Epiphyses Localization for Bone Age Assessment Using the Discriminative Generalized Hough Transform

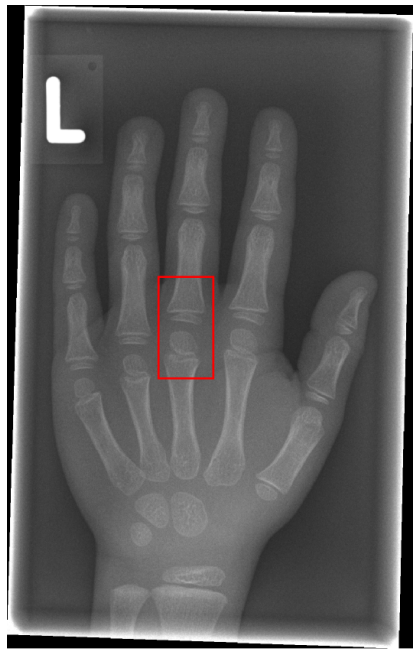
Ferdinand Hahmann, Dipl.-Inf.
(Gordon Böer, Thomas M. Deserno, Hauke Schramm)

Institute of Applied Computer Science
University of Applied Sciences Kiel

Aachen – 17.03.2014

Introduction

- Goal: Automatic extraction of epiphyseal regions of interest (eROIs) for automatic bone age assessment (BAA)
- State-of-the-Art
  - Several methods based on expert knowledge
  - BoneXpert [1]
  - Fischer [2]
- General object localization approaches:
  - Marginal space learning [3]
  - Random Forests [4]
  - Discriminative Generalized Hough Transform (DGHT) [5,6]

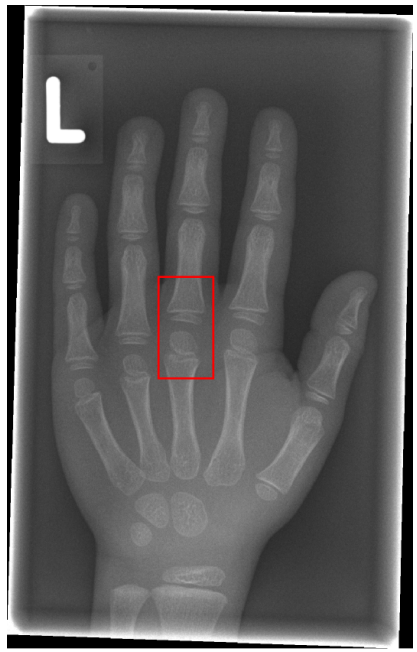


Left hand radiograph with marked eROI

[1]: H. Thodberg, et al., The BoneXpert method for automated determination of skeletal maturity, 2009.
[2]: B. Fischer, et al., Structural scene analysis and contentbased image retrieval applied to bone age assessment, 2009.
[3]: Y. Zheng, et al., Marginal space learning for efficient detection of 2D/3D anatomical structures in medical images, 2009.
[4]: A. Criminisi, et al., Regression forests for efficient anatomy detection and localization in CT studies, 2011.
[5]: H. Schramm, Automatic 3-D object detection, Patent, 2007.
[6]: H. Ruppertshofen. Automatic Modeling of Anatomical Variability for Object Localization in Medical Images. PhD thesis, 2013.

Introduction

- Goal: Automatic extraction of epiphyseal regions of interest (eROIs) for automatic bone age assessment (BAA)
- State-of-the-Art
  - Several methods based on expert knowledge
  - BoneXpert [1]
  - Fischer [2]
- General object localization approaches:
  - Marginal space learning [3]
  - Random Forests [4]
  - Discriminative Generalized Hough Transform (DGHT) [5,6]

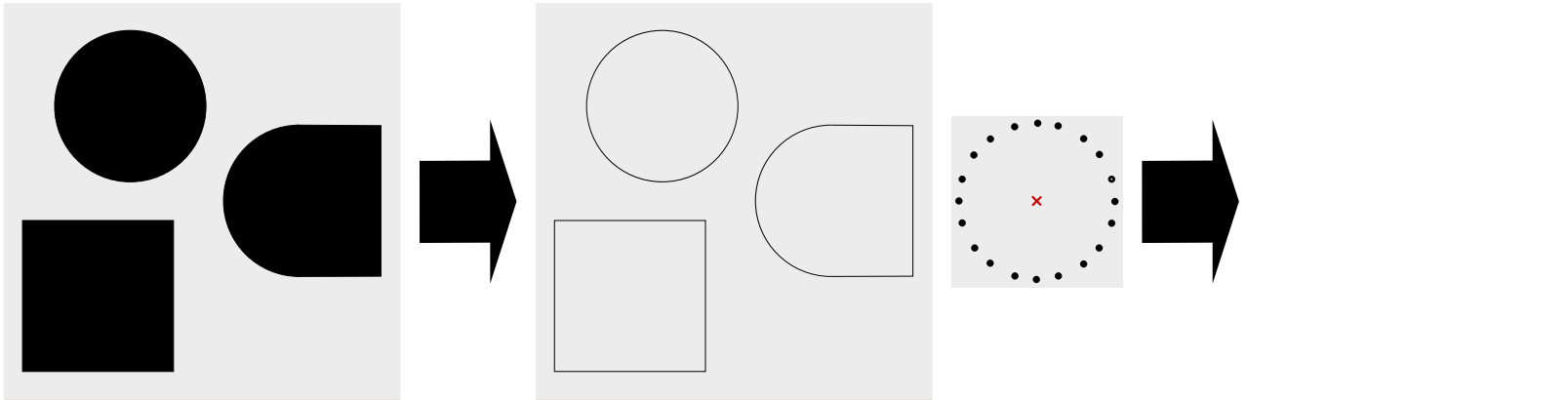


Left hand radiograph with marked eROI

[1]: H. Thodberg, et al., The BoneXpert method for automated determination of skeletal maturity, 2009.
[2]: B. Fischer, et al., Structural scene analysis and contentbased image retrieval applied to bone age assessment, 2009.
[3]: Y. Zheng, et al., Marginal space learning for efficient detection of 2D/3D anatomical structures in medical images, 2009.
[4]: A. Criminisi, et al., Regression forests for efficient anatomy detection and localization in CT studies, 2011.
[5]: H. Schramm, Automatic 3-D object detection, Patent, 2007.
[6]: H. Ruppertshofen. Automatic Modeling of Anatomical Variability for Object Localization in Medical Images. PhD thesis, 2013.

