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(54) **UNIT-SELECTION TEXT-TO-SPEECH SYNTHESIS USING CONCATENATION-SENSITIVE NEURAL NETWORKS**

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(58) **Field of Classification Search**

None

See application file for complete search history.

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(57) **ABSTRACT**

Systems and processes for performing unit-selection text-to-speech synthesis are provided. In one example process, a sequence of target units can represent a spoken pronunciation of text. A set of predicted acoustic model parameters of a second target unit can be determined using a set of acoustic features of a first candidate speech segment of a first target unit and a set of linguistic features of the second target unit. A likelihood score of the second candidate speech segment with respect to the first candidate speech segment can be determined using the set of predicted acoustic model parameters of the second target unit and a set of acoustic features of the second candidate speech segment of the second target unit. The second candidate speech segment can be selected for speech synthesis based on the determined likelihood score. Speech corresponding to the received text can be generated using the selected second candidate speech segment.

27 Claims, 11 Drawing Sheets

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Tactile Output Generator(s) 167
Other Input Control Devices 116

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Event Sorter
170
171
Event Monitor
172
Hit View Determination Module
173
Active Event Recognizer Determination Module
174
Event Dispatcher Module
Event Recognizer 180
Event Receiver 182
Event Comparator 184
Event Definitions 186
Event 1 187-1
Event 2 187-2
...
Metadata 183
Event Delivery 188
Event Recognizer 180
...
Event Recognizer 180
Event Data 179
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Application
Application View 191
...
Application View 191
Event Handler 190
Data Updater 176
Object Updater 177
GUI Updater 178
...
Event Handler 190
...
Application Internal State 192

FIG. 1B

Portable Multifunction Device 100
206
210
212
Speaker 111
Optical Sensor 164
Proximity Sensor 166
208
200
208
210 is SIM card slot
212 is headphone jack
202
Touch Screen 112
Contact Intensity Sensor(s) 165
Tactile Output Generator(s) 167
203
Microphone 113
Home 204
Accelerometer(s) 168
External Port 124

FIG. 2

Memory 370
Operating System 126
Communication Module 128
Contact/Motion Module 130
Graphics Module 132
Haptic Feedback Module 133
Text Input Module 134
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Contacts Module 137
Telephone Module 138
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E-mail Client Module 140
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Weather Widget 149-1
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Device 300
310
CPU(s)
320
330
I/O Interface
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Touchpad 355
Tactile Output Generator(s) 357
Sensor(s) 359
360
Network Communications Interface

FIG. 3

Portable Multifunction Device
100
206
Speaker 111
Optical Sensor 164
Proximity Sensor 166
400
208
208
405
402
Current Time 404
406
Messages 424
Tuesday 30
Calendar 426
Photos 428
Camera 430
Online Video 432
Stocks 434
280
Maps 436
73°
Weather 438
Clock 440
Workout Support 442
Notes 444
Settings 446
App Store
iTunes
Voice Memos
Utilities
414
410
4
6
Phone 416
Mail 418
Browser 420
iPod 422
408
Touch Screen 112
Microphone 113
Accelerometer(s) 168
204

FIG. 4A

450
468
470
453

451
460
462
Tactile Output Generator(s) 357
452
Contact Intensity Sensor(s) 359

FIG. 4B

Text-to-Speech Module
500
502
Text
Text Analysis Module
506
Acoustic Feature Prediction Model(s)
508
Speech Segment Database
504
Sequence of Target Units
Unit-Selection Module
510
Sequence of Selected Speech Segments
Speech Synthesizer Module
Speech Waveform

FIG. 5

Process
600
RECEIVE TEXT TO BE CONVERTED TO SPEECH
602
GENERATE SEQUENCE OF TARGET UNITS REPRESENTING SPOKEN PRONUNCIATION OF THE TEXT
604
SELECT FIRST CANDIDATE SPEECH SEGMENT FOR FIRST TARGET UNIT AND SECOND CANDIDATE SPEECH SEGMENT FOR SECOND TARGET UNIT
606
DETERMINE SET OF PREDICTED ACOUSTIC MODEL PARAMETERS OF SECOND TARGET UNIT USING SET OF ACOUSTIC FEATURES OF FIRST CANDIDATE SPEECH SEGMENT AND SET OF LINGUISTIC FEATURES OF SECOND TARGET UNIT
608
DETERMINE LIKELIHOOD SCORE OF SECOND CANDIDATE SPEECH SEGMENT WITH RESPECT TO FIRST CANDIDATE SPEECH SEGMENT USING SET OF PREDICTED ACOUSTIC MODEL PARAMETERS OF SECOND TARGET UNIT AND SET OF ACOUSTIC FEATURES OF SECOND CANDIDATE SPEECH SEGMENT
610
SELECT SECOND CANDIDATE SPEECH SEGMENT TO BE USED IN SPEECH SYNTHESIS BASED ON LIKELIHOOD SCORE
612
GENERATE SPEECH CORRESPONDING TO RECEIVED TEXT USING SECOND CANDIDATE SPEECH SEGMENT
614

FIG. 6

718
704
706
702
K1
K2
L1
L2
AA1
AA2
Z1
Z2
AH1
AH2
T1
T2
708
716
710
714
712

FIG. 7

Deep Neural Network
800
804
806
802
t_n
x_{n-1}
808
810
814
812
$E[x_n|x_{n-1},t_n]$
$Var[x_n|x_{n-1},t_n]$

FIG. 8

Electronic Device
900
902
Display Unit
903
Input Unit
904
Speaker Unit
906
Communication Unit
908
Processing Unit
910
Receiving Unit
912
Generating Unit
914
Selecting Unit
916
Determining Unit

FIG. 9

UNIT-SELECTION TEXT-TO-SPEECH SYNTHESIS USING CONCATENATION-SENSITIVE NEURAL NETWORKS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority from U.S. Provisional Ser. No. 62/232,042, filed on Sep. 24, 2015, entitled "Unit-Selection Text-to-Speech Synthesis Using Concatenation-Sensitive Neural Networks," which is hereby incorporated by reference in its entirety for all purposes.

FIELD

The present disclosure relates generally to text-to-speech synthesis, and more specifically to techniques for performing unit-selection text-to-speech synthesis.

BACKGROUND

Unit-selection text-to-speech (TTS) synthesis can be desirable for producing a more natural sounding voice quality compared to other TTS methods. Conventionally, unit-selection TTS synthesis can include three stages: front-end text analysis, unit selection, and waveform synthesis. In the unit-selection stage, a unit-selection algorithm can be implemented to select a sequence of speech units (e.g., speech segments, phones, sub-phones, etc.) from a database of audio units. The speech units can be obtained by segmenting recordings of a voice talent's speech that represent the spoken form of a corpus of text. Implementing a sophisticated unit-selection algorithm can be desirable to select the most suitable speech units from the database. The most suitable audio units can have acoustic properties that best match the target pronunciation of the text to be converted to speech, which can enable the synthesis of high-quality, natural sounding speech.

BRIEF SUMMARY

Systems and processes for performing unit-selection text-to-speech synthesis are provided. In one example process, text to be converted to speech can be received. A sequence of target units representing a spoken pronunciation of the text can be generated. A first candidate speech segment for a first target unit of the sequence of target units and a second candidate speech segment for a second target unit of the sequence of target units can be selected from a plurality of speech segments. A set of predicted acoustic model parameters of the second target unit can be determined using a set of acoustic features of the first candidate speech segment and a set of linguistic features of the second target unit. A likelihood score of the second candidate speech segment with respect to the first candidate speech segment can be determined using the set of predicted acoustic model parameters of the second target unit and a set of acoustic features of the second candidate speech segment. The second candidate speech segment to be used in speech synthesis can be selected based on the determined likelihood score. Speech corresponding to the received text can be generated using the second candidate speech segment.

BRIEF DESCRIPTION OF THE FIGURES

For a better understanding of the various described embodiments, reference should be made to the Description of Embodiments below, in conjunction with the following drawings in which like reference numerals refer to corresponding parts throughout the figures.

FIG. **1**A is a block diagram illustrating a portable multifunction device with a touch-sensitive display in accordance with some examples.

FIG. **1**B is a block diagram illustrating exemplary components for event handling in accordance with some embodiments.

FIG. **2** illustrates a portable multifunction device having a touch screen in accordance with some embodiments.

FIG. **3** is a block diagram of an exemplary multifunction device with a display and a touch-sensitive surface in accordance with some embodiments.

FIGS. **4**A and **4**B illustrate an exemplary user interface for a menu of applications on a portable multifunction device in accordance with some embodiments.

FIG. **5** illustrates an exemplary schematic block diagram of a text-to-speech module in accordance with some embodiments.

FIG. **6** illustrates a flow diagram of an exemplary process for unit-selection text-to-speech synthesis in accordance with some embodiments.

FIG. **7** illustrates an exemplary sequence of target units with one or more candidate speech segments selected for each target unit in accordance with some embodiments.

FIG. **8** illustrates an exemplary deep neural network for determining a set of predicted acoustic model parameters of a current target unit in accordance with some embodiments.

FIG. **9** illustrates a functional block diagram of an electronic device in accordance with some embodiments.

DESCRIPTION OF EMBODIMENTS

In the following description of the disclosure and embodiments, reference is made to the accompanying drawings in which it is shown by way of illustration of specific embodiments that can be practiced. It is to be understood that other embodiments and examples can be practiced and changes can be made without departing from the scope of the disclosure.

Techniques for performing unit-selection text-to-speech synthesis using concatenation-sensitive neural networks are provided. In one example process, a spoken pronunciation of text to be converted to speech can be represented by a sequence of target units. Based on the linguistic features of the target units, a first candidate speech segment for a first target unit of the sequence of target units and a second candidate speech segment for a second target unit of the sequence of target units can be selected from a plurality of speech segments. A set of predicted acoustic model parameters of the second target unit can be determined using a set of acoustic features of the first candidate speech segment and a set of linguistic features of the second target unit. Because the set of acoustic features of the first candidate speech segment are used to determine the set of predicted acoustic model parameters of the second target unit, the acoustic context preceding the second target unit is taken into account in determining the set of predicted acoustic model parameters. This can enable a more accurate and natural sounding selection of candidate speech segments corresponding to the sequence of target units. Additionally, determining a separate concatenation cost (or join cost) in conjunction with a target cost is not required for selecting suitable candidate speech segments. This can reduce the need to manually optimize the weights for each cost, which simplifies the unit-selection process.

Although the following description uses terms first, second, etc. to describe various elements, these elements should not be limited by the terms. These terms are only used to distinguish one element from another. For example, a first contact could be termed a second contact, and, similarly, a second contact could be termed a first contact, without departing from the scope of the present invention. The first contact and the second contact are both contacts, but they are not the same contact.

The terminology used in the description of the various described embodiments herein is for the purpose of describing particular embodiments only and is not intended to be limiting. As used in the description of the various described embodiments 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 "includes," "including," "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.

The term "if" may be construed to mean "when" or "upon" or "in response to determining" or "in response to detecting," depending on the context. Similarly, the phrase "if it is determined" or "if [a stated condition or event] is detected" may be construed to mean "upon determining" or "in response to determining" or "upon detecting [the stated condition or event]" or "in response to detecting [the stated condition or event],," depending on the context.

Embodiments of electronic devices, systems for performing unit-selection text-to-speech synthesis on such devices, and associated processes for using such devices are described. In some embodiments, the device is a portable communications device, such as a mobile telephone, that also contains other functions, such as PDA and/or music player functions. Exemplary embodiments of portable multifunction devices include, without limitation, the iPhone®, iPod Touch®, and iPad® devices from Apple Inc. of Cupertino, Calif. Other portable devices, such as laptops or tablet computers with touch-sensitive surfaces (e.g., touch screen displays and/or touch pads), may also be used. Exemplary embodiments of laptop and tablet computers include, without limitation, the iPad® and MacBook® devices from Apple Inc. of Cupertino, Calif. It should also be understood that, in some embodiments, the device is not a portable communications device, but is a desktop computer. Exemplary embodiments of desktop computers include, without limitation, the Mac Pro® from Apple Inc. of Cupertino, Calif.

In the discussion that follows, an electronic device that includes a display and a touch-sensitive surface is described. It should be understood, however, that the electronic device optionally includes one or more other physical user-interface devices, such as button(s), a physical keyboard, a mouse, and/or a joystick.

The device may support a variety of applications, such as one or more of the following: a drawing application, a presentation application, a word processing application, a website creation application, a disk authoring application, a spreadsheet application, a gaming application, a telephone application, a video conferencing application, an e-mail application, an instant messaging application, a workout support application, a photo management application, a digital camera application, a digital video camera application, a web browsing application, a digital music player application, and/or a digital video player application.

