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METHODS OF UTILIZING REINFORCEMENT LEARNING FOR ENHANCED TEXT SUGGESTIONS, AND SYSTEMS AND DEVICES THEREFOR

Abstract

Techniques and apparatuses for enhanced text suggestions are described. An example method includes detecting a user gesture performed by a user of the computing system based on data from one or more neuromuscular sensors and identifying a set of text characters corresponding to the user gesture. The method further includes causing display of the set of text terms in a user interface and determining whether a cognitive load of the user meets one or more criteria. The method also includes providing a text suggestion to the user based on the set of text characters in accordance with a determination that the cognitive load of the user meets the one or more criteria, and forgoing providing the text suggestion to the user based on the set of text characters, in accordance with a determination that the cognitive load of the user does not meet the one or more criteria.

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Background/Summary

PRIORITY [0001] This application claims priority to U.S. Provisional Patent Application No. 63/551,937, entitled "Methods of Utilizing Reinforcement Learning for Enhanced Text Suggestions, and Systems and Devices Therefor" filed Feb. 9, 2024, which is hereby incorporated by reference in its entirety.

TECHNICAL FIELD
[0002] The present disclosure relates generally to providing text suggestions (e.g., text corrections and/or completions) to a user based on reinforcement learning, including, but not limited to, techniques and apparatuses for detecting writing via sensors of wearable electronic devices and providing the text suggestions based on an estimated cognitive load of the user.
BACKGROUND
[0003] Automatic correction is a function that automatically makes or suggests corrections for mistakes in spelling or grammar made while writing (e.g., typing on a keyboard). Automatic completion is a function that automatically makes or suggests the rest of a word or phrase that a user is writing. Large language models (LLMs) have been useful components in autocorrection and autocompletion. Conventional LLM systems determine whether to show such completions and corrections to a user based on a confidence value of the model. These systems have limited expressivity with one dimension (the confidence value).
[0004] Therefore, these systems may make completion/corrections too often or not often enough for a particular user, which causes the systems to reduce the particular user's writing speed (e.g., adjusted word per minute (aWPM)) and/or reduce the particular user's satisfaction with the systems. This makes for an inefficient user-machine interface and can lead to user frustration.
SUMMARY
[0005] The present disclosure describes, among other things, systems and methods of using reinforcement learning to provide personalized suggestions (e.g., completions/corrections) to users. The systems and methods described herein take into account user context and/or cognitive load of the user to make suggestions at appropriate times during the user's writing. As described in more detail below, taking into account user context improves the quality of suggestions, and taking into account cognitive load can improve the timing of suggestions, which can increase text input speed (e.g., user writing speed) and can also reduce user frustration.
[0006] In accordance with some embodiments, a method of text suggestions includes: (i) detecting a user gesture associated with a user task, the user gesture performed by a user of the computing system based on data from one or more neuromuscular sensors; (ii) identifying a set of text characters corresponding to the user gesture; (iii) causing display, via a display device, of the set of text terms in a user interface; (iv) estimating, based on context information, a cognitive load of the user corresponding to performing the user task at the computing system; (v) determining whether the estimated cognitive load meets one or more predefined criteria; (vi) in accordance with a determination that the estimated cognitive load meets the one or more predefined criteria, providing a text suggestion to the user based on the set of text characters; and (vii) in accordance with a determination that the estimated cognitive load does not meet the one or more predefined criteria, forgoing providing the text suggestion to the user based on the set of text characters. In some embodiments, the neuromuscular sensors include one or more electromyography (EMG) sensors, mechanomyography sensors, and/or sonomyography sensors. Techniques for processing neuromuscular signals are described in commonly owned U.S. Patent Publication No. US 2020/0310539, which is incorporated by reference herein for all purposes, including, for example,

the techniques shown and described with reference to FIGS. **29-30** in the incorporated publication, which can be applied in one example to process neuromuscular signals to allow for detecting the in-air hand gestures described herein.

[0007] In accordance with some embodiments, a computing system is provided, such as a wearable device, a server system, a personal computer system, or other electronic device. The computing system includes control circuitry and memory storing one or more sets of instructions. The one or more sets of instructions include instructions for performing any of the methods described herein (e.g., the method **300** that is described in detail below).

[0008] In accordance with some embodiments, a non-transitory computer-readable storage medium is provided. The non-transitory computer-readable storage medium stores one or more sets of instructions for execution by a computing system (e.g., a wrist-wearable device or a head-mounted device or an intermediary device such as a smart phone or desktop or laptop computer that can be configured to coordinate operations at the wrist-wearable device and the head-mounted device). The one or more sets of instructions include instructions for performing any of the methods described herein (e.g., the method **300** that is described in detail below).

[0009] Thus, methods, apparatuses, devices, and systems are disclosed for providing text suggestions. Such methods, apparatuses, devices, and systems may complement or replace conventional methods for providing text suggestions.

[0010] The features and advantages described in the specification are not necessarily all inclusive and, in particular, some additional features and advantages will be apparent to one of ordinary skill in the art in view of the drawings, specification, and claims provided in this disclosure. Moreover, it should be noted that the language used in the specification has been principally selected for readability and instructional purposes and has not necessarily been selected to delineate or circumscribe the subject matter described herein.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] So that the present disclosure can be understood in greater detail, a more particular description can be had by reference to the features of various embodiments, some of which are illustrated in the appended drawings. The appended drawings, however, merely illustrate pertinent features of the present disclosure and therefore are not to necessarily to be considered limiting, for the description can admit to other effective features as the person of skill in the art will appreciate upon reading this disclosure.

[0012] FIGS. **1**A-**1**E illustrate an example scenario of a system providing text suggestions in accordance with some embodiments.

[0013] FIGS. **2**A-**2**F illustrate another example scenario of a system providing text suggestions in accordance with some embodiments.

[0014] FIG. **3** shows a flow chart for an example method of providing text suggestions in accordance with some embodiments.

[0015] FIGS. **4**A, **4**B, **4**C-**1**, **4**C-**2**, **4**D-**1**, and **4**D-**2** illustrate example artificial-reality (AR) systems in accordance with some embodiments.

[0016] FIGS. **5**A-**5**B illustrate an example wrist-wearable device in accordance with some embodiments.

[0017] FIGS. **6**A, **6**B-**1**, **6**B-**2**, and **6**C illustrate example AR systems in accordance with some embodiments.

[0018] FIGS. **7**A-**7**B illustrate an example handheld device in accordance with some embodiments.

[0019] FIGS. **8**A-**8**C illustrate example wearable gloves in accordance with some embodiments.

[0020] In accordance with common practice, the various features illustrated in the drawings are not necessarily drawn to scale, and like reference numerals can be used to denote like features throughout the specification and figures.

DETAILED DESCRIPTION

[0021] The present disclosure describes systems and methods for providing suggestions, completions, and corrections while a user is providing inputs (e.g., typing, writing, or otherwise gesturing). As described herein, a cognitive load of the user (e.g., for the input task) can be estimated and the estimation can be used to identify when to provide the suggestions, completions, and/or corrections. The cognitive load of the user may be estimated based on context information for the user and/or context information regarding the user's inputs. Using estimated cognitive load to identify when to provide suggestions, completions, and/or corrections can improve the man-machine interface, improve input speed, and/or reduce user frustration.

[0022] Embodiments of this disclosure can include or be implemented in conjunction with various types or embodiments of AR systems. Artificial-reality (AR), as described herein, is any superimposed functionality and or sensory-detectable presentation provided by an artificial-reality system within a user's physical surroundings. Such artificial-realities can include and/or represent virtual reality (VR), augmented reality, mixed artificial-reality (MAR), or some combination and/or variation of one of these. For example, a user can perform a swiping in-air hand gesture to cause a song to be skipped by a song-providing API providing playback at, for example, a home speaker. An AR environment, as described herein, includes, but is not limited to, VR environments (including non-immersive, semi-immersive, and fully immersive VR environments); augmented-reality environments (including marker-based augmented-reality environments, markerless augmented-reality environments, location-based augmented-reality environments, and projection-based augmented-reality environments); hybrid reality; and other types of mixed-reality environments.

[0023] Artificial-reality content can include completely generated content or generated content combined with captured (e.g., real-world) content. The artificial-reality content can include video, audio, haptic events, or some combination thereof, any of which can be presented in a single channel or in multiple channels (such as stereo video that produces a three-dimensional effect to a viewer). Additionally, in some embodiments, artificial reality can also be associated with applications, products, accessories, services, or some combination thereof, which are used, for example, to create content in an artificial reality and/or are otherwise used in (e.g., to perform activities in) an artificial reality.

[0024] A hand gesture, as described herein, can include an in-air gesture, a surface-contact gesture, and or other gestures that can be detected and determined based on movements of a single hand (e.g., a one-handed gesture performed with a user's hand that is detected by one or more sensors of a wearable device (e.g., electromyography (EMG) and/or inertial measurement units (IMUs) of a wrist-wearable device) and/or detected via image data captured by an imaging device of a wearable device (e.g., a camera of a head-wearable device)) or a combination of the user's hands. “In-air” means, in some embodiments, that the user hand does not contact a surface, object, or portion of an electronic device; in other words the gesture is performed in open air in 3D space and without contacting a surface, an object, or an electronic device. Surface-contact gestures (contacts at a surface, object, body part of the user, or electronic device) more generally are also contemplated in which a contact (or an intention to contact) is detected at a surface (e.g., a single- or double-finger tap on a table, on a user's hand or another finger, on the user's leg, a couch, a steering wheel, etc.). The different hand gestures disclosed herein can be detected using image data and/or sensor data (e.g., neuromuscular signals sensed by one or more biopotential sensors (e.g., EMG sensors) or other types of data from other sensors, such as proximity sensors, time-of-flight sensors, sensors of an inertial measurement unit, etc.) detected by a wearable device worn by the user and/or other electronic devices in the user's possession (e.g., smartphones, laptops, imaging devices, intermediary devices, and/or other devices described herein).

[0025] FIGS. **1**A-**1**E illustrate an example scenario of a system providing text suggestions in accordance with some embodiments. FIG. **1**A shows a user **102** wearing a head-wearable device **104** and a wrist-wearable device **106**. In some embodiments, the head-wearable device **104** is an augmented-reality device (e.g., the AR device **800** or the VR device **810**, FIG. **6**C). The wrist-wearable device **106** may be a smartwatch or other type of wearable device (e.g., the wrist-wearable device **700**, FIG. **5**A). The user **102** in FIG. **1**A is holding a stylus **108** and performing a user gesture **114**. In some embodiments, the stylus **108** includes one or more sensors (e.g., is an electronic stylus). For example, the stylus **108** may include one or more of the sensors described below with respect to FIG. **5**B. In some embodiments, the user gesture **114** is detected by one or more of the head-wearable device **104** (e.g., via image sensors), the wrist-wearable device **106** (e.g., via neuromuscular sensors), and the stylus **108** (e.g., via accelerators). FIG. **1**A further shows a scene **110** that includes a message **112** that is displayed by the head-wearable device **104**. In some embodiments, the scene **110** corresponds to a VR scene. In some embodiments, the scene **110** corresponds to an augmented reality scene (e.g., with virtual objects overlaid with real world objects). In some embodiments, the message **112** corresponds to a messenger application (e.g., executing on the head-wearable device **104** and/or the wrist-wearable device **106**). In accordance with some embodiments, the message **112** includes text ("Hey Alex, The ne") corresponding to gestures previously performed by the user **102**. For example, the user **102** had previously typed or written the text shown in FIG. **1**A.

[0026] FIG. **1**A also shows an estimated cognitive load **116** (equal to 0.9 in FIG. **1**A) and top suggestions **118** (e.g., provided by a machine-learning component based on the text of message **112**). Each of the top suggestions **118** in FIG. **1**A has a corresponding confidence value (e.g., the first suggestion of "new" has a corresponding confidence value of 0.6). The top suggestions **118** correspond to completing a word that starts with "ne." In some embodiments, suggestions (e.g., the top suggestions **118**) are based on context information (e.g., information about the user **102**, such as previous messages, calendar information, contact information, and/or location information). In some embodiments, the confidence value is based on existing text (e.g., the text of the message **112**) and context information. In some embodiments, the suggestions are obtained as the top results (e.g., the results having the highest corresponding confidence scores) from a machine-learning model (e.g., an LLM). The top suggestions **118** are calculated by the head-wearable device **104** as indicated by the dotted line in FIG. **1**A. In some embodiments, the top suggestions **118** are calculated by a different device or system component (e.g., the wrist-wearable device **106** or a companion device). The top suggestions **118** are not shown to the user **102** (e.g., in accordance with a determination that the estimated cognitive load **116** of the user **102** is above a threshold).

[0027] FIG. **1**B illustrates a transition from FIG. **1**A in response to the user gesture **114**. In the example of FIGS. **1**A and **1**B, the user gesture **114** corresponds to text **120** (e.g., "xt ga"). FIG. **1**B shows the message **112** updated to include the text **120** in response to the user gesture **114**. FIG. **1**B further shows an estimated cognitive load **122** of 0.5 and top suggestions **124**. The cognitive load **122** of 0.5 in FIG. **1**B indicates that the user **102** has a lower estimated cognitive load in FIG. **1**B as compared to FIG. **1**A. Each of the top suggestions **124** in FIG. **1**B has a corresponding confidence value (e.g., the first suggestion of "game is tomorrow afternoon at 2:00 pm" has a corresponding confidence value of 0.55). The top suggestions **124** correspond to completing a word that starts with "ga". The first suggestion further includes a phrase following the suggested word of "game" (e.g., "is tomorrow afternoon at 2:00 pm"). In some embodiments, the suggested phrase is based on calendar information for the user **102** (e.g., a scheduled game with Alex). The top suggestions **124** are calculated by the head-wearable device **104** as indicated by the dotted line in FIG. **1**B. In some embodiments, the top suggestions **124** are calculated by a different device.

[0028] FIG. **1**C illustrates a transition from FIG. **1**B (e.g., in accordance with a determination that an estimated cognitive load of the user meets one or more criteria and/or a determination that a confidence value of a suggestion meets one or more criteria). In FIG. **1**C a suggestion **128** is displayed in the scene **110**. The suggestion **128** corresponds to the first suggestion in FIG. **1**B. In some embodiments, the suggestion **128** is displayed via the head-wearable device **104**. In some embodiments, the head-wearable device **104** determines (or otherwise obtains) a set of top potential suggestions (e.g., the top suggestions **124**) and presents one of the top potential suggestions to the user **102**. In some embodiments, the suggestion **128** is received by the head-wearable device **104** from another device (e.g., the wrist-wearable device **106**). For example, another device may obtain a set of top potential suggestions from a machine-learning component and then select one of the potential suggestions and send it to the head-wearable device **104** for display to the user. In some embodiments, more than one suggestion is presented to the user **102** (e.g., a pop-up or menu is presented with two or more suggestions). In some embodiments, in accordance with a determination that the estimated cognitive load is below a preset threshold (e.g., below a threshold of 0.51), a suggestion is provided for the user. In some embodiments, in accordance with a determination that the estimated cognitive load is above a preset threshold (e.g., above a threshold of 0.51), no suggestion is provided to the user (e.g., regardless of confidence value). In some embodiments, presenting a suggestion (e.g., the suggestion **128**) includes activating one or more sensors (e.g., in order to detect a subsequent suggestion acceptance gesture). In some embodiments, activating a sensor includes operating the sensor in a higher power mode and/or processing data collected by the sensor. In some embodiments, a suggestion (e.g., the suggestion **128**) is presented in accordance with a user request (e.g., a user request for a suggestion). For example, the user **102** may perform a gesture (or issue a voice command) that is mapped to a function to provide a suggestion.

[0029] In some embodiments, the suggestion **128** is visually distinguished from the text **120** (e.g., the suggestion **128** is in a different font, color, or style than the text **120**). In some embodiments, the suggestion **128** is presented with underlining, italics, and/or other highlighting. In some embodiments, the suggestion **128** is presented with an indication of how to accept the suggestion **128** (e.g., indication of a command/gesture for accepting the suggestion that is presented with the message **112**). For example, a swipe gesture (e.g., a swipe-down gesture or swipe-right gesture) may be mapped to a command for accepting suggestions. In this example, an indication of the swipe gesture may be presented to the user **102** (e.g., a message such as “swipe down to accept suggestion” may be displayed). In some embodiments, a suggestion is displayed with a message/document, but is not added/stored to the message/document unless accepted. FIG. **1**C further shows the user **102** performing a gesture **130** (e.g., a swipe-down gesture). In some embodiments, the gesture **130** is a first type of gesture, and the first type of gesture is mapped to a suggestion-acceptance function. In some embodiments, the first type of gesture is mapped to the suggestion-acceptance function while a suggestion is displayed (and is mapped to other functions when no suggestions are displayed).

[0030] FIG. **1**D illustrates a transition from FIG. **1**C in response to the user gesture **130** (e.g., accepting the suggestion **128**). In FIG. **1**D, the scene **110** shows a message **132** that includes the suggestion **128** (e.g., the suggestion **128** has been added to the message **112**). In some embodiments, an accepted suggestion is stored to the message/document with the user-entered text (e.g., the text **120**). In some embodiments, an accepted suggestion is not visually distinguished from user-entered text (e.g., any highlighting or differences in color or style are removed when the suggestion is accepted). In some embodiments, accepting a suggestion causes the system (e.g., a system that includes the head-wearable device **104** and the wrist-wearable device **106**) to transition modes (e.g., from an editing mode to a display mode).

[0031] FIG. **1**D further shows the user **102** performing a gesture **134** (e.g., a double-tap gesture). In some embodiments, the gesture **134** is a second type of gesture, and the second type of gesture is mapped to a message-send function. In some embodiments, the second type of gesture is mapped to the message-send function while a message application is active (and is mapped to other functions when other applications are active). In some embodiments, the second type of gesture is mapped to the message-send function while a message editing mode and/or message display mode is active.

[0032] FIG. **1**E illustrates a transition from FIG. **1**D in response to the user gesture **134** (e.g., requesting the message **132** be sent). In FIG. **1**E, the scene **110** shows the message **132** and a notification **136** that the message **132** has been sent (e.g., to a recipient named “Alex” in the user's contact list). In some embodiments, in accordance with sending the message **132**, the message **132** is no longer displayed. In some embodiments, in accordance with sending the message **132**, the message **132** is displayed in a different user interface and/or in a different manner than before the message **132** is sent. In some embodiments, a second type of gesture is mapped to the message send function, a third type of gesture is mapped to a message-save function, a fourth type of gesture is mapped to an undo/delete function, and/or a fifth type of gesture is mapped to a new-suggestion function. In some embodiments, different gesture mappings are available to the user in accordance with sending the message **132**. For example, a mode of the system changes in accordance with sending the message (e.g., from a message-drafting mode to a message-display mode) and different gesture mappings are used with each mode.

[0033] Although FIGS. **1**A-**1**E illustrate the user **102** holding the stylus **108**, in some other embodiments the user **102** performs the gestures described above without using a stylus or other hand-held device (e.g., the user performs the gestures without holding anything). For example, the user **102** may perform the user gesture **114** as though holding an imaginary pencil or may perform the user gesture **114** as though writing with a finger (e.g., the index finger).

[0034] FIGS. **2**A-**2**F illustrate another example scenario of a system providing text suggestions in accordance with some embodiments. FIG. **2**A illustrates the user **102** wearing the head-wearable device **104** and the wrist-wearable device **106**. The user **102** in FIG. **2**A is performing a gesture **202** (e.g., a typing gesture). In some embodiments, the gesture **202** is performed as an in-air gesture, while in other embodiments, the gesture **202** is performed on a surface (e.g., a countertop or wall). In some embodiments, the user gesture **202** is detected by the head-wearable device **104** (e.g., via image sensors) and/or the wrist-wearable device **106** (e.g., via neuromuscular sensors). FIG. **2**A further shows the scene **110** that includes a message **204** and a virtual keyboard **206** that is displayed by the head-wearable device **104**. In some embodiments, the message **204** corresponds to a messenger application (e.g., executing on the head-wearable device **104** and/or the wrist-wearable device **106**). In accordance with some embodiments, the message **204** includes text (“Hi B”) corresponding to gestures previously performed by the user **102**. For example, the user **102** had previously typed, written, or spoken the text shown in FIG. **2**A.

