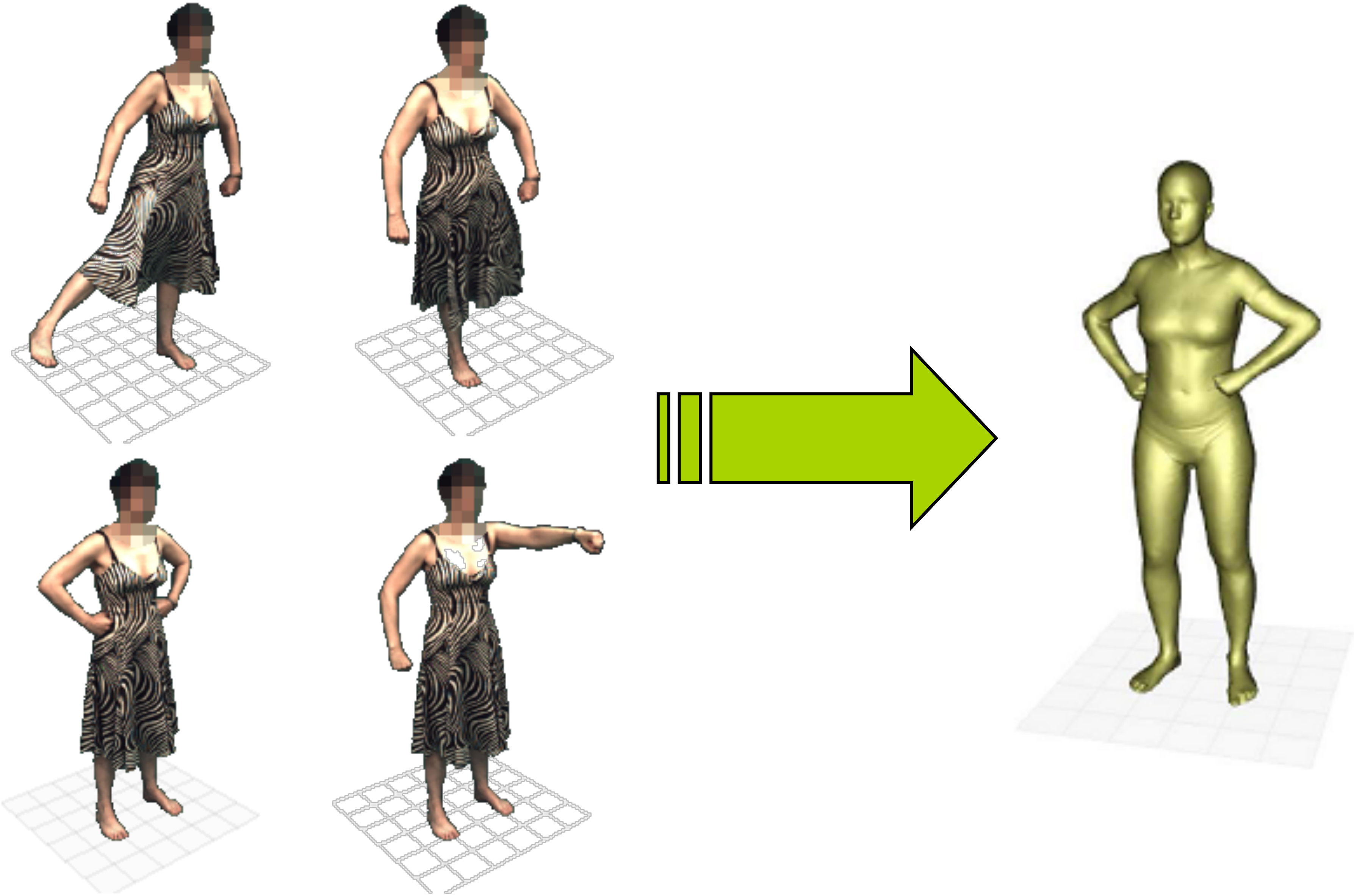
Shape Under Clothing

Alexandru Balan Michael Black
Brown University

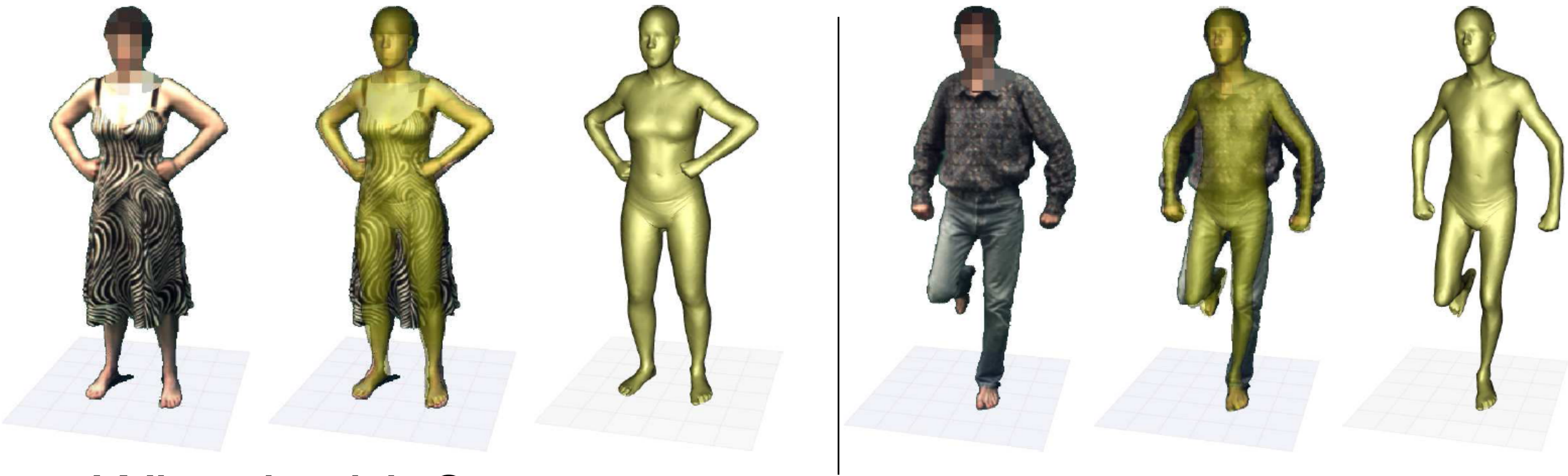
Problem: Shape under Clothing



Problem: Shape under Clothing

More general:

- estimate hidden (unobserved) structure



Why do this?

- Shape scanning
- Biometric for forensic video analysis

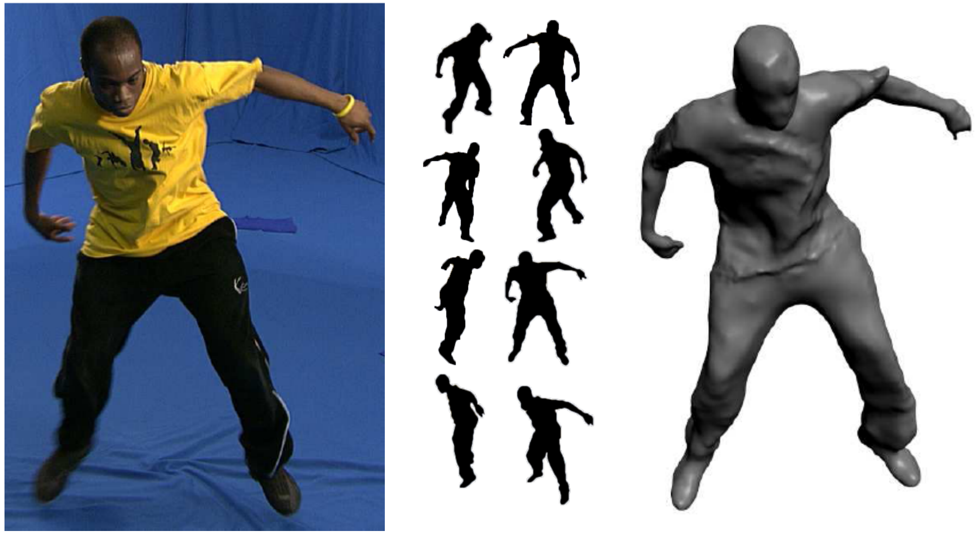
“Real” X-Ray

- Specialized active scanning systems
  - backscatter X-ray
  - infra-red cameras
  - radio waves
- Downside:
  - Invasive
  - They really “see” through clothing
- Can we do this in a non-invasive way using images?

