recognize an emotional expression in neutral-content speech with about 60 percent accuracy, choosing from among about six different affective labels [10]. Computer algorithms match or slightly beat this accuracy, e.g., [11], [12]. Note that computer speech recognition that works at about 90 percent accuracy on neutrally-spoken speech tends to drop to 50-60 percent accuracy on emotional speech [13]. Improved handling of emotion in speech is important for recognizing what is said, as well as how it was said.

Facial expression recognition is easier for people, e.g., 70-98 percent accurate on six categories of facial expressions exhibited by actors [14] and the rates computers obtain range from 80-98 percent accuracy when recognizing 5-7 classes of emotional expression on groups of 8-32 people [15], [16]. Other research has focused not so much on recognizing a few categories of emotional expressions but on recognizing specific facial actions—the fundamental muscle movements that comprise Paul Ekman's Facial Action Coding System—which can be combined to describe all facial expressions. Recognizers have already been built for a handful of the facial actions [17], [18], [19], [20], and the automated recognizers have been shown to perform comparably to humans trained in recognizing facial actions [18]. These facial actions are essentially *facial phonemes*, which can be assembled to form facial expressions. There are also recent efforts that indicate that combining audio and video signals for emotion recognition can give improved results [21], [22], [23].

Although the progress in facial, vocal, and combined facial/vocal expression recognition is promising, all of the results above are on presegmented data of a small set of sometimes exaggerated expressions or on a small subset of hand-marked singly-occurring facial actions. The state-of-the-art in affect recognition is similar to that of speech recognition several decades ago when the computer could classify the carefully articulated digits, "$0, 1, 2, \ldots, 9$," spoken with pauses in between, but could not accurately detect these digits in the many ways they are spoken in larger continuous conversations.

Emotion recognition research is also hard because understanding emotion is hard; after over a century of research, emotion theorists still do not agree upon what emotions are and how they are communicated. One of the big questions in emotion theory is whether distinct physiological patterns accompany each emotion [24]. The physiological muscle movements comprising what looks to an outsider to be a facial expression may not always correspond to a real underlying emotional state. Emotion consists of more than its outward physical expression; it also consists of internal feelings and thoughts, as well as other internal processes of which the person having the emotion may not be aware.

The relation between internal bodily feelings and externally observable expression is still an open research area, with a history of controversy. Historically, James was the major proponent of emotion as an experience of bodily changes, such as your heart pounding or your hands perspiring [25]. This view was challenged by Cannon [26] and again by Schachter and Singer who argued that the experience of physiological changes was not sufficient to discriminate emotions. Schachter and Singer's experiments showed that, if a bodily arousal state was induced, then subjects could be put into two distinct moods simply by being put in two different situations. They argued that physiological responses such as sweaty palms and a rapid heart beat inform our brain that we are aroused and then the brain must appraise the situation we are in before it can label the state with an emotion such as fear or love [27].

Since the classic work of Schachter and Singer, there has been a debate about whether or not emotions are accompanied by specific physiological changes other than simply arousal level. Ekman et al. [28] and Winton et al. [29] provided some of the first findings showing significant differences in autonomic nervous system signals according to a small number of emotional categories or dimensions, but there was no exploration of automated classification. Fridlund and Izard [30] appear to have been the first to apply pattern recognition (linear discriminants) to classification of emotion from physiological features, attaining rates of 38-51 percent accuracy (via cross-validation) on subject-dependent classification of four different facial expressions (happy, sad, anger, fear) given four facial electromyogram signals. Although there are over a dozen published efforts aimed at finding physiological correlates when examining small sets of emotions (from 2-7 emotions according to a recent overview [31]), most have focused on t-test or analysis of variance comparisons, combining data over many subjects, where each was measured for a relatively small amount of time (seconds or minutes). Relatively few of the studies have included neutral control states where the subject relaxed and passed time feeling no specific emotion, and none to our knowledge have collected data from a person repeatedly, over many weeks, where disparate sources of noise enter the data. Few efforts beyond Fridlund's have employed linear discriminants, and we know of none that have applied more sophisticated pattern recognition to physiological features.

The work in this paper is novel in trying to classify physiological patterns for a set of eight emotions (including neutral), by applying pattern recognition techniques beyond that of simple discriminants to the problem (we use new features, feature selection, spatial transformations of features, and combinations of these methods) and by focusing on "felt" emotions of a single subject gathered over sessions spanning many weeks. The results we obtain are also independent of psychological debates on the universality of emotion categories [32], focusing instead on user-defined emotion categories.

The contributions of this paper include not only a new means for pattern analysis of affective states from physiology, but also the finding of significant classification rates from physiological patterns corresponding to eight affective states measured from a subject over many weeks of data. Our results also reveal significant discrimination among both most commonly described dimensions of emotion: valence and arousal. We show that the day-to-day variations in physiological signals are large, even when the same emotion is expressed, and this effect undermines recognition accuracy if it is not appropriately handled. This paper proposes and compares techniques for handling