The various applications that are executed on the device optionally use at least one common physical user-interface device, such as the touch-sensitive surface. One or more functions of the touch-sensitive surface as well as corresponding information displayed on the device are, optionally, adjusted and/or varied from one application to the next and/or within a respective application. In this way, a common physical architecture (such as the touch-sensitive surface) of the device optionally supports the variety of applications with user interfaces that are intuitive and transparent to the user.

FIGS. **1**A and **1**B are block diagrams illustrating exemplary portable multifunction device **100** with touch-sensitive displays **112** in accordance with some embodiments. Touch-sensitive display **112** is sometimes called a "touch screen" for convenience. Device **100** may include memory **102**. Device **100** may include memory controller **122**, one or more processing units (CPU's) **120**, peripherals interface **118**, RF circuitry **108**, audio circuitry **110**, speaker **111**, microphone **113**, input/output (I/O) subsystem **106**, other input or control devices **116**, and external port **124**. Device **100** may include one or more optical sensors **164**. Bus/signal lines **103** may allow these components to communicate with one another. Device **100** is one example of an electronic device that could be used to perform the techniques described herein. Specific implementations involving device **100** 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 FIGS. **1**A and **1**B may be implemented in hardware, software, or a combination of both. The components also can be implemented using one or more signal processing and/or application specific integrated circuits.

Memory **102** may include one or more computer readable storage mediums. The computer readable storage mediums may be tangible and non-transitory. Memory **102** may include high-speed random access memory and may also include non-volatile memory, such as one or more magnetic disk storage devices, flash memory devices, or other non-volatile solid-state memory devices. Memory controller **122** may control access to memory **102** by other components of device **100**.

Peripherals interface **118** can be used to couple input and output peripherals of the device to CPU **120** and memory **102**. The one or more processors **120** run or execute various software programs and/or sets of instructions stored in memory **102** to perform various functions for device **100** and to process data. In some embodiments, peripherals interface **118**, CPU **120**, and memory controller **122** may be implemented on a single chip, such as chip **104**. In some other embodiments, they may be implemented on separate chips.

RF (radio frequency) circuitry **108** receives and sends RF signals, also called electromagnetic signals. RF circuitry **108** converts electrical signals to/from electromagnetic signals and communicates with communications networks and other communications devices via the electromagnetic signals. RF circuitry **108** may include well-known circuitry for performing these functions, including but not limited to an antenna system, an RF transceiver, one or more amplifiers, a tuner, one or more oscillators, a digital signal processor, a CODEC chipset, a subscriber identity module (SIM) card, memory,

and so forth. RF circuitry **108** may communicate with networks, such as the Internet, also referred to as the World Wide Web (WWW), 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 by wireless communication. The wireless communication may use any of a plurality of communications standards, protocols and technologies, including but not limited to Global System for Mobile Communications (GSM), Enhanced Data GSM Environment (EDGE), high-speed downlink packet access (HSDPA), wideband code division multiple access (W-CDMA), code division multiple access (CDMA), time division multiple access (TDMA), Bluetooth, Bluetooth Low Energy (BTLE), Wireless Fidelity (Wi-Fi) (e.g., IEEE 502.11a, IEEE 502.11b, IEEE 802.11g and/or IEEE 802.11n), voice over Internet Protocol (VoIP), Wi-MAX, a protocol for e-mail (e.g., Internet message access protocol (IMAP) and/or post office protocol (POP)), instant messaging (e.g., extensible messaging and presence protocol (XMPP), Session Initiation Protocol for Instant Messaging and Presence Leveraging Extensions (SIMPLE), Instant Messaging and Presence Service (IMPS)), and/or Short Message Service (SMS), or any other suitable communication protocol, including communication protocols not yet developed as of the filing date of this document.

Audio circuitry **110**, speaker **111**, and microphone **113** provide an audio interface between a user and device **100**. Audio circuitry **110** receives audio data from peripherals interface **118**, converts the audio data to an electrical signal, and transmits the electrical signal to speaker **111**. Speaker **111** converts the electrical signal to human-audible sound waves. Audio circuitry **110** also receives electrical signals converted by microphone **113** from sound waves. Audio circuitry **110** converts the electrical signal to audio data and transmits the audio data to peripherals interface **118** for processing. Audio data may be retrieved from and/or transmitted to memory **102** and/or RF circuitry **108** by peripherals interface **118**. In some embodiments, audio circuitry **110** also includes a headset jack (e.g., **212**, FIG. **2**). The headset jack provides an interface between audio circuitry **110** and removable audio input/output peripherals, such as output-only headphones or a headset with both output (e.g., a headphone for one or both ears) and input (e.g., a microphone).

I/O subsystem **106** couples input/output peripherals on device **100**, such as touch screen **112** and other input control devices **116**, to peripherals interface **118**. I/O subsystem **106** may include display controller **156** and one or more input controllers **160** for other input or control devices. The one or more input controllers **160** receive/send electrical signals from/to other input or control devices **116**. The other input control devices **116** may include physical buttons (e.g., push buttons, rocker buttons, etc.), dials, slider switches, joysticks, click wheels, and so forth. In some alternate embodiments, input controller(s) **160** may be coupled to any (or none) of the following: a keyboard, infrared port, USB port, and a pointer device such as a mouse. The one or more buttons (e.g., **208**, FIG. **2**) may include an up/down button for volume control of speaker **111** and/or microphone **113**. The one or more buttons may include a push button (e.g., **206**, FIG. **2**). A quick press of the push button may disengage a lock of touch screen **112** or begin a process that uses gestures on the touch screen to unlock the device, as described in U.S. patent application Ser. No. 11/322,549, "Unlocking a Device by Performing Gestures on an Unlock Image," filed Dec. 23, 2005, U.S. Pat. No. 7,657,849, which is hereby incorporated by reference in its entirety. A longer press of the push button (e.g., **206**) may turn power to device **100** on or off. The user may be able to customize a functionality of one or more of the buttons. Touch screen **112** is used to implement virtual or soft buttons and one or more soft keyboards.

Touch-sensitive display **112** provides an input interface and an output interface between the device and a user. Display controller **156** receives and/or sends electrical signals from/to touch screen **112**. Touch screen **112** displays visual output to the user. The visual output may include graphics, text, icons, video, and any combination thereof (collectively termed "graphics"). In some embodiments, some or all of the visual output may correspond to user-interface objects.

Touch screen **112** has a touch-sensitive surface, sensor or set of sensors that accepts input from the user based on haptic and/or tactile contact. Touch screen **112** and display controller **156** (along with any associated modules and/or sets of instructions in memory **102**) detect contact (and any movement or breaking of the contact) on touch screen **112** and converts the detected contact into interaction with user-interface objects (e.g., one or more soft keys, icons, web-pages or images) that are displayed on touch screen **112**. In an exemplary embodiment, a point of contact between touch screen **112** and the user corresponds to a finger of the user.

Touch screen **112** may use LCD (liquid crystal display) technology, LPD (light emitting polymer display) technology, or LED (light emitting diode) technology, although other display technologies may be used in other embodiments. Touch screen **112** and display controller **156** may detect contact and any movement or breaking thereof using any of a plurality of touch sensing technologies now known or later developed, including but not limited to capacitive, resistive, infrared, and surface acoustic wave technologies, as well as other proximity sensor arrays or other elements for determining one or more points of contact with touch screen **112**. In an exemplary embodiment, projected mutual capacitance sensing technology is used, such as that found in the iPhone® and iPod Touch® from Apple Inc. of Cupertino, Calif.

A touch-sensitive display in some embodiments of touch screen **112** may be analogous to the multi-touch sensitive touchpads described in the following U.S. Pat. No. 6,323,846 (Westerman et al.), U.S. Pat. No. 6,570,557 (Westerman et al.), and/or U.S. Pat. No. 6,677,932 (Westerman), and/or U.S. Patent Publication 2002/0015024A1, each of which is hereby incorporated by reference in its entirety. However, touch screen **112** displays visual output from device **100**, whereas touch sensitive touchpads do not provide visual output.

A touch-sensitive display in some embodiments of touch screen **112** may be as described in the following applications: (1) U.S. patent application Ser. No. 11/381,313, "Multipoint Touch Surface Controller," filed May 2, 2006; (2) U.S. patent application Ser. No. 10/840,862, "Multipoint Touchscreen," filed May 6, 2004; (3) U.S. patent application Ser. No. 10/903,964, "Gestures For Touch Sensitive Input Devices," filed Jul. 30, 2004; (4) U.S. patent application Ser. No. 11/048,264, "Gestures For Touch Sensitive Input Devices," filed Jan. 31, 2005; (5) U.S. patent application Ser. No. 11/038,590, "Mode-Based Graphical User Interfaces For Touch Sensitive Input Devices," filed Jan. 18, 2005; (6) U.S. patent application Ser. No. 11/228,758, "Virtual Input Device Placement On A Touch Screen User Interface," filed Sep. 16, 2005; (7) U.S. patent application Ser. No. 11/228,

700, "Operation Of A Computer With A Touch Screen Interface," filed Sep. 16, 2005; (8) U.S. patent application Ser. No. 11/228,737, "Activating Virtual Keys Of A Touch-Screen Virtual Keyboard," filed Sep. 16, 2005; and (9) U.S. patent application Ser. No. 11/367,749, "Multi-Functional Hand-Held Device," filed Mar. 3, 2006. All of these applications are incorporated by reference herein in their entirety.

Touch screen **112** may have a video resolution in excess of 100 dpi. In some embodiments, the touch screen has a video resolution of approximately 160 dpi. The user may make contact with touch screen **112** using any suitable object or appendage, such as a stylus, a finger, and so forth. In some embodiments, the user interface is designed to work primarily with finger-based contacts and gestures, which can be less precise than stylus-based input due to the larger area of contact of a finger on the touch screen. In some embodiments, the device translates the rough finger-based input into a precise pointer/cursor position or command for performing the actions desired by the user.

In some embodiments, in addition to the touch screen, device **100** may include a touchpad (not shown) for activating or deactivating particular functions. In some embodiments, the touchpad is a touch-sensitive area of the device that, unlike the touch screen, does not display visual output. The touchpad may be a touch-sensitive surface that is separate from touch screen **112** or an extension of the touch-sensitive surface formed by the touch screen.

Device **100** also includes power system **162** for powering the various components. Power system **162** may include a power management system, one or more power sources (e.g., battery, alternating current (AC)), a recharging system, a power failure detection circuit, a power converter or inverter, a power status indicator (e.g., a light-emitting diode (LED)) and any other components associated with the generation, management and distribution of power in portable devices.

Device **100** may also include one or more optical sensors **164**. FIGS. **1**A and **1**B show an optical sensor coupled to optical sensor controller **158** in I/O subsystem **106**. Optical sensor **164** may include charge-coupled device (CCD) or complementary metal-oxide semiconductor (CMOS) phototransistors. Optical sensor **164** receives light from the environment, projected through one or more lens, and converts the light to data representing an image. In conjunction with imaging module **143** (also called a camera module), optical sensor **164** may capture still images or video. In some embodiments, an optical sensor is located on the back of device **100**, opposite touch screen display **112** on the front of the device, so that the touch screen display may be used as a viewfinder for still and/or video image acquisition. In some embodiments, an optical sensor is located on the front of the device so that the user's image may be obtained for videoconferencing while the user views the other video conference participants on the touch screen display. In some embodiments, the position of optical sensor **164** can be changed by the user (e.g., by rotating the lens and the sensor in the device housing) so that a single optical sensor **164** may be used along with the touch screen display for both video conferencing and still and/or video image acquisition.

Device **100** may also include one or more proximity sensors **166**. FIGS. **1**A and **1**B show proximity sensor **166** coupled to peripherals interface **118**. Alternately, proximity sensor **166** may be coupled to input controller **160** in I/O subsystem **106**. Proximity sensor **166** may perform as described in U.S. patent application Ser. No. 11/241,839, "Proximity Detector In Handheld Device"; Ser. No. 11/240,788, "Proximity Detector In Handheld Device"; Ser. No. 11/620,702, "Using Ambient Light Sensor To Augment Proximity Sensor Output"; Ser. No. 11/586,862, "Automated Response To And Sensing Of User Activity In Portable Devices"; and Ser. No. 11/638,251, "Methods And Systems For Automatic Configuration Of Peripherals," which are hereby incorporated by reference in their entirety. In some embodiments, the proximity sensor turns off and disables touch screen **112** when the multifunction device is placed near the user's ear (e.g., when the user is making a phone call).

