Understanding: Dual-arm folding of a piece of garment on the CloPeMa testbed

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CloPeMa team

- Centre for Research and Technology, Hellas, Thessaloniki (coordinator)

- University of Glasgow, U.K.
- Czech Technical University in Prague, Czech Republic
- University of Genova, Italy
- Neovision s.r.o., Czech Republic (SME)

Introduction, task formulation

CloPeMa project overview:

CloPeMa (Feb 2012 - Jan 2015) is a STREP which aims at:

- Advancing the state of the art in the autonomous perception and dual-arm manipulation of all kinds of fabrics, textiles and garments.
- Novelty of CloPeMa is in its generality – random pile, unfolding, folding sorting.
- Integration of perception, action, learning, and reasoning.
- CloPeMa hand.

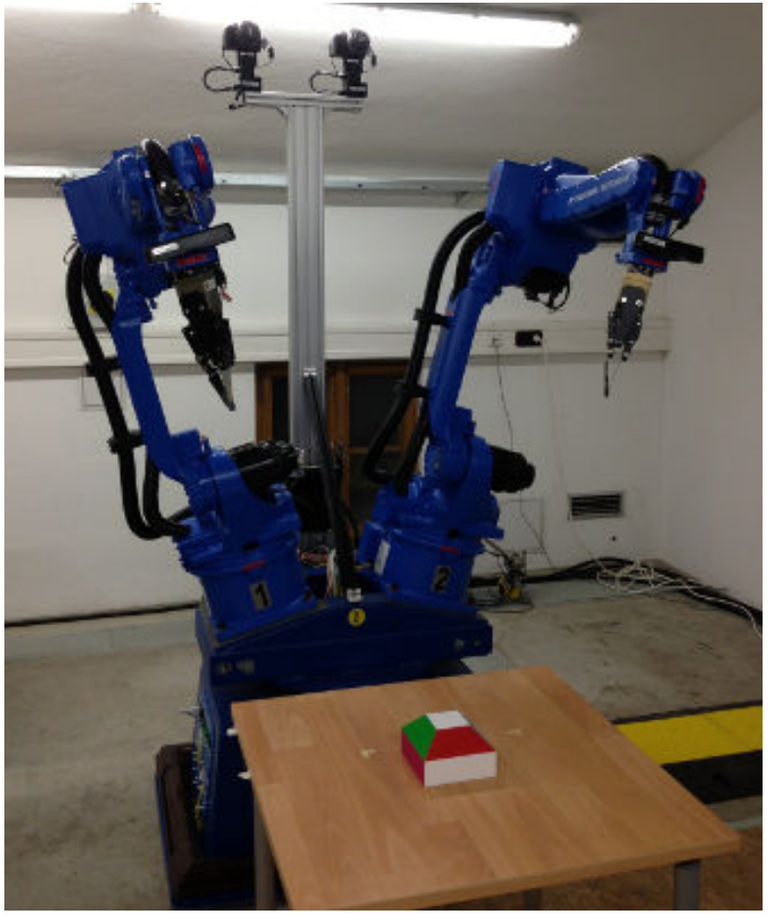
Our coordinator
Maria Petrou
$*1953$ - $\dagger 2012$

This talk:

- A brief intro to CloPeMa testbed.
- Demo of the current abilities after Year 2. The much improved polygonal model of the garment.
- Thoughts about understanding which is needed: scene with garment representation, modeling and reasoning.

