Tracking with Structure in Computer Vision

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Final Report: Tracking with Structure in Computer Vision (TWIST-CV)

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1 Introduction

The TWIST-CV project was funded by the Austrian Science Fund – Fond zur Foerderung der wissenschaftlichen Forschung (FWF) – under the grant FWF-P18716-N13. This final project report informs about the development of the research work (Section 2.1), the most important results (Section 2.2), the running of the project (Section 2.3), personnel development (Section 2.4), and the effects of project outside the scientific field (Section 3). Additionally, there are lists enumerating project participants (Section4), publications (Section 5), participation in scientific conferences (Section 6), collaborations (Section 7) and theses (Section8)

2 Report on scientific work

2.1 Development of the research work

This section presents the goals of the project and the development of the research work (changes in the scientific concept).

The main goal of this project was to develop a framework based on graphs and graph pyramids, which enables solutions to problems of computer vision, where the structure of objects and their environment is significant (e.g. Segmentation, Tracking and Stereo Vision).

There were three subgoals with proposed solutions employing graphs and graph pyramids:

1) **Finding object correspondences in image sequences:** The input is a video sequence from a stationary or moving camera. The structure of the target object (e.g. pedestrian, car, ...) is represented in a graph or graph pyramid and correspondence is found by graph matching. The advantage of using a graph pyramid is that it would allow grouping of structures and hence simplify graph matching (NP-complete).
2) **Finding object correspondences in images from different view points:** Given are two (or more) images taken from different viewpoints at the same time instant. It

was planned to again use a structural representation e.g. a graph pyramid representation of single images and find the correspondences by graph matching. Structural representation should in this respect (i) allow a faster correspondence search (ii) be more robust against single mismatches.

3) Finding object correspondences in image sequences from different view points: The input are two (or more) image sequences recorded from different viewpoints. From the input images of a single time instant a structural representation (e.g. graph pyramid) is derived. This representation includes 3D information about the object and its scene. The resulting sequence of representations of the 3D structure is used to establish correspondences over time (by graph matching as in subgoal 1).

During the analysis of the state of the art we learned that recent progress in tracking methods has lead to fast and simple ways to find correspondences in image sequences. We decided to use these tracking methods to avoid the complex problem of graph matching. By combining tracking methods like Mean Shift with our structural representation (graph, graph pyramid), we were able to efficiently establish the necessary correspondences and additionally to overcome some of the weaknesses of those tracking methods (e.g. sensitivity to noise, occlusions, ...).

2.2 Most important results

Representations

Hierarchical spring systems: Spring systems allow to describe spatial relationships between features of object parts in a tolerant and deformable way. Instead of tracking multiple features (e.g. interest points) of object parts independently, our representation integrates the underlying structure into the tracking process. The spring system is represented by an attributed graph (attributes are features of object parts and represented by vertices). During tracking the spring system produces offset vectors for each feature to correct the estimated positions of the tracking algorithm. With the help of spring systems one is able to successfully associate the features of objects in ambiguous cases (e.g. features of background are similar to target object, occlusions, ...). We extended our first concepts of this representation [26] to articulated objects consisting of multiple object parts [40, 43] and then to a hierarchical spring system (attributed graph pyramid), where the information is transfered over articulation points from one spring system to the other [41]. The resulting representation allows to describe objects of arbitrary complexity (e.g. rigid object, articulated objects consisting of several parts and joints). Figure 1 and 2 shows some results.

Compositional representation: We incrementally generated a part-based description by grouping simple local features (edge segments) to part combinations. This part-based representation is built from a large set of features (edge segments) by hierarchically grouping them depending on their spatial and temporal density. The grouping process leads to a set of stable part combinations with increasing complexity, which can efficiently guide a spatio-temporal association step (find correspondences) of coherently moving image regions, which are part of the same target object. See Figure 3 and 4.

