
25 Future Possibilities for Interface Technologies that Enhance Universal Access to Health Care Devices and Services

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Accessible

Medical Instrumentation

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ABSTRACT

Human–technology interfaces are going through an evolutionary transformation, one that is likely to impact on future medical device interfaces. This chapter reviews technical trends in interfaces, especially as related multimodal interaction. This is followed by consideration of approaches for enhancing universal access to health care devices and services, where universal access is assumed to include barriers of distance and cost as well as direct accessibility of the interface. Such approaches include considerations of the procedural nature of most use of health care devices, recognition of the distinctions between accessibility and usability and how this can impact on access, and a trend toward approaches that emphasize personalized interfaces.

25.1 INTRODUCTION

At a workshop in 1999 on home care technologies for the 21st century, many health care and policy experts expressed the sense that society was on the verge of a paradigm shift towards consumer-driven health care [1,2]. Although the momentum has perhaps slowed, seeds for change remain, such as our aging society and remarkable technological advances. There are many possible actors and paths that could lead to such transformation, and it could take many forms. Technology transfer specialists often refer to conceptual “forces” that can “push” and “pull” to yield change. One technical push is the continued advances in information technologies that are promoting greater interconnectivity and interoperability, which may inevitably cause the medical device industry to ride this wave and adapt its product lines. A possible society push is that research investments combined with relatively new laws and guidelines will cause enhanced access to and usability of certain types of products and services by people with diverse abilities and economic status. A market-driven consumer pull is that as baby boomers age they will demand better and more convenient access, likely including a greater focus on usability testing of products. Still another force is a potential obstacle that is nonetheless also an opportunity: the multifaceted social pull to bring down spiraling health care costs. In reality all of these dynamic processes have benefits, and evolutionary change can take many forms.

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Such converging trends provide a window of opportunity for systems change that could impact the degree of universal access to health care products and services. But will this evolutionary process yield products that are more accessible for persons with disabilities and older adults? It is difficult to tell. The nature of an evolutionary process is that often some individuals can be left behind, especially those with less power or ability to adapt. If we are not careful, many individuals might not have the opportunity to participate in, and thus benefit from, a consumer-driven paradigm shift. It is certainly not automatic. Framing the questions and questioning the frameworks may be necessary.

This chapter addresses a narrow window within this health care challenge: the evolutionary trends in interfaces, specifically as related to promoting accessible medical instrumentation. This framing of the challenge reflects a bias: as often suggested by authors of chapters in this book, many of the key challenges and opportunities rest with issues related to human–technology interfaces, issues with both a social and technical dimension. Along with Chapter 24 of this book that provides the vision from a societal and policy perspective, and Chapter 26 that provides a perspective of the trends and challenges from a technical and business perspective, this chapter is intended to help set the conceptual stage for discussions on emerging trends and future directions.

This chapter also reflects part of the mission of the Rehabilitation Engineering Research Center on Accessible Medical Instrumentation (RERC-AMI), specifically as related to anticipating future trends and selecting strategic opportunities for demonstrating possibilities for more accessible health care interfaces. Examples are given in Chapter 27 and Chapter 28 of this book. But these are just examples, constrained by the reality of limited resources that can be invested in such activities. To help envision the broader possibilities that are the scope of this chapter, consider the following scenario:

Imagine it is the year 2010. An elderly couple lives at home, the husband with stroke-induced disability and high blood pressure, and the wife with severe arthritis that affects hand function plus mild diabetes that includes a degree of visual impairment. He's a retired engineer and manager who is quite goal-directed, though seemingly more and more absent-minded. He follows a computer-assisted rehabilitation therapy that bears similarity to the vision described in Chapter Pt4_Feng. His "universal gym" of arm and leg exercise technologies adjust settings based on his recent history of performance as well as his mood and aims, as interpreted from his answers to several questions initiated by the system.

An interface is established when he's in their family room and says, "OK, healthy time." The picture-in-picture of his HDTV then functions as his health/performance monitor. In the primary picture he typically views the interactive game he's playing, a sports event (especially when doing more routine and "boring" aerobics) or, occasionally, his brother or daughter or his remote therapist or a nurse. Typically his interactive games are played remotely against his brother or daughter, with the sound off when he plays against his brother unless he wins, and the sound up and video available in the picture-in-picture when he plays against his daughter; this all adjusts automatically as a default. He also is prompted to record his resting heart rate and blood pressure each morning and evening, using a system that automatically stores and uploads this information, and even adjusts the dose of his blood pressure medication and sends reminders if he forgets to take the pills.

His wife uses a similar system, but typically chooses to use it in full talking mode. Her glucose monitor also talks with her, as well as transparently communicating with her personalized health record. Something (she's not sure what) sends reminders to her wristwatch to take blood glucose level measurements, and something else provides her with an appropriate dose of insulin that can be automatically administered without her needing to use her hands. She also uses her husband's exercise system to provide gentle stretching exercises to her hands and feet, and head-neck, typically during the commercials while she and her husband are watching TV. To her husband's chagrin, she also insists that all of the "wireless technology stuff" stay in the family room. The exception is when her daughter calls, during which the system automatically works everywhere within range; indeed, this even extends to carrying on three-way hands-free conversations that often continue during walks, or four-ways when one of the grandkids is on.

All aspects of the preceding vision are technically feasible. Indeed, many are already possible, especially in innovative countries such as Japan that seem more ready to embrace ubiquitous technology that is assistive. Although there are technical challenges, such as reliable integration of products across diverse product lines and from different companies (challenges of reliability and interoperability), most of the challenges reside at the human-technology interface, an interface that is typically two-way. As the preceding example suggests, a human brings a diversity of abilities, preferences, experiences, aims and moods to this interface. And humans can change, sometimes within seconds, sometimes over the course of years. The interface technology, to be effective in delivering the intended uses of the device and have it be embraced by its owner, would ideally adapt to this dynamically changing partner that it is designed to serve.

Here we also assume that by 2010, there will be leadership within our larger community which will insist that, as much as possible, society move toward the vision that all members of this community have access to the intended use of all products. Right now there are just a few select domains where accessibility is required; for the U.S., this specifically applies to architectural design, transportation systems, and electronic and information technologies (E&IT). These domains could, and should, include medical devices. Such a new playing field, as long it is level through use of ~~with the~~ well-defined rules, should satisfy companies. Indeed, for the medical device industry in which the client base for many products includes a disproportionately larger number of users with disabilities, it makes special sense — for many products such policy opens up larger markets, both nationally and internationally. It would also stimulate the type of commercial environment that enables creative designers to innovate.