CloPeMa Testbed

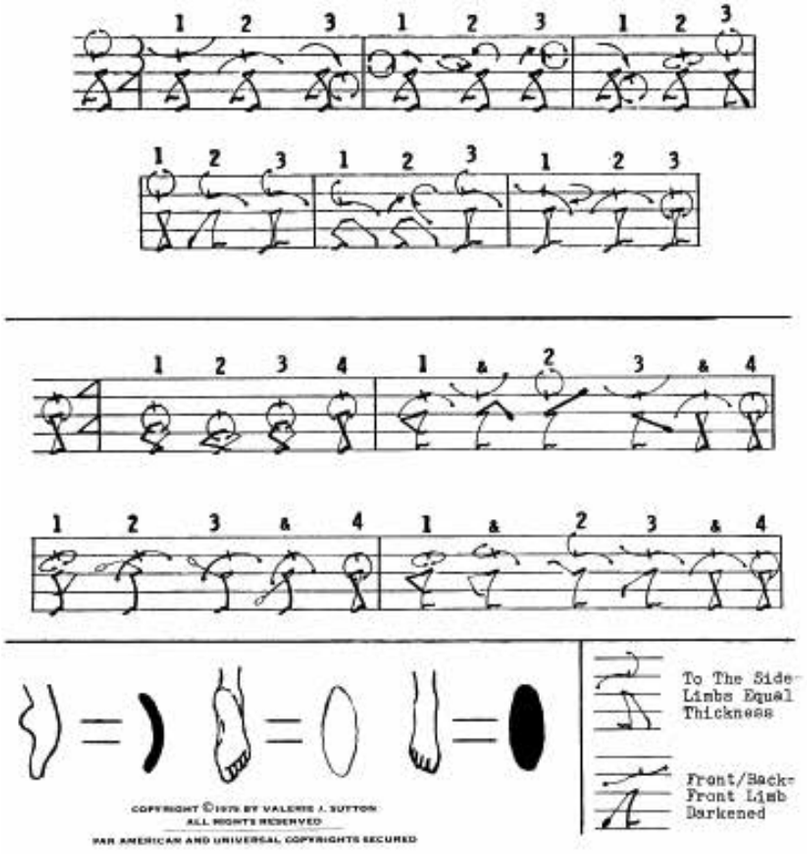
- 13 DOF dual-arm robot based on two welding hollow-wrist manipulators Motoman MA 1400.
- Testbed serves as the experimental platform for soft material manipulation.
- Openness achieved also through ROS.
- Sensors: high-resolution optical stereo, 3 Kinects, force/torque sensors between the last manipulator join and the CloPeMa hand.
- CloPeMa hand: 2 fingers, tactile sensor on one finger, rubbing motion, photometric stereo for detailed analysis of the cloth.



Beating the complexity – divide and conquer

- Hierarchy of modules of various complexity (top-down).
- Terminology: (robotic) skill → activity → action → atomic action.
- Example: T-shirt folding → gravity-folding → lifting the grabbed garment → gripping the garment from the side.
- The first aim is to compose (plan) a skill automatically from available activities, etc.

- The second aim is to learn activities, actions empirically with more and more autonomy.