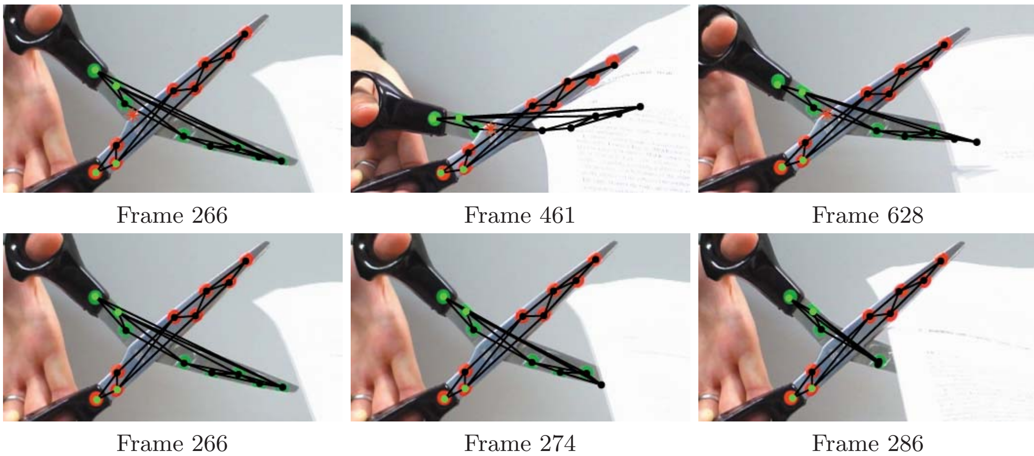

Fig. 1. Experiment with scissors. Top row: Tracking with a spring system and articulation point. The red star-like symbol represents the estimated articulation point. Bottom row: Tracking without a spring system.

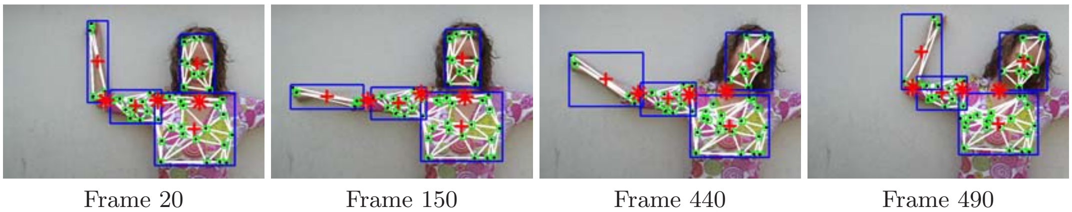

Fig. 2. Experiment with human. Tracking four parts of a human with three articulation points (joints).

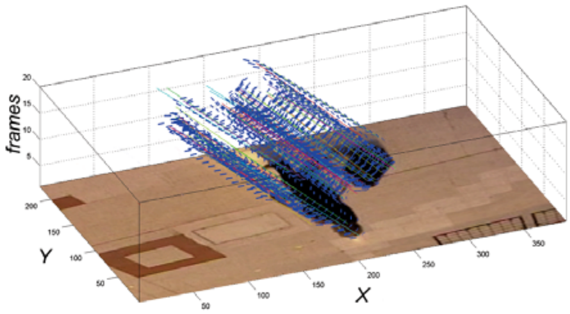

Fig. 3. Space-time plot showing all stable combinations describing a moving object (pedestrian, shown upside-down) and obeying the same motion model.

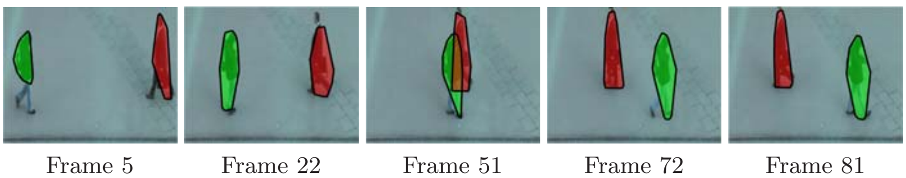

Fig. 4. Convex hull of tracked objects.

Graph pyramids: A Laplacian irregular graph pyramid was developed, which combines the principles of the Laplacian pyramid with the flexibility of the irregular graph pyramid. The Laplacian irregular graph pyramid allows to represent an image in multi-resolution while keeping the topological structures intact [55].

We worked on a concept for describing multiple views of a 3D object by a 2D manifold represented by a graph pyramid. The object representation is extended/updated when new object parts become visible [56]. There is also an initial concept on how to expand a graph pyramid to describe different scales of an object (e.g. add new details observed from an approaching object) [56].

In an approach to efficiently track an object with an irregular graph pyramid, we propose to find correspondences for an object only by the representative features in the top vertex of the pyramid. A state of the art tracking algorithm is used to associate the top vertex. Then, the information about the transformation is spread to the lower levels of the pyramid in a top down process by employing so-called *correction vectors* [60]. See Figure 5 for a visualization.