Generalized Hough Transform (GHT)

- Introduced by Ballard 1981 [7]
- General model-based method for object localization



Here:

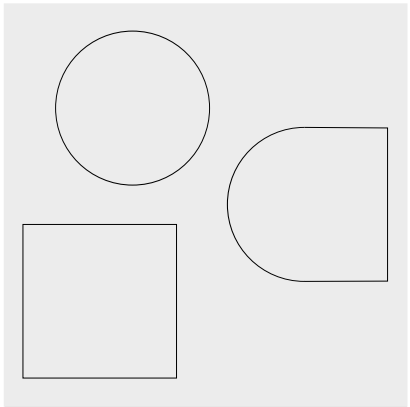
- Application of Canny edge features
- Considered model transformations restricted to translation

[7]: D. Ballard, Generalizing the Hough transform to detect arbitrary shapes, 1981.

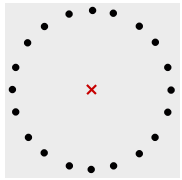
Discriminative Generalized Hough Transform (DGHT)

Motivation

- Discriminative GHT Model:

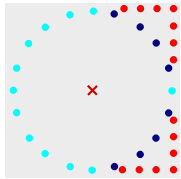


feature image



model

Hough space



weighted model

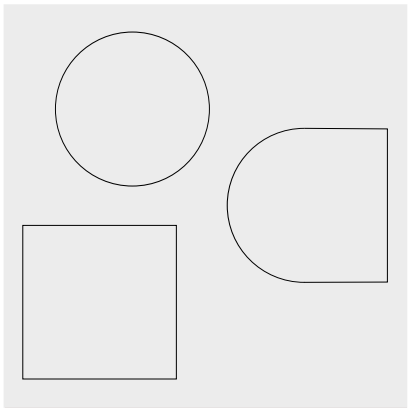
model point weights:
• = 0.5 • = 1 • = -1

weighted Hough space

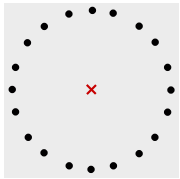
- Model is composed of
  - geometric model layout
    $\rightarrow$ learned from training examples
  - individual weights of model points
    $\rightarrow$ discriminative weighting procedure

Discriminative Generalized Hough Transform (DGHT)

Discriminative GHT Model:

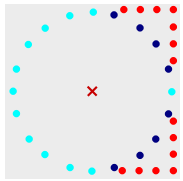


feature image



model

Hough space



weighted model

model point weights:
• = 0.5 • = 1 • = -1

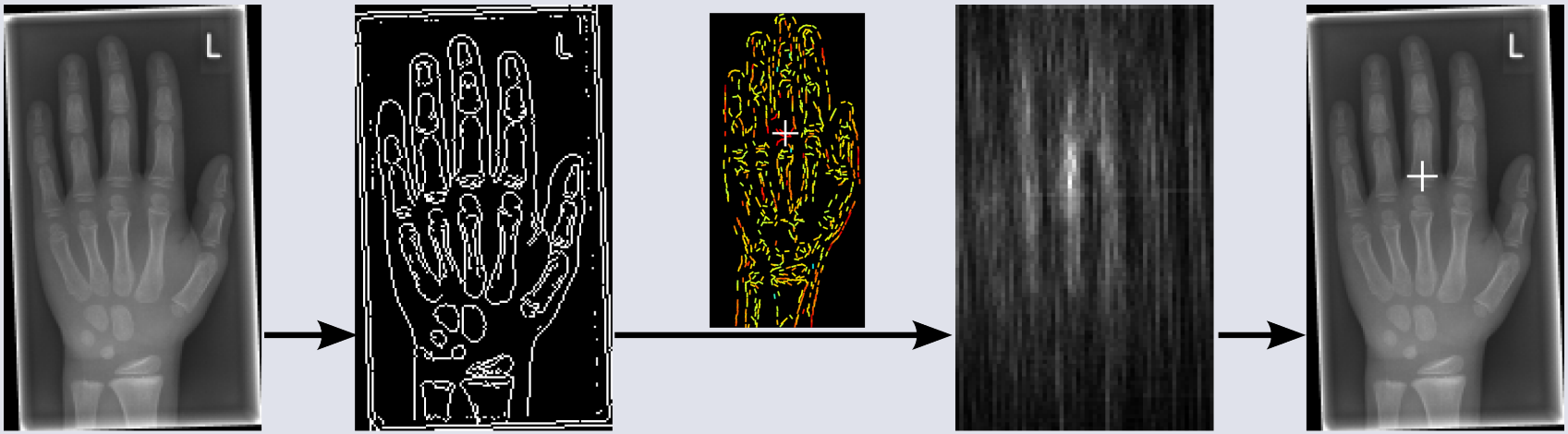
weighted Hough space

Model point weight estimation

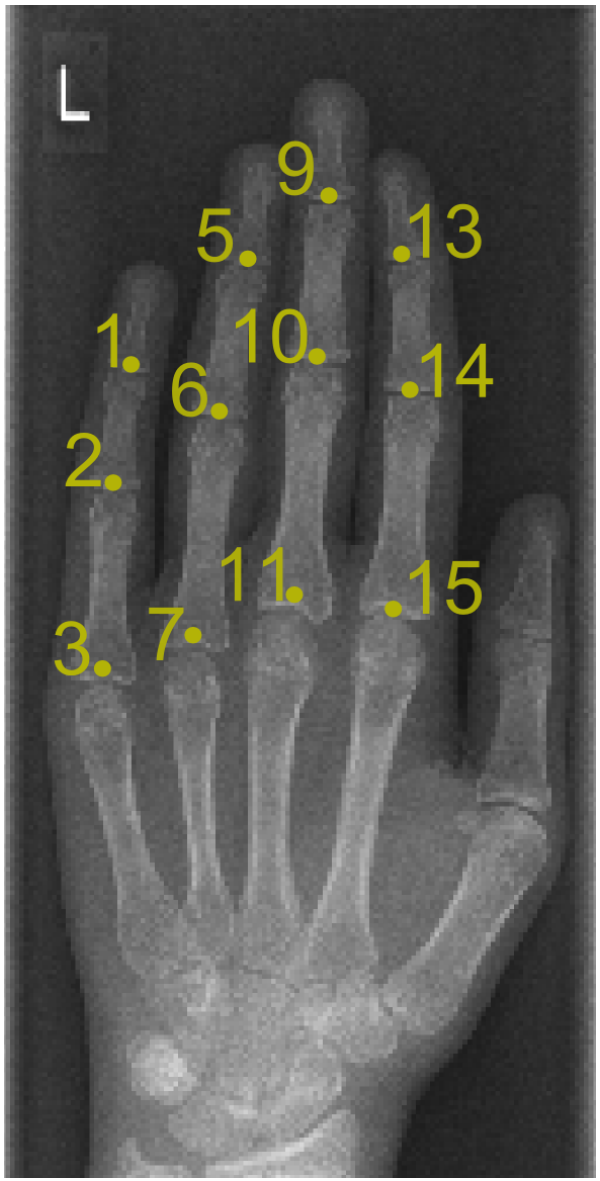
- Goal: Minimization of error rate on training images
- Determination of individual model point contributions
- Weighted recombination of these contributions into Maximum Entropy Distribution
- Error-based optimization of model point specific weights

Discriminative Generalized Hough Transform (DGHT)

Usage of DGHT Models:



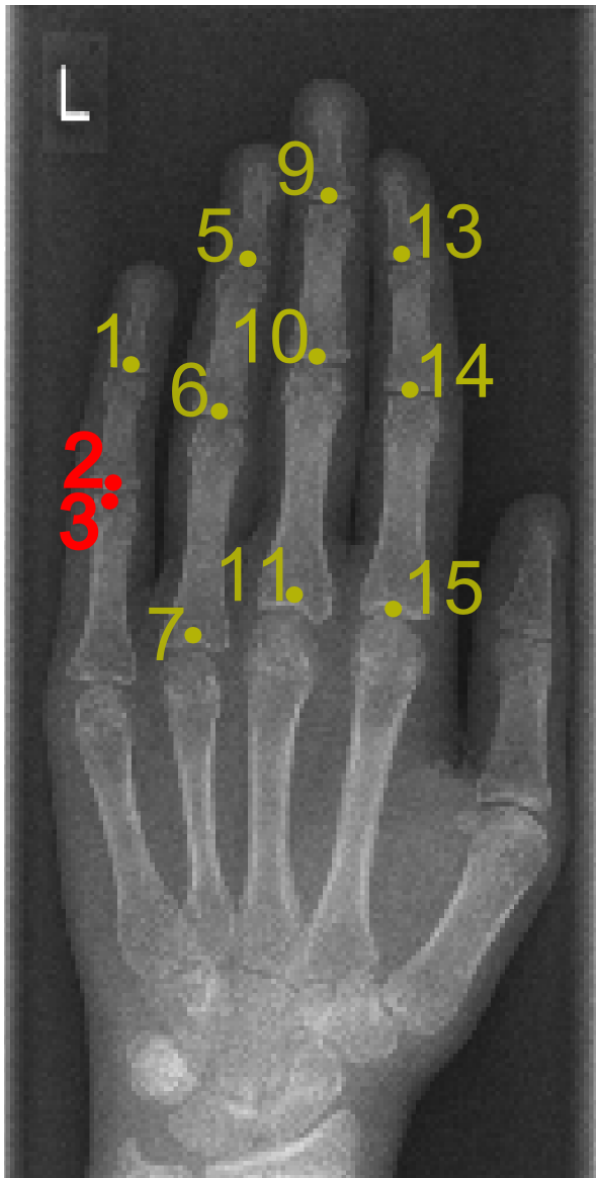
Constrained Localization



Constrained Localization

- Goal: avoid confusion of eROIs
- Method:
  - combine DGHT localization results with anatomical constraints
  - find global optimum for all eROIs