[0035] FIG. **2**A also shows an estimated cognitive load **208** (equal to 0.6 in FIG. **2**A) and top suggestions **210** (e.g., provided by a machine-learning component based on the text of message **204**). Each of the top suggestions **210** in FIG. **2**A has a corresponding confidence value (e.g., the first suggestion of “Barbara” has a corresponding confidence value of 0.7). The top suggestions **210** correspond to completing a word that starts with “B.” In some embodiments, suggestions (e.g., the top suggestions **210**) are based on context information (e.g., information about the user **102**, such as previous messages, calendar information, contact information, and/or location information). In some embodiments, the top suggestions **210** are identified based on names in a contact list of the user **102**. In some embodiments, the confidence value is based on existing text (e.g., the text of the message **204**) and context information. In some embodiments, the suggestions are obtained as the top results (e.g., the results having the highest corresponding confidence scores) from a machine-learning model (e.g., an LLM). The top suggestions **210** are calculated by the wrist-wearable device **106** as indicated by the dotted line in FIG. **2**A. In some embodiments, the top suggestions **210** arc calculated by a different device or system component (e.g., the head-wearable device **104** or a companion device).

[0036] FIG. **2**B illustrates a transition from FIG. **2**A (e.g., in accordance with a determination that an estimated cognitive load of the user meets one or more criteria and/or a determination that a confidence value of a suggestion meets one or more criteria). In FIG. **2**B a suggestion **214** is displayed in the message **204** in the scene **110**. The suggestion **214** corresponds to the first suggestion in FIG. **2**A. In some embodiments, the suggestion **214** is displayed via the head-wearable device **104**. In some embodiments, the suggestion **214** is received by the head-wearable device **104** from another device (e.g., the wrist-wearable device **106**). For example, another device may obtain a set of top potential suggestions from a machine-learning component and then select one of the potential suggestions and send it to the head-wearable device **104** for display to the user. FIG. **2**B further shows the user **102** performing a gesture **216** (e.g., a typing gesture).

[0037] FIG. **2**C illustrates a transition from FIG. **2**B in response to the user gesture **216**. In the example of FIGS. **2**B and **2**C, the user gesture **216** corresponds to text **220** (e.g., "ran,"). FIG. **2**C shows the message **204** updated to include the text **220** in response to the user gesture **216**. In some embodiments, in accordance with the user **102** performing a gesture that is not mapped to accepting the suggestion **214**, the suggestion **214** is considered to be rejected (and ceases to be displayed). In some embodiments, the suggestion **214** ceases to be displayed in accordance with the user **102** entering new text (e.g., via a typing gesture, writing gesture, or voice command). In some embodiments, a suggestion being rejected (e.g., the suggestion **214**) causes negative feedback (e.g., a negative reward) to be provided to a machine-learning component that provided the suggestion (e.g., a component configured for reinforcement learning). FIG. **2**C further shows the user **102** performing a gesture **222** (e.g., a typing gesture).

[0038] FIG. **2**D illustrates a transition from FIG. **2**C in response to the user gesture **222**. In the example of FIGS. **2**C and **2**D, the user gesture **222** corresponds to text **224** (e.g., "I'm running"). FIG. **2**D shows the message **223** updated to include the text **224** in response to the user gesture **222**. FIG. **2**D further shows an estimated cognitive load **226** of 0.3 and top suggestions **228**. Each of the top suggestions **228** in FIG. **2**D has a corresponding confidence value (e.g., the first suggestion of "5 minutes late to our meeting." has a corresponding confidence value of 0.7). The top suggestions **228** correspond to completing a phrase that starts with "I'm running." In some embodiments, the suggested phrases are based on context information of the user **102** (e.g., calendar information, location information, and/or inventory information). The top suggestions **228** are calculated by the wrist-wearable device **106** as indicated by the dotted line in FIG. **2**D. In some embodiments, the top suggestions **228** are calculated by a different device.

[0039] FIG. **2**E illustrates a transition from FIG. **2**D (e.g., in accordance with a determination that an estimated cognitive load of the user meets one or more criteria and/or a determination that a confidence value of a suggestion meets one or more criteria). In FIG. **2**E a suggestion **230** is displayed in the message **223** in the scene **110**. The suggestion **230** corresponds to the first suggestion in FIG. **2**D. In some embodiments, the suggestion **230** is displayed via the head-wearable device **104**. In some embodiments, the suggestion **230** is received by the head-wearable device **104** from another device (e.g., the wrist-wearable device **106**). For example, another device may obtain a set of top potential suggestions from a machine-learning component and then select one of the potential suggestions and send it to the head-wearable device **104** for display to the user. In some embodiments, a suggestion (e.g., the suggestion **230**) is automatically inserted into (e.g., stored to) a message/document (e.g., the message **223**) in accordance with a confidence level of the suggestion being above a certain threshold (e.g., indicating greater than 90%, 95%, or 99% confidence).

[0040] The message **223** in FIG. **2**E is displayed with a notification **232** indicating that the user **102** may trigger a virtual Tab key to accept the suggestion and send the message (e.g., send the message to a contact of the user **102** named "Bran"). In some embodiments, the scene **110** includes a notification indicating a gesture that the user may perform to accept the suggestion without sending the message (e.g., in addition to, or alternatively to, providing the notification **232**). FIG. **2**E further shows the user **102** performing a gesture **234** (e.g., a tap gesture).

[0041] FIG. **2**F illustrates a transition from FIG. **2**E in response to the user gesture **234** (e.g., requesting the suggestion be accepted and the message **223** be sent). In FIG. **2**F, the scene **110** shows the message **223** and a notification **236** that the message **223** has been sent (e.g., to a recipient named “Bran” in the user's contact list). In some embodiments, in accordance with sending the message **223**, the message **223** is no longer displayed. In some embodiments, in accordance with sending the message **223**, the message **223** is displayed in a different user interface and/or in a different manner than before the message **223** is sent. In some embodiments, a messenger application is closed or minimized in accordance with the message **223** being sent. In some embodiments, different gesture mappings are available to the user in accordance with sending the message **223**. For example, a mode of the system changes in accordance with sending the message (e.g., from a message-drafting mode to a message-display mode) and different gesture mappings are used with each mode. In some embodiments, a conversation between the user **102** and the recipient “Bran” is displayed in accordance with the message **232** being sent.

[0042] Although FIGS. **1**A-**1**E and **2**A-**2**F illustrate the user **102** wearing the head-wearable device **104** and the wrist-wearable device **106**, in some other embodiments, the user **102** is using other types of devices. For example, the user **102** may use only the wrist-wearable device **106** (e.g., alone or in conjunction with a separate display device). In some embodiments, the user **102** uses a different type of wearable device than shown in FIGS. **1**A-**1**E (e.g., a ring and/or a wearable garment such as a glove or sleeve). For example, the user **102** may use a wearable garment in addition to, or alternatively to, wearing the wrist-wearable device **106**. Other examples of wearable devices include rings, anklets, armbands, neckbands, headbands, and smart clothing (e.g., clothing with integrated sensors and electronics). In some embodiments, the gestures described above with respect to FIGS. **1**A-**1**E and **2**A-**2**F are detected via sensors of the head-wearable device **104** (e.g., image sensors), the wrist-wearable device **106** (e.g., neuromuscular sensors), and/or the stylus **108** (e.g., force sensors and/or accelerometers).

[0043] Although FIGS. **1**A-**1**E and **2**A-**2**F illustrate examples of suggestions corresponding to text completion, in some embodiments, suggestions correspond to text corrections. For example, in response to a user writing/typing the term “runing” a suggestion is provided to replace the term “runing” with the word “running.” In some embodiments, a text correction is automatically applied in accordance with a confidence score for the text correction being above a certain threshold (e.g., indicating greater than 90%, 95%, or 99% confidence). In some embodiments, text correction suggestions are indicated by emphasis/highlighting applied to the term to be replaced by the correction. In some embodiments, text correction suggestions are presented adjacent to the term to be replaced. In some embodiments, a text correction suggestion is displayed in place of the term to be replaced (e.g., with a different emphasis, highlighting, and/or style than other text in the message/document to indicate that it is a suggestion). In some embodiments, the system learns user preferences (e.g., a preference for using a slang term or a particular spelling) based on whether the user accepts or reject/ignores the suggestions.

[0044] Although FIGS. **1**A-**1**E and **2**A-**2**F illustrate examples in which explicit values are calculated for estimated cognitive loads, in some embodiments estimating cognitive loads does not include calculating explicit values. In some embodiments, cognitive loads are estimated in a qualitative manner. For example, a cognitive load may be estimated based on a user's history of accepting or not accepting suggestions. In some embodiments, a machine learning model determines whether an estimated cognitive load meets one or more criteria without calculating and/or outputting a cognitive load value.

[0045] FIG. **3** shows a flow chart for a method **300** of providing text suggestions in accordance with some embodiments. The method **300** is performed at a computing system (e.g., a wearable device, a mobile device, and/or intermediary device) having one or more processors and memory. In some embodiments, the memory stores one or more programs configured for execution by the one or more processors. At least some of the operations shown in FIG. **3** correspond to instructions stored in a computer memory or computer-readable storage medium (e.g., the memory **780**, the memory **850**A, and/or the memory **850**B). In some embodiments, the computing system is, or includes, a wearable device, such as the wrist-wearable device **106** or the head-wearable device **104**. In some embodiments, the computing system is, or includes, an intermediary device such as a smartphone, a tablet, or other electronic device.

[0046] The computing system detects (**302**) a user gesture (e.g., the user gesture **114** in FIG. **1**A) performed by a user based on data from one or more neuromuscular sensors (e.g., the EMG sensor **765** in FIG. **5**B). In some embodiments, the user gesture is detected by a wearable device (e.g., the wrist-wearable device **106**). In some embodiments, the user gesture comprises a handwriting motion (e.g., with a stylus, pencil, or empty hand).

[0047] The computing system identifies (**304**) a set of text characters corresponding to the user gesture (e.g., the text **120** in FIG. **1**B). In some embodiments, the set of text characters is identified based on a mapping between neuromuscular data and text characters. In some embodiments, the set of text characters is appended to a set of pre-existing text in a document (e.g., the text **120** is appended to the text of the message **112** in FIG. **1**B).

[0048] The computing system causes display (**306**), via a display device, of the set of text terms in a user interface (e.g., the text **120** is displayed in the message **112** in FIG. **1**B). In some embodiments, the set of text terms is provided in a manner that is distinct from how the set of text terms was gestured (e.g., the user writes in shorthand and/or cursive and the text appears in print characters).

[0049] The computing system determines (**308**) whether a cognitive load of the user (e.g., the estimated cognitive load **122** in FIG. **1**B) meets one or more predefined criteria. In some embodiments, a cognitive load threshold is set based on explicit/implicit user preferences (e.g., preferences of the user performing the gesture and/or similar users). In some embodiments, the cognitive load is estimated based on context information for the user and/or context information regarding the set of text characters.

[0050] In accordance with a determination that the cognitive load of the user meets the one or more predefined criteria, the computing system provides (**310**) a text suggestion (e.g., the suggestion **128**) to the user based on the set of text characters. In some embodiments, the one or more predefined criteria are based on one or more user preferences of the user. In some embodiments, the text suggestion is visually distinguished from the set of text characters (e.g., a different color, size, font, and/or with different emphasis). In some embodiments, the text suggestion is generated based on the set of text characters, a set of preexisting characters, and/or information about the user (e.g., context information). In some embodiments, the text suggestion is provided by a machine-learning component. In some embodiments, the machine-learning component is trained based on the data from the one or more neuromuscular sensors. In some embodiments, a set of suggestions, including the text suggestion, is obtained from the machine-learning component.

[0051] In accordance with a determination that the cognitive load of the user does not meet the one or more predefined criteria, the computing system forgoes providing (**312**) the text suggestion to the user based on the set of text characters. For example, in the example of FIGS. **1**A and **1**B, a suggestion is not provided based on the text in FIG. **1**A in accordance with the estimated cognitive load **116** not meeting one or more predefined criteria. In some embodiments, the computing system (e.g., an ML model of the computing system) determines whether or not the cognitive load of the user meets the one or more predefined criteria without deterministically calculating a value for the cognitive load. For example, an ML model may be trained to provide an inference regarding whether to provide a suggestion. The inference is related to whether or not the cognitive load of the user meets the one or more predefined criteria, but does not include a value for the cognitive load.

[0052] In some embodiments, in accordance with the user accepting the text suggestion, the computing system provides (**314**) a reward to a machine-learning component. In some embodiments, in accordance with the user accepting the text suggestion, the computing system provides a positive reward. In some embodiments, in accordance with the user declining/ignoring the text suggestion, the computing system provides a negative reward. In some embodiments, the machine-learning component provides suggestions and estimates the cognitive load and, in response to receiving the reward, the machine-learning component updates one or more weights. In some embodiments, the reward is proportional to a length of the text suggestion.

[0053] In some embodiments, in accordance with the user accepting the text suggestion, the computing system applies (**316**) the text suggestion. For example, FIG. **1**D shows the suggestion **128** being accepted in response to the user gesture **130** in FIG. **1**C. In some embodiments, in accordance with a determination that the user input does not correspond to the command to accept the text suggestion, the computing system ceases to display the text suggestion (and optionally provides negative feedback to a machine-learning component). In some embodiments, applying the text suggestion includes executing a function of the computing system in accordance with the text suggestion (e.g., sending the corresponding message to a recipient).

[0054] It should be understood that the particular order in which the operations in FIG. **3** have been described is merely an example and is not intended to indicate that the described order is the only order in which the operations could be performed. One of ordinary skill in the art would recognize various ways to reorder the operations described herein. Having thus described example scenarios and processes, attention will now be turned to example devices and systems.

Example Systems

[0055] AR systems may be implemented in a variety of different form factors and configurations. Some artificial-reality systems include a near-eye display (NED), which provides visibility into the real world (e.g., the augmented-reality system **800** in FIG. **6**A) or that visually immerses a user in an artificial reality (e.g., the virtual-reality system **810** in FIG. **6**B-**1**). While some artificial-reality devices are self-contained systems, other artificial-reality devices communicate and/or coordinate with external devices to provide an artificial-reality experience to a user. Examples of such external devices include handheld controllers, mobile devices, desktop computers, devices worn by a user (e.g., the wrist-wearable device **700** in FIG. **5**A), devices worn by one or more other users, and/or any other suitable external system.

[0056] FIGS. **4**A-**4**D illustrate example AR systems in accordance with some embodiments. FIG. **4**A shows an AR system **600***a* and first example user interactions using a wrist-wearable device **700**, a head-wearable device (e.g., AR system **800**), and/or a handheld intermediary processing device (HIPD) **900**. FIG. **4**B shows an AR system **600***b* and second example user interactions using the wrist-wearable device **700**, the AR system **800**, and/or an HIPD **900**. FIGS. **4**C-**1** and **4**C-**2** show an AR system **600***c* and third example user interactions using a wrist-wearable device **700**, a head-wearable device (e.g., VR headset **810**), and/or an HIPD **900**. FIGS. **4**D-**1** and **4**D-**2** show a fourth AR system **600***d* and fourth example user interactions using a wrist-wearable device **700**, VR headset **810**, and/or device **1000** (e.g., wearable haptic gloves). The above-example AR systems (described in detail below) can include the various components and/or circuits described above and/or perform the various functions and/or operations described above with reference to FIGS. **1**-**3**.

[0057] The wrist-wearable device **700** and its components are described below in reference to FIGS. **5**A-**5**B; the head-wearable devices and their components are described below in reference to FIGS. **6**A-**6**C; and the HIPD **900** and its components are described below in reference to FIGS. **7**A-**7**B. Wearable gloves and their components are described below in reference to FIGS. **8**A-**8**C. As shown in FIG. **4**A, the wrist-wearable device **700**, the head-wearable devices, and/or the HIPD **900** can communicatively couple via a network **625** (e.g., cellular, near field, Wi-Fi, personal area network, or wireless LAN). Additionally, the wrist-wearable device **700**, the head-wearable devices, and/or the HIPD **900** can also communicatively couple with one or more servers **630**, computers **640** (e.g., laptops, computers, etc.), mobile devices **651** (e.g., smartphones, tablets, etc.), and/or other electronic devices via the network **625** (e.g., cellular, near field, Wi-Fi, personal area network, and/or wireless local area network (LAN)) Similarly, the device **1000** can also communicatively couple with the wrist-wearable device **700**, the head-wearable devices, the HIPD

900, the one or more servers **630**, the computers **640**, the mobile devices **651**, and/or other electronic devices via the network **625**.

[0058] Turning to FIG. **4**A, a user **602** is shown wearing the wrist-wearable device **700** and the AR system **800** and having the HIPD **900** on their desk. The wrist-wearable device **700**, the AR system **800**, and the HIPD **900** facilitate user interaction with an AR environment. In particular, as shown by the AR system **600***a*, the wrist-wearable device **700**, the AR system **800**, and/or the HIPD **900** cause presentation of one or more avatars **604**, digital representations of contacts **606**, and virtual objects **608**. As discussed below, the user **602** can interact with the one or more avatars **604**, digital representations of the contacts **606**, and virtual objects **608** via the wrist-wearable device **700**, the AR system **800**, and/or the HIPD **900**.

[0059] The user **602** can use any of the wrist-wearable device **700**, the AR system **800**, and/or the HIPD **900** to provide user inputs. For example, the user **602** can perform one or more hand gestures that are detected by the wrist-wearable device **700** (e.g., using one or more EMG sensors and/or IMUs, described below in reference to FIGS. **5**A-**5**B) and/or AR system **800** (e.g., using one or more image sensors or cameras, described below in reference to FIGS. **6**A-**6**B) to provide a user input. Alternatively, or additionally, the user **602** can provide a user input via one or more touch surfaces of the wrist-wearable device **700**, the AR system **800**, and/or the HIPD **900**, and/or voice commands captured by a microphone of the wrist-wearable device **700**, the AR system **800**, and/or the HIPD **900**. In some embodiments, the wrist-wearable device **700**, the AR system **800**, and/or the HIPD **900** include a digital assistant to help the user in providing a user input (e.g., completing a sequence of operations, suggesting different operations or commands, providing reminders, or confirming a command). In some embodiments, the user **602** provides a user input via one or more facial gestures and/or facial expressions. For example, cameras of the wrist-wearable device **700**, the AR system **800**, and/or the HIPD **900** can track the user **602**'s eyes for navigating a user interface.

[0060] The wrist-wearable device **700**, the AR system **800**, and/or the HIPD **900** can operate alone or in conjunction to allow the user **602** to interact with the AR environment. In some embodiments, the HIPD **900** is configured to operate as a central hub or control center for the wrist-wearable device **700**, the AR system **800**, and/or another communicatively coupled device. For example, the user **602** can provide an input to interact with the AR environment at any of the wrist-wearable device **700**, the AR system **800**, and/or the HIPD **900**, and the HIPD **900** can identify one or more back-end and front-end tasks to cause the performance of the requested interaction and distribute instructions to cause the performance of the one or more back-end and front-end tasks at the wrist-wearable device **700**, the AR system **800**, and/or the HIPD **900**. In some embodiments, a back-end task is a background processing task that is not perceptible by the user (e.g., rendering content, decompression, or compression), and a front-end task is a user-facing task that is perceptible to the user (e.g., presenting information to the user or providing feedback to the user). As described below in reference to FIGS. **7**A-**7**B, the HIPD **900** can perform the back-end tasks and provide the wrist-wearable device **700** and/or the AR system **800** operational data corresponding to the performed back-end tasks such that the wrist-wearable device **700** and/or the AR system **800** can perform the front-end tasks. In this way, the HIPD **900**, which can have more computational resources and greater thermal headroom than the wrist-wearable device **700** and/or the AR system **800**, performs computationally intensive tasks and reduces the computer resource utilization and/or power usage of the wrist-wearable device **700** and/or the AR system **800**.

