UNIVERSITÉ DE STRASBOURG

Spatial Matching of Animated Meshes

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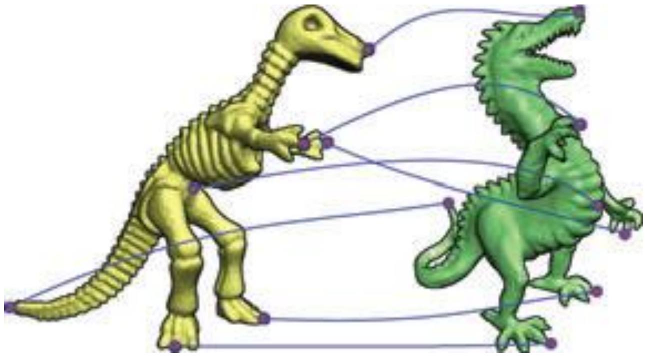
Context



Finding correspondence

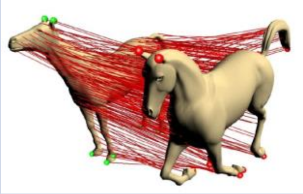
- Fundamental problem in **CG**, IP, CV
- Used in higher level algorithms
  - Recognition, retrieval, attribute transfer, statistical modeling

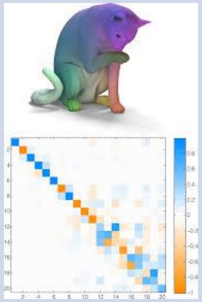
Specialized in different ways:

- **Correspondence** vs. registration
- **Inter-subject** vs. intra-subject
- **Sparse** vs. dense
- **Full** vs. partial

Previous work 1/2

Surface Correspondence



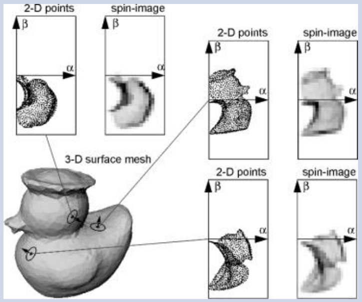
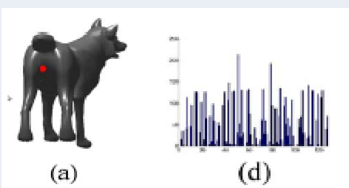
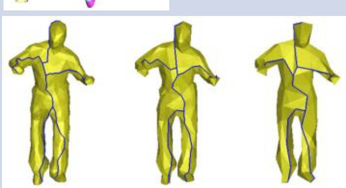


- Spectral clustering :
(Leordeanu &Hebert 2005)
- Embedding :
(JAIN et al 2007), (LIPMAN &FUNKHOUSER 2009), (Kim et al 2011)
- RANSAC & PLANSAC:
(Tevs et al 2009), (Tevs et al 2011)
- Efficient pruning of search tree:
(FUNKHOUSER and SHILANE 2006), (ZHANG et al 2008)
- Graph matching :
(Mykhalchuk et al 2013)
- Functional maps:
(Ovsjanikov et al 2012)

* Co-correspondence finding: Kim et al 2012

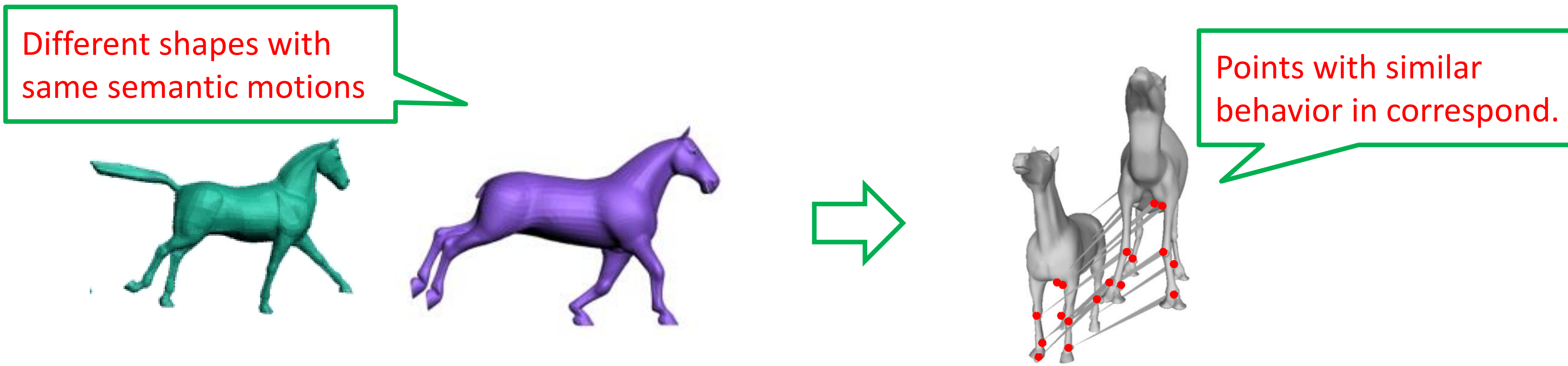
Pairwise similarity + approximate isometry

Previous work 2/2

local shape descriptors, S-T feature descriptors	
	Spin image: Johnson 1997, Darom and Keller 2012 Geodesic fan: Zelika et al 2004 Curvature map: Gatzke, Grimm et al. 2005, Integral volume: Gelfand, Mitra et al. 2005, HMM-based: Castellani, Cristani et al. 2008, HKS: Sun, Ovsjanikov et al. 2009,
	LD-SIFT: Darom and Keller 2012 MeshHOG: Zaharescu, Boyer et al. 2009, HOG3D: Klaeser et al. 2008, 3D Shape context: KÖRTGEN et al 2003
	Spatial segmentation of animation mesh: SATTLER et al 2005, DE AGUIAR et al 2008, ARCILA et al 2010, ARCILA et al 2013 Tung and Matsuyama 2013, Tung and Matsuyama 2014

Our work

- A new surface correspondence technique which exploits deformation/motion properties



  - A new descriptor – encodes local motion property
  - Adopt a graph matching technique [TKR13]

[TKR13] Torresani, L., Kolmogorov, V., Rother, C.: A dual decomposition approach to feature correspondence. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 35, 2 (2013), pp.259–271.