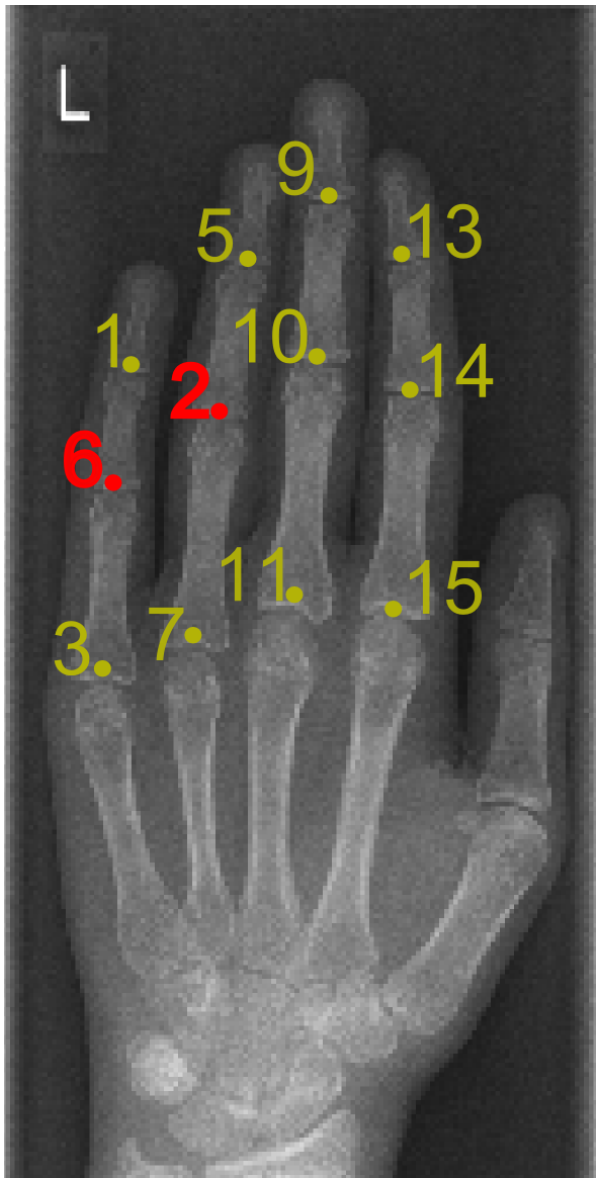
Constrained Localization



Applied Anatomical Constraints

- Minimum distance of eROIs
- Correct positioning of fingers
- Correct eROI positioning per finger

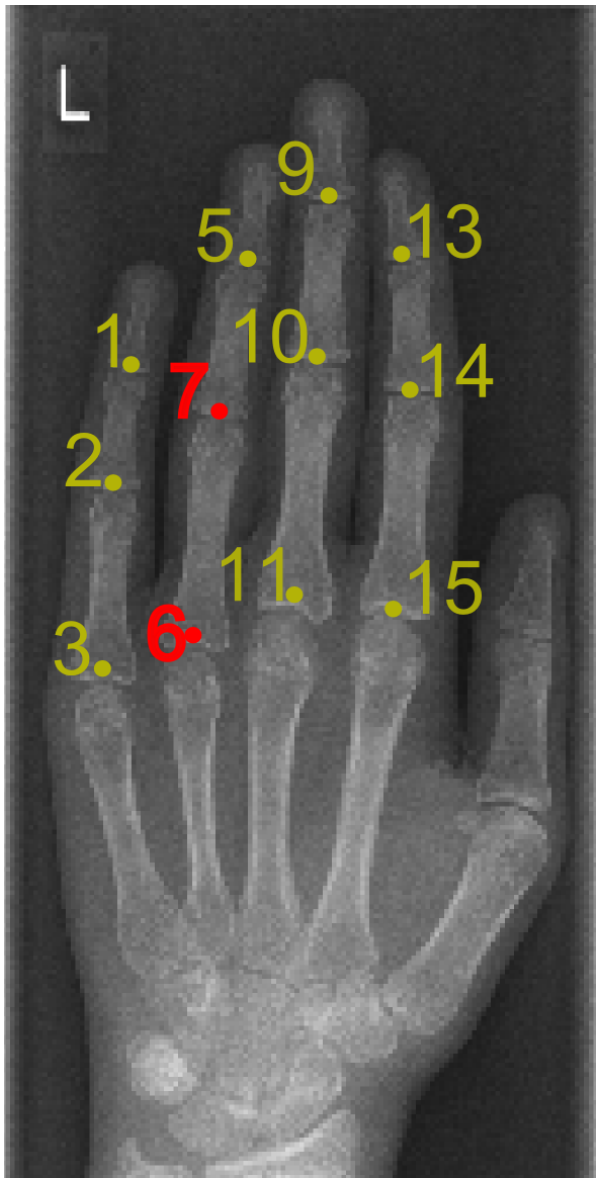
Constrained Localization



Applied Anatomical Constraints

- Minimum distance of eROIs
- Correct positioning of fingers
- Correct eROI positioning per finger

