the upstream sound detector is initiated in response to other conditions being satisfied. For example, in some implementations, the upstream sound detector is initiated in response to determining that the device is not being stored in an enclosed space (e.g., based on a light detector detecting a threshold level of light).

The sound-type detector **404** monitors the audio channel to determine whether a sound input corresponds to a certain type of sound, such as sound that is characteristic of a human voice, whistle, clap, etc. The type of sound that the sound-type detector **404** is configured to recognize will correspond to the particular trigger sound(s) that the voice trigger is configured to recognize. In implementations where the trigger sound is a spoken word or phrase, the sound-type detector **404** includes a "voice activity detector" (VAD). In some implementations, the sound-type detector **404** uses frequency-domain analysis of the sound input. For example, the sound-type detector **404** generates a spectrogram of a received sound input (e.g., using a Fourier transform), and analyzes the spectral components of the sound input to determine whether the sound input is likely to correspond to a particular type or category of sounds (e.g., human speech).

Thus, in implementations where the trigger sound is a spoken word or phrase, if the audio channel is picking up ambient sound (e.g., traffic noise) but not human speech, the VAD will not initiate the trigger sound detector **406**.

In some implementations, the sound-type detector **404** remains active for as long as predetermined conditions of any downstream sound detector (e.g., the noise detector **402**) are satisfied. For example, in some implementations, the sound-type detector **404** remains active as long as the sound input includes sound above a predetermined amplitude threshold (as determined by the noise detector **402**), and is deactivated when the sound drops below the predetermined threshold. In some implementations, once initiated, the sound-type detector **404** remains active until a condition is met, such as the expiration of a timer (e.g., for 1, 2, 5, or 10 seconds, or any other appropriate duration), the expiration of a certain number of on/off cycles of the sound-type detector **404**, or the occurrence of an event (e.g., the amplitude of the sound falls below a second threshold, as determined by the noise detector **402** and/or the sound-type detector **404**).

As mentioned above, if the sound-type detector **404** determines that the sound input corresponds to a predetermined type of sound, it initiates an upstream sound detector (e.g., by providing a control signal to initiate one or more processing routines, and/or by providing power to the upstream sound detector), such as the trigger sound detector **406**.

The trigger sound detector **406** is configured to determine whether a sound input includes at least part of certain predetermined content (e.g., at least part of the trigger word, phrase, or sound). In some implementations, the trigger sound detector **406** compares a representation of the sound input (an "input representation") to one or more reference representations of the trigger word. If the input representation matches at least one of the one or more reference representations with an acceptable confidence, the trigger sound detector **406** initiates the speech-based service **408** (e.g., by providing a control signal to initiate one or more processing routines, and/or by providing power to the upstream sound detector). In some implementations, the input representation and the one or more reference representations are spectrograms (or mathematical representations thereof), which represent how the spectral density of a signal varies with time. In some implementations, the representations are other types of audio signatures or voiceprints. In some implementations, initiating the speech-based service **408** includes bringing one or more circuits, programs, and/or processors out of a standby mode, and invoking the sound-based service. The sound-based service is then ready to provide more comprehensive speech recognition, speech-to-text processing, and/or natural language processing.

In some implementations, the voice-trigger system **400** includes voice authentication functionality, so that it can determine if a sound input corresponds to a voice of a particular person, such as an owner/user of the device. For example, in some implementations, the sound-type detector **404** uses a voiceprinting technique to determine that the sound input was uttered by an authorized user. Voice authentication and voiceprinting are described in more detail in U.S. patent application Ser. No. 13/053,144, assigned to the assignee of the instant application, which is hereby incorporated by reference in its entirety. In some implementations, voice authentication is included in any of the sound detectors described herein (e.g., the noise detector **402**, the sound-type detector **404**, the trigger sound detector **406**, and/or the speech-based service **408**). In some implementations, voice authentication is implemented as a separate module from the sound detectors listed above (e.g., as voice authentication module **426**, FIG. **4**), and may be operationally positioned after the noise detector **402**, after the sound-type detector **404**, after the trigger sound detector **406**, or at any other appropriate position.

In some implementations, the trigger sound detector **406** remains active for as long as conditions of any downstream sound detector(s) (e.g., the noise detector **402** and/or the sound-type detector **404**) are satisfied. For example, in some implementations, the trigger sound detector **406** remains active as long as the sound input includes sound above a predetermined threshold (as detected by the noise detector **402**). In some implementations, it remains active as long as the sound input includes sound of a certain type (as detected by the sound-type detector **404**). In some implementations, it remains active as long as both of the foregoing conditions are met.

In some implementations, once initiated, the trigger sound detector **406** remains active until a condition is met, such as the expiration of a timer (e.g., for 1, 2, 5, or 10 seconds, or any other appropriate duration), the expiration of a certain number of on/off cycles of the trigger sound detector **406**, or the occurrence of an event (e.g., the amplitude of the sound falls below a second threshold).

In some implementations, when one sound detector initiates another detector, both sound detectors remain active. However, the sound detectors may be active or inactive at various times, and it is not necessary that all of the downstream (e.g., the lower power and/or sophistication) sound detectors be active (or that their respective conditions are met) in order for upstream sound detectors to be active. For example, in some implementations, after the noise detector **402** and the sound-type detector **404** determine that their respective conditions are met, and the trigger sound detector **406** is initiated, one or both of the noise detector **402** and the sound-type detector **404** are deactivated and/or enter a standby mode while the trigger sound detector **406** operates. In other implementations, both the noise detector **402** and the sound-type detector **404** (or one or the other) stay active while the trigger sound detector **406** operates. In various implementations, different combinations of the sound detectors are active at different times, and whether one is active or inactive may depend on the state of other sound detectors, or may be independent of the state of other sound detectors.

While FIG. **4** describes three separate sound detectors, each configured to detect different aspects of a sound input, more or fewer sound detectors are used in various implementations of the voice trigger. For example, in some implementations, only the trigger sound detector **406** is used. In some implementations, the trigger sound detector **406** is used in conjunction with either the noise detector **402** or the sound-type detector **404**. In some implementations, all of the detectors **402-406** are used. In some implementations, additional sound detectors are included as well.

Moreover, different combinations of sound detectors may be used at different times. For example, the particular combination of sound detectors and how they interact may depend on one or more conditions, such as the context or operating state of a device. As a specific example, if a device is plugged in (and thus not relying exclusively on battery power), the trigger sound detector **406** is active, while the noise detector **402** and the sound-type detector **404** remain inactive. In another example, if the device is in a pocket or backpack, all sound detectors are inactive.

By cascading sound detectors as described above, where the detectors that require more power are invoked only when necessary by detectors that require lower power, power efficient voice triggering functionality can be provided. As described above, additional power efficiency is achieved by operating one or more of the sound detectors according to a duty cycle. For example, in some implementations, the noise detector **402** operates according to a duty cycle so that it performs effectively continuous noise detection, even though the noise detector is off for at least part of the time. In some implementations, the noise detector **402** is on for 10 milliseconds and off for 90 milliseconds. In some implementations, the noise detector **402** is on for 20 milliseconds and off for 500 milliseconds. Other on and off durations are also possible.

