A Hybrid Semi-Automatic Method for Liver Segmentation Based on Level-Set Methods Using Multiple Seed Points

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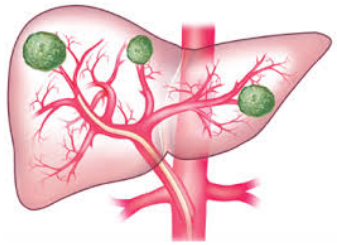
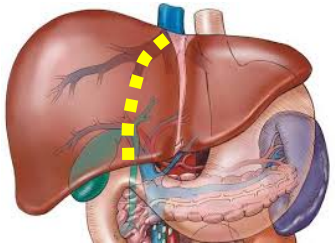
Agenda

- **Introduction**
  - State-of-the-Art
  - Objectives of the Study
- **Hybrid Semi-Auto Liver Segmentation Method Development**
- **Evaluation**
- **Discussion**

Necessity of Preoperative Liver Volume Measurement

- Important for prediction of hepatectomy safety
  - Serious hepatic dysfunction occurs if relative residual liver volume (%RLV) < 26.6% (Schindl et al., 2005)
  - Hepatectomy is safe if %RLV > 26.5% with healthy liver and %RLV > 31% for impaired liver (Ferrero et al., 2007)

Recipient	Donor
	
Too **small graft** ⇒ Posttransplant complications such as **small-for-size** syndrome	Too **much loss** of liver **tissue** ⇒ High risk of postoperative **liver failure**

Regression Models for Liver Volume Estimation

- Explaining statistical relationship between liver volume and body dimensions such as height and weight

Author	Regression models	Adjusted R^2	Errors*				Sample		
			Mean	Median	SD	SE	Nation	Size	Age
Yu et al. (2004)	$LV = 21.585 \times BW^{0.732} \times BH^{0.225}$	0.590	-27.96	-27.78	275.4	275.8	Korea	652	42.4 (16.5)
Urata et al. (1995)	$LV = 2.4 + 706.2 \times BSA$	0.962†	226.90	213.31	289.4	289.6	Japanese	96	11.1 (8.8)
Heinemann et al. (1999)	$LV = -345.7 + 1072.8 \times BSA$	0.300†	-30.64	-29.88	281.5	281.7	Caucasian	1332	50.6 (18.9)

*Differences between actual LV data and corresponding regression estimates
†Values reported by Heinemann et al. and Urata et al.
BW: body weight, BH: body height, BSA: body surface area

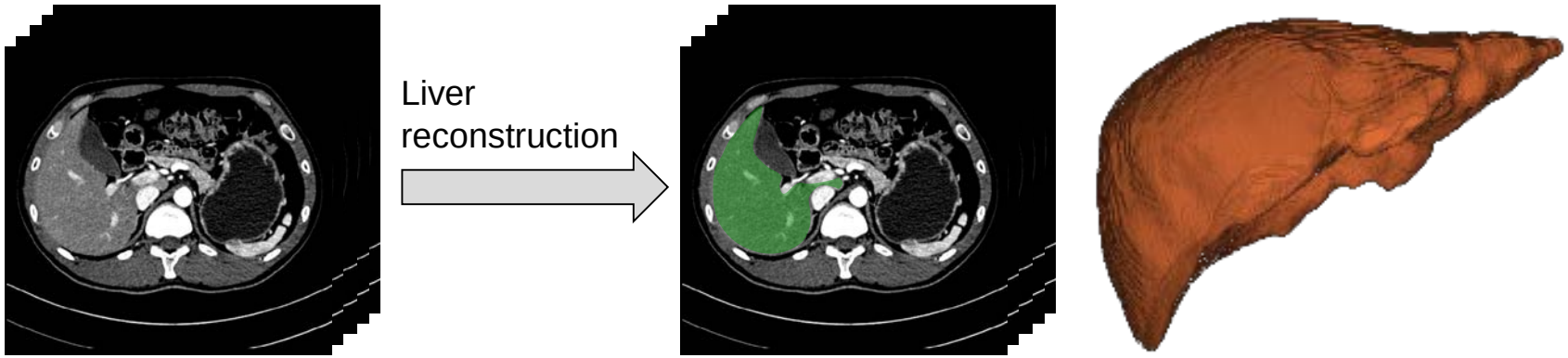
Limitation:

- Accuracy sacrificed in liver volume estimation

Image Processing Methods for Liver Volume Estimation

- Liver segmentation from CT images by image processing methods.

  Then calculate volume of the reconstructed liver



- Liver segmentation methods
  - Manual drawing
  - Semi-automatic
  - Fully automatic

Fully Automatic Liver Segmentation Methods

- No initialization such as seed points

Source	Methods	Accuracy (Overlap ratio: %)	Time Efficiency (Processing time per data: min)
Jiang and Cheng, 2009	Mathematical morphology: applied to separate the liver from others using the erosion and dilation operations	94.6	10.5
Massoptier and Casciaro, 2008	Statistical analysis to separate the liver region from others since it has minimal S.D. in intensity compared to other regions	94.2	13.3
Ruskó et al., 2007	• Automatic seed region identification using histogram analysis • Region growing method used to extract the liver	89.3	N/A

Limitation:

- Accuracy sacrificed since it is hard to separate the liver from others due to intensity similarity (Lee et al., 2007)

Semi-Automatic Liver Segmentation Methods

- Initialization needed such as seed points or seed regions

Source	Methods	Accuracy (Overlap ratio: %)	Interaction Time (min)
Dawant et al., 2007	• Delineation of initial liver contours • Interpolation applied to extract other slices	90.2	10
Hermoye et al., 2005	• Seed region (a circle) selection on each slice • Geometric deformable models and level-set method used to extract the liver	N/A	5
Pan and Dawant, 2007	• Seed region (a circle) selection on each slice • Level-set method used to extract the liver	95.8	N/A