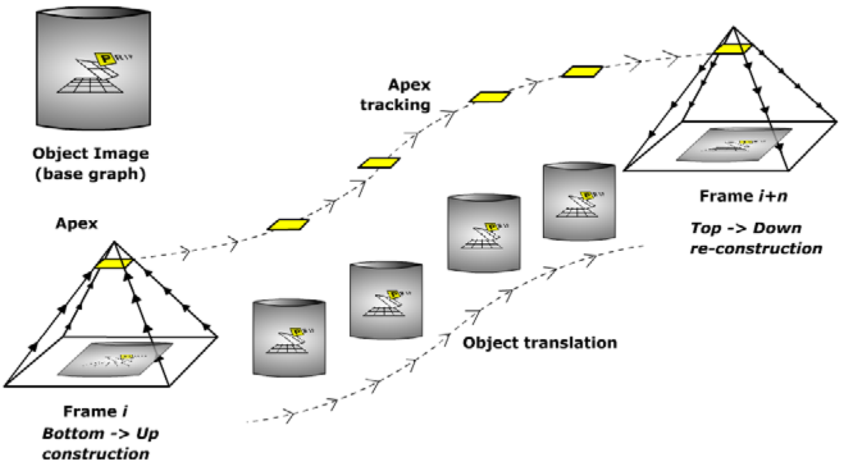

Fig. 5. Tracking with an irregular graph pyramid by storing information (position, rotation) in the apex.

Extraction of object structure A method was developed to automatically extract the structure (parts and joints) of objects (articulated, but also rigid). First, the movement and behavior of features (e.g. corner points) in a triangulated graph is analyzed over time in order to select interest points belonging to object parts (see Figure 6). The corresponding triangles are labeled as relevant (on an object) or separating (connecting different objects). Then a Minimum Spanning Tree pyramid (see next result for details) is built to group relevant triangles and identify the 'rigid' parts of the articulated foreground object (see Figure 7). Joints connecting the parts are determined and verified with the trajectories and orientation changes of the parts in the video sequence. Related publications [37, 42, 51].

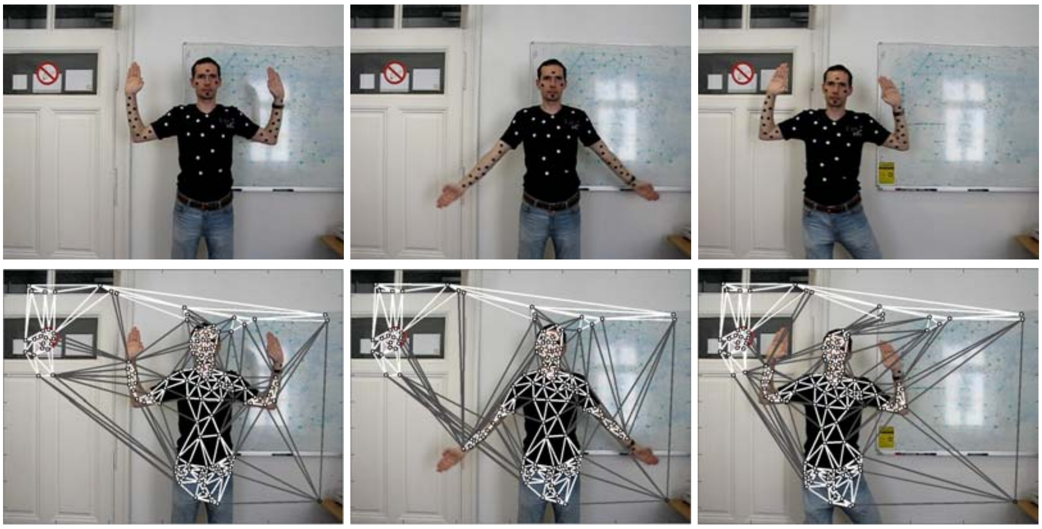

Fig. 6. Three frames of a video sequence showing an articulated object. Top line: frame, bottom line: frame with labeled triangulated graph. White: *relevant*, gray: *separating*.