In some implementations, if the noise detector **402** detects a noise during its "on" interval, the noise detector **402** will remain on in order to further process and/or analyze the sound input. For example, the noise detector **402** may be configured to initiate an upstream sound detector if it detects sound above a predetermined amplitude for a predetermined amount of time (e.g., 100 milliseconds). Thus, if the noise detector **402** detects sound above a predetermined amplitude during its 10 millisecond "on" interval, it will not immediately enter the "off" interval. Instead, the noise detector **402** remains active and continues to process the sound input to determine whether it exceeds the threshold for the full predetermined duration (e.g., 100 milliseconds).

In some implementations, the sound-type detector **404** operates according to a duty cycle. In some implementations, the sound-type detector **404** is on for 20 milliseconds and off for 100 milliseconds. Other on and off durations are also possible. In some implementations, the sound-type detector **404** is able to determine whether a sound input corresponds to a predetermined type of sound within the "on" interval of its duty cycle. Thus, the sound-type detector **404** will initiate the trigger sound detector **406** (or any other upstream sound detector) if the sound-type detector **404** determines, during its "on" interval, that the sound is of a certain type. Alternatively, in some implementations, if the sound-type detector **404** detects, during the "on" interval, sound that may correspond to the predetermined type, the detector will not immediately enter the "off" interval. Instead, the sound-type detector **404** remains active and continues to process the sound input and determine whether it corresponds to the predetermined type of sound. In some implementations, if the sound detector determines that the predetermined type of sound has been detected, it initiates the trigger sound detector **406** to further process the sound input and determine if the trigger sound has been detected.

Similar to the noise detector **402** and the sound-type detector **404**, in some implementations, the trigger sound detector **406** operates according to a duty cycle. In some implementations, the trigger sound detector **406** is on for 50 milliseconds and off for 50 milliseconds. Other on and off durations are also possible. If the trigger sound detector **406** detects, during its "on" interval, that there is sound that may correspond to a trigger sound, the detector will not immediately enter the "off" interval. Instead, the trigger sound detector **406** remains active and continues to process the sound input and determine whether it includes the trigger sound. In some implementations, if such a sound is detected, the trigger sound detector **406** remains active to process the audio for a predetermined duration, such as 1, 2, 5, or 10 seconds, or any other appropriate duration. In some implementations, the duration is selected based on the length of the particular trigger word or sound that it is configured to detect. For example, if the trigger phrase is "Hey, SIRI," the trigger word detector is operated for about 2 seconds to determine whether the sound input includes that phrase.

In some implementations, some of the sound detectors are operated according to a duty cycle, while others operate continuously when active. For example, in some implementations, only the first sound detector is operated according to a duty cycle (e.g., the noise detector **402** in FIG. **4**), and upstream sound detectors are operated continuously once they are initiated. In some other implementations, the noise detector **402** and the sound-type detector **404** are operated according to a duty cycle, while the trigger sound detector **406** is operated continuously. Whether a particular sound detector is operated continuously or according to a duty cycle depends on one or more conditions, such as the context or operating state of a device. In some implementations, if a device is plugged in and not relying exclusively on battery power, all of the sound detectors operate continuously once they are initiated. In other implementations, the noise detector **402** (or any of the sound detectors) operates according to a duty cycle if the device is in a pocket or backpack (e.g., as determined by sensor and/or microphone signals), but operates continuously when it is determined that the device is likely not being stored. In some implementations, whether a particular sound detector is operated continuously or according to a duty cycle depends on the battery charge level of the device. For example, the noise detector **402** operates continuously when the battery charge is above 50%, and operates according to a duty cycle when the battery charge is below 50%.

In some implementations, the voice trigger includes noise, echo, and/or sound cancellation functionality (referred to collectively as noise cancellation). In some implementations, noise cancellation is performed by the audio subsystem **226** (e.g., by the audio DSP **416**). Noise cancellation reduces or removes unwanted noise or sounds from the sound input prior to it being processed by the sound detectors. In some cases, the unwanted noise is background noise from the user's environment, such as a fan or the clicking from a keyboard. In some implementations, the unwanted noise is any sound above, below, or at predetermined amplitudes or frequencies. For example, in some implementations, sound above the typical human vocal range (e.g., 3,000 Hz) is filtered out or removed from the signal. In some implementations, multiple microphones (e.g., the microphones **230**) are used to help determine what components of received sound should be reduced and/or removed. For example, in some implementations, the audio subsystem **226** uses beam forming techniques to identify sounds or portions of sound inputs that appear to originate from a single point in space (e.g., a user's mouth). The audio subsystem **226** then focuses on this sound by removing from the sound input sounds that are received equally by all microphones (e.g., ambient sound that does not appear to originate from any particular direction).

In some implementations, the DSP **416** is configured to cancel or remove from the sound input sounds that are being output by the device on which the digital assistant is operating. For example, if the audio subsystem **226** is outputting music, radio, a podcast, a voice output, or any other audio content (e.g., via the speaker **228**), the DSP **416** removes any of the outputted sound that was picked up by a microphone and included in the sound input. Thus, the sound input is free of the outputted audio (or at least contains less of the outputted audio). Accordingly, the sound input that is provided to the sound detectors will be cleaner, and the triggers more accurate. Aspects of noise cancellation are described in more detail in U.S. Pat. No. 7,272,224, assigned to the assignee of the instant application, which is hereby incorporated by reference in its entirety.

In some implementations, different sound detectors require that the sound input be filtered and/or preprocessed in different ways. For example, in some implementations, the noise detector **402** is configured to analyze time-domain audio signal between 60 and 20,000 Hz, and the sound-type detector is configured to perform frequency-domain analysis of audio between 60 and 3,000 Hz. Thus, in some implementations, the audio DSP **46** (and/or other audio DSPs of the device **104**) preprocesses received audio according to the respective needs of the sound detectors. In some implementations, on the other hand, the sound detectors are configured to filter and/or preprocess the audio from the audio subsystem **226** according to their specific needs. In such cases, the audio DSP **416** may still perform noise cancellation prior to providing the sound input to the sound detectors.

In some implementations, the context of the electronic device is used to help determine whether and how to operate the voice trigger. For example, it may be unlikely that users will invoke a speech-based service, such as a voice-based digital assistant, when the device is stored in their pocket, purse, or backpack. Also, it may be unlikely that users will invoke a speech-based service when they are at a loud rock concert. For some users, it is unlikely that they will invoke a speech-based service at certain times of the day (e.g., late at night). On the other hand, there are also contexts in which it is more likely that a user will invoke a speech-based service using a voice trigger. For example, some users will be more likely to use a voice trigger when they are driving, when they are alone, when they are at work, or the like. Various techniques are used to determine the context of a device. In various implementations, the device uses information from any one or more of the following components or information sources to determine the context of a device: GPS receivers, light sensors, microphones, proximity sensors, orientation sensors, inertial sensors, cameras, communications circuitry and/or antennas, charging and/or power circuitry, switch positions, temperature sensors, compasses, accelerometers, calendars, user preferences, etc.

The context of the device can then be used to adjust how and whether the voice trigger operates. For example, in certain contexts, the voice trigger will be deactivated (or operated in a different mode) as long as that context is maintained. For example, in some implementations, the voice trigger is deactivated when the phone is in a predetermined orientation (e.g., lying face-down on a surface), during predetermined time periods (e.g., between 10:00 PM and 8:00 AM), when the phone is in a "silent" or a "do not disturb" mode (e.g., based on a switch position, mode setting, or user preference), when the device is in a substantially enclosed space (e.g., a pocket, bag, purse, drawer, or glove box), when the device is near other devices that have a voice trigger and/or speech-based services (e.g., based on proximity sensors, acoustic/wireless/infrared communications), and the like. In some implementations, instead of being deactivated, the voice trigger system **400** is operated in a low-power mode (e.g., by operating the noise detector **402** according to a duty cycle with a 10 millisecond "on" interval and a 5 second "off" interval). In some implementations, an audio channel is monitored more infrequently when the voice trigger system **400** is operated in a low-power mode. In some implementations, a voice trigger uses a different sound detector or combination of sound detectors when it is in a low-power mode than when it is in a normal mode. (The voice trigger may be capable of numerous different modes or operating states, each of which may use a different amount of power, and different implementations will use them according to their specific designs.)