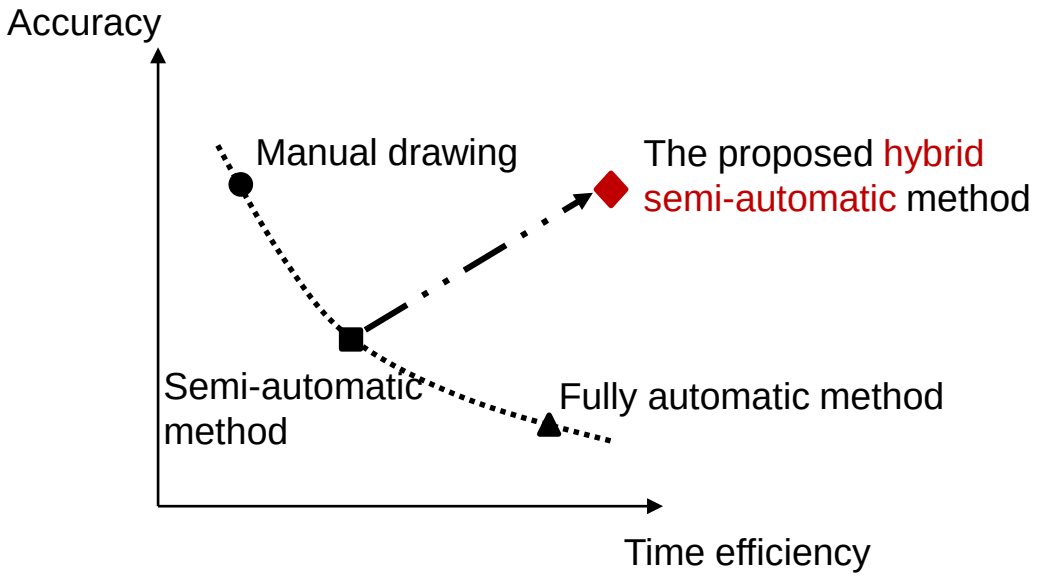
Limitation:

- Long user interaction required to generate initial contours or seed regions

  ⇒ Cumbersome to use

Objectives of the Study

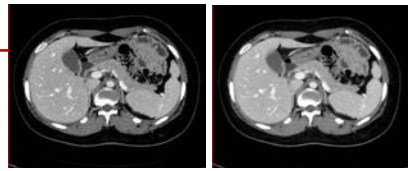
- Develop a hybrid semi-automatic liver segmentation method which has
  - Better accuracy and time efficiency
  - Minimum user interaction for initialization
- Evaluate the proposed method



Hybrid Semi-Auto Liver Segmentation Method Development

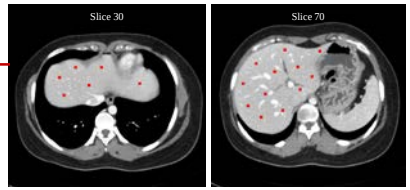
- Developed a five-step procedure for liver segmentation

S1. Preprocessing of CT images
(1) Denoising



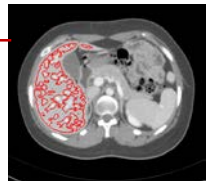
Denoising

S2. Selection of multiple seed points



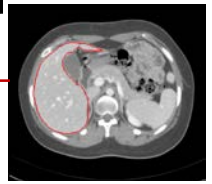
Seed point selection

S3. Formation of initial liver regions



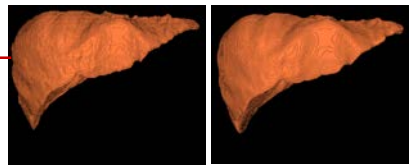
Initial liver formation

S4. Liver extraction based on the initial liver regions



Liver segmentation

S5. Post-processing of the extracted liver
(1) Liver surface smoothing

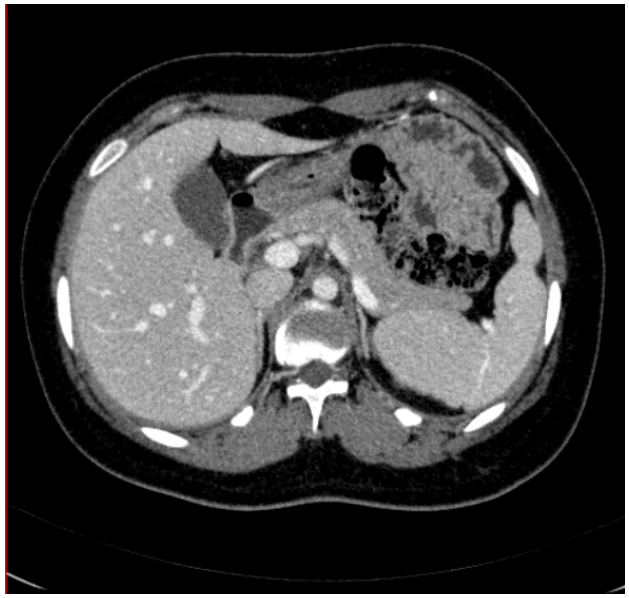


Surface smoothing

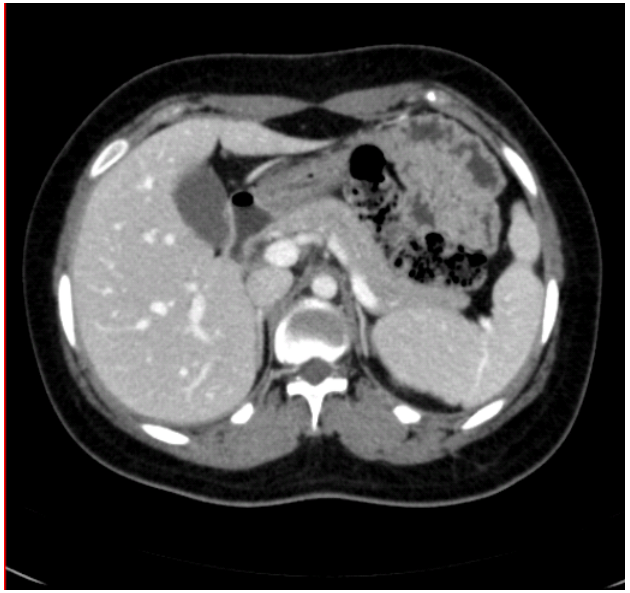
S1. Pre-Processing

- Reduce Noises of the CT images by an anisotropic diffusion filter
  (Perona and Malik, 1990)