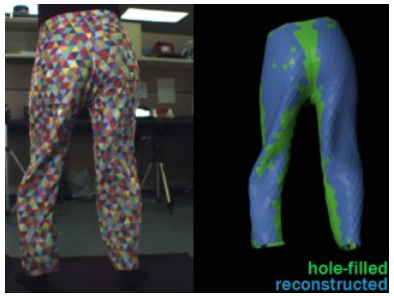
Backscatter X-ray

Related Work – Clothing & Shape

- Surface Capture
  - Visual hull (shape from silhouettes)
    [Vlasic et al. ’08] [Laurentini ’94]
  - Multi-view stereo
    [Stark & Hilton ’07]
    [Furukawa & Ponce ’07]
  - Shape + pose + appearance
    [Ahmed et al. ‘08], [Aguiar et al. ‘08]
    [Theobalt et al. ‘07]
- Garment Capture
    [Bradley et al. ’08], [White et al. ’07]
    [Scholz et al. ’05]
- We want to recover the shape *under* the clothes



[Stark & Hilton ’07]



[White et al. ’07]

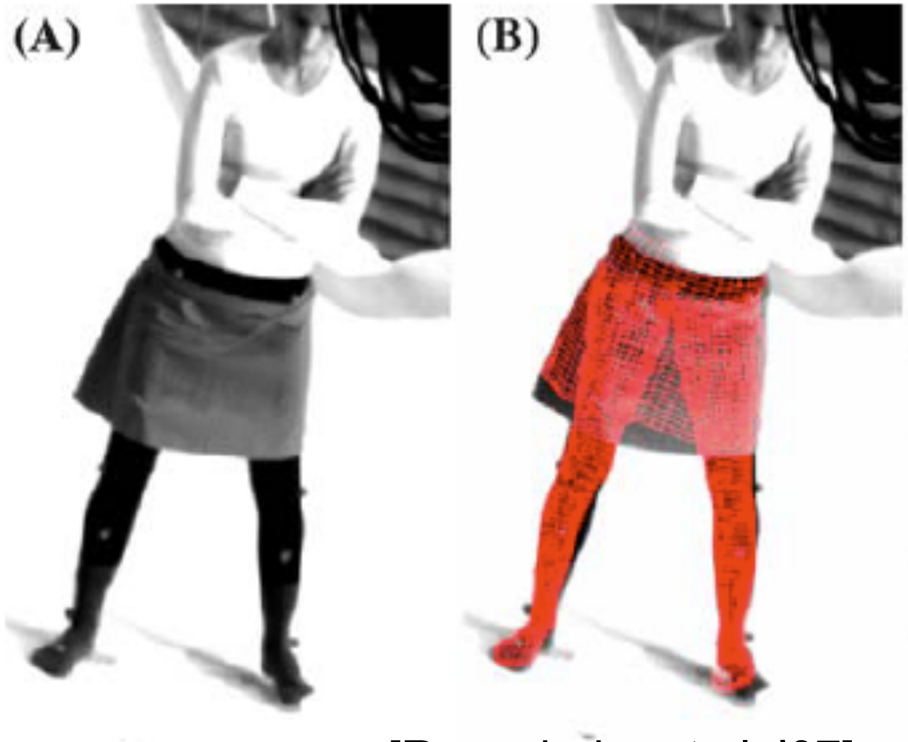
[Bradley et al. ’08]

Related Work - Tracking

- Recover body and garment kinematics

Limitation:

- Assumes known shape dimensions for the body and the garment



[Rosenhahn et al. ’07]

How to generalize this to the case of unknown shape and clothing?

Challenges

- Problem is under-constrained
- The structure we want to recover is unobserved / hidden
  - Body shape is occluded by clothes
  - Many possible shapes can fit under the clothes
- Large variability in clothes and poses
  - Difficult to learn a direct mapping from image observations to intrinsic shape and pose jointly
  - Discriminative models would require vast training data

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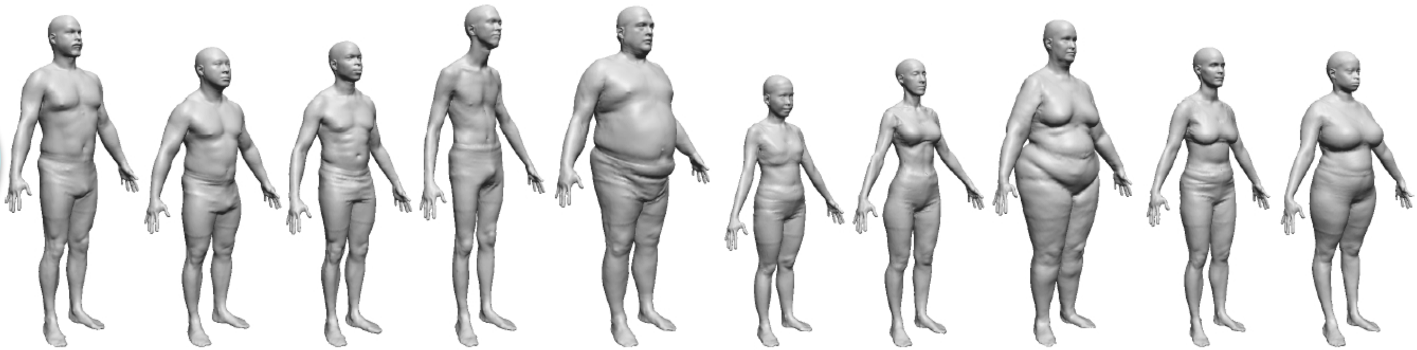
Our Approach

Low-dimensional statistical model of body shape



[Allen et al. ’03]