So with these presuppositions, where are we? Of the many paths toward improved access to the intended use of products, most can be categorized into one of the following two alternative strategies:

- Design the interface using approaches motivated by universal design (UD), i.e., "design for all" strategies (e.g., Chapter 6 and Chapter 8 of this book).

- Personalize (customize) the interface based on the abilities and preferences of a specific user or the user's agent (e.g., Chapter 26, Chapter 27, and Chapter 28 of this book).

Undoubtedly some colleagues will disagree with this simplification, because it views these as fundamentally distinct approaches (despite some procedural overlap). This battle has a long history within the rehabilitation community, as assistive technologies and universally designed products each make the most sense within the context of addressing certain real challenges. The accessibility-oriented laws of the U.S. bear this out, and thus it is acceptable for a product to either be directly accessible (often called *direct access*) or to provide an interface for a user's personal assistive technology that provides them with roughly equivalent access to the intended use of the product or service (called *compatible access*). Specifically, the E&IT Accessibility Standards maintained by the U.S. Access Board [3] include, under Subpart C — Functional Performance Criteria, a collection of guidelines of the following form (§ 1194.31):

At least one mode of operation and information retrieval that does not require [user sensory or motor ability] shall be provided, or support for assistive technology used by people who are ...

Furthermore, from this author's perspective the Web Content Accessibility Guidelines represented a paradigm shift towards personalized interface design by formalizing requirements such as text equivalents with the specific intent that a user's assistive technology or user agent can provide an accessible interface (see, ~~however,~~ Chapter 23 of this book for a broader perspective). From the perspective of access, the two strategies cannot become one, as much as well-intentioned people might try. Given the product diversity among the roughly 30,000 devices within the health care field, it is suggested that both approaches need to be proactively pursued and nurtured if universal access is to become a reality.

In this chapter Section 25.2 reviews current technology trends as related to interfaces, with emphasis on anticipated emerging technologies that have the potential to change the landscape for certain areas of health care interfaces and health care practice. This does not imply that such changes will occur, but simply that from a technical perspective there are opportunities for significant impact.

Section 25.3 then proposes conceptual foundations for framing the problem. Specifically, it develops a broader perspective for considering future possibilities for interface technologies that move toward universal access to health care procedures. Note the use of the word *access*. This chapter is not about universal usability, but about the civil right of access to the intended use of a product or service, to a degree that is readily achievable. Here ~~readily achievable~~ is a hard-to-see line drawn in the sand of difficulty to access that can (and should) shift as technology enables greater inclusiveness and flexibility in use.

Because this chapter is about future possibilities, there are no results or discussion sections, as the future must still evolve. Instead, there is a future directions section that considers a few product categories that the RERC-AMI's national consumer

survey (Chapter 2 of this book) revealed contain considerable barriers to access. For these, some future priorities and directions are suggested.

25.2 BACKGROUND: TECHNOLOGICAL TRENDS IN INTERFACES

The word *interface* seems so simple. Yet it is complex, largely because humans are complex, adaptive creatures. Humans are so adaptive that the design of the interface for a product often has been almost an afterthought, yet certain types of products succeed financially. In such cases users simply adapt to it, if they are able. Yet in the year 2005, it was well understood that subtle considerations in interface design can make or break a product, or even a company. Indeed, a past statement by Microsoft's Bill Gates that the future is in the human-technology interface now seems obvious. Well-designed interfaces add value to a product. Companies such as Microsoft or Nokia would not dream of putting a product on the market without first having it go through usability evaluation, including testing with intended users.

In this section, we outline alternative technologies and emerging technological trends for interfaces, using a systems input-output conceptualization of the interface, as is presented in Figure 25.1. Notice the assumption of two layers — a physical layer and a conceptual layer.

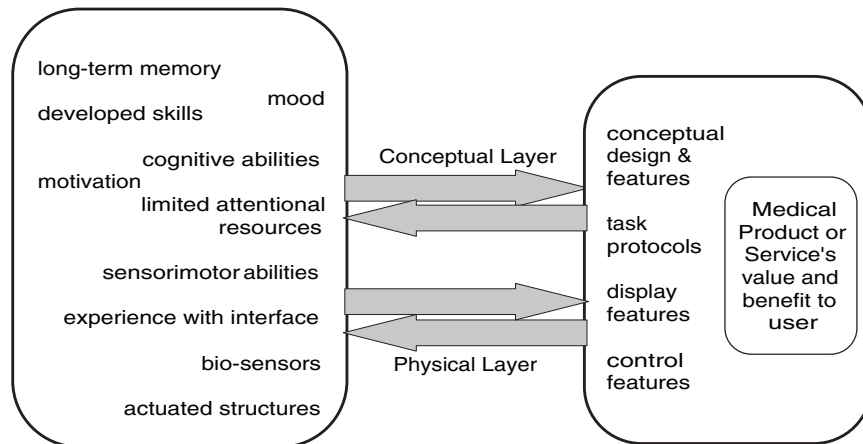


FIGURE 25.1 A systems representation of human-technology interfaces. The human is represented as having sensorimotor capabilities that often include sensors and actuators that support alternative strategies for completing a given subtask, attentional resources that include short-term memory and adaptation, cognitive abilities, and longer-term memory that stores adaptive learning. The medical product is assumed to be used in a procedural way. Using a computer analogy, this interface is conceptualized as including both a lower-level control/display interface (physical layer) and a middle-level conceptual motivational interface (conceptual layer).

25.2.1 TRENDS IN PHYSICAL LAYER INTERFACES

25.2.1.1 Physics of the Physical Layer: One-Way and Two-Way Interfaces

Scientifically, interfaces in the physical world can be inherently two-way (e.g., physical contact between a human and device) or one-way (e.g., sound waves triggering a multistage mechanical process within the inner ear that cause signal changes in sensory neurons). Interfaces can be viewed as transmitting power or information, depending on the “impedance” across the interface. If it is reasonably matched, interaction is usually viewed as a two-way power transfer, whereas if it is dramatically mismatched, one-way information (a signal) is transferred.