On the other hand, when the device is in some other contexts, the voice trigger will be activated (or operated in a different mode) so long as that context is maintained. For example, in some implementations, the voice trigger remains active while it is plugged into a power source, when the phone is in a predetermined orientation (e.g., lying face-up on a surface), during predetermined time periods (e.g., between 8:00 AM and 10:00 PM), when the device is travelling and/or in a car (e.g., based on GPS signals, BLUETOOTH connection or docking with a vehicle, etc.), and the like. Aspects of determining when a device is in a vehicle are described in more detail in U.S. Provisional Patent Application No. 61/657,744, assigned to the assignee of the instant application, which is hereby incorporated by reference in its entirety. Several specific examples of how to determine certain contexts are provided below. In various embodiments, different techniques and/or information sources are used to detect these and other contexts.

As noted above, whether or not the voice trigger system **400** is active (e.g., listening) can depend on the physical orientation of a device. In some implementations, the voice trigger is active when the device is placed "face-up" on a surface (e.g., with the display and/or touchscreen surface visible), and/or is inactive when it is "face-down." This provides a user with an easy way to activate and/or deactivate the voice trigger without requiring manipulation of settings menus, switches, or buttons. In some implementations, the device detects whether it is face-up or face-down on a surface using light sensors (e.g., based on the difference in incident light on a front and a back face of the device **104**), proximity sensors, magnetic sensors, accelerometers, gyroscopes, tilt sensors, cameras, and the like.

In some implementations, other operating modes, settings, parameters, or preferences are affected by the orientation and/or position of the device. In some implementations, the particular trigger sound, word, or phrase of the voice trigger is listening for depends on the orientation and/or position of the device. For example, in some implementations, the voice trigger listens for a first trigger word, phrase, or sound when the device is in one orientation (e.g., laying face-up on a surface), and a different trigger word, phrase, or sound when the device is in another orientation (e.g., laying face-down). In some implementations, the trigger phrase for a face-down orientation is longer and/or more complex than for a face-up orientation. Thus, a user can place a device face-down when they are around other people or in a noisy environment so that the voice trigger can still be operational while also reducing false accepts, which may be more frequent for shorter or simpler trigger words. As a specific example, a face-up trigger phrase may be "Hey, SIRI," while a face-down trigger phrase may be "Hey, SIRI, this is Andrew, please wake up." The longer trigger phrase also provides a larger voice sample for the sound detectors and/or voice authenticators to process and/or analyze, thus increasing the accuracy of the voice trigger and decreasing false accepts.

In some implementations, the device **104** detects whether it is in a vehicle (e.g., a car). A voice trigger is particularly beneficial for invoking a speech-based service when the user is in a vehicle, as it helps reduce the physical interactions that are necessary to operate the device and/or the speech based service. Indeed, one of the benefits of a voice-based digital assistant is that it can be used to perform tasks where looking at and touching a device would be impractical or unsafe. Thus, the voice trigger may be used when the device is in a vehicle so that the user does not have to touch the device in order to invoke the digital assistant. In some implementations, the device determines that it is in a vehicle by detecting that it has been connected to and/or paired with a vehicle, such as through BLUETOOTH communications (or other wireless communications) or through a docking connector or cable. In some implementations, the device determines that it is in a vehicle by determining the device's location and/or speed (e.g., using GPS receivers, accelerometers, and/or gyroscopes). If it is determined that the device is likely in a vehicle, because it is travelling above 20 miles per hour and is determined to be travelling along a road, for example, then the voice trigger remains active and/or in a high-power or more sensitive state.

In some implementations, the device detects whether the device is stored (e.g., in a pocket, purse, bag, a drawer, or the like) by determining whether it is in a substantially enclosed space. In some implementations, the device uses light sensors (e.g., dedicated ambient light sensors and/or cameras) to determine that it is stored. For example, in some implementations, the device is likely being stored if light sensors detect little or no light. In some implementations, the time of day and/or location of the device are also considered. For example, if the light sensors detect low light levels when high light levels would be expected (e.g., during the day), the device may be in storage and the voice trigger system **400** not needed. Thus, the voice trigger system **400** will be placed in a low-power or standby state.

In some implementations, the difference in light detected by sensors located on opposite faces of a device can be used to determine its position, and hence whether or not it is stored. Specifically, users are likely to attempt to activate a voice trigger when the device is resting on a table or surface rather than when it is being stored in a pocket or bag. But when a device is lying face-down (or face-up) on a surface such as a table or desk, one surface of the device will be occluded so that little or no light reaches that surface, while the other surface will be exposed to ambient light. Thus, if light sensors on the front and back face of a device detect significantly different light levels, the device determines that it is not being stored. On the other hand, if light sensors on opposite faces detect the same or similar light levels, the device determines that it is being stored in a substantially enclosed space. Also, if the light sensors both detect a low light level during the daytime (or when the device would expect the phone to be in a bright environment, the device determines with a greater confidence that it is being stored.

In some implementations, other techniques are used (instead of or in addition to light sensors) to determine whether the device is stored. For example, in some implementations, the device emits one or more sounds (e.g., tones, clicks, pings, etc.) from a speaker or transducer (e.g., speaker **228**), and monitors one or more microphones or transducers (e.g., microphone **230**) to detect echoes of the omitted sound(s). (In some implementations, the device emits inaudible signals, such as sound outside of the human hearing range.) From the echoes, the device determines characteristics of the surrounding environment. For example, a relatively large environment (e.g., a room or a vehicle) will reflect the sound differently than a relatively small, enclosed environment (e.g., a pocket, purse, bag, drawer, or the like).

In some implementations, the voice trigger system **400** operates differently if it is near other devices (such as other devices that have voice triggers and/or speech-based services) than if it is not near other devices. This may be useful, for example, to shut down or decrease the sensitivity of the voice trigger system **400** when many devices are close together so that if one person utters a trigger word, other surrounding devices are not triggered as well. In some implementations, a device determines proximity to other devices using RFID, near-field communications, infrared/acoustic signals, or the like.

Voice triggers are particularly useful when a device is being operated in a hands-free mode, such as when the user is driving. In such cases, users often use external audio systems, such as wired or wireless headsets, watches with speakers and/or microphones, a vehicle's built-in microphones and speakers, etc., to free themselves from having to hold a device near their face to make a call or dictate text inputs. For example, wireless headsets and vehicle audio systems may connect to an electronic device using BLUETOOTH communications, or any other appropriate wireless communication. However, it may be inefficient for a voice trigger to monitor audio received via a wireless audio accessory because of the power required to maintain an open audio channel with the wireless accessory. In particular, a wireless headset may hold enough charge in its battery to provide a few hours of continuous talk-time, and it is therefore preferable to reserve the battery for when the headset is needed for actual communication, instead of using it to simply monitor ambient audio and wait for a possible trigger sound. Moreover, wired external headset accessories may require significantly more power than on-board microphones alone, and keeping the headset microphone active will deplete the device's battery charge. This is especially true considering that the ambient audio received by the wireless or wired headset will typically consist mostly of silence or irrelevant sounds. Thus, in some implementations, the voice trigger system **400** monitors audio from the microphone **230** on the device even when the device is coupled to an external microphone (wired or wireless). Then, when the voice trigger detects the trigger word, the device initializes an active audio link with the external microphone in order to receive subsequent sound inputs (such as a command to a voice-based digital assistant) via the external microphone rather than the on-device microphone **230**.