Device **100** optionally also includes one or more tactile output generators **167**. FIG. **1**A shows a tactile output generator coupled to haptic feedback controller **161** in I/O subsystem **106**. Tactile output generator **167** optionally includes one or more electroacoustic devices such as speakers or other audio components and/or electromechanical devices that convert energy into linear motion such as a motor, solenoid, electroactive polymer, piezoelectric actuator, electrostatic actuator, or other tactile output generating component (e.g., a component that converts electrical signals into tactile outputs on the device). Contact intensity sensor **165** receives tactile feedback generation instructions from haptic feedback module **133** and generates tactile outputs on device **100** that are capable of being sensed by a user of device **100**. In some embodiments, at least one tactile output generator is collocated with, or proximate to, a touch-sensitive surface (e.g., touch-sensitive display system **112**) and, optionally, generates a tactile output by moving the touch-sensitive surface vertically (e.g., in/out of a surface of device **100**) or laterally (e.g., back and forth in the same plane as a surface of device **100**). In some embodiments, at least one tactile output generator sensor is located on the back of device **100**, opposite touch screen display **112**, which is located on the front of device **100**.

Device **100** may also include one or more accelerometers **168**. FIGS. **1**A and **1**B show accelerometer **168** coupled to peripherals interface **118**. Alternately, accelerometer **168** may be coupled to an input controller **160** in I/O subsystem **106**. Accelerometer **168** may perform as described in U.S. Patent Publication No. 20050190059, "Acceleration-based Theft Detection System for Portable Electronic Devices," and U.S. Patent Publication No. 20060017692, "Methods And Apparatuses For Operating A Portable Device Based On An Accelerometer," both of which are incorporated by reference herein in their entirety. In some embodiments, information is displayed on the touch screen display in a portrait view or a landscape view based on an analysis of data received from the one or more accelerometers. Device **100** optionally includes, in addition to accelerometer(s) **168**, a magnetometer (not shown) and a GPS (or GLONASS or other global navigation system) receiver (not shown) for obtaining information concerning the location and orientation (e.g., portrait or landscape) of device **100**.

In some embodiments, the software components stored in memory **102** include operating system **126**, communication module (or set of instructions) **128**, contact/motion module (or set of instructions) **130**, graphics module (or set of instructions) **132**, text input module (or set of instructions) **134**, Global Positioning System (GPS) module (or set of instructions) **135**, and applications (or sets of instructions) **136**. Furthermore, in some embodiments memory **102** stores device/global internal state **157**, as shown in FIGS. **1**A, **1**B and **3**. Device/global internal state **157** includes one or more of: active application state, indicating which applications, if any, are currently active; display state, indicating what applications, views or other information occupy various regions of touch screen display **112**; sensor state, including

information obtained from the device's various sensors and input control devices **116**; and location information concerning the device's location and/or attitude.

Operating system **126** (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 communication between various hardware and software components.

Communication module **128** facilitates communication with other devices over one or more external ports **124** and also includes various software components for handling data received by RF circuitry **108** and/or external port **124**. External port **124** (e.g., Universal Serial Bus (USB), FIREWIRE, etc.) is adapted for coupling directly to other devices or indirectly over a network (e.g., the Internet, wireless LAN, etc.). In some embodiments, the external port is a multi-pin connector that is the same as, or similar to and/or compatible with the 5-pin and/or 30-pin connectors used on devices made by Apple Inc.

Contact/motion module **130** may detect contact with touch screen **112** (in conjunction with display controller **156**) and other touch sensitive devices (e.g., a touchpad or physical click wheel). Contact/motion module **130** includes various software components for performing various operations related to detection of contact, such as determining if contact has occurred (e.g., detecting a finger-down event), determining if there is movement of the contact and tracking the movement across the touch-sensitive surface (e.g., detecting one or more finger-dragging events), and determining if the contact has ceased (e.g., detecting a finger-up event or a break in contact). Contact/motion module **130** receives contact data from the touch-sensitive surface. Determining movement of the point of contact, which is represented by a series of contact data, may include determining speed (magnitude), velocity (magnitude and direction), and/or an acceleration (a change in magnitude and/or direction) of the point of contact. These operations may be applied to single contacts (e.g., one finger contacts) or to multiple simultaneous contacts (e.g., "multitouch"/multiple finger contacts). In some embodiments, contact/motion module **130** and display controller **156** detects contact on a touchpad. In some embodiments, contact/motion module **130** and controller **160** detects contact on a click wheel.

Contact/motion module **130** may detect a gesture input by a user. Different gestures on the touch-sensitive surface have different contact patterns. Thus, a gesture may be detected by detecting a particular contact pattern. For example, detecting a finger tap gesture includes detecting a finger-down event followed by detecting a finger-up (lift off) event at the same position (or substantially the same position) as the finger-down event (e.g., at the position of an icon). As another example, detecting a finger swipe gesture on the touch-sensitive surface includes detecting a finger-down event followed by detecting one or more finger-dragging events, and subsequently followed by detecting a finger-up (lift off) event.

Graphics module **132** includes various known software components for rendering and displaying graphics on touch screen **112** or other display, including components for changing the intensity of graphics that are displayed. As used herein, the term "graphics" includes any object that can be displayed to a user, including without limitation text, web-pages, icons (such as user-interface objects including soft keys), digital images, videos, animations and the like. In some embodiments, graphics module **132** stores data representing graphics to be used. Each graphic may be assigned a corresponding code. Graphics module **132** receives, from applications etc., one or more codes specifying graphics to be displayed along with, if necessary, coordinate data and other graphic property data, and then generates screen image data to output to display controller **156**.

Haptic feedback module **133** includes various software components for generating instructions used by tactile output generator(s) **167** to produce tactile outputs at one or more locations on device **100** in response to user interactions with device **100**.

Text input module **134**, which may be a component of graphics module **132**, provides soft keyboards for entering text in various applications (e.g., contacts **137**, e-mail **140**, IM **141**, browser **147**, and any other application that needs text input).

GPS module **135** determines the location of the device and provides this information for use in various applications (e.g., to telephone **138** for use in location-based dialing, to camera **143** as picture/video metadata, and to applications that provide location-based services such as weather widgets, local yellow page widgets, and map/navigation widgets).

Applications **136** may include the following modules (or sets of instructions), or a subset or superset thereof:

- Contacts module **137** (sometimes called an address book or contact list);
- Telephone module **138**;
- Video conferencing module **139**;
- E-mail client module **140**;
- Instant messaging (IM) module **141**;
- Workout support module **142**;
- Camera module **143** for still and/or video images;
- Image management module **144**;
- Video player module;
- Music player module;
- Browser module **147**;
- Calendar module **148**;
- Widget modules **149**, which may include one or more of: weather widget **149-1**, stocks widget **149-2**, calculator widget **149-3**, alarm clock widget **149-4**, dictionary widget **149-5**, and other widgets obtained by the user, as well as user-created widgets **149-6**;
- Widget creator module **150** for making user-created widgets **149-6**;
- Search module **151**;
- Video and music player module **152**, which merges video player module and music player module;
- Notes module **153**;
- Map module **154**; and/or
- Online video module **155**.

Examples of other applications **136** that may be stored in memory **102** include other word processing applications, other image editing applications, drawing applications, presentation applications, JAVA-enabled applications, encryption, digital rights management, voice recognition, and voice replication.

In conjunction with touch screen **112**, display controller **156**, contact/motion module **130**, graphics module **132**, and text input module **134**, contacts module **137** may be used to manage an address book or contact list (e.g., stored in application internal state **192** of contacts module **137** in memory **102** or memory **370**), including: adding name(s) to the address book; deleting name(s) from the address book; associating telephone number(s), e-mail address(es), physical address(es) or other information with a name; associating an image with a name; categorizing and sorting names;

providing telephone numbers or e-mail addresses to initiate and/or facilitate communications by telephone **138**, video conference module **139**, e-mail **140**, or IM **141**; and so forth.

In conjunction with RF circuitry **108**, audio circuitry **110**, speaker **111**, microphone **113**, touch screen **112**, display controller **156**, contact/motion module **130**, graphics module **132**, and text input module **134**, telephone module **138** may be used to enter a sequence of characters corresponding to a telephone number, access one or more telephone numbers in address book **137**, modify a telephone number that has been entered, dial a respective telephone number, conduct a conversation and disconnect or hang up when the conversation is completed. As noted above, the wireless communication may use any of a plurality of communications standards, protocols and technologies.

In conjunction with RF circuitry **108**, audio circuitry **110**, speaker **111**, microphone **113**, touch screen **112**, display controller **156**, optical sensor **164**, optical sensor controller **158**, contact module **130**, graphics module **132**, text input module **134**, contacts module **137**, and telephone module **138**, video conference module **139** includes executable instructions to initiate, conduct, and terminate a video conference between a user and one or more other participants in accordance with user instructions.

In conjunction with RF circuitry **108**, touch screen **112**, display controller **156**, contact/motion module **130**, graphics module **132**, and text input module **134**, e-mail client module **140** includes executable instructions to create, send, receive, and manage e-mail in response to user instructions. In conjunction with image management module **144**, e-mail client module **140** makes it very easy to create and send e-mails with still or video images taken with camera module **143**.

In conjunction with RF circuitry **108**, touch screen **112**, display controller **156**, contact module **130**, graphics module **132**, and text input module **134**, the instant messaging module **141** includes executable instructions to enter a sequence of characters corresponding to an instant message, to modify previously entered characters, to transmit a respective instant message (for example, using a Short Message Service (SMS) or Multimedia Message Service (MMS) protocol for telephony-based instant messages or using XMPP, SIMPLE, or IMPS for Internet-based instant messages), to receive instant messages and to view received instant messages. In some embodiments, transmitted and/or received instant messages may include graphics, photos, audio files, video files and/or other attachments as are supported in a MMS and/or an Enhanced Messaging Service (EMS). As used herein, "instant messaging" refers to both telephony-based messages (e.g., messages sent using SMS or MMS) and Internet-based messages (e.g., messages sent using XMPP, SIMPLE, or IMPS).

In conjunction with RF circuitry **108**, touch screen **112**, display controller **156**, contact module **130**, graphics module **132**, text input module **134**, GPS module **135**, map module **154**, and music player module, workout support module **142** includes executable instructions to create workouts (e.g., with time, distance, and/or calorie burning goals); communicate with workout sensors (sports devices); receive workout sensor data; calibrate sensors used to monitor a workout; select and play music for a workout; and display, store and transmit workout data.

In conjunction with touch screen **112**, display controller **156**, optical sensor(s) **164**, optical sensor controller **158**, contact/motion module **130**, graphics module **132**, and image management module **144**, camera module **143** includes executable instructions to capture still images or video (including a video stream) and store them into memory **102**, modify characteristics of a still image or video, or delete a still image or video from memory **102**.

In conjunction with touch screen **112**, display controller **156**, contact/motion module **130**, graphics module **132**, text input module **134**, and camera module **143**, image management module **144** includes executable instructions to arrange, modify (e.g., edit), or otherwise manipulate, label, delete, present (e.g., in a digital slide show or album), and store still and/or video images.

In conjunction with touch screen **112**, display controller **156**, contact/motion module **130**, graphics module **132**, audio circuitry **110**, and speaker **111**, video player module **145** includes executable instructions to display, present or otherwise play back videos (e.g., on touch screen **112** or on an external, connected display via external port **124**).

In conjunction with touch screen **112**, display system controller **156**, contact module **130**, graphics module **132**, audio circuitry **110**, speaker **111**, RF circuitry **108**, and browser module **147**, music player module **146** includes executable instructions that allow the user to download and play back recorded music and other sound files stored in one or more file formats, such as MP3 or AAC files. In some embodiments, device **100** may include the functionality of an MP3 player, such as an iPod (trademark of Apple Inc.).

In conjunction with RF circuitry **108**, touch screen **112**, display controller **156**, contact/motion module **130**, graphics module **132**, and text input module **134**, browser module **147** includes executable instructions to browse the Internet in accordance with user instructions, including searching, linking to, receiving, and displaying web-pages or portions thereof, as well as attachments and other files linked to web-pages.

In conjunction with RF circuitry **108**, touch screen **112**, display controller **156**, contact/motion module **130**, graphics module **132**, text input module **134**, e-mail client module **140**, and browser module **147**, calendar module **148** includes executable instructions to create, display, modify, and store calendars and data associated with calendars (e.g., calendar entries, to do lists, etc.) in accordance with user instructions.

In conjunction with RF circuitry **108**, touch screen **112**, display controller **156**, contact/motion module **130**, graphics module **132**, text input module **134**, and browser module **147**, widget modules **149** are mini-applications that may be downloaded and used by a user (e.g., weather widget **149-1**, stocks widget **149-2**, calculator widget **149-3**, alarm clock widget **149-4**, and dictionary widget **149-5**) or created by the user (e.g., user-created widget **149-6**). In some embodiments, a widget includes an HTML (Hypertext Markup Language) file, a CSS (Cascading Style Sheets) file, and a JavaScript file. In some embodiments, a widget includes an XML (Extensible Markup Language) file and a JavaScript file (e.g., Yahoo! Widgets).