Interfaces involving physical contact, for instance between the hand and device, are often inherently two-way unless the device impedance is either really high (e.g., pushing against a wall) or really low (pushing against air). Such interfaces exist in physical space, and have locations and orientations. One example is hand tools. With experience and practice, the body can often discover such two-way interfaces to the point where they can become an almost subconscious extension of the body. This is the extended physiological proprioception (EPP) concept that was first proposed by Simpson [4], which although originally applied to body-powered upper extremity prostheses, also applies to use of products such as a tennis racquet, a pencil, or many machine tools. It turns out that the key criteria are: (1) that a pair of signals (e.g., a force–velocity pair, whose product is mechanical power) cross the interface, (2) that the mechanical behavior on the other side of the interface be predictable so that it can be discoverable by the neuromotor system, and (3) that there be enough richness in the interaction so as to assist this discovery process. The result can be wonderful — a technology that is assistive, functioning essentially as a subconscious extension of the body. Similarly, other types of well-designed physical interfaces are subconsciously forgotten, for instance forgetting that one is sitting in a comfortable chair or wearing a hat. Thus, a well-designed two-way interface becomes subconscious; either it is used as a subconscious extension of self, or its existence is forgotten. The most effective designs exhibit both features.

One-way information transfer interfaces are also common and, indeed, more commonly the subject of analysis. Often, these are integrated into a pair ~~so as to~~ include one-way information in both directions. If information is being transferred from the device to the human without human intervention, we often call it a display. With this definition, displays can take many forms, the most common of which is visual. If information is being transferred from the human to the device, we often call it a *control*. Controls can also take many forms.

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25.2.1.2 Display Technologies for Sensory Input and Cognitive Use

A *display*, defined broadly, provides information that can be sensed and subsequently perceived as information. At the physical layer, displays may be perceived

through use of senses such as vision, hearing, touching, or even smelling. Each of these modes has their strengths and weaknesses. The visual system excels at both spatial and temporal processing of signals, but optimum sensing requires the use of eye movements to foveate on an area of interest (e.g., see Chapter 10 of this book). The auditory system extracts both magnitude and frequency content from a signal and is especially **strong** at temporal recognition. Tactile sensing includes limited spatial and temporal resolution and is best for displays transmitting a few bits of information.

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Visual displays take too many forms to fully review here, but a few key trends [5] are:

- Flat panel displays that are replacing CRT displays, with better luminescence and reduced cost
- Low-cost LCD panels, including lower-cost paintable flexible displays
- Heads-up displays and eyeglass displays that can be worn by a user and project a virtual display of various sizes and increasing resolution
- Virtual environment enhancements such as three-dimensional displays that improve perceptual visualizations and augmented realities that project objects

Of special note is that some are mobile (e.g., display on PDA device) and wearable (heads-up and eyeglass displays) and that the trend has been toward better clarity at reduced cost. These seem especially suitable for future use in personalized interfaces.

Also available for enhancing vision are augmentation devices and magnifiers/telescopes. These are normally applied as an assistive technology that is personalized to an individual, **much** similar to how eyeglasses are used by a person who uses them occasionally. However, they could also be integrated into universally designed products (e.g., display magnifier integrated into an exercise ergometer).

Finally, and perhaps most importantly, improved video compression algorithms such as MPEG 4 and bandwidth are setting the stage for more universally transmittable video [2]. This especially has applications for personalized interfaces. One particularly important vision is that of universal wall monitors that could be used on the fly to display text and images from mobile devices in larger size.

Auditory displays also continue to improve in terms of technological capabilities, and specifically in terms of flexibility for use. Wireless technologies, especially built on the Bluetooth or WiFi standards, can now reliably transmit an audio signal to a very small earpiece from a PDA, cell phone, or household device. Furthermore, improved compression algorithms combined with the iPod digital music phenomenon are resulting in a considerable variety of consumer options.

Both text-to-speech and speech recognition technologies continue to improve, with clearer and more personalized synthesized voice and a better rate of speech recognition (see also Chapter 10 of this book). Trends such as home networking and W3C (World Wide Web Consortium) standards activities (see Chapter 26 of this book) for speech will make personalized audio display and speech control more and more ubiquitous within the home and office environment. Advances are also occurring in personal mobility/orientation/navigation devices.



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Kinesthetic feedback displays enable a user to sense forces applied by a device, with the primary cases of interest involving computer mice (vibration) and joysticks (vibrations or actual applied forces); these are used extensively for the UniTherapy technology described in Chapter 27 of this book). Other examples include Braille displays, duplicators, and embossers.

One final point relates to the trend towards mobile device for health care, including use of cell phones. For such devices displays are very small, and often a tradeoff has to be made between navigation and information content or controls per screen (e.g., see Chapter 24—Danturthi). It is interesting that because of such challenges, the W3C groups on device independence, accessibility, and multimodal interfaces have recognized a need to combine expertise, because users of mobile devices essentially have capability limitations similar to disability [6]. Thus, there are reasons well beyond disability for considering multimodal displays.

25.2.1.3 Control (Action) Technologies for Manipulation and Expression

Most of these technologies in some way sample information that is based on neuromotor expression that causes muscle activity, and in turn causes skeletal motion that is expressed at a body endpoint such as the hand. Common modes of such expression include the hand, foot, mouth, and head, and gestures of the arms, head, lips, or face. Another possibility, currently at an early research stage, is the use of indirect brain control to operate switches or move external objects.

There have been continued advances in a range of interface technologies that sense human motor abilities, including the following:

1. Direct-actuated and operated input technologies:
 - **Mouse and joystick/gamepad technologies:** Although most of the capabilities of these technologies have existed for some time for more expensive virtual reality and teleoperator systems, there have been advances especially for wireless mice that enable mouse control by movement of the hand or a device (such as a virtual tennis racket) in the hand in physical space or by an optical pointing device on a screen. Currently, the primary application has been high-end virtual game therapy, but the potential applications are high (e.g., see Chapter 27 of this book).
 - **Keyboard technologies, including special keyboards:** Most keyboards are operated by the hand. These range in size from large to miniature, gentle touch of key to keys requiring greater excursion or force, and from integrated into portable devices to wireless units to foldable fabrics to projected on a tabletop. A variety of specialized keyboards also have been proposed that include keyboard shapes intended to promote good ergonomic postures and minimize repetitive motion disorders, keyboards that sense finger forces without significant motion, and head- or eyegaze-operated keyboards. It is expected, however, that keyboard operation may be less common in the future.