Motivation

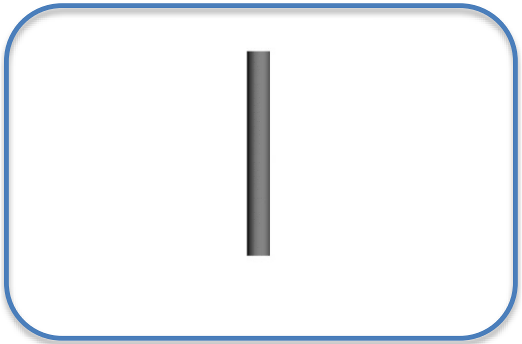
- Animating/time-varying shapes are common nowadays..

3D Animator

Motion Capture

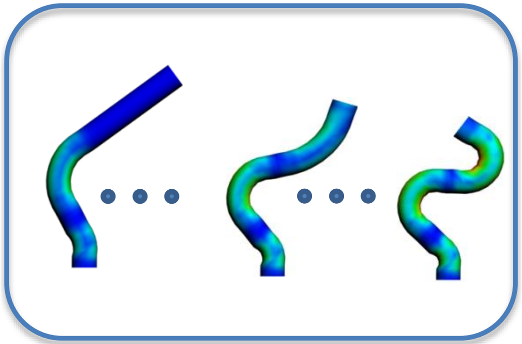
I. Detection of deformation feature

Overview : dynamic feature extraction



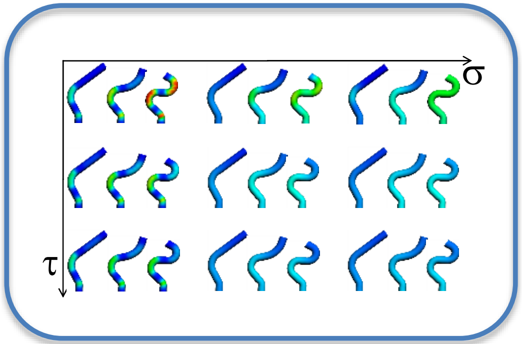
Input: Animated mesh $\mathcal{M}$
(**fixed mesh connectivity**)

Step 1



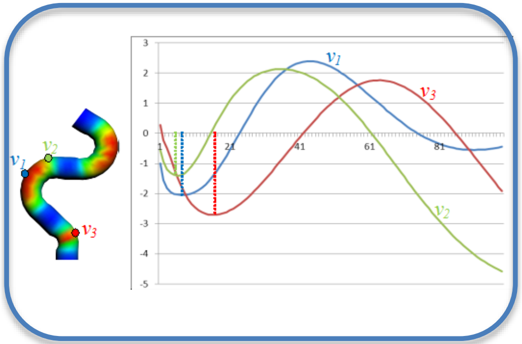
Deformation characteristics

Step 2



Multiscale representation of deformation characteristics

Step 3



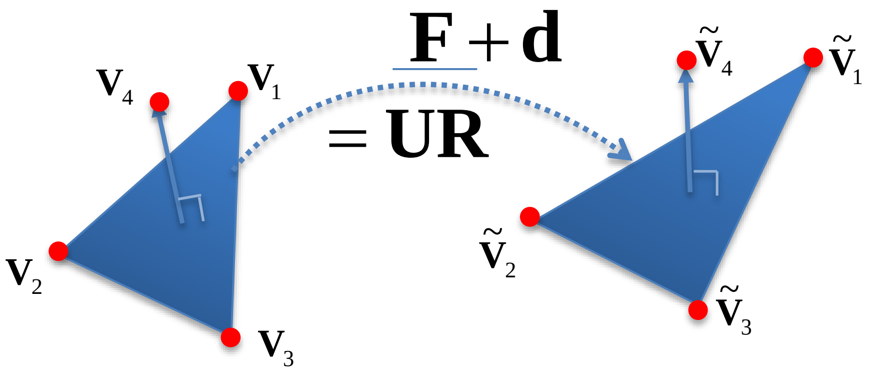
Difference-of-Gaussians
Feature response

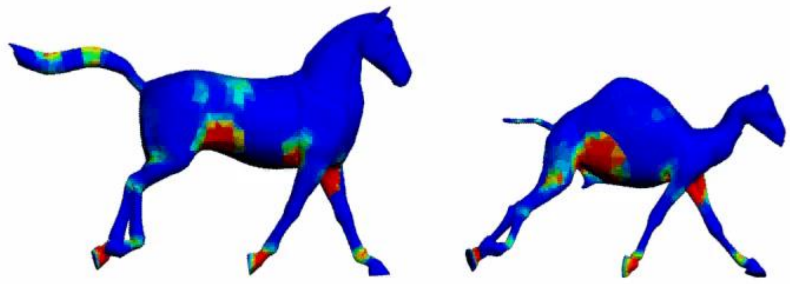
MYKHALCHUK, V., SEO, H., CORDIER, F.: On Spatio- Temporal Feature Point Detection for Animated Meshes, *The Visual Computer,* 31, 11 (2015), pp. 1471−1486.

D. Feature 1/3: Deformation characterestic

- $\mathrm{d}(\mathbf{p}^f) = \alpha \cdot \mathrm{c}(\mathbf{p}^f) + (1-\alpha) \cdot s(\mathbf{p}^f).$