<Original image>

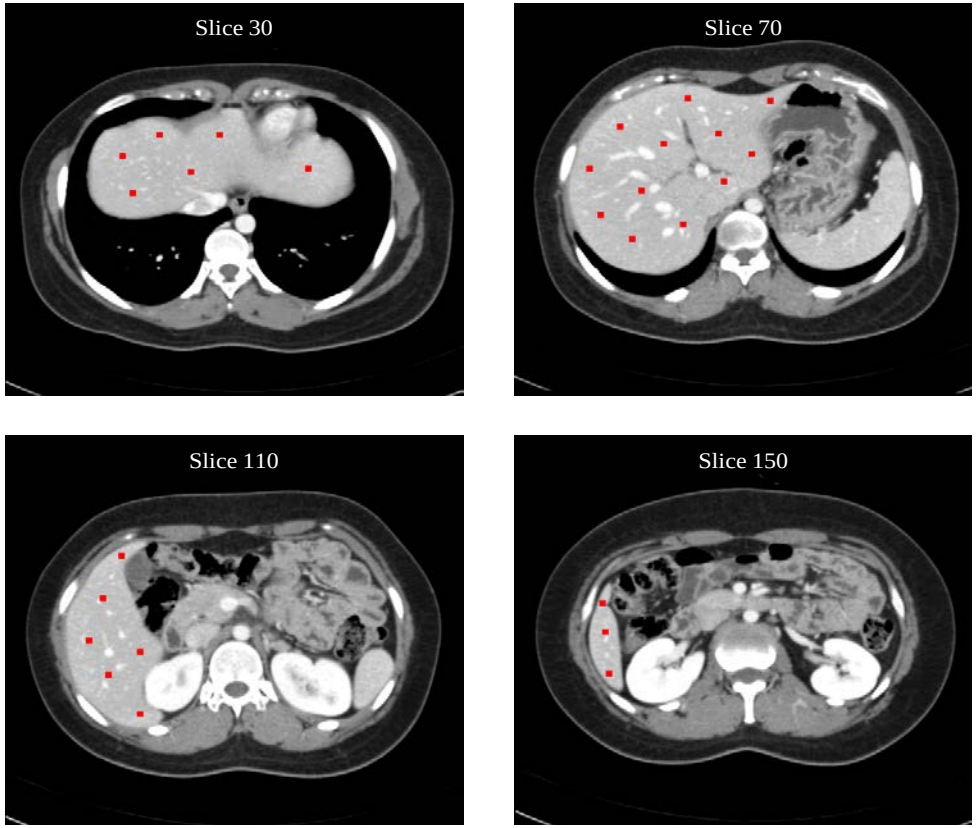


<Denoised image>



S2. Multiple Seed Points Selection

- Select multiple seed points (20 ~ 30) from different CT slices (4 ~ 5)



Selection of 27 seed points from four slices with an interval of 40 for a CT volume of 184 slices (selection time: 30 sec)

S3. Initial Liver Region Identification

- Form an optimal initial liver region automatically from the selected seed points by a customized fast-marching level-set method (Sethian, 1996)

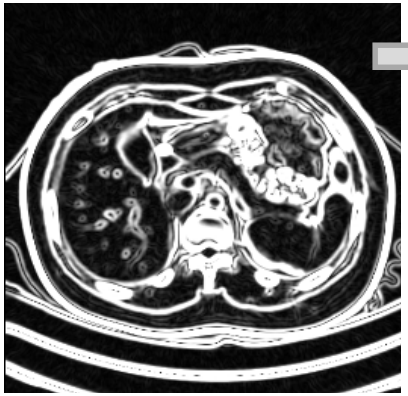
S1. Calculate image gradient magnitude

S2. Calculate contour propagation speed

S3. Calculate arrival time of the propagating contour at each voxel

S4. Extract the initial liver region

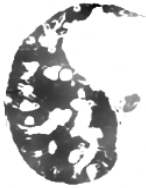
<Image gradient magnitude>



<Propagation speed>

<Initial liver region>

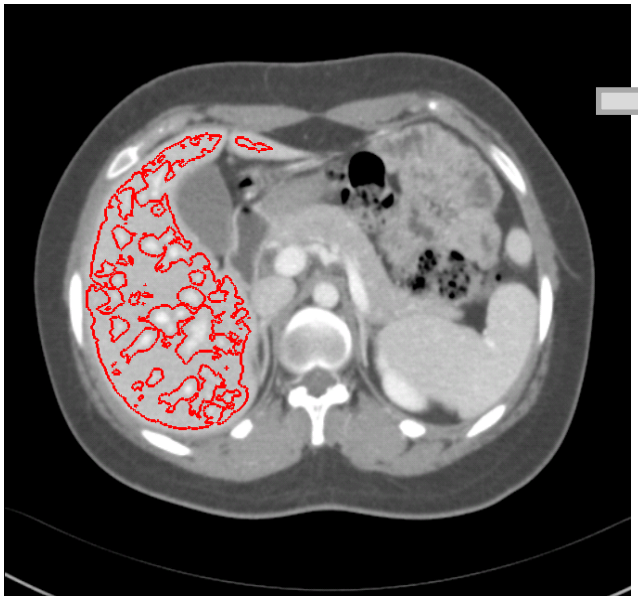
<Arrival time>



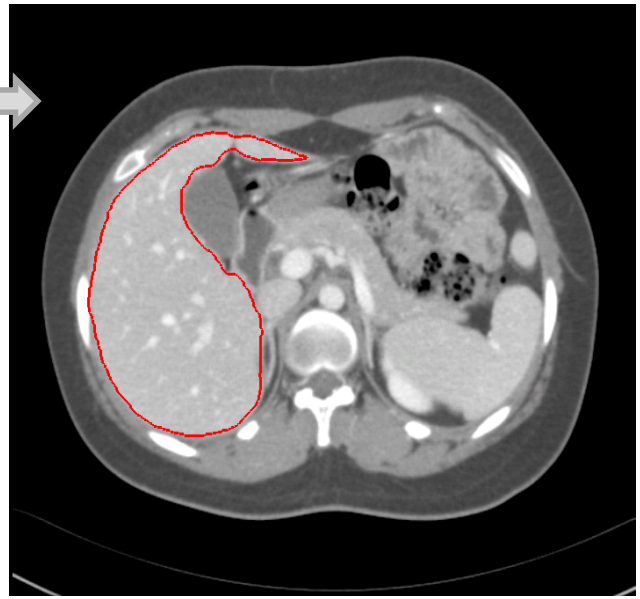
S4. Liver Extraction Based on Initial Liver Region