[0061] In the example shown by the AR system **600***a*, the HIPD **900** identifies one or more back-end tasks and front-end tasks associated with a user request to initiate an AR video call with one or more other users (represented by the avatar **604** and the digital representation of the contact **606**) and distributes instructions to cause the performance of the one or more back-end tasks and front-end tasks. In particular, the HIPD **900** performs back-end tasks for processing and/or rendering image data (and other data) associated with the AR video call and provides operational data associated with the performed back-end tasks to the AR system **800** such that the AR system **800** performs front-end tasks for presenting the AR video call (e.g., presenting the avatar **604** and the digital representation of the contact **606**).

[0062] In some embodiments, the HIPD **900** operates as a focal or anchor point for causing the presentation of information. This allows the user **602** to be generally aware of where information is presented. For example, as shown in the AR system **600***a*, the avatar **604** and the digital representation of the contact **606** are presented above the HIPD **900**. In particular, the HIPD **900** and the AR system **800** operate in conjunction to determine a location for presenting the avatar **604** and the digital representation of the contact **606**. In some embodiments, information can be presented at a predetermined distance from the HIPD **900** (e.g., within 5 meters). For example, as shown in the AR system **600***a*, virtual object **608** is presented on the desk some distance from the HIPD **900**. Similar to the above example, the HIPD **900** and the AR system **800** can operate in conjunction to determine a location for presenting the virtual object **608**. Alternatively, in some embodiments, presentation of information is not bound by the HIPD **900**. More specifically, the avatar **604**, the digital representation of the contact **606**, and the virtual object **608** do not have to be presented within a predetermined distance of the HIPD **900**.

[0063] User inputs provided at the wrist-wearable device **700**, the AR system **800**, and/or the HIPD **900** are coordinated such that the user can use any device to initiate, continue, and/or complete an operation. For example, the user **602** can provide a user input to the AR system **800** to cause the AR system **800** to present the virtual object **608** and, while the virtual object **608** is presented by the AR system **800**, the user **602** can provide one or more hand gestures via the wrist-wearable device **700** to interact with and/or manipulate the virtual object **608**.

[0064] FIG. **4**B shows the user **602** wearing the wrist-wearable device **700** and the AR system **800** and holding the HIPD **900**. In the AR system **600***b*, the wrist-wearable device **700**, the AR system **800**, and/or the HIPD **900** are used to receive and/or provide one or more messages to a contact of the user **602**. In particular, the wrist-wearable device **700**, the AR system **800**, and/or the HIPD **900** detect and coordinate one or more user inputs to initiate a messaging application and prepare a response to a received message via the messaging application.

[0065] In some embodiments, the user **602** initiates, via a user input, an application on the wrist-wearable device **700**, the AR system **800**, and/or the HIPD **900** that causes the application to initiate on at least one device. For example, in the AR system **600***b* the user **602** performs a hand gesture associated with a command for initiating a messaging application (represented by messaging user interface **612**); the wrist-wearable device **700** detects the hand gesture; and, based on a determination that the user **602** is wearing AR system **800**, causes the AR system **800** to present a messaging user interface **612** of the messaging application. The AR system **800** can present the messaging user interface **612** to the user **602** via its display (e.g., as shown by user **602**'s field of view **610**). In some embodiments, the application is initiated and run on the device (e.g., the wrist-wearable device **700**, the AR system **800**, and/or the HIPD **900**) that detects the user input to initiate the application, and the device provides another device operational data to cause the presentation of the messaging application. For example, the wrist-wearable device **700** can detect the user input to initiate a messaging application, initiate and run the messaging application, and provide operational data to the AR system **800** and/or the HIPD **900** to cause presentation of the messaging application. Alternatively, the application can be initiated and run at a device other than the device that detected the user input. For example, the wrist-wearable device **700** can detect the hand gesture associated with initiating the messaging application and cause the HIPD **900** to run the messaging application and coordinate the presentation of the messaging application.

[0066] Further, the user **602** can provide a user input provided at the wrist-wearable device **700**, the AR system **800**, and/or the HIPD **900** to continue and/or complete an operation initiated are at another device. For example, after initiating the messaging application via the wrist-wearable device **700** and while the AR system **800** present the messaging user interface **612**, the user **602** can provide an input at the HIPD **900** to prepare a response (e.g., shown by the swipe gesture performed on the HIPD **900**). The user **602**'s gestures performed on the HIPD **900** can be provided to and/or displayed on another device. For example, the user **602**'s swipe gestures performed on the HIPD **900** are displayed on a virtual keyboard of the messaging user interface **612** displayed by the AR system **800**.

[0067] In some embodiments, the wrist-wearable device **700**, the AR system **800**, the HIPD **900**, and/or other communicatively coupled device presents one or more notifications to the user **602**. The notification can be an indication of a new message, an incoming call, an application update, or a status update. The user **602** can select the notification via the wrist-wearable device **700**, the AR system **800**, or the HIPD **900**, and cause presentation of an application or operation associated with the notification on at least one device. For example, the user **602** can receive a notification that a message was received at the wrist-wearable device **700**, the AR system **800**, the HIPD **900**, and/or other communicatively coupled device and provide a user input at the wrist-wearable device **700**, the AR system **800**, and/or the HIPD **900** to review the notification, and the device detecting the user input can cause an application associated with the notification to be initiated and/or presented at the wrist-wearable device **700**, the AR system **800**, and/or the HIPD **900**.

[0068] While the above example describes coordinated inputs used to interact with a messaging application, the skilled artisan will appreciate upon reading the descriptions that user inputs can be coordinated to interact with any number of applications including, but not limited to, gaming applications, social media applications, camera applications, web-based applications, and financial applications. For example, the AR system **800** can present to the user **602** game application data and the HIPD **900** can use a controller to provide inputs to the game. Similarly, the user **602** can use the wrist-wearable device **700** to initiate a camera of the AR system **800**, and the user can use the wrist-wearable device **700**, the AR system **800**, and/or the HIPD **900** to manipulate the image capture (e.g., zoom in or out, apply filters, etc.) and capture image data.

[0069] Having discussed example AR systems, devices for interacting with such AR systems, and other computing systems more generally, will now be discussed in greater detail below. Some definitions of devices and components that can be included in some or all of the example devices discussed below are defined here for ease of reference. A skilled artisan will appreciate that certain types of the components described below may be more suitable for a particular set of devices, and less suitable for a different set of devices. But subsequent reference to the components defined here should be considered to be encompassed by the definitions provided.

[0070] In some embodiments discussed below, example devices and systems, including electronic devices and systems, will be discussed. Such example devices and systems are not intended to be limiting, and one of skill in the art will understand that alternative devices and systems to the example devices and systems described herein may be used to perform the operations and construct the systems and devices that are described herein.

[0071] As described herein, an electronic device is a device that uses electrical energy to perform one or more functions. It can be any physical object that contains electronic components such as transistors, resistors, capacitors, diodes, and integrated circuits. Examples of electronic devices include smartphones, laptops, digital cameras, televisions, gaming consoles, and music players, as well as the example electronic devices discussed herein. As described herein, an intermediary electronic device is a device that sits between two other electronic devices, and/or a subset of components of one or more electronic devices and facilitates communication, and/or data processing and/or data transfer between the respective electronic devices and/or electronic components.

[0072] As described herein, a processor (e.g., a central processing unit (CPU)), is an electronic component that is responsible for executing instructions and controlling the operation of an electronic device (e.g., a computer). There are various types of processors that may be used interchangeably, or may be specifically required, by embodiments described herein. For example, a processor may be: (i) a general processor designed to perform a wide range of tasks, such as running software applications, managing operating systems, and performing arithmetic and logical operations; (ii) a microcontroller designed for specific tasks such as controlling electronic devices, sensors, and motors; (iii) a graphics processing unit (GPU) designed to accelerate the creation and rendering of images, videos, and animations (e.g., virtual-reality animations, such as three-dimensional modeling); (iv) a field-programmable gate array (FPGA) that can be programmed and reconfigured after manufacturing, and/or can be customized to perform specific tasks, such as signal processing, cryptography, and machine learning; (v) a digital signal processor (DSP) designed to perform mathematical operations on signals such as audio, video, and radio waves. One of skill in the art will understand that one or more processors of one or more electronic devices may be used in various embodiments described herein.

[0073] As described herein, memory refers to electronic components in a computer or electronic device that store data and instructions for the processor to access and manipulate. Examples of memory can include: (i) random access memory (RAM) configured to store data and instructions temporarily; (ii) read-only memory (ROM) configured to store data and instructions permanently (e.g., one or more portions of system firmware, and/or boot loaders); (iii) flash memory, which can be configured to store data in electronic devices (e.g., universal serial bus (USB) drives, memory cards, and/or solid-state drives (SSDs); and (iv) cache memory configured to temporarily store frequently accessed data and instructions. Memory, as described herein, can include structured data (e.g., SQL databases, MongoDB databases, GraphQL data, and/or JSON data). Other examples of memory can include: (i) profile data, including user account data, user settings, and/or other user data stored by the user; (ii) sensor data detected and/or otherwise obtained by one or more sensors; (iii) media content data including stored image data, audio data, documents, and the like; (iv) application data, which can include data collected and/or otherwise obtained and stored during use of an application; and/or any other types of data described herein.

[0074] As described herein, controllers are electronic components that manage and coordinate the operation of other components within an electronic device (e.g., controlling inputs, processing data, and/or generating outputs). Examples of controllers can include: (i) microcontrollers, including small, low-power controllers that are commonly used in embedded systems and Internet of Things (IoT) devices; (ii) programmable logic controllers (PLCs) that may be configured to be used in industrial automation systems to control and monitor manufacturing processes; (iii) system-on-a-chip (SoC) controllers that integrate multiple components such as processors, memory, I/O interfaces, and other peripherals into a single chip; and/or DSPs.

[0075] As described herein, a power system of an electronic device is configured to convert incoming electrical power into a form that can be used to operate the device. A power system can include various components, including: (i) a power source, which can be an alternating current (AC) adapter or a direct current (DC) adapter power supply; (ii) a charger input, and can be configured to use a wired and/or wireless connection (which may be part of a peripheral interface, such as a USB, micro-USB interface, near-field magnetic coupling, magnetic inductive and magnetic resonance charging, and/or radio frequency (RF) charging); (iii) a power-management integrated circuit, configured to distribute power to various components of the device and to ensure that the device operates within safe limits (e.g., regulating voltage, controlling current flow, and/or managing heat dissipation); and/or (iv) a battery configured to store power to provide usable power to components of one or more electronic devices.

[0076] As described herein, peripheral interfaces are electronic components (e.g., of electronic devices) that allow electronic devices to communicate with other devices or peripherals, and can provide a means for input and output of data and signals. Examples of peripheral interfaces can include: (i) USB and/or micro-USB interfaces configured for connecting devices to an electronic device; (ii) Bluetooth interfaces configured to allow devices to communicate with each other, including Bluetooth low energy (BLE); (iii) near field communication (NFC) interfaces configured to be short-range wireless interfaces for operations such as access control; (iv) POGO pins, which may be small, spring-loaded pins configured to provide a charging interface; (v) wireless charging interfaces; (vi) global positioning system (GPS) interfaces; (vii) Wi-Fi interfaces for providing a connection between a device and a wireless network; (viii) sensor interfaces.

[0077] As described herein, sensors are electronic components (e.g., in and/or otherwise in electronic communication with electronic devices, such as wearable devices) configured to detect physical and environmental changes and generate electrical signals. Examples of sensors can include: (i) imaging sensors for collecting imaging data (e.g., including one or more cameras disposed on a respective electronic device); (ii) biopotential-signal sensors; (iii) IMUs for detecting, for example, angular rate, force, magnetic field, and/or changes in acceleration; (iv) heart-rate sensors for measuring a user's heart rate; (v) SpO2 sensors for measuring blood oxygen saturation and/or other biometric data of a user; (vi) capacitive sensors for detecting changes in potential at a portion of a user's body (e.g., a sensor-skin interface); and light sensors (e.g., time-of-flight sensors, infrared light sensors, visible light sensors, etc.). As described herein biopotential-signal-sensing components are devices used to measure electrical activity within the body (e.g., biopotential-signal sensors). Some types of biopotential-signal sensors include: (i) electroencephalography (EEG) sensors configured to measure electrical activity in the brain to diagnose neurological disorders; (ii) electrocardiogramhy (ECG or EKG) sensors configured to measure electrical activity of the heart to diagnose heart problems; (iii) EMG sensors configured to measure the electrical activity of muscles and to diagnose neuromuscular disorders; (iv) electrooculography (EOG) sensors configured to measure the electrical activity of eye muscles to detect eye movement and diagnose eye disorders.

[0078] As described herein, an application stored in the memory of an electronic device (e.g., software) includes instructions stored in the memory. Examples of such applications include: (i) games; (ii) word processors; messaging applications; media-streaming applications; financial applications; calendars; clocks; communication interface modules for enabling wired and/or wireless connections between different respective electronic devices (e.g., IEEE 802.15.4, Wi-Fi, ZigBee, 6LoWPAN, Thread, Z-Wave, Bluetooth Smart, ISA100.11a, WirelessHART, or MiWi), custom or standard wired protocols (e.g., Ethernet or HomePlug), and/or any other suitable communication protocols.

[0079] As described herein, a communication interface is a mechanism that enables different systems or devices to exchange information and data with each other, including hardware, software, or a combination of both hardware and software. For example, a communication interface can refer to a physical connector and/or port on a device that enables communication with other devices (e.g., USB, Ethernet, HDMI, Bluetooth). In some embodiments, a communication interface can refer to a software layer that enables different software programs to communicate with each other (e.g., application programming interfaces (APIs) and/or protocols like HTTP and TCP/IP).

[0080] As described herein, a graphics module is a component or software module that is designed to handle graphical operations and/or processes, and can include a hardware module and/or a software module.

[0081] As described herein, non-transitory computer-readable storage media are physical devices or storage medium that can be used to store electronic data in a non-transitory form (e.g., such that the data is stored permanently until it is intentionally deleted or modified).

[0082] Turning to FIGS. **4**C-**1** and **4**C-**2**, the user **602** is shown wearing the wrist-wearable device **700** and the VR device **810**, and holding the HIPD **900**. In the third AR system **600***c*, the wrist-wearable device **700**, the VR device **810**, and/or the HIPD **900** are used to interact within an AR environment, such as a VR game or other AR application. While the VR device **810** presents a representation of a VR game (e.g., first AR game environment **620**) to the user **602**, the wrist-wearable device **700**, the VR device **810**, and/or the HIPD **900** detect and coordinate one or more user inputs to allow the user **602** to interact with the VR game.

[0083] In some embodiments, the user **602** provides a user input via the wrist-wearable device **700**, the VR device **810**, and/or the HIPD **900** that causes an action in a corresponding AR environment. For example, the user **602** in the third AR system **600***c* (shown in FIG. **4**C-**1**) raises the HIPD **900** to prepare for a swing in the first AR game environment **620**. The VR device **810**, responsive to the user **602** raising the HIPD **900**, causes the AR representation of the user **622** to perform a similar action (e.g., raise a virtual object, such as a virtual sword **624**). In some embodiments, each device uses respective sensor data and/or image data to detect the user input and provide an accurate representation of the user **602**'s motion. For example, imaging sensors **826** (e.g., SLAM cameras or other cameras discussed below in FIGS. **6**A and **6**B) of the HIPD **900** can be used to detect a position of the HIPD **900** relative to the user **602**'s body such that the virtual object can be positioned appropriately within the first AR game environment **620**; sensor data from the wrist-wearable device **700** can be used to detect a velocity at which the user **602** raises the HIPD **900** such that the AR representation of the user **622** and the virtual sword **624** are synchronized with the user **602**'s movements; and image sensors **826** of the VR device **810** can be used to represent the user **602**'s body, boundary conditions, or real-world objects within the first AR game environment **620**.

[0084] In FIG. **4**C-**2**, the user **602** performs a downward swing while holding the HIPD **900**. The user **602**'s downward swing is detected by the wrist-wearable device **700**, the VR device **810**, and/or the HIPD **900** and a corresponding action is performed in the first AR game environment **620**. In some embodiments, the data captured by each device is used to improve the user's experience within the AR environment. For example, sensor data of the wrist-wearable device **700** can be used to determine a speed and/or force at which the downward swing is performed and image sensors of the HIPD **900** and/or the VR device **810** can be used to determine a location of the swing and how it should be represented in the first AR game environment **620**, which, in turn, can be used as inputs for the AR environment (e.g., game mechanics, which can use detected speed, force, locations, and/or aspects of the user **602**'s actions to classify a user's inputs (e.g., user performs a light strike, hard strike, critical strike, glancing strike, miss) or calculate an output (e.g., amount of damage)).

[0085] While the wrist-wearable device **700**, the VR device **810**, and/or the HIPD **900** arc described as detecting user inputs, in some embodiments, user inputs are detected at a single device (with the single device being responsible for distributing signals to the other devices for performing the user input). For example, the HIPD **900** can operate an application for generating the first AR game environment **620** and provide the VR device **810** with corresponding data for causing the presentation of the first AR game environment **620**, as well as detect the user **602**'s movements (while holding the HIPD **900**) to cause the performance of corresponding actions within the first AR game environment **620**. Additionally, or alternatively, in some embodiments, operational data (e.g., sensor data, image data, application data, device data, and/or other data) of one or more devices is provided to a single device (e.g., the HIPD **900**) to process the operational data and cause respective devices to perform an action associated with processed operational data.

[0086] In FIGS. **4**D-**1** and **4**D-**2**, the user **602** is shown wearing the wrist-wearable device **700**, the VR device **810**, and smart textile-based garments **1000**. In the fourth AR system **600***d*, the wrist-wearable device **700**, the VR device **810**, and/or the smart textile-based garments **1000** are used to interact within an AR environment (e.g., any AR system described above, such as in reference to FIGS. **4**A through **4**C-**2**). While the VR device **810** presents a representation of a VR game (e.g., second AR game environment **631**) to the user **602**, the wrist-wearable device **700**, the VR device **810**, and/or the smart textile-based garments **1000** detect and coordinate one or more user inputs to allow the user **602** to interact with the AR environment.

[0087] In some embodiments, the user **602** provides a user input via the wrist-wearable device **700**, the VR device **810**, and/or the smart textile-based garments **1000** that causes an action in a corresponding AR environment. For example, the user **602** in the fourth AR system **600***d* (shown in

FIG. **4**D-**1**) raises a hand wearing the smart textile-based garments **1000** to prepare to cast a spell or throw an object within the second AR game environment **631**. The VR device **810**, responsive to the user **602** holding up their hand (wearing smart textile-based garments **1000**), causes the AR representation of the user **622** to perform a similar action (e.g., hold a virtual object or throw a fireball **634**). In some embodiments, each device uses respective sensor data and/or image data to detect the user input and provides an accurate representation of the user **602**'s motion.

[0088] In FIG. **4**D-**2**, the user **602** performs a throwing motion while wearing the smart textile-based garment **1000**. The user **602**'s throwing motion is detected by the wrist-wearable device **700**, the VR device **810**, and/or the smart textile-based garments **1000**, and a corresponding action is performed in the second AR game environment **631**. As described above, the data captured by each device is used to improve the user's experience within the AR environment. Although not shown, the smart textile-based garments **1000** can be used in conjunction with a VR device **810** and/or an HIPD **900**.