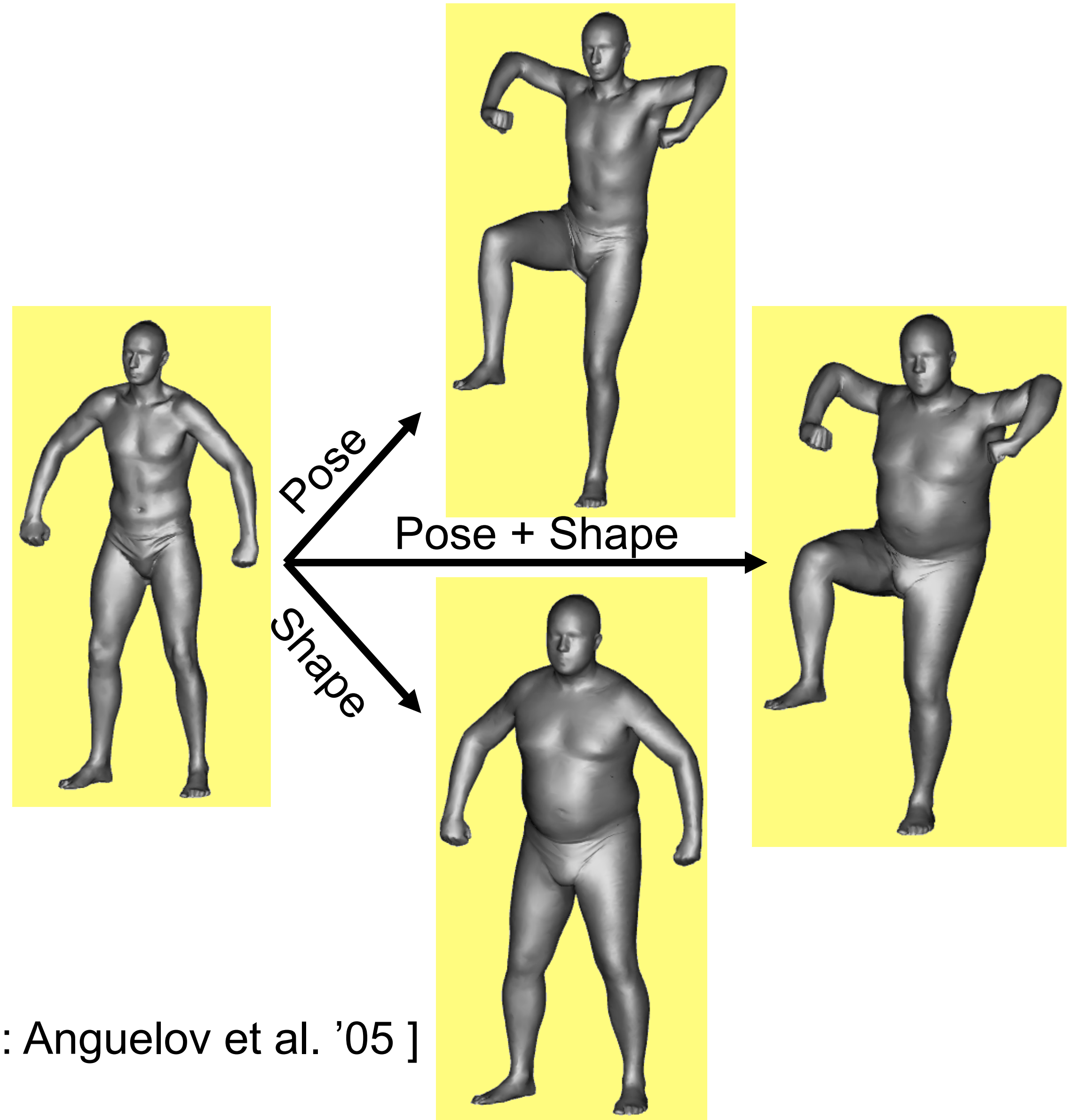
Combine constraints across pose

Exploit regions un-occluded by clothes

Consistent 3D body model fit to observations

Parametric Body Model

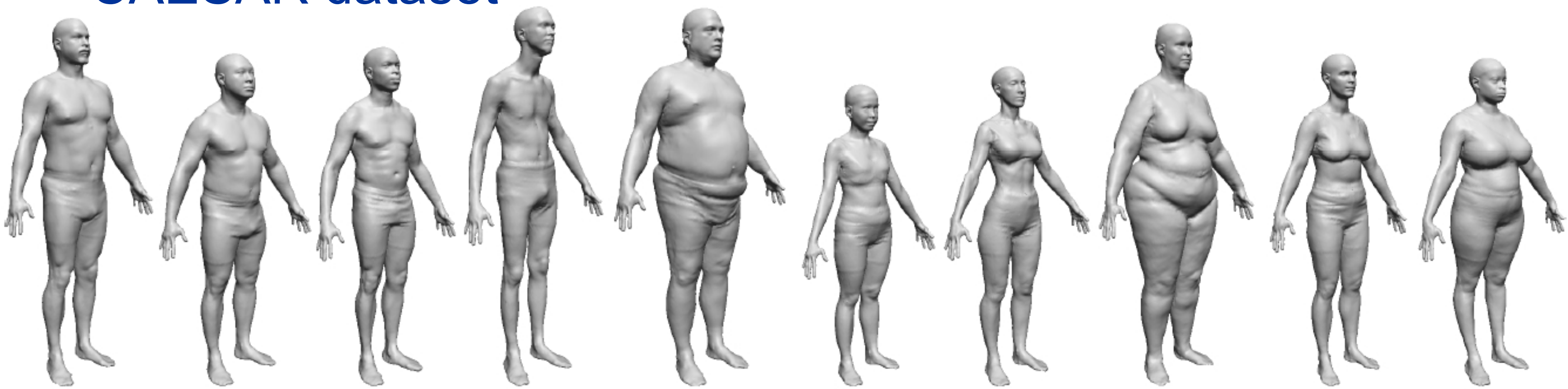
- Low dimensional parameterization learned from examples
- We use an intrinsic shape representation *invariant* to pose
- Encoding is based on shape deformation gradients



[SCAPE: Anguelov et al. ’05]

Statistical Model of Human Shape

CAESAR dataset

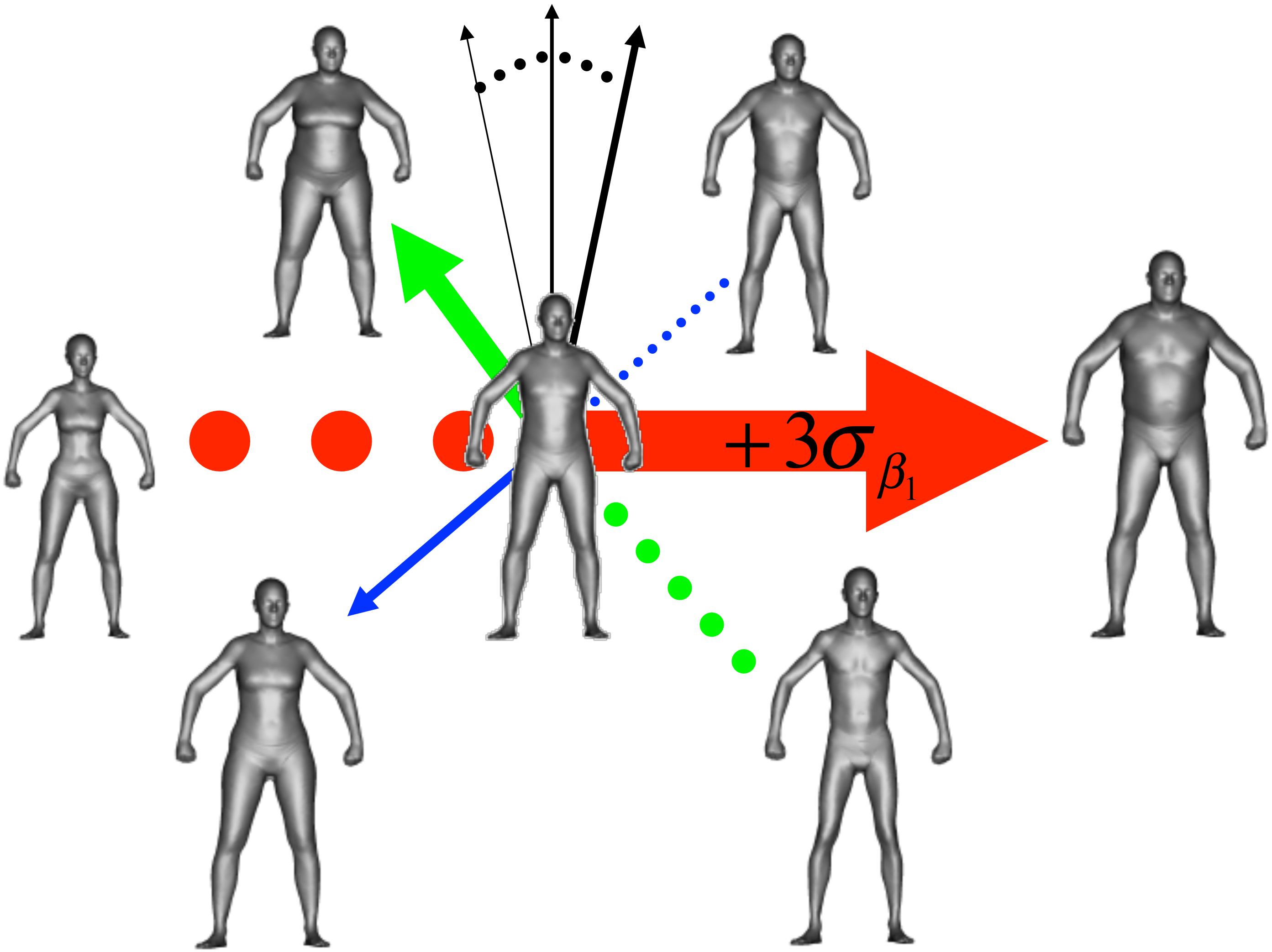


[Allen et al. ‘03]

- 2000+ laser scans
- Full correspondence with a reference mesh
- Learn low dimensional shape embedding using incremental Principal Component Analysis (PCA)