In conjunction with RF circuitry **108**, touch screen **112**, display controller **156**, contact/motion module **130**, graphics module **132**, text input module **134**, and browser module **147**, the widget creator module **150** may be used by a user to create widgets (e.g., turning a user-specified portion of a web-page into a widget).

In conjunction with touch screen **112**, display controller **156**, contact/motion module **130**, graphics module **132**, and text input module **134**, search module **151** includes executable instructions to search for text, music, sound, image, video, and/or other files in memory **102** that match one or more search criteria (e.g., one or more user-specified search terms) in accordance with user instructions.

In conjunction with touch screen **112**, display controller **156**, contact/motion module **130**, graphics module **132**, audio circuitry **110**, speaker **111**, RF circuitry **108**, and browser module **147**, video and music player module **152** includes executable instructions that allow the user to download and play back recorded music and other sound files stored in one or more file formats, such as MP3 or AAC files, and executable instructions to display, present, or otherwise play back videos (e.g., on touch screen **112** or on an external, connected display via external port **124**). In some embodiments, device **100** optionally includes the functionality of an MP3 player, such as an iPod (trademark of Apple Inc.).

In conjunction with touch screen **112**, display controller **156**, contact/motion module **130**, graphics module **132**, and text input module **134**, notes module **153** includes executable instructions to create and manage notes, to -do lists, and the like in accordance with user instructions.

In conjunction with RF circuitry **108**, touch screen **112**, display controller **156**, contact/motion module **130**, graphics module **132**, text input module **134**, GPS module **135**, and browser module **147**, map module **154** may be used to receive, display, modify, and store maps and data associated with maps (e.g., driving directions; data on stores and other points of interest at or near a particular location; and other location-based data) in accordance with user instructions.

In conjunction with touch screen **112**, display controller **156**, contact/motion module **130**, graphics module **132**, audio circuitry **110**, speaker **111**, RF circuitry **108**, text input module **134**, e-mail client module **140**, and browser module **147**, online video module **155** includes instructions that allow the user to access, browse, receive (e.g., by streaming and/or download), play back (e.g., on the touch screen or on an external, connected display via external port **124**), send an e-mail with a link to a particular online video, and otherwise manage online videos in one or more file formats, such as H.264. In some embodiments, instant messaging module **141**, rather than e-mail client module **140**, is used to send a link to a particular online video. Additional description of the online video application can be found in U.S. Provisional Patent Application No. 60/936,562, "Portable Multifunction Device, Method, and Graphical User Interface for Playing Online Videos," filed Jun. 20, 2007, and U.S. patent application Ser. No. 11/968,067, "Portable Multifunction Device, Method, and Graphical User Interface for Playing Online Videos," filed Dec. 31, 2007, the contents of which are hereby incorporated by reference in their entirety.

Each of the above identified modules and applications corresponds to a set of executable instructions for performing one or more functions described above and the methods described in this application (e.g., the computer-implemented methods and other information processing methods described herein). These modules (e.g., sets of instructions) need not be implemented as separate software programs, procedures or modules, and thus various subsets of these modules may be combined or otherwise rearranged in various embodiments. For example, video player module may be combined with music player module into a single module (e.g., video and music player module **152**, FIG. **1**B). In some embodiments, memory **102** may store a subset of the modules and data structures identified above. Furthermore, memory **102** may store additional modules and data structures not described above.

In some embodiments, device **100** is a device where operation of a predefined set of functions on the device is performed exclusively through a touch screen and/or a touchpad. By using a touch screen and/or a touchpad as the primary input control device for operation of device **100**, the number of physical input control devices (such as push buttons, dials, and the like) on device **100** may be reduced.

The predefined set of functions that may be performed exclusively through a touch screen and/or a touchpad include navigation between user interfaces. In some embodiments, the touchpad, when touched by the user, navigates device **100** to a main, home, or root menu from any user interface that may be displayed on device **100**. In such embodiments, a "menu button" is implemented using a touchpad. In some other embodiments, the menu button is a physical push button or other physical input control device instead of a touchpad.

FIG. **1**B is a block diagram illustrating exemplary components for event handling in accordance with some embodiments. In some embodiments, memory **102** (in FIG. **1**A) or **370** (FIG. **3**) includes event sorter **170** (e.g., in operating system **126**) and a respective application **136-1** (e.g., any of the aforementioned applications **137-151**, **155**, **380-390**).

Event sorter **170** receives event information and determines the application **136-1** and application view **191** of application **136-1** to which to deliver the event information. Event sorter **170** includes event monitor **171** and event dispatcher module **174**. In some embodiments, application **136-1** includes application internal state **192**, which indicates the current application view(s) displayed on touch sensitive display **112** when the application is active or executing. In some embodiments, device/global internal state **157** is used by event sorter **170** to determine which application(s) is(are) currently active, and application internal state **192** is used by event sorter **170** to determine application views **191** to which to deliver event information.

In some embodiments, application internal state **192** includes additional information, such as one or more of: resume information to be used when application **136-1** resumes execution, user interface state information that indicates information being displayed or that is ready for display by application **136-1**, a state queue for enabling the user to go back to a prior state or view of application **136-1**, and a redo/undo queue of previous actions taken by the user.

Event monitor **171** receives event information from peripherals interface **118**. Event information includes information about a sub-event (e.g., a user touch on touch-sensitive display **112**, as part of a multi-touch gesture). Peripherals interface **118** transmits information it receives from I/O subsystem **106** or a sensor, such as proximity sensor **166**, accelerometer(s) **168**, and/or microphone **113** (through audio circuitry **110**). Information that peripherals interface **118** receives from I/O subsystem **106** includes information from touch-sensitive display **112** or a touch-sensitive surface.

In some embodiments, event monitor **171** sends requests to the peripherals interface **118** at predetermined intervals. In response, peripherals interface **118** transmits event information. In other embodiments, peripherals interface **118** transmits event information only when there is a significant event (e.g., receiving an input above a predetermined noise threshold and/or for more than a predetermined duration). In some embodiments, event sorter **170** also includes a hit view determination module **172** and/or an active event recognizer determination module **173**.

Hit view determination module **172** provides software procedures for determining where a sub-event has taken place within one or more views, when touch sensitive display **112** displays more than one view. Views are made up of controls and other elements that a user can see on the display.

Another aspect of the user interface associated with an application is a set of views, sometimes herein called application views or user interface windows, in which information is displayed and touch-based gestures occur. The application views (of a respective application) in which a touch is detected may correspond to programmatic levels within a programmatic or view hierarchy of the application. For example, the lowest level view in which a touch is detected may be called the hit view, and the set of events that are recognized as proper inputs may be determined based, at least in part, on the hit view of the initial touch that begins a touch-based gesture.

Hit view determination module **172** receives information related to sub-events of a touch-based gesture. When an application has multiple views organized in a hierarchy, hit view determination module **172** identifies a hit view as the lowest view in the hierarchy which should handle the sub-event. In most circumstances, the hit view is the lowest level view in which an initiating sub-event occurs (e.g., the first sub-event in the sequence of sub-events that form an event or potential event). Once the hit view is identified by the hit view determination module **172**, the hit view typically receives all sub-events related to the same touch or input source for which it was identified as the hit view.

Active event recognizer determination module **173** determines which view or views within a view hierarchy should receive a particular sequence of sub-events. In some embodiments, active event recognizer determination module **173** determines that only the hit view should receive a particular sequence of sub-events. In other embodiments, active event recognizer determination module **173** determines that all views that include the physical location of a sub-event are actively involved views, and therefore determines that all actively involved views should receive a particular sequence of sub-events. In other embodiments, even if touch sub-events were entirely confined to the area associated with one particular view, views higher in the hierarchy would still remain as actively involved views.

Event dispatcher module **174** dispatches the event information to an event recognizer (e.g., event recognizer **180**). In embodiments including active event recognizer determination module **173**, event dispatcher module **174** delivers the event information to an event recognizer determined by active event recognizer determination module **173**. In some embodiments, event dispatcher module **174** stores in an event queue the event information, which is retrieved by a respective event receiver **182**.

In some embodiments, operating system **126** includes event sorter **170**. Alternatively, application **136-1** includes event sorter **170**. In yet other embodiments, event sorter **170** is a stand-alone module, or a part of another module stored in memory **102**, such as contact/motion module **130**.

In some embodiments, application **136-1** includes a plurality of event handlers **190** and one or more application views **191**, each of which includes instructions for handling touch events that occur within a respective view of the application's user interface. Each application view **191** of the application **136-1** includes one or more event recognizers **180**. Typically, a respective application view **191** includes a plurality of event recognizers **180**. In other embodiments, one or more of event recognizers **180** are part of a separate module, such as a user interface kit (not shown) or a higher level object from which application **136-1** inherits methods and other properties. In some embodiments, a respective event handler **190** includes one or more of: data updater **176**, object updater **177**, GUI updater **178**, and/or event data **179** received from event sorter **170**. Event handler **190** may utilize or call data updater **176**, object updater **177**, or GUI updater **178** to update the application internal state **192**. Alternatively, one or more of the application views **191** include one or more respective event handlers **190**. Also, in some embodiments, one or more of data updater **176**, object updater **177**, and GUI updater **178** are included in a respective application view **191**.

A respective event recognizer **180** receives event information (e.g., event data **179**) from event sorter **170** and identifies an event from the event information. Event recognizer **180** includes event receiver **182** and event comparator **184**. In some embodiments, event recognizer **180** also includes at least a subset of: metadata **183**, and event delivery instructions **188** (which may include sub-event delivery instructions).

Event receiver **182** receives event information from event sorter **170**. The event information includes information about a sub-event, for example, a touch or a touch movement. Depending on the sub-event, the event information also includes additional information, such as location of the sub-event. When the sub-event concerns motion of a touch the event information may also include speed and direction of the sub-event. In some embodiments, events include rotation of the device from one orientation to another (e.g., from a portrait orientation to a landscape orientation, or vice versa), and the event information includes corresponding information about the current orientation (also called device attitude) of the device.

Event comparator **184** compares the event information to predefined event or sub-event definitions and, based on the comparison, determines an event or sub-event, or determines or updates the state of an event or sub-event. In some embodiments, event comparator **184** includes event definitions **186**. Event definitions **186** contain definitions of events (e.g., predefined sequences of sub-events), for example, event **1** (**187-1**), event **2** (**187-2**), and others. In some embodiments, sub-events in an event (**187**) include, for example, touch begin, touch end, touch movement, touch cancellation, and multiple touching. In one example, the definition for event **1** (**187-1**) is a double tap on a displayed object. The double tap, for example, comprises a first touch (touch begin) on the displayed object for a predetermined phase, a first liftoff (touch end) for a predetermined phase, a second touch (touch begin) on the displayed object for a predetermined phase, and a second liftoff (touch end) for a predetermined phase. In another example, the definition for event **2** (**187-2**) is a dragging on a displayed object. The dragging, for example, comprises a touch (or contact) on the displayed object for a predetermined phase, a movement of the touch across touch-sensitive display **112**, and liftoff of the touch (touch end). In some embodiments, the event also includes information for one or more associated event handlers **190**.

In some embodiments, event definitions **187** include a definition of an event for a respective user-interface object. In some embodiments, event comparator **184** performs a hit test to determine which user-interface object is associated with a sub-event. For example, in an application view in which three user-interface objects are displayed on touch-sensitive display **112**, when a touch is detected on touch-sensitive display **112**, event comparator **184** performs a hit test to determine which of the three user-interface objects is associated with the touch (sub-event). If each displayed object is associated with a respective event handler **190**, the event comparator uses the result of the hit test to determine which event handler **190** should be activated. For example,

event comparator **184** selects an event handler associated with the sub-event and the object triggering the hit test.

In some embodiments, the definition for a respective event (**187**) also includes delayed actions that delay delivery of the event information until after it has been determined whether the sequence of sub-events does or does not correspond to the event recognizer's event type.

When a respective event recognizer **180** determines that the series of sub-events do not match any of the events in event definitions **186**, the respective event recognizer **180** enters an event impossible, event failed, or event ended state, after which it disregards subsequent sub-events of the touch-based gesture. In this situation, other event recognizers, if any, that remain active for the hit view continue to track and process sub-events of an ongoing touch-based gesture.

In some embodiments, a respective event recognizer **180** includes metadata **183** with configurable properties, flags, and/or lists that indicate how the event delivery system should perform sub-event delivery to actively involved event recognizers. In some embodiments, metadata **183** includes configurable properties, flags, and/or lists that indicate how event recognizers may interact, or are enabled to interact, with one another. In some embodiments, metadata **183** includes configurable properties, flags, and/or lists that indicate whether sub-events are delivered to varying levels in the view or programmatic hierarchy.