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- **Glove technologies:** The primary motivation for the glove technologies that matured in the 1990s was high-tech virtual reality applications. The more expensive systems measure many degrees of freedom of hand movement and finger forces. Lower-cost ones use fairly crude technologies and have not really caught on.
- **Motor expression recognition technologies,**
- **Speech recognition:** These technologies have been around for a long time, with early use by persons with disabilities. But the systems continue to improve, with fewer recognition errors and lower costs, suggesting that speech recognition could become appropriate as an alternate modal control. This represents a critical component of the multimodal suite.
- **Pen-based handwriting recognition:** Advances in handwriting recognition coupled with a greater variety of digital pen and pad/tablet interfaces represent intriguing technologies for both text entry and as controls. These would seem well positioned for many medical device applications as an alternative modal control.
- **Gesture recognition:** These technologies have used mostly image-based recognition approaches, transducing hand, arm, body, and facial movements and using them to control switches and for text input. It is difficult to see how this could be reliably used for a medical device, but perhaps as switches for positioning.
- **Lip recognition (augmented with acoustic information):** Although intriguing, such technologies do not seem particularly viable for medical device applications.
- **Biometric recognition:** There are many advances in this area, as related to personal identification. Technologies include fingerprint, retinal scans, and voice recognition. These have considerable potential for medical devices, both for personal access and security and as a way of adding robustness to the device interface, for instance, by helping the device recognize a person and adapt its display and control interface strategy to the user's abilities and preferences. It is especially relevant for personalized interfaces.

25.2.1.4 Two- and One-Way Positioning and Orienting Interfaces and Tools

The RERC-AMI's national consumer survey shows that many accessibility barriers relate to positioning and orienting of individuals relative to medical equipment (Chapter [Pt1_JillWinters](#)). There are no new technological trends to report, except to note the following (1) advances in load-history-dependent materials that are used for cushioning, (2) the greater availability of antigravity mechanisms that can be operated with little or no external power, and (3) the trend toward exam tables/chairs/beds with more accessible features (most commonly attained by the "brute force" approach of increasing the device power requirements and the cost of the equipment by adding motors to address more degrees of freedom such as table height or the angle of a seatback).

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Of note is that powered operations normally involve one-way control switches, and do not use EPP. Such approaches may add to accessibility and improve access when cost is not a barrier. But the negative is that the user becomes an observer of an open-loop control operation rather than an interactive operator. However, there are alternatives that could in principle be applied to medical equipment. One alternative would be to augment human power, similar in concept to power steering for a car; this can be designed to follow EPP principles, but can get expensive. Another option of potentially moderate cost is to compensate for gravity by creating an antigravity potential energy field through the use of strategically placed springs and DC magnets; such strategies are being used, for instance, in newer weight-training equipment.

25.2.2 CONCEPTUAL LAYER INTERFACES

The human–device interface is much more than physical. Indeed, often the focus of a usability analysis is what is here called the *conceptual interface* — that part of the interface that intangibly connects to the perceptual, cognitive, motivational, and adaptive part of the human user. In a recent best-selling book called *The World is Flat* by well-known author and syndicated columnist Thomas Friedman, one of the overriding themes was that technology is about to change how people interact with products and each other to a degree that is unprecedented in history. Access barriers such as distance will break down, and products and services will be accessible to consumers in new, creative ways. This implies opportunity and also suggests that companies that do not adapt may be left behind. It also suggests the importance of outside-the-box thinking about the interface as a means for interaction within an increasingly flattened world where technical access should improve and, importantly, the (conceptual) interface takes on increasing importance. It is particularly hard to imagine medical monitoring technologies and approaches not changing dramatically, especially products or services that target clients in the home setting.

The number of emerging software technologies and standards that are taking up the challenge of supporting more conceptual and intelligent interfaces is staggering and will not be reviewed here. Two other chapters in this book address many of these trends — Chapter 26 on software trends for interface standards and Chapter 27 on integrated treatment of personalized interfaces connecting to Web-based services. Here we briefly highlight some key trends:

- Decoupling and modularizing of physical and middleware layers in information technology standards, promoting greater product interoperability and leveraging investments, and enabling innovation at the physical layer as well as the conceptual layer
- Continued growth in computing power (memory times speed), and in the development of smaller devices
- Networking and interface standards that promote ubiquitous and distributed computing
- Emergence of an international computing language for expressing structure and concepts (XML) that can be used as a base to establish consensus



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protocols and guidelines to be used by the technical community interested in accessibility

- Emergence of the semantic Web standard for structuring more natural interaction between human and machine, which among other applications can promote access for persons with cognitive disabilities and performance enhancement for individuals with many forms of activity limitations (see also Chapter 23 and Chapter 26 of this book)
- Advances in intelligent systems, specifically intelligent agents and intelligent assistants

Historically, medical products that employ E&IT interfaces tend to have about a 3 to 5 year lag in adoption of technology standards. For instance, many companies are just starting to explore USB connectivity. One interesting question in this context is, “In an increasingly flat world where creative innovation can find a worldwide market, are medical device companies and their regulators ready to handle a world of devices that are more modular, interoperable and operate with more intelligent conceptual interfaces?”

medical device

25.3 METHODS: APPROACHES ENHANCING ACCESS TO HEALTH CARE

Given the breadth of emerging technologies described in the previous section, it is clear that future designers of devices that enhance access to health care products and services are going to have an ever-richer variety of interface technologies from which to select. This includes both at the low-level physical layer and the more conceptual and motivational middle layer. The potential is certainly there for enhanced access. How does one make a selection from these varied technologies?

25.3.1 CLASSIFYING PROCEDURAL USE OF HEALTH CARE DEVICES

To develop accessible interfaces, it is worthwhile to start by understanding how a device and its interface participate in the health care process. The interface is part of an encounter that involves the device and at least one user.

25.3.1.1 Recognize Overall Reasons for a Health Care Encounter

Classic aims for a health care encounter include the following:

- Obtaining or gathering information on health status (e.g., diagnosis and health assessment)
- Assisting with providing a procedural service (e.g., dental or eye exam)
- Providing therapy of (assumed) therapeutic benefit (e.g., physical therapy)

This is not a perfect classification as there can be overlap (e.g., a dentist provides a procedural service that includes use of diagnostic tools such as x-rays and then

provides a form of therapeutic intervention). Use of an assistive technology within the context of health care also often integrates into a procedural framework. The interface takes many forms, in part because there are many goals for health care procedures. More specifically, there is often a goal-directed sequence of tasks.