curvature change



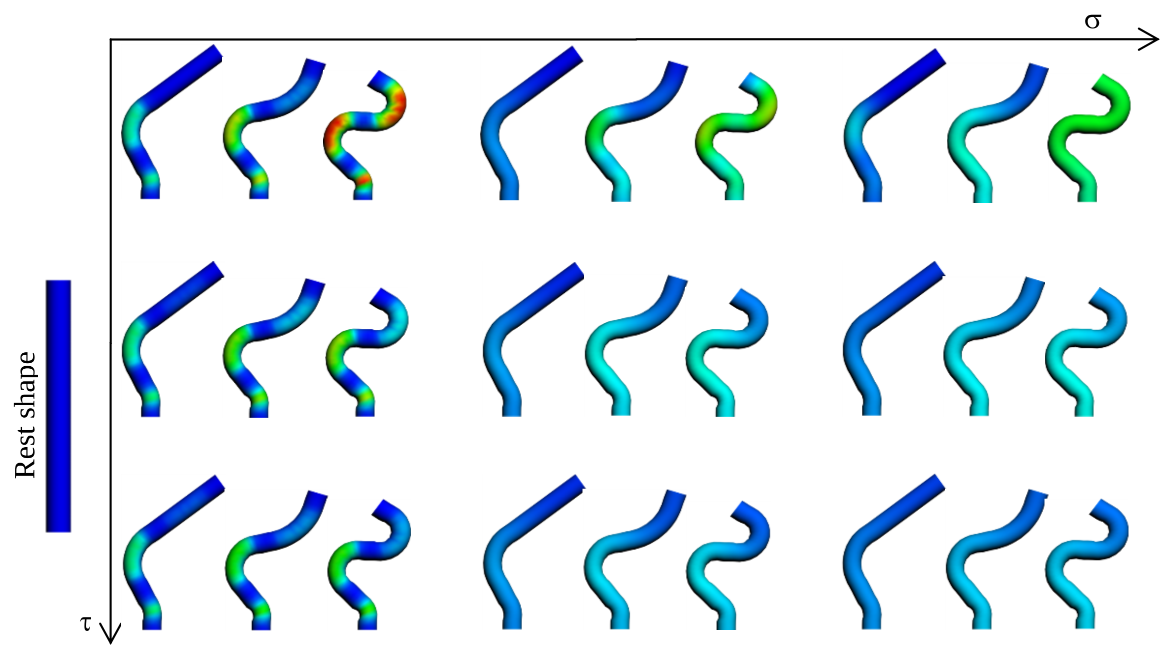


- ➢ Invariant to global rotation, translation, uniform scale
- ➢ Robust over shape difference

D. Feature 2/3: Multiscale representation

$L_{ij}(i \in \Sigma=0,\ldots N, j \in \mathrm{T}=0,\ldots K)$

octave scale	σ_1	σ_2	…	σ_N
τ_1	L_{11}	L_{12}	…	L_{1N}
τ_2	L_{21}	L_{22}	…	L_{2N}
⋮	⋮	⋮		⋮
τ_K	L_{K1}	L_{K2}	…	L_{KN}



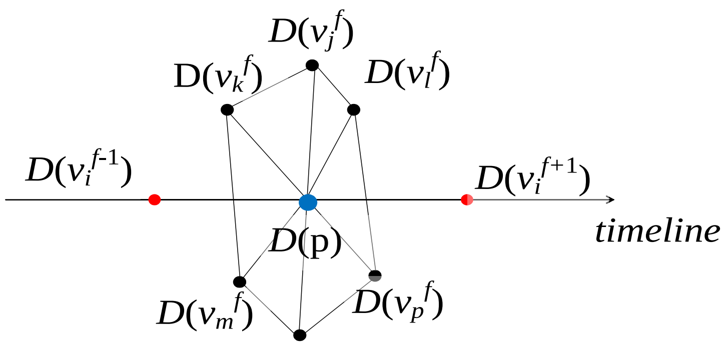
(a) Multi-scale deformation characteristics

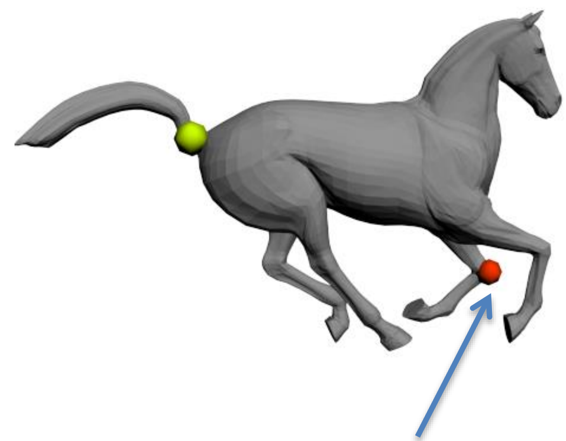
(b) Visual representation

D. Feature 3/3: Feature detection

- **Local minima in space-time (intra-octave)**

$$P_{kl} = \{p \in \mathcal{M} \mid \ \forall p_i \in N_{st}(p), D_{kl}(p) < D_{kl}(p_i) \text{ and } D_{kl}(p) < \varepsilon_{st}\},$$





(*p*, σ, τ)

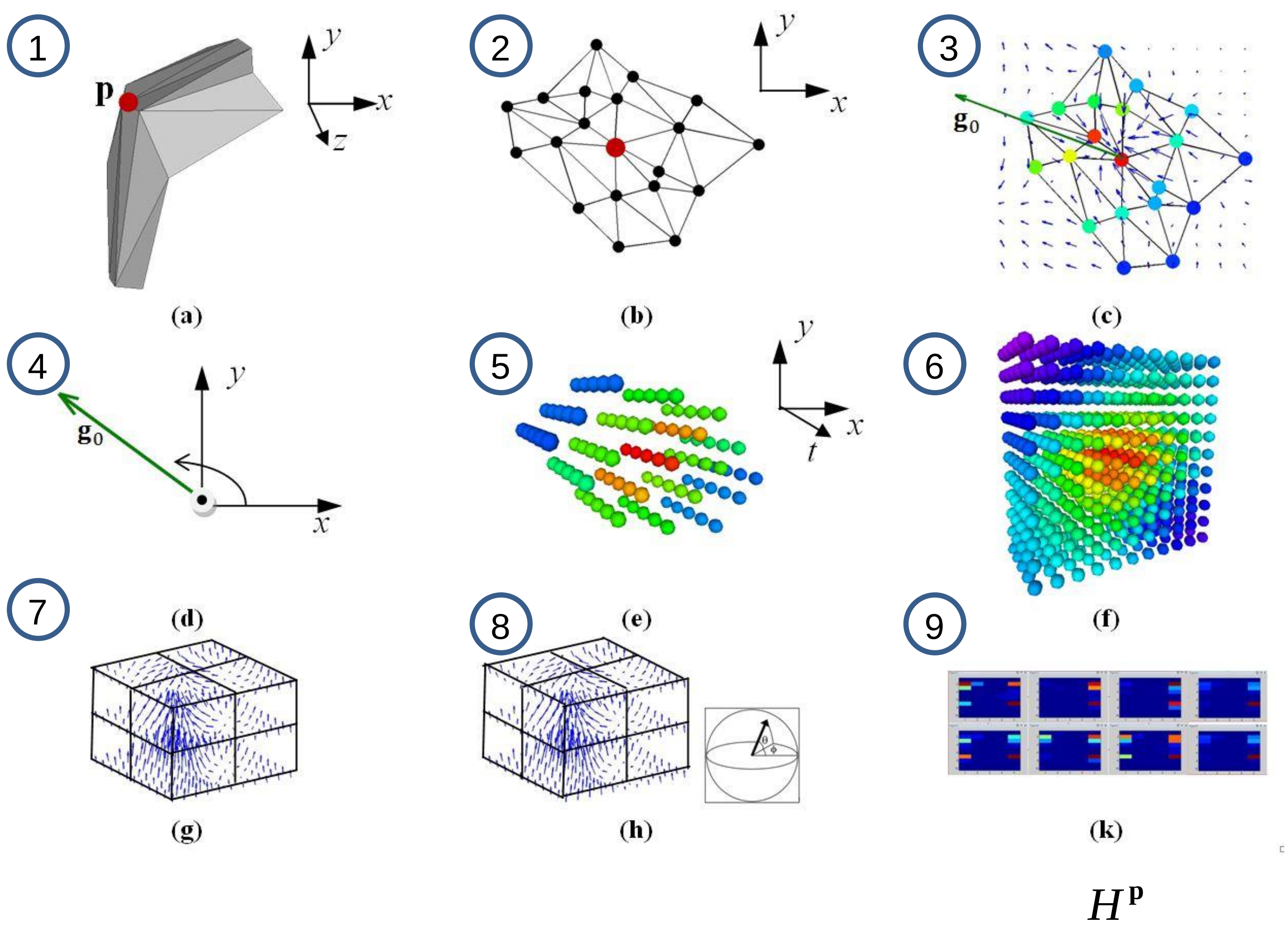
- **Local minima in scale (inter-octave)**

