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Human Body Shape Prediction and Analysis Using Predictive Clustering Tree

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Abstract—Predictive modeling aims at constructing models that predict a target property of an object based on its descriptions. In digital human modeling, it can be applied to predicting human body shape from images, measurements, or descriptive features. While images and measurements can be converted to numerical values, it is difficult to assign numerical values to descriptive features and therefore regression based methods cannot be applied. In this work, we propose to use Predictive Clustering Trees (PCT) to predict human body shapes from demographic information. We build PCTs using a dataset of demographic attributes and body shape descriptors. We demonstrate empirically that the PCT-based method has similar predicting power as the numerical approaches using body measurements. The PCTs also reveal interesting structures of the training dataset and provide interpretations of the body shape variations from the perspective of the demographic attributes.

Keywords-Predictive modeling; digital human modeling; predictive clustering tree; demographic attributes;

I. INTRODUCTION

Many applications require realistic 3D models of human shape. One way of doing this is through digitizing real humans using 3D imaging techniques like range scanning. Indeed, large databases of range scans have been collected to form samples of entire populations. The scans can be further processed to build statistical models in which the variability of human shape can be analyzed. The statistical models allow parameterizing the space of human shape and thus generate an arbitrary number of virtual, but statistically real human shapes.

A statistical model of the human shape can also be used as priors to infer 3D shapes from partial shape information. For example, Blanz and Vetter [7] use a statistical model, called *morphable model*, built from 3D scans of faces to reconstruct 3D face models from 2D images. 3D body shapes can also be generated from traditional anthropometric measurements such as height, waist circumferences, and the lengths of the limbs [2].

In practice, demographic data are also collected in 3D anthropometry surveys. For example, in the CAESAR survey (CAESAR - Civilian American and European Surface Anthropometry Resource), information such as age, ethnicity, marital status, occupation, etc. are collected [14]. Many of these attributes are non-numerical. For example, marital

status may have values like “single”, “married”, “divorced” or “widowed”. Intuitively, some of these attributes must relate to body shape. Natural questions arise: can we predict human body shape from some of these demographic attributes? If so, to what extent can we predict? The answers to these questions have potential applications in many areas. For example, in a forensic investigation where a suspect’s picture is not available, face or body shape may be predicted from other features, e.g., age, ethnicity, marital status and occupation. One may also use this kind of prediction for designing and marketing products for targeted populations.

In this paper, we predict human body shapes from descriptive features. We propose to exploit the relationship between human body shape and demographic information using Predictive Clustering Trees (PCTs) [8]. PCTs capture the structure of the data by building hierarchical clusters. Once the PCTs are constructed from the training data, prediction is done by traversing the trees using the descriptive attributes. Besides shape prediction, the PCTs also provide induction rules that help us analyze the shape data from the perspective of the descriptive attributes.

We test the proposed approach on the CAESAR database which consists of 5,000 full-body scans sampled from the North American and European populations. Each scan is accompanied with 44 traditional anthropometric measurements and 19 demographic attributes. We compare our approach using the demographic data with the prediction using numerical anthropometric measurements as it is done by Allen et al. [2]. Our experiments show that the PCT-based approach has similar predictive power.

The contributions of this work consist of two parts:

- 3D body shape prediction from demographic attributes. This is particularly useful when body measurements are not available.
- an interpretation of body shape difference with respect to demographic attributes.

II. RELATED WORK

Much work has been done on the statistical shape analysis of human heads [7], [11], [20] and bodies [1], [4], [5], [18]. Parameterization of raw scans creates new representations which are consistent on head or body features. This enables a morphable shape model being built for training-based

applications, which include reconstruction from measurements [1], [2], [15], 2D images [6], [7], [9], [16], [19], landmarks [1], [4], and partial scans [3], [4].

Allen et al. [1] introduce a consistent parameterization approach by fitting a generic body model to each body scan, and thus build a morphable shape model. This model can be used for feature analysis by learning a linear mapping from body measurements to Principal Component Analysis (PCA) coordinates [2].

Blanz and Vetter [7] apply a morphable face model to reconstructing face models from sample images by fitting a 3D morphable model to 2D images. Facial attributes, such as gender, attractiveness and expressions are controllable through modifying parameters. Similar to this approach, Seo et al. [16] suggest a data-driven approach to reconstructing human body shape from the silhouettes.

Anguelov et al. [4] introduces a pose deformation model and a shape model for shape completion to partial view completion and motion capture animation. Amberg et al. [3] introduces an expression-invariant method for face recognition by fitting an identity/expression separated 3D morphable model to shape data.