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25.3.1.2 Recognize Roles for Entities Participating in a Health Care Encounter

One of the most thoroughly thought-out representations of the health care encounter involves the scheme used by Health Level 7 (HL7), a mature international standard for health care messaging and informatics that is used extensively for interoperable communication of health care information. Figure 25.2 summarizes the basic structure that is implemented in the XML-based HL7 version 3.0. The key concept is that “an *entity* in a *role* participates in an *act*,” where there is extensive significance within an object-oriented structure for each of the four emphasized words. Each of these terms is carefully defined as follows:

- *Entity* — The physical objects in health care, which are nouns that can represent a person, place, or thing (e.g., device).
- *Role* — Ascertains the part that entities play as they partake in health care acts; roles for individuals range from physician to patient and include caregiver, and roles for devices range from an entity measuring blood pressure to an exam table.
- *Act* — The health care actions or activities, a verb. An act relationship can be used to “bind” a series of acts.
- *Participate* — Instances of an “entity-in-a-role” performing an act [7].

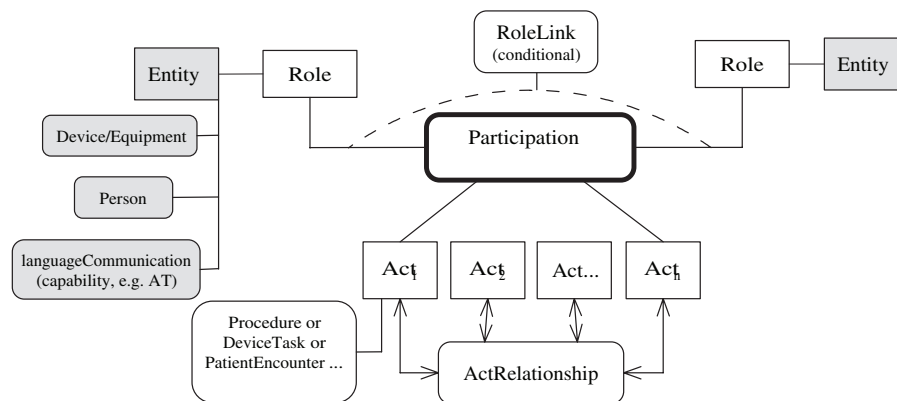


FIGURE 25.2 Model of health care procedures based on the Reference Information Model (RIM) of the international Health Level 7 (HL7) standard that is used for medical messaging (e.g., for communication between products, for documenting billable activities and procedures). In this model, an entity describes the physical objects in health care, such as medical devices and people. They only participate in health care acts in the context of a role, which ascertains the part that an entity plays. An act is a health care action or activity, and an act relationship provides the binding for a series of acts that often constitute a procedure.

Notice that an entity can include an individual with disability. This person can participate in roles such as a patient or consumer. Thus a patient or a consumer refers to the person only in the context of a certain role. Until a role is established, it is not possible to participate in an act.

In this formalism, when an individual uses an interface to a medical device, both the person and the device are participating in its use (e.g., act sequence) from the context of their roles. The interface is part of the entity called *device* and is critical to its role in the encounter and to the form of the participation. The advantage of this construct is its clarity, which was developed over a multiyear consensus process and has stood the test of having been used for millions of reimbursable encounters in health care settings.

25.3.1.3 Recognize the Strengths of Tools Available for Analysis

The chapters of this book provide a plethora of viable approaches for evaluating and designing interfaces for medical equipment. We see effective use of ergonomics (Chapter 11 in this book), human factors engineering (Chapter 16 in this book), UD (Chapter 6 and Chapter 8 in this book), usability and accessibility evaluation (Chapter 13 in this book), accessibility evaluation (Chapter 22 in this book), and accessibility standards (Chapter 15 and Chapter 23 in this book). One could add human performance analysis and perhaps cost-benefit analysis. Each approach has its own procedures and tools associated with design and evaluation of health care interfaces. All have strengths, and, indeed, all have, over time, extended their field to encompass a range of interface issues. Thus, although ergonomics may have a primary focus on the biomechanical study of work, the approach extends to visual displays and cognitive considerations. Similarly, UD concepts are positioned to include aspects of usability and accessibility analysis.

So what to use? It depends on the aims of the analysis. A good starting point is human factors engineering, because that is the FDA's frame of reference (Chapter 17 of this book), and it provides a good frame of reference for addressing safety and user error. A useful analogy is the diversity of religious faiths, which suggests there are many paths toward the aim of enlightenment. But as with religions, subtleties in the different approaches in fact may result in different solutions. In this next section the context for this analysis is emphasized by perceiving the light at the end of the tunnel — universal access.

25.3.2 FRAMEWORK FOR UNDERSTANDING UNIVERSAL ACCESS

Universal access was purposely used in the title of this chapter despite having become a controversial, hard-to-define concept. To the U.S. Federal Communications Commission (FCC), it relates to the rights of access to telecommunications services across distance. To the disability community, it is a sort of combination of the valued concepts of accessibility and UD. To standards bodies that have agreed to disagree on precise definition of the term *accessibility* and therefore often do not define the term, it can range from being an all-inclusive term meaning everyone and everything

(which then threatens becoming meaningless) or a targeted conceptual framework that can be used once its dimensions are defined.

So the key challenge seems to be to define the dimensions of universal access — the types of barriers that are to be overcome to enable access by the largest number and greatest diversity of people. In this case, we are concerned with access to products that deliver or support health care interventions and assessments. Three barriers, and their associated domains, stand out:

1. Barrier of access to an accessible interface, i.e. one that will enable a user to have access to the intended use or benefit of a health care intervention or assessment capability
2. Barrier of distance, which ranges from challenges related to position and orientation of a person relative to a nearby product within their local environment to challenges due to larger distances of geographical separation between an individual and beneficial products or services
3. Barrier of access because of economic status, which for the present purposes meaning serious consideration of the cost of a product

For the present purposes, we will use an operational definition of universal access that addresses these three important domains of interest — the ability to access a product or service by all who can benefit from the health care intervention or assessment, by overcoming barriers related to the accessibility of the interface, to distance, and to cost. The word *services* is included because so many health interventions and assessments require access to a trained health professional. This definition has an interesting implication: an interface that adds accessibility features by increasing its cost may or may not have increased its degree of universal access. It also implies that a product with some accessible features but without distance-aware support can have a lower degree of universal access than a product with fewer accessible features but with greater means for supporting access across distance or personalized interfaces. These implications might be controversial and subject to discussion, but they seem consistent with policy research within the disability community, such as reviewed in Chapter 14 of this book.