Sutton Dance Writing 1975

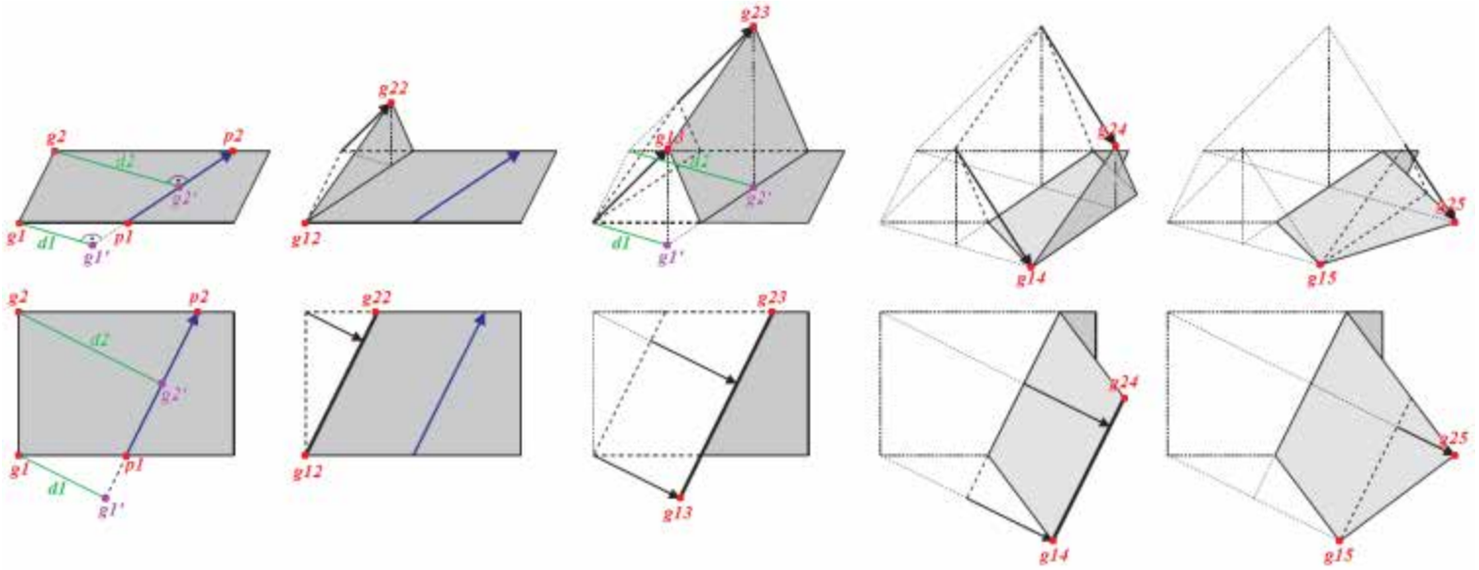
Example: Gravity Based Folding

Researcher: Vladimír Petrík, master student, Libor Wagner (project engineer).

Inspired by: J. van den Berg, S. Miller, K. Goldberg, P. Abbeel *Gravity-Based Robotic Cloth Folding*. Proceedings of WAFR 2010, U of California, Berkeley.

Algorithm outline

- Original g-fold is defined by the folding line and the grasping points.
- Extended by the orientation of the gripper (input parameter).
- Improved by the gripper rotation around the folding line (input parameter).
- It is difficult to find a possible g-fold within the working space when folding the whole garment. (the orientation of the gripper limits the working space).



Gravity Based Folding, manipulation example

Polygonal Model of Clothing (1)

Researcher: Jan Stria (Ph.D. student), V. Hlavac, connection to CloPeMa testbed Libor Wagner (project engineer).

Inspired by: S. Miller, M. Fritz, T. Darrell, and P. Abbeel. *Parametrized shape models for clothing. In Proceeding of the International Conference on Robotics and Automation (ICRA 2011), Shanghai, China, May 2011.*

Overview:

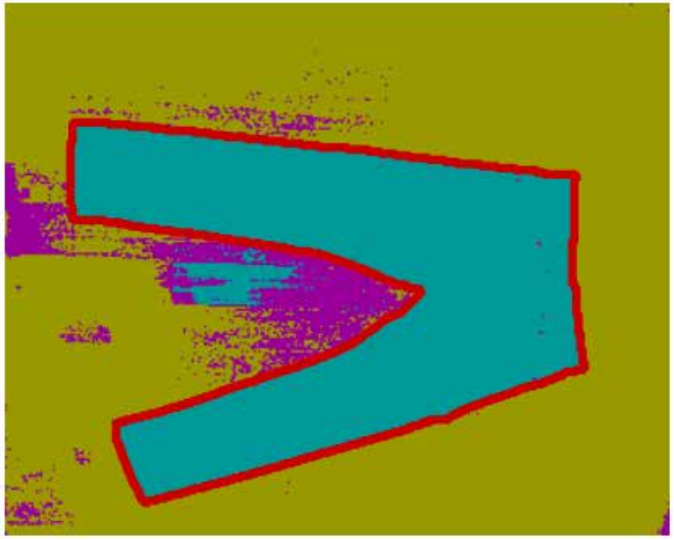
- ***Input**: a single image of a piece of garment spread on the table.*
- ***Segmentation**: Gaussian mixture model and GRABCUT algorithm.*
- ***Contour simplification** by a polygonal curve approximation, Perez, Vidal, 1994. Suboptimal dynamic programming approach.*
- ***Model mapping**: locally optimal dynamic programming approach.*
- ***Output**: Positions of landmark points on the garmetnt contour (e.g. armpit, crotch, endpoints of a trouser leg).*

