**Stable Dynamic 3D Shape Models**

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**Motivation: Model-based Segmentation**

### Segmentation

Segmentation should incorporate **shape knowledge**. Therefore, models will be used.

Models should be **locally controllable** for better possibilities of correction and user control.

No training should be necessary.

### Mass spring models

Mass spring models are **prototypes** of the structure to segment. They can be deformed to fit this structure.

They are **physically based models**, consisting of masses linked by springs. They move according to Newtonian mechanics. Sensors at the masses pull them to image positions, where specific image features are present, whereas the springs try to conserve the original appearance. Eventually, an equilibrium is reached.

\[
\vec{v}_{i+1} = \left( \vec{r}_i + \frac{w_f \cdot \sum F_j + w_s \cdot \vec{F}_i}{m_i} \cdot \Delta t \right) \cdot (1 - d)
\]

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**Theory: Stable Mass Spring Models (SMSMs)**

### Torsion forces

A new force component is introduced to stabilize the model. It is called **torsion force**. It acts tangentially on each spring and pushes it towards its original direction, which is called its **rest direction**.

\[
\vec{F}_{ij} = \frac{\vec{r}_i - \vec{r}_j}{||\vec{r}_i - \vec{r}_j||} \cdot \vec{v}_{ij} \quad \text{with} \quad \vec{v}_{ij} = \vec{r}_{ij} - \frac{\vec{r}_{ij}}{||\vec{r}_{ij}||^2} \cdot \vec{r}_{ij}
\]

Torsion forces stabilize even sparse mass spring models, which preserves their flexibility. Shape and size control is nearly independent via weighting of the torsion respective spring forces.

- with / without torsion forces (2D)
- with / without torsion forces (3D)

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### Mass rotation

Because of the **absolute rest direction** of a spring, model rotation is nearly impossible. To achieve a **relative rest direction**, masses have to be rotated according to the co-torsion of the incident springs.

\[
Q_i = \left( \prod_{j=1}^{n} Q_{\vec{a}_{ij}} \right)^{-1} \quad \text{with} \quad Q_{\vec{a}_{ij}} = \left( \begin{array}{cc}
\cos \frac{\vec{a}_{ij}}{2} & -\sin \frac{\vec{a}_{ij}}{2} \\
\sin \frac{\vec{a}_{ij}}{2} & \cos \frac{\vec{a}_{ij}}{2}
\end{array} \right)
\]

Models can rotate during adaption. The rotation of the springs can be done relative to 3 reference frames: world, model, incident mass

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**Application: Left Ventricle in 3D-SPECT**

### Task

The **left ventricle** should be segmented in **3D SPECT Images**. These functional images have a high noise level. But the biggest problem was the fact that ventricles could contain gaps caused by infarcts. These gaps should be bridged by the segmentation.

We had 41 datasets for testing. For 7, we had a gold standard from a medical expert.

Our automatic, model-based approach using SMSMs always segmented the left ventricle successfully. The segmentation’s variations from the gold standard lay completely within the inter-observer variance.

### Model

We generated an SMSM automatically from a sample segmentation by a heuristic approach. This SMSM consisted of 3 sub-models:

- the ventricle inner region model
- the ventricle wall region model
- the ventricle wall surface model

This SMSM was used on all given datasets. It consisted of 153 masses and 630 springs. The average degree of crosslinking was 8.24.

### Segmentation

Automatic model adaption took place in a few seconds. Even from bad starting positions, the left ventricle was found properly. Gaps in the ventricle wall were bridged.

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