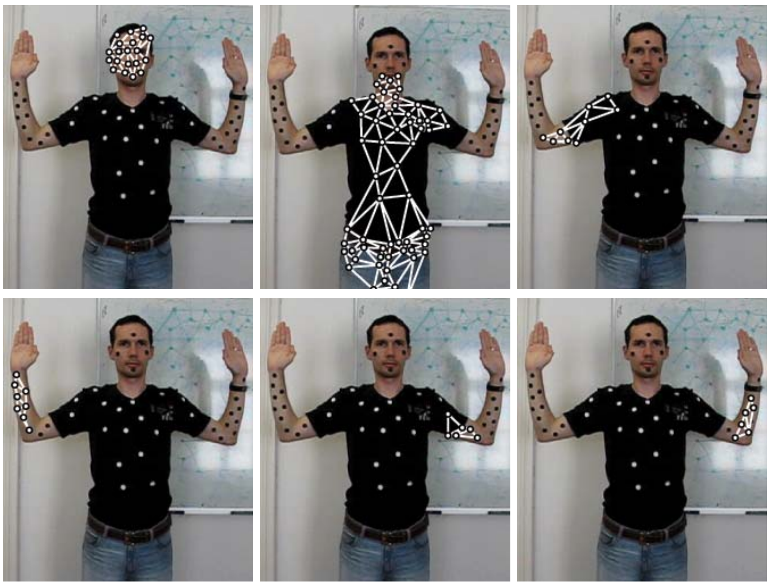

Fig. 7. Extracted structure. Receptive fields of top vertices of graph pyramid representing the identified rigid parts of the object.

Minimum Spanning Tree pyramid segmentation The minimum spanning tree (MST) pyramid is a hierarchical image segmentation method. Its input is a weighted neighborhood graph (NG), associating a vertex to each image pixel and connecting two neighboring vertices by an edge weighted with the distance of the two pixel values in some feature space (e.g. gray scale or RGB color). The MST pyramid method produces a hierarchy of partitions by using the minimum spanning tree (MST) algorithm by Boruvka and region internal/external contrast concepts. This segmentation method is well-suited for parallel processing, as the decisions in the merging process of the regions are taken locally. The results of our segmentation method are comparable to the well-known Normalized Cut segmentation. Related publications [21, 14, 24, 59].

Eccentricity transform The Eccentricity transform (ECC) of a shape assigns to each point the length of the shortest geodesics to the points farthest away from it. We showed that it is quasi-invariant to articulated motion and robust against salt and pepper noise (which creates holes in the shape) [10]. This transform was used to develop a coordinate system for point correspondences of 2D articulated shapes [34, 33, 35, 54, 53] and to match 2D and 3D shapes [18, 32, 52]. Other related publications [35, 17, 20].

Framework The research results of the TWIST-CV project are related and can be seen as a framework. First there is the extraction of the object structure using the MST pyramid, which is a necessary initialization step for all following processing steps. For the extraction method it is necessary to track features in a video sequence. These features could be corner points, but also image regions resulting from our MST pyramid segmentation. The representations describing the extracted structure can be used to successfully find correspondences of objects in image sequences and overcome well-known problems of state of the art tracking methods (e.g. occlusions). The coordinate system based on the ECC allows to address features of objects in an elegant and robust way. This coordinate system, if extended to 3D, will be able to find point correspondences in images from different view points.

2.3 Running of the project

The TWIST-CV project had a planned duration of three years and budget to finance two research positions at PostDoc level. As we were not able to find two qualified PostDocs for the period of three years, there was enough budget left to extend the duration of the project for additional 9 months.

In the project proposal, ACV (= Advanced Computer Vision) was mentioned as cooperation partner of PIRP. During the run time of the TWIST-CV project, the people involved in the project transfered to the parent company ARC (= Austrian Research Centers), which was renamed as AIT (= Austrian Institute of Technology).

No large equipment was bought and except of the above mentioned points there were no other deviations.

2.4 Personnel development

The following paragraph is only an excerpt of the personnel development of the people involved in the TWIST-CV project.

Walter G. Kropatsch was invited to give a keynote talk at the 14th Iberoamerican Congress on Pattern Recognition in 2009 with the title “When Pyramids Learned Walking”. **Yll Haxhimusa** was able to collect valuable scientific experiences, which allowed him to successfully apply for a PostDoc position at the Department of Psychological Sciences at Purdue University. The project enabled **Nicole M. Artner** to start her PhD and collect important scientific experiences (e.g. writing papers, visiting conferences, presenting scientific results, and so on). The project allowed her to participate in the 32nd Workshop of the Austrian Association for Pattern Recognition in 2008, where she won the best paper award. **Adrian Ion** contributed significantly to the success of the TWIST-CV project and was able to finish his PhD with excellent marks. **Thomas Illetschko** contributed to further developments on combinatorial maps (a representation related to graph pyramids), won the price of the best master thesis of the faculty of informatics of Vienna University of Technology and the best paper award of the Workshop of the Austrian Association for Pattern Recognition in 2006. **Allan Hanbury** was able to gain valuable experiences in acquiring research projects by contributing to the project proposal of TWIST-CV and he successfully finished his “Habilitation” in 2008.