Polygonal Model of Clothing (2)

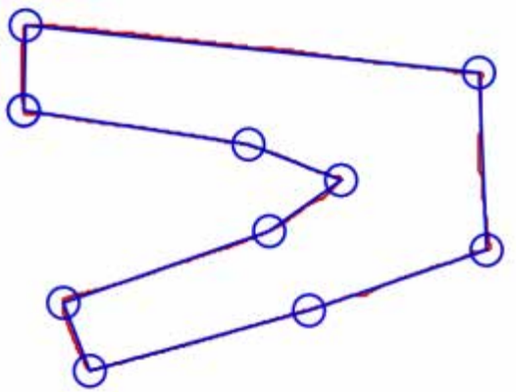
- **Novelty**:
  - GRABCUT segmentation parameters learned empirically. No need for the user input in the exploitation phase.
  - A different polygonal model of the garment than the state-of-the-art.
  - Two orders of magnitude faster performance. Our time = 4 seconds.
- **Dissemination**:
  - The initial version of the vision pipeline submitted to ICPR 2014.
  - The enhanced version (a more robust model fitting, folded models of garments) submitted to IROS 2014.

Segmentation, contour approximation

original



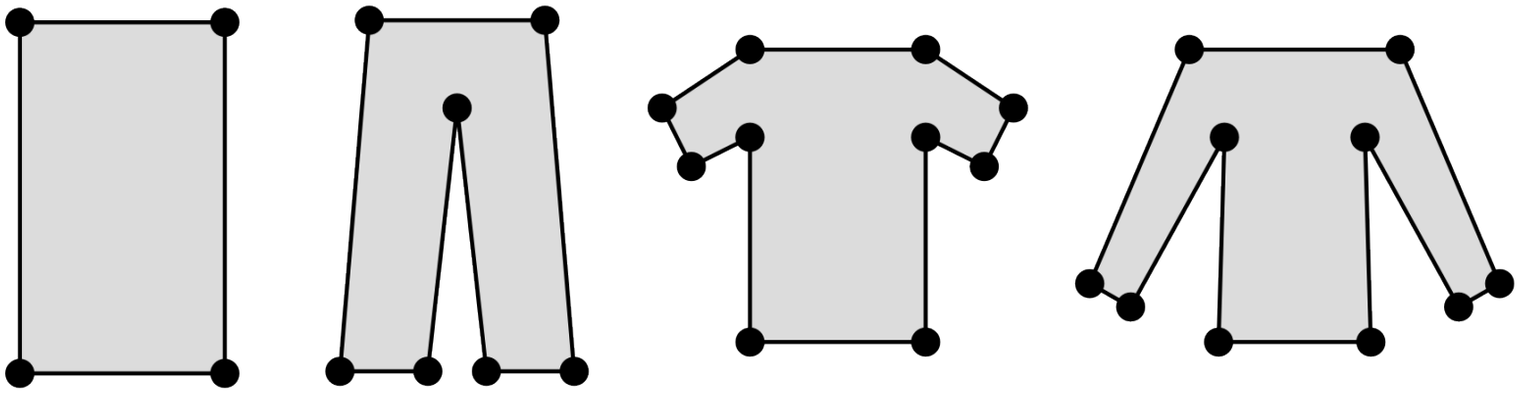
segmented



polygon

Polygonal models (1)

- Various categories of clothing can be described by polygonal models.