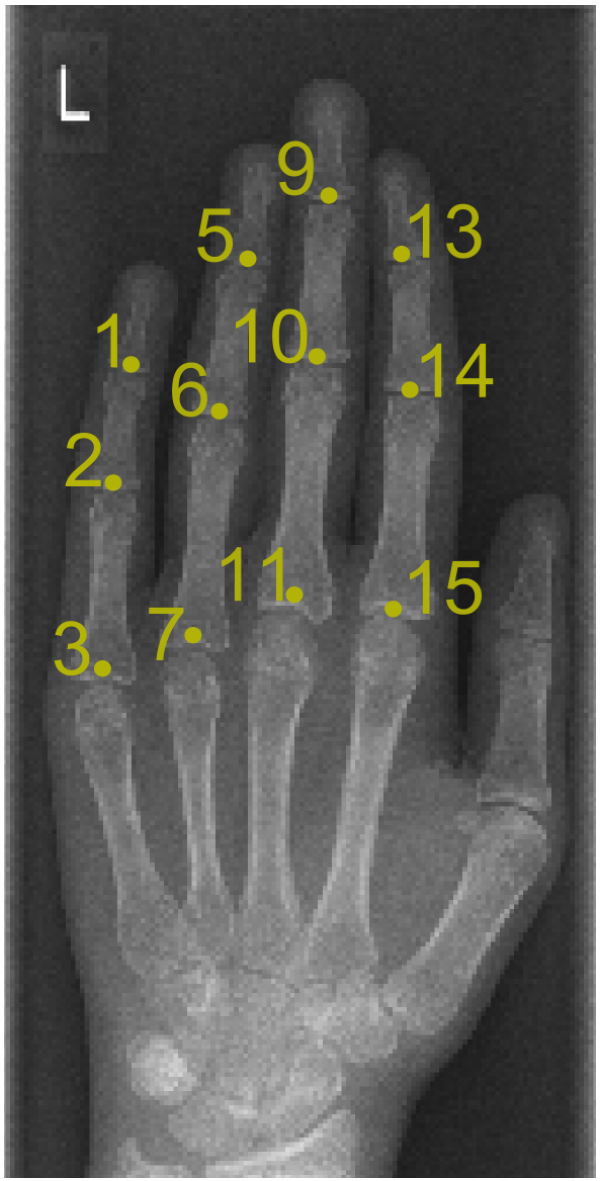
Constrained Localization



Applied Anatomical Constraints

- Minimum distance of eROIs
- Correct positioning of fingers
- Correct eROI positioning per finger

Constrained Localization

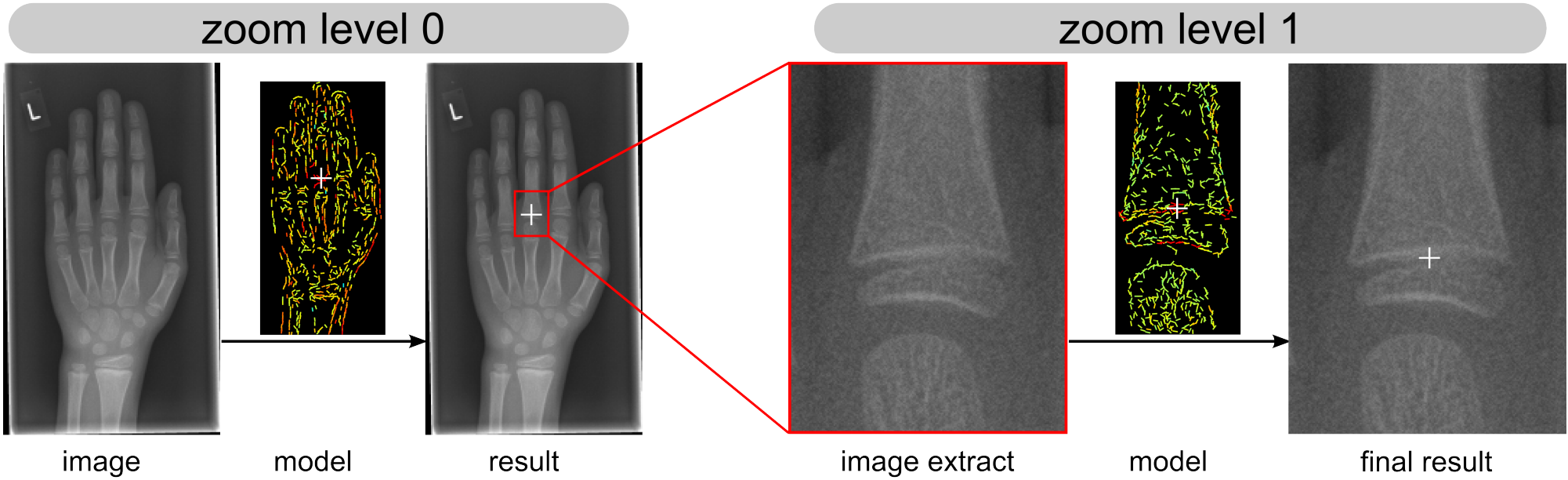


Constrained Optimization

- Count number of unmet anatomical constraints for each eROI
- Identify eROI with most violated constraints
- Correct localization result:
  Select solution w.r.t. constraints from 10-best DGHT localization list
- Iterative repetition until
  - all constraints fulfilled or
  - all eROIs changed.

Multi-Level-Approach

- Zooming-in strategy based on Gaussian pyramid
- Stepwise increase image resolution around detected point

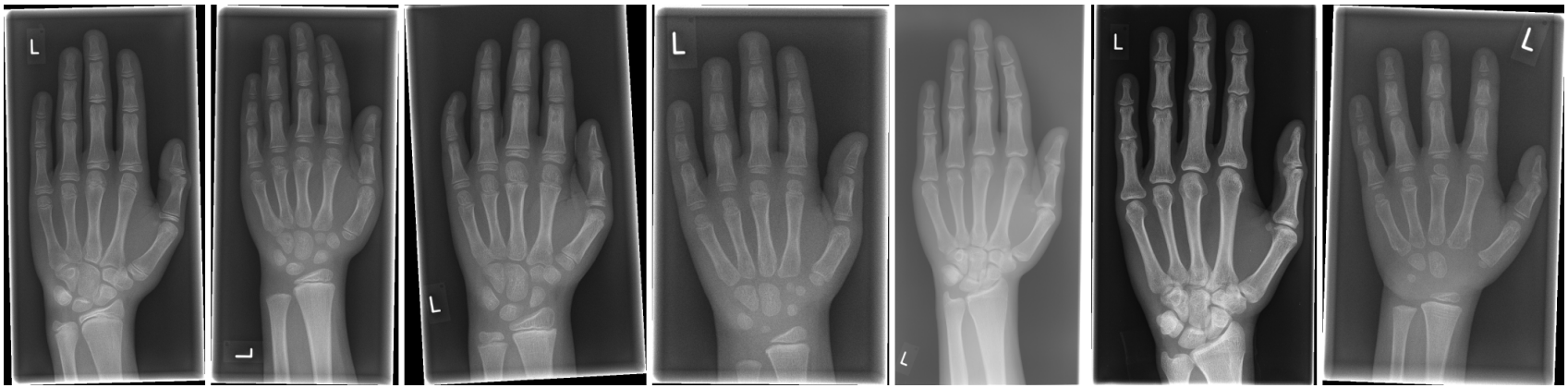


- Specifically trained DGHT model on each level
  $\rightarrow$ Capturing of different level-specific details
- Good trade-off between model accuracy and reduced confusion with concurrent objects