When certain conditions are met, though, an active communication link can be maintained between an external audio system **416** (which may be communicatively coupled to the device **104** via wires or wirelessly) and the device so that the voice trigger system **400** can listen for a trigger sound via the external audio system **416** instead of (or in addition to) the on-device microphone **230**. For example, in some implementations, characteristics of the motion of the electronic device and/or the external audio system **416** (e.g., as determined by accelerometers, gyroscopes, etc. on the respective devices) are used to determine whether the voice trigger system **400** should monitor ambient sound using the on-device microphone **230** or an external microphone **418**. Specifically, the difference between the motion of the device and the external audio system **416** provides information about whether the external audio system **416** is actually in use. For example, if both the device and a wireless headset are moving (or not moving) substantially identically, it may be determined that the headset is not in use or is not being worn. This may occur, for example, because both devices are near to each other and idle (e.g., sitting on a table or stored in a pocket, bag, purse, drawer, etc.). Accordingly, under these conditions, the voice trigger system **400** monitors the on-device microphone, because it is unlikely that the headset is actually being used. If there is a difference in motion between the wireless headset and the device, however, it is determined that the headset is being worn by a user. These conditions may occur, for example, because the device has been set down (e.g., on a surface or in a bag), while the headset is being worn on the user's head (which will likely move at least a small amount, even when the wearer is relatively still). Under these conditions, because it is likely that the headset is being worn, the voice trigger system **400** maintains an active communication link and monitors the microphone **418** of the headset instead of (or in addition to) the on-device microphone **230**. And because this technique focuses on the difference in the motion of the device and the headset, motion that is common to both devices can be canceled out. This may be useful, for example, when a user is using a headset in a moving vehicle, where the device (e.g., a cellular phone) is resting in a cup holder, empty seat, or in the user's pocket, and the headset is worn on the user's head. Once the motion that is common to both devices is cancelled out (e.g., the vehicle's motion), the relative motion of the headset as compared to the device (if any) can be determined in order to determine whether the headset is likely in use (or, whether the headset is not being worn). While the above discussion refers to wireless headsets, similar techniques are applied to wired headsets as well.

Because people's voices vary greatly, it may be necessary or beneficial to tune a voice trigger to improve its accuracy in recognizing the voice of a particular user. Also, people's voices may change over time, for example, because of illnesses, natural voice changes relating to aging or hormonal changes, and the like. Thus, in some implementations, the voice trigger system **400** is able to adapt its voice and/or sound recognition profiles for a particular user or group of users (e.g., by using an adaptive speech recognition model).

As described above, sound detectors (e.g., the sound-type detector **404** and/or the trigger sound detector **406**) may be configured to compare a representation of a sound input (e.g., the sound or utterance provided by a user) to one or more reference representations. For example, if an input representation matches the reference representation to a predetermined confidence level, the sound detector will determine that the sound input corresponds to a predetermined type of sound (e.g., the sound-type detector **404**), or that the sound input includes predetermined content (e.g., the trigger sound detector **406**). In order to tune the voice trigger system **400**, in some implementations, the device adjusts the reference representation to which the input representation is compared. In some implementations, the reference representation is adjusted (or created) as part of a voice enrollment or "training" procedure, where a user outputs the trigger sound several times so that the device can adjust (or create) the reference representation. The device can then create a reference representation using that person's actual voice.

In some implementations, the device uses trigger sounds that are received under normal use conditions to adjust the reference representation. For example, after a successful voice triggering event (e.g., where the sound input was found to satisfy all of the triggering criteria) the device will use information from the sound input to adjust and/or tune the reference representation. In some implementations, only sound inputs that were determined to satisfy all or some of the triggering criteria with a certain confidence level are used to adjust the reference representation. Thus, when the voice trigger is less confident that a sound input corresponds to or includes a trigger sound, that voice input may be ignored for the purposes of adjusting the reference representation. On the other hand, in some implementations, sound inputs that satisfied the voice trigger system **400** to a lower confidence are used to adjust the reference representation.

In some implementations, the device **104** iteratively adjusts the reference representation (using these or other techniques) as more and more sound inputs are received so that slight changes in a user's voice over time can be accommodated. For example, in some implementations, the device **104** (and/or associated devices or services) adjusts the reference representation after each successful triggering event. In some implementations, the device **104** analyzes the sound input associated with each successful triggering event and determines if the reference representations should be adjusted based on that input (e.g., if certain conditions are met), and only adjusts the reference representation if it is appropriate to do so. In some implementations, the device **104** maintains a moving average of the reference representation over time.

In some implementations, the voice trigger system **400** detects sounds that do not satisfy one or more of the triggering criteria (e.g., as determined by one or more of the sound detectors), but that may actually be attempts by an authorized user to do so. For example, voice trigger system **400** may be configured to respond to a trigger phrase such as "Hey, SIRI", but if a user's voice has changed (e.g., due to sickness, age, accent/inflection changes, etc.), the voice trigger system **400** may not recognize the user's attempt to activate the device. (This may also occur when the voice trigger system **400** has not been properly tuned for that user's particular voice, such as when the voice trigger system **400** is set to default conditions and/or the user has not performed an initialization or training procedure to customize the voice trigger system **400** for his or her voice.) If the voice trigger system **400** does not respond to the user's first attempt to active the voice trigger, the user is likely to repeat the trigger phrase. The device detects that these repeated sound inputs are similar to one another, and/or that they are similar to the trigger phrase (though not similar enough to cause the voice trigger system **400** to activate the speech-based service). If such conditions are met, the device determines that the sound inputs correspond to valid attempts to activate the voice trigger system **400**. Accordingly, in some implementations, the voice trigger system **400** uses those received sound inputs to adjust one or more aspects of the voice trigger system **400** so that similar utterances by the user will be accepted as valid triggers in the future. In some implementations, these sound inputs are used to adapt the voice trigger system **400** only if certain conditions or combinations of conditions are met. For example, in some implementations, the sound inputs are used to adapt the voice trigger system **400** when a predetermined number of sound inputs are received in succession (e.g., 2, 3, 4, 5, or any other appropriate number), when the sound inputs are sufficiently similar to the reference representation, when the sound inputs are sufficiently similar to each other, when the sound inputs are close together (e.g., when they are received within a predetermined time period and/or at or near a predetermined interval), and/or any combination of these or other conditions.

In some cases, the voice trigger system **400** may detect one or more sound inputs that do not satisfy one or more of the triggering criteria, followed by a manual initiation of the speech-based service (e.g., by pressing a button or icon). In some implementations, the voice trigger system **400** determines that, because speech-based service was initiated shortly after the sound inputs were received, the sound inputs actually corresponded to failed voice triggering attempts. Accordingly, the voice trigger system **400** uses those received sound inputs to adjust one or more aspects of the voice trigger system **400** so that utterances by the user will be accepted as valid triggers in the future, as described above.

