method of training a more general class of HMM, called the "Coupled Hidden Markov Model." Coupled HMM's allow each hand to be described by a separate state model, and the interactions between them to be modeled explicitly and economically. The consequence is that much less training data is required, and the HMM parameter estimation process is much better conditioned [6].

Almost every room has a chair, and body posture information is important for assessing user alertness and comfort. Therefore, our smart chair senses the pressure distribution patterns in the chair and classifies the seating postures of its user (See Tan below). Two Tekscan sensor sheets (each consisting of a 42-

Haptic Interfaces

Hong Z. Tan

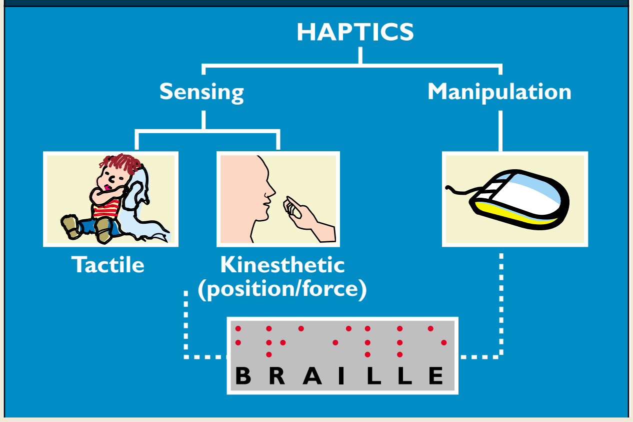
Creating interfaces that envelop a sense of touch has met with measured success.

The term "haptics" refers to sensing and manipulation through the sense of touch. Although the word haptics may be new to you, chances are that you're already using haptic interfaces (for example, your keyboard and mouse). As Figure 1 shows, the haptic sensory system (or taction) is usually regarded as having two components: *tactile* (or cutaneous) sensing, and *kinesthetic* sensing (or proprioception). Tactile sensing refers to an awareness of stimulation to the outer surface of the body (the softness of a blanket). Kinesthetic sensing refers to an awareness of limb position and movement (for example, an ability to touch your nose with your eyes closed), as well as muscle tension (for example, estimation of object weights) [1]. Unlike vision and audition that are mainly input systems for the human observer, the haptic system is bidirectional. Many activities, such as the reading of Braille text by the blind, require the use of both the sensing and manipulation aspects of the haptic system.

Of the five major human senses—vision, audition, taction, olfaction, and gustation—only the first three have been engaged in most human-machine interface research. Of these three, a disproportional majority of work has been conducted on visual and auditory systems. Historically, work on haptic display has been motivated by the desire to develop sensory-substitution systems for the visually or hearing impaired. Examples include the Optacon (Telesensory Corp., Mountain View, Calif.,), a reading aid for the blind [4]; and TactaidVII (Audiological Engineering Corp., Somerville, Mass.,), a hearing aid for the deaf [6]. These systems can be characterized by an array of vibrators that transform optical or acoustic energy into spatial vibrational patterns. In the past two decades, force-feedback devices (a type of kinesthetic display) have played an important role in teleoperation and virtual reality systems by improving an operator's task performance and by enhancing a user's sense of telepresence. Examples include the Impulse Engine™ (Immersion Corp., San Jose, Calif.) and the popular PHANToM™ (SensAble Technologies Inc., Cambridge, Mass.) [5].

Depending on the direction of information flow (see Figure 2), a human observer would either regard a haptic interface as a display (for example, Optacon, TactaidVII, Impulse Engine, and PHANToM) or a controller (computer mouse). A computer would either render a haptic world through devices such as the PHANToM, or perceive haptic information through contact sensors. An example of a haptic perceptive UI is the sensing chair. Originally conceived at the MIT Media Lab and currently being developed at Purdue University, the sensing chair project is aimed toward a real-time system that tracks the sitting postures of a user through the use of surface-mounted contact sensors (enclosed in the green protective pouches as shown in Figure 3). The realization of a robust tracking system will lead to many exciting applications

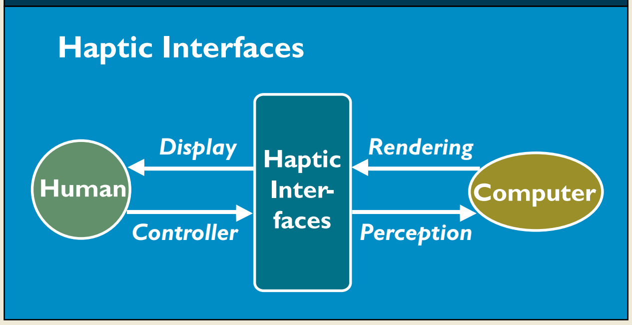
Figure 1. Definition of haptics.



by-48 array of force-sensitive resistor units) are mounted to the seatpan and the backrest of the chair and output 8-bit pressure distribution data. This data is collected and the posture is classified using image modeling and classification algorithms.

The current version of the real-time seating posture classification system uses a statistical classification method originally developed for face recognition. For each new pressure distribution map to be classified, a "distance-from-feature-space" error measure is calculated for each of the M postures and compared to a threshold. The posture class that corresponds to the smallest error is used to label the current pressure map, except when all error values exceed the threshold

Figure 2. Information flow with haptic interfaces.



such as automatic control of airbag deployment forces, ergonomics of furniture design, and biometric authentication for computer security.[1]

Figure 3. The sensing chair is a haptic PUI

Despite the progress made in the past two decades (see Srinivasan in [3]), haptic interfaces have not yet become commonplace. One reason, I think, is the technological challenge associated with the design and fabrication of interfaces that make physical contact with human users. This, however, will change as haptic technology matures. The other reason is the lack of killer apps for haptic user interfaces.

To really appreciate the human haptic sensory system requires an understanding of what happens if we are deprived of it. Imagine what happens if one loses the tactile sense. We have all experienced the lack of dexterity with a gloved hand. What happens if one loses the kinesthetic sense? Such cases are rare, but one is well documented in Cole's book on Ian Waterman who, at the age of 19, lost all sensation below his neck [2]. Without that sixth sense of joint and limb positions in space, he fell on the floor in a heap, unable to stand or walk. With sheer courage and determination, Waterman eventually taught himself to walk again by constant visual monitoring of his body position. However, as Cole pointed out, Waterman's new way of walking was like "a wooden puppet activated by a novice." It lacked the grace observed in our movements of walking, dancing, and running.

The fact that Waterman could walk at all with visual feedback alone attests to our ability to accomplish almost any task with vision. The fact that he could no longer walk gracefully suggests to me that perhaps the killer app of haptic interfaces is to make human-computer interactions more intuitive, natural, and above all, graceful. **C**

[1] It is much easier to change one's appearance or voice than to fake the distance between the ischial tuberosities (sitting bones), something that is readily detectable by our chair sensors.

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