In some embodiments, a respective event recognizer **180** activates event handler **190** associated with an event when one or more particular sub-events of an event are recognized. In some embodiments, a respective event recognizer **180** delivers event information associated with the event to event handler **190**. Activating an event handler **190** is distinct from sending (and deferred sending) sub-events to a respective hit view. In some embodiments, event recognizer **180** throws a flag associated with the recognized event, and event handler **190** associated with the flag catches the flag and performs a predefined process.

In some embodiments, event delivery instructions **188** include sub-event delivery instructions that deliver event information about a sub-event without activating an event handler. Instead, the sub-event delivery instructions deliver event information to event handlers associated with the series of sub-events or to actively involved views. Event handlers associated with the series of sub-events or with actively involved views receive the event information and perform a predetermined process.

In some embodiments, data updater **176** creates and updates data used in application **136-1**. For example, data updater **176** updates the telephone number used in contacts module **137**, or stores a video file used in video player module. In some embodiments, object updater **177** creates and updates objects used in application **136-1**. For example, object updater **177** creates a new user-interface object or updates the position of a user-interface object. GUI updater **178** updates the GUI. For example, GUI updater **178** prepares display information and sends it to graphics module **132** for display on a touch-sensitive display.

In some embodiments, event handler(s) **190** includes or has access to data updater **176**, object updater **177**, and GUI updater **178**. In some embodiments, data updater **176**, object updater **177**, and GUI updater **178** are included in a single module of a respective application **136-1** or application view **191**. In other embodiments, they are included in two or more software modules.

It shall be understood that the foregoing discussion regarding event handling of user touches on touch-sensitive displays also applies to other forms of user inputs to operate multifunction devices **100** with input devices, not all of which are initiated on touch screens. For example, mouse movement and mouse button presses, optionally coordinated with single or multiple keyboard presses or holds; contact movements such as taps, drags, scrolls, etc. on touchpads; pen stylus inputs; movement of the device; oral instructions; detected eye movements; biometric inputs; and/or any combination thereof are optionally utilized as inputs corresponding to sub-events which define an event to be recognized.

FIG. **2** illustrates a portable multifunction device **100** having a touch screen **112** in accordance with some embodiments. The touch screen may display one or more graphics within user interface (UI) **200**. In this embodiment, as well as others described below, a user may select one or more of the graphics by making contact or touching the graphics, for example, with one or more fingers **202** (not drawn to scale in the figure) or one or more styluses **203** (not drawn to scale in the figure). In some embodiments, selection of one or more graphics occurs when the user breaks contact with the one or more graphics. In some embodiments, the contact may include a gesture, such as one or more taps, one or more swipes (from left to right, right to left, upward and/or downward) and/or a rolling of a finger (from right to left, left to right, upward and/or downward) that has made contact with device **100**. In some embodiments, inadvertent contact with a graphic may not select the graphic. For example, a swipe gesture that sweeps over an application icon may not select the corresponding application when the gesture corresponding to selection is a tap.

Device **100** may also include one or more physical buttons, such as "home" or menu button **204**. As described previously, menu button **204** may be used to navigate to any application **136** in a set of applications that may be executed on device **100**. Alternatively, in some embodiments, the menu button is implemented as a soft key in a GUI displayed on touch screen **112**.

In one embodiment, device **100** includes touch screen **112**, menu button **204**, push button **206** for powering the device on/off and locking the device, volume adjustment button(s) **208**, Subscriber Identity Module (SIM) card slot **210**, head set jack **212**, and docking/charging external port **124**. Push button **206** may be used to turn the power on/off on the device by depressing the button and holding the button in the depressed state for a predefined time interval; to lock the device by depressing the button and releasing the button before the predefined time interval has elapsed; and/or to unlock the device or initiate an unlock process. In an alternative embodiment, device **100** also may accept verbal input for activation or deactivation of some functions through microphone **113**.

FIG. **3** is a block diagram of an exemplary multifunction device with a display and a touch-sensitive surface in accordance with some embodiments. Device **300** need not be portable. In some embodiments, device **300** is a laptop computer, a desktop computer, a tablet computer, a multimedia player device, a navigation device, an educational device (such as a child's learning toy), a gaming system, or a control device (e.g., a home or industrial controller). Device **300** typically includes one or more processing units (CPU's) **310**, one or more network or other communications interfaces **360**, memory **370**, and one or more communication buses **320** for interconnecting these components. Communication buses **320** may include circuitry (sometimes called a chipset) that interconnects and controls communications between system components. Device **300** includes input/output (I/O) interface **330** comprising display **340**,

which is typically a touch screen display. I/O interface **330** also may include a keyboard and/or mouse (or other pointing device) **350** and touchpad **355**. Memory **370** includes high-speed random access memory, such as DRAM, SRAM, DDR RAM or other random access solid state memory devices; and may include non-volatile memory, such as one or more magnetic disk storage devices, optical disk storage devices, flash memory devices, or other non-volatile solid state storage devices. Memory **370** may optionally include one or more storage devices remotely located from CPU(s) **310**. In some embodiments, memory **370** stores programs, modules, and data structures analogous to the programs, modules, and data structures stored in memory **102** of portable multifunction device **100** (FIG. **1**), or a subset thereof. Furthermore, memory **370** may store additional programs, modules, and data structures not present in memory **102** of portable multifunction device **100**. For example, memory **370** of device **300** may store drawing module **380**, presentation module **382**, word processing module **384**, website creation module **386**, disk authoring module **388**, and/or spreadsheet module **390**, while memory **102** of portable multifunction device **100** (FIG. **1**) may not store these modules.

Each of the above identified elements in FIG. **3** may be stored in one or more of the previously mentioned memory devices. Each of the above identified modules corresponds to a set of instructions for performing a function described above. The above identified modules or programs (i.e., sets of instructions) need not be implemented as separate software programs, procedures or modules, and thus various subsets of these modules may be combined or otherwise re-arranged in various embodiments. In some embodiments, memory **370** may store a subset of the modules and data structures identified above. Furthermore, memory **370** may store additional modules and data structures not described above.

Attention is now directed towards embodiments of user interfaces ("UI") that may be implemented on portable multifunction device **100**. FIG. **4**A illustrates exemplary user interfaces for a menu of applications on portable multifunction device **100** in accordance with some embodiments. Similar user interfaces may be implemented on device **300**. In some embodiments, user interface **400** includes the following elements, or a subset or superset thereof:

- Signal strength indicator(s) **402** for wireless communication(s), such as cellular and Wi-Fi signals;
- Time **404**;
- Bluetooth indicator **405**;
- Battery status indicator **406**;
- Tray **408** with icons for frequently used applications, such as:
  - Icon **416** for telephone module **138**, labeled "Phone," which optionally includes an indicator **414** of the number of missed calls or voicemail messages;
  - Icon **418** for e-mail client module **140**, labeled "Mail," which optionally includes an indicator **410** of the number of unread e-mails;
  - Icon **420** for browser module **147**, labeled "Browser;" and
  - Icon **422** for video and music player module **152**, also referred to as iPod (trademark of Apple Inc.) module **152**, labeled "iPod;" and
- Icons for other applications, such as:
  - Icon **424** for IM module **141**, labeled "Messages;"
  - Icon **426** for calendar module **148**, labeled "Calendar;"
  - Icon **428** for image management module **144**, labeled "Photos;"
  - Icon **430** for camera module **143**, labeled "Camera;"
  - Icon **432** for online video module **155**, labeled "Online Video;"
  - Icon **434** for stocks widget **149-2**, labeled "Stocks;"
  - Icon **436** for map module **154**, labeled "Maps;"
  - Icon **438** for weather widget **149-1**, labeled "Weather;"
  - Icon **440** for alarm clock widget **149-4**, labeled "Clock;"
  - Icon **442** for workout support module **142**, labeled "Workout Support;"
  - Icon **444** for notes module **153**, labeled "Notes;" and
  - Icon **446** for a settings application or module, labeled "Settings," which provides access to settings for device **100** and its various applications **136**.

FIG. **4**B illustrates an exemplary user interface on a device (e.g., device **300**, FIG. **3**) with a touch-sensitive surface **451** (e.g., a tablet or touchpad **355**, FIG. **3**) that is separate from the display **450** (e.g., touch screen display **112**). Although many of the examples which follow will be given with reference to inputs on touch screen display **112** (where the touch sensitive surface and the display are combined), in some embodiments, the device detects inputs on a touch-sensitive surface that is separate from the display, as shown in FIG. **4**B. In some embodiments the touch sensitive surface (e.g., **451**) has a primary axis (e.g., **452**) that corresponds to a primary axis (e.g., **453**) on the display (e.g., **450**). In accordance with these embodiments, the device detects contacts (e.g., **460** and **462**) with the touch-sensitive surface **451** at locations that correspond to respective locations on the display (e.g., **460** corresponds to **468** and **462** corresponds to **470**). In this way, user inputs (e.g., contacts **460** and **462**, and movements thereof) detected by the device on the touch-sensitive surface (e.g., **451**) are used by the device to manipulate the user interface on the display (e.g., **450**) of the multifunction device when the touch-sensitive surface is separate from the display. It should be understood that similar methods may be used for other user interfaces described herein.

Additionally, while the following examples are given primarily with reference to finger inputs (e.g., finger contacts, finger tap gestures, finger swipe gestures), it should be understood that, in some embodiments, one or more of the finger inputs are replaced with input from another input device (e.g., a mouse-based input or stylus input). For example, a swipe gesture is, optionally, replaced with a mouse click (e.g., instead of a contact) followed by movement of the cursor along the path of the swipe (e.g., instead of movement of the contact). As another example, a tap gesture is, optionally, replaced with a mouse click while the cursor is located over the location of the tap gesture (e.g., instead of detection of the contact followed by ceasing to detect the contact). Similarly, when multiple user inputs are simultaneously detected, it should be understood that multiple computer mice are, optionally, used simultaneously, or a mouse and finger contacts are, optionally, used simultaneously.

As used in the specification and claims, the term "open application" refers to a software application with retained state information (e.g., as part of device/global internal state **157** and/or application internal state **192**). An open (e.g., executing) application is any one of the following types of applications:

- an active application, which is currently displayed on display **112** (or a corresponding application view is currently displayed on the display);
- a background application (or background process), which is not currently displayed on display **112**, but one or

more application processes (e.g., instructions) for the corresponding application are being processed by one or more processors **120** (i.e., running);

a suspended application, which is not currently running, and the application is stored in a volatile memory (e.g., DRAM, SRAM, DDR RAM, or other volatile random access solid state memory device of memory **102**); and

a hibernated application, which is not running, and the application is stored in a non-volatile memory (e.g., one or more magnetic disk storage devices, optical disk storage devices, flash memory devices, or other non-volatile solid state storage devices of memory **102**).

As used herein, the term "closed application" refers to software applications without retained state information (e.g., state information for closed applications is not stored in a memory of the device). Accordingly, closing an application includes stopping and/or removing application processes for the application and removing state information for the application from the memory of the device. Generally, opening a second application while in a first application does not close the first application. When the second application is displayed and the first application ceases to be displayed, the first application becomes a background application.

FIG. **5** illustrates an exemplary schematic block diagram of text-to-speech module **500** in accordance with some embodiments. In some embodiments, text-to-speech module **500** can be implemented using one or more multifunction devices including but not limited to devices **100**, **400**, and **900** (FIGS. **1**A, **2**, **4**A-B, and **9**). In particular, memory **102** (in FIG. **1**A) or **370** (FIG. **3**) can include text-to-speech module **500**. Text-to-speech module **500** can enable speech synthesis capabilities in a multifunctional device.

As shown in FIG. **5**, text-to-speech module **500** can be configured to receive text to be converted to speech and output a speech waveform corresponding to the spoken form of the received text. The text is received by text analysis module **502** of text-to-speech module **500**. Text analysis module **502** can be configured to convert the text into a sequence of target units representing the spoken pronunciation of the text. Each target unit of the sequence of target units can include a speech unit (e.g., phone, diphone, half-phone, etc.). Further, each target unit can include linguistic features (e.g., speech segment position, syllables, syllabic stress, syllable position, phrase length, part of speech, word prominence, etc.). In some examples, text analysis module **502** can apply orthographic rules and grammar rules to convert the text into the sequence of target units. In other examples, text analysis module **502** can include a lexicon where words in text form can be mapped to their corresponding target units. The sequence of target units with corresponding linguistic features can be forwarded to unit-selection module **504**.

Speech segment database **508** can include a plurality of speech segments derived from recorded speech corresponding to a corpus of text. Each speech segment can include a set of linguistic features and a set of acoustic features (e.g., spectral shape, pitch, duration, Mel-frequency cepstral coefficients, fundamental frequency, etc.). The plurality of speech segments can be indexed and stored in speech segment database **508** according to the linguistic features and acoustic features.