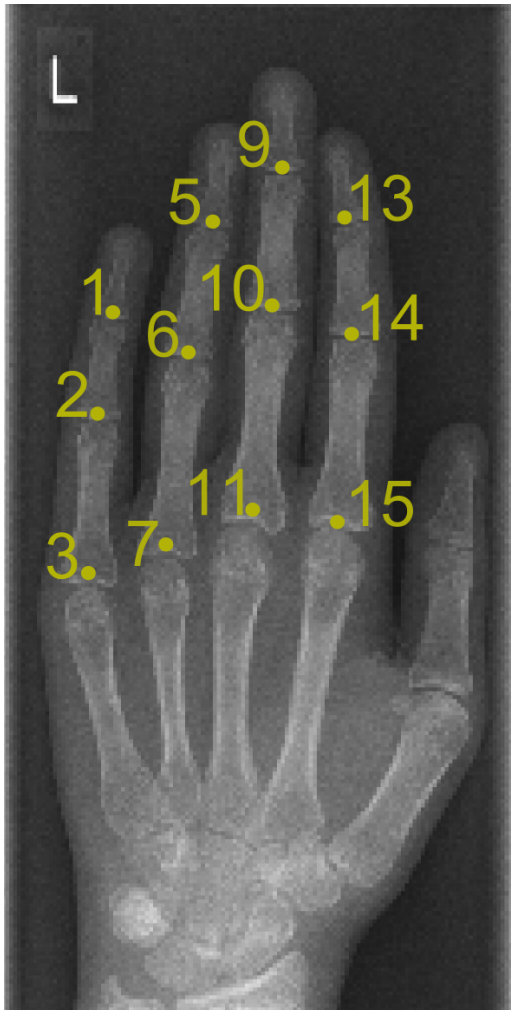
Setup

Data:

- Origin: University Hospital Aachen
- 812 unnormalized radiographs of the left hand
- Average size per image: 1185 $\times$ 2066 pixel
- Age range of subjects: 3 to 19 years
- Male and female subjects
- Training on 400 randomly selected images
- Evaluation on remaining 412 images



Setup



Setup:

- Aim: Localization of 12 eROIs
- Multi-level approach with 2 levels
- Constrained Localization in level 1

Allowed error distance:

- For BAA task: inside bounding box of 50×100 pixel around target point
- For human observer [8]: Euclidean distance of $6/256$ pixel of image height

[8]: B. Fischer, et al., Structural scene analysis and content based image retrieval applied to bone age assessment, 2009.