While the adaptation techniques described above refer to adjusting a reference representation, other aspects of the trigger sound detecting techniques may be adjusted in the same or similar manner in addition to or instead of adjusting the reference representation. For example, in some implementations, the device adjusts how sound inputs are filtered and/or what filters are applied to sound inputs, such as to focus on and/or eliminate certain frequencies or ranges of frequencies of a sound input. In some implementations, the device adjusts an algorithm that is used to compare the input representation with the reference representation. For example, in some implementations, one or more terms of a mathematical function used to determine the difference between an input representation and a reference representation are changed, added, or removed, or a different mathematical function is substituted.

In some implementations, adaptation techniques such as those described above require more resources than the voice trigger system **400** is able to or is configured to provide. In particular, the sound detectors may not have, or have access to, the amount or the types of processors, data, or memory that are necessary to perform the iterative adaptation of a reference representation and/or a sound detection algorithm (or any other appropriate aspect of the voice trigger system **400**). Thus, in some implementations, one or more of the above described adaptation techniques are performed by a more powerful processor, such as an application processor (e.g., the processor(s) **204**), or by a different device (e.g., the server system **108**). However, the voice trigger system **400** is designed to operate even when the application processor is in a standby mode. Thus, the sound inputs which are to be used to adapt the voice trigger system **400** are received when the application processor is not active and cannot process the sound input. Accordingly, in some implementations, the sound input is stored by the device so that it can be further processed and/or analyzed after it is received. In some implementations, the sound input is stored in the memory buffer **414** of the audio subsystem **226**. In some implementations, the sound input is stored in system memory (e.g., memory **250**, FIG. **2**) using direct memory access (DMA) techniques (including, for example, using a DMA engine so that data can be copied or moved without requiring the application processor to be initiated). The stored sound input is then provided to or accessed by the application processor (or the server system **108**, or another appropriate device) once it is initiated so that the application processor can execute one or more of the adaptation techniques described above.

FIGS. **5**A and **5**B are flow diagrams representing methods for obtaining training data to update an adaptive speech recognition model, according to certain implementations. The methods are, optionally, governed by instructions that are stored in a computer memory or non-transitory computer readable storage medium (e.g., memory **250** of client device **104**, memory **302** associated with the digital assistant system **300**) and that are executed by one or more processors of one or more computer systems of a digital assistant system, including, but not limited to, the server system **108**, and/or the user device **104***a*. The computer readable storage medium may include a magnetic or optical disk storage device, solid state storage devices such as Flash memory, or other non-volatile memory device or devices. The computer readable instructions stored on the computer readable storage medium may include one or more of: source code, assembly language code, object code, or other instruction format that is interpreted by one or more processors. In various implementations, some operations in each method may be combined and/or the order of some operations may be changed from the order shown in the figures. Also, in some implementations, operations shown in separate figures and/or discussed in association with separate methods may be combined to form other methods, and operations shown in the same figure and/or discussed in association with the same method may be separated into different methods. Moreover, in some implementations, one or more operations in the methods are performed by modules of the digital assistant system **300** and/or an electronic device (e.g., the user device **104**), including, for example, the natural language processing module **332**, the dialogue flow processing module **334**, the audio subsystem **226**, the noise detector **402**, the sound-type detector **404**, the trigger sound detector **406**, the speech-based service **408**, and/or any sub modules thereof.

FIGS. **5**A-**5**B illustrate a method **500** of obtaining training data to update an adaptive speech recognition model, according to some implementations. In some implementations, the method **500** is performed at a system including one or more processors and memory storing instructions for execution by the one or more processors (e.g., server system **108** in FIG. **1**). The system determines (**502**) that a first user of a first mobile communication device (e.g., a mobile telephone) is engaged in a call over a communications network (e.g., communications network(s) **110** in FIG. **1**). For example, a device (e.g., device **104***a* in FIG. **1**) receives a user request (e.g., via audio subsystem **226** in FIG. **2**) to initiate a call. In another example, a device receives a call request through a communications network (e.g., via communication subsystem(s) **224** in FIG. **2**). In some implementations, the call is a mobile telephone call (e.g., telephony service **122-5** in FIG. **1**). In some implementations, the call is a multimedia communication. In some implementations, the call is a VoIP communication. In some implementations, the call comprises an interaction between the first user of the first mobile communication device and a second mobile device. In some implementations, the call comprises a conversation between the first user of the first mobile communication device and a user of a second device. As an example, a call may comprise a conversation between a user of device **104***a* and a user of device **104***b* in FIG. **1**.

The system provides (**504**) an adaptive speech recognition model. In some implementations, the system provides a speaker-independent model (e.g., a canonical model). For example, in some implementations, the system determines that a speaker-dependent model has not been stored for a corresponding user and, in accordance with that determination, provides an initial speaker-independent model. In another example, the system determines that the first mobile communication device is not associated with any stored speaker-dependent models and, in accordance with that determination, provides a speaker-independent model. In some implementations, the system provides a speaker-dependent model associated with a user of the first mobile communication device. For example, the system determines that a stored speaker-dependent model corresponds to the user and, in accordance with that determination, provides the stored speaker-dependent model

The system analyzes (**506**) into an outbound audio channel of the first mobile communication device to obtain a call audio signal corresponding to audio input from one or more microphones of the first mobile communication device. In some implementations, analyzing the outbound audio channel includes analyzing a baseband unit (e.g., baseband subsystem **412** in FIG. **4**) of the first mobile communication device. In some implementations, analyzing the outbound audio channel includes analyzing an audio DSP (e.g., audio DSP **416** in FIG. **4**) of the first mobile communication device. In some implementations, analyzing the outbound audio channel includes analyzing an application processor (e.g., application processor **418** in FIG. **4**) of the first mobile communication device.

In some implementations, prior to analyzing the outbound audio channel, the system converts the audio signal from an analog audio signal to a digital audio signal. For example, in some implementations, the system converts the audio signal in a codec (e.g., codec **410** in FIG. **4**) prior to analyzing the outbound audio channel in an application processor (e.g., application processor **418** in FIG. **4**). In some implementations, prior to analyzing the outbound audio channel, the system determines that the mobile communication device is in an adaptive-speaker-training mode. For example, in some implementations, prior to analyzing the outbound audio channel, the system sends the user of a mobile communication device a request to enter into a speaker-training mode, the user accepts the request, and in accordance with the user's acceptance, the device enters a speaker-training mode. In this example, if the user does not want the system to analyze the outbound audio channel (e.g., the user has a problem affecting the user's voice and/or the user is not the primary user of the mobile device), then the user can reject the request to enter into speaker-training mode. In some implementations, the captured audio is rendered through the application processor where an embedded recognition engine is used to recognize sound units for updating model statistics.

In some embodiments, analyzing the outbound audio channel comprises utilizing (**508**) a voice activity detector (VAD) to determine when there is active speech on the outbound audio channel; in accordance with a determination that there is active speech on the outbound audio channel, analyzing the outbound audio channel; and in accordance with a determination that there is not active speech on the outbound audio channel, forgoing analyzing the outbound audio channel. For example, in some embodiments, the system utilizes a VAD included within a voice trigger system (e.g., voice trigger system **400** in FIG. **4**). Thus, in some implementations, if the outbound audio channel is picking up ambient sound (e.g., traffic noise) but not human speech, the system will utilize the VAD to determine that there is no active speech on the outbound audio channel.