- Liver segmentation from the initial liver region by a threshold-based level-set method (Hsu et al., 2010; Lefohn et al., 2003)

<Initial liver region>



<Refined liver region>

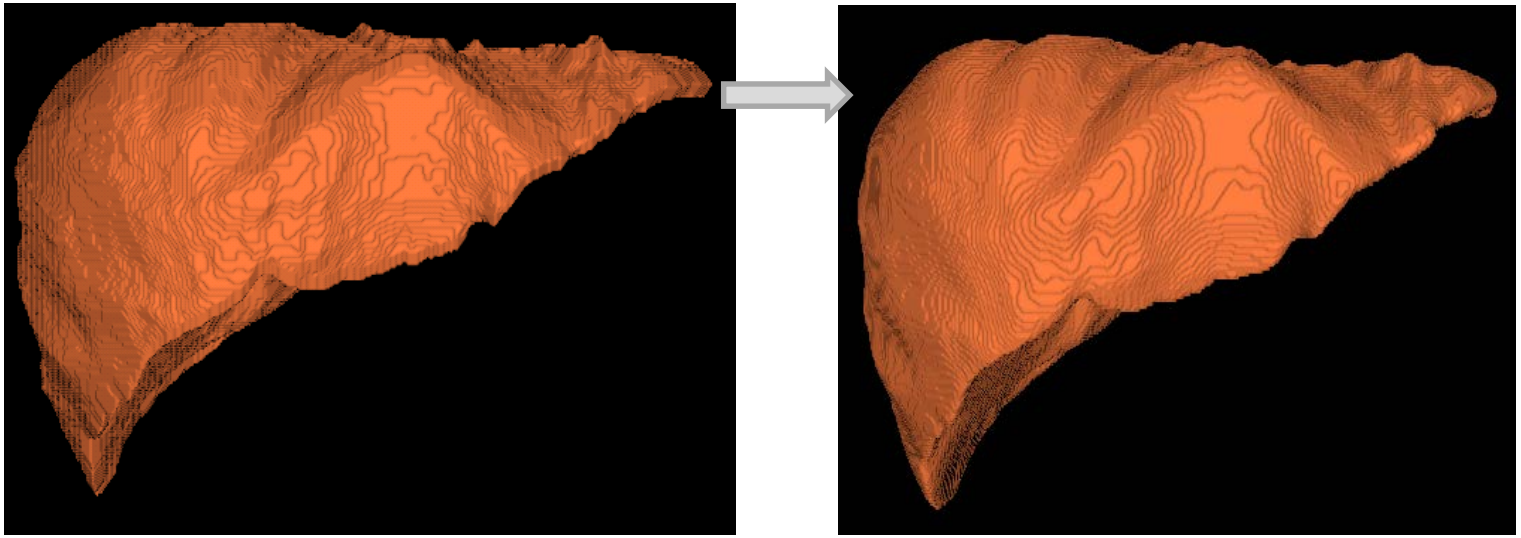


S5. Post-Processing

- Liver surface smoothing by a binary median smoothing filter
  (Nodes and Gallagher, 1982)

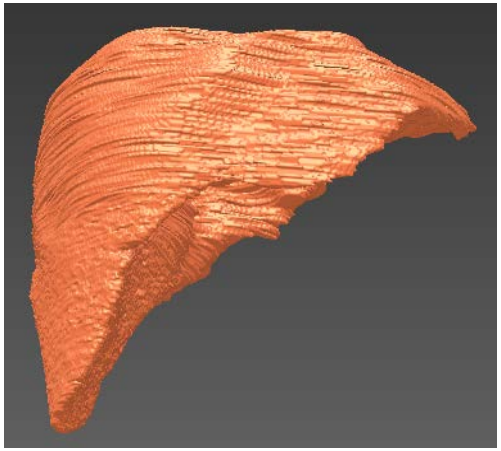
<Before smoothing>

<After smoothing>

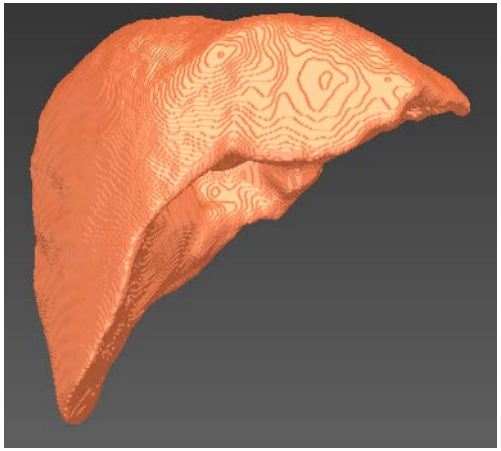


Evaluation: Compare to OsiriX 2D Region Growing Method

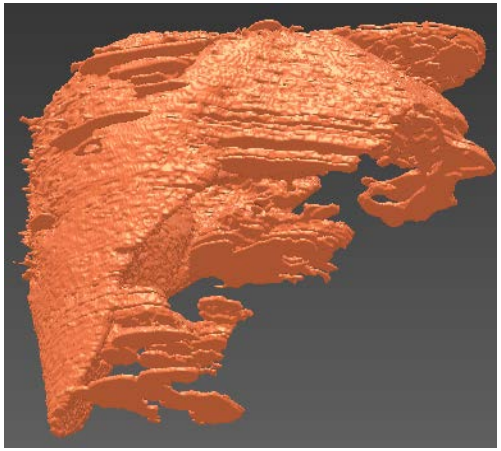
- Visual inspection of segmentation accuracy
  - Proposed hybrid method > OsiriX 2D region growing method