Through the continuous publication of the research results of TWIST-CV, we were able to attract further PhD students from Spain, Cuba, United States of America, Mexico, and China. This students allowed to create an excellent personal network, through which the results of the project are spreading and new research collaborations emanate. An example is the WTZ (Wissenschaftlich-Technische Zusammenarbeit) project “Visual Attention using Combinatorial Pyramids (VACOP)” between PRIP, University of Technology (Walter G. Kropatsch) and the department of Tecnologia Electronica, ETSI Telecomunicacion, Universidad de Malaga (Antonio J. Bandera Rubio).

3 Effects of the project outside the scientific field

This section informs about the effects of the project outside the field of computer vision.

3.1 Organization of symposiums and conferences

The 14th Computer Vision Winter Workshop was organized by the Pattern Recognition and Image Processing (PRIP) Group, including several people directly employed in the TWIST-CV project or collaboration partners. It was held on February 4 - 6, in Eibiswald, Austria. For more information visit the website[3] of the workshop.

Ahmed Nabil Belbachir of the AIT, Austrian Institute of Technology, helped organizing the Fifth IEEE Workshop on Embedded Computer Vision as program chair.

3.2 Relevance for the developments in teaching

The lectures “Selected Chapters in Image Processing” and “Selected Chapters in Pattern Recognition” are influenced in their content and speakers by the results and collaborations of the TWIST-CV project. For example the selected chapters in pattern recognition in the winter term 2009/2010 was given by Luc Brun (Prof. at ENSICAEN, L’Ecole Nationale Supérieure d’Ingénieurs de Caen) with topics including “Non-Hierarchical Image

[3] http://www.prip.tuwien.ac.at/events/conferences/cvww09

Partitions and Hierarchical Models: Regular Pyramids" and "Irregular Pyramids". The selected chapters in image processing in the summer term 2010 will be given by Rocio Gonzales Diaz (Prof. at the University of Sevilla) with topics about how to build a topological pyramid. Besides the selected chapters, there is the lecture "Structural Pattern Recognition", which partly covers topics highly related to the research in TWIST-CV e.g. "Trees, Graphs, Maps, Formal Grammars", "Embedding, Planarity, Pyramids", "Spectral Graph Theory" and "Structure in Motion".

3.3 Particular honors and prizes

Best Student Paper Award for the publication with the title "Kernel-based Tracking Using Spatial Structure" at the 32nd Workshop of the Austrian Association for Pattern Recognition 2008 [26] by Nicole Artner.

Best Student Paper Award for the publication with the title "Collapsing 3D Combinatorial Maps" at the 30th Workshop of the Austrian Association for Pattern Recognition 2006 [6] by Thomas Illetschko.

Best master thesis of the faculty of informatics of Vienna University of Technology in the year 2006 for Thomas Illetschko.

3.4 Effects on future projects

The research and results of the TWIST-CV project led to and influenced the proposals of future projects. The work on compositional representation (see Section 2) inspired the proposal for a project by AIT about critical content filtering employing image grammars based on compositional combination of low-level features. The success of TWIST-CV and the fruitful cooperation between PRIP and AIT led to the proposal of the common project with the title "Structural Spatio-Temporal Representations for Visual Computing (STRUC)".

4 Information on project participants

Here you can find a list of people (with their current titles) who contributed to the TWIST-CV project. This list is ordered alphabetically by surname and shows the internationality of our team.