25.3.2.1 Product Access and Acceptance through Designing for Abilities

It has already been mentioned within the context of conceptual interfaces (Subsection 25.2.2) that a key part of interface design involves taking advantage of the abilities of the user. Here is a list of abilities to consider for characterizing an interface, some targeting the human and some the communication technologies that are behind the device interface:

1. Accessibility (ability to access)
2. Usability (ability to use effectively)
3. Reliability (ability to depend on)
4. Interoperability and cooperability (ability to work with other entities)

of all persons to fully
the intended uses of
for which there is potential
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24

5. Learnability (ability to learn)
6. “Safeability” (ability to safely access for intended use)

These represent the classic “big five” abilities plus a new term, *safeability*. Each of these could be viewed as being the most important, depending on the purpose of the analysis. For instance, a product regulatory body such as the FDA would be expected to care most about product safeability, especially in the context of its usability and reliability. Safety and human error is also an important societal issue [8]. Practitioners typically care foremost about reliability. The disability community cares about all of these, but the one that stands out is accessibility, which has been the push within this community in terms of civil rights and laws. The educational community cares especially about learnability, and it is instructive to consider the six principles for accessible learning that form the framework for consensus online learning accessibility guidelines maintained by the IMS Global Learning Consortium [9]:

1. Allow for customization based on user preference
2. Provide equivalent access to auditory and visual content based on user preference
3. Provide compatibility with assistive technologies and include complete keyboard access
4. Provide context and orientation information
5. Follow IMS specifications and other relevant specifications, standards, and guidelines
6. Consider the use of XML

Notice the emphasis on personalized learning interfaces. Brewer (Chapter 23 of this book) makes the case that Weblike interfaces might increase learnability for certain types of medical instrumentation.

As an RERC, the RERC-AMI’s first constituency is the disability community. Hence accessibility must be our first priority. (It is even in our book’s title.) But it is tricky. On the surface, one might think that it is possible for a design to reasonably satisfy all of these criteria. In reality, however, although more often than not there is clear synergy between these concepts, there are clear cases of conflict. For instance, designing for accessibility may lower usability for some or even most people, and potentially reliability and interoperability. Interestingly, the RERC-AMI’s national survey results suggests that individuals care strongly about safe use as well as accessibility (Chapter 2 of this book), and video-based identification of biomechanical access barriers tend to trend closely with identification of safety events (Chapter 14 of this book).

There are approaches for dealing with all of these criteria under one umbrella. The most logical approach is to use the tool of fuzzy logic — a theory and associated collection of technologies that are made for reasoning of this type. This helps explain why, starting with commercial products from Japanese companies during 1980s, many billions of dollars’ worth of products such as cars and washing machines have embedded fuzzy controllers. These fuzzy systems add robustness to their products

i.e., degrees of membership

because this type of logic-based framework approximates the reasoning of human experts. It is a technical tool that can be used to formalize the concept of relative importance. For this reason, the accessibility and preferences taxonomy that our group is developing (see Chapter 28 in this book for an early activity) is recognizing that there can be degrees of abilities and preferences.

Finally, human abilities evolve, especially as a user becomes more experienced with an interface. Abilities include short- and long-term memory, cognition, and skill acquisition. A novice user of a device brings different abilities to the encounter than an experienced user.

25.3.2.2 Distinctions in Dimensions of Accessibility and Usability

, and benefit from use

When those involved in designing and evaluating devices think about making a product more accessible, it is nearly habitual to think in terms of enhancing usability. But the paths for maximizing accessibility and maximizing usability often diverge. Although they are often synergistic, optimizing an interface for accessibility (ability to access) may (and often should) yield different solutions than optimizing for usability (ability to use). This is often not apparent because the abstract ultimate consequences — universal access and universal usability — tend to converge because both use words such as *all* or *everyone*.

Figure 25.3 represents an attempt to explain this difference. At a core level, the domains differ. One cannot assume a monotonically increasing relationship between these two. There are many classic examples. For instance, the Access Board's ADA Accessibility Guidelines [3] include requirements for including design features (e.g., multimodal options) that can make an interface more complex and potentially harder to use. At the level of the individual, a person who has previously lacked access may receive so much benefit from access to a product or service that they may be more than willing to put up with otherwise poor usability. Alternatively, someone with access may prefer greater usability, perhaps even if it denies access to others. Indeed, one of the missions of the RERC on Telecommunications Access is to look out for technological innovation that benefits many but may eliminate previous access for a few (e.g., people with hearing impairments).

Both accessibility and usability can be applied to the needs of an individual or a population. Both are amendable to approaches based on task procedure analysis or design feature analysis, which happen to be the two core pillars of the MED-AUDIT tool that the RERC-AMI is working on as an accessibility metric (Chapter 14 and Chapter 22 of this book).

For individuals, there can be degrees of both accessibility and usability, but with several distinctions, some shown in Figure 25.3b. From the perspective of a task analysis approach, if any subtask during use is impossible, the product cannot be accessed for its intended use and the degree of accessibility is zero for that person. In contrast, a usability analysis may find that it is partially usable by that person. People have remarkable adaptive capabilities, and if an individual finds a creative solution to overcoming a difficulty and thus accesses the intended use of the product, then the product is accessible, perhaps to a large degree, for that person. But from

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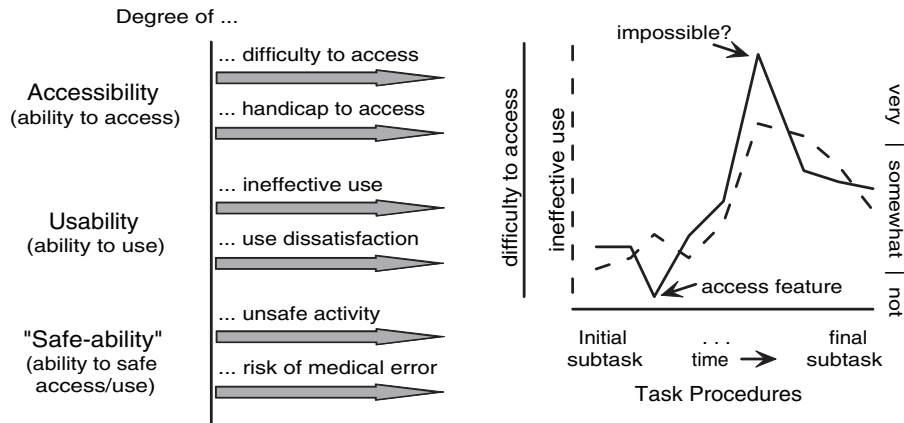


FIGURE 25.3 Possible dimensions of representation, here two each for accessibility, usability and safe-ability. Each is not black-and-white, but rather there are degrees. On the right is a conceptual example showing two of the six dimensions overplotted, with a time axis that represents healthcare task procedures associated with use of a device. This is somewhat similar to how the Mobile Usability Lab (see Chapter 13, [Winters et al.](#)) is used to capture events that are mildly difficult, difficult or impossible for a subject. Notice that on the "difficulty to access" domain, an "impossible" event means the device is not accessible for that person; it is a nonlinear effect. Notice also that an event marked by use of an accessibility feature caused complexity and less effective use. Overall, in comparison to the "difficulty" domain the "ineffective use" domain is more integrative of the whole task.

in this book

a usability perspective, it might be an awful design. If the person needs to use a device feature to obtain access to the product, as long as they can achieve the intended use, then the product is accessible, though there may be degrees of difficulty to access that are worthwhile to evaluate; that is, there may be degrees of usability of an accessibility feature.