towel *pants* *T-shirt (short s.)* *Shirt (long s.)*

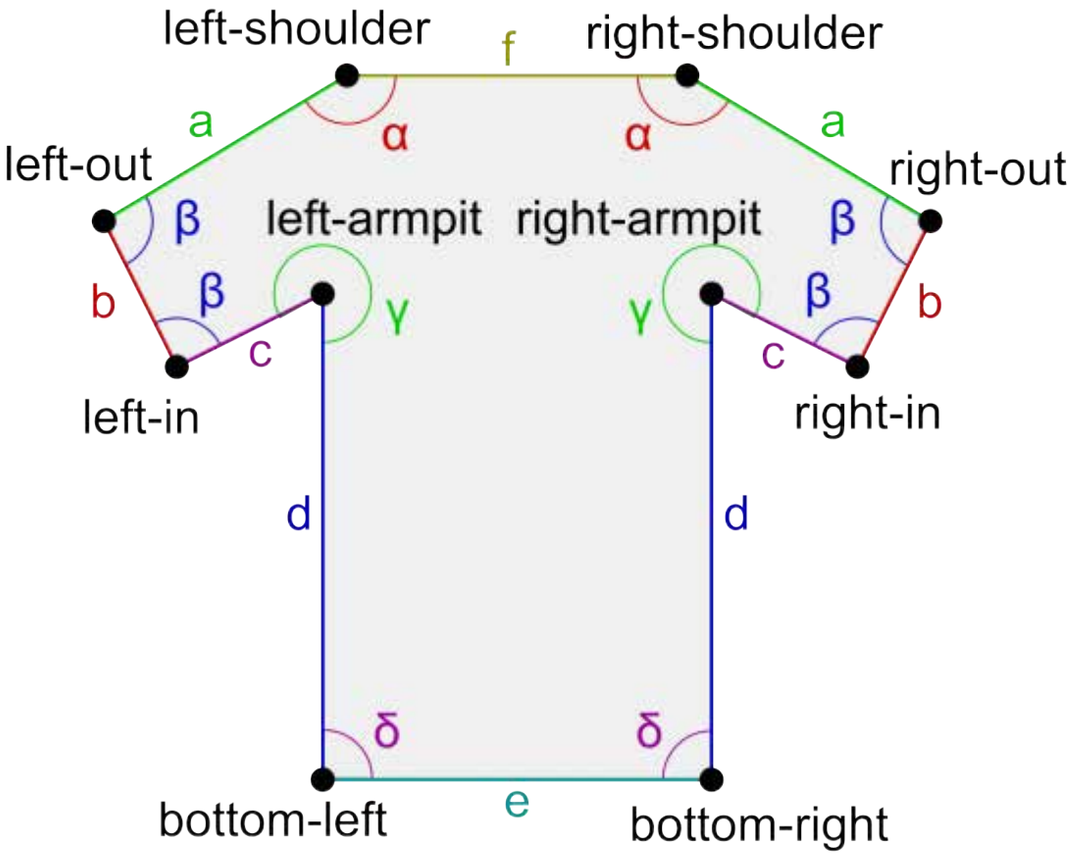
- Q: Flexibility?

  A: Each garment model is enriched by a probability distribution of inner angles adjacent polygon vertices and relative lengths of polygon edges.

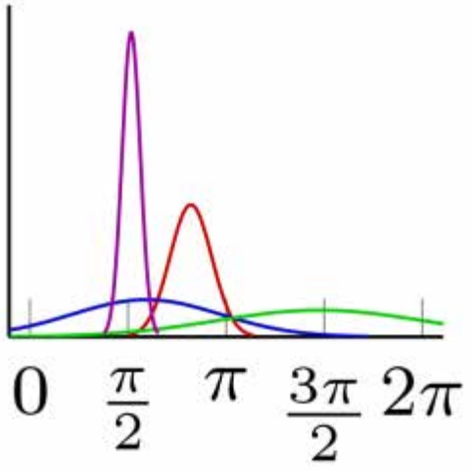
  - Modeled by independent normal distributions.
  - Learned using the maximum likelihood principle from training data.