A common character in the above approaches is that the input can be converted to numerical values. For example, contours extracted from an input image are represented by coordinates of sampled 2D points. These approaches may fail if descriptive features become part or all of the input. In this work, we introduce data mining techniques that are suitable for handling nonnumeric inputs.

Blockeel et al. [8] introduce an approach which adapts the basic top-down induction of decision trees towards clustering. It employs the principles of instance based learning. According to Langley [13], each node of the tree corresponds to a concept or a cluster, and the tree as a whole thus represents a kind of taxonomy or a hierarchy.

A Predictive Clustering Tree (PCT) introduced by Dzeroski et al. [12] allows for predicting multiple target variables. Human body shape in a statistical shape space can be represented by multiple variables like PCA coordinates. Therefore, it is naturally applicable to predicting body shapes from descriptive features.

III. STATISTICAL MODEL

In CAESAR database, every raw scan of human body contains about 150,000 vertices and 300,000 triangles. For shape correspondence (also called consistent shape parameterization), we implemented a template-based approach as that of [18]. For data compression, we performed PCA on the parameterized shape data. A shape space is thus built with the following steps.

- 1) Represent each parameterized shape as a vector x_i , $i = 1, \dots, m_1$ (m_1 is the number of subjects used for building a shape space), and arrange all the vectors into a matrix $X = (x_1, x_2, \dots, x_{m_1})$. A covariance

matrix $cov(X) = \sum (x_i - \bar{x})(x_i - \bar{x})^T$ is calculated, where \bar{x} is the mean vector of all the x_i .

- 2) We next perform eigen-decomposition of the covariance matrix. It creates a series of eigen vectors Φ_j and their corresponding eigen values λ_j , where $j = 1, \dots, (m_1 - 1)$. The eigen values are in a descending order.
- 3) Since all the Φ_j are orthogonal to each other, they form the bases of the shape space. Organizing Φ_j in columns forms a new matrix Φ . Each shape vector x_i can be mapped into this space through

$$B_i = \Phi^T(x_i - \bar{x}) \quad (1)$$

which is comprised of mapped coordinates along the principal components. It is thus a new representation of the original 3D shape vector.

- 4) If a vector of coordinates b_j is given, a new shape x_{new} can be reconstructed through:

$$x_{new} = \bar{x} + \sum_{j=1}^{m_2} \Phi_j b_j \quad (2)$$

where $m_2 (< m_1)$ is the number of principal components to be used for reconstruction.

IV. PREDICTIVE CLUSTERING TREE

Predictive clustering is a general framework that combines clustering and prediction [8]. It partitions a dataset into clusters so that variations in each cluster are minimal and those between clusters are maximal. It is similar to clustering but differs in that predictive clustering builds a predictive model (an induction rule) to each cluster.

Predictive clustering tree constructs a model for predicting a multi-objective target based on its description. The model is learned from a set of examples for building a decision tree. They have the form (D, T) , where D means descriptions and T denotes the target object. At each node, the PCT tries to find the best partition rule using D through minimizing the variations of clustered T . As a result, each leaf node represents a cluster, and the conjunction of the conditions on the path from the root to the leaf forms the induction rule [12].

A. Example for building a PCT

As an example, we look at a hypothetical weather prediction problem. We build a PCT using a small set of training data [17] listed in Table I, where weather outlook and wind conditions are input D and temperature and humidity are output T .

Building a PCT amounts to trying different partition tests and computing the in-cluster and between-cluster variations. In this example, the first test is trying “Outlook = sunny” and putting testing cases into one cluster if the condition is met and those into another cluster otherwise. Following this partition is to calculate the in-cluster and between-cluster

Outlook	Windy	Temperature	Humidity
sunny	no	34	50
sunny	no	30	55
overcast	no	20	70
overcast	yes	11	75
rainy	no	20	88
rainy	no	18	95
rainy	yes	10	95
rainy	yes	8	90

Table I
THE TRAINING DATA FOR A WEATHER EXAMPLE.

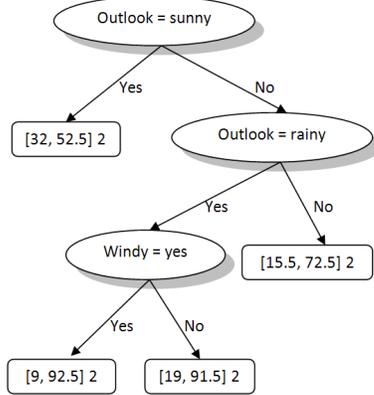


Figure 1. A PCT tree built on weather outlook, condition, temperature and humidity.

variations using “Temperature” and “Humidity” values of the training cases in each cluster. Changing the partition condition and selecting the one if it yields maximum between-cluster and minimum in-cluster variations. In this example, “Outlook = sunny” happens to be the partition condition at the root node.