[0089] Having discussed example AR systems, devices for interacting with such AR systems, and other computing systems more generally, devices and components will now be discussed in greater detail below. Some definitions of devices and components that can be included in some or all of the example devices discussed below are defined here for case of reference. A skilled artisan will appreciate that certain types of the components described below may be more suitable for a particular set of devices and less suitable for another particular set of devices. But subsequent references to the components defined here should be considered to be encompassed by the definitions provided.

[0090] In some embodiments discussed below, example devices and systems, including electronic devices and systems, will be discussed. Such example devices and systems are not intended to be limiting, and one of skill in the art will understand that alternative devices and systems to the example devices and systems described herein may be used to perform the operations and construct the systems and devices that are described herein.

[0091] As described herein, an electronic device is a device that uses electrical energy to perform a specific function. It can be any physical object that contains electronic components such as transistors, resistors, capacitors, diodes, and integrated circuits. Examples of electronic devices include smartphones, laptops, digital cameras, televisions, gaming consoles, and music players, as well as the example electronic devices discussed herein. As described herein, an intermediary electronic device is a device that sits between two other electronic devices and/or a subset of components of one or more electronic devices, which facilitates communication, and/or data processing, and/or data transfer between the respective electronic devices and/or electronic components.

Example Wrist-Wearable Devices

[0092] FIGS. **5**A and **5**B illustrate the wrist-wearable device **700** in accordance with some embodiments. FIG. **5**A illustrates components of the wrist-wearable device **700**, which can be used individually or in combination, including combinations that include other electronic devices and/or electronic components.

[0093] FIG. **5**A shows a wearable band **710** and a watch body **720** (or capsule) being coupled, as discussed below, to form the wrist-wearable device **700**. The wrist-wearable device **700** can perform various functions and/or operations associated with navigating through user interfaces and selectively opening applications, as well as the functions and/or operations described above with reference to FIGS. **1**-**3**.

[0094] As will be described in more detail below, operations executed by the wrist-wearable device **700** can include: (i) presenting content to a user (e.g., displaying visual content via a display **705**); (ii) detecting (e.g., sensing) user input (e.g., sensing a touch on peripheral button **723** and/or at a touch screen of the display **705**), a hand gesture detected by sensors (e.g., biopotential sensors); (iii) sensing biometric data via one or more sensors **713** (e.g., neuromuscular signals, heart rate, temperature, and/or sleep); messaging (e.g., text, speech, and/or video); image capture via one or more imaging devices or cameras **725**; wireless communications (e.g., cellular, near field, Wi-Fi, and/or personal area network); location determination; financial transactions; providing haptic feedback; alarms; notifications; biometric authentication; health monitoring; sleep monitoring; etc.

[0095] The above-example functions can be executed independently in the watch body **720**, independently in the wearable band **710**, and/or via an electronic communication between the watch body **720** and the wearable band **710**. In some embodiments, functions can be executed on the wrist-wearable device **700** while an AR environment is being presented (e.g., via one of the AR systems **600***a* to **600***d*). As the skilled artisan will appreciate upon reading the descriptions provided herein, the novel wearable devices described herein can be used with other types of AR environments.

[0096] The wearable band **710** can be configured to be worn by a user such that an inner surface of the wearable band **710** is in contact with the user's skin. When worn by a user, sensors **713** contact the user's skin. The sensors **713** can sense biometric data such as a user's heart rate, saturated oxygen level, temperature, sweat level, neuromuscular signal sensors, or a combination thereof. The sensors **713** can also sense data about a user's environment including a user's motion, altitude, location, orientation, gait, acceleration, position, or a combination thereof. In some embodiment, the sensors **713** are configured to track a position and/or motion of the wearable band **710**. The one or more sensors **713** can include any of the sensors defined above and/or discussed below with respect to FIG. **5**B.

[0097] The one or more sensors **713** can be distributed on an inside and/or an outside surface of the wearable band **710**. In some embodiments, the one or more sensors **713** are uniformly spaced along the wearable band **710**. Alternatively, in some embodiments, the one or more sensors **713** are positioned at distinct points along the wearable band **710**. As shown in FIG. **5**A, the one or more sensors **713** can be the same or distinct. For example, in some embodiments, the one or more sensors **713** (e.g., sensor **713***a*) can be shaped as a pill, an oval, a circle, a square, an oblong (e.g., sensor **713***c*) and/or any other shape that maintains contact with the user's skin (e.g., such that neuromuscular signal and/or other biometric data can be accurately measured at the user's skin). In some embodiments, the one or more sensors **713** are aligned to form pairs of sensors (e.g., for sensing neuromuscular signals based on differential sensing within each respective sensor). For example, sensor **713***b* is aligned with an adjacent sensor to form sensor pair **714***a* and sensor **713***d* is aligned with an adjacent sensor to form sensor pair **714***b*. In some embodiments, the wearable band **710** does not have a sensor pair. Alternatively, in some embodiments, the wearable band **710** has a predetermined number of sensor pairs (e.g., one pair of sensors, three pairs of sensors, four pairs of sensors, six pairs of sensors, or sixteen pairs of sensors).

[0098] The wearable band **710** can include any suitable number of sensors **713**. In some embodiments, the number and arrangement of sensors **713** depend on the particular application for which the wearable band **710** is used. For instance, a wearable band **710** configured as an armband, wristband, or chestband may include a plurality of sensors **713** with a different number of sensors **713** and different arrangement for each use case, such as medical use cases as compared to gaming or general day-to-day use cases.

[0099] In accordance with some embodiments, the wearable band **710** further includes an electrical ground electrode and a shielding electrode. The electrical ground and shielding electrodes, like the sensors **713**, can be distributed on the inside surface of the wearable band **710** such that they contact a portion of the user's skin. For example, the electrical ground and shielding electrodes can be at an inside surface of coupling mechanism **716** or an inside surface of a wearable structure **711**. The electrical ground and shielding electrodes can be formed and/or use the same components as the sensors **713**. In some embodiments, the wearable band **710** includes more than one electrical ground electrode and more than one shielding electrode.

[0100] The sensors **713** can be formed as part of the wearable structure **711** of the wearable band

710. In some embodiments, the sensors **713** are flush or substantially flush with the wearable structure **711** such that they do not extend beyond the surface of the wearable structure **711**. While flush with the wearable structure **711**, the sensors **713** are still configured to contact the user's skin (e.g., via a skin-contacting surface). Alternatively, in some embodiments, the sensors **713** extend beyond the wearable structure **711** at a predetermined distance (e.g., 0.1-2 mm) to make contact and depress into the user's skin. In some embodiments, the sensors **713** are coupled to an actuator (not shown) configured to adjust an extension height (e.g., a distance from the surface of the wearable structure **711**) of the sensors **713** such that the sensors **713** make contact and depress into the user's skin. In some embodiments, the actuators adjust the extension height between 0.01 mm-1.2 mm. This allows the user to customize the positioning of the sensors **713** to improve the overall comfort of the wearable band **710** when worn while still allowing the sensors **713** to contact the user's skin. In some embodiments, the sensors **713** are indistinguishable from the wearable structure **711** when worn by the user.

[0101] The wearable structure **711** can be formed of an elastic material, elastomers, etc., configured to be stretched and fitted to be worn by the user. In some embodiments, the wearable structure **711** is a textile or woven fabric. As described above, the sensors **713** can be formed as part of a wearable structure **711**. For example, the sensors **713** can be molded into the wearable structure **711** or be integrated into a woven fabric (e.g., the sensors **713** can be sewn into the fabric and mimic the pliability of fabric (e.g., the sensors **713** can be constructed from a series of woven strands of fabric)).

[0102] The wearable structure **711** can include flexible electronic connectors that interconnect the sensors **713**, the electronic circuitry, and/or other electronic components (described below in reference to FIG. 5B) that are enclosed in the wearable band **710**. In some embodiments, the flexible electronic connectors are configured to interconnect the sensors **713**, the electronic circuitry, and/or other electronic components of the wearable band **710** with respective sensors and/or other electronic components of another electronic device (e.g., watch body **720**). The flexible electronic connectors are configured to move with the wearable structure **711** such that the user adjustment to the wearable structure **711** (e.g., resizing, pulling, and/or folding) does not stress or strain the electrical coupling of components of the wearable band **710**.

[0103] As described above, the wearable band **710** is configured to be worn by a user. In particular, the wearable band **710** can be shaped or otherwise manipulated to be worn by a user. For example, the wearable band **710** can be shaped to have a substantially circular shape such that it can be configured to be worn on the user's lower arm or wrist. Alternatively, the wearable band **710** can be shaped to be worn on another body part of the user, such as the user's upper arm (e.g., around a bicep), forearm, chest, or legs. The wearable band **710** can include a retaining mechanism **712** (e.g., a buckle or a hook-and-loop fastener) for securing the wearable band **710** to the user's wrist or other body part. While the wearable band **710** is worn by the user, the sensors **713** sense data (referred to as sensor data) from the user's skin. In particular, the sensors **713** of the wearable band **710** obtain (e.g., sense and record) neuromuscular signals.

[0104] The sensed data (e.g., sensed neuromuscular signals) can be used to detect and/or determine the user's intention to perform certain motor actions. In particular, the sensors **713** sense and record neuromuscular signals from the user as the user performs muscular activations (e.g., movements and/or gestures). The detected and/or determined motor actions (e.g., phalange (or digit) movements, wrist movements, hand movements, and/or other muscle intentions) can be used to determine control commands or control information (instructions to perform certain commands after the data is sensed) for causing a computing device to perform one or more input commands. For example, the sensed neuromuscular signals can be used to control certain user interfaces displayed on the display **705** of the wrist-wearable device **700** and/or can be transmitted to a device responsible for rendering an artificial-reality environment (e.g., a head-mounted display) to perform an action in an associated artificial-reality environment, such as to control the motion of a virtual device displayed to the user. The muscular activations performed by the user can include static gestures, such as placing the user's hand palm down on a table; dynamic gestures, such as grasping a physical or virtual object; and covert gestures that are imperceptible to another person, such as slightly tensing a joint by co-contracting opposing muscles or using sub-muscular activations. The muscular activations performed by the user can include symbolic gestures (e.g., gestures mapped to other gestures, interactions, or commands, for example, based on a gesture vocabulary that specifics the mapping of gestures to commands).

[0105] The sensor data sensed by the sensors **713** can be used to provide a user with an enhanced interaction with a physical object (e.g., devices communicatively coupled with the wearable band **710**) and/or a virtual object in an artificial-reality application generated by an artificial-reality system (e.g., user interface objects presented on the display **705**, or another computing device (e.g., a smartphone)).

[0106] In some embodiments, the wearable band **710** includes one or more haptic devices **746** (FIG. **5**B, e.g., a vibratory haptic actuator) that are configured to provide haptic feedback (e.g., a cutaneous and/or kinesthetic sensation) to the user's skin. The sensors **713**, and/or the haptic devices **746** can be configured to operate in conjunction with multiple applications including, without limitation, health monitoring, social media, games, and artificial reality (e.g., the applications associated with artificial reality).

[0107] The wearable band **710** can also include coupling mechanism **716** (e.g., a cradle or a shape of the coupling mechanism can correspond to shape of the watch body **720** of the wrist-wearable device **700**) for detachably coupling a capsule (e.g., a computing unit) or watch body **720** (via a coupling surface of the watch body **720**) to the wearable band **710**. In particular, the coupling mechanism **716** can be configured to receive a coupling surface proximate to the bottom side of the watch body **720** (e.g., a side opposite to a front side of the watch body **720** where the display **705** is located), such that a user can push the watch body **720** downward into the coupling mechanism **716** to attach the watch body **720** to the coupling mechanism **716**. In some embodiments, the coupling mechanism **716** is configured to receive a top side of the watch body **720** (e.g., a side proximate to the front side of the watch body **720** where the display **705** is located) that is pushed upward into the cradle, as opposed to being pushed downward into the coupling mechanism **716**. In some embodiments, the coupling mechanism **716** is an integrated component of the wearable band **710** such that the wearable band **710** and the coupling mechanism **716** are a single unitary structure. In some embodiments, the coupling mechanism **716** is a type of frame or shell that allows the watch body **720** coupling surface to be retained within or on the wearable band **710** coupling mechanism **716** (e.g., a cradle, a tracker band, a support base, or a clasp).

[0108] The coupling mechanism **716** can allow for the watch body **720** to be detachably coupled to the wearable band **710** through a friction fit, magnetic coupling, a rotation-based connector, a shear-pin coupler, a retention spring, one or more magnets, a clip, a pin shaft, a hook-and-loop fastener, or a combination thereof. A user can perform any type of motion to couple the watch body **720** to the wearable band **710** and to decouple the watch body **720** from the wearable band **710**. For example, a user can twist, slide, turn, push, pull, or rotate the watch body **720** relative to the wearable band **710**, or a combination thereof, to attach the watch body **720** to the wearable band **710** and to detach the watch body **720** from the wearable band **710**. Alternatively, as discussed below, in some embodiments, the watch body **720** can be decoupled from the wearable band **710** by actuation of the release mechanism **729**.

[0109] The wearable band **710** can be coupled with a watch body **720** to increase the functionality of the wearable band **710** (e.g., converting the wearable band **710** into a wrist-wearable device **700**, adding an additional computing unit and/or battery to increase computational resources and/or a battery life of the wearable band **710**, adding additional sensors to improve sensed data, etc.). As described above, the wearable band **710** (and the coupling mechanism **716**) is configured to operate independently (e.g., execute functions independently) from watch body **720**. For example, the coupling mechanism **716** can include one or more sensors **713** that contact a user's skin when the wearable band **710** is worn by the user and provide sensor data for determining control commands.

[0110] A user can detach the watch body **720** (or capsule) from the wearable band **710** in order to reduce the encumbrance of the wrist-wearable device **700** to the user. For embodiments in which the watch body **720** is removable, the watch body **720** can be referred to as a removable structure, such that in these embodiments the wrist-wearable device **700** includes a wearable portion (e.g., the wearable band **710**) and a removable structure (the watch body **720**).

[0111] Turning to the watch body **720**, the watch body **720** can have a substantially rectangular or circular shape. The watch body **720** is configured to be worn by the user on their wrist or on another body part. More specifically, the watch body **720** is sized to be easily carried by the user, attached on a portion of the user's clothing, and/or coupled to the wearable band **710** (forming the wrist-wearable device **700**). As described above, the watch body **720** can have a shape corresponding to the coupling mechanism **716** of the wearable band **710**. In some embodiments, the watch body **720** includes a single release mechanism **729** or multiple release mechanisms (e.g., two release mechanisms **729** positioned on opposing sides of the watch body **720**, such as spring-loaded buttons) for decoupling the watch body **720** and the wearable band **710**. The release mechanism **729** can include, without limitation, a button, a knob, a plunger, a handle, a lever, a fastener, a clasp, a dial, a latch, or a combination thereof.

[0112] A user can actuate the release mechanism **729** by pushing, turning, lifting, depressing, shifting, or performing other actions on the release mechanism **729**. Actuation of the release mechanism **729** can release (e.g., decouple) the watch body **720** from the coupling mechanism **716** of the wearable band **710**, allowing the user to use the watch body **720** independently from wearable band **710**, and vice versa. For example, decoupling the watch body **720** from the wearable band **710** can allow the user to capture images using rear-facing camera **725**B. Although the release mechanism **729** is shown positioned at a corner of watch body **720**, the release mechanism **729** can be positioned anywhere on watch body **720** that is convenient for the user to actuate. In addition, in some embodiments, the wearable band **710** can also include a respective release mechanism for decoupling the watch body **720** from the coupling mechanism **716**. In some embodiments, the release mechanism **729** is optional, and the watch body **720** can be decoupled from the coupling mechanism **716** as described above (e.g., via twisting or rotating).

[0113] The watch body **720** can include one or more peripheral buttons **723** and **727** for performing various operations at the watch body **720**. For example, the peripheral buttons **723** and **727** can be used to turn on or wake (e.g., transition from a sleep state to an active state) the display **705**, unlock the watch body **720**, increase or decrease a volume, increase or decrease a brightness, interact with one or more applications, and/or interact with one or more user interfaces. Additionally, or alternatively, in some embodiments, the display **705** operates as a touch screen and allows the user to provide one or more inputs for interacting with the watch body **720**.

[0114] In some embodiments, the watch body **720** includes one or more sensors **721**. The sensors **721** of the watch body **720** can be the same or distinct from the sensors **713** of the wearable band **710**. The sensors **721** of the watch body **720** can be distributed on an inside and/or an outside surface of the watch body **720**. In some embodiments, the sensors **721** are configured to contact a user's skin when the watch body **720** is worn by the user. For example, the sensors **721** can be placed on the bottom side of the watch body **720**, and the coupling mechanism **716** can be a cradle with an opening that allows the bottom side of the watch body **720** to directly contact the user's skin. Alternatively, in some embodiments, the watch body **720** does not include sensors that are configured to contact the user's skin (e.g., including sensors internal and/or external to the watch body **720** that are configured to sense data of the watch body **720** and the watch body **720**'s surrounding environment). In some embodiment, the sensors **713** are configured to track a position and/or motion of the watch body **720**.

[0115] The watch body **720** and the wearable band **710** can share data using a wired communication method (e.g., a Universal Asynchronous Receiver/Transmitter (UART) or a USB transceiver) and/or a wireless communication method (e.g., near field communication or Bluetooth). For example, the watch body **720** and the wearable band **710** can share data sensed by the sensors **713** and **721**, as well as application and device specific information (e.g., active and/or available applications), output devices (e.g., display and/or speakers), input devices (e.g., touch screen, microphone, and/or imaging sensors).

[0116] In some embodiments, the watch body **720** can include, without limitation, a front-facing camera **725**A and/or a rear-facing camera **725**B, sensors **721** (e.g., a biometric sensor, an IMU, a heart-rate sensor, a saturated oxygen sensor, a neuromuscular signal sensor, an altimeter sensor, a temperature sensor, a bioimpedance sensor, a pedometer sensor, an optical sensor (e.g., imaging sensor **763**; FIG. **5**B), a touch sensor, a sweat sensor, etc.). In some embodiments, the watch body **720** can include one or more haptic devices **776** (FIG. **5**B; a vibratory haptic actuator) that is configured to provide haptic feedback (e.g., a cutaneous and/or kinesthetic sensation) to the user. The sensors **721** and/or the haptic device **776** can also be configured to operate in conjunction with multiple applications including, without limitation, health monitoring applications, social media applications, game applications, and artificial reality applications (e.g., the applications associated with artificial reality).

[0117] As described above, the watch body **720** and the wearable band **710**, when coupled, can form the wrist-wearable device **700**. When coupled, the watch body **720** and wearable band **710** operate as a single device to execute functions (operations, detections, and/or communications) described herein. In some embodiments, each device is provided with particular instructions for performing the one or more operations of the wrist-wearable device **700**. For example, in accordance with a determination that the watch body **720** does not include neuromuscular signal sensors, the wearable band **710** can include alternative instructions for performing associated instructions (e.g., providing sensed neuromuscular signal data to the watch body **720** via a different electronic device). Operations of the wrist-wearable device **700** can be performed by the watch body **720** alone or in conjunction with the wearable band **710** (e.g., via respective processors and/or hardware components) and vice versa. In some embodiments, operations of the wrist-wearable device **700**, the watch body **720**, and/or the wearable band **710** can be performed in conjunction with one or more processors and/or hardware components of another communicatively coupled device (e.g., the HIPD **900**; FIGS. **7**A-**7**B).

[0118] As described below with reference to the block diagram of FIG. **5**B, the wearable band **710** and/or the watch body **720** can each include independent resources required to independently execute functions. For example, the wearable band **710** and/or the watch body **720** can each include a power source (e.g., a battery), a memory, data storage, a processor (e.g., a central processing unit (CPU)), communications, a light source, and/or input/output devices.