It is not always obvious how to determine a population effect from individual effects, or from device effects. Consider the following possible use of "bins" to establish subgroups of the whole population. How would the following be ordered?

1. Considerable difficulty with one essential feature, but no difficulty with all other essential and nonessential features and subtasks
2. Difficulty with most essential features, but able to use and complete task
3. Difficulty with a few essential features, and alternative strategies (one requiring an assistive technology) can be successfully used but with great effort

The order depends largely on the domain being used.

As pointed out in Chapter 18 and Chapter 24 of this book, a population is really a collection of individuals whose traits need to be defined carefully. It is the developers or evaluators who determine the population, either implicitly or explicitly, by how they choose to approach the problem of identifying the characteristics of the

intended users. Ideally, they represent a diverse range of abilities and opinions. For a population, there can be a collection of design features that may be required so as to reasonably accommodate these intended users. Accessibility guidelines try to extend the size of the population of intended users to include everyone or nearly everyone. Furthermore, as developed in Chapter 8 of this book, accessibility guidelines include statements such as the following:

Provide one mode that is operable without: pointing, vision, fast response, fine motor, simultaneous action, speech, presence of body parts.

Perhaps the clearest distinction between accessibility and usability comes with how standards bodies treat the two concepts (not how they define them). Accessibility guidelines permeate many recent standards activities and tend to take the form of a design features approach, e.g., in the form of a checklist (e.g., see Chapter Pt2_Gardner-Bonneau). Engineers tend to like such guidance as it provides concrete design specifications. But the result can be accessible products that may or may not be usable. Usability standards and human factors standards tend to focus primarily on processes and practice techniques that shape designer strategies and user performance.

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(e.g., see Chapters 16 and 17 of this book)

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25.3.2.3 Whenever Feasible, Design for Abilities and to Extend Proprioception

Many human–device interfaces work despite the limitations of the designer. For instance, kids who are really engaged in playing video games can learn virtually any mapping that the game designer employs between game functions and the joystick or gamepad controls. This reflects the remarkable capacity of human to learn and adapt. For instance, humans have the potential capability to:

1. Excel at pattern recognition
2. Adjust to or even find alternative interfaces
3. Use redundancy that is built into their system (e.g., many more muscles than joint degrees of freedom, more joint degrees of freedom than endpoint degrees of freedom, massive degrees of sensor redundancy and perhaps central processing structures) to find alternative solutions or discover ways to use multimodal interfaces
4. Have the highest ability to learn of any creature that we are aware of
5. Acquire new skills (over time)
6. Be easily overwhelmed by a novel interface or context

When an individual has functional impairments, they often find that other functional abilities can become enhanced. Examples abound — the blind person with remarkable ability to process sound, the manual wheelchair user with impressive arm strength, or the deaf person with exceptional observational skills.

Consider the combined human–device system. The user and the device both bring abilities to the encounter. When viewed together, it makes sense to enhance

overall system performance by taking advantage of available abilities of the human system. For instance, it is typically best for the human to act as supervisor. Yet it is often worthwhile for the human to delegate control for tedious tasks to the device.

Often the user desires consistency, predictability, and control when interacting with a device. Also, the device is often used as a tool, usually in a two-way (bi-causal) contact interface mode. As noted earlier, EPP is a concept that was defined by Simpson [4] based on observations of users of body-powered upper extremity prostheses. With practice, often the device became a true prosthesis, or a part of self, as if the two had become one. The device had essentially become encompassed into the physical apparatus that was under direct neuromotor control and subconscious use ~~with~~ minimal requirements for attentional resources. EPP can apply to objects such as a pencil, tennis racket, or computer mouse. It is an ideal, ~~highly usable~~ interface to be strived for, ~~when possible~~, that is often overlooked as a possibility.

, with



25.3.2.4 Recognize Alternatives of Universal Design and Personalized Design

As mentioned in Section 25.1, UD and personalized interface design are viewed here as alternative strategies. Sometimes both may be integrated into a strategy for an accessible interface design.

UD describes the characteristics that make a design more universally usable. As noted in Chapter 18 of this ~~chapter~~, UD is the highest standard of usability, and represents an unachievable goal for most types of products that is nonetheless worth striving for. In other words, it has ceiling (saturation) effects, ~~i.e., limitations~~, depending on the type of product. Key concepts related to universally designed interfaces are ~~designing for~~ integrating ~~in~~ redundancy and direct access ~~to~~ operation, and ~~all content without~~ relying on the aid of an individual's assistive technology or user agent.

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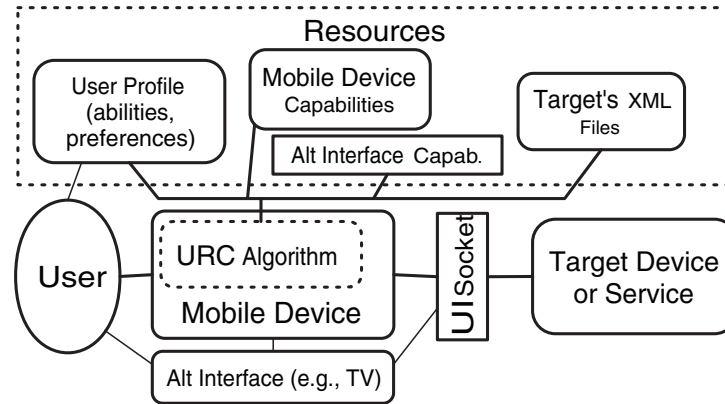
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Personalized interface designs are customized to the abilities and preferences of the user. In contrast to interface redundancy, personalized interfaces emphasize establishing equivalency of modes and compatible access. Specifically, the interface is designed with "hooks" to the user's assistive technology or user agent. These hooks are often based on standardized interface protocols. Motivation for this approach is described especially in Chapter 27 of this book. Interestingly, the examples presented there and in Chapter 28 of this book describe a standard called a user interface socket (UI Socket), which is defined by a collection of XML files that are used to form a presentation mapping between the personalized interface (called a universal remote console) and the target device or service [10]. Such a universal technical interface or socket supports a remapping of the interaction across the human-technology interface. In this sense, it can be viewed as a sort of assistive technology that travels with a person as their personalized user agent interface. This UR interface may itself take advantage of UD concepts, but it also may not need to. One consequence of personalized design is that although it may be less inclusive, such an interface can potentially enable higher user performance. It also can add consistency and predictability for the user. This perhaps explains the learning