The system updates (**510**) the adaptive speech recognition model with training data (e.g., one or more speaker-dependent sound units) derived from the call audio signal. In some implementations, prior to updating the adaptive speech recognition model, the system determines that the call has ended. In some implementations, updating the adaptive speech recognition model comprises replacing the adaptive speech recognition model with a new adaptive speech recognition model generated from the training data. For example, in some of these implementations, the system discards the provided adaptive speech recognition model and stores a new adaptive speech recognition model generated from the training data obtained during the call.

In some implementations, updating the adaptive speech recognition model comprises generating a speaker-dependent model from the data, comparing the speaker-dependent model to the adaptive speech recognition model, and updating the adaptive speech recognition model based on the comparison. In some of these implementations, updating the adaptive speech recognition model based on the comparison includes directly adapting the model parameters. In some other implementations, updating the adaptive speech recognition model based on the comparison includes applying Linear transforms (e.g., an MLLR transform) for a set of Gaussians to the model parameters. In some implementations, updating the adaptive speech recognition model based on the comparison includes aligning a user's speech to phonetic sound units. These alignments are subsequently used to update each sound unit in the adaptive speech recognition model. In some implementations, the system updates the adaptive speech recognition model with training data only if the amount of training data reaches a predetermined threshold (e.g., batch adaptation). In some of these implementations, the system updates the adaptive speech recognition model with training data derived from the call audio signal and discards any prior data.

In some implementations, the system utilizes the adaptive speech recognition model to authenticate a user on a device (e.g., the first mobile communication device). For example, in some of these implementations, voice-trigger system **400** includes voice authentication module **426** and voice authentication module **426** utilizes the adaptive speech recognition model to authenticate the user. In some of these implementations, the adaptive speech recognition model comprises a Gaussian mixture model that models the unique characteristics of the associated user. A statistical likelihood measure is used to render an authentication by how the user's voice matches the adaptive speech recognition model versus a second model calculated from large amounts of anti-user data.

In some embodiments, updating the adaptive speech recognition model comprises comparing (**512**) the call audio signal with the adaptive speech recognition model, generating a confidence score based on the comparison; in accordance with a determination that the confidence score is at or above a predetermined threshold, updating the adaptive speech recognition model with the training data derived from the call audio signal; and, in accordance with a determination that the confidence score is below the predetermined threshold, forgoing the updating of the adaptive speech recognition model. For example, a confidence score below the predetermined threshold may indicate that a user is not associated with the provided adaptive speech recognition model or that the user is sick or that conditions have temporarily altered the user's voice. In these examples, forgoing the updating of the adaptive speech recognition model prevents a potential decrease in the model's accuracy which may result from updating the model with the training data.

In some embodiments, the training data derived from the call audio signal includes (**514**) one or more speaker-dependent sound units (e.g., phonemes). In these embodiments, updating the adaptive speech recognition model comprises comparing at least a subset of the one or more speaker-dependent sound units to the adaptive speech recognition model, generating one or more adaptive speech vectors based on the comparison, and modifying the adaptive speech recognition model based on at least a subset of the one or more adaptive speech vectors.

In some embodiments, the system stores (**516**) the adaptive speech recognition model in memory. In some implementations, the memory is a component of the first mobile device (e.g., memory **250** in FIG. **2**). In some implementations, the memory is a component of a server (e.g., memory **302** in FIG. **3**A).

In some embodiments, the system modifies (**518**) the adaptive speech recognition model with training data derived from audio user interaction with a digital assistant. In some implementations, the adaptive speech recognition model is updated with training data obtained both from calls and from audio user interactions with a digital assistant. For example, the adaptive speech recognition model is updated when a user makes a call and is then updated again when the user audibly interacts with a digital assistant.

In some embodiments, after said updating, the system receives (**520**) invocation of the digital assistant, receives speech input from a second user, generates speech-to-text output corresponding to the speech input, and provides the speech-to-text output to the digital assistant. For example, a user (e.g., a user of device **104***a* in FIG. **1**) invokes a digital assistant (e.g., digital assistant **102***a* in FIG. **1**) and the system uses the updated adaptive speech recognition model to generate the speech-to-text output (e.g., in STT processing module **330** in FIG. **3**B).

In some embodiments, generating speech-to-text output corresponding to the speech input comprises comparing (**522**) the speech input with the adaptive speech recognition model; in accordance with a determination that the second user is the same as the first user, performing automatic speech recognition using the adaptive speech recognition model to generate speech-to-text output; and in accordance with a determination that the second user is distinct from the first user, performing automatic speech recognition using a speaker-independent model to generate speech-to-text output. For example, a user (e.g., a user of device **104***a* in FIG. **1**) invokes a digital assistant (e.g., digital assistant **102***a* in FIG. **1**) and if the updated adaptive speech recognition model corresponds to the user then the system uses the updated adaptive speech recognition model to generate the speech-to-text output. Conversely, in this example, if the updated adaptive speech recognition model does not correspond to the user then the system uses a speaker-independent model to generate speech-to-text output.

In accordance with some implementations, FIG. **6** shows a functional block diagram of a system **600** configured in accordance with the principles of the invention as described above. The functional blocks of the device may be implemented by hardware, software, or a combination of hardware and software to carry out the principles of the invention. It is understood by persons of skill in the art that the functional blocks described in FIG. **6** may be combined or separated into sub-blocks to implement the principles of the invention as described above. Therefore, the description herein may support any possible combination or separation or further definition of the functional blocks described herein.

As shown in FIG. **6**, system **600** includes sound receiving unit **602** configured to receive sound input. System **600** also includes processing unit **604** coupled to sound receiving unit **602**. In some implementations, voice activity detecting unit **606** is coupled to sound receiving unit **602** and processing unit **604**. In some implementations, processing unit **604** includes determining unit **608**, model providing unit **610**, analyzing unit **612**, model updating unit **614**, model modifying unit **616**, speech-to-text (STT) generating unit **618**, STT providing unit **620**, speech comparing unit **622**, storing unit **624**, score generating unit **626**, and speech vector generating unit **628**. In some implementations, model updating unit **614** is the same as model modifying unit **616**. In some implementations, STT generating unit **618** corresponds to STT processing module **330**. In some implementations, STT providing unit **620** corresponds to STT processing module **330**. In some implementations, storing unit **624** corresponds to memory interface **202**. In some implementations, storing unit **624** corresponds to memory **302**. In some implementations, model providing unit **610** corresponds to digital assistant client module **264**. In some implementations, model providing unit **610** corresponds to I/O processing module **328**.

Processing unit **604** is configured to: determine (e.g., with determining unit **608**) that a first user of a first mobile communication device is engaged in a call over a communications network and providing an adaptive speech recognition mode; analyze (e.g., with analyzing unit **612**) an outbound audio channel of the first mobile communication device to obtain a call audio signal corresponding to audio input from one or more microphones of the first mobile communication device; and update (e.g., with model updating unit **614**) the adaptive speech recognition model with training data derived from the call audio signal.

In some implementations, processing unit **604** is part of said first mobile communication device having said one or more microphones. In some implementations, processing unit **604** is part of a server system distinct from said first mobile communication device.

In some implementations, processing unit **604** is further configured to modify (e.g., with model modifying unit **616**) the adaptive speech recognition model with training data derived from audio user interaction with a digital assistant.

In some implementations, processing unit **604** is further configured to, after said updating, receive invocation of the digital assistant, receive speech input from a second user, generate (e.g., with STT generating unit **618**) speech-to-text output corresponding to the speech input, and provide (e.g., with STT providing unit **620**) the speech-to-text output to the digital assistant.