[0119] FIG. **5**B shows block diagrams of a computing system **730** corresponding to the wearable band **710**, and a computing system **760** corresponding to the watch body **720**, according to some embodiments. A computing system of the wrist-wearable device **700** includes a combination of components of the wearable band computing system **730** and the watch body computing system **760**, in accordance with some embodiments.

[0120] The watch body **720** and/or the wearable band **710** can include one or more components shown in watch body computing system **760**. In some embodiments, a single integrated circuit includes all or a substantial portion of the components of the watch body computing system **760**. Alternatively, in some embodiments, components of the watch body computing system **760** are included in a plurality of integrated circuits that are communicatively coupled. In some embodiments, the watch body computing system **760** is configured to couple (e.g., via a wired or wireless connection) with the wearable band computing system **730**, which allows the computing systems to share components, distribute tasks, and/or perform other operations described herein (individually or as a single device).

[0121] The watch body computing system **760** can include one or more processors **779**, a controller **777**, a peripherals interface **761**, a power system **795**, and memory (e.g., a memory **780**), each of which is defined above and described in more detail below.

[0122] The power system **795** can include a charger input **796**, a power-management integrated circuit (PMIC) **797**, and a battery **798**, each are which is defined above. In some embodiments, a watch body **720** and a wearable band **710** can have respective batteries (e.g., battery **798** and **759**) and can share power with each other. The watch body **720** and the wearable band **710** can receive a charge using a variety of techniques. In some embodiments, the watch body **720** and the wearable band **710** can use a wired charging assembly (e.g., power cords) to receive the charge. Alternatively, or in addition, the watch body **720** and/or the wearable band **710** can be configured for wireless charging. For example, a portable charging device can be designed to mate with a portion of watch body **720** and/or wearable band **710** and wirelessly deliver usable power to a battery of watch body **720** and/or wearable band **710**. The watch body **720** and the wearable band **710** can have independent power systems (e.g., power systems **795** and **756**) to enable each to operate independently. The watch body **720** and wearable band **710** can also share power (e.g., one can charge the other) via respective PMICs (e.g., PMICs **797** and **758**) that can share power over power and ground conductors and/or over wireless charging antennas.

[0123] In some embodiments, the peripherals interface **761** can include one or more sensors **721**, many of which listed below are defined above. The sensors **721** can include one or more coupling sensors **762** for detecting when the watch body **720** is coupled with another electronic device (e.g., a wearable band **710**). The sensors **721** can include imaging sensors **763** (one or more of the cameras **725**, and/or separate imaging sensors **763** (e.g., thermal-imaging sensors)). In some embodiments, the sensors **721** include one or more SpO2 sensors **764**. In some embodiments, the sensors **721** include one or more biopotential-signal sensors (e.g., EMG sensors **765**, which may be disposed on a user-facing portion of the watch body **720** and/or the wearable band **710**). In some embodiments, the sensors **721** include one or more capacitive sensors **766**. In some embodiments, the sensors **721** include one or more heart rate sensors **767**. In some embodiments, the sensors **721** include one or more IMU sensors **768**. In some embodiments, one or more IMU sensors **768** can be configured to detect movement of a user's hand or other location that the watch body **720** is placed or held.

[0124] In some embodiments, the peripherals interface **761** includes a near-field communication (NFC) component **769**, a global-position system (GPS) component **770**, a long-term evolution (LTE) component **771**, and/or a Wi-Fi and/or Bluetooth communication component **772**. In some embodiments, the peripherals interface **761** includes one or more buttons **773** (e.g., the peripheral buttons **723** and **727** in FIG. **5**A), which, when selected by a user, cause operation to be performed at the watch body **720**. In some embodiments, the peripherals interface **761** includes one or more indicators, such as a light emitting diode (LED), to provide a user with visual indicators (e.g., message received, low battery, active microphone and/or camera).

[0125] The watch body **720** can include at least one display **705**, for displaying visual representations of information or data to the user, including user-interface elements and/or three-dimensional virtual objects. The display can also include a touch screen for inputting user inputs, such as touch gestures, swipe gestures, and the like. The watch body **720** can include at least one speaker **774** and at least one microphone **775** for providing audio signals to the user and receiving audio input from the user. The user can provide user inputs through the microphone **775** and can also receive audio output from the speaker **774** as part of a haptic event provided by the haptic controller **778**. The watch body **720** can include at least one camera **725**, including a front camera **725**A and a rear camera **725**B. The cameras **725** can include ultra-wide-angle cameras, wide-angle cameras, fish-eye cameras, spherical cameras, telephoto cameras, a depth-sensing cameras, or other types of cameras.

[0126] The watch body computing system **760** can include one or more haptic controllers **777** and associated componentry (e.g., haptic devices **776**) for providing haptic events at the watch body **720** (e.g., a vibrating sensation or audio output in response to an event at the watch body **720**). The haptic controllers **778** can communicate with one or more haptic devices **776**, such as electroacoustic devices, including a speaker of the one or more speakers **774** and/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). The haptic controller **778** can provide haptic events to that are capable of being sensed by a user of the watch body **720**. In some embodiments, the one or more haptic controllers **778** can receive input signals from an application of the applications **782**.

[0127] In some embodiments, the computer system **730** and/or the computing system **760** can include memory **780**, which can be controlled by a memory controller of the one or more controllers **777**. In some embodiments, software components stored in the memory **780** include one or more applications **782** configured to perform operations at the watch body **720**. In some embodiments, the one or more applications **782** include games, word processors, messaging applications, calling applications, web browsers, social media applications, media streaming applications, financial applications, calendars, and/or clocks. In some embodiments, software components stored in the memory **780** include one or more communication interface modules **783** as defined above. In some embodiments, software components stored in the memory **780** include one or more graphics modules **784** for rendering, encoding, and/or decoding audio and/or visual data; and one or more data management modules **785** for collecting, organizing, and/or providing access to the data **787** stored in memory **780**. In some embodiments, one or more of applications **782** and/or one or more modules can work in conjunction with one another to perform various tasks at the watch body **720**. In some embodiments, the memory **780** includes a machine-learning module **7100**. In some embodiments, the machine-learning module **7100** includes one or more models (e.g., language models). In some embodiments, the machine-learning (ML) module **7100** is configured for reinforcement learning. In some embodiments, the machine-learning module **7100** is configured to determine text suggestions (e.g., text corrections and/or text completions). In some embodiments, the machine-learning module **7100** is configured to estimate a cognitive load of a user (e.g., based on user attention (e.g., focus), user context information, and/or other information).

[0128] In some embodiments, software components stored in the memory **780** can include one or more operating systems **781** (e.g., a Linux-based operating system or an Android operating system). The memory **780** can also include data **787**. The data **787** can include profile data **788**A, sensor data **789**A, media content data **790**, and application data **791**. In some embodiments, the data **787** includes machine-learning data (e.g., model states, model parameter values, model training data, and/or model validation data).

[0129] It should be appreciated that the watch body computing system **760** is an example of a computing system within the watch body **720**, and that the watch body **720** can have more or fewer components than shown in the watch body computing system **760**, combine two or more components, and/or have a different configuration and/or arrangement of the components. The various components shown in watch body computing system **760** are implemented in hardware, software, firmware, or a combination thereof, including one or more signal processing and/or application-specific integrated circuits.

[0130] Turning to the wearable band computing system **730**, one or more components that can be included in the wearable band **710** are shown. The wearable band computing system **730** can include more or fewer components than shown in the watch body computing system **760**, combine two or more components, and/or have a different configuration and/or arrangement of some or all of the components. In some embodiments, all, or a substantial portion of, the components of the wearable band computing system **730** are included in a single integrated circuit. Alternatively, in some embodiments, components of the wearable band computing system **730** are included in a plurality of integrated circuits that are communicatively coupled. As described above, in some embodiments, the wearable band computing system **730** is configured to couple (e.g., via a wired or wireless connection) with the watch body computing system **760**, which allows the computing systems to share components, distribute tasks, and/or perform other operations described herein (individually or as a single device).

[0131] The wearable band computing system **730**, similar to the watch body computing system **760**, can include one or more processors **749**; one or more controllers **747** (including one or more haptics controllers **748**); a peripherals interface **731** that can include one or more sensors **713**; and other peripheral devices, power source (e.g., a power system **756**), and memory (e.g., a memory **750**) that includes an operating system (e.g., an operating system **751**), data (e.g., data **754** including profile data **788**B and/or sensor data **789**B), and one or more modules (e.g., a communications interface module **752** and/or a data management module **753**). In some embodiments, the data **754** includes machine-learning data (e.g., model states, model parameter values, model training data, and/or model validation data).

[0132] The one or more sensors **713** can be analogous to sensors **721** of the computing system **760** and in light of the definitions above. For example, sensors **713** can include one or more coupling sensors **732**, one or more SpO2 sensors **734**, one or more EMG sensors **735**, one or more capacitive sensors **736**, one or more heart rate sensors **737**, and one or more IMU sensors **738**.

[0133] The peripherals interface **731** can also include other components analogous to those included in the peripheral interface **761** of the computing system **760**, including an NFC component **739**, a GPS component **740**, an LTE component **741**, a Wi-Fi and/or Bluetooth communication component **742**, and/or one or more haptic devices **776** as described above in reference to peripherals interface **761**. In some embodiments, the peripherals interface **761** includes one or more buttons **743**, a display **733**, a speaker **744**, a microphone **745**, and a camera **755**. In some embodiments, the peripherals interface **761** includes one or more indicators such as an LED.

[0134] It should be appreciated that the wearable band computing system **730** is an example of a computing system within the wearable band **710**, and that the wearable band **710** can have more or fewer components than shown in the wearable band computing system **730**, combine two or more components, and/or have a different configuration and/or arrangement of the components. The various components shown in wearable band computing system **730** can be implemented in one or a combination of hardware, software, or firmware, including one or more signal processing and/or application-specific integrated circuits.

[0135] The wrist-wearable device **700** with respect to FIG. **5**A is an example of the wearable band **710** and the watch body **720** coupled, so the wrist-wearable device **700** will be understood to include the components shown and described for the wearable band computing system **730** and the watch body computing system **760**. In some embodiments, wrist-wearable device **700** has a split architecture (e.g., a split mechanical architecture, a split electrical architecture) between the watch body **720** and the wearable band **710**. In other words, all of the components shown in the wearable band computing system **730** and the watch body computing system **760** can be housed or otherwise disposed in a combined watch device **700**, or within individual components of the watch body **720**, wearable band **710**, and/or portions thereof (e.g., a coupling mechanism **716** of the wearable band **710**).

[0136] The techniques described above can be used with any device for sensing neuromuscular signals, including the arm-wearable devices of FIGS. **5**A-**5**B, but could also be used with other types of wearable devices for sensing neuromuscular signals (such as body-wearable or head-wearable devices that might have neuromuscular sensors closer to the brain or spinal column).

[0137] In some embodiments, a wrist-wearable device **700** can be used in conjunction with a head-wearable device described below (e.g., AR system **800** and VR headset **810**) and/or an HIPD **900**; and the wrist-wearable device **700** can also be configured to be used to allow a user to control an aspect of the artificial reality (e.g., by using EMG-based gestures to control user interface objects in the artificial reality and/or by allowing a user to interact with the touchscreen on the wrist-wearable device to also control aspects of the artificial reality). In some embodiments, a wrist-wearable device **700** can also be used in conjunction with a wearable garment, such as the wearable gloves described below in reference to FIGS. **8**A-**8**C. Having thus described example wrist-wearable device, attention will now be turned to example head-wearable devices, such AR system **800** and VR headset **810**.

Example Head-Wearable Devices

[0138] FIGS. **6**A-**6**C show example artificial-reality systems, including the AR system **800**. In some embodiments, the AR system **800** is an eyewear device as shown in FIG. **6**A. In some embodiments, the VR system **810** includes a head-mounted display (HMD) **812**, as shown in FIGS. **6**B-**1** and **6**B-**2**. In some embodiments, the AR system **800** and the VR system **810** include one or more analogous components (e.g., components for presenting interactive artificial-reality environments, such as processors, memory, and/or presentation devices, including one or more displays and/or one or more waveguides), some of which are described in more detail with respect to FIG. **6**C. As described herein, a head-wearable device can include components of the eyewear device **802**, and/or the head-mounted display **812**. Some embodiments of head-wearable devices do not include any displays, such as any of the displays described with respect to the AR system **800** and/or the VR system **810**. While the example artificial-reality systems are respectively described herein as the AR system **800** and the VR system **810**, either or both of the example AR systems described herein can be configured to present fully immersive VR scenes presented in substantially all of a user's field of view, additionally or alternatively to subtler augmented-reality scenes that are presented within a portion, less than all, of the user's field of view.

[0139] FIG. **6**A shows an example visual depiction of the AR system **800** (which may also be described herein as augmented-reality glasses, and/or smart glasses). The AR system **800** can include additional electronic components that are not shown in FIG. **6**A, such as a wearable accessory device and/or an intermediary processing device, in electronic communication or otherwise configured to be used in conjunction with the eyewear device. In some embodiments, the wearable accessory device and/or the intermediary processing device may be configured to couple with the eyewear device via a coupling mechanism in electronic communication with a coupling sensor **824**, where the coupling sensor **824** can detect when an electronic device becomes physically or electronically coupled with the eyewear device. In some embodiments, the eyewear device is configured to couple to a housing **890**, which may include one or more additional coupling mechanisms configured to couple with additional accessory devices. The components shown in FIG. **6**A can be implemented in hardware, software, firmware, or a combination thereof, including one or more signal-processing components and/or application-specific integrated circuits (ASICs).

[0140] The eyewear device includes mechanical glasses components, including a frame **804** configured to hold one or more lenses (e.g., one or both lenses **806-1** and **806-2**). One of ordinary skill in the art will appreciate that the eyewear device can include additional mechanical components, such as hinges configured to allow portions of the frame **804** of the eyewear device **802** to be folded and unfolded, a bridge configured to span the gap between the lenses **806-1** and **806-2** and rest on the user's nose, nose pads configured to rest on the bridge of the nose and provide support for the eyewear device, earpieces configured to rest on the user's ears and provide additional support for the eyewear device, temple arms configured to extend from the hinges to the earpieces of the eyewear device, and the like. One of ordinary skill in the art will further appreciate that some examples of the AR system **800** can include none of the mechanical components described herein. For example, smart contact lenses configured to present artificial reality to users may not include any components of the eyewear device.

[0141] The eyewear device includes electronic components, many of which will be described in more detail below with respect to FIG. **6**C. Some example electronic components are illustrated in

FIG. **6**A, including sensors **825-1**, **825-2**, **825-3**, **825-4**, **825-5**, and **825-6**, which can be distributed along a substantial portion of the frame **804** of the eyewear device. The eyewear device also includes a left camera **839**A and a right camera **839**B, which are located on different sides of the frame **804**. And the eyewear device includes a processor **848** (e.g., an integral microprocessor, such as an ASIC) that is embedded into a portion of the frame **804**.

[0142] FIGS. **6**B-**1** and **6**B-**2** show a VR system **810** that includes a head-mounted display (HMD) **812** (e.g., also referred to herein as an artificial-reality headset, a head-wearable device, or a VR headset), in accordance with some embodiments. As noted, some artificial-reality systems may (e.g., the AR system **800**), instead of blending an artificial reality with actual reality, substantially replace one or more of a user's sensory perceptions of the real world with a virtual experience (e.g., the AR systems **600***c* and **600***d*).

[0143] The HMD **812** includes a front body **814** and a frame **816** (e.g., a strap or band) shaped to fit around a user's head. In some embodiments, the front body **814** and/or the frame **816** includes one or more electronic elements for facilitating presentation of and/or interactions with an AR and/or VR system (e.g., displays, IMUs, tracking emitter or detectors). In some embodiments, the HMD **812** includes output audio transducers (e.g., an audio transducer **818-1**), as shown in FIG. **6**B-**2**. In some embodiments, one or more components, such as the output audio transducer(s) **818-1** and the frame **816**, can be configured to attach and detach (e.g., are detachably attachable) to the HMD **812** (e.g., a portion or all of the frame **816**, and/or the audio transducer **818-1**), as shown in FIG. **6**B-**2**. In some embodiments, coupling a detachable component to the HMD **812** causes the detachable component to come into electronic communication with the HMD **812**.

[0144] FIGS. **6**B-**1** and **6**B-**2** also show that the VR system **810** has one or more cameras, such as the left camera **839**A and the right camera **839**B, which can be analogous to the left and right cameras on the frame **804** of the eyewear device **802**. In some embodiments, the VR system **810** includes one or more additional cameras (e.g., cameras **839**C and **839**D), which can be configured to augment image data obtained by the cameras **839**A and **839**B by providing more information. For example, the camera **839**C can be used to supply color information that is not discerned by cameras **839**A and **839**B. In some embodiments, one or more of the cameras **839**A to **839**D can include an optional infrared (IR) cut filter configured to remove IR light from being received at the respective camera sensors.

[0145] FIG. **6**C illustrates a computing system **820** and an optional housing **890**, each of which shows components that can be included in the AR system **800** and/or the VR system **810**. In some embodiments, more or fewer components can be included in the optional housing **890** depending on practical restraints of the respective AR system being described.

[0146] In some embodiments, the computing system **820** and/or the optional housing **890** can include one or more peripheral interfaces **822**, one or more power systems **842**, one or more controllers **846** (including one or more haptic controllers **847**), one or more processors **848** (as defined above, including any of the examples provided), and memory **850** (e.g., memory **850**A and memory **850**B), which can all be in electronic communication with each other. For example, the one or more processors **848** can be configured to execute instructions stored in the memory **850**, which can cause a controller of the one or more controllers **846** to cause operations to be performed at one or more peripheral devices of the peripherals interface **822**. In some embodiments, each operation described can occur based on electrical power provided by the power system **842**.

[0147] In some embodiments, the peripherals interface **822** can include one or more devices configured to be part of the computing system **820**, many of which have been defined above and/or described with respect to wrist-wearable devices shown in FIGS. **5**A and **5**B. For example, the peripherals interface can include one or more sensors **823**. Some example sensors include: one or more coupling sensors **824**, one or more acoustic sensors **825**, one or more imaging sensors **826**, one or more EMG sensors **827**, one or more capacitive sensors **828**, and/or one or more IMU sensors **829**, and/or any other types of sensors defined above or described with respect to any other embodiments discussed herein.

[0148] In some embodiments, the peripherals interface can include one or more additional peripheral devices, including one or more NFC devices **830**, one or more GPS devices **831**, one or more LTE devices **832**, one or more Wi-Fi and/or Bluetooth devices **833**, one or more buttons **834** (e.g., including buttons that are slidable or otherwise adjustable), one or more displays **835**, one or more speakers **836**, one or more microphones **837**, one or more cameras **838** (e.g., including the left camera **839**A and/or a right camera **839**B), and/or one or more haptic devices **840**, and/or any other types of peripheral devices defined above or described with respect to any other embodiments discussed herein.

[0149] AR systems can include a variety of types of visual feedback mechanisms (e.g., presentation devices). For example, display devices in the AR system **800** and/or the VR system **810** can include one or more liquid-crystal displays (LCDs), LED displays, organic LED (OLED) displays, and/or any other suitable types of display screens. Artificial-reality systems can include a single display screen (e.g., configured to be seen by both eyes), and/or can provide separate display screens for each eye, which can allow for additional flexibility for varifocal adjustments and/or for correcting a refractive error associated with the user's vision. Some embodiments of AR systems also include optical subsystems having one or more lenses (e.g., conventional concave or convex lenses, Fresnel lenses, or adjustable liquid lenses) through which a user can view a display screen.