Ground truth
(manually segmented by a radiologist)



Proposed hybrid method

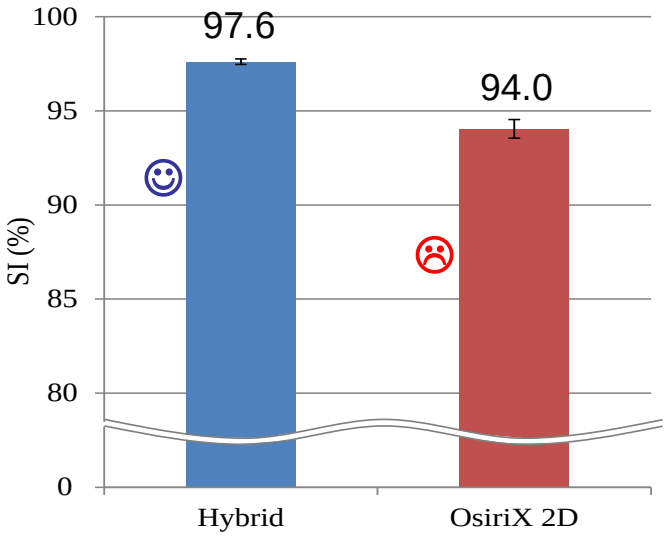


OsiriX 2D region growing method

Segmentation Accuracy

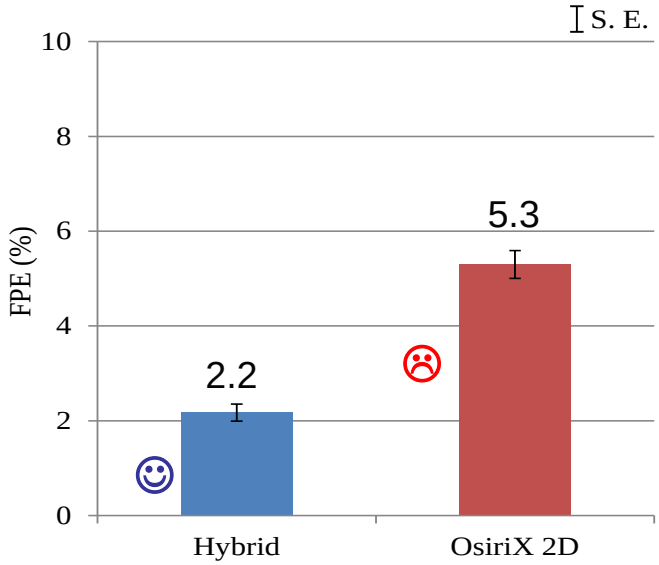
Similarity index (%)

($t(16) = 6.92$, $p < .001$)



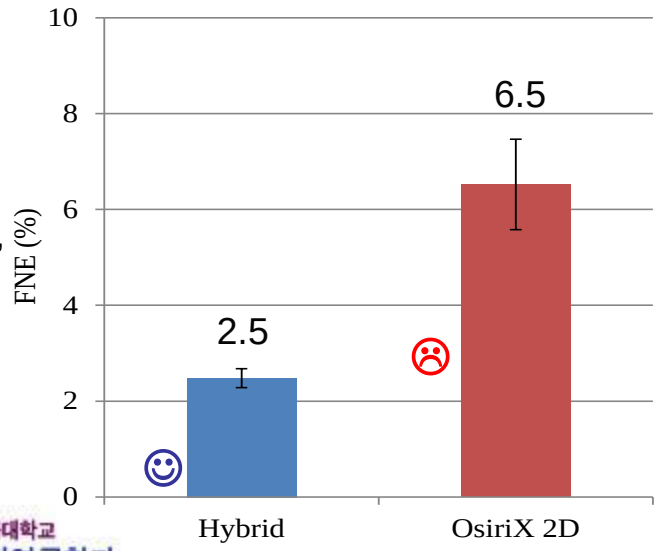
False positive error (%)

($t(23) = -9.07$, $p < .001$)



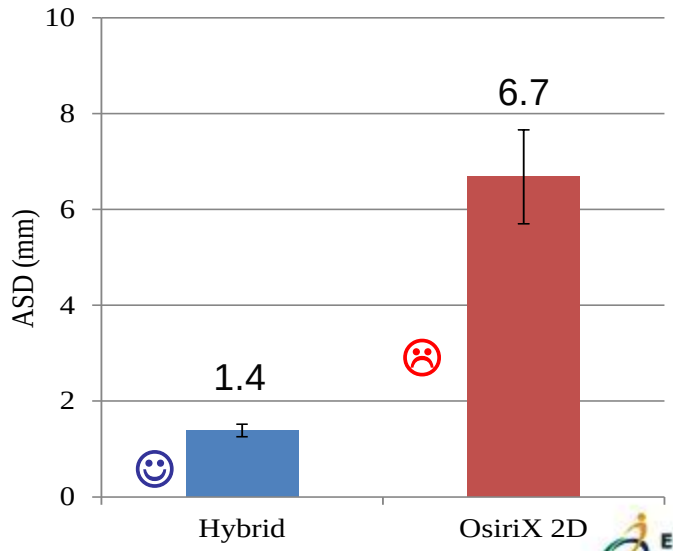
False negative error (%)

($t(15) = -4.19$, $p = .001$)