$$P = \{p \in \mathcal{M} \mid \forall (i,j) \in \mathcal{N}_{\sigma\tau}, D_{ij}(p) > D(p) \ and \ D(p) < \varepsilon_{\sigma\tau}\}$$

$D_{\sigma-1\tau-1}$	$D_{\sigma\tau-1}$	$D_{\sigma+1\tau}$
$D_{\sigma-1\tau}$	$D_{\sigma\tau}$	$D_{\sigma+1\tau}$
$D_{\sigma-1\tau}$	$D_{\sigma\tau+1}$	$D_{\sigma+1\tau+1}$

II. Feature descriptor and spatial matching

Dyn. Sig. #1: Animated mesh Histogram-of-Gradients



Dyn. Sig. #2: Normalized curves

Displacement curve

$$\mathrm{D}^{\mathbf{p}} : [1, M] \to R$$

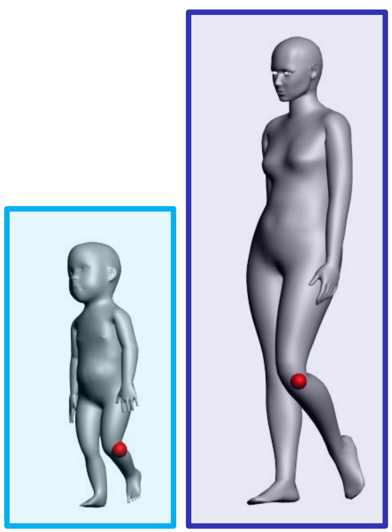
$$\Delta^{\mathbf{p}}(f) = \left\| \mathbf{p}^{f+1} - \mathbf{p}^{f} \right\|, f \in [1, M]$$

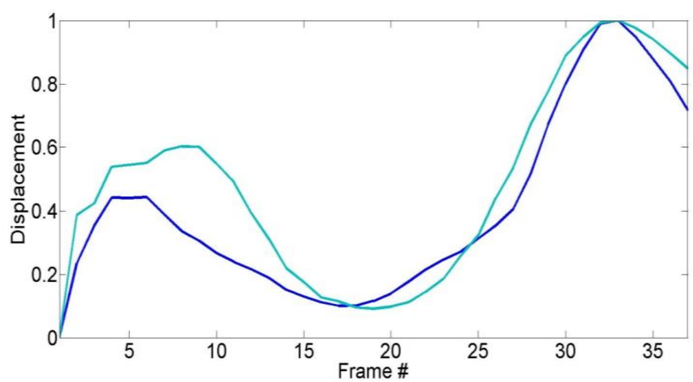
$$\widetilde{\Delta}^{\mathbf{p}}(f) = \frac{\Delta^{\mathbf{p}}(f)}{\Delta_{\max}}, \Delta_{\max} = \max \Delta^{\mathbf{v}}$$

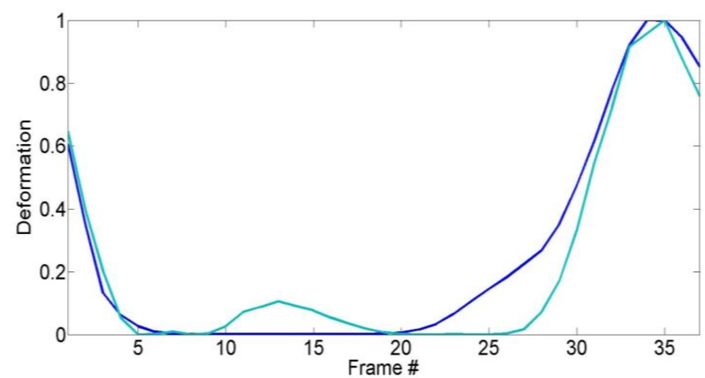
Deformation characteristics curve

$$c_d^{\mathbf{p}} : [1, M] \to R$$

$$c_d^{\mathbf{p}}(f) = \frac{d(\mathbf{p}^{f})}{d_{\max}}, d_{\max} = \max_{\mathbf{v}}(d(\mathbf{v}))$$