- **Financed by project:**
  - MSc. Esther Antunez (11 months), Spain
  - MSc. Nicole M. Artner (26 months), Austria
  - MSc. Chien-Chia Cheng (3 months), Taiwan
  - DI Stephan Fiel
  - DI Paul Guerreor
  - DI Dr. Yll Haxhimusa (10 months), Austria
  - MSc. Mabel Iglesias-Ham (10 months), Cuba
  - DI Thomas Illetschko, Austria
  - DI Dr. Adrian Ion (8 months), Romania
  - DI Salvador Lopéz Mármol (8,5 months), Spain
  - MSc. Luis A. Mateos (9 months), Mexico

  - MSc. Dan Shao (8 months), China
  - DI Dr. Maria Wild, Germany
- **Not financed by project:**
  - DI Dr. Csaba Beleznai (26 months), Hungary
  - DI Dr. Markus Clabian (45 months), Austria
  - Prof. Dr. Allan Hanbury (2 months), Austria
  - DI Dr. Adrian Ion (37 months, PhD), Romania
  - o. Univ. Prof. Dr. Walter G. Kropatsch (45 months), Austria

5 Scientific publications

This section covers all publications directly related to the TWIST-CV project. If not explicitly stated (*in press*, *accepted*, *submitted*, *in preparation*) the status of the publications is *published*.

In the scope of this project we published:

- **2 book chapters** [19, 21]
- **7 journal papers** [13, 57, 49, 46, 51, 52, 45]
- **16 conference papers** [16, 4, 3, 10, 17, 20, 25, 37, 30, 33, 41, 42, 56, 55, 54, 44]
- **26 workshop papers** [8, 2, 9, 6, 18, 14, 23, 22, 35, 36, 27, 26, 32, 28, 29, 40, 34, 43, 39, 50, 47, 38, 53, 59, 58, 60]
- **9 technical reports** [1, 5, 7, 12, 11, 15, 24, 31, 48].

6 Project-related participation in scientific conferences

In this section all conference participations are listed by title of the conference, year and alphabetical list of speakers.

6.1 Conference participations - invited lectures

- Nov. 2009, 14th Iberoamerican Congress on Pattern Recognition, Walter G. Kropatsch, "When Pyramids Learned Walking"
- Nov. 2008, Workshop on New Perspectives on Human Problem Solving, Walter G. Kropatsch
- Nov. 2006, 11th Iberoamerican Congress on Pattern Recognition, Walter G. Kropatsch, invited keynote: "Hierarchies relating Topology and Geometry"

6.2 Conference participations - lectures

- Nov. 2009, 14th Iberoamerican Congress on Pattern Recognition, Nicole M. Artner, Luis A. Mateos
- Sep. 2009, 13th International Conference on Computer Analysis of Images and Patterns, Nicole M. Artner
- Aug. 2009, 2nd Workshop on Computational Topology in Image Context, Mabel Iglesias-Ham
- May 2009, 33nd Annual Workshop of the Austrian Association for Pattern Recognition, Esther Antúnez, Nicole M. Artner

– May 2009, 7th IAPR-TC-15 Workshop on Graph-based Representations in Pattern Recognition, Nicole M. Artner, Rocio Gonzalez-Diaz
– Feb. 2009, 14th Computer Vision Winter Workshop, Nicole M. Artner, Adrian Ion
– Nov. 2008, International Workshop on Computational Algebraic Topology within Image Context, Walter G. Kropatsch
– Sep. 2008, 13th Iberoamerican Congress on Pattern Recognition, Salvador B. López Mármol
– Jun. 2008, CVPR Workshop on Search in 3D, Walter G. Kropatsch
– May 2008, 32nd Annual Workshop of the Austrian Association for Pattern Recognition, Nicole M. Artner
– Apr. 2008, 12th Central European Seminar on Computer Graphics, Nicole M. Artner
– Feb. 2008, 13th Computer Vision Winter Workshop, Salvador B. López Mármol
– Mar. 2007, Wintergraph, Walter G. Kropatsch
– Aug. 2006, Mathematical Psychology Workshop, Vancouver, Canada, Yll Haxhimusa
– May 2006, 30th Annual Workshop of the Austrian Association for Pattern Recognition, Yll Haxhimusa

6.3 Conference participations - posters

– Jun. 2009, 4th Iberian Conference on Pattern Recognition and Image Analysis, Esther Antúnez
– May 2009, 33nd Annual Workshop of the Austrian Association for Pattern Recognition, Adrian Ion
– Dec. 2008, 19th International Conference on Pattern Recognition, Adrian Ion
– Dec. 2008, Joint IAPR International Workshops on Structural and Syntactic Pattern Recognition and Statistical Techniques in Pattern Recognition, Nicole M. Artner
– Sep. 2008, 13th Iberoamerican Congress on Pattern Recognition, Mabel Iglesias-Ham
– Aug. 2007, 12th International Conference on Computer Analysis of Images and Patterns, Maria Wild
– Oct. 2006, 13th International Conference on Discrete Geometry for Computer Imagery, Yll Haxhimusa, Adrian Ion
– Aug. 2006, 18th International Conference of Pattern Recognition, Yll Haxhimusa