The clusters can be further partitioned into smaller ones, until meeting a termination condition set by the user. In this example, we set the number of training cases in each cluster to be at least two. Every leaf node then contains a number of training cases and the centroid of them is used for prediction. Figure 1 shows the complete PCT. Traversing from root to the very right leaf node leads to an induction rule “If Outlook = rainy and Windy = No Then [Temperature, Humidity] = [15.5, 72.5]”. In the leaf node, 2 is the number of training cases in the cluster.

B. Algorithms for building a PCT

The following summarizes the algorithms for building the PCT.

Algorithm 1 depicts an iterative partitioning process. It calls on Algorithm 2 to find the best partition for the current unclustered training set [12]. Using the returned partitioning condition $Ptest$, we create a new node and a local partition $Parts$. It then calls on itself for further partitioning the sub-clusters from the local partition. By setting a termination

Algorithm 1 Generic PCT induction algorithm PCT

Input: $I = \{D, T\}$
Output: a predictive clustering tree

- 1: $(Ptest, Parts) = BestPartition(I)$
- 2: **if** $Ptest = none$ **then**
- 3: return $Node(centroid(I))$
- 4: **else**
- 5: **for** each $Part_j \in Parts$ **do**
- 6: $tree_j = PCT(I_j)$
- 7: **end for**
- 8: return $Node(Ptest, \cup_j \{tree_j\})$
- 9: **end if**

Algorithm 2 Best partition algorithm $BestPartition$

Input: $I = \{D, T\}$
Output: $(Ptest, Parts)$

- 1: $(Ptest, Parts) = (none, \emptyset)$
- 2: $Var = \text{Min Double}$
- 3: **for** each possible partition test $Ptest^*$ **do**
- 4: $Parts^* = \text{partitions induced by } Ptest^* \text{ on } I$
- 5: $Var^* = \sum_{i \neq j} VarBetweenClusters(i, j) - \sum_k VarInCluster(k)$
- 6: **if** $(Var^* > Var)$ **then**
- 7: $(Var, Parts, Ptest) = (Var^*, Parts^*, Ptest^*)$
- 8: **end if**
- 9: **end for**
- 10: return $(Ptest, Parts)$

condition, this iterative partitioning process will stop if it reaches a node where no more partitions are allowed.

Algorithm 2 searches the current training set for the best partitioning condition, which results in clusters having the minimal in-class and maximal between-class variations. The algorithm initializes the value of global variations Var with the minimum value of double type variables. It returns the found partition condition and the derived partitions.

A variation to the general PCT is a weighted predictive clustering tree. This means assigning weights to the targets when computing in-class and between-class variations. In the weather prediction example, we can assign weight 0.6 to “Temperature” and 0.4 to “Humidity”, if predicting “Temperature” is more useful than “Humidity”.

C. PCT for prediction and analysis

After a PCT is built using a training set, it can be used for prediction using a testing set. Traversing from the root to a leaf node using the descriptions of a new testing case, the centroid of training cases in the leaf node becomes the prediction.

Since the conjunction of conditions from root to leaf node naturally forms an induction rule, we can make shorter rules by pruning the full tree. This can be accomplished by setting a higher threshold for the minimum number of cases clustered in each node. The induced rules from the pruned clustering tree thus allow easier interpretation of the relationship between the descriptions D and target object T .

site	reported height	occupation
civilian	reported weight	education
birth-state	shoe size	number of children
subgroup number	age	gender
car make	fitness	marital status
car year	ethnicity	family income
car model		

Table II
THE DEMOGRAPHIC ATTRIBUTES.

V. BODY SHAPE PREDICTION

A. Selection of training and testing datasets

We select 3D models of 1035 males and 1133 females from North America in the CAESAR database. Two thirds (1453) of the dataset have been randomly selected for building a full PCT to do shape prediction. The same set is also used for pruning the PCT to do shape analysis. Remaining data (715) are used for testing the prediction performance of the full PCT.

B. Selection of PCA coordinates

According to PCA result, the first ten and fifty principal components represent 89.99% and 98.50% variations in the dataset respectively. Therefore in the body shape prediction, we use the first fifty normalized PCA coordinates because it yields a high accuracy. In the body shape analysis, we limit PCA coordinates to the first ten because they represent most of the interesting body shape variations in the dataset.