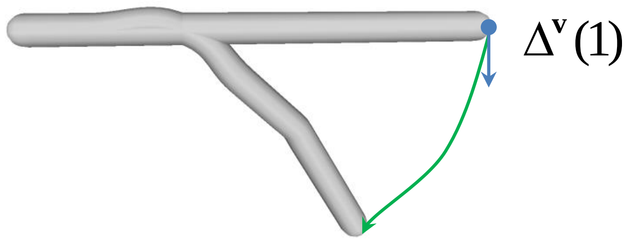




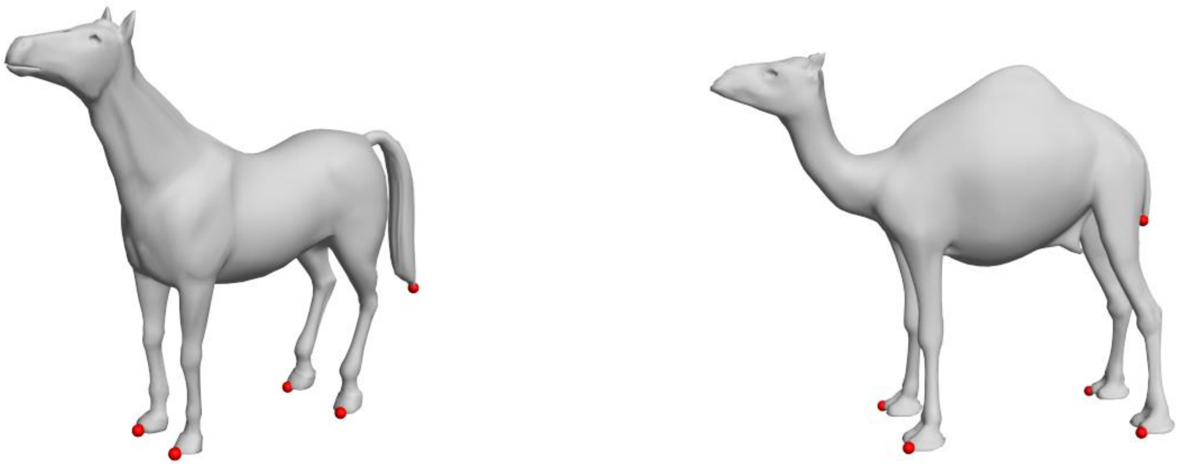
Displacement feature points

$$T(\Delta^{\mathbf{v}}) = \sum_{f=1}^{M} \Delta^{\mathbf{v}}(f)$$

$$\forall \mathbf{u} \in N_s(\mathbf{v}) : (\Delta^{\mathbf{v}} > \Delta^{\mathbf{u}}) \wedge (\Delta^{\mathbf{v}} > h^{\Delta})$$



- **Capture tips of articulated animated meshes**



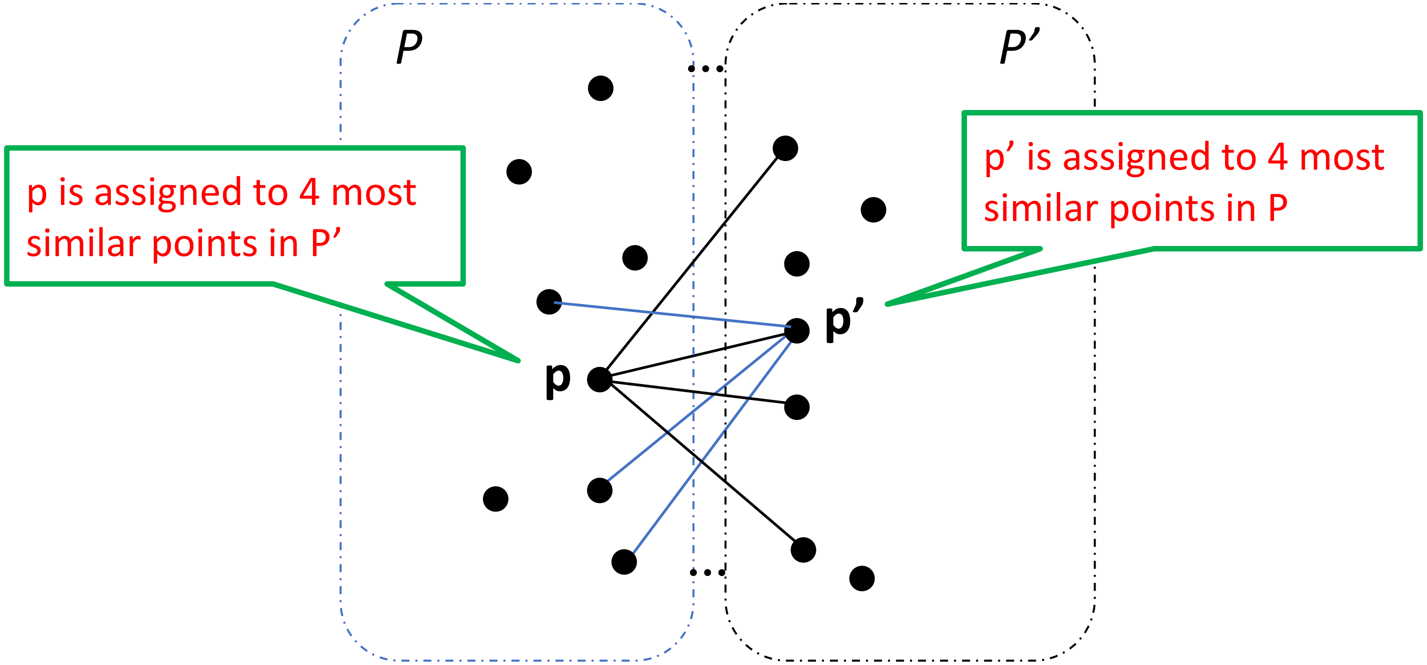
{*Dynamic feature points*} U {*Displacement feature points*}

Feature correspondence

- Correspondences as a graph matching:
  Energy function with **x, x**ϵ{0,1}^{A}, A ⊆ PxP'