Polygonal model (2)

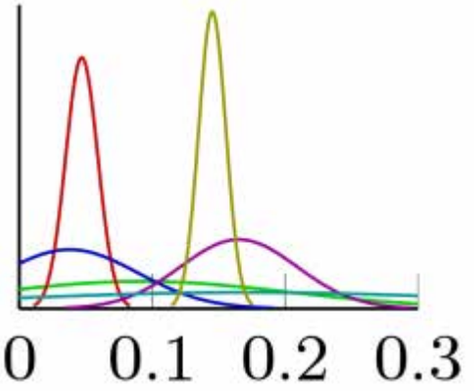
Example: T-shirt, short sleaves.



Polygonal model.



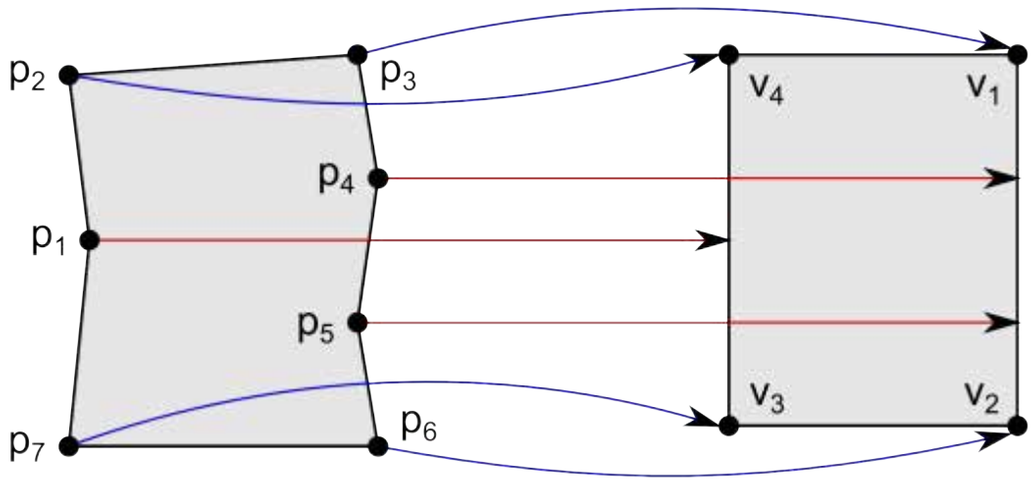
Distribution of inner angles.



Distribution of relative lengths.

Mapping contours to models (1)

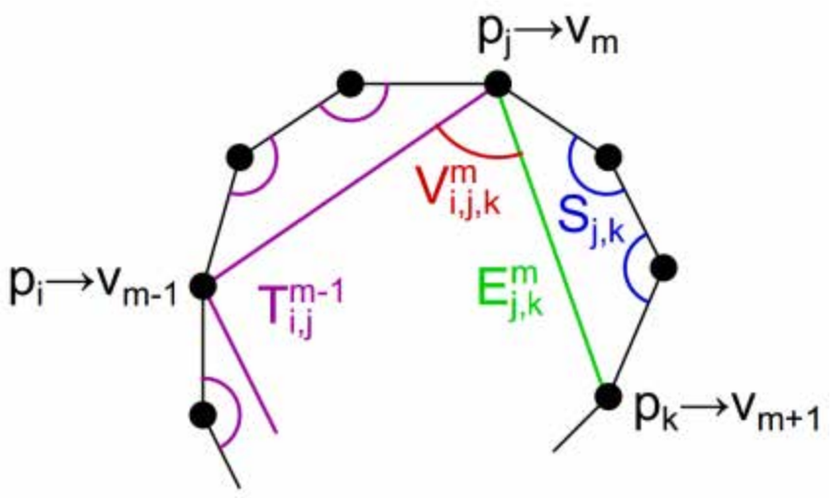
- The observed simplified contour is mapped to the learned polygonal model.



- Conditions:
  - The mapping preserves ordering of contour points and model vertices in a clockwise direction.
  - Some contour points are mapped to a segment instead of vertex because the simplified contour has less points than is the number of model vertices.