Unit-selection module **504** can be configured to select suitable speech segments from speech segment database **508** that best match the sequence of target units. In particular, unit-selection module **504** can be configured to pre-select one or more candidate speech segments from speech segment database **508** for each target unit of the sequence of target units. The pre-selection can be based on a target cost that indicates how well the linguistic features of a particular candidate speech segment match the linguistic features of the target unit.

Using one or more statistical models stored in acoustic feature prediction model(s) **506**, unit-selection module **504** can be configured to determine one or more sets of predicted acoustic model parameters for each target unit of the sequence of target units. The set of predicted acoustic model parameters can be a set of predicted acoustic features of the target unit. Alternatively, the set of predicted acoustic model parameters can be a set of statistical parameters of predicted acoustic features of the target unit. The one or more statistical models can be trained using speech corresponding to a corpus of text. In some examples, the one or more statistical models can include a deep neural network (e.g., deep network **800** of FIG. **8**, described below). The linguistic features of the current target unit can be used to determine the set of predicted acoustic model parameters of the current target unit. Additionally, the acoustic features of a pre-selected candidate speech segment of a preceding target unit can be used to determine the set of predicted acoustic model parameters of the current target unit.

Unit-selection module **504** can be further configured to determine a likelihood score that indicates the likelihood that a pre-selected candidate speech segment matches a target unit given the determined set of predicted acoustic model parameters of the target unit and the acoustic features of the pre-selected candidate speech segment. Based on the likelihood scores associated with each pre-selected candidate speech segment, unit-selection module **504** can be configured to select a suitable sequence of speech segments that best match the sequence of target units.

Speech synthesizer module **510** can be configured to receive the selected sequence of speech segments from unit-selection module **504** and join the sequence of speech segments into a continuous speech waveform. Speech synthesizer module **510** can be further configured to apply various signal processing algorithms to smooth out the acoustic features between speech segments to generate a smooth, continuous speech waveform. The speech waveform can be an audio rendering of the spoken form of the text received at text analysis module **502**. In particular, the speech waveform can be in the form of an audio signal or audio data file (e.g., .wav, .mp3, .wma, etc.).

FIG. **6** illustrates a flow diagram of an exemplary process **600** for unit-selection text-to-speech synthesis in accordance with some embodiments. The process **600** can be performed using one or more of devices **100**, **300**, and **900** (FIGS. **1**A, **2**, **3**A-B, and **9**). In particular, process **600** can be performed using a text-to-speech module (e.g., text-to-speech module **500** of FIG. **5**), implemented on the one or more devices. It should be appreciated that some operations in process **600** can be combined, the order of some operations can be changed, and some operations can be omitted.

At block **602**, text to be converted to speech can be received. In some examples, the text can be received via user input (e.g., on a keyboard, touch screen, etc.). In other examples, the text can be received from a digital assistant implemented on the electronic device. In particular, the digital assistant can generate a text response to satisfy a user request. The text response can be received from a remote digital assistant server or a local client digital assistant module. In yet other examples, the text can be received from an application (e.g., applications **136**) of the electronic device. The text can be in the form of a sequence of tokens

representing the text. In an illustrative example shown in FIG. **7**, the received text can be the word "closet."

At block **604**, a sequence of target units representing a spoken pronunciation of the text can be generated. The sequence of target units can be generated using a text analysis module (e.g., text analysis module **502**) of the electronic device. In particular, the text can be converted to the sequence of target units. The sequence of target units can be a phonetic transcription or a phonemic transcription of the text. In particular, each target unit can include a speech unit (e.g., phone, diphone, half-phone, etc.). Further, each target unit in the sequence of target units can include a set of linguistic features (also referred to as text features) corresponding to the respective speech unit. In particular, the set of linguistic features can include various context of the speech unit (e.g., phone position, syllable position, phrase length, part of speech, etc.). The set of linguistic features can be extracted from the text by applying a set of predetermined rules or using a database that can map words of the text to corresponding linguistic features. It should be recognized that the text may be pre-processed (e.g., cleaned and normalized) prior to converting the text to the sequence of target units.

In one example, depicted in FIG. **7**, the text "closet" can be converted to sequence of target units **702** "K**1**-K**2**-L**1**-L**2**-AA**1**-AA**2**-Z**1**-Z**2**-AH**1**-AH**2**-T**1**-T**2**," where each target unit is associated with a half-phone. Further, each target unit includes a set of linguistic features that are extracted from the text. In this example, sequence of target units **702** includes first target unit **704** (e.g., AA**1**) and second target unit **706** (e.g., AA**2**). First target unit **704** precedes second target unit **706** in sequence of target units **702**. In particular, first target unit **704** immediately precedes second target unit **706** such that no other target unit is between first target unit **704** and second target unit **706**. The sequence of target units can be represented mathematically as $T=\{t_1, t_2, \ldots t_N\}$, where each target unit, t_n, is a vector of the linguistic features corresponding to the respective target unit. Thus, first target unit **704** can be represented as the linguistic feature vector t_5 and second target unit **706** can be represented as the linguistic feature vector t_6.

At block **606**, a first candidate speech segment for a first target unit of the sequence of target units and a second candidate speech segment for a second target unit of the sequence of target units can be selected from a plurality of speech segments. Blocks **606-612** can be performed using a unit-selection module (e.g., unit-selection module **504**) of the electronic device.

The plurality of speech segments can be derived from recorded speech corresponding to a corpus of text. In some examples, the recorded speech can be spoken by a single person. Each speech segment (including the first candidate speech segment and the second candidate speech segment) can be a segment (e.g., speech unit, phone, diphone, half-phone, etc.) of the recorded speech. Further, each speech segment can include a set of linguistic features (e.g., speech segment position, syllables, syllabic stress, syllable position, phrase length, part of speech, word prominence, etc.) and a set of acoustic features (e.g., spectral shape, pitch, duration, Mel-frequency cepstral coefficients, fundamental frequency, etc.). The plurality of speech segments and the corresponding linguistic and acoustic features can be stored in an indexed speech segment database (e.g., speech segment database **508**). The set of acoustic features of each speech segment can be represented by the vector x_n.

With reference to FIG. **7**, for each target unit of sequence of target units **702**, one or more candidate speech segments **708** can be selected from the plurality of speech segments based on the set of linguistic features of the respective target unit. Specifically, the indexed speech segment database can be searched to find the one or more candidate speech segments having linguistic features that closely match (e.g., a target score that is greater than a predetermined value) the linguistic features of the respective target unit. In the present example, five candidate speech segments, including first candidate speech segment **710**, are selected for first target unit **704** and four candidate speech segments, including second candidate speech segment **712**, are selected for second target unit **706**.

At block **608**, a set of predicted acoustic model parameters of the second target unit can be determined using a set of acoustic features of the first candidate speech segment and a set of linguistic features of the second target unit. The predicted acoustic model parameters of the second target unit can be determined using a statistical model. The statistical model can be generated (e.g., trained) using recorded speech samples corresponding to a corpus of text. In some examples, the statistical model can be configured to receive as inputs, a set of linguistic features of a current target unit (e.g., second target unit **706**) and a set of acoustic features of a candidate speech segment of a preceding target unit (e.g., first target unit **704**), and be configured to output a set of predicted acoustic model parameters of the current target unit (e.g., second target unit **706**). The statistical model can thus be trained to predict a set of current acoustic features (e.g., x_n) that should follow a given set of preceding acoustic features (e.g., x_{n-1}) and a given set of current linguistic features (e.g., t_n). Accordingly, the set of predicted acoustic model parameters of the current target unit are a function of the set of linguistic features of the current target unit and the set of acoustic features of the candidate speech segment of the preceding target unit.

In some examples, the set of predicted acoustic model parameters of the current target unit can be a set of predicted acoustic features (e.g., spectral shape, pitch, duration, Mel-frequency cepstral coefficients, fundamental frequency, etc.) of the current target unit. In other examples, the set of predicted acoustic model parameters can be a set of statistical parameters of the predicted acoustic features of the current target unit. In a specific example, the set of predicted acoustic model parameters can include the mean and variance of the predicted acoustic features of the current target unit.

In some examples, the statistical model can be a deep neural network. With reference to FIG. **8**, exemplary deep neural network **800** for determining a set of predicted acoustic model parameters of a current target unit is depicted. Deep neural network **800** can include multiple layers. In particular, deep neural network **800** can include input layer **802**, output layer **804**, and one or more hidden layers **806** disposed between input layer **802** and output layer **804**. In this example, deep neural network **800** includes three hidden layers **806**. It should be recognized, however, that in other examples, deep neural network **800** can include any number of hidden layers **806**.

Each layer of deep neural network **800** can include multiple units. The units can be the basic computational elements of deep neural network **800** and can be referred to as dimensions, neurons, or nodes. As shown in FIG. **8**, input layer **802** can include input units **808**, hidden layers **806** can include hidden units **810**, and output layer **804** can include output units **812**. Hidden layers **806** can each include any number of hidden units **810**. In a specific example, hidden layers **806** can each include **2048** hidden units **810**. The units

can be interconnected by connections **814**. Specifically, connections **814** can connect the units of one layer to the units of a subsequent layer. Further, each connection **814** can be associated with a weighting value and a bias followed by a nonlinear activation function. For simplicity, the weighting values and biases are not shown in FIG. **8**.

Input layer **802** can be configured to receive as inputs the set of linguistic features (e.g., t_n) of the current target unit and the set of acoustic features (e.g., x_{n-1}) of the candidate speech segment of the preceding target unit. Output layer **804** can be configured to output the set of predicted acoustic model parameters of the current target unit. In some examples, output layer **804** can be configured to directly output predicted acoustic features, x_n, of the current target unit. In these examples, deep neural network **800** can be a feedforward deep neural network. In other examples, output layer **804** can be configured to output statistical parameters of the current target unit's predicted acoustic features. For example, output layer **804** can output the mean ($E(x_n|x_{n-1}, t_n)$ and variance ($var(x_n|x_{n-1},t_n)$ of the current target unit's predicted acoustic features. In these examples, deep neural network **800** can be a mixture density network. In particular, output layer **804** can apply exponential activation functions for the portion of the output layer that generates the variance parameters, and linear activation functions for the portion of the output layer that generates the mean parameters.

In other examples, deep neural network **800** can be more complex where output layer **804** is configured to output multiple mean vectors ($E_1(x_n|x_{n-1},t_n)$, $E_2(x_n|x_{n-1},t_n)$, . . . , $E_M(x_n|x_{n-1},t_n)$), multiple variance vectors ($var_1(x_n|x_{n-1},t_n)$, $var_2(x_n|x_{n-1},t_n)$, . . . , $var_M(x_n|x_{n-1},t_n)$), and density weights ($k_1, k_2, \ldots, k_m$) assuming that the likelihood function is the linear combination of M multiple densities, such as a Gaussian Mixture Model (GMM). In these examples, the set of predicted acoustic model parameters of the second target unit can include means of the predicted acoustic features of the second target unit, variances of the predicted acoustic features of the second target unit, and density weights of the predicted acoustic features of the second target unit, assuming a model composed by a mixture of probability distributions (e.g., GMM).

It should be appreciated that because deep neural network **800** utilizes the set of acoustic features (e.g., x_{n-1}) of the candidate speech segment of the preceding target unit, the acoustic context is taken into account when predicting the acoustic model parameters of the current target unit. Deep neural network **800** can thus be considered "concatenation-sensitive" since acoustic information associated with a candidate speech segment of a preceding target unit is incorporated into the predicted acoustic model parameters of the current target unit, thereby enabling the selection of candidate speech segments with acoustic features that more naturally join together. Further, it should be recognized that the output of deep neural network **800** for the preceding target unit is not fed back to the input of deep neural network **800** for determining the predicted acoustic model parameters of the current target unit. Rather, the output of deep neural network **800** for the preceding target unit is mapped to a candidate speech segment that actually exists in the database (a segment of actual recorded speech) and the acoustic features of that candidate speech segment are fed into the input of deep neural network **800** for determining the predicted acoustic model parameters of the current target unit. This enables speech segments to be selected based on actual data rather than arbitrarily defined acoustic features that are envisioned as ideal, which results in more natural sounding synthesized speech.

In some examples, the set of predicted acoustic model parameters of the current target unit (e.g., second target unit **706**) can be determined using only the set of acoustic features of a candidate speech segment of the preceding target unit and the set of linguistic features of the current target unit. Specifically, the statistical model used to determine the set of predicted acoustic model parameters can be configured such that only the set of acoustic features of the candidate speech segment of the preceding target unit and the set of linguistic features of the current target unit are accepted as inputs. Thus, in these examples, each set of predicted acoustic model parameters of the current target unit can be determined using the set of acoustic features of a candidate speech segment of only one preceding target unit.