6.4 Conference participations - other

– Feb. 2010, 15th Computer Vision Winter Workshop, Nicole M. Artner (prog. com.)
– Nov. 2009, 13th International Workshop on Combinatorial Image Analysis, Walter G. Kropatsch (progr. com., session chair)
– Nov. 2009, 14th Iberoamerican Congress on Pattern Recognition, Walter G. Kropatsch (prog. com., session chair, award committee)
– Sep. - Oct. 2009, 12th International Conference on Computer Vision and Workshops, Nicole Artner (visitor)
– Sep. - Oct. 2009, 15-th IAPR International Conference on Discrete Geometry for Computer Imagery, Walter G. Kropatsch (prog. com.)
– Sep. 2009, 13th International Conference on Computer Analysis of Images and Patterns, Walter G. Kropatsch (prog. com., session chair)

- Aug. 2009, 2nd Workshop on Computational Topology in Image Context, Walter G. Kropatsch (co-chair, prog. com., session chair)
- May 2009, 7th IAPR-TC-15 Workshop on Graph-based Representations in Pattern Recognition, Walter G. Kropatsch (prog. com., session chair), Esther Antúnez (visitor), Mabel Iglesias-Ham (visitor)
- Feb. 2009, 14th Computer Vision Winter Workshop, Nicole M. Artner (local organization), Adrian Ion (chair), Walter G. Kropatsch (co-chair)
- Dec. 2008, 19th International Conference on Pattern Recognition, Walter G. Kropatsch (prog. com., session chair, IAPR ExCo and GB meetings), Nicole M. Artner (visitor)
- Dec. 2008, Joint IAPR International Workshops on Structural and Syntactic Pattern Recognition and Statistical Techniques in Pattern Recognition, Walter G. Kropatsch (prog. com.)
- Nov. 2008, Workshop on New Perspectives on Human Problem Solving, Walter G. Kropatsch (session chair)
- Nov. 2008, International Workshop on Computational Algebraic Topology within Image Context, Walter G. Kropatsch (prog. com., session chair)
- Sep. 2008, 13th Iberoamerican Congress on Pattern Recognition, Walter G. Kropatsch (co-Chair, session chair), Nicole M. Artner (visitor)
- Jun. 2008, 1st Workshop on Computational Topology in Image Context, Walter G. Kropatsch (prog.com)
- May 2008, 32nd Annual Workshop of the Austrian Association for Pattern Recognition, Salvador B. López Mármol (visitor)
- Apr. 2008, 14th International Conference on Discrete Geometry for Computer Imagery, Walter G. Kropatsch (prog. com, session chair)
- Feb. 2008, 13th Computer Vision Winter Workshop, Walter G. Kropatsch, (prog. com., session chair), Nicole M. Artner (visitor), Mabel Iglesias-Ham (visitor)
- 2008, EuCognition 5th Meeting, Walter G. Kropatsch
- Nov. 2007, 12th Iberoamerican Congress on Pattern Recognition, Walter G. Kropatsch (prog. com.)
- Aug. 2007, 12th International Conference on Computer Analysis of Images and Patterns, Walter G. Kropatsch (general chair, prog. com.)
- Jun. 2007, 6th IAPR -TC-15 Workshop on Graph-based Representations in Pattern Recognition, Walter G. Kropatsch (prog. com.)
- Feb. 2007, 12th Computer Vision Winter Workshop, Walter G. Kropatsch (prog. com., session chair)
- 2007, EuCognition 3rd and 4th Meeting, Walter G. Kropatsch
- Nov. 2006, 11th Iberoamerican Congress on Pattern Recognition, Walter G. Kropatsch, (prog.com., session chair)
- Oct. 2006, 13th International Conference on Discrete Geometry for Computer Imagery, Walter G. Kropatsch (prog. com., session chair)
- Sep. 2006, 28th Annual Symposium of the German Association for Pattern Recognition, Walter G. Kropatsch (prog. com.)
- Aug. 2006, Joint IAPR International Workshops on Structural and Syntactic Pattern Recognition and Statistical Techniques in Pattern Recognition, Walter G. Kropatsch (prog. com.), Yll Haxhimusa (visitor)
- Aug. 2006, 18th International Conference of Pattern Recognition, Walter G. Kropatsch (prog. com., IAPR ExCo and GB meetings, banquet speech)

– Jun. 2006, IEEE Computer Society Conference on Computer Vision and Pattern Recognition, Walter G. Kropatsch (visitor)
– 2006, EuCognition Inaugural Meeting, Walter G. Kropatsch

7 Development of collaborations

Table 1 lists the five most important collaborations ordered alphabetically (by the first surname).