In PCA, the degree of the variations in the training dataset is linearized by the eigen values along the principal components (PCs). Scaling the mapped coordinates along the PCs using eigen values yields a normalized representation of the original 3D shape in the new shape space. The normalized PCA coordinates are used for computing the variations in and between clusters.

C. Selection of demographic attributes

The demographic attributes in Table II are used for making partitions in PCT. The attributes “reported height” and “reported weight” are from what people reported at scanning, and thus may not be accurate.

D. Weight selection for building a weighted PCT

The selection on weights for building a weighted PCT is numerous. Here, we assign on each PCA coordinate i a weight $\sqrt{\lambda_i}$ (λ_i as in section III) for the computations of variations in and between clusters. This selection is based on the fact that $\sqrt{\lambda_i}$ represents the shape variation depicted by the i -th principal component. A weighted PCT is thus built by setting the minimal number of training cases in each leaf node to 20. Due to page limitations, we put the PCT in supplementary materials.

Acromial Height, Sitting	Ankle Circumference
Spine-to-Shoulder	Spine-to-Elbow
Arm Length (Spine to Wrist)	Arm Length (Shoulder to Wrist)
Arm Length (Shoulder to Elbow)	Armscye Circumference
Bizygomatic Breadth	Chest Circumference
Buttock-Knee Length	Chest Girth at Scye
Crotch Height	Elbow Height, Sitting
Eye Height, Sitting	Face Length
Foot Length	Hand Circumference
Hand Length	Head Breadth
Head Circumference	Head Length
Hip Breadth, Sitting	Hip Circumference, Maximum
Hip Circ Max Height	Knee Height
Neck Base Circumference	Shoulder Breadth
Sitting Height	Stature
Subscapular Skinfold	Thigh Circumference
Thigh Circumference Max Sitting	Thumb Tip Reach
TTR 1	TTR 2
TTR 3	Triceps Skinfold
Total Crotch Length (Crotch Length)	Vertical Trunk Circumference
Waist Circumference, Pref	Waist Front Length
Waist Height, Preferred	Weight (kg)

Table III
THE BODY MEASUREMENTS.

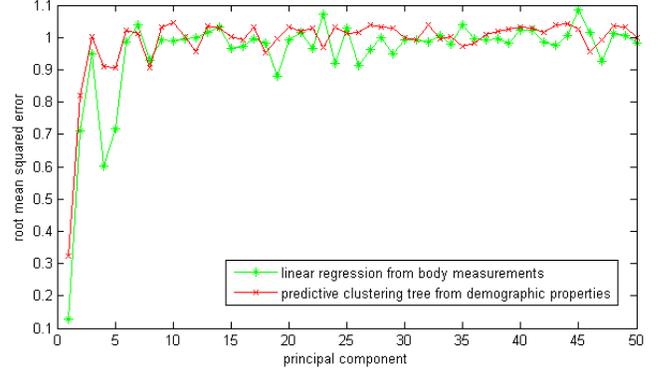


Figure 2. Prediction accuracy comparison along the first fifty components by linear regression and predictive clustering tree.

E. Evaluation of shape prediction performance

We use the demographic attributes from the testing dataset and traverse the weighted PCT for shape predictions. Denote the predicted PCA coordinate vector for testing case i as $PC_i^* = [PC_{i,1}^*, \dots, PC_{i,50}^*]$ and the actual PCA coordinate vector as $PC_i = [PC_{i,1}, \dots, PC_{i,50}]$, where $i = 1, 2, \dots, 715$. A distance vector can be computed as $D_i = [(PC_{i,1}^* - PC_{i,1})^2, \dots, (PC_{i,50}^* - PC_{i,50})^2]$. For all the testing cases, a global prediction error vector can be calculated as $E_{PCT} = [\sqrt{\sum_{i=1}^{715} D_{i,0} / 715}, \dots, \sqrt{\sum_{i=1}^{715} D_{i,50} / 715}]$.

