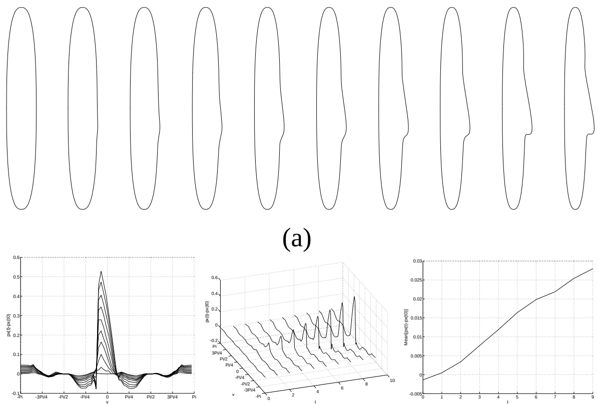
that the model under consideration ($\mathbf{m}_0$) was instantiated, k is an a priori defined constant and $\mathbf{d}$ is the vector of local deformations.



(a)

(b) (c) (d)

Figure 5: As the protrusions to a shape are evolving over time (Fig.(a)), we monitor the local deformations of the model (shown superimposed in Fig.(b) and over time in Fig.(c)) and the variation of the mean of their magnitude (Fig. (d)).

Parametric Composition Algorithm

I: Determine the extent of the area of the maximum variation of local deformations at $\mathbf{m}_0$.

II: Perform an eigenvector analysis on the data points that correspond to this area of the model, to approximate the parameters of a deformable model $\mathbf{m}_1$ which can describe these data.

III: Construct a composed parametric primitive $\mathbf{m}$ with defining primitives $\mathbf{m}_0$ and $\mathbf{m}_1$ (as explained in section 2.1).

IV: Update the list L, by replacing the model $\mathbf{m}_0$ with the composed model $\mathbf{m}$.

HBPDS - Step 3b: We continuously fit the models of the updated list L to the time-varying data. In the case of a composed model, we monitor the parameters of its defining primitives. If these parameters indicate that the defining primitives are moving with respect to one another then this indicates that we have two distinct parts. We determine the existence of two parts using the following criterion.

Part Decomposition Criterion A: Decompose a composed model $\mathbf{m}$ (with underlying primitives $\mathbf{m}_0$ and $\mathbf{m}_1$), when its generalized coordinates satisfy the relation $\|\Delta\theta(t) - \Delta\theta(t_{\text{init}})\| > k_A \ \vee \ \|\Delta\mathbf{q}_c(t) - \Delta\mathbf{q}_c(t_{\text{init}})\| > k_B$, where k_A and k_B are two *a priori* defined constants and t_{init} is the time that the composed model was instantiated. In addition, $\Delta\theta(t)$ is the angle between the reference frames of the defining primitives and $\Delta\mathbf{q}_c(t) = \mathbf{q}_{c_1}(t) - \mathbf{q}_{c_0}(t)$.

Part Decomposition Algorithm A

I: Construct two new models $\mathbf{n}_A$ and $\mathbf{n}_B$ using the parameters of the defining models of the composed model $\mathbf{m}$.

II: Update G and L, by replacing $\mathbf{m}$ with $\mathbf{n}_A$ and $\mathbf{n}_B$.

Later, joints between the parts are estimated employing the algorithm for joint estimation described in [5].

HBPDS - Step 3c: We now discuss the significance of the appearance of a hole within the outline. The visual event of a hole appearing within the outline indicates that parts which were initially occluded are gradually becoming visible. During this process though, the regions of the part that become visible are not contiguous, thus the appearance of the hole. Therefore, when a hole is present within the outline of a shape with large local deformations (e.g., $\mathbf{m}_0$), we do not invoke the parametric composition algorithm. We monitor the evolution of the hole, and when the hole ceases to exist (and the shape of the model exhibits large local deformations), then we invoke the Part Decomposition Algorithm C. To this end, we hypothesize that the data points that belong to the area of $\mathbf{m}_0$ with large local deformations, belong to a second part. We initialize a new deformable model $\mathbf{m}_1$, and replace $\mathbf{m}_0$ with the models $\mathbf{m}(t_{\text{init}})$ and $\mathbf{m}_1$. We fit these models to the given data, using our weighted-force assignment algorithm [5] and the physics-based framework introduced in [9]. In the following, we describe the modifications to the framework which are needed to accommodate fitting of composed models to time-varying data.

3.1 Dynamics of fitting a composed model

In the physics-based framework, the geometric degrees of freedom of a shape (translation, rotation, global and local parameters) form the generalized coordinates of the model. For a composed model, $\mathbf{q}_0 = (\mathbf{q}_{c_0}^\top, \mathbf{q}_{\theta_0}^\top, \mathbf{q}_{s_0}^\top, \mathbf{q}_{d_0}^\top)^\top$ and $\mathbf{q}_1 = (\mathbf{q}_{c_1}^\top, \mathbf{q}_{\theta_1}^\top, \mathbf{q}_{s_1}^\top, \mathbf{q}_{d_1}^\top)^\top$ are the generalized coordinates of the root and intersecting primitives, respectively. $\mathbf{q}_{c_i} = \mathbf{c}_i(t)$, $\mathbf{q}_{\theta_i}$ is the quaternion that represents $\mathbf{R}_i(t)$, $\mathbf{q}_{s_i}$ is the vector of global parameters, and $\mathbf{q}_{d_i}$ is the vector that specifies local deformations (i=0,1). The generalized coordinates of the composed primitive are: $\mathbf{q} = (\mathbf{q}_0^\top, \mathbf{q}_1^\top, \mathbf{q}_{\text{com}}^\top)^\top$, where $\mathbf{q}_{\text{com}} = (v_{\min}, v_{\max}, c)^\top$ are the generalized coordinates of the composition function. For the purposes of shape and motion estimation, we recover the generalized coordinates $\mathbf{q}$ in a physics-based way. Following the notation in [9], $\dot{\mathbf{x}}_0 = \mathbf{L}_0\dot{\mathbf{q}}_0$ and $\dot{\mathbf{x}}_1 = \mathbf{L}_1\dot{\mathbf{q}}_1$. From (1) we obtain:

$$\dot{\mathbf{x}} = [(1-\delta(v))\mathbf{L}_0 \mid \delta(v)\mathbf{L}_1 \mid (\mathbf{x}_1(v) - \mathbf{x}_0(v))\frac{\partial\delta(v)}{\partial\mathbf{q}_{\text{com}}}]\,\dot{\mathbf{q}}$$

Therefore, the jacobian of the composed model depends on the jacobians of the defining models. The degree of dependence is regulated by the values of the composition function.

4 Experiments

We have performed several experiments demonstrating our integrated approach to segmentation, shape and nonrigid motion estimation of human body outlines.The input