In some implementations, generating speech-to-text (e.g., with STT generating unit **618**) output corresponding to the speech input comprises: comparing (e.g., with speech comparing unit **622**) the speech input with the adaptive speech recognition model; in accordance with a determination that the second user is the same as the first user, performing automatic speech recognition using the adaptive speech recognition model to generate speech-to-text output; and in accordance with a determination that the second user is distinct from the first user, performing automatic speech recognition using a speaker-independent model to generate speech-to-text output.

In some implementations, processing unit **604** is further configured to store (e.g., with storing unit **624**) the adaptive speech recognition model in memory.

In some implementations, analyzing (e.g., with analyzing unit **612**) into the outbound audio channel comprises: utilizing a voice activity detector to determine when there is active speech on the outbound audio channel; in accordance with a determination that there is active speech on the outbound audio channel, analyzing the outbound audio channel; and in accordance with a determination that there is not active speech on the outbound audio channel, forgoing analyzing the outbound audio channel.

In some implementations, updating (e.g., with model updating unit **614**) the adaptive speech recognition model comprises: comparing (e.g., with speech comparing unit **622**) the call audio signal with the adaptive speech recognition model; generating (e.g., with score generating unit **626**) a confidence score based on the comparison; in accordance with a determination that the confidence score is at or above a predetermined threshold, updating the adaptive speech recognition model with the training data derived from the call audio signal; and in accordance with a determination that the confidence score is below the predetermined threshold, forgoing to update the adaptive speech recognition model.

In some implementations, the training data derived from the call audio signal includes one or more speaker-dependent sound units; and updating (e.g., with model updating unit **614**) the adaptive speech recognition model comprises: comparing at least a subset of the one or more speaker-dependent sound units to the adaptive speech recognition model; generating (e.g., with speech vector generating unit **628**) one or more adaptive speech vectors based on the comparison; and modifying the adaptive speech recognition model based on at least a subset of the one or more adaptive speech vectors.

As described above, one aspect of the present technology is the gathering and use of data available from various sources to improve the delivery to users of invitational content or any other content that may be of interest to them. The present disclosure contemplates that in some instances, this gathered data can include personal information data that uniquely identifies or can be used to contact or locate a specific person. Such personal information data can include demographic data, location-based data, telephone numbers, email addresses, home addresses, or any other identifying information.

The present disclosure recognizes that the use of such personal information data, in the present technology, can be used to the benefit of users. For example, the personal information data can be used to deliver targeted content that is of greater interest to the user. Accordingly, use of such personal information data enables calculated control of the delivered content. Further, other uses for personal information data that benefit the user are also contemplated by the present disclosure.

The present disclosure further contemplates that the entities responsible for the collection, analysis, disclosure, transfer, storage, or other use of such personal information data will comply with well-established privacy policies and/or privacy practices. In particular, such entities should implement and consistently use privacy policies and practices that are generally recognized as meeting or exceeding industry or governmental requirements for maintaining personal information data private and secure. For example, personal information from users should be collected for legitimate and reasonable uses of the entity and not shared or sold outside of those legitimate uses. Further, such collection should occur only after receiving the informed consent of the users. Additionally, such entities would take any needed steps for safeguarding and securing access to such personal information data and ensuring that others with access to the personal information data adhere to their privacy policies and procedures. Further, such entities can subject themselves to evaluation by third parties to certify their adherence to widely accepted privacy policies and practices.

Despite the foregoing, the present disclosure also contemplates examples in which users selectively block the use of, or access to, personal information data. That is, the present disclosure contemplates that hardware and/or software elements can be provided to prevent or block access to such personal information data. For example, in the case of advertisement delivery services, the present technology can be configured to allow users to select to "opt in" or "opt out" of participation in the collection of personal information data during registration for services. In another example, users can select not to provide location information for targeted content delivery services. In yet another example, users can select to not provide precise location information, but permit the transfer of location zone information.

Therefore, although the present disclosure broadly covers use of personal information data to implement one or more various disclosed examples, the present disclosure also contemplates that the various examples can also be implemented without the need for accessing such personal information data. That is, the various examples of the present technology are not rendered inoperable due to the lack of all or a portion of such personal information data. For example, content can be selected and delivered to users by inferring preferences based on non-personal information data or a bare minimum amount of personal information, such as the content being requested by the device associated with a user, other non-personal information available to the content delivery services, or publicly available information.

The foregoing description, for purpose of explanation, has been described with reference to specific implementations. However, the illustrative discussions above are not intended to be exhaustive or to limit the disclosed implementations to the precise forms disclosed. Many modifications and variations are possible in view of the above teachings. The implementations were chosen and described in order to best explain the principles and practical applications of the disclosed ideas, to thereby enable others skilled in the art to best utilize them with various modifications as are suited to the particular use contemplated.

It will be understood that, although the terms "first," "second," etc. may be used herein to describe various elements, these elements should not be limited by these terms. These terms are only used to distinguish one element from another. For example, a first sound detector could be termed a second sound detector, and, similarly, a second sound detector could be termed a first sound detector, without changing the meaning of the description, so long as all occurrences of the "first sound detector" are renamed consistently and all occurrences of the "second sound detector" are renamed consistently. The first sound detector and the second sound detector are both sound detectors, but they are not the same sound detector.

The terminology used herein is for the purpose of describing particular implementations only and is not intended to be limiting of the claims. As used in the description of the implementations and the appended claims, the singular forms "a", "an" and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will also be understood that the term "and/or" as used herein refers to and encompasses any and all possible combinations of one or more of the associated listed items. It will be further understood that the terms "comprises" and/or "comprising," when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

As used herein, the term "if" may be construed to mean "when" or "upon" or "in response to determining" or "in accordance with a determination" or "in response to detecting," that a stated condition precedent is true, depending on the context. Similarly, the phrase "if it is determined [that a stated condition precedent is true]" or "if [a stated condition precedent is true]" or "when [a stated condition precedent is true]" may be construed to mean "upon determining" or "upon a determination that" or "in response to determining" or "in accordance with a determination" or "upon detecting" or "in response to detecting" that the stated condition precedent is true, depending on the context.

What is claimed is:

1. A machine-implemented method, comprising:

determining that a first user of a first mobile communication device is engaged in a call over a communications network;

providing an adaptive speech recognition model comprising a speaker-dependent speech recognition model;

after providing the adaptive speech recognition model, analyzing an outbound audio channel of a baseband unit of the first mobile communication device to obtain a call audio signal corresponding to audio input from one or more microphones of the first mobile communication device; and

updating the adaptive speech recognition model with training data derived from the call audio signal.

2. The method of claim **1**, wherein the method is performed by said first mobile communication device having said one or more microphones.

3. The method of claim **1**, further comprising modifying the adaptive speech recognition model with training data derived from audio user interaction with a digital assistant.

4. The method of claim **3**, further comprising, after said updating:

receiving invocation of the digital assistant;

receiving speech input from a second user;

generating speech-to-text output corresponding to the speech input; and

providing the speech-to-text output to the digital assistant.

5. The method of claim **4**, wherein generating speech-to-text output corresponding to the speech input comprises:

comparing the speech input with the adaptive speech recognition model;

in accordance with a determination that the second user is the same as the first user, performing automatic speech recognition using the adaptive speech recognition model to generate speech-to-text output; and

in accordance with a determination that the second user is distinct from the first user, performing automatic speech recognition using a speaker-independent model to generate speech-to-text output.