For comparison, we also implemented the linear regression approach [2]. Using the same training cases as weighted PCT, we pulled the forty-four body measurements (see Table III) from the CAESAR dataset and used the normalized PCA coordinates for building a linear mapping. Testing with the same cases as weighted PCT, a global prediction error

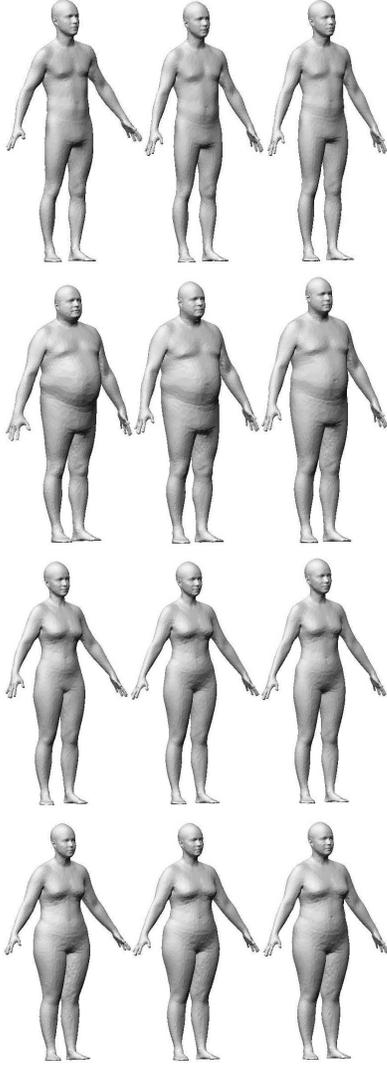


Figure 3. Shape prediction results. On each row from left to right: the original shape, predicted shape using linear regression and predicted shape using PCT.

vector $E_{regression}$ is calculated for comparison to E_{PCT} . The comparison made in Figure 2 shows a close prediction accuracy between the linear regression approach using 44 measurements and the weighted PCT using 19 demographic attributes.

Besides the comparison on prediction errors, we also compare visually the body shapes reconstructed through Equation 2. Figure 3 shows examples of male and female prediction using the linear regression and weighted PCT approaches. It is no wonder that linear regression creates shapes being close to the original because it uses 44 body measurements for constraints. The reconstructions using the weighted PCT also show a close shape as the original.

VI. PRUNED PCT FOR BODY SHAPE ANALYSIS

For shape analysis, we concentrate on the first ten components, among which we also limit our analysis to principal components 1, 2, 4, 5 and 8. The reason is that the other components within the first ten all relate to posture variations. Figure 4 shows the shape variations along the selected principal components, by blending the global mean shape and shapes at $\pm 3\sqrt{\lambda_j}$ ($j = 1, 2, 4, 5, 8$) [10]. $PC1$ is showing shape variations between a short female body and a tall male body. $PC2$ shows weight gains mainly around the waist line with both arms opening up. $PC4$ displays longer arms and legs, and weight gains around the waist line. $PC5$ shows weight gains on the upper body, including torso and arms.

From the 19 demographic attributes listed in Table II, we select 6 of them for shape analysis (the third column). These attributes offers interesting analysis because they are related to shape but the relationship is not obvious. In contrast, the attributes in the first column are not related to shape and the attributes in the second column are directly related to shape.

With the six selected demographic attributes, we rebuild the PCT and set the minimal number of cases in a leaf node to 150. The pruned new PCT is displayed in Figure 5. From this tree we find that family income is not as related as the other five attributes because it is not used in any of the partition nodes.

The first interesting thing we find from the pruned PCT is that for males, body shape is mostly related to marital status and education being the second. For females, the most important factor is occupation, then number of children, leaving education the least related factor. It is also found that body shape in males is less affected by occupation than that in females.

We only put in Figure 5 those partition conditions having a short list of possible values, but list in full the following nine rules created by the pruned predictive clustering tree. The number at the end of each rule is the number of training cases in that cluster.

- Rule 1 IF Gender = Male AND Marital-Status = ' Single' THEN [CLUSTER 1]: 355
- Rule 2 IF Gender = Male AND Marital-Status in {' Married', ' Divorced', ' Widowed', ' Engaged', ' No Response' } AND Education in {' High School', ' Bachelors', ' Associates', ' None of the above' } THEN [CLUSTER 2]: 292
- Rule 3 IF Gender = Male AND Marital-Status in {' Married', ' Divorced', ' Widowed', ' Engaged', ' No Response' } AND Education in {' Masters', ' Doctorate', ' Post-Doctoral Studies' } THEN [CLUSTER 3]: 230
- Rule 4 IF Gender = Male AND Marital-Status in {' Married', ' Divorced', ' Widowed', ' Engaged', ' No Response' } AND Education in {' Technical Training', ' No Response', ' Some College' } THEN [CLUSTER 4]: 158
- Rule 5 IF Gender = Female AND Occupation in {' Technician', ' Administrative Support', ' Machine Operator', ' Retired', ' Unemployed' } THEN [CLUSTER 5]: 293
- Rule 6 IF Gender = Female AND Occupation in {' No Response', ' Service Occupation', ' Computer Programmer/Software Engineer', ' Homemaker' } THEN [CLUSTER 6]: 150