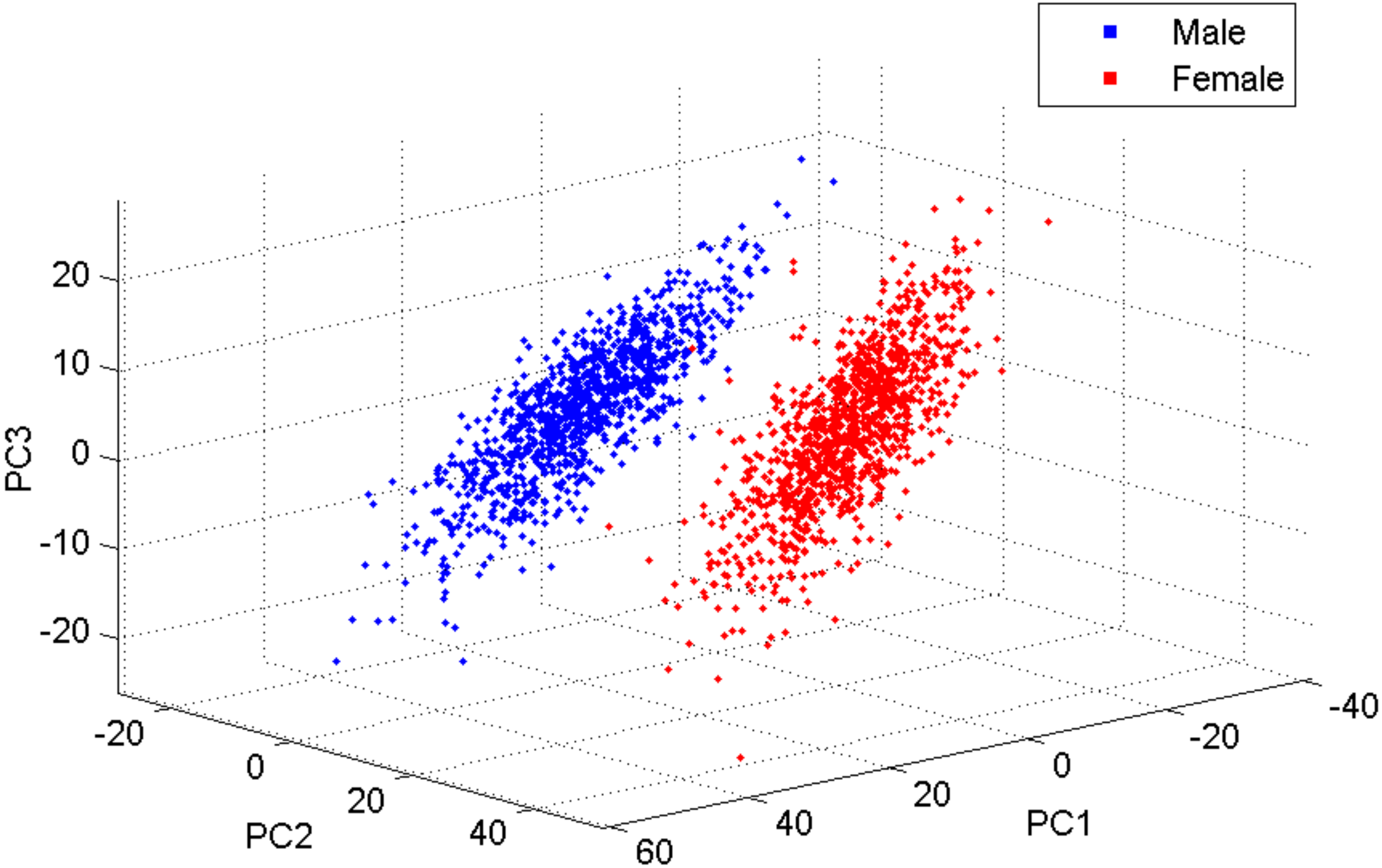
  [Brand ECCV ’02]
- Express shapes compactly using a few shape coefficients (β)

Eigen-People

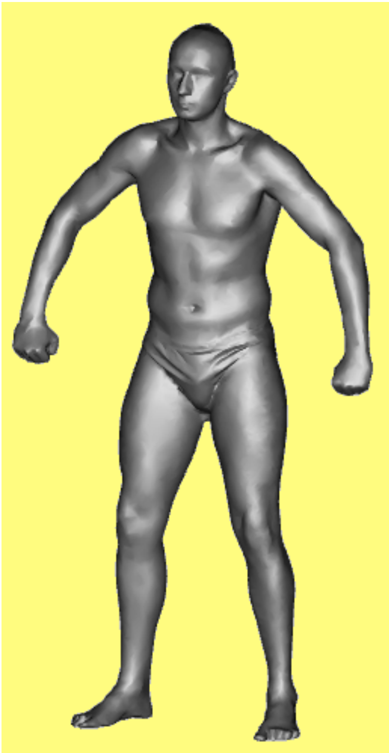


PCA defines a probability distribution over the shape parameters

Gender Separation



Body Mesh Parameterization



$$\xrightarrow{(\beta_\chi, \theta)}$$

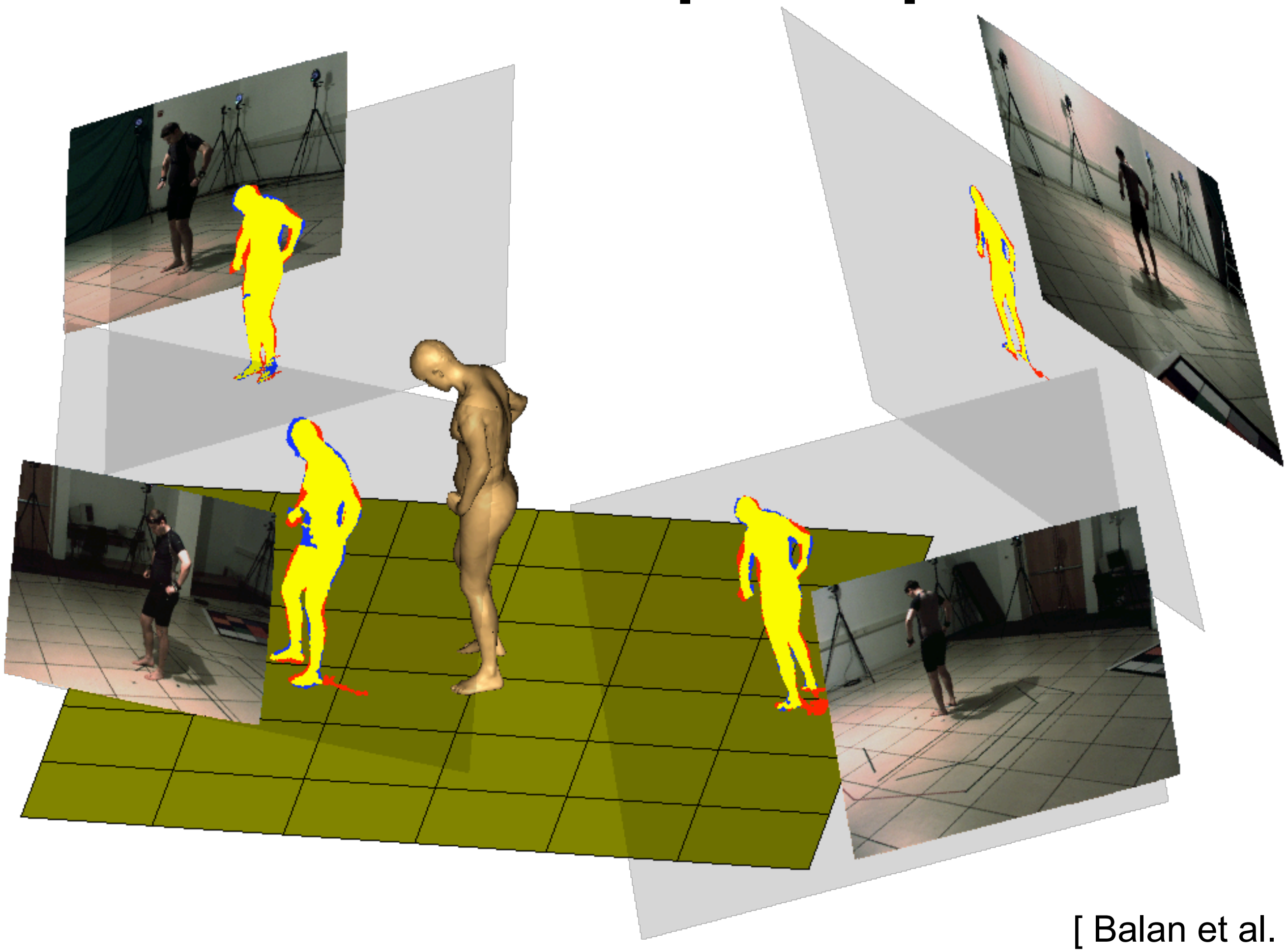
Parameters (state): $s = (\beta_\chi, \theta)$