6. The method of claim **1**, wherein analyzing the outbound audio channel comprises:

utilizing a voice activity detector to determine when there is active speech on the outbound audio channel;

in accordance with a determination that there is active speech on the outbound audio channel, analyzing the outbound audio channel; and

in accordance with a determination that there is not active speech on the outbound audio channel, forgoing analyzing the outbound audio channel.

7. The method of claim **1**, wherein updating the adaptive speech recognition model comprises:

comparing the call audio signal with the adaptive speech recognition model;

generating a confidence score based on the comparison;

in accordance with a determination that the confidence score is at or above a predetermined threshold, updating the adaptive speech recognition model with the training data derived from the call audio signal; and

in accordance with a determination that the confidence score is below the predetermined threshold, forgoing to update the adaptive speech recognition model.

8. The method of claim **1**, wherein the training data derived from the call audio signal includes one or more speaker-dependent sound units; and

updating the adaptive speech recognition model comprises:

comparing at least a subset of the one or more speaker-dependent sound units to the adaptive speech recognition model;

generating one or more adaptive speech vectors based on the comparison; and

modifying the adaptive speech recognition model based on at least a subset of the one or more adaptive speech vectors.

9. A system, comprising:

one or more processors;

memory; and

one or more programs stored in the memory, the one or more programs comprising instructions to:

determine that a first user of a first mobile communication device is engaged in a call over a communications network;

provide an adaptive speech recognition model comprising a speaker-dependent speech recognition model;

after providing the adaptive speech recognition model, analyze an outbound audio channel of a baseband unit of the first mobile communication device to obtain a call audio signal corresponding to audio input from one or more microphones of the first mobile communication device; and

update the adaptive speech recognition model with training data derived from the call audio signal.

10. The system of claim **9**, wherein the system comprises said first mobile communication device having said one or more microphones.

11. The system of claim **9**, the one or more programs further comprising instructions to modify the adaptive speech recognition model with training data derived from audio user interaction with a digital assistant.

12. The system of claim **11**, the one or more programs further comprising instructions for, after said updating:

receiving invocation of the digital assistant;

receiving speech input from a second user;

generating speech-to-text output; and

providing the speech-to-text output to the digital assistant.

13. The system of claim **12**, wherein generating speech-to-text output comprises:

comparing the speech input with the adaptive speech recognition model;

in accordance with a determination that the second user is the same as the first user, performing automatic speech recognition using the adaptive speech recognition model to generate speech-to-text output; and

in accordance with a determination that the second user is distinct from the first user, performing automatic speech recognition using a speaker-independent model to generate speech-to-text output.

14. The system of claim **9**, wherein detecting the outbound audio channel comprises:

utilizing a voice activity detector to determine when there is active speech on the outbound audio channel;

in accordance with a determination that there is active speech on the outbound audio channel, detecting the outbound audio channel; and

in accordance with a determination that there is not active speech on the outbound audio channel, forgoing detecting the outbound audio channel.

15. The system of claim 9, wherein updating the adaptive speech recognition model comprises:
comparing the call audio signal with the adaptive speech recognition model;
generating a confidence score based on the comparison;
in accordance with a determination that the confidence score is at or above a predetermined threshold, updating the adaptive speech recognition model with the training data derived from the call audio signal; and
in accordance with a determination that the confidence score is below the predetermined threshold, forgoing to update the adaptive speech recognition model.

16. The system of claim 9, wherein the training data derived from the call audio signal includes one or more speaker-dependent sound units; and
updating the adaptive speech recognition model comprises:
comparing at least a subset of the one or more speaker-dependent sound units to the adaptive speech recognition model;
generating one or more adaptive speech vectors based on the comparison; and
modifying the adaptive speech recognition model based on at least a subset of the one or more adaptive speech vectors.

17. A non-transitory computer readable storage medium storing one or more programs configured for execution by a device, the one or more programs comprising instructions to:
determine that a first user of a first mobile communication device is engaged in a call over a communications network;
provide an adaptive speech recognition model comprising a speaker-dependent speech recognition model;
after providing the adaptive speech recognition model, analyze an outbound audio channel of a baseband unit of the first mobile communication device to obtain a call audio signal corresponding to audio input from one or more microphones of the first mobile communication device; and
update the adaptive speech recognition model with training data derived from the call audio signal.

18. The non-transitory computer readable storage medium of claim 17, wherein the method is performed by said first mobile communication device having said one or more microphones.

19. The non-transitory computer readable storage medium of claim 17, further comprising modifying the adaptive speech recognition model with training data derived from audio user interaction with a digital assistant.

20. The non-transitory computer readable storage medium of claim 19, further comprising, after said updating:
receiving invocation of the digital assistant;
receiving speech input from a second user;
generating speech-to-text output corresponding to the speech input; and
providing the speech-to-text output to the digital assistant.

21. The non-transitory computer readable storage medium of claim 20, wherein generating speech-to-text output corresponding to the speech input comprises:
comparing the speech input with the adaptive speech recognition model;
in accordance with a determination that the second user is the same as the first user, performing automatic speech recognition using the adaptive speech recognition model to generate speech-to-text output; and
in accordance with a determination that the second user is distinct from the first user, performing automatic speech recognition using a speaker-independent model to generate speech-to-text output.

22. The non-transitory computer readable storage medium of claim 17, wherein analyzing the outbound audio channel comprises:
utilizing a voice activity detector to determine when there is active speech on the outbound audio channel;
in accordance with a determination that there is active speech on the outbound audio channel, analyzing the outbound audio channel; and
in accordance with a determination that there is not active speech on the outbound audio channel, forgoing analyzing the outbound audio channel.

23. The non-transitory computer readable storage medium of claim 17, wherein updating the adaptive speech recognition model comprises:
comparing the call audio signal with the adaptive speech recognition model;
generating a confidence score based on the comparison;
in accordance with a determination that the confidence score is at or above a predetermined threshold, updating the adaptive speech recognition model with the training data derived from the call audio signal; and
in accordance with a determination that the confidence score is below the predetermined threshold, forgoing to update the adaptive speech recognition model.

24. The non-transitory computer readable storage medium of claim 17, wherein the training data derived from the call audio signal includes one or more speaker-dependent sound units; and
updating the adaptive speech recognition model comprises:
comparing at least a subset of the one or more speaker-dependent sound units to the adaptive speech recognition model;
generating one or more adaptive speech vectors based on the comparison; and
modifying the adaptive speech recognition model based on at least a subset of the one or more adaptive speech vectors.

25. An electronic device, comprising:
one or more microphones;
one or more processors; and
memory storing one or more programs, the one or more programs comprising instructions, which when executed by the one or more processors, cause the one or more processors to:
determine that a user is engaged in a call over a communications network;
analyze an outbound audio channel of a baseband unit of the electronic device to obtain a call audio signal corresponding to audio input from the one or more microphones;
determine whether a speaker-dependent speech recognition model corresponding to the user is stored in the memory; and
in response to determining that a speaker-dependent speech recognition model corresponding to the user is stored in the memory, update the speaker-dependent speech recognition model with training data derived from the call audio signal.

26. The electronic device of claim 25, wherein the instructions further cause the one or more processors to:
in response to determining that a speaker-dependent speech recognition model corresponding to the user is not stored in the memory:

obtain a speaker-independent speech recognition model; and

generate a speaker-dependent speech recognition model using the speaker-independent speech recognition model and the training data derived from the call audio signal.

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