In other examples, the acoustic features of candidate speech segments of multiple preceding target units can be used to determine each set of predicted acoustic model parameters of the current target unit. In these examples, the statistical model can be configured to receive as inputs, the sets of acoustic features of candidate speech segments of multiple preceding target units. For example, with reference to FIG. **7**, third candidate speech segment **716** can be selected from the plurality of speech segments for third target unit **718** at block **606**. In the sequence of target units **702**, third target unit **718** can precede both first target unit **704** and second target unit **706**. In this example, the set of predicted acoustic model parameters of second target unit **706** can be determined using the set of acoustic features of first candidate speech segment **710**, the set of acoustic features of third candidate speech segment **716**, and the set of linguistic features of second target unit **706**. In particular, the statistical model can be configured to receive as input, the set of acoustic features of first candidate speech segment **710**, the set of acoustic features of third candidate speech segment **716**, and the set of linguistic features of second target unit **706** and output the set of predicted acoustic model parameters of second target unit **706**. It should be appreciated that the acoustic features of candidate speech segments of any number of preceding target units can be used to determine the set of predicted acoustic model parameters of the current target unit.

In some examples, separate sets of predicted acoustic model parameters of a particular candidate speech segment of the current target unit can be determined for each candidate speech segment of the preceding target unit. For example with reference to FIG. **7**, first target unit **704** is associated with five candidate speech segments. In this example, a respective set of predicted acoustic model parameters of second target unit **706** can be determined for each of the five candidate speech segments associated with first target unit **704**. This can be repeated for each target unit with respect to the candidate speech segments of the preceding target unit. In this way, a set of predicted acoustic model parameters can be determined for each target unit with respect to each candidate speech segment of the preceding target unit. For the start target unit at the beginning of sequence of target units **702** (e.g., K1), a set of constant acoustic features can be used to determine the set of predicted acoustic model parameters for each candidate speech segment of the start target unit. The set of constant acoustic features can be a vector of zeros (null vector) or the mean of the acoustic features of all silent speech segments.

In some examples, a set of predicted acoustic model parameters of the current target unit may not be determined for every preceding candidate speech segment. For example, with reference to FIG. **7**, first target unit **704** is associated

with five candidate speech segments. As will become apparent in the description at block **610** below, likelihood scores are associated with each candidate speech segment of first target unit **704** with respect to the candidate speech segments of preceding third target unit **718**. In these examples, a set of predicted acoustic model parameters of second target unit **706** can be determined for only a subset of the candidate speech segments of first target unit **704** (less than all of the five candidate speech segments). In particular, a set of predicted acoustic model parameters of second target unit **706** can be determined for only the candidate speech segments of first target unit **704** associated with the n highest accumulated likelihood score(s) (e.g., above a predetermined value, or the top predetermined number of likelihood scores), where n is less than five in the present example. The n highest accumulated likelihood scores can correspond to n sequences of candidate speech segments associated with the target units preceding second target unit **706** (e.g., target units K**1**, K**2**, L**1**, L**2**, and AA**1**). Each sequence of candidate speech segments in the n sequences of candidate speech segments associated with the target units preceding second target unit **706** can include a candidate speech segment in the subset of the candidate speech segments of first target unit **704**. The subset can include only one candidate speech segment of first target unit **704** (e.g., with the highest accumulated likelihood score) or a plurality of candidate speech segments (but less than all) of first target unit **704** (e.g., with the n highest accumulated likelihood scores).

At block **610**, a likelihood score of the second candidate speech segment with respect to the first candidate speech segment can be determined using the set of predicted acoustic model parameters of the second target unit and a set of acoustic features of the second candidate speech segment. The likelihood score can be determined using a likelihood function, such as a log-likelihood function or a cost function. In some examples, the likelihood score can be determined by a Gaussian Mixture Model using the set of acoustic features of the second candidate speech segment as an observed set of acoustic features. In some examples, the likelihood score can represent a likelihood of the set of acoustic features of the current target unit's candidate speech segment (e.g., second candidate speech segment **712**) given the set of predicted acoustic model parameters of the current target unit (e.g., second target unit **706**) and the set of acoustic features of the preceding target unit's candidate speech segment (e.g., first candidate speech segment **710**). In some examples, the likelihood score can represent a difference between the set of predicted acoustic features of the current target unit (e.g., second target unit **706**) and the set of acoustic features of the current target unit's candidate speech segment (e.g., second candidate speech segment **712**). In particular, a higher likelihood score can indicate a closer match between the set of predicted acoustic features of the current target unit and the set of acoustic features of the current target unit's candidate speech segment, whereas a lower likelihood score can indicate a greater difference between the set of predicted acoustic features of the current target unit and the set of acoustic features of the current target unit's candidate speech segment

In some examples, the likelihood score can be determined using only two sets of variables: the set of predicted acoustic model parameters of the current target unit (e.g., second target unit **706**) and the set of acoustic features of the current target unit's candidate speech segment (e.g., second candidate speech segment **712**). In particular, the preceding target unit's candidate speech segment (e.g., first candidate speech segment **710**) may not be directly inputted into the likelihood function to determine the likelihood score. Rather, the preceding target unit's candidate speech segment may only be used to determine the set of predicted acoustic model parameters of the current target unit and the set of predicted acoustic model parameters of the current target unit may be directly inputted into the likelihood function to determine the likelihood score.

Likelihood scores can be determined for each candidate speech segment of a target unit with respect to each candidate speech segment of the preceding target unit. In particular, with reference to FIG. **7**, connections can join the candidate speech segments of a target unit with candidate speech segments of the preceding target unit (e.g., connection **714** joins second candidate speech segment **712** with first candidate speech segment **710**). A likelihood score can be associated with each connection. In this way a Viterbi search lattice can be constructed. Each path through the lattice can represent a possible sequence of candidate speech segments that can be joined to synthesize the phrase "closet." Further, each path can have an accumulated likelihood score.

At block **612**, second candidate speech segment **712** can be selected for speech synthesis based on the likelihood score of block **610**. In particular, with reference to FIG. **7**, the most likely sequence of candidate speech segments can be selected by determining a path (e.g., the path indicated in bold in FIG. **7**) through the lattice that maximizes the accumulated likelihood score. In the present example, selecting first candidate speech segment **710** and second candidate speech segment **712** over the other candidate speech segments associated with first target unit **704** and second target unit **706** can maximize the accumulated likelihood score. Specifically, the first candidate speech segment and the second candidate speech segment can be part of a sequence of candidate speech segments associated with a maximum accumulated likelihood score. The maximum accumulated likelihood score can be determined based on the likelihood score of block **610**.

It should be appreciated that no separate concatenation cost is considered in selecting second candidate speech segment **712**. In particular, no concatenation cost is determined to ensure that the joined sequence of second candidate speech segment **712** with first candidate speech segment **710** will sound smooth. This avoids the application of arbitrary weights or linear combinations of target cost and concatenation cost in selecting candidate speech segments. Rather, the acoustic context is already considered by the statistical model when determining the predicted acoustic model parameters of the current target unit and thus only a single likelihood score needs to be considered. This results in a simpler and more accurate unit-selection process.

Further, in other examples, if a concatenation score (e.g., determined based on concatenation costs) is desired to be implemented in process **600**, it should be recognized that the determined concatenation score can be combined with the likelihood score and the combined score can be used to select the most suitable sequence of candidate speech segments.

At block **614**, speech corresponding to the received text can be generated using second candidate speech segment **712**. In particular, the sequence of candidate speech segments determined to maximize the accumulated likelihood score can be utilized to generate speech corresponding to the received text. With reference to FIG. **7**, the sequence of candidate speech segments that maximizes the accumulated likelihood score can include first speech segment **710** and second speech segment **712**. The sequence of candidate

speech segments can be joined together to form a continuous speech waveform. Further, various signal processing methods known in the art can be implemented to achieve a smooth speech audio waveform. The generated speech can be in the form of an audio signal representing the spoken form of the text received at block **602**. Alternatively, the generated speech can be an audio file (e.g., .wav, .mp3, .wma, etc.) representing the spoken form of the text received at block **602**.

In accordance with some embodiments, FIG. **9** shows a functional block diagram of an electronic device **900** configured in accordance with the principles of the various described embodiments, including those described with reference to FIG. **6**. The functional blocks of the device are, optionally, implemented by hardware, software, or a combination of hardware and software to carry out the principles of the various described embodiments. It is understood by persons of skill in the art that the functional blocks described in FIG. **9** are, optionally, combined or separated into sub-blocks to implement the principles of the various described embodiments. Therefore, the description herein optionally supports any possible combination or separation or further definition of the functional blocks described herein.

As shown in FIG. **9**, electronic device **900** can include input unit **903** configured to receive user input, such as text input, speaker unit **904** configured to output speech, and communication unit **906** configured to send and receive information (e.g., text) from external devices via a network. In some examples, electronic device **900** can optionally include a display unit **902** configured to display objects or text and receive touch/gesture input. Electronic device **900** can further include processing unit **908** coupled to input unit **903**, speaker unit **904**, communication unit **906**, and optionally display unit **902**. In some examples, processing unit **908** can include receiving unit **910**, generating unit **912**, selecting unit **914**, and determining unit **916**.

In accordance with some embodiments, processing unit **908** is configured to receive (e.g., with receiving unit **910**) text to be converted to speech. The text can be received via one of display unit **902**, input unit **903**, or communication unit **906**. Processing unit **908** is configured to generate (with generating unit **912**) a sequence of target units representing a spoken pronunciation of the text. Processing unit **908** is configured to select (e.g., with selecting unit **914**), from a plurality of speech segments, a first candidate speech segment for a first target unit of the sequence of target units and a second candidate speech segment for a second target unit of the sequence of target units. Processing unit **908** is configured to determine (e.g., with determining unit **916**), using a set of acoustic features of the first candidate speech segment and a set of linguistic features of the second target unit, a set of predicted acoustic model parameters of the second target unit. Processing unit **908** is configured to determine (e.g., with determining unit **916**), using the set of predicted acoustic model parameters of the second target unit and a set of acoustic features of the second candidate speech segment, a likelihood score of the second candidate speech segment with respect to the first candidate speech segment. Processing unit **908** is configured to select (e.g., with selecting unit **914**) the second candidate speech segment to be used in speech synthesis based on the determined likelihood score. Processing unit **908** is configured to generate (e.g., with generating unit **912**) speech corresponding to the received text using the second candidate speech segment.

In accordance with some implementations, the first target unit precedes the second target unit in the sequence of target units.

In accordance with some implementations, the predicted acoustic model parameters of the second target unit are determined using a statistical model.

In accordance with some implementations, the statistical model is generated using recorded speech samples corresponding to a corpus of text.

In accordance with some implementations, the statistical model is configured to receive, as inputs, a set of linguistic features of a current target unit and a set of acoustic features of a candidate speech segment of a preceding target unit and output a set of predicted acoustic model parameters of the current target unit.

In accordance with some implementations, the statistical model is a deep neural network comprising an input layer configured to receive as inputs the set of linguistic features of the current target unit and the set of acoustic features of the candidate speech segment of the preceding target unit, an output layer configured to output the set of predicted acoustic model parameters of the current target unit, and at least one hidden layer.

In accordance with some implementations, the set of predicted acoustic model parameters of the second target unit comprise a set of predicted acoustic features of the second target unit.

In accordance with some implementations, the set of predicted acoustic model parameters of the second target unit comprise a set of statistical parameters of predicted acoustic features of the second target unit.

In accordance with some implementations, the set of predicted acoustic model parameters include a mean of the predicted acoustic features of the second target unit and a variance of the predicted acoustic features of the second target unit.

In accordance with some implementations, the set of predicted acoustic model parameters include means of the predicted acoustic features of the second target unit, variances of the predicted acoustic features of the second target unit, and density weights of the predicted acoustic features of the second target unit, assuming a model composed by a mixture of probability distributions.

In accordance with some implementations, the set of predicted acoustic model parameters of the second target unit are determined using only the set of acoustic features of the first candidate speech segment and the set of linguistic features of the second target unit.

In accordance with some implementations, processing unit **908** is further configured to select (e.g., using selecting unit **914**), from the plurality of speech segments, a third candidate speech segment for a third target unit of the sequence of target units, where the third target unit precedes the first target unit in the sequence of target units. Processing unit **908** is further configured to determine (e.g., using determining unit **916**) the set of predicted acoustic model parameters of the second target unit using a set of acoustic features of the third candidate speech segment.

In accordance with some implementations, the likelihood score represents a likelihood of the set of acoustic features of the second candidate speech segment given the set of predicted acoustic model parameters of the second target unit and the set of acoustic features of the first candidate speech segment.

