# A 2D Human Body Model Dressed in Eigen Clothing

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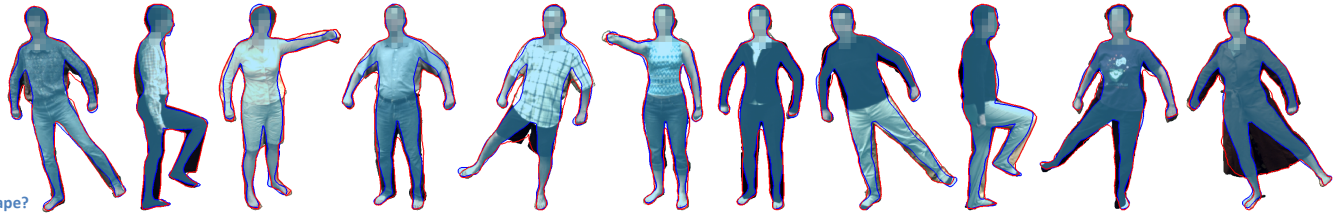
## Goals:
- 2D body shape from 1 image
- recognize clothing on body

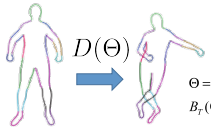
## Problems:
- Clothing obscures body shape
- Lack of 2D clothing model
- How does clothing change 2D shape?



## Approach:
- Use Contour Person model [1]
- Model clothing deformation
- Learn 2D eigen clothing model
- Build a prior on clothing coefficients
- 2D shape estimation under clothing
- 2D clothing category recognition

## Contour Person Model (Freifeld et al. 2010) [1]

**Factored model of shape, pose, and camera**



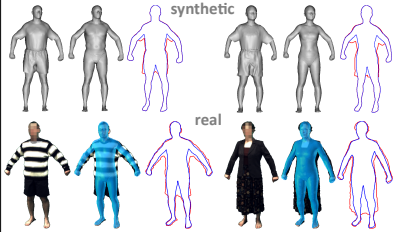
$D(\Theta)$

$\Theta = \{\theta_{shape}, \theta_{pose}, \theta_{camera}\}$

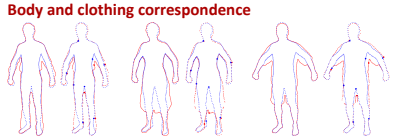
$B_T(\Theta) = D(\theta_{camera}) D(\theta_{pose}) D(\theta_{shape}) T$

**Generative model of 2D body shape and pose**

## Training Set (body and clothing)




**Body and clothing correspondence**



Body: $B_T(\Theta) = P = \{q_1, q_2, ..., q_N\}$

Clothing: $Q = \{q_1, q_2, ..., q_M\}$, where $M >> N$

Pick a subset of $N$ points $G = \{q_{k_1}, q_{k_2}, ..., q_{k_N}\}$ from $Q$ that minimizes $\sum_{i=1}^{N} \| p_i - q_{k_i} \|^2$ such that the ordering, $k_r < k_s$ is preserved for $1 \le r \le s \le N$. [4]

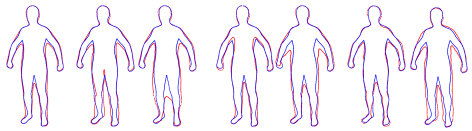
## Method

**Point displacement model:**

Convert point list $G$ to vector $\hat{G} = \{x_1, y_1, x_2, y_2, ..., x_N, y_N\}$

Clothing deformation is defined by: $\delta = \hat{G} - B_T(\Theta)$

PCA on deformations gives low-dimensional eigen-clothing model:



mean: $\Delta_{mean}$ PC 1 ±3 std PC 2 ±3 std PC 4 ±3 std

**Generative model:**

$$C(\Theta, \eta) = B_T(\Theta) + \Delta_{mean} + \sum_{i=1}^{N_\eta} \eta_i \cdot \Delta_i$$

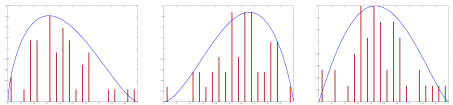
clothing basis vectors

clothing coefficients

**Problem:**

Can generate "negative clothing."

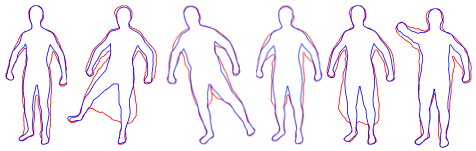
**Solution. Prior on PCA coefficients:**



Use **Beta** distribution to capture symmetric, positively skewed, and negatively skewed statistics.

$$\mathbf{Beta}(x; \alpha, \beta) = \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)} x^{\alpha-1}(1-x)^{\beta-1}$$

**Dressed contour person model (DCP). Samples:**



Blue: Contour person. Red: Clothing model.