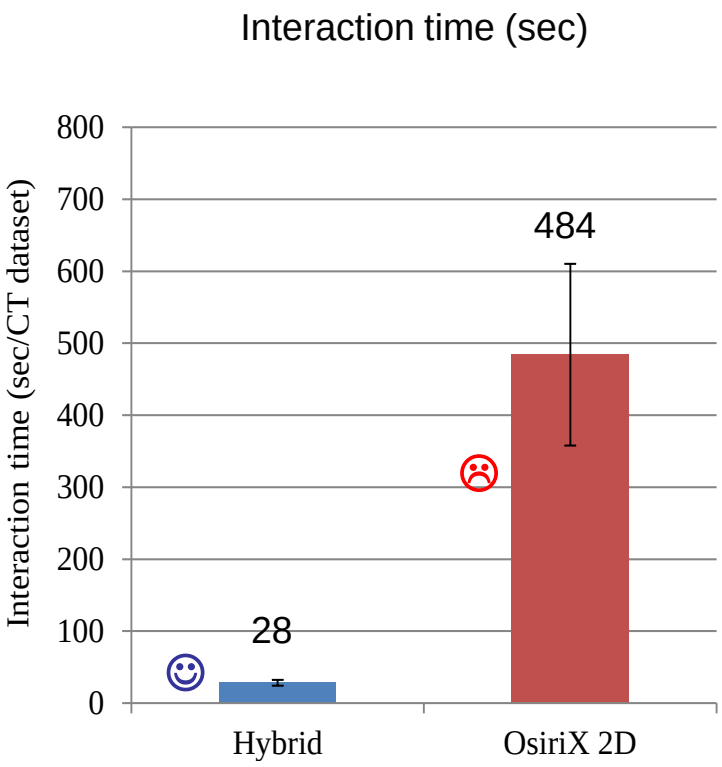


Average symmetric surface distance (mm)

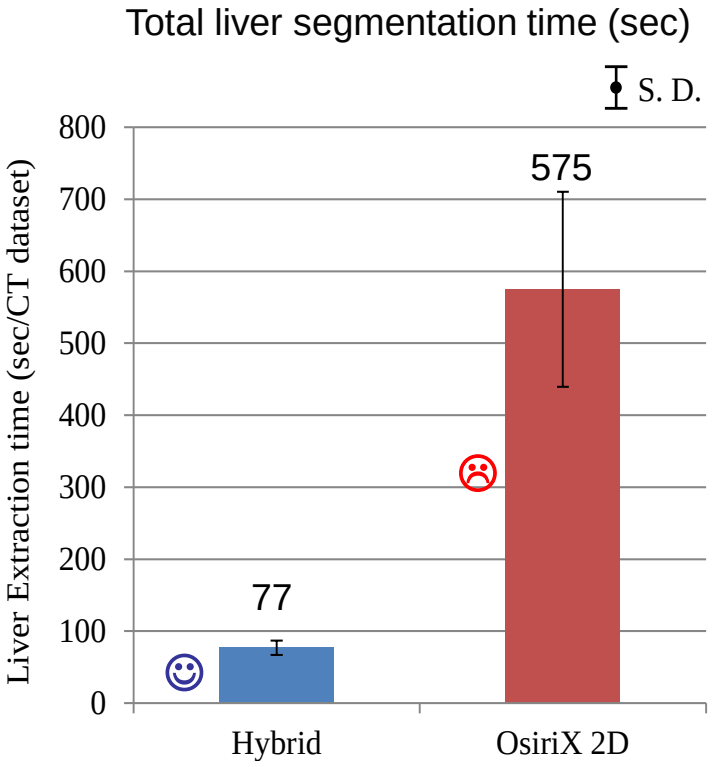
($t(14) = -5.35$, $p < .001$)



Time Efficiency



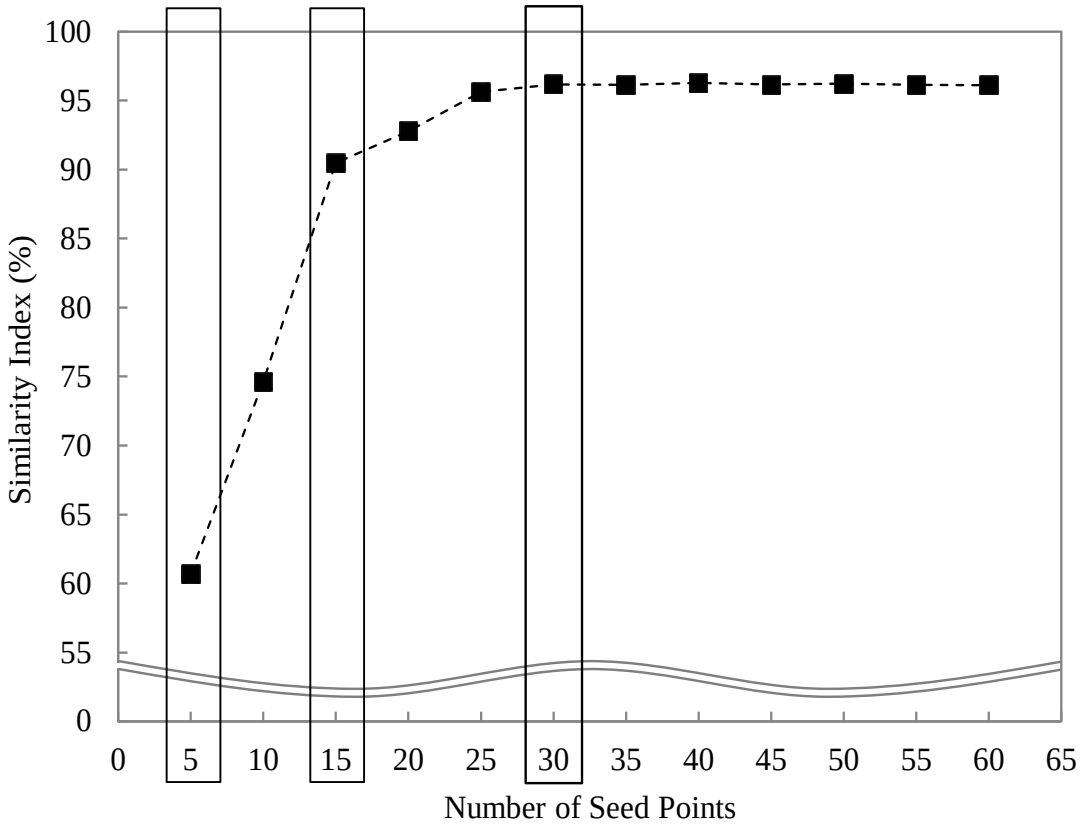
($t(14) = -13.97$, $p < .001$)