Table 1. Collaborations. Nature: **N** (National), **E** (European), **I** (other international cooperation); Extend: **E1** (low, e.g. no joint publications but mention in acknowledgments or similar), **E2** (medium, collaboration e.g. with occasional joint publications, exchange of materials or similar but no longer-term exchange of personnel), **E3** (high, extensive collaboration with mutual hosting of group members for research stays, regular joint publications etc.); Discipline: **D** (within the discipline), **T** (transdisciplinary);

Nature	Extend	Discipline	Collaboration partner / content of the collaboration
I	E2	D	**Names**: Prof. Dr. Narendra Ahuja and MSc. Tim Chang; **Institution**: Beckman Institute for Advanced Science and Technology, USA; **Content**: Tim Chang visited PRIP and was employed by the project for 3 month;
E	E3	D	**Names**: Prof. Dr. Antonio Bandera, Prof. Dr. Rebecca Marfil, and MSc. Esther Antunez-Ortiz; **Institution**: University of Málaga, Spain; **Content**: Esther Antunez-Ortiz was employed by the TWIST-CV project for 11 month at PRIP, WTZ (Wissenschaftlich-Technische Zusammenarbeit) project "Visual Attention using Combinatorial Pyramids (VACOP)", joint publications [38, 45, 44, 58, 60];
I	E2	D	**Name**: Prof. Dr. Sven Dickinson; **Institution**: University of Toronto, Department of Computer Science; **Content**: visits of Adrian Ion and Walter G. Kropatsch;
I	E3	D	**Names**: Dr. Edel B. García Reyes and MSc. Mabel Iglesias; **Institution**: Advanced Technologies Applications Center, Havana, Cuba; **Content**: Mabel Iglesias visited PRIP and was financed for 9 month by the TWIST-CV project, joint publications [30, 46, 48, 50, 47];
E	E3	D	**Names**: Prof. Dr. Rocio Gonzalez-Diaz, Prof. Dr. Pedro Real, and MSc. Helena Molina Abril; **Institution**: University of Sevilla, Spain; **Content**: joint work in the field of topology, quest professors at Vienna University of Technology, joint publications [46, 48, 47, 50];

8 Theses

This theses where written by people who were involved in the TWIST-CV project.

– **Finished theses:**
  - **Yll Haxhimusa**, *Structurally Optimal Dual Graph Pyramid and its Application in Image Partitioning*, Vienna University of Technology, Faculty of Informatics, Institute of Computer Aided Automation, Pattern Recognition and Image Processing Group, 2006.
  - **Thomas Illetschko**, *Minimal Combinatorial Maps for Analyzing 3D Data*, Vienna University of Technology, Faculty of Informatics, Institute of Computer Aided Automation, Pattern Recognition and Image Processing Group, 2006.

- **Adrian Ion**, *The Eccentricity Transform of n-Dimensional Shapes with and without Boundary*, Vienna University of Technology, Faculty of Informatics, Institute of Computer Aided Automation, Pattern Recognition and Image Processing Group, 2009.

– **Theses in work:**
  - **Esther Antunez** started to work on her PhD in Feb. 2009.
  - **Nicole M. Artner** started to work on her PhD in Oct. 2007. The working title is *Tracking with structure* and it is planned to be finished end of 2011.
  - **Mabel Iglesias-Ham** started her PhD in 2008.
  - **Luis A. Mateos** started to work on his PhD in April 2009.
  - **Dan Shao** started to work on her PhD in May 2009.

9 Applications for follow-up projects

We applied for a follow-up FWF stand-alone project. The title of the project will be "Structural Spatio-Temporal Representations for Visual Computing" or short *STRUC*.

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1. Stefan Fiel and Paul Guerrero. Motion Tracking with Normalized Cut and Minimum Spanning Tree. Technical Report PRIP-TR-105, PRIP, TU Wien, 2006.
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