χ - gender attribute

β_χ - shape parameters under the χ gender shape model

θ - joint angles + global position / orientation

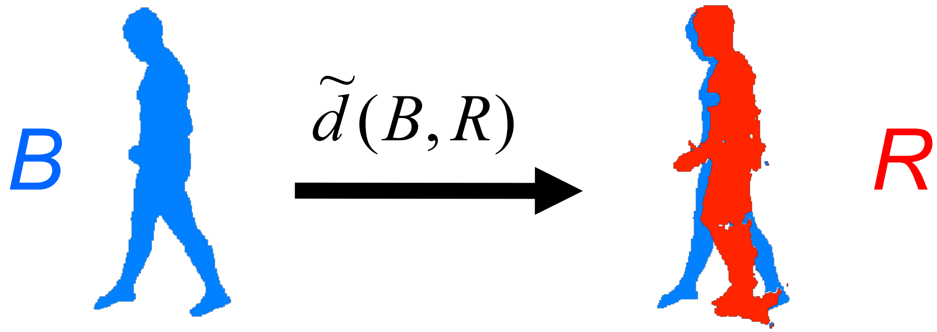
Pose and shape optimization



[Balan et al. CVPR '07]

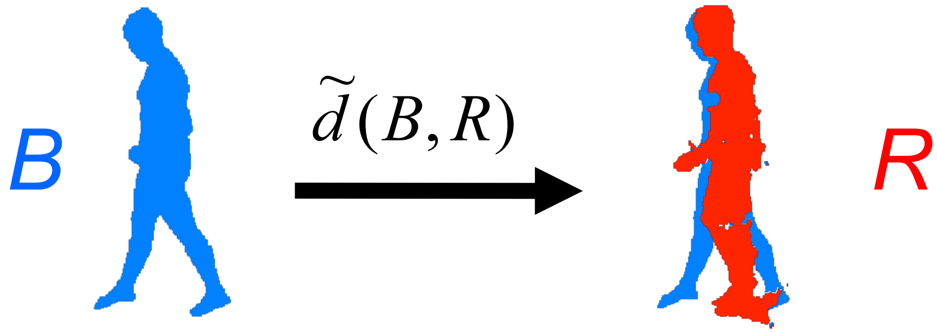
$$\text{Recover}: \; s = \left(\beta_{\chi}, \theta\right)$$

Silhouette Distance Measure



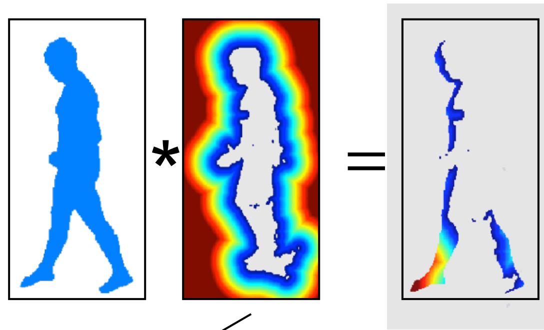
- Uni-directional distance between 2 silhouettes ($B \rightarrow R$)
- Measure how much B is outside of R
- Measure how much B is not explained by R

Silhouette Distance Measure



- Uni-directional distance between 2 silhouettes ($B \rightarrow R$)
- Measure how much B is outside of R
- Measure how much B is not explained by R

$$\tilde{d}(B,R) \doteq \frac{1}{Z_B} \sum_{ij} B_{ij} \cdot C_{ij}(R) =$$



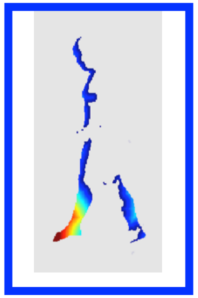
Sminchisescu & Triggs

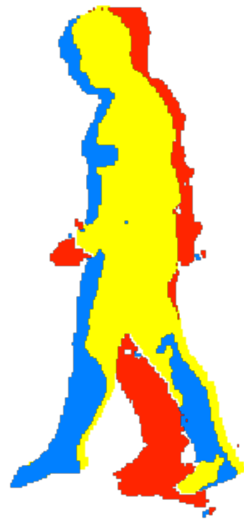
Euclidean Distance Transform

Objective Function – Naked Case

Estimated model silhouette $F_k^e(s)$ should be inside the

observed image silhouette F_k^o and explain most of it





Minimize

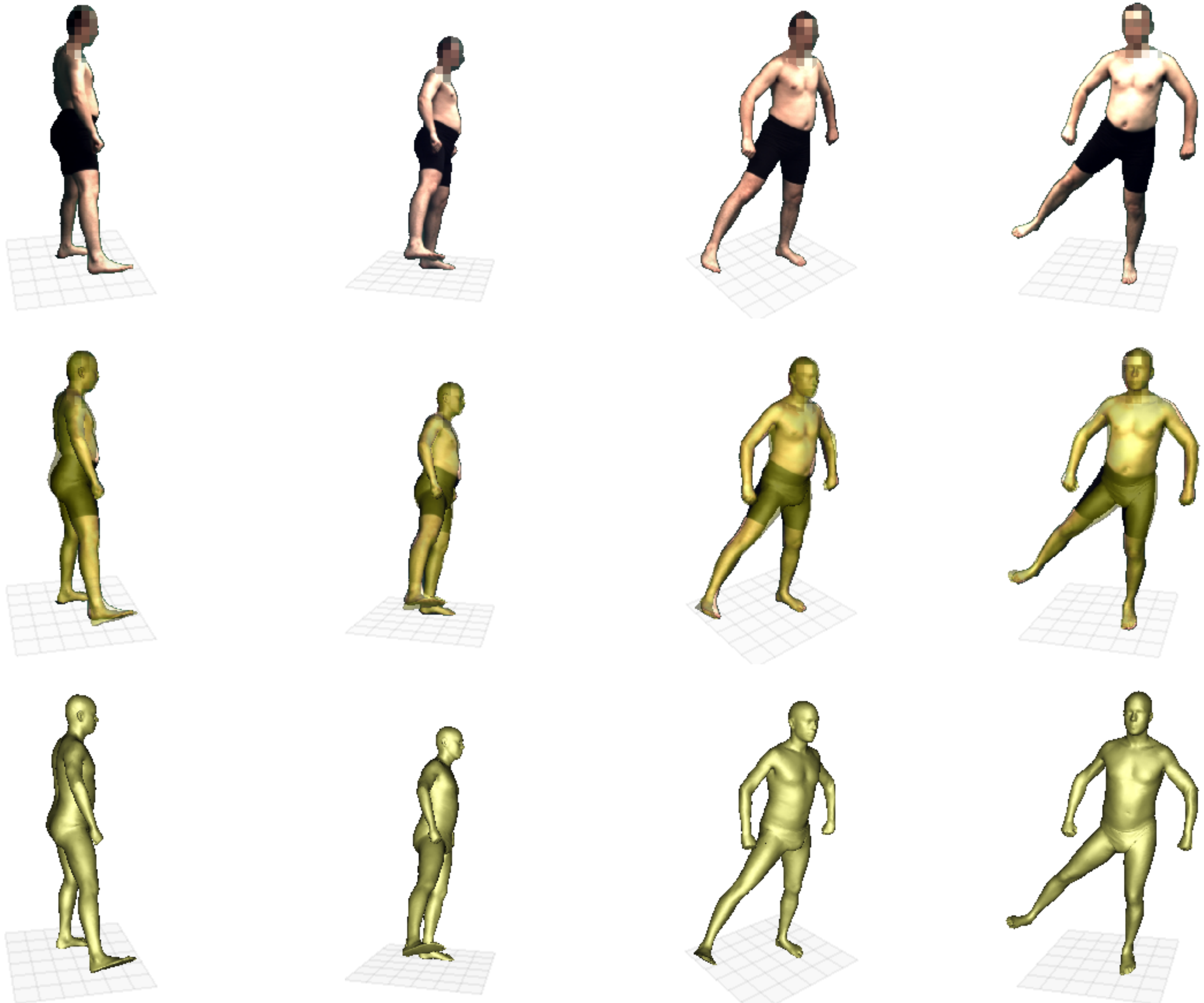
$$E(s) = \sum_{k=1}^{K} \tilde{d}\left(F_k^e(s), F_k^o\right) + \tilde{d}\left(F_k^o, F_k^e(s)\right)$$

