Semi-Automatic Central-Chest Lymph-Node Definition from 3D MDCT Images

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Motivation

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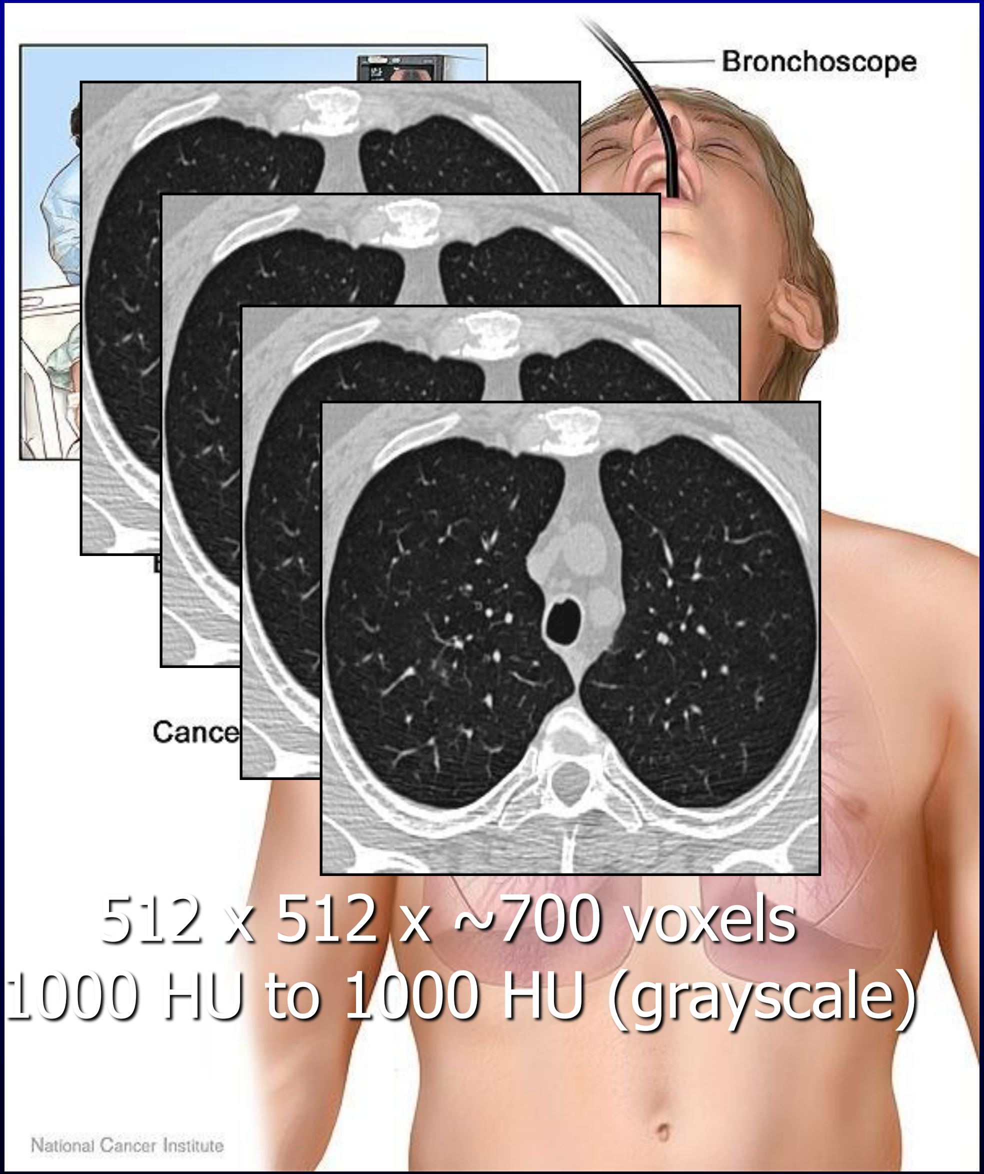
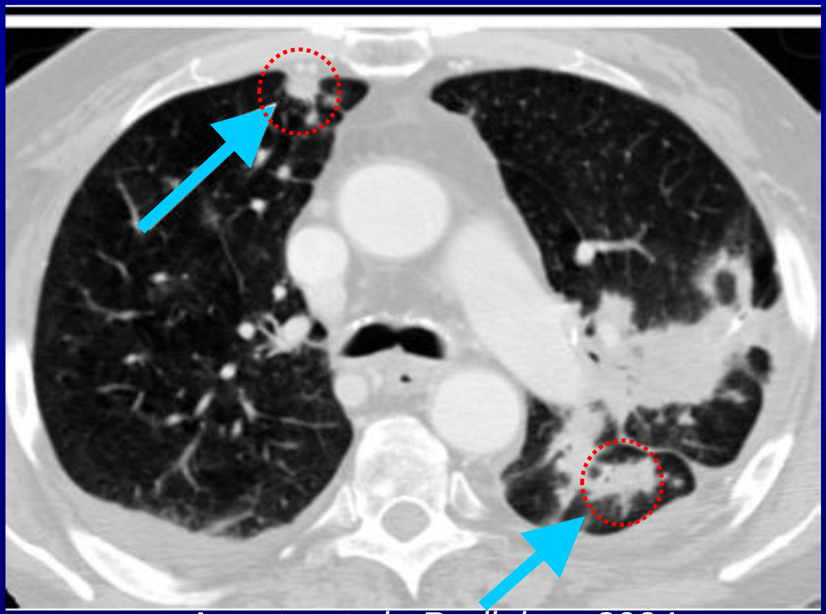
- Lung cancer is the leading cause of cancer death
- Early lung cancer detection could increase survival rate
- Diagnosis procedures:
  - 3D MDCT chest image assessment
  - Follow-on diagnostic bronchoscopy