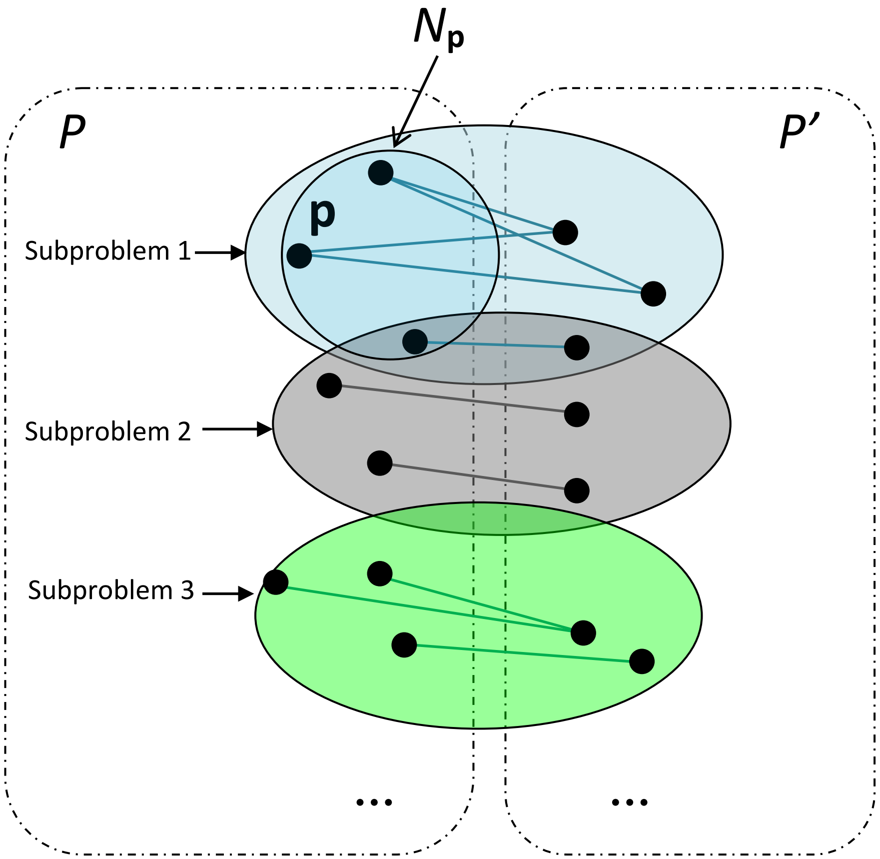
$$\operatorname*{argmin}_{\mathbf{x}} E(\mathbf{x}) = \lambda^{dscr} E^{dscr}(\mathbf{x}) + \lambda^{geod} E^{geod}(\mathbf{x}) + \lambda^{unmat} E^{unmat}(\mathbf{x})$$

subject to the unique assignment constraint



Feature correspondence optimization

- Dual decomposition approach (Torresani et al 2013)



$$\mathcal{N} = \{\langle(\mathbf{p},\mathbf{p}'),(\mathbf{q},\mathbf{q}')\rangle \in A \times A \mid \mathbf{p} \in N_S^k(\mathbf{q}) \vee \mathbf{q} \in N_S^k(\mathbf{p}) \vee \mathbf{p}' \in N_S^k(\mathbf{q}') \vee \mathbf{q}' \in N_S^k(\mathbf{p}')\},$$

Feature correspondence optimization

- Correspondences as unknowns **x**

$$\operatorname*{argmin}_{\mathbf{x}} E(\mathbf{x}) = \lambda^{dscr} E^{dscr}(\mathbf{x}) + \lambda^{geod} E^{geod}(\mathbf{x}) + \lambda^{unmat} E^{unmat}(\mathbf{x})$$

$$E^{dscr}(\mathbf{x}) = \sum \theta_a x_a$$: **Descriptor** energy term

$$\theta_a \leftarrow D_{\mathcal{H}}(\mathbf{p}, \mathbf{p}') = w_1 \cdot D_{\Delta^{\mathbf{p}}}(\mathbf{p}, \mathbf{p}') + w_2 \cdot D_{c_d^{\mathbf{p}}}(\mathbf{p}, \mathbf{p}') + w_3 \cdot D_{H^{\mathbf{p}}}(\mathbf{p}, \mathbf{p}')$$

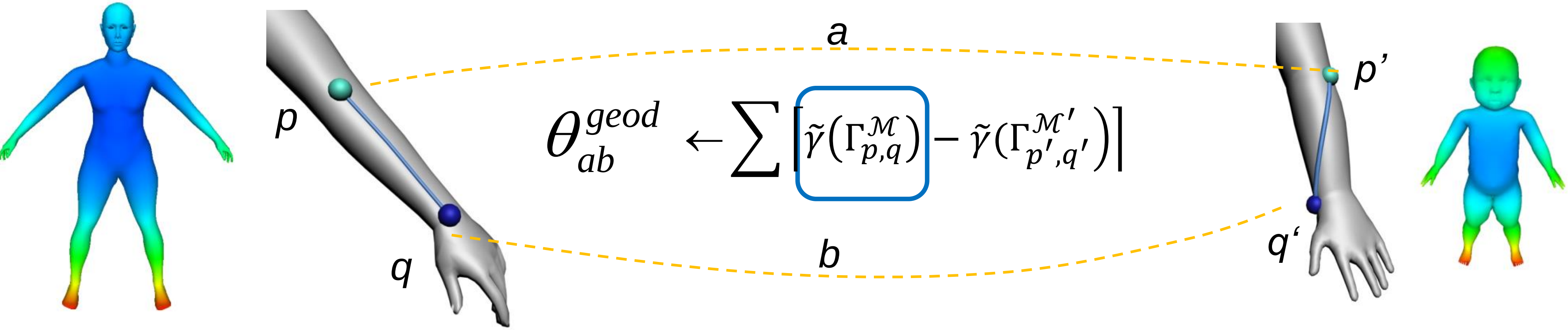
$\theta_a \leftarrow \infty$ when $\mathbf{p}, \mathbf{p}'$ are of different types

Feature correspondence optimization

- Correspondences as unknowns **x**

$$\underset{\mathbf{x}}{\operatorname{argmin}}\, E(\mathbf{x}) = \lambda^{dscr} E^{dscr}(\mathbf{x}) + \lambda^{geod} E^{geod}(\mathbf{x}) + \lambda^{unmat} E^{unmat}(\mathbf{x})$$

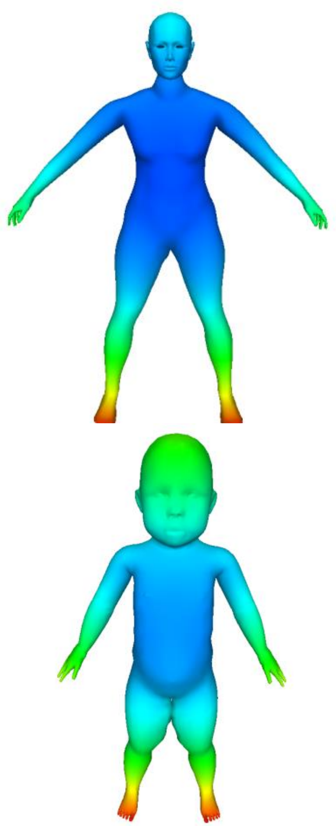
$$E^{geod}(\mathbf{x}) = \sum \theta_{ab}^{geod} x_a x_b$$: **Geodesic distortion** term



