Using Power Watersheds to Segment Benign Thyroid Nodules in Ultrasound Image Data

E. Kollorz[1,2], E. Angelopoulou[1], M. Beck[2], D. Schmidt[2], T. Kuwert[2]
[1]Pattern Recognition Lab, Department of Computer Science, University of Erlangen-Nuremberg, Erlangen, Germany
[2]Department of Nuclear Medicine, University Hospital Erlangen, Erlangen, Germany

Motivation

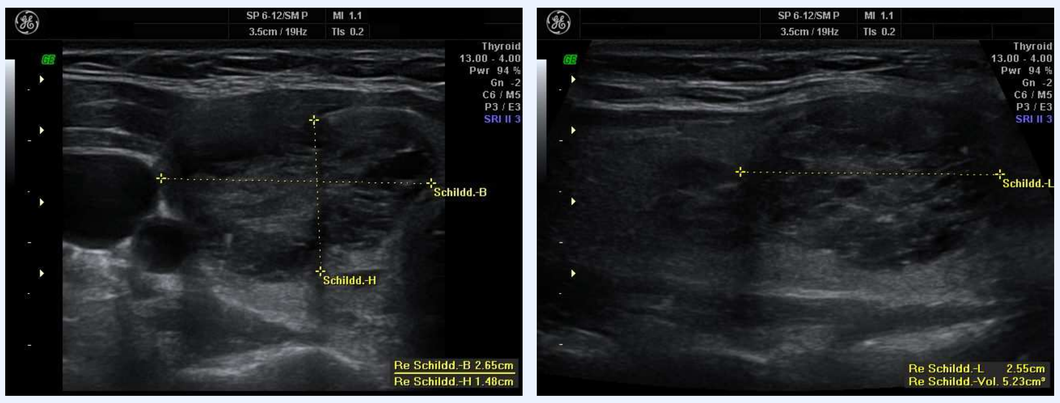
Largest study of human thyroid glands (96,278 participants) in Germany in 2001/2002 under the Papillon initiative showed that

- Every 3^{rd} adult has abnormal changes in thyroid that (s)he was unaware of
- Every 4^{th} adult has nodules in the thyroid gland
- Every 2^{nd} person over 45 years already has problems with the thyroid gland
- Men and women are equally affected

Medical Background

Typical thyroid nodule examination

- 2D ultrasound (US) is used
- Two, ideally orthogonal, slices are used in measuring the nodule volume using the ellipsoid formula
  Vol $= 0.5229 \times$ Height $\times$ Width $\times$ Depth [cm^3]
- Follow-up is done approx. every 3 months



(a) axial section plane (b) sagittal section plane

Figure 1: 2D measurements of an echo complex thyroid nodule with 5.23 cm^3 volume size

Alternative examination methods

- Contrast-enhanced US [1]
- US Elastography [3]
- Color Power Doppler US (analysis of vascularization of thyroid nodules) [5]

Purpose

Semi-automatic segmentation of nodule volume, because

(1) volume can be used as input for nodule analysis (classification)
(2) volume growth or shrinkage can be better tracked

Methods: Power Watersheds

Definitions:

- Watershed: Given a topographic surface, a drop of water could flow towards different minima. The watershed then corresponds to the borders between adjacent catchment basins of water [2].
  $\Rightarrow$ Watersheds can be estimated by computing the *optimal spanning forests* in a graph
- Graph $G = (V, E)$, vertices $v \in V$, edges $e \in E \subseteq V \times V$, cardinality: $n = |V|$, $m = |E|$, e_{ij}: edge between vertex v_i and v_j, (non-negative) weight w_{ij} is assigned to each edge e_{ij} as follows:

$$w_{ij} = I_{MAX} - |I(v_i) - I(v_j)|, \quad (1)$$

  where I_{MAX} is the maximum intensity and $I(v_i)$ the intensity at vertex v_i
- Plateau: subgraph consisting of the maximal set of vertices which are connected with edges having the same weight