[Balan et al. CVPR ’07]

Optimize using *fminsearch*

Alternate between optimizing pose and shape in an incremental fashion

Result for Naked Shape



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Problem: Clothing

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Principle: Shape Under Clothing

- Silhouettes are larger when there is clothing

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- Silhouettes are larger when there is clothing
  - Body must fit inside silhouettes

$$E_{\text{inside}}(s) = \tilde{d}\left(\mathrm{F}_{k,s}^{e}, \mathrm{F}_{k}^{o}\right)$$

Principle: Shape Under Clothing

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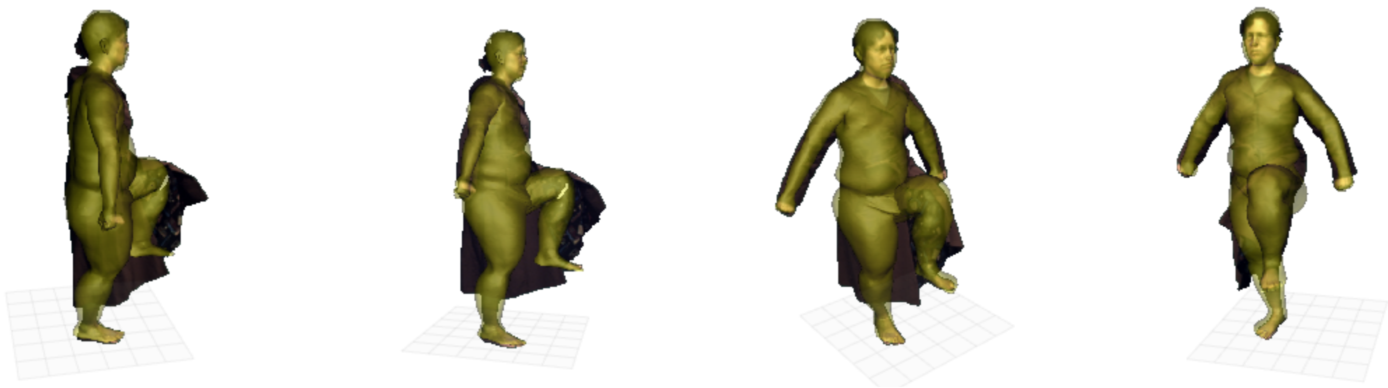
$$E_{\text{inside}}(s) = \tilde{d}\left(\mathrm{F}_{k,s}^{e}, \mathrm{F}_{k}^{o}\right)$$

  - Should not try to explain the entire image silhouette

$$\tilde{d}\left(\mathrm{F}_{k}^{o}, \mathrm{F}_{k,s}^{e}\right)$$ **- NO**



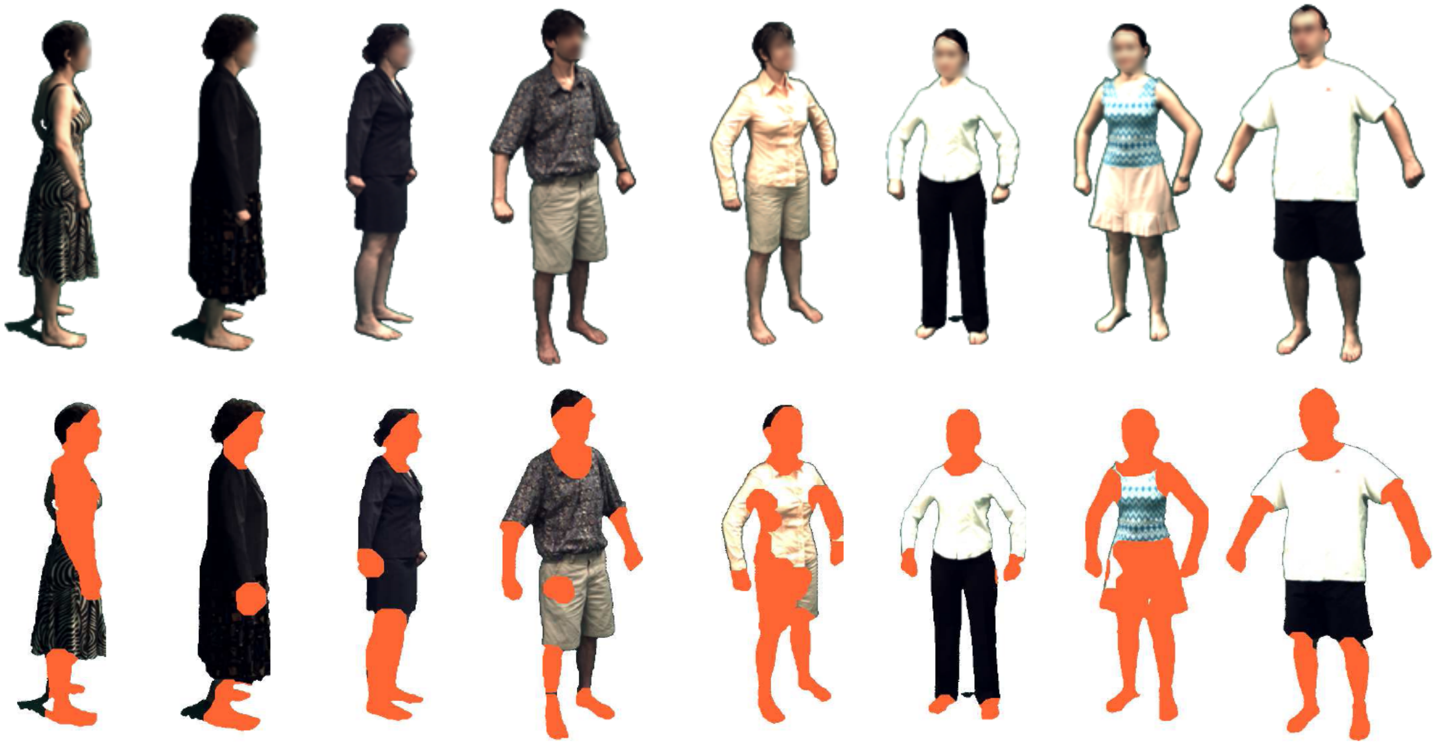
Principle: Shape Under Clothing

- Silhouettes are larger when there is clothing
  - Body must fit inside silhouettes
  - Constraints are tight in regions without clothes

Principle: Shape Under Clothing

- Silhouettes are larger when there is clothing
  - Body must fit inside silhouettes
  - Constraints are tight for skin regions

    Skin Detection



Principle: Shape Under Clothing

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$$E_{\text{expand}}(s) = \tilde{d}\left(\underbrace{S_k^o}_{\text{skin}}, \underbrace{F_{k,s}^e}_{\text{model}}\right) + \underbrace{\lambda}_{\lambda < 1} \tilde{d}\left(\underbrace{F_k^o \setminus S_k^o}_{\text{non-skin}}, \underbrace{F_{k,s}^e}_{\text{model}}\right)$$

