two legs do not fully occlude each other), the actor flexes the foot. Then, the actor bends the knee. In the second phase, from the position where the left (or right) leg is extended, the actor steps forward and raises the rear leg. Again, when the rear leg reaches a comfortable position, the actor flexes the foot and then bends the knee.

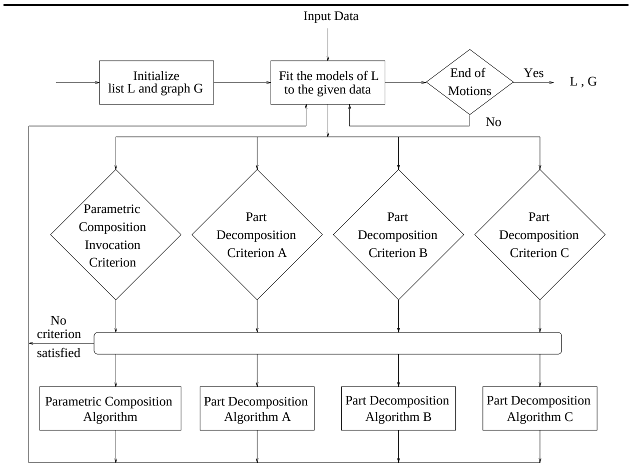

Figure 3: Flow diagram of the Human Body Part Decomposition Algorithm.

To accomplish the goal of segmentation of human body outlines, we apply the following strategy (Fig. 3).

Human Body Part Decomposition Strategy (HBPDS)

Step 1: Assume that the human body consists of a single part. Initiate a list of deformable models L (with one entry initially) that will be used to model the parts of the human body. In addition, initiate a graph G with one node. The nodes of the graph G denote the parts of the human body recovered by the algorithm. The edges of the graph denote which parts are connected by joints (Fig. 4 (a-f)).

Step 2: If not all the frames of the motion sequence have been processed, fit the models of the list L to the given data using our physics-based shape and motion estimation framework. Otherwise, output L and G.

Step 3: Perform the following steps in parallel:

a: For each model, determine if the *Parametric Composition Invocation Criterion* is satisfied.

b: For each composed model, determine if the *Part Decomposition Criterion A* is satisfied.

c: For each model, determine if the *Part Decomposition Criterion B* is satisfied.

d: For each model, determine if the *Part Decomposition Criterion C* is satisfied.

Step 4: At most one of the criteria specified in step 3 will be satisfied. Depending on the outcome, we determine which one of the following algorithms to apply.

- If 3a is satisfied, invoke the *Parametric Composition Algorithm* (as explained below). Then, go to step 2.
- If 3b is satisfied, invoke the *Part Decomposition Algorithm A*. Then, go to step 2.
- If 3c is satisfied, invoke the *Part Decomposition Algorithm B*. Then, go to step 2.
- If 3d is satisfied, invoke the *Part Decomposition Algorithm C*. Then, go to step 2.
- If none of the criteria detailed in step 3 apply, go to step 2.

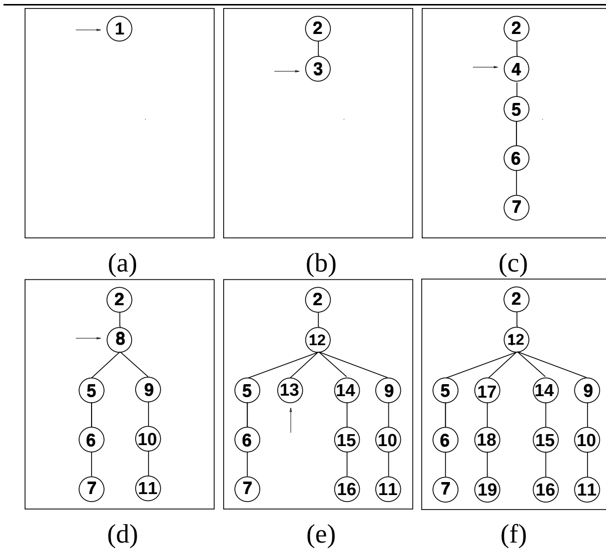

Figure 4: (a) Initially the graph of parts consists of one node. We denote by an arrow the node that has been refined in the next iteration. (b) At the completion of the head motion the graph consists of one node for the head and one for the rest of the body. (c) At the end of the motion of the left arm, the node for the rest of the body will be refined to consist of a node for the left arm, one for the left forearm, one for the left upper arm and one for the rest of the body. (d) Similarly, at the end of the motion of the right hand, our graph will contain nodes for the right upper body extremities. (e) At the end of the motion of the left leg, our graph will contain nodes for the lower body extremities. (f) The nodes of the graph at the end of all pre-specified motions.

The Part Decomposition Criterion C and the related algorithm apply to moving chain-like structures with non occluded parts (e.g., non occluded arms and legs) and have been described at [5]. In this paper, we extend that work in order to be able to fully segment human outlines. In the following, we present the criteria and the related algorithms in more detail.

HBPDS - Step 3a: As the actor attains new postures the outline changes dynamically. Large protrusions emerge at the outline as the result of the motion of the limbs. If there is no hole present at the outline [3], we represent the protrusions as the result of composition of two primitives when the following criterion holds.

Parametric Composition Invocation Criterion: Signal the need for parametric composition of primitives if no hole is present at the outline and $\|\mathbf{d}(v,t) - \mathbf{d}(v,t_{\text{init}})\| > k$, where t_{init} is the time

[3] We will discuss the significance of a hole within the outline, when we talk about step 3c.