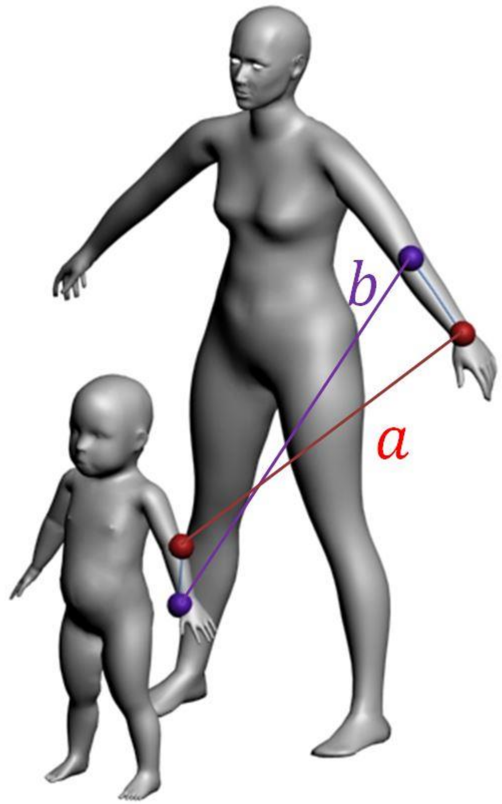
$$\theta_{ab}^{geod} \leftarrow \sum \left| \tilde{\gamma}\left(\Gamma_{p,q}^{\mathcal{M}}\right) - \tilde{\gamma}\left(\Gamma_{p',q'}^{\mathcal{M}'}\right) \right|$$

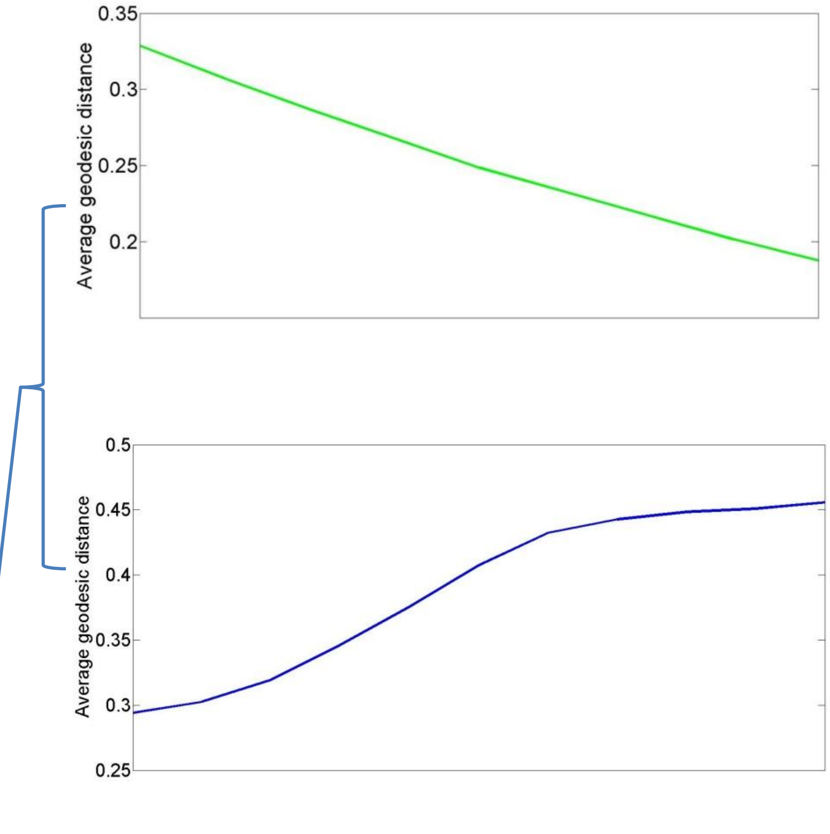
[HSK+01] HILAGA M., SHINAGAWA,Y. KOHMURA T., and KUNIi T. L.: Topology matching for fully automatic similarity estimation of 3D shapes. *Proc. the 28th annual conference on Computer graphics and interactive techniques* (SIGGRAPH '01), (2001), pp. 203–212.

Feature correspondence optimization



Average geodesic distance map





incompatible

$$\theta_{ab}^{geod} = +\infty$$

Feature correspondence optimization

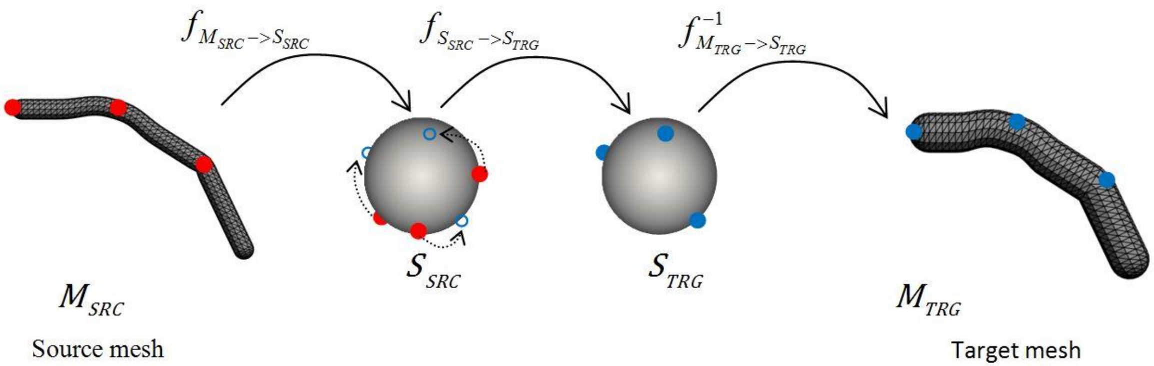
- Correspondences as unknowns **x**

$$E(\mathbf{x}) = \lambda^{dscr} E^{dscr}(\mathbf{x}) + \lambda^{geod} E^{geod}(\mathbf{x}) + \lambda^{unmat} E^{unmat}(\mathbf{x}) + \lambda^{coh} E^{coh}(\mathbf{x})$$