[0150] For example, respective displays can be coupled to each of the lenses **806-1** and **806-2** of the AR system **800**. The displays coupled to each of the lenses **806-1** and **806-2** can act together or independently to present an image or series of images to a user. In some embodiments, the AR system **800** includes a single display (e.g., a near-eye display) or more than two displays. In some embodiments, a first set of one or more displays can be used to present an augmented-reality environment, and a second set of one or more display devices can be used to present a virtual-reality environment. In some embodiments, one or more waveguides are used in conjunction with presenting artificial-reality content to the user of the AR system **800** (e.g., as a means of delivering light from one or more displays to the user's eyes). In some embodiments, one or more waveguides are fully or partially integrated into the eyewear device **802**. Additionally, or alternatively to display screens, some artificial-reality systems include one or more projection systems. For example, display devices in the AR system **800** and/or the virtual-reality system **810** can include micro-LED projectors that project light (e.g., using a waveguide) into display devices, such as clear combiner lenses that allow ambient light to pass through. The display devices can refract the projected light toward a user's pupil and can enable a user to simultaneously view both artificial-reality content and the real world. Artificial-reality systems can also be configured with any other suitable type or form of image projection system. In some embodiments, one or more waveguides are provided additionally or alternatively to the one or more display(s).

[0151] The computing system **820** and/or the optional housing **890** of the AR system **800** or the VR system **810** can include some or all of the components of a power system **842**. The power system **842** can include one or more charger inputs **843**, one or more PMICs **844**, and/or one or more batteries **845**.

[0152] The memory **850** includes instructions and data, some or all of which may be stored as non-transitory computer-readable storage media within the memory **850**. For example, the memory **850** can include one or more operating systems **851**, one or more applications **852**, one or more communication interface applications **853**, one or more graphics applications **854**, one or more AR processing applications **855**, and/or any other types of data defined above or described with respect to any other embodiments discussed herein. In some embodiments, the memory **850** (e.g., memory **850**A) includes a machine-learning module **8100**. In some embodiments, the machine-learning module **8100** includes one or more models (e.g., language models). In some embodiments, the machine-learning module **8100** is configured for reinforcement learning. In some embodiments, the machine-learning module **8100** is configured to determine text suggestions (e.g., text corrections and/or text completions). In some embodiments, the machine-learning module **8100** is configured to estimate a cognitive load of a user (e.g., based on user attention (e.g., focus), user context information, and/or other information).

[0153] The memory **850** also includes data **860** that can be used in conjunction with one or more of the applications discussed above. The data **860** can include: profile data **861**, sensor data **862**, media content data **863**, AR application data **864**, and/or any other types of data defined above or described with respect to any other embodiments discussed herein. In some embodiments, the data **860** includes machine-learning data (e.g., model states, model parameter values, model training data, and/or model validation data).

[0154] In some embodiments, the controller **846** of the eyewear device **802** processes information generated by the sensors **823** on the eyewear device **802** and/or another electronic device within the AR system **800**. For example, the controller **846** can process information from the acoustic sensors **825-1** and **825-2**. For each detected sound, the controller **846** can perform a direction-of-arrival (DOA) estimation to estimate a direction from which the detected sound arrived at the eyewear device **802** of the AR system **800**. As one or more of the acoustic sensors **825** detects sounds, the controller **846** can populate an audio data set with the information (e.g., represented in FIG. **6**C as sensor data **862**).

[0155] In some embodiments, a physical electronic connector can convey information between the eyewear device and another electronic device, and/or between one or more processors of the AR system **800** or the VR system **810** and the controller **846**. The information can be in the form of optical data, electrical data, wireless data, or any other transmittable data form. Moving the processing of information generated by the eyewear device to an intermediary processing device can reduce weight and heat in the eyewear device, making it more comfortable and safer for a user. In some embodiments, an optional wearable accessory device (e.g., an electronic neckband) is coupled to the eyewear device via one or more connectors. The connectors can be wired or wireless connectors and can include electrical and/or non-electrical (e.g., structural) components. In some embodiments, the eyewear device and the wearable accessory device can operate independently without any wired or wireless connection between them.

[0156] In some situations, pairing external devices, such as an intermediary processing device (e.g., the HIPD **900**) with the eyewear device **802** (e.g., as part of the AR system **800**), enables the eyewear device **802** to achieve a similar form factor of a pair of glasses while still providing sufficient battery and computation power for expanded capabilities. Some, or all, of the battery power, computational resources, and/or additional features of the AR system **800** can be provided by a paired device or shared between a paired device and the eyewear device **802**, thus reducing the weight, heat profile, and form factor of the eyewear device **802** overall while allowing the eyewear device **802** to retain its desired functionality. For example, the wearable accessory device can allow components that would otherwise be included on an eyewear device **802** to be included in the wearable accessory device and/or intermediary processing device, thereby shifting a weight load from the user's head and neck to one or more other portions of the user's body. In some embodiments, the intermediary processing device has a larger surface area over which to diffuse and disperse heat to the ambient environment. Thus, the intermediary processing device can allow for greater battery and computation capacity than might otherwise have been possible on the eyewear device **802**, standing alone. Because weight carried in the wearable accessory device can be less invasive to a user than weight carried in the eyewear device **802**, a user may tolerate wearing a lighter eyewear device and carrying or wearing the paired device for greater lengths of time than the user would tolerate wearing a heavier eyewear device standing alone, thereby enabling an artificial-reality environment to be incorporated more fully into a user's day-to-day activities.

[0157] AR systems can include various types of computer vision components and subsystems.

[0158] For example, the AR system **800** and/or the VR system **810** can include one or more optical sensors such as two-dimensional (2D) or three-dimensional (3D) cameras, time-of-flight depth sensors, single-beam or sweeping laser rangefinders, 3D LiDAR sensors, and/or any other suitable type or form of optical sensor. An AR system can process data from one or more of these sensors to identify a location of a user and/or aspects of the use's real-world physical surroundings, including the locations of real-world objects within the real-world physical surroundings. In some embodiments, the methods described herein are used to map the real world, to provide a user with context about real-world surroundings, and/or to generate digital twins (e.g., interactable virtual objects), among a variety of other functions. For example, FIGS. **6**B-**1** and **6**B-**2** show the VR system **810** having cameras **839**A to **839**D, which can be used to provide depth information for creating a voxel field and a two-dimensional mesh to provide object information to the user to avoid collisions.

[0159] In some embodiments, the AR system **800** and/or the VR system **810** can include haptic (tactile) feedback systems, which may be incorporated into headwear, gloves, body suits, handheld controllers, environmental devices (e.g., chairs or floormats), and/or any other type of device or system, such as the wearable devices discussed herein. The haptic feedback systems may provide various types of cutaneous feedback, including vibration, force, traction, shear, texture, and/or temperature. The haptic feedback systems may also provide various types of kinesthetic feedback, such as motion and compliance. The haptic feedback may be implemented using motors, piezoelectric actuators, fluidic systems, and/or a variety of other types of feedback mechanisms. The haptic feedback systems may be implemented independently of other artificial-reality devices, within other artificial-reality devices, and/or in conjunction with other artificial-reality devices (e.g., the haptic feedback system described with respect to FIGS. **8**A to **8**C).

[0160] In some embodiments of an AR system, such as the AR system **800** and/or the VR system **810**, ambient light (e.g., a live feed of the surrounding environment that a user would normally see) can be passed through a display element of a respective head-wearable device presenting aspects of the AR system. In some embodiments, ambient light can be passed through a portion less than all, of an AR environment presented within a user's field of view (e.g., a portion of the AR environment co-located with a physical object in the user's real-world environment that is within a designated boundary (e.g., a guardian boundary) configured to be used by the user while they are interacting with the AR environment). For example, a visual user interface element (e.g., a notification user interface element) can be presented at the head-wearable device, and an amount of ambient light (e.g., 15%-50% of the ambient light) can be passed through the user interface element such that the user can distinguish at least a portion of the physical environment over which the user interface element is being displayed.

Example Handheld Intermediary Processing Devices

[0161] FIGS. **7**A and **7**B illustrate an example handheld intermediary processing device (HIPD) **900**, in accordance with some embodiments. The HIPD **900** is an instance of the intermediary device described herein, such that the HIPD **900** should be understood to have the features described with respect to any intermediary device defined above or otherwise described herein, and vice versa. FIG. **7**A shows a top view **905** and a side view **925** of the HIPD **900**. The HIPD **900** is configured to communicatively couple with one or more wearable devices (or other electronic devices) associated with a user. For example, the HIPD **900** is configured to communicatively couple with a user's wrist-wearable device **700** (or components thereof, such as the watch body **720** and the wearable band **710**), AR system **800**, and/or VR headset **810**. The HIPD **900** can be configured to be held by a user (e.g., as a handheld controller), carried on the user's person (e.g., in their pocket, in their bag, etc.), placed in proximity of the user (e.g., placed on their desk while seated at the desk, on a charging dock, etc.), and/or placed at or within a predetermined distance from a wearable device or other electronic device (e.g., where, in some embodiments, the predetermined distance is the maximum distance (e.g., 10 meters) at which the HIPD **900** can successfully be communicatively coupled with an electronic device, such as a wearable device).

[0162] The HIPD **900** can perform various functions independently and/or in conjunction with one or more wearable devices (e.g., wrist-wearable device **700**, AR system **800**, and/or VR headset **810**). The HIPD **900** is configured to increase and/or improve the functionality of communicatively coupled devices, such as the wearable devices. The HIPD **900** is configured to perform one or more functions or operations associated with interacting with user interfaces and applications of communicatively coupled devices, interacting with an AR environment, interacting with VR environment, and/or operating as a human-machine interface controller. Additionally, as will be described in more detail below, functionality and/or operations of the HIPD **900** can include, without limitation, task offloading and/or handoffs; thermals offloading and/or handoffs; 6 degrees of freedom (6DoF) raycasting and/or gaming (e.g., using imaging devices or cameras **914**, which can be used for simultaneous localization and mapping (SLAM) and/or with other image processing techniques); portable charging; messaging; image capturing via one or more imaging devices or cameras **922**; sensing user input (e.g., sensing a touch on a touch input surface **902**); wireless communications and/or interlining (e.g., cellular, near field, Wi-Fi, personal area network, etc.); location determination; financial transactions; providing haptic feedback; alarms; notifications; biometric authentication; health monitoring; sleep monitoring; etc. The above-example functions can be executed independently in the HIPD **900** and/or in communication between the HIPD **900** and another wearable device described herein. In some embodiments, functions can be executed on the HIPD **900** in conjunction with an AR environment. As the skilled artisan will appreciate upon reading the descriptions provided herein, the novel the HIPD **900** described herein can be used with any type of suitable AR environment.

[0163] While the HIPD **900** is communicatively coupled with a wearable device and/or other electronic device, the HIPD **900** is configured to perform one or more operations initiated at the wearable device and/or the other electronic device. In particular, one or more operations of the wearable device and/or the other electronic device can be offloaded to the HIPD **900** to be performed. The HIPD **900** performs the one or more operations of the wearable device and/or the other electronic device and provides to data corresponded to the completed operations to the wearable device and/or the other electronic device. For example, a user can initiate a video stream using AR system **800** and back-end tasks associated with performing the video stream (e.g., video rendering) can be offloaded to the HIPD **900**, and the HIPD **900** performs those back-end tasks and provides corresponding data to the AR system **800** to perform remaining front-end tasks associated with the video stream (e.g., presenting the rendered video data via a display of the AR system **800**). In this way, the HIPD **900**, which has more computational resources and greater thermal headroom than a wearable device, can perform computationally intensive tasks for the wearable device to improve performance of an operation performed by the wearable device.

[0164] The HIPD **900** includes a multi-touch input surface **902** on a first side (e.g., a front surface) that is configured to detect one or more user inputs. In particular, the multi-touch input surface **902** can detect single-tap inputs, multi-tap inputs, swipe gestures and/or inputs, force-based and/or pressure-based touch inputs, held taps, and the like. The multi-touch input surface **902** is configured to detect capacitive touch inputs and/or force (and/or pressure) touch inputs. The multi-touch input surface **902** includes a touch-input surface **904** defined by a surface depression, and a touch-input surface **906** defined by a substantially planar portion. The touch-input surface **904** can be disposed adjacent to the touch-input surface **906**. In some embodiments, the touch-input surface **904** and the touch-input surface **906** can be different dimensions or shapes, and/or cover different portions of the multi-touch input surface **902**. For example, the touch-input surface **904** can be substantially circular and the touch-input surface **906** is substantially rectangular. In some embodiments, the surface depression of the multi-touch input surface **902** is configured to guide user handling of the HIPD **900**. In particular, the surface depression is configured such that the user holds the HIPD **900** upright when held in a single hand (e.g., such that the using imaging devices or cameras **914**A and **914**B are pointed toward a ceiling or the sky). Additionally, the surface depression is configured such that the user's thumb rests within the touch-input surface **904**.

[0165] In some embodiments, the different touch-input surfaces include a plurality of touch-input zones. For example, the touch-input surface **906** includes at least a touch-input zone **908** within a touch-input zone **906** and a touch-input zone **910** within the touch-input zone **908**. In some embodiments, one or more of the touch-input zones are optional and/or user defined (e.g., a user can speciyc a touch-input zone based on their preferences). In some embodiments, each touch-input surface and/or touch-input zone is associated with a predetermined set of commands. For example, a user input detected within the touch-input zone **908** causes the HIPD **900** to perform a first command, and a user input detected within the touch-input zone **906** causes the HIPD **900** to perform a second command distinct from the first. In some embodiments, different touch-input surfaces and/or touch-input zones are configured to detect one or more types of user inputs. The different touch-input surfaces and/or touch-input zones can be configured to detect the same or distinct types of user inputs. For example, the touch-input zone **908** can be configured to detect force touch inputs (e.g., a magnitude at which the user presses down) and capacitive touch inputs, and the touch-input zone **906** can be configured to detect capacitive touch inputs.

[0166] The HIPD **900** includes one or more sensors **951** for sensing data used in the performance of one or more operations and/or functions. For example, the HIPD **900** can include an IMU sensor that is used in conjunction with cameras **914** for three-dimensional object manipulation (e.g., enlarging, moving, or destroying an object) in an AR or VR environment. Non-limiting examples of the sensors **951** included in the HIPD **900** include a light sensor, a magnetometer, a depth sensor, a pressure sensor, and a force sensor. Additional examples of the sensors **951** are provided below in reference to FIG. **7**B.

[0167] The HIPD **900** can include one or more light indicators **912** to provide one or more notifications to the user. In some embodiments, the light indicators are LEDs or other types of illumination devices. The light indicators **912** can operate as a privacy light to notify the user and/or others near the user that an imaging device and/or microphone is active. In some embodiments, a light indicator is positioned adjacent to one or more touch-input surfaces. For example, a light indicator can be positioned around the touch-input surface **904**. The light indicators can be illuminated in different colors and/or patterns to provide the user with one or more notifications and/or information about the device. For example, a light indicator positioned around the touch-input surface **904** can flash when the user receives a notification (e.g., a message), change red when the HIPD **900** is out of power, operate as a progress bar (e.g., a light ring that is closed when a task is completed (e.g., 0% to 100%)), and/or operates as a volume indicator, etc.

[0168] In some embodiments, the HIPD **900** includes one or more additional sensors on another surface. For example, as shown FIG. **7**A, HIPD **900** includes a set of one or more sensors (e.g., sensor set **920**) on an edge of the HIPD **900**. The sensor set **920**, when positioned on an edge of the of the HIPD **900**, can be pre positioned at a predetermined tilt angle (e.g., 26 degrees) that allows the sensor set **920** to be angled toward the user when placed on a desk or other flat surface. Alternatively, in some embodiments, the sensor set **920** is positioned on a surface opposite the multi-touch input surface **902** (e.g., a back surface). The one or more sensors of the sensor set **920** are discussed in detail below.

[0169] The side view **925** of the of the HIPD **900** shows the sensor set **920** and camera **914**B. The sensor set **920** includes one or more cameras **922**A and **922**B, a depth projector **924**, an ambient light sensor **928**, and a depth receiver **930**. In some embodiments, the sensor set **920** includes a light indicator **926**. The light indicator **926** can operate as a privacy indicator to let the user and/or those around the user know that a camera and/or microphone is active. The sensor set **920** is configured to capture a user's facial expression such that the user can puppet a custom avatar (e.g., showing emotions, such as smiles and/or laughter on the avatar or a digital representation of the user). The sensor set **920** can be configured as a side stereo RGB system, a rear indirect Time-of-Flight (iToF) system, or a rear stereo RGB system. As the skilled artisan will appreciate upon reading the descriptions provided herein, the HIPD **900** described herein can use different sensor set **920** configurations and/or sensor set **920** placements.

[0170] In some embodiments, the HIPD **900** includes one or more haptic devices **971** (e.g., a vibratory haptic actuator) that are configured to provide haptic feedback (e.g., kinesthetic sensation). The sensors **951**, and/or the haptic devices **971**, can be configured to operate in conjunction with multiple applications and/or communicatively coupled devices including, without limitation, wearable devices, health monitoring applications, social media applications, game applications, and artificial reality applications (e.g., the applications associated with artificial reality).

[0171] The HIPD **900** is configured to operate without a display. However, in optional embodiments, the HIPD **900** can include a display **968** (FIG. **7**B). The HIPD **900** can also include one or more optional peripheral buttons **967** (FIG. **7**B). For example, the peripheral buttons **967** can be used to turn on or turn off the HIPD **900**. Further, the HIPD **900** housing can be formed of polymers and/or elastomer elastomers. The HIPD **900** can be configured to have a non-slip surface to allow the HIPD **900** to be placed on a surface without requiring a user to watch over the HIPD **900**. In other words, the HIPD **900** is designed such that it would not easily slide off surfaces. In some embodiments, the HIPD **900** include one or more magnets to couple the HIPD **900** to another surface. This allows the user to mount the HIPD **900** to different surfaces and provide the user with greater flexibility in use of the HIPD **900**.

[0172] As described above, the HIPD **900** can distribute and/or provide instructions for performing the one or more tasks at the HIPD **900** and/or a communicatively coupled device. For example, the HIPD **900** can identify one or more back-end tasks to be performed by the HIPD **900** and one or more front-end tasks to be performed by a communicatively coupled device. While the HIPD **900** is configured to offload and/or hand off tasks of a communicatively coupled device, the HIPD **900** can perform both back-end and front-end tasks (e.g., via one or more processors, such as CPU **977**; FIG. **7**B). The HIPD **900** can, without limitation, be used to perform augmented calling (e.g., receiving and/or sending 3D or 2.5D live volumetric calls, live digital human representation calls, and/or avatar calls), discreet messaging, 6DoF portrait/landscape gaming, AR/VR object manipulation, AR/VR content display (e.g., presenting content via a virtual display), and/or other AR/VR interactions. The HIPD **900** can perform the above operations alone or in conjunction with a wearable device (or other communicatively coupled electronic device).

[0173] FIG. **7**B shows block diagrams of a computing system **940** of the HIPD **900**, in accordance with some embodiments. The HIPD **900**, described in detail above, can include one or more components shown in HIPD computing system **940**. The HIPD **900** will be understood to include the components shown and described below for the HIPD computing system **940**. In some embodiments, all, or a substantial portion, of the components of the HIPD computing system **940** are included in a single integrated circuit. Alternatively, in some embodiments, components of the HIPD computing system **940** are included in a plurality of integrated circuits that are communicatively coupled.

[0174] The HIPD computing system **940** can include a processor (e.g., a CPU **977**, a GPU, and/or a CPU with integrated graphics), a controller **975**, a peripherals interface **950** that includes one or more sensors **951** and other peripheral devices, a power source (e.g., a power system **995**), and memory (e.g., a memory **978**) that includes an operating system (e.g., an operating system **979**), data (e.g., data **988**), one or more applications (e.g., applications **980**), and one or more modules (e.g., a communications interface module **981**, a graphics module **982**, a task and processing management module **983**, an interoperability module **984**, an AR processing module **985**, and/or a data management module **986**). The HIPD computing system **940** further includes a power system **995** that includes a charger input and output **996**, a PMIC **997**, and a battery **998**, all of which are defined above.