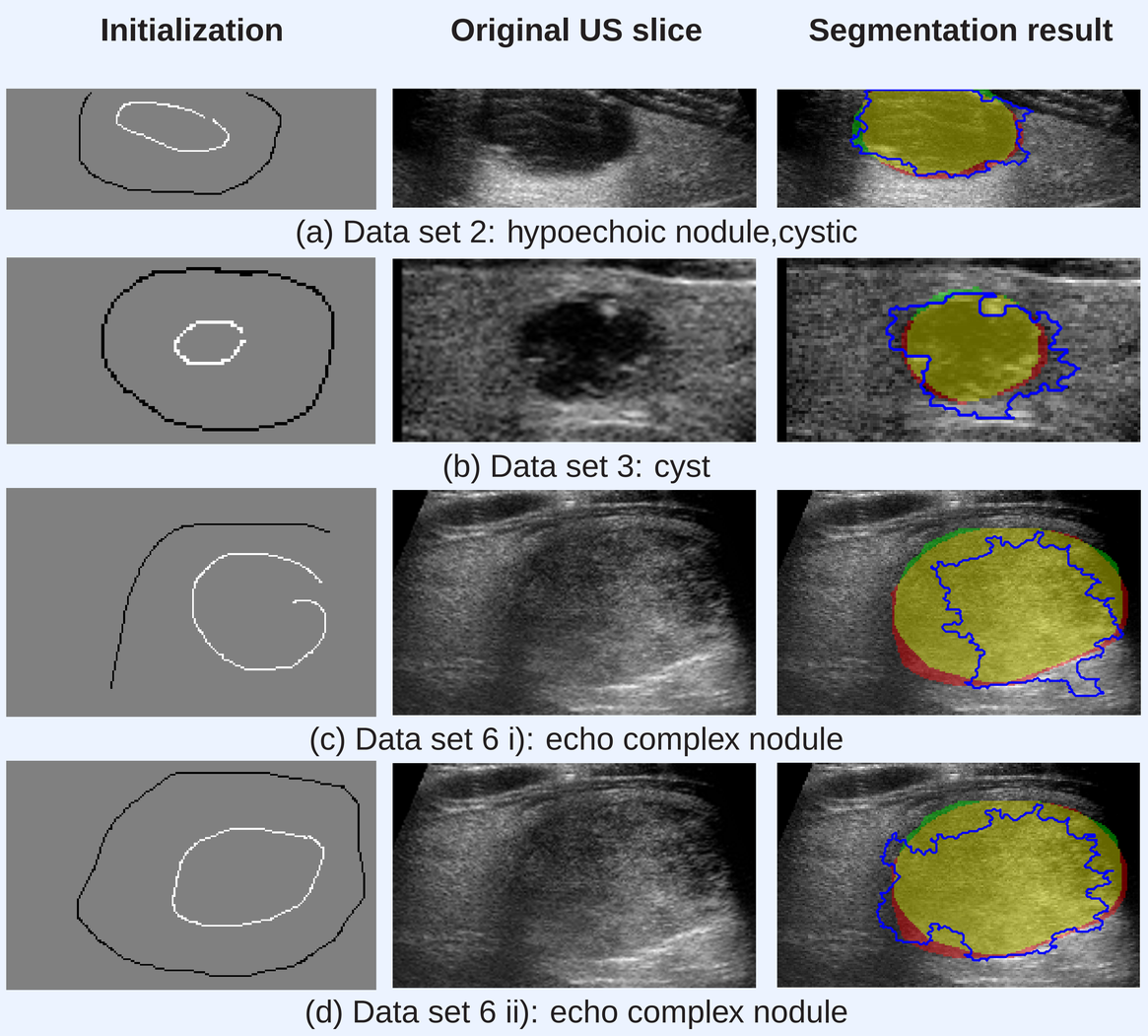
2-step Power Watershed (PW) algorithm:

(1) Maximum spanning forest (MSF) computation
  - realized with Kruskal's algorithm
  - equivalent to watershed transform on inverted gradient image
(2) Occurrence of plateaus $\Rightarrow$ Random Walker [4] on plateaus

Materials

- 6 data sets with echo complex nodules, hypoechoic nodules or cysts
- For each data set: 2 gold standard segmentations (GSS), manually outlined by a medical expert
- General Electric Healthcare US system Voluson 730 Pro with a RSP 6-16 MHz small part probe
- Individual parameter settings per data set (time gain compensation, focus, power)

Results



(a) Data set 2: hypoechoic nodule,cystic
(b) Data set 3: cyst
(c) Data set 6 i): echo complex nodule
(d) Data set 6 ii): echo complex nodule

Figure 2: Segmentation results of PW; first column: initialization (gray: area to segment, white: foreground, black: background), second column: original US slice; third column: segmentation result (blue) with manual gold standard segmentations (red, green; overlap: yellow); third and fourth row show results for different initializations

Computation time is on average 0.02 seconds for one slice on a standard PC.

$$SE = \frac{TP}{TP+FN}, \quad PRE = \frac{TP}{TP+FP},$$
$$DICE = \frac{2TP}{(TP+FP)+(TP+FN)}, \quad JAC = \frac{TP}{(TP+FP+FN)}$$

Data set	GSS 1 (green)				GSS 2 (red)				JAC
	SE [%]	PRE [%]	DICE	JAC	SE [%]	PRE [%]	DICE	JAC	GSS
1	74.79	85.09	0.80	0.66	57.37	95.98	0.72	0.56	0.68
2	94.96	90.38	0.93	0.86	94.38	92.43	0.93	0.87	0.88
3	91.70	67.26	0.78	0.63	93.91	72.19	0.81	0.68	0.87
4	76.25	90.39	0.83	0.70	72.34	90.11	0.80	0.67	0.93
5	70.00	97.34	0.81	0.68	71.79	98.60	0.83	0.71	0.88
6 i)	61.78	89.73	0.73	0.57	60.40	92.80	0.73	0.57	0.90
6 ii)	78.11	89.20	0.83	0.71	77.69	93.88	0.85	0.73	0.90

Table 1: Quantitative results of the six data sets: sensitivity (SE), precision (PRE), Dice coefficient (DICE), Jaccard index (JAC) of two gold standard segmentations (GSS) compared to the PW result. JAC GSS shows the JAC of the two GSS.

Conclusion

- **Easy and fast segmentation**
- Iterative computation with **(minimal) user interaction**
- At the moment accuracy is not high, but technique is promising

References

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