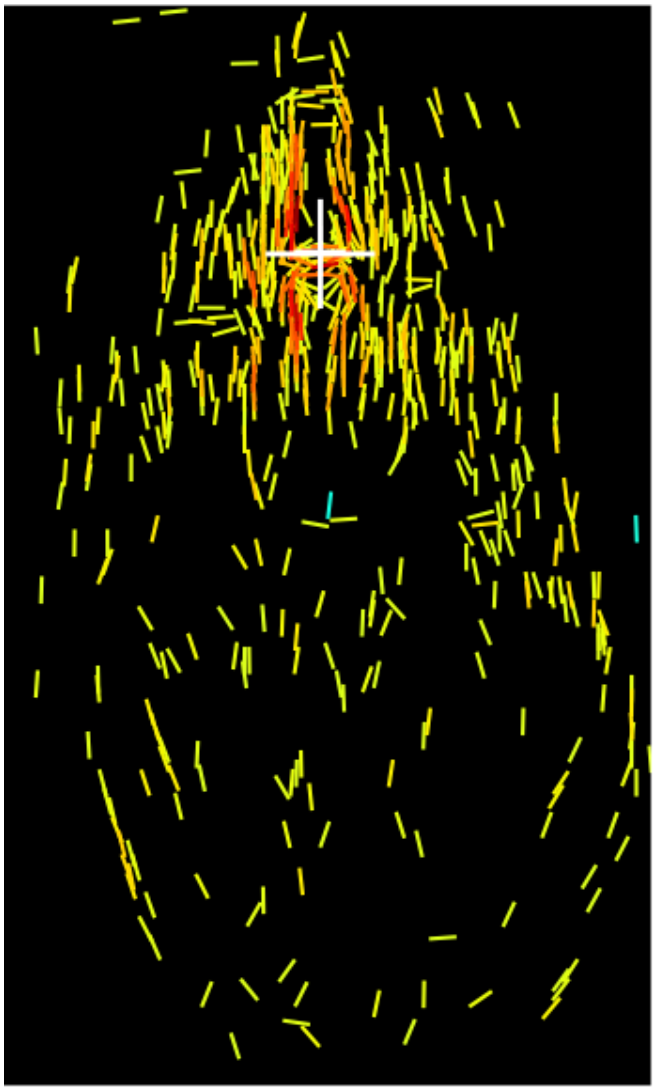
Results

Localization results

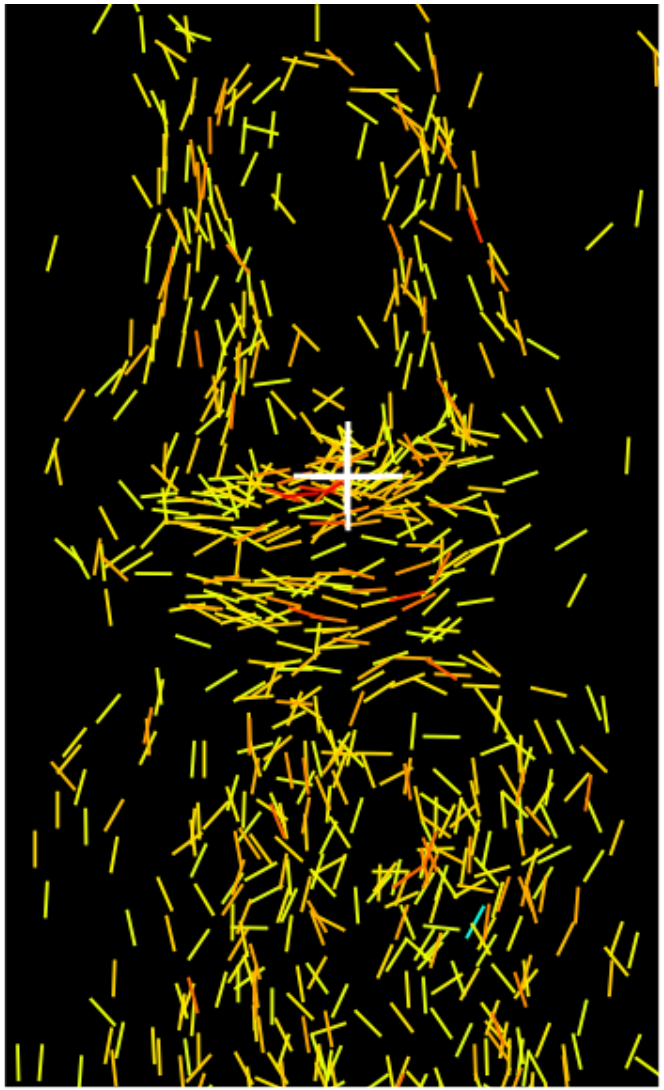
- Total number of eROIs: 4944 (412 images á 12 eROIs)
- Mean localization success rate over all eROIs: 98.1% (BAA task) / 97.6% (human observer)

Method	*Error tolerances:* BAA task	Human observer	Mean error (pixel)
DGHT	96.3%	93.7%	23.2
Constrained Localization	97.8%	94.2%	20.1
+ 2nd zoom-level	98.1%	97.6%	11.4