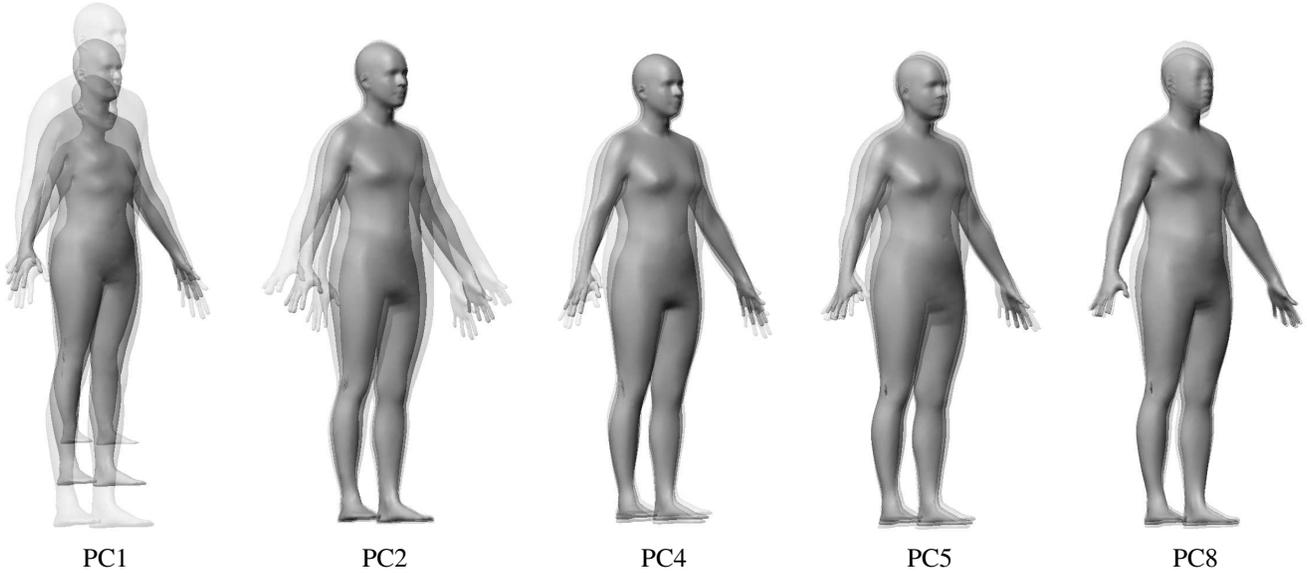


Figure 4. Shape variations along selected principal components

Rule 7 IF Gender = Female AND Occupation in {' Management', ' Degreed Engineer', ' Administrator', ' Other Specialty Occupation', ' Supervisor', ' Attorney or Judge', ' Transportation Occupation', ' Student', ' Scientist', ' Sales/Marketing', ' Classroom Teacher', ' Mechanic', ' Health Diagnosing Occupation', ' Armed Services', ' Construction', ' Material Handler', ' Other Legal/Judicial Occupation', ' Training/Continuing Education', ' Health Non-Diagnosing Occupation', ' Farm Occupation', ' Forestry or Fishing Occupation'} AND Number-of-Children in {0.0,4.0, ' No Response',5.0} AND Education in {' Technical Training', ' Bachelors', ' Masters', ' Post-Doctoral Studies'} THEN [CLUSTER 7]: 306

Rule 8 IF Gender = Female AND Occupation in {' Management', ' Degreed Engineer', ' Administrator', ' Other Specialty Occupation', ' Supervisor', ' Attorney or Judge', ' Transportation Occupation', ' Student', ' Scientist', ' Sales/Marketing', ' Classroom Teacher', ' Mechanic', ' Health Diagnosing Occupation', ' Armed Services', ' Construction', ' Material Handler', ' Other Legal/Judicial Occupation', ' Training/Continuing Education', ' Health Non-Diagnosing Occupation', ' Farm Occupation', ' Forestry or Fishing Occupation'} AND Number-of-Children in {0.0,4.0, ' No Response',5.0} AND Education in {' High School', ' Doctorate', ' Associates', ' No Response', ' None of the above', ' Some College'} THEN [CLUSTER 8]: 151