[0175] In some embodiments, the peripherals interface **950** can include one or more sensors **951**.

The sensors **951** can include analogous sensors to those described above in reference to FIG. **5**B. For example, the sensors **951** can include imaging sensors **954**, (optional) EMG sensors **956**, IMU sensors **958**, and capacitive sensors **960**. In some embodiments, the sensors **951** can include one or more pressure sensors **952** for sensing pressure data, an altimeter **953** for sensing an altitude of the HIPD **900**, a magnetometer **955** for sensing a magnetic field, a depth sensor **957** (or a time-of flight sensor) for determining a difference between the camera and the subject of an image, a position sensor **959** (e.g., a flexible position sensor) for sensing a relative displacement or position change of a portion of the HIPD **900**, a force sensor **961** for sensing a force applied to a portion of the HIPD **900**, and a light sensor **962** (e.g., an ambient light sensor) for detecting an amount of lighting. The sensors **951** can include one or more sensors not shown in FIG. **7**B.

[0176] Analogous to the peripherals described above in reference to FIGS. **5**B, the peripherals interface **950** can also include an NFC component **963**, a GPS component **964**, an LTE component **965**, a Wi-Fi and/or Bluetooth communication component **966**, a speaker **969**, a haptic device **971**, and a microphone **973**. As described above in reference to FIG. **7**A, the HIPD **900** can optionally include a display **968** and/or one or more buttons **967**. The peripherals interface **950** can further include one or more cameras **970**, touch surfaces **972**, and/or one or more light emitters **974**. The multi-touch input surface **902** described above in reference to FIG. **7**A is an example of touch surface **972**. The light emitters **974** can be one or more LEDs, lasers, etc., and can be used to project or present information to a user. For example, the light emitters **974** can include light indicators **912** and **926** described above in reference to FIG. **7**A. The cameras **970** (e.g., cameras **914** and **922** described above in FIG. **7**A) can include one or more wide angle cameras, fish-eye cameras, spherical cameras, compound eye cameras (e.g., stereo and multi cameras), depth cameras, RGB cameras, ToF cameras, RGB-D cameras (depth and ToF cameras), and/or other available cameras. Cameras **970** can be used for SLAM; **6** DoF ray casting, gaming, object manipulation, and/or other rendering; and facial recognition and facial expression recognition, etc.

[0177] Similar to the watch body computing system **760** and the wearable band computing system **730** described above in reference to FIG. **5**B, the HIPD computing system **940** can include one or more haptic controllers **976** and associated componentry (e.g., haptic devices **971**) for providing haptic events at the HIPD **900**.

[0178] Memory **978** can include high-speed, random-access memory and/or non-volatile memory, such as one or more magnetic disk storage devices, flash memory devices, or other non-volatile, solid-state memory devices. Access to the memory **978** by other components of the HIPD **900**, such as the one or more processors and the peripherals interface **950**, can be controlled by a memory controller of the controllers **975**. In some embodiments, the memory **978** includes a machine-learning module **9100**. In some embodiments, the machine-learning module **9100** includes one or more models (e.g., language models). In some embodiments, the machine-learning module **9100** is configured for reinforcement learning. In some embodiments, the machine-learning module **9100** is configured to determine text suggestions (e.g., text corrections and/or text completions). In some embodiments, the machine-learning module **9100** is configured to estimate a cognitive load of a user (e.g., based on user attention (e.g., focus), user context information, and/or other information).

[0179] In some embodiments, software components stored in the memory **978** include one or more operating systems **979**, one or more applications **980**, one or more communication interface modules **981**, one or more graphics modules **982**, one or more data management modules **986**, which are analogous to the software components described above in reference to FIG. **5**B.

[0180] In some embodiments, software components stored in the memory **978** include a task and processing management module **983** for identifying one or more front-end and back-end tasks associated with an operation performed by the user, performing one or more front-end and/or back-end tasks and/or providing instructions to one or more communicatively coupled devices that cause performance of the one or more front-end and/or back-end tasks. In some embodiments, the task and processing management module **983** uses data **988** (e.g., device data **990**) to distribute the one or more front-end and/or back-end tasks based on communicatively coupled devices' computing resources, available power, thermal headroom, ongoing operations, and/or other factors. For example, the task and processing management module **983** can cause the performance of one or more back-end tasks (of an operation performed at communicatively coupled AR system **800**) at the HIPD **900** in accordance with a determination that the operation is utilizing a predetermined amount (e.g., at least 70%) of computing resources available at the AR system **800**.

[0181] In some embodiments, software components stored in the memory **978** include an interoperability module **984** for exchanging and utilizing information received and/or provided to distinct communicatively coupled devices. The interoperability module **984** allows for different systems, devices, and/or applications to connect and communicate in a coordinated way without user input. In some embodiments, software components stored in the memory **978** include an AR module **985** that is configured to process signals based at least on sensor data for use in an AR and/or VR environment. For example, the AR module **985** can be used for 3D object manipulation, gesture recognition, facial and facial expression, and/or recognition.

[0182] The memory **978** can also include data **988**, including structured data. In some embodiments, the data **988** includes profile data **989**, device data **990** (including device data of one or more devices communicatively coupled with the HIPD **900**, such as device type, hardware, software, and/or configurations), sensor data **991**, media content data **992**, and application data **993**. In some embodiments, the data **988** includes machine-learning data (e.g., model states, model parameter values, model training data, and/or model validation data).

[0183] It should be appreciated that the HIPD computing system **940** is an example of a computing system within the HIPD **900**, and that the HIPD **900** can have more or fewer components than shown in the HIPD computing system **940**, combine two or more components, and/or have a different configuration and/or arrangement of the components. The various components shown in HIPD computing system **940** are implemented in hardware, software, firmware, or a combination thereof, including one or more signal-processing and/or application-specific integrated circuits.

[0184] The techniques described above in FIG. **7**A-**7**B can be used with any device used as a human-machine interface controller. In some embodiments, an HIPD **900** can be used in conjunction with one or more wearable devices such as a head-wearable device (e.g., AR system **800** and VR system **810**) and/or a wrist-wearable device **700** (or components thereof). In some embodiments, an HIPD **900** is used in conjunction with a wearable garment, such as the wearable gloves of FIGS. **8**A-**8**C. Having thus described example HIPD **900**, attention will now be turned to example feedback devices such as device **1000**.

Example Feedback Devices

[0185] FIGS. **8**A and **8**B show example haptic feedback systems (e.g., hand-wearable devices) for providing feedback to a user regarding the user's interactions with a computing system (e.g., an artificial-reality environment presented by the AR system **800** or the VR system **810**). In some embodiments, a computing system (e.g., the AR system **600***d*) may also provide feedback to one or more users based on an action that was performed within the computing system and/or an interaction provided by the AR system (e.g., which may be based on instructions that are executed in conjunction with performing operations of an application of the computing system). Such feedback may include visual and/or audio feedback and may also include haptic feedback provided by a haptic assembly, such as one or more haptic assemblies **1062** of the device **1000** (e.g., haptic assemblies **1062-1**, **1062-2**, and **1062-3**). For example, the haptic feedback may prevent (or, at a minimum, hinder/resist movement of) one or more fingers of a user from bending past a certain point to simulate the sensation of touching a solid coffee mug. In actuating such haptic effects, the device **1000** can change (either directly or indirectly) a pressurized state of one or more of the haptic assemblies **1062**.

[0186] Each of the haptic assemblies **1062** includes a mechanism that, at a minimum, provides resistance when the respective haptic assembly **1062** is transitioned from a first pressurized state (e.g., atmospheric pressure or deflated) to a second pressurized state (e.g., inflated to a threshold pressure). Structures of haptic assemblies **1062** can be integrated into various devices configured to be in contact or proximity to a user's skin, including, but not limited to devices such as glove worn devices, body-worn clothing devices, and headset devices.

[0187] As noted above, the haptic assemblies **1062** described herein can be configured to transition between a first pressurized state and a second pressurized state to provide haptic feedback to the user. Due to the ever-changing nature of artificial reality, the haptic assemblies **1062** may be required to transition between the two states hundreds, or perhaps thousands, of times during a single use. Thus, the haptic assemblies **1062** described herein are durable and designed to quickly transition from state to state. To provide some context, in the first pressurized state, the haptic assemblies **1062** do not impede free movement of a portion of the wearer's body. For example, one or more haptic assemblies **1062** incorporated into a glove are made from flexible materials that do not impede free movement of the wearer's hand and fingers (e.g., an electrostatic-zipping actuator). The haptic assemblies **1062** are configured to conform to a shape of the portion of the wearer's body when in the first pressurized state. However, once in the second pressurized state, the haptic assemblies **1062** can be configured to restrict and/or impede free movement of the portion of the wearer's body (e.g., appendages of the user's hand). For example, the respective haptic assembly **1062** (or multiple respective haptic assemblies) can restrict movement of a wearer's finger (e.g., prevent the finger from curling or extending) when the haptic assembly **1062** is in the second pressurized state. Moreover, once in the second pressurized state, the haptic assemblies **1062** may take different shapes, with some haptic assemblies **1062** configured to take a planar, rigid shape (e.g., flat and rigid) while some other haptic assemblies **1062** are configured to curve or bend, at least partially.

[0188] As a non-limiting example, the device **1000** includes a plurality of haptic devices (e.g., a pair of haptic gloves, and a haptics component of a wrist-wearable device (e.g., any of the wrist-wearable devices described with respect to FIGS. **5**A-**5**B. Each of them can include a garment component (e.g., a garment **1004**) and one or more haptic assemblies coupled (e.g., physically coupled) to the garment component. For example, each of the haptic assemblies **1062-1**, **1062-2**, **1062-3**, . . . **1062**-N is physically coupled to the garment **1004** and configured to contact respective phalanges of a user's thumb and fingers. As explained above, the haptic assemblies **1062** are configured to provide haptic simulations to a wearer of the device **1000**. The garment **1004** of each device **1000** can be one of various articles of clothing (e.g., gloves, socks, shirts, or pants). Thus, a user may wear multiple devices **1000** that are each configured to provide haptic stimulations to respective parts of the body where the devices **1000** are being worn.

[0189] FIG. **8**C shows block diagrams of a computing system **1040** of the device **1000**, in accordance with some embodiments. The computing system **1040** can include one or more peripheral interfaces **1050**, one or more power systems **1095**, one or more controllers **1075** (including one or more haptic controllers **1076**), one or more processors **1077** (as defined above, including any of the examples provided), and memory **1078**, which can all be in electronic communication with each other. For example, the one or more processors **1077** can be configured to execute instructions stored in the memory **1078**, which can cause a controller of the one or more controllers **1075** to cause operations to be performed at one or more peripheral devices of the peripherals interface **1050**. In some embodiments, each operation described can occur based on electrical power provided by the power system **1095**. The power system **1095** includes a charger input **1096**, a PMIC **1097**, and a battery **1098**.

[0190] In some embodiments, the peripherals interface **1050** includes one or more devices configured to be part of the computing system **1040**, many of which have been defined above and/or described with respect to wrist-wearable devices shown in FIGS. **5**A-BB. For example, the peripherals interface **1050** can include one or more sensors **1051**, such as one or more pressure sensors **1052**, one or more EMG sensors **1056**, one or more IMUs **1058**, one or more position sensors **1059**, one or more capacitive sensors **1060**, one or more force sensors **1061**, and/or any other types of sensors defined above or described with respect to any other embodiments discussed herein. In some embodiments, the peripherals interface can include one or more additional peripheral devices, including one or more Wi-Fi and/or Bluetooth devices **1068**, an LTE component **1069**, a GPS component **1070**, a microphone **1071**, one or more haptic assemblies **1062**, one or more support structures **1063** (which can include one or more bladders **1064**), one or more manifolds **1065**, one or more pressure-changing devices **1067**, one or more displays **1072**, one or more buttons **1073**, one or more speakers **1074**, and/or any other types of peripheral devices defined above or described with respect to any other embodiments discussed herein. In some embodiments, computing system **1040** includes more or fewer components than those shown in FIG. **8**C.

[0191] In some embodiments, the peripherals interface can include one or more additional peripheral devices, including one or more Wi-Fi and/or Bluetooth devices **1068**, one or more haptic assemblies **1062**, one or more support structures **1063** (which can include one or more bladders **1064**), one or more manifolds **1065**, one or more pressure-changing devices **1067**, and/or any other types of peripheral devices defined above or described with respect to any other embodiments discussed herein.

[0192] In some embodiments, each haptic assembly **1062** includes a support structure **1063**, and at least one bladder **1064**. The bladder **1064** (e.g., a membrane) is a sealed, inflatable pocket made from a durable and puncture-resistant material such as thermoplastic polyurethane (TPU), a flexible polymer, or the like. The bladder **1064** contains a medium (e.g., a fluid such as air, inert gas, or even a liquid) that can be added to or removed from the bladder **1064** to change a pressure (e.g., fluid pressure) inside the bladder **1064**. The support structure **1063** is made from a material that is stronger and stiffer than the material of the bladder **1064**. A respective support structure **1063** coupled to a respective bladder **1064** is configured to reinforce the respective bladder **1064** as the respective bladder changes shape and size due to changes in pressure (e.g., fluid pressure) inside the bladder.

[0193] The device **1000** also includes a haptic controller **1076** and a pressure-changing device **1067**. In some embodiments, the haptic controller **1076** is part of the computer system **1040** (e.g., in electronic communication with one or more processors **1077** of the computer system **1040**). The haptic controller **1076** is configured to control operation of the pressure-changing device **1067** and, in turn, operation of the device **1000**. For example, the controller **1076** sends one or more signals to the pressure-changing device **1067** to activate the pressure-changing device **1067** (e.g., turn it on and off). The one or more signals may specify a desired pressure (e.g., pounds-per-square inch) to be output by the pressure-changing device **1067**. Generation of the one or more signals, and in turn the pressure output by the pressure-changing device **1067**, may be based on information collected by the sensors in FIGS. **5**A and **5**B. For example, the one or more signals may cause the pressure-changing device **1067** to increase the pressure (e.g., fluid pressure) inside a haptic assembly **1062** at a first time, based on the information collected by the sensors in FIGS. **5**A and **5**B (e.g., the user makes contact with an artificial coffee mug). Then, the controller may send one or more additional signals to the pressure-changing device **1067** that cause the pressure-changing device **1067** to further increase the pressure inside the haptic assembly **1062** at a second time after the first time, based on additional information collected by the sensors **1051**. Further, the one or more signals may cause the pressure-changing device **1067** to inflate one or more bladders **1064** in a device **1000**-A, while one or more bladders **1064** in a device **1000**-B remain unchanged. Additionally, the one or more signals may cause the pressure-changing device **1067** to inflate one or more bladders **1064** in a device **1000**-A to a first pressure and inflate one or more other bladders **1064** in the device **1000**-A to a second pressure different from the first pressure. Depending on the number of devices **1000** serviced by the pressure-changing device **1067**, and the number of bladders therein, many different inflation configurations can be achieved through the one or more signals and the examples above are not meant to be limiting.

[0194] The device **1000** may include an optional manifold **1065** between the pressure-changing device **1067** and the devices **1000**. The manifold **1065** may include one or more valves (not shown) that pneumatically couple each of the haptic assemblies **1062** with the pressure-changing device **1067** via tubing. In some embodiments, the manifold **1065** is in communication with the controller **1075**, and the controller **1075** controls the one or more valves of the manifold **1065** (e.g., the controller generates one or more control signals). The manifold **1065** is configured to switchably couple the pressure-changing device **1067** with one or more haptic assemblies **1062** of the same or different devices **1000** based on one or more control signals from the controller **1075**. In some embodiments, one or more smart textile-based garments **1000** or other haptic devices can be coupled in a network of haptic devices, and the manifold **1065** can distribute the fluid between the coupled smart textile-based garments **1000**.

[0195] In some embodiments, instead of using the manifold **1065** to pneumatically couple the pressure-changing device **1067** with the haptic assemblies **1062**, the smart textile-based garment **1000** may include multiple pressure-changing devices **1067** where each pressure-changing device **1067** is pneumatically coupled directly with a single (or multiple) haptic assembly **1062**. In some embodiments, the pressure-changing device **1067** and the optional manifold **1065** can be configured as part of one or more of the smart textile-based garments **1000** (not illustrated), while, in other embodiments, the pressure-changing device **1067** and the optional manifold **1065** can be configured as external to the smart textile-based garments **1000**. In some embodiments, a single pressure-changing device **1067** can be shared by multiple smart textile-based garments **1000** or other haptic devices. In some embodiments, the pressure-changing device **1067** is a pneumatic device, hydraulic device, a pneudraulic device, or some other device capable of adding and removing a medium (e.g., fluid, liquid, or gas) from the one or more haptic assemblies **1062**.

[0196] The memory **1078** includes instructions and data, some or all of which may be stored as non-transitory computer-readable storage media within the memory **1078**. For example, the memory **1078** can include one or more operating systems **1079**; one or more communication interface applications **1081**, one or more interoperability modules **1084**, one or more AR processing applications **1085**, one or more data management modules **1086**, and/or any other types of data defined above or described with respect to any other embodiments discussed herein. In some embodiments, the memory **1078** includes a machine-learning module **1100**. In some embodiments, the machine-learning module **1100** includes one or more models (e.g., language models). In some embodiments, the machine-learning module **1100** is configured for reinforcement learning. In some embodiments, the machine-learning module **1100** is configured to determine text suggestions (e.g., text corrections and/or text completions). In some embodiments, the machine-learning module **1100** is configured to estimate a cognitive load of a user (e.g., based on user attention (e.g., focus), user context information, and/or other information).

[0197] The memory **1078** also includes data **1088** that can be used in conjunction with one or more of the applications discussed above. The data **1088** can include: device data **1090**, sensor data **1091**, and/or any other types of data defined above or described with respect to any other embodiments discussed herein. In some embodiments, the data **1088** includes machine-learning data (e.g., model states, model parameter values, model training data, and/or model validation data).

[0198] The devices shown in FIGS. **8**A to **8**C may be coupled via a wired connection (e.g., via busing). Alternatively, one or more of the devices shown in FIGS. **8**A to **8**C may be wirelessly connected (e.g., via short-range communication signals).

[0199] Having thus described system-block diagrams and then example devices, attention will now be directed to certain example processes and embodiments.

EXAMPLE ASPECTS AND EMBODIMENTS

[0200] (A1) In one aspect, a method (e.g., the method **300**) of providing suggestions is disclosed. The method is performed at a computing system (e.g., the AR system **600** shown in FIGS. **4**A-**4**D).