## Inference

**Minimize silhouette distance:**

Distance between two silhouettes:

$$d(S^r, S^t) = \frac{\sum_{i,j} S^r_{i,j} H_{i,j}(S^t)}{\sum_{i,j} S^r_{i,j}}$$

$S^r_{i,j}$ is a pixel inside silhouette $S^r$.
$H_{i,j}(S^t)$ is a distance function which is zero if the pixel $(i,j)$ is inside $S^t$ and is the distance to the closest point on the boundary of $S^t$ if it is outside.

**Cost function:**

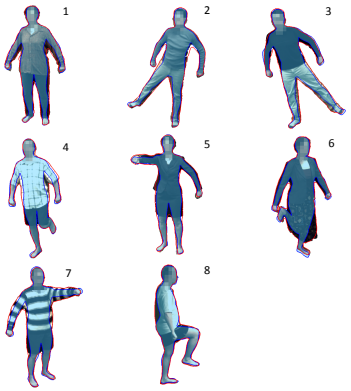
$$E_{data}(\Theta, \eta) = d(S^e(C(\Theta, \eta)), S^o) + d(S^o, S^e(C(\Theta, \eta)))$$

$$E_{prior}(\eta) = -\sum_m \log(\mathbf{Beta}(\eta_m, \alpha_m, \beta_m))$$

$$E(\Theta, \eta) = E_{data}(\Theta, \eta) + \lambda \cdot E_{prior}(\eta)$$

$S^o$ : observed silhouette.
$S^e(C(\Theta, \eta))$ : estimated silhouette.
$\eta_m$ : coefficient for the $m^{th}$ eigen vector.
$\alpha_m$ $\beta_m$ : prior **Beta** distribution parameters for the $m^{th}$ eigen vector estimated from the training set.

**Body shape estimation under clothing:**



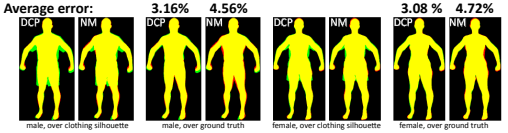

## 2D body shape under clothing:

$$err(S^{EST}, S^{GT}) = \frac{\sum_{i,j} |S^{EST}_{i,j} - S^{GT}_{i,j}|}{2 \sum_{i,j} S^{GT}_{i,j}}$$

NM: Naïve Method (try to ignore clothing effects)
DCP: Dressed Contour Person
NP3D: 3D-based shape estimation from 4 cameras [2]

**Synthetic dataset results:**

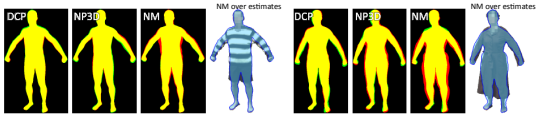
Average error: 3.16% 4.56% 3.08 % 4.72%




red: estimated 2D body. green: silhouette (clothing or ground truth). yellow: overlap (good).

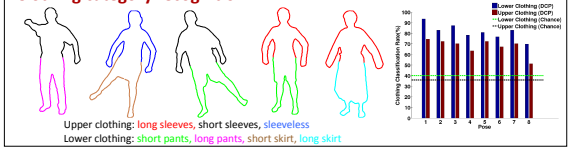
**Real dataset results:**

| Method, AEE | Pose1 | Pose2 | Pose3 | Pose4 | Pose5 | Pose6 | Pose7 | Pose8 | Average |
|---|---|---|---|---|---|---|---|---|---|
| DCP | 0.0372 | 0.0525 | 0.0508 | 0.0437 | 0.0433 | 0.0451 | 0.0503 | 0.0668 | 0.0487 |
| NP3D | 0.0411 | 0.0628 | 0.0562 | 0.0484 | 0.0494 | 0.046 | 0.0472 | 0.0723 | 0.0529 |
| NM | 0.0865 | 0.0912 | 0.0846 | 0.0835 | 0.0877 | 0.0921 | 0.0902 | 0.1184 | 0.0918 |
| Significance ($p$-value) | | | | | | | | | |
| DCP vs NP3D | 0.38 | 0.13 | 0.34 | 0.46 | 0.36 | 0.89 | 0.66 | 0.54 | 0.07 |
| DCP vs NM | 6.4e-7 | 4.9e-4 | 2.1e-4 | 2.1e-4 | 6.7e-8 | 1.0e-5 | 1.0e-6 | 2.3e-4 | 9.9e-17 |




red: estimated 2D body. green: ground truth 2D body. yellow: overlap (good).

## Clothing category recognition:



Upper clothing: long sleeves, short sleeves, sleeveless
Lower clothing: short pants, long pants, short skirt, long skirt

## References

[1] Freifeld, O., Weiss, A., Zuffi, S., Black, M.J.: Contour people: A parameterized model of 2D articulated human shape CVPR. (2010)
[2] Balan, A., Black, M.J.: The naked truth: Estimating body shape under clothing. ECCV. (2008) 15-29
[3] Cootes, T., Taylor, C.: Active shape models-smart snakes. In: BMCV, pp. 266-275 (1992)
[4] Oliveira, F., Tavares, J.: Algorithm of dynamic programming for optimization of the global matching between two contours defined by ordered points. Computer Modeling in eng. & Sciences 31, 1-11(2008)

## Acknowledgements

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