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Nonlinear Dynamics and Motion In Human Face Image Space

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Oral /Poster Presentation

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Short Abstract

The main contribution of this research is two-fold: (a) we provide a rigorous substitute for the intuitive regularity observed in visual perception, by appealing to information geometry; and, (b) we provide a set of algorithms for estimating measures of curvilinear invariants of data space through nonparametric statistical estimation of natural dynamics within the set of images. We relate the nonlinearity of the image space of human faces to temporal dynamics in facial movements and other optically detectable variations.

Perceptual Geometry And Dynamics In Human Face Image Space

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1 Purpose

Working with "real world" data sets from natural images, such the human face, in recognition or classification tasks is inherently difficult because we do not have access to spatial distribution of the feature vectors representing the data. We propose a method for extracting information about the curvilinear geometry of parameters that optimally represent (constrained by resolution, error tolerance and scale) such data based on locally linear methods and a new theory that integrates globally the extracted local structures. We apply these techniques to human face data to describe nonlinear and approximately linear parts of the image space. Our results lead to interpretations the role of nonlinear dynamics of the brain in binding problems of visual perception.

2 Method

Differential geometry emerged from application of estimating local variations of geometric structures defined by a set of parameters, typically, a coordinate system on a manifold. The majority of such estimates are linear, and occasionally some second order estimates when the two orders must be combined in one framework. The success of differentiation, however, depends on rigor in the infinitesimal calculus of such estimations, and in turn, highly dependent on assumptions about smoothness of the variation of the underlying set of parameters. When dealing with a massive data set, the investigator encounters at least two difficulties. First, the large number of data points eliminates the possibility of combinatorial sorting of the points, and any intuition or heuristics that human perception is capable of associating geometric formalisms to a finite set of points. Therefore, the so-called combinatorial explosion is a manifest of our lack of cognitive capability to conceptualize and associatively accommodate spatial organization of a set of points beyond a few handfuls. The second difficulty is the so-called curse of dimensionality, where the space containing the feature vectors is usually of a dimension higher than what could be “visualized”, or more precisely, conceptualized in terms of more familiar structural associations. In exceptional circumstances, these difficulties could be surmounted, and logical inferences from data become available. Beyond strict limitations of number and dimension, statistical inference from massive data sets remains on a case-by-case problem, very much dependent on the nature of data and methods of measurements. When dealing with natural images, such as faces, the great variability of features makes traditional learning methods subject to both combinatorial explosion and curse of dimensionality. This complexity is however, balanced by the intuitively high degree of regularity of spatial organization of salient features.

In this paper, we propose a solution for describing the nonlinear dependencies between two principal components of data in the two-dimensional plane. Describing the nonlinearity of data is sometimes referred to as *nonlinear feature extraction*. When we are given a data set, it is usually just a sample of some population that itself could be of infinite size. To complicate matters, our sampling method is almost always subject to noise. With this in mind, extracting the feature from a data set is an ill-posed problem in the mathematical sense.

Our solution to the feature extraction problem involves use of what we have termed *local-to-global principal component analysis* (LGPCA). This idea is inspired by the geometric theory of dynamical systems. In this theory, the system of equations is represented by non-parametric regression to constructing a collection of pointwise orthogonal vector fields. These vectors are tangent to *integral submanifolds*: the solution of a linear system of differential equations with given boundary conditions. Our solution involves the use of a variant of PCA applied locally to neighborhoods of points to compute the local principal components.

3 Results

The main contribution of this research is two-fold: (a) we provide a rigorous substitute for the intuitive regularity by appealing to information geometry; and, (b) we provide a set of algorithms for estimating measures of curvilinear invariants of data space through nonparametric statistical estimation of natural dynamics within the set of images. We demonstrate the effectiveness of our technique when applied to both synthetic and real data. In particular, we are able to relate the nonlinearity of the image space of human faces to temporal dynamics in facial movements and other optically detectable variations.

4 New or breakthrough aspects of work, and biological relevance

We have determined an efficient method for describing the nonlinearity of a data space of human face images. Moreover, we have analyzed stability of principal components using nonlinear dynamical systems, and use this to understand the geometric reason for our perception of regularity of human faces despite such great diversity. Our work applies to compression of face images and their movement, emotion, etc.