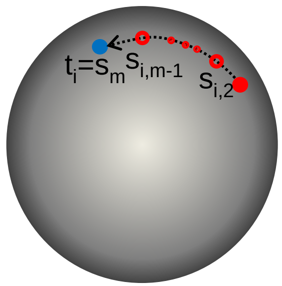
$$\arg\min_{\mathbf{x}} E(\mathbf{x})$$

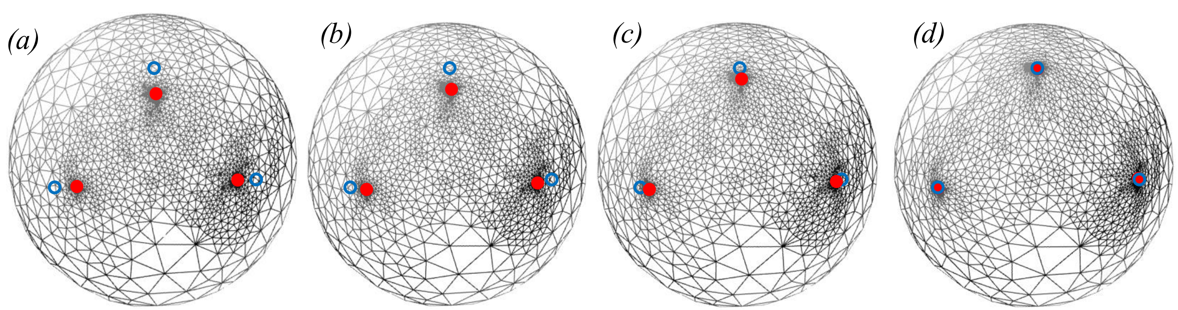
$$E^{unmat}(\mathbf{x}) = 1 - \frac{\sum x_a}{\min\{|P|, |P'|\}}$$

Unmatched features penalty



(Seo and Cordier 2010)





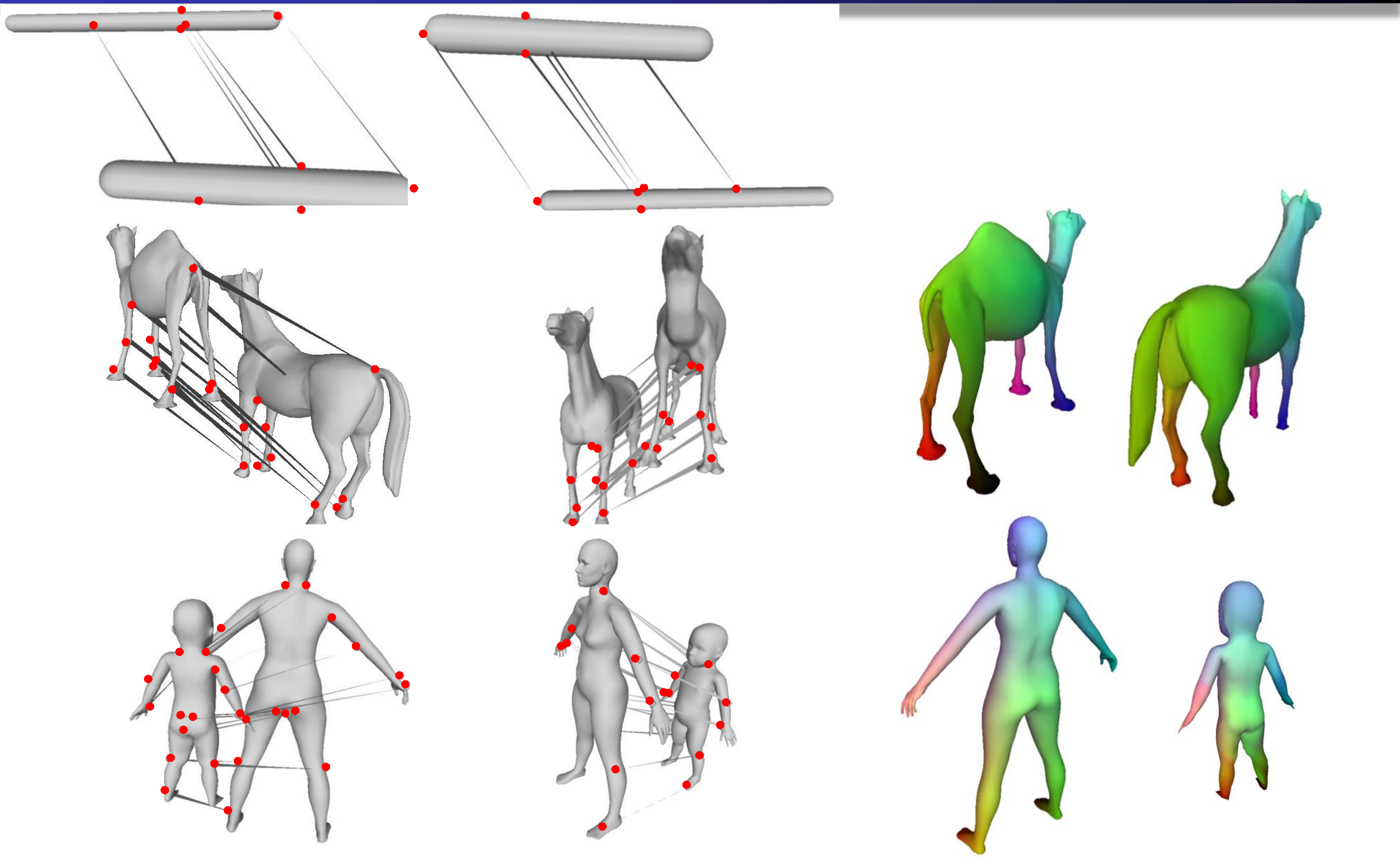
Results

- Comparison with the ground truth

	Normalized displacement curve	Normalized deformation characteristic curve	AnimHOG
Cylinders	5/5 (0%)	5/5 (0%)	5/5 (0%)
Horse & Camel	14/19 (26.3%)	12/19 (36.8%)	17/19 (10.5%)
Woman & Baby	12/15 (20%)	13/15 (13.3%)	12/15 (20%)

- Matching error becomes close to 0 when we use **composite descriptor**.

Results: Coarse feature correspondence



Conclusion & Future work

Shape correspondence technique for animated meshes

- Introduced a new dynamic point descriptor
- Adopted a DD graph matching to the feature correspondence
- Can produce more reliable results

In the future,

- Spatio-temporal correspondence
- Medical applications (e.g. heart)
- Statistical shape analysis

Thank you !

Gratification to:

French national project ANR SHARED

M. Vasyl Mykhalchuk, M. Alexis Renault