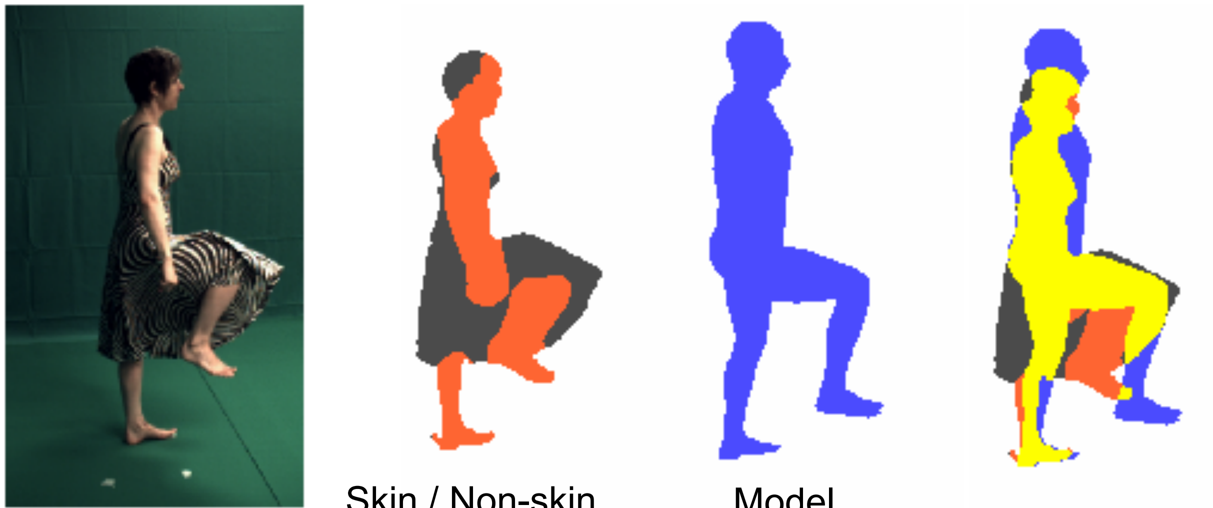


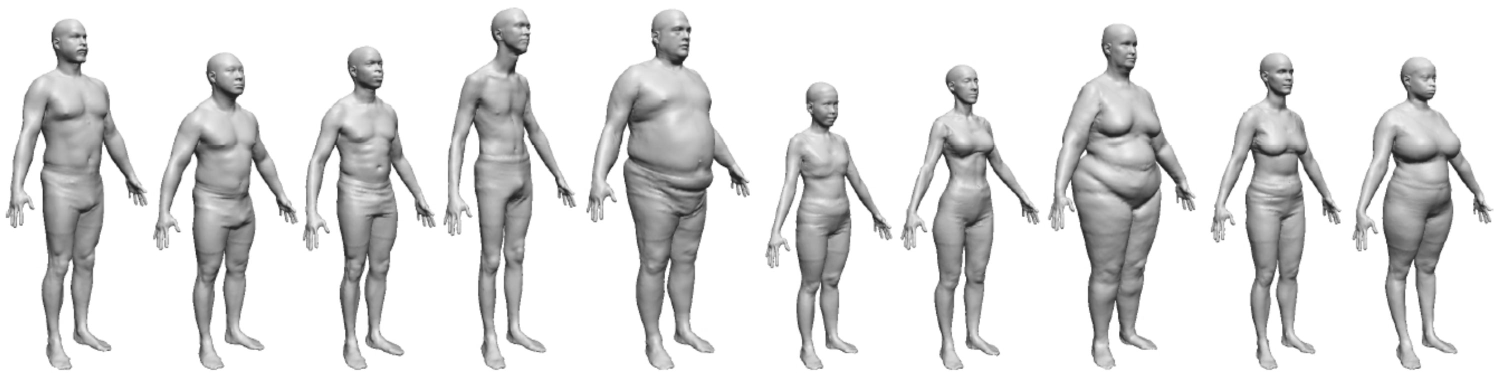
Image | Skin / Non-skin Silhouettes | Model Silhouette | Overlap

Principle: Shape Under Clothing

- Silhouettes are larger when there is clothing
  - Body must fit inside silhouettes
  - Constraints are tight for skin regions
- True shape not observable
  - Family of human body shapes (known statistics)

$$E_{shape}(\beta) = \sum_j \max\left(0, \frac{|\beta_j|}{\sigma_{\beta,j}} - \sigma_{thresh}\right)^2$$

$$E_{pose}(\theta)$$



[Allen et al. '03]

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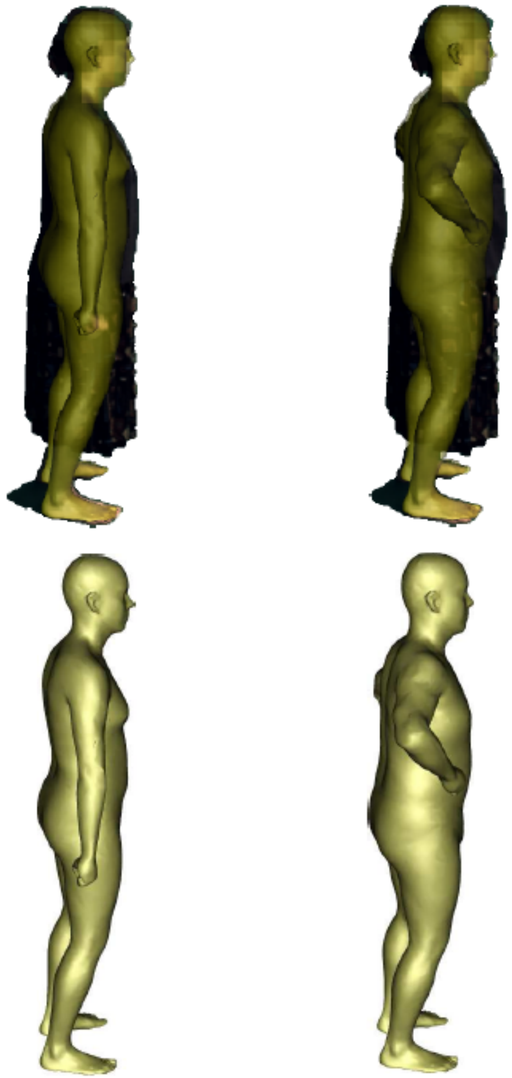
Objective Function

$$E_{\text{clothes}}(s) = \sum_{k=1}^{K} E_{\text{inside}}(s) + E_{\text{expand}}(s) + E_{\text{shape}}(\beta) + E_{\text{pose}}(\theta)$$

Comparison

Fitting as Naked

Single-pose Fitting with Clothes



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- **Combine constraints across pose**