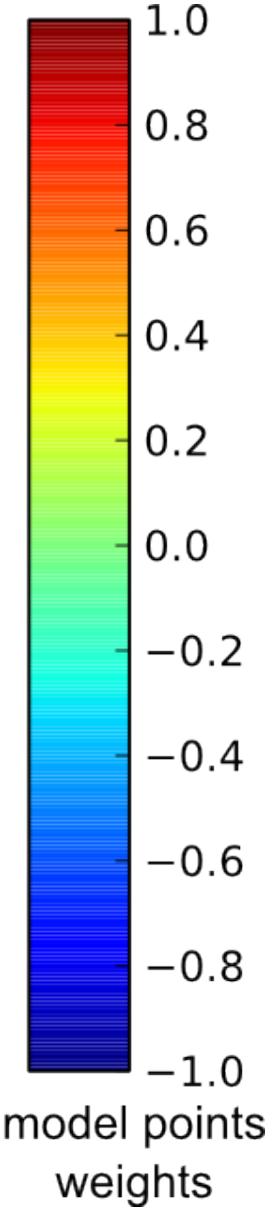
DGHT Models



zoom level 0

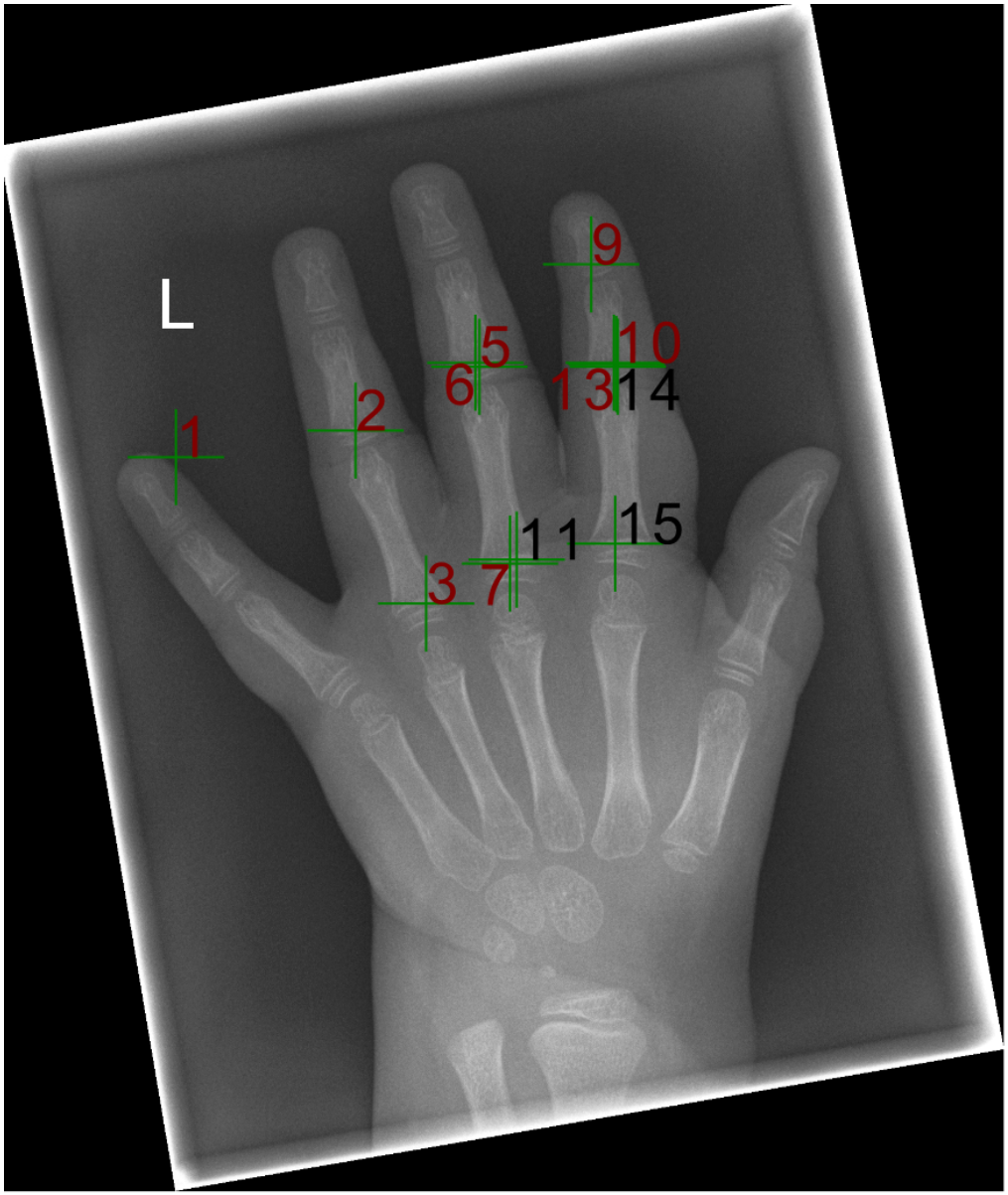


zoom level 1

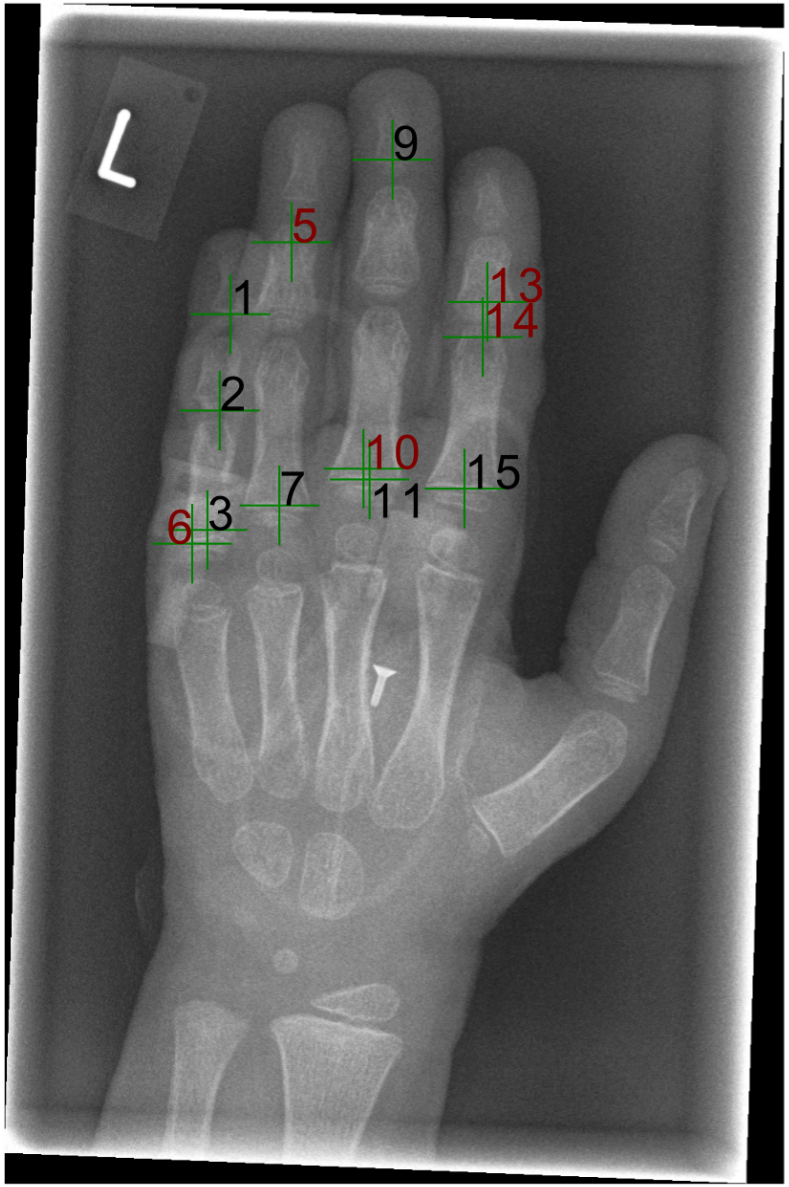


model points weights

Error cases



Error cases



Conclusion

- The Discriminative Generalized Hough Transform is a general object localization technique.
- Data-driven machine learning approach with minimal user interaction and no required expert knowledge
- First successful application to eROI localization
- General model for the full age range from 3 to 19 years
- Significant improvement using anatomical constraints
- Next step:
  - Investigate alternative approach: Markov Random Fields
  - Integration into fully automated BAA framework

Thank you!