($t(14) = -14.20$, $p < .001$)

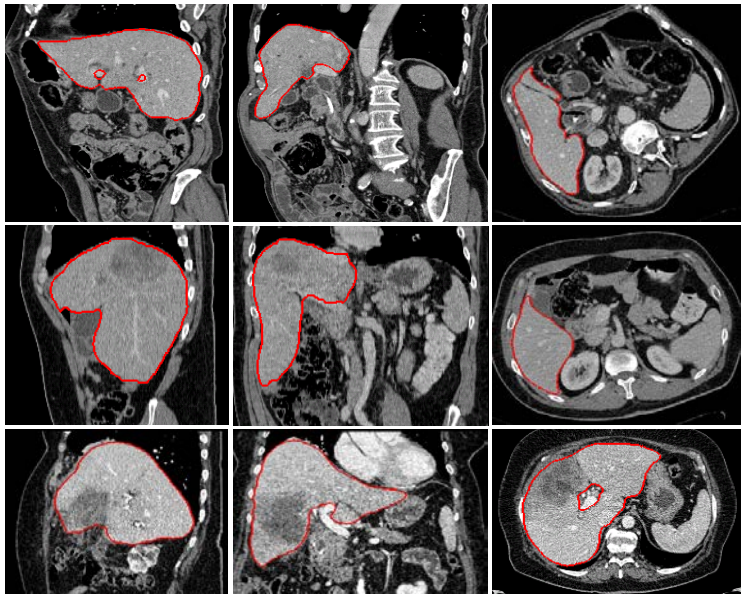
Sensitivity Study

- Effect of seed point selection on segmentation accuracy
  - SI increased rapidly when the number of seed points increased from 5 to 15, slowed down from 15 to 30, and leveled off after 30



Onsite Competition at SLIVER07 of MICCAI 2007 Workshop

- Evaluated using 10 onsite test data sets provided by MICCAI 2007 Workshop
- Evaluation score: 78.9; ranked as 11 among 72 submissions (http://sliver07.org/results.php)



Left to right: sagittal, coronal, and transversal slices;
Top to bottom: easy (no lesion), middle (middle size lesion), and difficult cases (large size lesion)

SLIVER07

Home Rules Results Register Download Submit FAQ

Results

For a table with more detailed results, click on the rank of the submission you are interested in.

Rank	Team	System	Submission Date	Avg Total Score
1	Niki-Lab	Semi-automatic	2013-07-29	85.7
2	Niki-Lab	Semi-automatic	2013-01-10	85.3
3	LME Erlangen	Semi-automatic	2010-01-14	84.6
4	Niki-Lab	Semi-automatic	2012-11-02	84.5
5	Niki-Lab	Semi-automatic	2013-06-28	84.0
6	LiverPlanner	Interactive	2008-02-25	82.1
7	Afifi	Semi-automatic	2011-11-24	81.8
8	liver sirD	Semi-automatic	2011-11-30	80.5
9	liver SirA	Semi-automatic	2011-11-02	80.0
10	Niki-Lab	Semi-automatic	2011-08-23	79.7
11	EDT	Semi-automatic	2013-04-19	78.9
12	SmartPaint	Interactive	2013-06-17	78.6

Limitation of the ranking system

- Limited measures: similarity index, Average symmetric surface distance (FPE, FNE not considered)
- Time efficiency not considered
- Large vessel branches not excluded from the liver

Achievement of the Hybrid Semi-Automatic Liver Extraction Method

- Published at the Computer Methods and Programs in Biomedicine in January, 2014

COMPUTER METHODS AND PROGRAMS IN BIOMEDICINE 113 (2014) 69–79

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A hybrid semi-automatic method for liver segmentation based on level-set methods using multiple seed points

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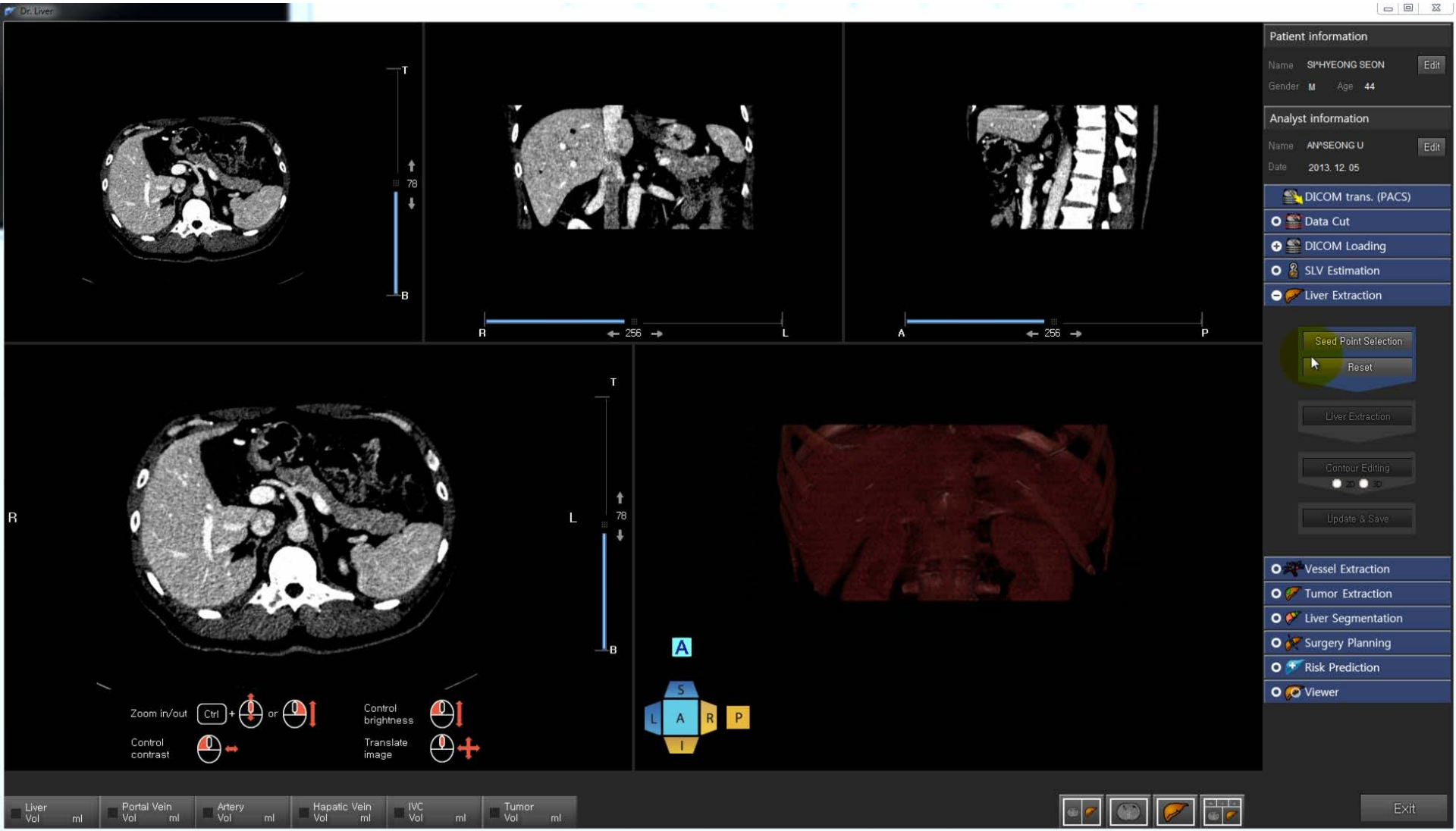
ABSTRACT