Principle: Shape Under Clothing

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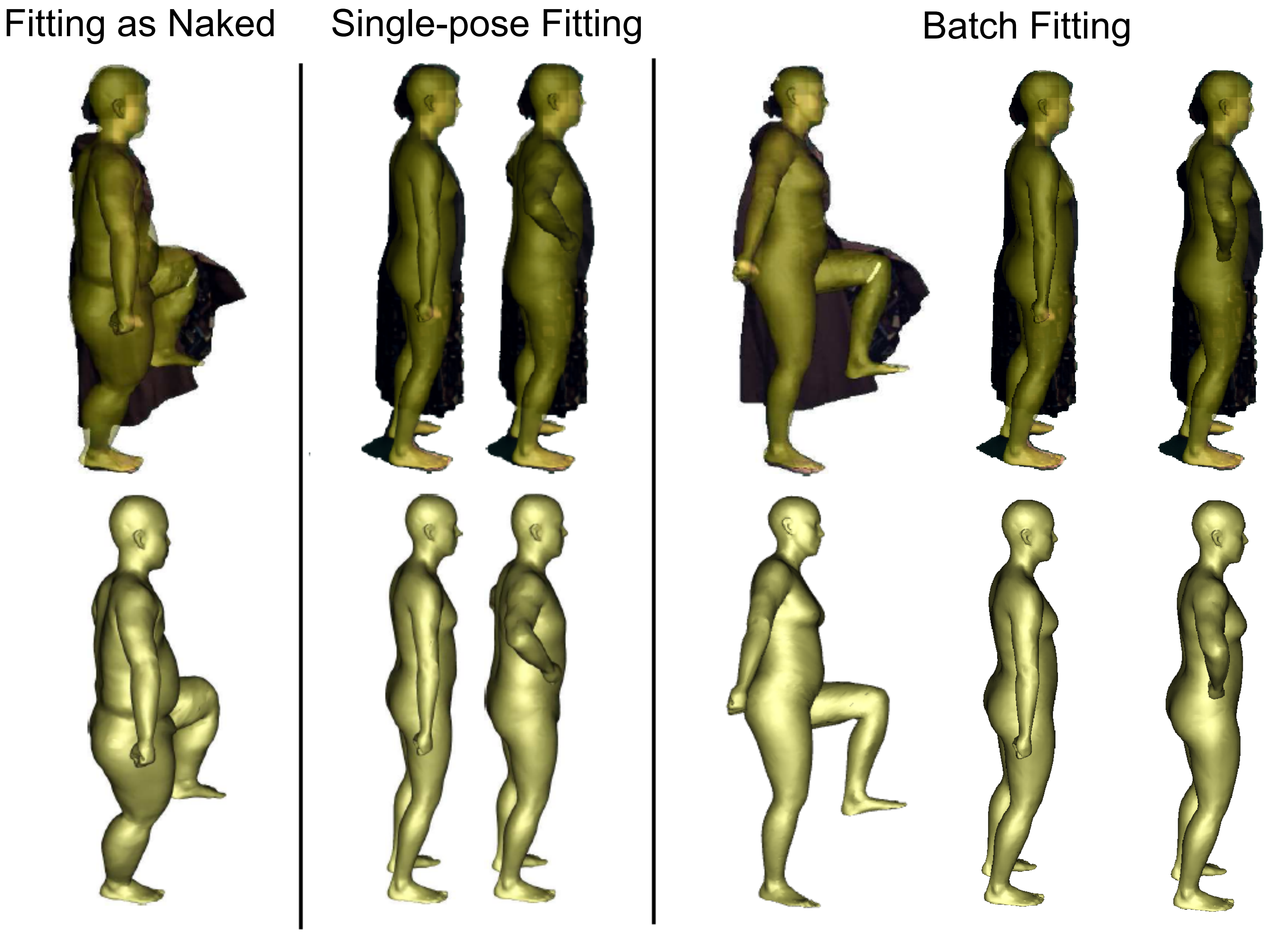
- Combine constraints across pose

New "batch" objective function

$$E_{\text{clothes}}(\beta, \Theta) = \sum_{p=1}^{P} \sum_{k=1}^{K} E_{\text{inside}}(\beta, \theta_p) + E_{\text{expand}}(\beta, \theta_p) + E_{\text{shape}}(\beta) + E_{\text{pose}}(\theta_p)$$

$$\Theta = \theta_1, \ldots, \theta_P$$

Comparison



Clothing Dataset

Gender

Gender fitting

- Optimize pose and shape using the gender-neutral shape model
- Fit shape parameters for each gender-specific model
- Choose the most likely gender model under the objective function

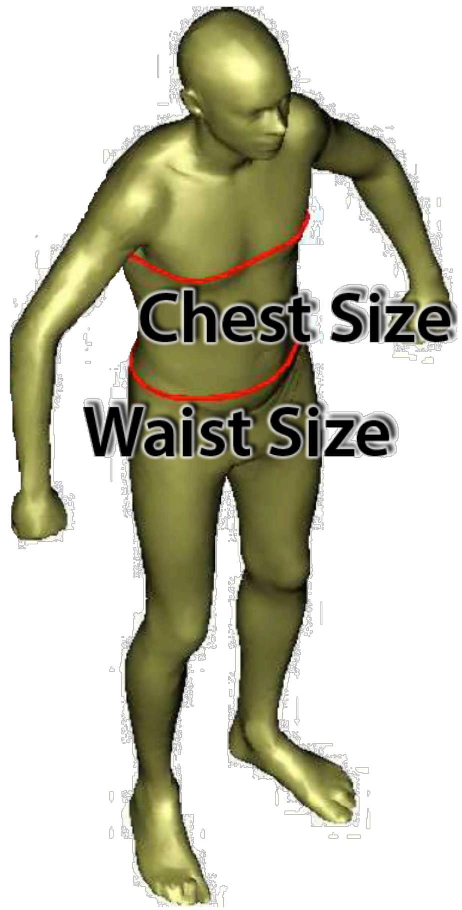
$$\chi^* = \arg\min_{\chi} \left(E_{\text{clothes}}(\beta_\chi, \Theta) \right)$$

Gender classification results on clothing dataset

- Single-pose fitting: 86% accuracy out of 583 cases
  - Majority within a trial: 90.6% out of 53 trials
- Batch fitting: 94.3% accuracy out of 53 trials

Batch Fitting Results

Quantitative Evaluation



Failure Case

Single-pose fitting

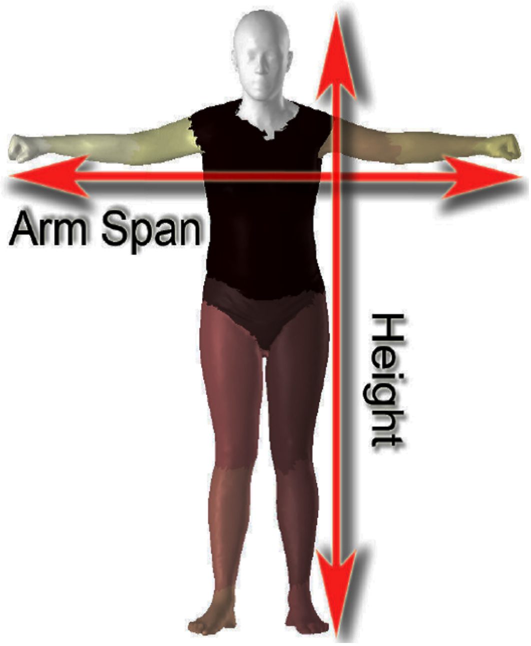
Batch fitting

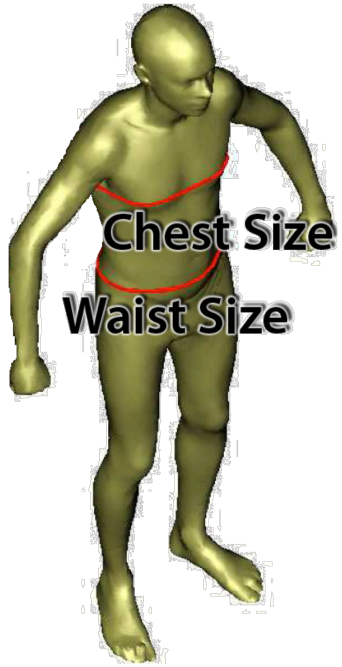
Applications - Metrology

Forensic video analysis

- Identify suspects in surveillance video
- Recover anthropometric measurements
  - height, weight (volume), waist size, chest size

[Criminisi ’02]





Applications - Fashion

Fashion design, manufacturing, e-commerce

– synthesize motion with different garments on a specific body shape

[Thomaszewski et al. '08], [Pabst et al. '08], [Decaudin et al. '06], [Choi & Ko, '05, '02], [Volino et al. '04], [Terzopoulos et al. '87, '88]

Virtual Try-On from MIRALab
http://research.miralab.unige.ch/clothes/VirtualTryOn.htm

Conclusions

- Shape under clothing
  - Inference problem subject to multiple constraints
    - Shape constancy across poses
    - Tight constraints in un-clothed regions
    - Statistical model of human shapes
  - Gender classification
- Privacy considerations
  - Our approach does not *see through* clothing

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Future Directions

- Find a minimal set of poses that constrain body shape effectively
- Integrate skin detection with model fitting
- Learn statistics of clothing variation
  - Tightness of clothing varies with pose
  - Learn when/where it is tight and when/where it is loose
  - Enforce different bounds
- Learn material- and style-specific constraints
  - Different materials fit the body differently (leather, lycra, wool, etc.) as do different types of clothing (dresses, t-shirts, suits, etc.)
- Detect and deal with hair / hats / shoes

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