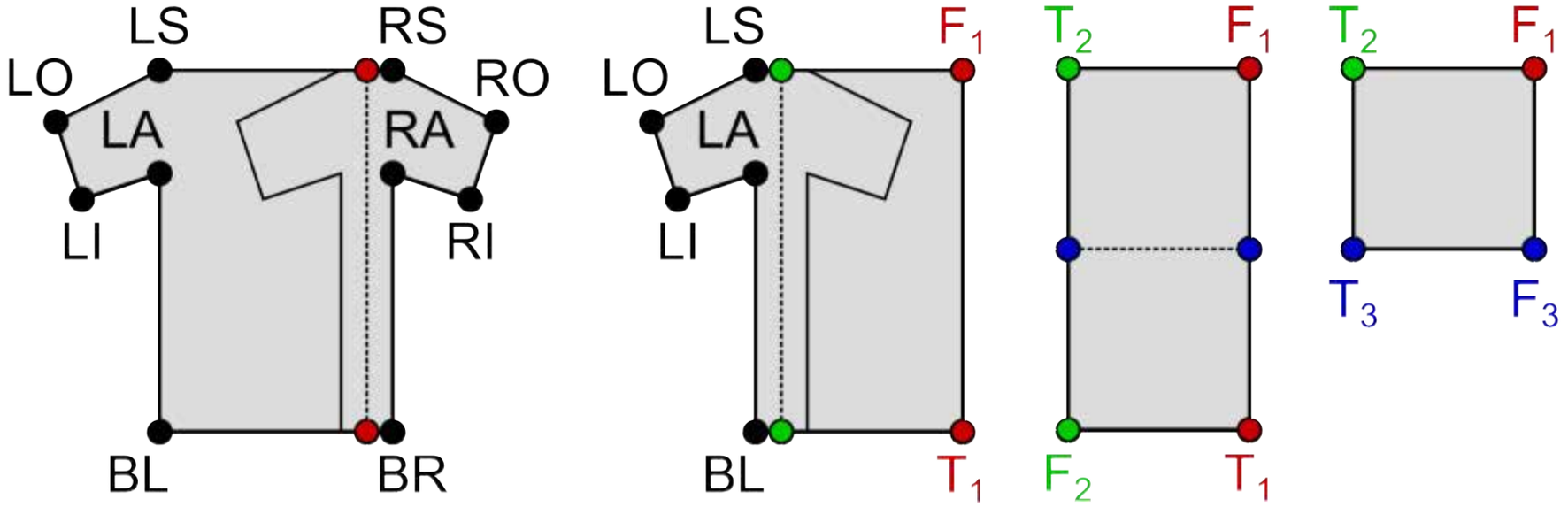
Mapping contours to models (2)

- The goal is to find the optimal mapping with respect to a cost function.
  - The cost is based on proposed angles and lengths distributions.
  - It would be inefficient to evaluate all possible mappings.
- Efficient incremental construction of the optimal mapping utilizing dynamic programming.
- Total matching cost $T^m_{j,k}$ is given by summing previous total cost $T^{m-1}_{i,j}$, vertex cost $V^m_{i,j,k}$, edge cost $E^m_{j,k}$ and segment cost $S_{j,k}$.



Polygonal models of folded garments

- The model of a particular piece of garment contains possible folds.
- Polygonal models of a folded garment follow automatically from the initial model and knowledge about performed folds.
- The vision-based sensing is repeated after each fold performed by a robot to cope with random disturbances.



T-shirt case *towel case*

Polygonal model-based folding, video, 2014-02

CloPeMa needs more intelligence

CloPeMa needs ability to:

- Represent knowledge, including commonsense knowledge.
- Learn.
- Plan using a reasoning engine (e.g. a probabilistic Prolog).
- Divide and conquer strategy: a collection of basic manipulation / perception skills to compose a more complex behaviour autonomously.
- Sense / act.
- Dynamics (not treated yet).