The present study developed a hybrid semi-automatic method to extract the liver from abdominal computerized tomography (CT) images. The proposed hybrid method consists of a customized fast-marching level-set method for detection of an optimal initial liver region from multiple seed points selected by the user and a threshold-based level-set method for extraction of the actual liver region based on the initial liver region. The performance of the hybrid method was compared with those of the 2D region growing method implemented in OsiriX using abdominal CT datasets of 15 patients. The hybrid method showed a significantly higher accuracy in liver extraction (similarity index, SI = 97.6 ± 0.5%; false positive error, FPE = 2.2 ± 0.7%; false negative error, FNE = 2.5 ± 0.8%; average symmetric surface distance, ASD = 1.4 ± 0.5 mm) than the 2D (SI = 94.0 ± 1.9%; FPE = 5.3 ± 1.1%; FNE = 6.5 ± 3.7%; ASD = 6.7 ± 3.8 mm) region growing method. The total liver extraction time per CT dataset of the hybrid method (77 ± 10 s) is significantly less than the 2D region growing method (575 ± 136 s). The interaction time per CT dataset between the user and a computer of the hybrid method (28 ± 4 s) is significantly shorter than the 2D region growing method (484 ± 126 s). The proposed hybrid method was found preferred for liver segmentation in preoperative virtual liver surgery planning.

http://www.sciencedirect.com/science/article/pii/S0169260713002988

Video Demo of Liver Extraction



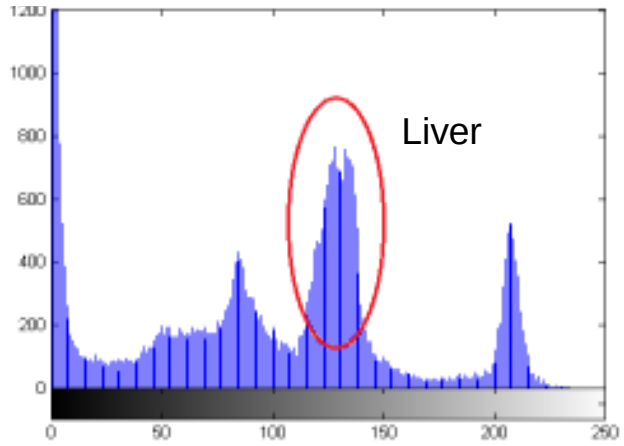
Discussion

- The proposed hybrid semi-automatic method sequentially incorporates a customized fast-marching level-set method and a threshold-based level-set method to achieve better accuracy (SI = 97.6%) and time efficiency (77 sec/CT dataset) in liver extraction
- The proposed method overcomes the weaknesses of 2D region growing method in terms of accuracy and user interaction time (< 30 sec)
- The proposed method is superior to most methods at the onsite competition SLIVER07 of MICCAI 2007 workshop
- The proposed method is applicable to tumor segmentation in the liver

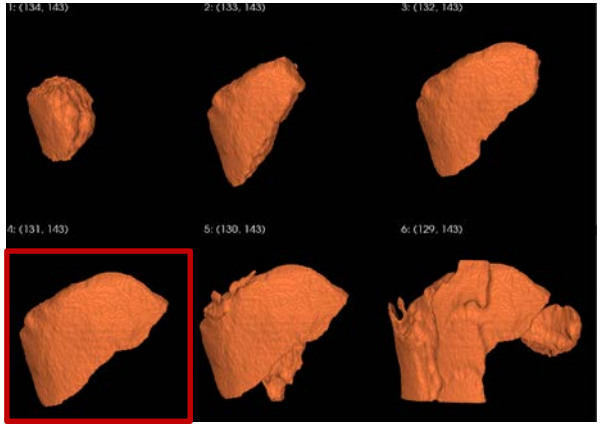
Future Work

- Develop a fully automatic seed point selection method to change the proposed hybrid semi-automatic method into fully automatic
  - Automatic identification of ROI through histogram analysis of CT images
- Provide multiple intermediate segmentation candidates for users to select the best one

Abdominal CT Histogram
(Kumar & Moni, 2010)



Multiple Segmentation Candidates



Q & A