In some embodiments, the computing system includes one or more processors (e.g., CPU(s), GPU(s), and/or NPU(s)) and memory. In some embodiments, the computing system includes one or more wearable devices (e.g., the wrist-wearable device **106** and/or the head-wearable device **104**). In some embodiments, the computing system includes one or more intermediary devices (e.g., a smartphone, laptop, or gaming console). In some embodiments, the computing system includes one or more handheld devices (e.g., a controller and/or the HIPD **900**). In some embodiments, the method includes (i) detecting a user gesture (e.g., the user gesture **216**) associated with a user task based on data from one or more neuromuscular sensors (e.g., the EMG sensor **765**); (ii) identifying a set of text characters (e.g., the text **220**) corresponding to the user gesture; (iii) causing display, via a display device (e.g., the display **705** or the display **835**A), of the set of text terms in a user interface (e.g., a message/document user interface); (iv) estimating, based on context information, a cognitive load of the user (e.g., the estimated cognitive load **226**) corresponding to performing the user task at the computing system; (v) determining whether the estimated cognitive load meets one or more predefined criteria (e.g., is less than a preset load threshold); (vi) in accordance with a determination that the estimated cognitive load meets the one or more predefined criteria, providing a text suggestion to the user based on the set of text characters (e.g., displaying the text suggestion **230**); and (vii) in accordance with a determination that the estimated cognitive load does not meet the one or more predefined criteria, forgoing providing the text suggestion to the user based on the set of text characters (e.g., no suggestion is provided to the user **102** in FIG. **1**B in accordance with the estimated cognitive load **116** not meeting one or more criteria). In some embodiments, the user gesture is performed by a user of the computing system. In some embodiments, one or more partial characters are detected based on the data from the one or more neuromuscular sensors (e.g., one or more strokes or ballistic movements). In some embodiments, the text suggestion is further based on the one or more partial characters. In some embodiments, providing the text suggestion to the user includes displaying the text suggestion via the display device. In some embodiments, the text suggestion is visually distinguished from the set of text characters (e.g., a different color, size, font, and/or with different emphasis). [0201] (A2) In some embodiments of A1, the user gesture includes a handwriting motion. For example, the user gesture may correspond to the user writing one or more characters in a cursive or block (print) style. In some embodiments, the handwriting motion is performed as an in-air gesture. In some embodiments, the handwriting motion is performed as a surface gesture (e.g., performed while the user's hand is in contact with a surface). [0202] (A3) In some embodiments of A1 or A2, the set of text characters is appended to a set of pre-existing text in a document, and the text suggestion is based on the set of text characters and the set of pre-existing text. In some embodiments, the text suggestion is based on one or more phrases and/or one or more sentences of text. For example, the text suggestion may be based on a full-sentence context. For example, the top suggestions **124** in FIG. **1**B may be based on the text **120** and pre-existing text of the message **112** (e.g., the name “Alex”). [0203] (A4) In some embodiments of any of A1-A3, the text suggestion is generated based on the set of text characters and information about the user. For example, the text suggestion may include user information (e.g., contact information for the user). As another example, the text suggestion may be based on calendar information, location information, context information, and/or historical information of the user. For example, the first suggestion of the top suggestions **124** in FIG. **1**B may be generated using calendar information of the user **102**. [0204] (A5) In some embodiments of any of A1-A4, the text suggestion is provided by a machine-learning component (e.g., the ML modules **7100**, **8100**, **9100**, and/or **1100**). In some embodiments, the machine-learning component includes one or more machine-learning models (e.g., one or more large language models). In some embodiments, the system utilizes a Markov decision process (MDP) to determine whether/when to provide text suggestions. In some embodiments, the MDP action is obtained using reinforcement learning (RL). For example, the RL can be performed in an offline manner (e.g., offline training to produce a new model version for production) or an online manner (e.g., training the model while in the model is production). In some embodiments, the machine-learning component includes an embedder configured to generate embeddings from the neuromuscular sensor data. In some embodiments, the machine-learning component is configured to predict an intent of the user. [0205] (A6) In some embodiments of A5, the machine-learning component is trained based on the data from the one or more neuromuscular sensors (e.g., the sensor data **789**A and/or **789**B). For example, EMG data and character errors are simulated using offline data. In some embodiments, character suggestions are generated based on sample sentences in the target domain (e.g., text messaging, letter writing, and/or other writing domains). In some embodiments, the machine-learning model is trained to leverage additional EMG signals to narrow down a current word prediction with potential suggestions trailing it. For example, the EMG signal is discretize based on a predefined time window (e.g., 40 ms, 20 ms, 10 ms, or 5 ms) and the EMG embeddings are input into the model. In some embodiments, a first model is used to identify characters based on EMG data and a second model is used to provide text suggestions based on the identified characters. [0206] (A7) In some embodiments of A5 or A6, a set of suggestions, including the text suggestion, is obtained from the machine-learning component. In some embodiments, the set of suggestions consists of the top K suggestions obtained from the machine-learning component. In some embodiments, an option to forgo providing a suggestion is included in the set of suggestions (or compared to the set of suggestions to determine whether to provide a suggestion at a given time). In some embodiments, an RL policy is trained to choose among K possible completions or a no-op action. In some embodiments, the no-op action is weighted based on the user's sensitivity to cognitive load. [0207] (A8) In some embodiments of any of A5-A7, the method further includes: (i) in accordance with the user accepting of the text suggestion, providing a reward to the machine-learning component; and (ii) in accordance with the user forgoing accepting the text suggestion, forgoing providing the reward to the machine-learning component. In some embodiments, (i) in accordance with the user accepting of the text suggestion, the system provides a positive reward to the machine-learning component; and (ii) in accordance with the user forgoing accepting the text suggestion, the system provides a negative reward to the machine-learning component. In some embodiments, the machine-learning component includes a reinforcement learning component. In some embodiments, the machine-learning component is trained using data from a plurality of users. In some embodiments, the machine-learning component is personalized (e.g., fine-tuned) to the particular user. In some embodiments, forgoing accepting the text suggestion includes rejecting or ignoring the text suggestion. In some embodiments, the system provides a reward to the machine-learning component in response to explicit user feedback (e.g., the user rates the quality of the text suggestion). For example, the machine-learning component is configured to update based on implicit user feedback (e.g., selection of a suggestion) and explicit user feedback (e.g., a user rating the usefulness of the test suggestion). [0208] (A9) In some embodiments of A8, the reward is proportional to a length of the text suggestion. For example, a per-step reward function has a penalty for each suggestion proportional to the length of the suggestion α*len(a) representing the cognitive load. In this example, accepted suggestions are rewarded based on the length of suggestion. In this example, when no suggestion is provided the reward is zero. In some embodiments, the reward is scaled based on suggestion length and/or sentence length. In some embodiments, a scaled reward is obtained by dividing an initial reward value by a corresponding sentence length. In some embodiments, the amount of the reward is based on an estimated impact of the text suggestion on the user's writing speed (e.g., aWPM). In some embodiments, the aWPM is calculated using Equation 1:

[00001] Equation1 - AdjustedWordsPerMinute

$$aWPM = \frac{1}{5}(1 - \text{CharacterErrorRate}) * (\text{CharacterPerMinute})$$

[0209] In some embodiments, the amount of the reward is based on an estimated cognitive load of the text suggestion. In some embodiments, the amount of the reward is based on an estimated user satisfaction with the text suggestion (e.g., based on gaze, muscle tension, posture, and/or other behavioral responses of the user). [0210] (A10) In some embodiments of any of A1-A9, the estimated cognitive load is determined based on context information for the user. For example, the context information includes information about the environs of the user (e.g., a private or public setting), a speed at which the user is gesturing (e.g., a writing/typing speed), an amount of time elapsed since the user's gesture (e.g., has the user paused after gesturing), an amount of time elapsed since a prior text suggestion, and/or a user history (e.g., data about whether a user has accepted text suggestions in similar circumstances in the past). For example, the elapsed time since the prior text suggestion may be composed of both thinking time and writing time. The thinking time may be composed of thinking about both what the next character should be and the time to consider the shown suggestion (if one is shown), which corresponds to a cognitive load. In some embodiments, the system is trained on the user's historical elapsed time between characters and/or between suggestions. In some embodiments, the estimated cognitive load is determined based on active applications and/or devices for the user. In some embodiments, the estimated cognitive load is determined based on an adjusted words per minute (aWPM) for the user (e.g., a comparison of a current aWPM and a historical aWPM for the user). In some embodiments, the estimated cognitive load is determined based on a gesture flow (e.g., a handwriting flow) of the user. In some embodiments, the estimated cognitive load is, or includes, a cognitive load associated with considering the text suggestion. In some embodiments, the cognitive load is estimated based on a determined user focus with performing the user gesture. In some embodiments, the cognitive load is estimated based on a determination of user attention (e.g., whether the user is focused on the task and/or has divided attention between tasks). For example, the computing system may determine whether the user is looking at the display or paying attention to something else (e.g., looking at the keyboard instead of the display). [0211] (A11) In some embodiments of any of A1-A10, the estimated cognitive load is determined based on context information regarding the set of text characters. In some embodiments, the context information regarding the set of text characters includes a confidence level associated with providing the text suggestion based on the set of text characters, a predicted confidence level associated with providing a different text suggestion at a later time, a length of the text suggestion, and/or a predicted length associated with providing the different text suggestion at the later time. For example, the system may forgo providing a text suggestion corresponding to a single term (e.g., a single-word suggestion) in favor of providing a subsequent text suggestion corresponding to multiple terms (e.g., a sentence-completion suggestion). [0212] (A12) In some embodiments of any of A1-A11, providing the text suggestion includes displaying the text suggestion, and the method further includes: (i) while displaying the text suggestion, detecting a user input; (ii) in accordance with a determination that the user input corresponds to a command to accept the text suggestion, applying the text suggestion to the user interface; and (iii) in accordance with a determination that the user input does not correspond to the command to accept the text suggestion, ceasing to display the text suggestion. In some embodiments, applying the text suggestion includes adding/storing text (e.g., one or more characters, words, and/or other text) to the user interface. For example, the user gesture **130** detected while the text suggestion **128** is displayed in FIG. **1**C causes the text suggestion **128** to be accepted, and the user gesture **216** detected while the text suggestion **214** is displayed in FIG. **2**B causes the text suggestion **214** to be rejected (e.g., ceased to be displayed). For example, the text suggestion characters are shown but not added/stored to the user interface until accepted. In some embodiments, applying the text suggestion includes replacing at least a subset of the set of text characters with text of the text suggestion. In some embodiments, the user input includes a hand gesture (e.g., an in-air hand gesture). In some embodiments, the user input includes activation of a button (e.g., a virtual or physical button). [0213] (A13) In some embodiments of A12, applying the text suggestion includes executing a function of the computing system in accordance with the text suggestion. For example, applying the text suggestion may include inserting text into a message and sending the message. As another example, applying the text suggestion may include opening an application and inserting the text into the application. In some embodiments, applying the text suggestion includes selecting a button, menu option, or other affordance in the user interface. For example, the user may write “msg Matt hey, where” and the text suggestion may be “msg <contact: Matt>: ‘Hey, where are you?’”. In this example, accepting the text suggestion causes a messaging application to open and the message “Hey, where are you?” to be sent to a contact named “Matt” via the messaging application. [0214] (A14) In some embodiments of A12 or A13, applying the text suggestion includes activating one or more sensors. For example, one or more sensors for gaze tracking or gesture detection may be activated. In some embodiments, the one or more sensors correspond to location data, pose data, eye tracking, and/or other limb tracking (e.g., arm, hand, and/or leg tracking). [0215] (A15) In some embodiments of any of A12-A14, applying the text suggestion includes deactivating one or more sensors. In some embodiments, deactivating the one or more sensors includes switching the sensors to a low-power mode, switching the sensors off, and/or discarding data from the sensors. [0216] (A16) In some embodiments of any of A12-A15, applying the text suggestion includes executing an application at the computing system (e.g., executing a messenger application, a calendar application, and/or a digital assistant application). [0217] (A17) In some embodiments of any of A12-A16, applying the text suggestion includes switching the computing system from a first mode (e.g., a data input mode) to a second mode (e.g., a data display mode). In some embodiments, switching modes includes activating and/or deactivating one or more sensors. In some embodiments, switching modes includes adding and/or removing available commands. In some embodiments, switching modes includes adjusting a power consumption of the computing system. [0218] (A18) In some embodiments of any of A1-A17, the text suggestion is, or includes, a text-completion suggestion. For example, the text suggestion includes a suggestion for completing a current word and/or suggesting subsequent words. In some embodiments, the text suggestion includes a word completion. [0219] (A19) In some embodiments of any of A1-A18, the text suggestion is, or includes, a text-correction suggestion. For example, the text suggestion includes a spelling correction and/or a grammar correction. In some embodiments, the set of text characters includes a set of shorthand terms and the text suggestion includes a corresponding set of longhand terms. For example, the user writes “thx” and the text suggestion is “thanks”. [0220] (A20) In some embodiments of any of A1-A19, the user gesture is, or includes, an in-air hand gesture. In some embodiments, the user gesture is, or includes, a surface hand gesture (e.g., the user traces characters on a table or wall). In some embodiments, the user gesture is performed by moving one or more digits of the user's hand. In some embodiments, the user gesture is performed while the user is holding an object (e.g., a stylus or controller, such as the stylus **108**). [0221] (A21) In some embodiments of any of A1-A20, the user gesture is detected based on the data from the one or more neuromuscular sensors and data from one or more imaging sensors (e.g., the imaging sensor **826**). For example, the user gesture is detected based on fusion of data from the one or more neuromuscular sensors and data from the one or more imaging sensors. In some embodiments, the user gesture is detected by one or more non-neuromuscular sensors (e.g., image sensors, motion sensors, and/or other types of sensors) in addition to, or alternatively to, detecting the user gesture with the one or more neuromuscular sensors. [0222] (A22) In some embodiments of any of A1-A21, the display device is a component of the computing system (e.g., is a component of the head-wearable device **104**). In some embodiments, the display device is distinct from the computing system (e.g., the computing system is communicatively coupled to the display device). In some embodiments, the display device is, or includes, an augmented-reality device. [0223] (A23) In some embodiments of any of A1-A22, the one or more neuromuscular sensors are components of the computing system (e.g., are components of the wrist-wearable device **106**). In some embodiments, the one or more neuromuscular sensors are communicatively coupled to the computing system. In some embodiments, the one or more neuromuscular sensors include one or more EMG sensors. [0224] (A24) In some embodiments of any of A1-A23, the computing system is or includes a wearable device (e.g., the head-wearable device **104** and/or the wrist-wearable device **106**). In some embodiments, the wearable device is a head-wearable device (e.g., an artificial-reality device). In some embodiments, the wearable device is a wrist-wearable device (e.g., a smartwatch or bracelet). In some embodiments, the wearable device is a piece of clothing (e.g., a glove, a sleeve, or other article of clothing).

[0225] In another aspect, some embodiments include a computing system with one or more processors and memory coupled to the one or more processors, the memory storing one or more programs configured to be executed by the one or more processors, and the one or more programs including instructions for performing any of the methods described herein (e.g., methods **300** and A1-A24 above).

[0226] In yet another aspect, some embodiments include a non-transitory, computer-readable storage medium storing one or more programs for execution by one or more processors of a computing system, the one or more programs including instructions for performing any of the methods described herein (e.g., methods **300** and A1-A24 above).

[0227] Any data collection performed by the devices described herein and/or any devices configured to perform or cause the performance of the different embodiments described above in reference to any of the Figures, hereinafter the “devices,” is done with user consent and in a manner that is consistent with all applicable privacy laws. Users are given options to allow the devices to collect data, as well as the option to limit or deny collection of data by the devices. A user is able to opt in or opt out of any data collection at any time. Further, users are given the option to request the removal of any collected data.

[0228] It will be understood that, although the terms “first,” “second,” etc., may be used herein to describe various elements, these elements should not be limited by these terms. These terms are only used to distinguish one element from another.

[0229] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the claims. As used in the description of the 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 “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.

[0230] As used herein, the term “if” can be construed to mean “when” or “upon” or “in response to determining” or “in accordance with a determination” or “in response to detecting,” that a stated condition precedent is true, depending on the context. Similarly, the phrases “if it is determined [that a stated condition precedent is true]” or “if [a stated condition precedent is true]” or “when [a stated condition precedent is true]” can be construed to mean “upon determining” or “in response to determining” or “in accordance with a determination” or “upon detecting” or “in response to detecting” that the stated condition precedent is true, depending on the context.

[0231] The foregoing description, for purpose of explanation, has been described with reference to specific embodiments. However, the illustrative discussions above are not intended to be exhaustive or to limit the claims to the precise forms disclosed. Many modifications and variations are possible in view of the above teachings. The embodiments were chosen and described in order to best explain principles of operation and practical applications to thereby enable others skilled in the art.

Claims

1. A method performed at a computing system having memory and one or more processors, the method comprising: detecting a user gesture associated with a user task based on data from one or more neuromuscular sensors, the user gesture performed by a user of the computing system; identifying a set of text characters corresponding to the user gesture; causing display, via a display device, of the set of text terms in a user interface; estimating, based on context information, a cognitive load of the user corresponding to performing the user task at the computing system; determining whether the estimated cognitive load meets one or more predefined criteria; in accordance with a determination that the estimated cognitive load meets the one or more predefined criteria, providing a text suggestion to the user based on the set of text characters; and in accordance with a determination that the estimated cognitive load does not meet the one or more predefined criteria, forgoing providing the text suggestion to the user based on the set of text characters.

2. The method of claim 1, wherein the user gesture comprises a handwriting motion.

3. The method of claim 1, wherein the set of text characters is appended to a set of pre-existing text in a document, and wherein the text suggestion is based on the set of text characters and the set of pre-existing text.

4. The method of claim 1, wherein the text suggestion is generated based on the set of text characters and information about the user.

5. The method of claim 1, wherein the text suggestion is provided by a machine-learning component trained based on the data from the one or more neuromuscular sensors.

6. The method of claim 5, wherein a set of suggestions, including the text suggestion, is obtained from the machine-learning component.

7. The method of claim 5, further comprising: in accordance with the user accepting of the text suggestion, providing a reward to the machine-learning component; and in accordance with the user forgoing accepting the text suggestion, forgoing providing the reward to the machine-learning component.

8. The method of claim 7, wherein the reward is proportional to a length of the text suggestion.

9. The method of claim 1, wherein the estimated cognitive load is determined based on context information for the user.

10. The method of claim 1, wherein the estimated cognitive load is determined based on context information regarding the set of text characters.

11. A computing system, comprising: control circuitry; memory; and one or more sets of instructions stored in the memory and configured for execution by the control circuitry, the one or more sets of instructions comprising instructions for: detecting a user gesture associated with a user task based on data from one or more neuromuscular sensors, the user gesture performed by a user of the computing system; identifying a set of text characters corresponding to the user gesture; causing display, via a display device, of the set of text terms in a user interface; estimating, based on context information, a cognitive load of the user corresponding to performing the user task at the computing system; determining whether the estimated cognitive load meets one or more predefined criteria; in accordance with a determination that the estimated cognitive load meets the one or more predefined criteria, providing a text suggestion to the user based on the set of text characters; and in accordance with a determination that the estimated cognitive load does not meet the one or more predefined criteria, forgoing providing the text suggestion to the user based on the set of text characters.

12. The computing system of claim 11, wherein the user gesture comprises a handwriting motion.

13. The computing system of claim 11, wherein the set of text characters is appended to a set of pre-existing text in a document, and wherein the text suggestion is based on the set of text characters and the set of pre-existing text.

14. The computing system of claim 11, wherein the text suggestion is generated based on the set of text characters and information about the user.

15. The computing system of claim 11, wherein the text suggestion is provided by a machine-learning component trained based on the data from the one or more neuromuscular sensors.

16. A non-transitory computer-readable storage medium storing one or more sets of instructions configured for execution by a computing device having control circuitry and memory, the one or more sets of instructions comprising instructions for: detecting a user gesture associated with a user task based on data from one or more neuromuscular sensors, the user gesture performed by a user of the computing system; identifying a set of text characters corresponding to the user gesture; causing display, via a display device, of the set of text terms in a user interface; estimating, based on context information, a cognitive load of the user corresponding to performing the user task at the computing system; determining whether the estimated cognitive load meets one or more predefined criteria; in accordance with a determination that the estimated cognitive load meets the one or more predefined criteria, providing a text suggestion to the user based on the set of text characters; and in accordance with a determination that the estimated cognitive load does not meet the one or more predefined criteria, forgoing providing the text suggestion to the user based on the set of text characters.

17. The non-transitory computer-readable storage medium of claim 16, wherein the user gesture comprises a handwriting motion.

18. The non-transitory computer-readable storage medium of claim 16, wherein the set of text characters is appended to a set of pre-existing text in a document, and wherein the text suggestion is based on the set of text characters and the set of pre-existing text.

19. The non-transitory computer-readable storage medium of claim 16, wherein the text suggestion is generated based on the set of text characters and information about the user.

20. The non-transitory computer-readable storage medium of claim 16, wherein the text suggestion is provided by a machine-learning component trained based on the data from the one or more neuromuscular sensors.