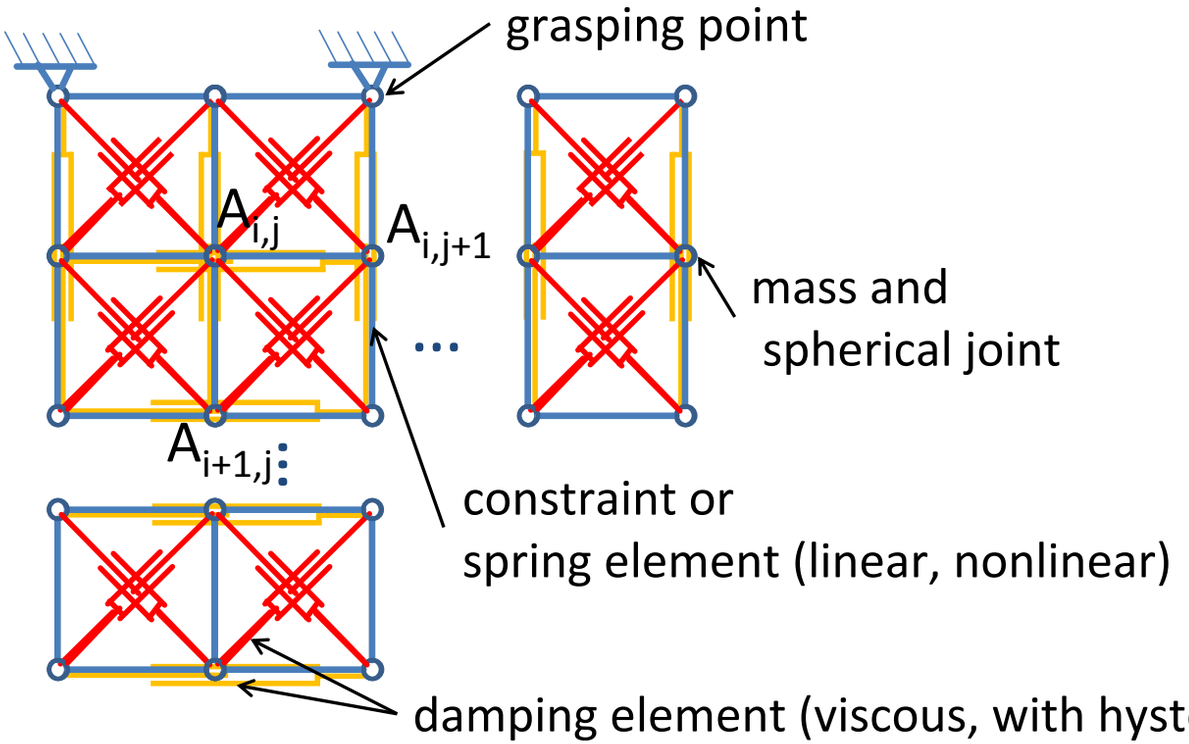
Representation:

- CloPeMa world model: Robot world, scene, a piece of garment.
- We sense a metric model (depth map, intensity images, tactile, force/torque).
- Functional garment model, e.g. the presented polygonal one.
- Physics-based model, pragmatic, task-oriented.
- Topological model of the garment. 2D manifold embedded in 3D space.

Mechanical model of a piece of fabric, ongoing

Researchers: Vladimír Smutný, Michal Neoral, Zbyněk Šika (Faculty of Mechanical Engineering), Pavel Krsek

- A piece of a garment is described as a dynamic system.
- It is similar to the finite element representation.
- We would like to estimate the model parameters from measurements.
- Ongoing work. Capturing process is prepared and the preliminary data measured.



Topological model of the garment, ongoing

2D manifold embedded in 3D Euclidean space.

- Motivated by Helmut Pottmann's research in computer graphics.
- Planar Quadrilateral Mesh.
- Mesh to be learned / re-learned from point clouds sensed by the CloPeMa testbed.
- The aim is to represent free-folded piece of cloth, e.g. a towel, including a rough representation of the 'invisible'.