Harmonic skeleton for realistic character animation

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Building an animated 3D character requires to:

1. Create a 3D mesh
2. Set the 3D position and hierarchy of skeleton joints
3. Set the 3D orientation of skeleton joints
4. Create high-level controllers for animation (IK, constraints)
5. Define skinning weights
Related works

Skeleton computation

- Nowadays:
  - By hand
  - By experts

- Automatic methods:
  - Little control over the result
  - Provide noisy skeletons (unwanted joints)
  - Rely only on the geometry of the shape
    \(~\sim not the anatomy of the model (bone structure)\)

[Liu PG'03]  [Lien SPM'06]  [Tierny PG'06]

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Harmonic skeleton for realistic character animation
Our idea

Control of the extrema thanks to a harmonic function
Related works

Our idea

Control of the extrema thanks to a harmonic function

⇒

⇒

⇒

Automatic association of semantic information to nodes/joints
Our idea

Control of the extrema thanks to a harmonic function

⇓

⇓

⇒

Automatic association of semantic information to nodes/joints

⇓

⇓

⇓

Adapted refinement to match handmade IK skeletons
Our idea

Control of the extrema thanks to a harmonic function

⇒

⇒

⇒

Automatic association of **semantic information** to nodes/joints

⇒

⇒

⇒

**Adapted refinement** to match handmade IK skeletons

⇒

**Help for both experts and non-experts**
Contributions

A skeleton generation algorithm with the following properties:

- **Semantic decomposition** of both skeleton and shape
- **Specialized heuristics** for bipeds and quadruped mammals
- **Robustness** (pose+deformation: see paper)
- **Fast and almost no user intervention**, but control is possible
Related works

Algorithm overview

Mesh + source vertex

Harmonic graph

Harmonic skeleton

A priori knowledge

Adapted refinement

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Reeb graph of $f = M/\sim$

$x_1 \sim x_2 \iff \begin{cases} f(x_1) = f(x_2) \\ \text{and } x_1 \text{ and } x_2 \text{ belong to the same connected component of } f^{-1}(f(x_1)) \end{cases}$
Harmonic function

Laplace equation with boundary conditions:

\[
\begin{aligned}
\triangle f(x) &= 0 \quad \forall x \in M \\
f(x) &= g(x) \quad \forall x \in B_M
\end{aligned}
\]

- \(B_M\) = set of vertices: extrema of the graph
- \(g(x)\) = approx. geodesic distance to source vertex

height  distance to source  harmonic
Harmonic graph computation

1. Extrema selection
   - Automatic or not
   - Source vertex on the head (by hand)
Harmonic graph computation

1. Extrema selection

2. Harmonic function $f$ computation
Harmonic graph computation

1. Extrema selection

2. Harmonic function $f$ computation

3. Reeb graph computation
   - In $O(n \log n)$ time
     
     [Cole McLaughlin SoCG’03]

Harmonic skeleton for realistic character animation
Harmonic graph computation

1. Extrema selection

2. Harmonic function $f$ computation

3. Reeb graph computation

4. Graph filtering
   - Small (for $f$) edges removal
   - Related to persistence
     \[ Edelsbrunner \text{ FOCS’00} \]
   - Can be done automatically
     \[ Pascucci \text{ SIGGRAPH’07} \]

$\Rightarrow$ morphology recovered
From a Reeb graph to a skeleton

**Algorithm overview**

Mesh + source vertex

→

Harmonic graph

→

Harmonic skeleton

→

A priori knowledge

→

Adapted refinement
Symmetry axis detection

- Symmetry of the *morphology* (2 arms, 2 feet, \ldots)
- Finding symmetries on a graph: **NP-complete**
- Assumptions:
  - **Source node** on the symmetry axis
  - No cycle
  - 2 subtrees *isomorphic* $\iff$ same depth + same degree for root nodes

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Simple embedding

Not straightforward solution for saddle nodes
- Insert regular nodes
- Use the symmetry axis
Joint hierarchy and orientation

Hierarchy:
- Use symmetry axis: e.g. last joint = root joint

Orientation:
- Use the direction of the embedding of the symmetry axis

Skeleton refinement:
- Add regular nodes on the graph
- Embedding: center of mass of their connected component for $f$
Algorithm overview

Mesh + source vertex

Harmonic graph

Harmonic skeleton

Adapted refinement

A priori knowledge
The symmetry axis gives **semantic information**!

New nodes inserted:
- Edges subdivided
- **New extremum** for the jaw (biped)/the top of the head (quadruped)

Reference frame
\[
(\text{Spine}, \frac{P_1P_2}{\|P_1P_2\|}, \text{Spine} \times \frac{P_1P_2}{\|P_1P_2\|})
\]
Heuristics

- Some nodes are **shifted** along one of the directions of the reference frame
- New nodes:
  - mean Euclidean position
  - or mean value for $f$
  - or fitting some geometric features [Tiery PG’06]
Heuristics

- Some nodes are **shifted** along one of the directions of the reference frame
- New nodes:
  - mean Euclidean position
  - or mean value for $f$
  - or fitting some geometric features [Tierny PG’06]

**Example:** spine joints, quadruped case

- $SP$ divided into 4 edges
- All joints lifted up along $Spine \times \frac{P_1 P_2}{\|P_1 P_2\|}$

\[
J_{\text{new}} = J_{\text{simple}} + c \cdot \|J_{\text{simple}} B\| \quad Spine \times \frac{P_1 P_2}{\|P_1 P_2\|}
\]

- $c = 0.8/0.76/0.72/0.64$, $S$ so that $Spine$ not modified

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Results

- 14,000 faces, 0.8s
- 296,000 faces, 36s
- 850 faces, 0.05s
- 4,000 faces, 0.2s
- 7,000 faces, 0.6s
- 38,000 faces, 3s

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Video: use for animation
Conclusion

Input:
- Manifold mesh
- Source vertex (on the head)
- A priori knowledge about character’s real anatomy

Output:
- IK skeleton closely matching handmade skeleton
- Semantic information attached to joints (symmetry axis, anatomy)

Computed Handmade (previous)
Future work

- **Enhancement**
  - Robust feature extraction [Zhang ToG’05]
  - Reeb graph for non-manifold meshes [Pascucci SIGGRAPH’07]

- **Skinning**
  - Use $f$ values: vertices ↔ joints
  - Use joint *semantics* to define adapted weights
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