(see Figure 25.4)



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FIGURE 25.4 UI Socket as an interface between a URC and a target, here from the perspective of the URC algorithm that must generate an interface. It is assumed that URC algorithm functions as an intelligent agent of the user that often “knows” something about the user’s abilities and preferences by reading a user profile resource. It is also assumed that the user has a mobile device (e.g., PDA), but may take advantage of alternative devices (e.g., TV monitor) when they are in range and available.

User Interface (UI)

community’s seeming preference for personalized access interfaces, as reflected by the IMS Global Learning Consortium’s published principles and guidelines [9].

Technologies related to personalized interfaces, such as those related to personalized medicine, will continue to advance simply because of the magnitude of the commercial investment in the area, especially as related to mobile devices. The W3C’s Device Independence Working Group is an example of the degree of interest in industry and the recognition of need for more intelligent interfaces that include multimodal interaction capabilities. This is very promising for future universal access. Intelligent interfaces can be conceptualized into two types [5]: intelligent/user assistants and intelligent/user agents. The main difference between an assistant and an agent is that an intelligent assistant works as an AT that actively assists the client, for example, in performing tasks associated with device use. This can include reminders, functioning as a predictable assistive technology, or providing direct cooperative functional assistance. In contrast, a supervised intelligent agent acts as a broker on behalf of the client, interacting with other entities on their behalf when the activity is discerned to be within the scope of their accepted role [11]. An analogy is an effective administrative assistant who has learned when to function in the role of assistant and when to function in the role of agent.

Both have value.

Multi-modal interfaces fit conceptually with either UD or personalized interface design, depending on the context and circumstances. However, rarely is multimodality transparent and, thus, in addition to enhancing accessibility it often adds complexity to the interface. There are also performance tradeoffs between modes, for instance, between sensory modes of visual and audio displays, and between motor modes of hand and speech operation.

Given that individuals with disabilities make disproportionately large use of medical devices and services, how will this impact on future medical device interfaces? Could the medical device industry provide leadership in interface innovation or will this generally conservative and late-adopting industry lag behind? And in any case, what might these changes be? What will be the drivers?

25.3.2.5 Recognize That in Striving toward Universal Access, We Cannot Sacrifice Safety or Increase Risk of Use Error

16 and 17

As reviewed in Chapter 3 of this book in the context of practitioner use and Chapter 16 of this book for device evaluation, statistics show that use error is a major societal challenge. The medical device industry is regulated, and within the U.S. the responsible agency is the FDA, which has been given the charge of evaluating products using the criteria of safety and efficacy. Considering that the eighth leading cause of death in the U.S. is said to be medical error [8], it is apparent that there is a need for study of the “science of people” in the context of interfaces. For many health care products, especially ones used within the home setting, the proportion of intended users with activity limitations or disabilities greatly exceeds the 19% of the general population that has a disability. In considering the possibility of enhancing access to products and noting that accessibility is not the same as usability, what are the risks? This is an important question, one that needs answers.

25.4 FUTURE DIRECTIONS: INITIATIVES AND OPPORTUNITIES

The title of this chapter indicated a focus on future possibilities for interfaces that enhance universal access to health care devices and services. It has been suggested that the designer of the future is going to have considerably more options to consider and, furthermore, the conceptual framework and design and evaluation methodology will impact on her or his choices. It has also been emphasized that given the considerable variety of roles for health care devices and services, many types of solutions should be expected. Finally, a definition of *universal access* was proposed, which suggested that in addition to accessible interface features, cost and distance should also be considered.

the selected

With this as a context, several future possibilities are put forward for consideration, with an emphasis on areas of major need, as reflected by results of the RERC-AMI’s national consumer survey (Chapter 2 of this book).

For exam tables, exam chairs, and beds, consider the following:

- Mechanical “gravity-assist” that minimizes power by the human through potential energy fields operating on device interface
- Mechanical “power-assist” that uses EPP, with force-assist and velocity matching (where F is force and v is velocity at an interface):

requirements
at the

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- $F_{\text{user}} * v_{\text{user}} = K * (F_{\text{device}} * v_{\text{device}}) = (K * F_{\text{device}}) * v_{\text{device}}$.
- Orientation-assist multimodal cues to help users orient a user to EPP controllers, and URC for a PD interface that serves to control access to the EPP interface, ~~plus remotely control~~ any non-EPP powered degrees of freedom

while also providing remote control for

For medical monitors intended for shared hospital use by trained clinicians/technicians under time pressure, consider the following:

- Design a default interface for UD, but then have a PD interface (e.g., customized remote control, customized voice recognition), so as to improve both performance and shared access (e.g., across distance) to changing settings.
- Encourage PDs with open standards for certain classes of devices, including both for interfaces and for transparent medical informatics, with both supported by intelligent agents.

using

principles

For health care monitors and infusion products intended for home use and remote support, consider the following:

- Start with assumption that any such system should include universal access across the domains of interface accessibility, distance, and cost. Also, that home-based monitoring and infusion systems of the future will be primarily mobile devices, continuing a recent trend.
- Design a simple interface using basic UD (a bit more involved for infusion systems), augmented by a proactive multimodal PD system that includes a URC interface that can also make use of other available home display devices such as TV monitors.
- Provide proactive telesupport, including automatic remote transfer of monitoring data, interactive reminders, and an intuitive multimedia interface (that supports image transfer, videoconferencing, educational streaming).

an

which is

For exercise ergometers for home use:

Proactively incorporate UD principles into the

Provide

Provide

- ~~Have~~ physical apparatus ~~that proactively incorporates UD strategies~~
- ~~Have~~ a display/control interface that proactively incorporates multimodal PD that furthermore supports either a built-in modular display (perhaps with virtual reality goggles) or use of alternative display/control (e.g., local TV/computer monitor)
- ~~Have~~ support for alternatives of possible interest to clients, including telemonitoring, automated storage, tele-encounters, and virtual gaming.

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