Rule 9 IF Gender = Female AND Occupation in {' Management', ' Degreed Engineer', ' Administrator', ' Other Specialty Occupation', ' Supervisor', ' Attorney or Judge', ' Transportation Occupation', ' Student', ' Scientist', ' Sales/Marketing', ' Classroom Teacher', ' Mechanic', ' Health Diagnosing Occupation', ' Armed Services', ' Construction', ' Material Handler', ' Other Legal/Judicial Occupation', ' Training/Continuing Education', ' Health Non-Diagnosing Occupation', ' Farm Occupation', ' Forestry or Fishing Occupation'} AND Number-of-Children in {3.0,1.0,2.0,6.0, ' 7 or more'} THEN [CLUSTER 9]: 233

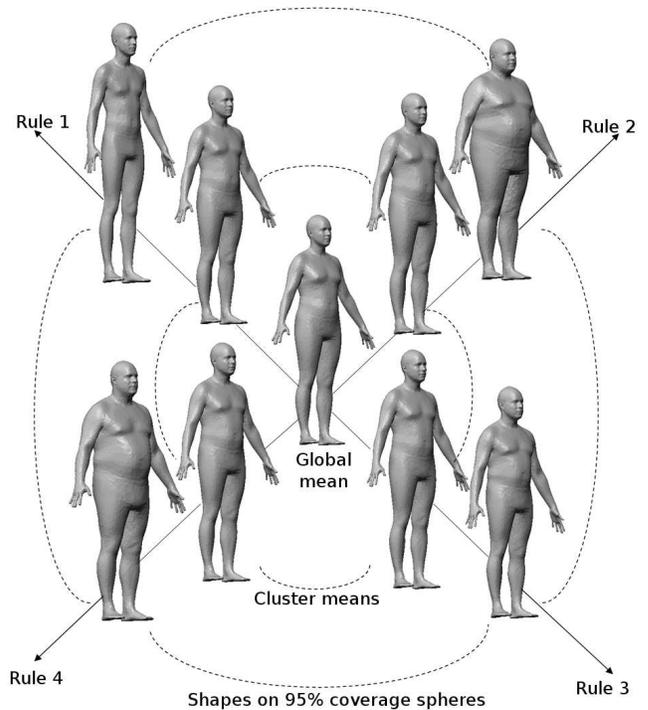


Figure 6. Male body shapes on cluster centers and 95% coverage spheres.

To have a better understanding of the actual body shape in each cluster, we reconstruct the (i) global mean shape, (ii) the shapes at the centroids of clusters, and (iii) the shapes being farthest from the global mean and inside the 95% covering sphere of each cluster. Figure 6 and 7

shows for males (Rules 1 to 4) and females (Rules 5 to 9) the reconstructed shapes described here. In each figure, the center body shape is the global mean and it is the same for males and females. The global mean shape is first

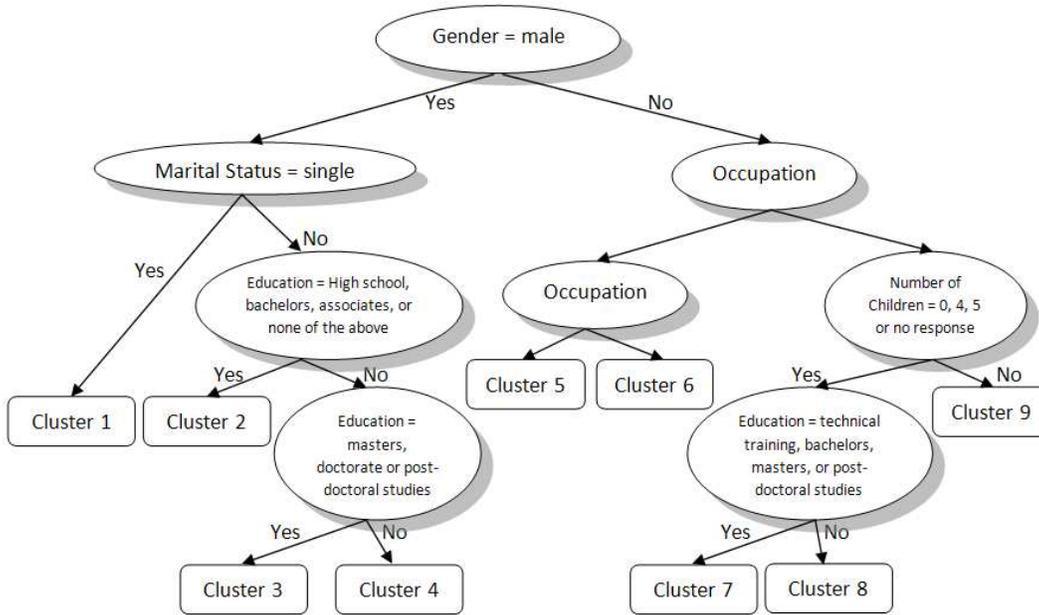


Figure 5. Pruned predictive clustering tree for shape analysis.

surrounded by shapes at the centroids of clusters, then by shapes meeting the criterion (iii) above.