In accordance with some implementations, the likelihood score is determined based on a cost function.

In accordance with some implementations, the likelihood score is determined by a Gaussian Mixture Model using the set of acoustic features of the second candidate speech segment as an observed set of acoustic features.

In accordance with some implementations, the likelihood score represents a difference between a set of predicted acoustic features of the second target unit and the set of acoustic features of the second candidate speech segment.

In accordance with some implementations, the first candidate speech segment and the second candidate speech segment are associated with a maximum accumulated likelihood score. The maximum accumulated likelihood score is determined based on the likelihood score.

In accordance with some implementations, the likelihood score is determined using only the set of predicted acoustic model parameters of the second target unit and the set of acoustic features of the second candidate speech segment.

In accordance with some implementations, the second candidate speech segment is not selected based on a separate concatenation score associated with joining the first candidate speech segment with the second candidate speech segment.

In accordance with some implementations, the first target unit is associated with a first plurality of candidate speech segments. Processing unit **908** is further configured to determine (e.g., using determining unit **916**), for each candidate speech segment of the first plurality of candidate speech segments, a respective set of predicted acoustic model parameters of the second target unit.

In accordance with some implementations, the first target unit is associated with a first plurality of candidate speech segments, where each candidate speech segment of the first plurality of candidate speech segment is associated with an accumulated likelihood score. Processing unit **908** is further configured to determine (e.g., using determining unit **916**), for each candidate speech segment in a subset of the first plurality of candidate speech segments, a respective set of predicted acoustic model parameters of the second target unit, where the subset includes candidate speech segments of the first plurality of candidate speech segments associated with highest accumulated likelihood scores.

In accordance with some implementations, the first candidate speech segment and the second candidate speech segment each comprise a segment of recorded speech.

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.

The operation described above with respect to FIG. **6** is, optionally, implemented by components depicted in FIGS. **1**A-B, **3**, **5**, and **9**. For example, receiving operation **602** and generating operation **604** can be implemented by text analysis module **502**. Selecting operations **606**, **612** and determining operations **608**, **610** can be implemented by unit-selection module **504**, acoustic feature prediction model(s) **506**, and speech segment database **508**. Generating operation **614** can be implemented by speech synthesizer module **510**. It would be clear to a person of ordinary skill in the art how other processes can be implemented based on the components depicted in FIGS. **1**A-B, **3**, **5**, and **9**.

It is understood by persons of skill in the art that the functional blocks described in FIG. **9** are, optionally, combined or separated into sub-blocks to implement the principles of the various described embodiments. Therefore, the description herein optionally supports any possible combination or separation or further definition of the functional blocks described herein. For example, processing unit **908** can have an associated "controller" unit that is operatively coupled with processing unit **908** to enable operation. This controller unit is not separately illustrated in FIG. **9** but is understood to be within the grasp of one of ordinary skill in the art who is designing a device having a processing unit **908**, such as device **900**. As another example, one or more units, such as receiving unit **910**, may be hardware units outside of processing unit **908** in some embodiments. The description herein thus optionally supports combination, separation, and/or further definition of the functional blocks described herein.

Although the disclosure and examples have been fully described with reference to the accompanying figures, it is to be noted that various changes and modifications will become apparent to those skilled in the art. Such changes and modifications are to be understood as being included within the scope of the disclosure and examples as defined by the appended claims.

What is claimed is:

1. A non-transitory computer-readable storage medium storing one or more programs, the one or more programs comprising instructions which, when executed by one or more processors of an electronic device, cause the electronic device to:

receive text to be converted to speech;

generate a sequence of target units representing a spoken pronunciation of the text;

select, from a plurality of speech segments, a first candidate speech segment for a first target unit of the sequence of target units and a second candidate speech segment for a second target unit of the sequence of target units;

determine, using a set of acoustic features of the first candidate speech segment and a set of linguistic features of the second target unit, a set of predicted acoustic model parameters of the second target unit;

determine, using the set of predicted acoustic model parameters of the second target unit and a set of acoustic features of the second candidate speech segment, a likelihood score of the second candidate speech segment with respect to the first candidate speech segment;

select the second candidate speech segment to be used in speech synthesis based on the determined likelihood score; and

generate speech corresponding to the received text using the second candidate speech segment.

2. The non-transitory computer-readable storage medium of claim **1**, wherein the first target unit precedes the second target unit in the sequence of target units.

3. The non-transitory computer-readable storage medium of claim 1, wherein the predicted acoustic model parameters of the second target unit are determined using a statistical model.

4. The non-transitory computer-readable storage medium of claim 3, wherein the statistical model is generated using recorded speech samples corresponding to a corpus of text.

5. The non-transitory computer-readable storage medium of claim 3, wherein the statistical model is configured to:

receive, as inputs, a set of linguistic features of a current target unit and a set of acoustic features of a candidate speech segment of a preceding target unit; and

output a set of predicted acoustic model parameters of the current target unit.

6. The non-transitory computer-readable storage medium of claim 5, wherein the statistical model is a deep neural network comprising:

an input layer configured to receive as inputs the set of linguistic features of the current target unit and the set of acoustic features of the candidate speech segment of the preceding target unit;

an output layer configured to output the set of predicted acoustic model parameters of the current target unit; and

at least one hidden layer.

7. The non-transitory computer-readable storage medium of claim 1, wherein the set of predicted acoustic model parameters of the second target unit comprises a set of predicted acoustic features of the second target unit.

8. The non-transitory computer-readable storage medium of claim 1, wherein the set of predicted acoustic model parameters of the second target unit comprises a set of statistical parameters of predicted acoustic features of the second target unit.

9. The non-transitory computer-readable storage medium of claim 8, wherein the set of predicted acoustic model parameters includes a mean of the predicted acoustic features of the second target unit and a variance of the predicted acoustic features of the second target unit.

10. The non-transitory computer-readable storage medium of claim 8, wherein the set of predicted acoustic model parameters includes means of the predicted acoustic features of the second target unit, variances of the predicted acoustic features of the second target unit, and density weights of the predicted acoustic features of the second target unit assuming a model composed by a mixture of probability distributions.

11. The non-transitory computer-readable storage medium of claim 1, wherein the set of predicted acoustic model parameters of the second target unit is determined using only the set of acoustic features of the first candidate speech segment and the set of linguistic features of the second target unit.

12. The non-transitory computer-readable storage medium of claim 1, wherein the one or more programs further comprise instructions that cause the electronic device to:

select, from the plurality of speech segments, a third candidate speech segment for a third target unit of the sequence of target units, the third target unit preceding the first target unit in the sequence of target units, wherein the set of predicted acoustic model parameters of the second target unit is further determined using a set of acoustic features of the third candidate speech segment.

13. The non-transitory computer-readable storage medium of claim 1, wherein the likelihood score represents a likelihood of the set of acoustic features of the second candidate speech segment given the set of predicted acoustic model parameters of the second target unit and the set of acoustic features of the first candidate speech segment.

14. The non-transitory computer-readable storage medium of claim 13, wherein the likelihood score is determined by a Gaussian Mixture Model using the set of acoustic features of the second candidate speech segment as an observed set of acoustic features.

15. The non-transitory computer-readable storage medium of claim 1, wherein the likelihood score represents a difference between a set of predicted acoustic features of the second target unit and the set of acoustic features of the second candidate speech segment.

16. The non-transitory computer-readable storage medium of claim 1, wherein the first candidate speech segment and the second candidate speech segment are associated with a maximum accumulated likelihood score, and wherein the maximum accumulated likelihood score is determined based on the likelihood score.

17. The non-transitory computer-readable storage medium of claim 1, wherein the likelihood score is determined using only the set of predicted acoustic model parameters of the second target unit and the set of acoustic features of the second candidate speech segment.

18. The non-transitory computer-readable storage medium of claim 1, wherein the second candidate speech segment is not selected based on a separate concatenation score associated with joining the first candidate speech segment with the second candidate speech segment.

19. The non-transitory computer-readable storage medium of claim 1, wherein the first target unit is associated with a first plurality of candidate speech segments, and wherein the one or more programs further comprise instructions that cause the electronic device to:

for each candidate speech segment of the first plurality of candidate speech segments, determine a respective set of predicted acoustic model parameters of the second target unit.

20. The non-transitory computer-readable storage medium of claim 1, wherein the first target unit is associated with a first plurality of candidate speech segments, wherein each candidate speech segment of the first plurality of candidate speech segments is associated with an accumulated likelihood score, and wherein the one or more programs further comprise instructions that cause the electronic device to:

for each candidate speech segment in a subset of the first plurality of candidate speech segments, determine a respective set of predicted acoustic model parameters of the second target unit, wherein the subset includes candidate speech segments of the first plurality of candidate speech segments associated with the highest accumulated likelihood scores.

21. The non-transitory computer-readable storage medium of claim 1, wherein the first candidate speech segment and the second candidate speech segment each comprise a segment of recorded speech.

22. The non-transitory computer-readable medium of claim 1, wherein the one or more programs comprising instructions that cause the electronic device to select, from the plurality of speech segments, the first candidate speech segment for the first target unit and the second candidate segment for the second target unit comprises instructions that cause the electronic device to:

select the first candidate speech segment for the first target unit based on a degree of matching between a set of

linguistic features of the first candidate speech segment and a set of linguistic features of the first target unit; and

select the second candidate speech segment for the second target unit based on a degree of matching between a set of linguistic features of the second candidate speech segment and the set of linguistic features of the second target unit.

23. The non-transitory computer-readable medium of claim **1**, wherein the one or more programs further comprises instructions that cause the electronic device to:

select, from the plurality of speech segments, one or more additional candidate speech segments for the first target unit of the sequence of target units; and

select, from the plurality of speech segments, one or more additional candidate speech segments for the second target unit of the sequence of target units.

24. The non-transitory computer-readable medium of claim **23**, wherein the one or more programs further comprises instructions that cause the electronic device to:

determine, using a set of acoustic features of each of the additional candidate speech segments for the first target unit and the set of linguistic features of the second target unit, a respective set of predicted acoustic model parameters for each of the additional candidate speech segments for the second target unit; and

determine, using the respective set of the predicted acoustic model parameters for each of the additional candidate speech segments for the second target unit and a set of acoustic features of a corresponding additional candidate speech segment for the second target unit, a likelihood score of each of the additional candidate speech segments for the second target unit with respect to each of the candidate speech segments for the first target unit.

25. The non-transitory computer-readable medium of claim **24**, wherein the one or more programs comprising instructions that cause the electronic device to select the second candidate speech segment to be used in speech synthesis based on the determined likelihood score comprises instructions that cause the electronic device to:

determine whether the likelihood score of the second candidate speech segment with respect to the first candidate speech segment maximizes an accumulated likelihood score; and

in accordance with a determination that the likelihood score of the second candidate speech segment with respect to the first candidate speech segment maximizes the accumulated likelihood score, select the second candidate speech segment to be used in speech synthesis.

26. A method for performing unit-selection text-to-speech synthesis, comprising:

at an electronic device having a processor and memory:

receiving text to be converted to speech;

generating a sequence of target units representing a spoken pronunciation of the text;

selecting, from a plurality of speech segments, a first candidate speech segment for a first target unit of the sequence of target units and a second candidate speech segment for a second target unit of the sequence of target units;

determining, using a set of acoustic features of the first candidate speech segment and a set of linguistic features of the second target unit, a set of predicted acoustic model parameters of the second target unit;

determining, using the set of predicted acoustic model parameters of the second target unit and a set of acoustic features of the second candidate speech segment, a likelihood score of the second candidate speech segment with respect to the first candidate speech segment;

selecting the second candidate speech segment to be used in speech synthesis based on the determined likelihood score; and

generating speech corresponding to the received text using the second candidate speech segment.

27. A system for performing unit-selection text-to-speech synthesis, the system comprising:

one or more processors; and

memory storing one or more programs, wherein the one or more programs include instructions which, when executed by the one or more processors, cause the one or more processors to:

receive text to be converted to speech;

generate a sequence of target units representing a spoken pronunciation of the text;

select, from a plurality of speech segments, a first candidate speech segment for a first target unit of the sequence of target units and a second candidate speech segment for a second target unit of the sequence of target units;

determine, using a set of acoustic features of the first candidate speech segment and a set of linguistic features of the second target unit, a set of predicted acoustic model parameters of the second target unit;

determine, using the set of predicted acoustic model parameters of the second target unit and a set of acoustic features of the second candidate speech segment, a likelihood score of the second candidate speech segment with respect to the first candidate speech segment;

select the second candidate speech segment to be used in speech synthesis based on the determined likelihood score; and

generate speech corresponding to the received text using the second candidate speech segment.

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