Figure 6 shows that centroids and extreme shapes of Rule 2, 3 and 4 gained more body weight than those in Rule 1, which belongs to a cluster of single males. For those other than being single, subjects having education in “Masters, Doctorate, Post-doctorate” (Rule 3) have a lower body weight and height than those who do not have the education (Rules 2 and 4).

Figure 7 shows that a difference in occupation as described in Rules 5 and 6 creates two clusters of females in a different height. According to the pruned tree, clusters 7 and 8 as a whole have less number of children than cluster 9. The reconstructed shapes show that females in clusters 7 and 8 have a lower body weight than cluster 9. Between cluster 7 and 8, the attribute difference is on education (according to the tree) and the shape difference is mainly on body height (according to Figure 7). The female subjects having received a higher education (Rule 7) are lower in height than those who did not (Rule 8).

VII. DISCUSSION

In the weighted PCT, the first partition node is always gender. This is important in that the predicted body shape will have the right gender. If not using the weight, gender may not be the first partition node.

The predictive clustering tree also works in cases when both measurements and demographic attributes are available. Adding body measurements to the training set grows the predictive clustering tree. When a set of attributes or

measurements are missing, the clustering tree can make a prediction by combining its leaf clusters.

In shape analysis according to the demographic attributes, the induction rules for males are easier for reading than those for females. Occupation as the main factor for clustering females has more possible attribute values than the rest of the demographic attributes. This prevents us from comparing between a combined cluster (clusters 5 and 6) and another combined cluster (clusters 7, 8 and 9).

VIII. CONCLUSION

In this work, we propose a predictive clustering tree, which has proved to be a robust and flexible tool for body shape prediction. It is also a fine analyzer for relations from demographics to body shape.

Building a weighted predictive clustering tree yields similar prediction accuracy as the linear regression approach. Also note that the clustering tree uses only 19 demographic attributes and the linear regression uses 44 body measurements. What is common in this comparison is that both approaches use 50 principal components.

Analysis on relation between body shape and demographic attributes creates some interesting findings. In analysis to body shape, the most related demographic attributes through a pruned PCT are marital status and occupation for males and females respectively.

For males other than being single, higher education leads to human bodies with a lower weight. For females, occupation does make the biggest difference; however, those with more children are likely to have a heavier weight.

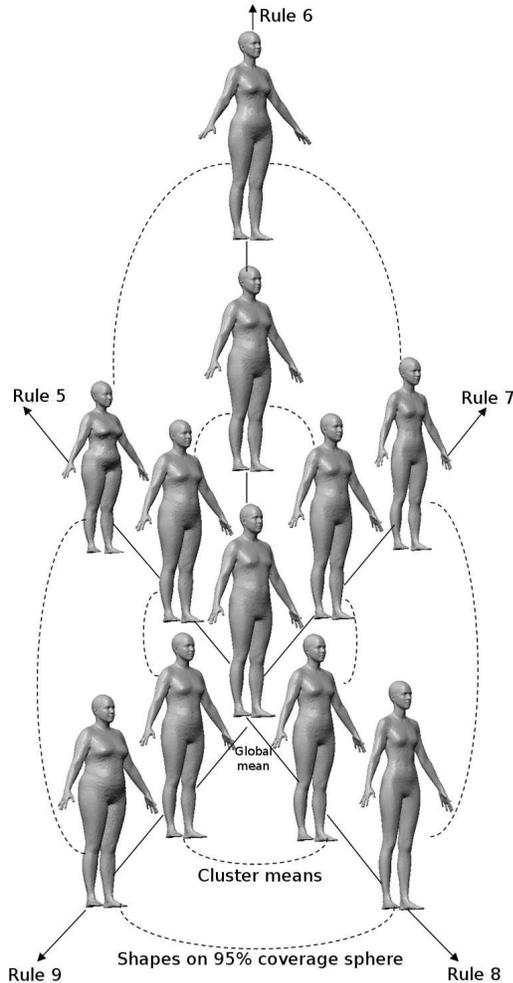


Figure 7. Female body shapes on cluster centers and 95% coverage spheres.

Our future work may include conducting leave-one-out experiment on the demographic attributes and testing the shape prediction performance.

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