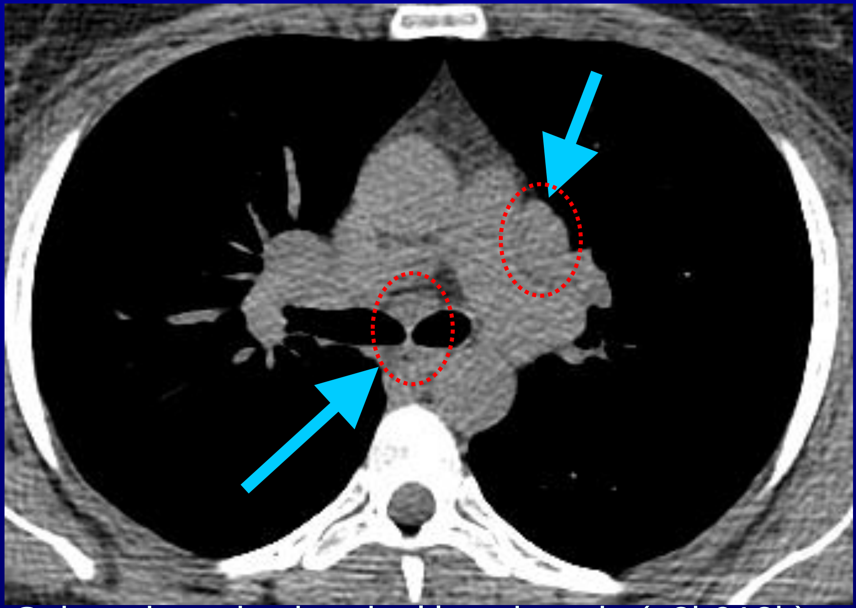


Drawing by Terese Winslow, "Bronchoscopy," *NCI Visuals Online*, National Cancer Institute

Motivation



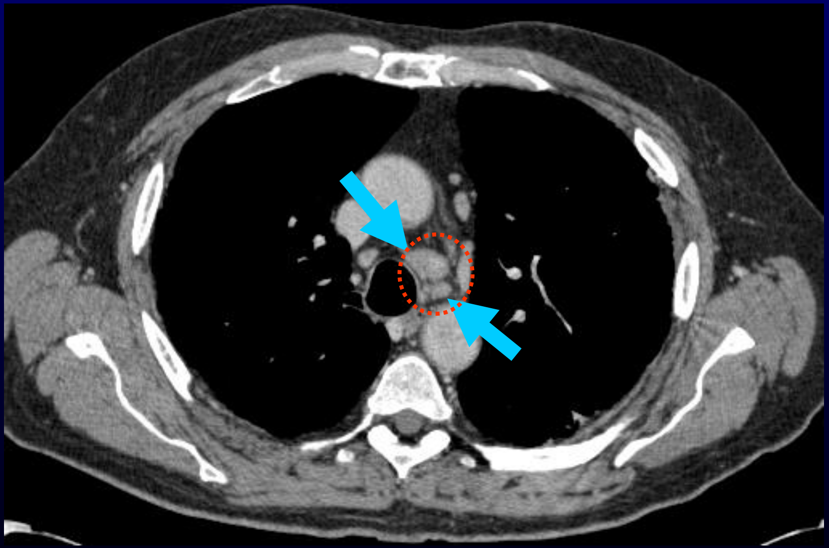
Armato *et al.*, *Radiology* 2004



Subaortic and subcarinal lymph node (p2h012b)

- ROIs involve complex phenomena
- Manual slice tracing – not feasible
- Automatic methods
  – application dependent
- Semi-automatic methods
  – more practical

Live Wire



Lower para-tracheal lymph node (IRB20349.3.3)

Prior Work

2D Live Wire:

- Mortensen and Barrett (*Graphical Models and Medical Imaging 1998*)
- Falcão *et al.* (*Graphical Models and Medical Imaging 1998*)
- Lu and Higgins (*Int. J. CARS 2007)*

3D Live Wire:

- Falcão and Udupa (*Medical Image Analysis 2000*)
- Hamarneh *et al.* (*SPIE Medical Imaging 2005*)
- König and Hesser (*SPIE Medical Imaging 2005)*
- Souza *et al.* (*SPIE Medical Imaging 2006*)
- Lu and Higgins (*Int. J. CARS 2007)*
- Poon *et al.* (*SPIE Medical Imaging 2007 and CMIG 2008)*

Prior Work

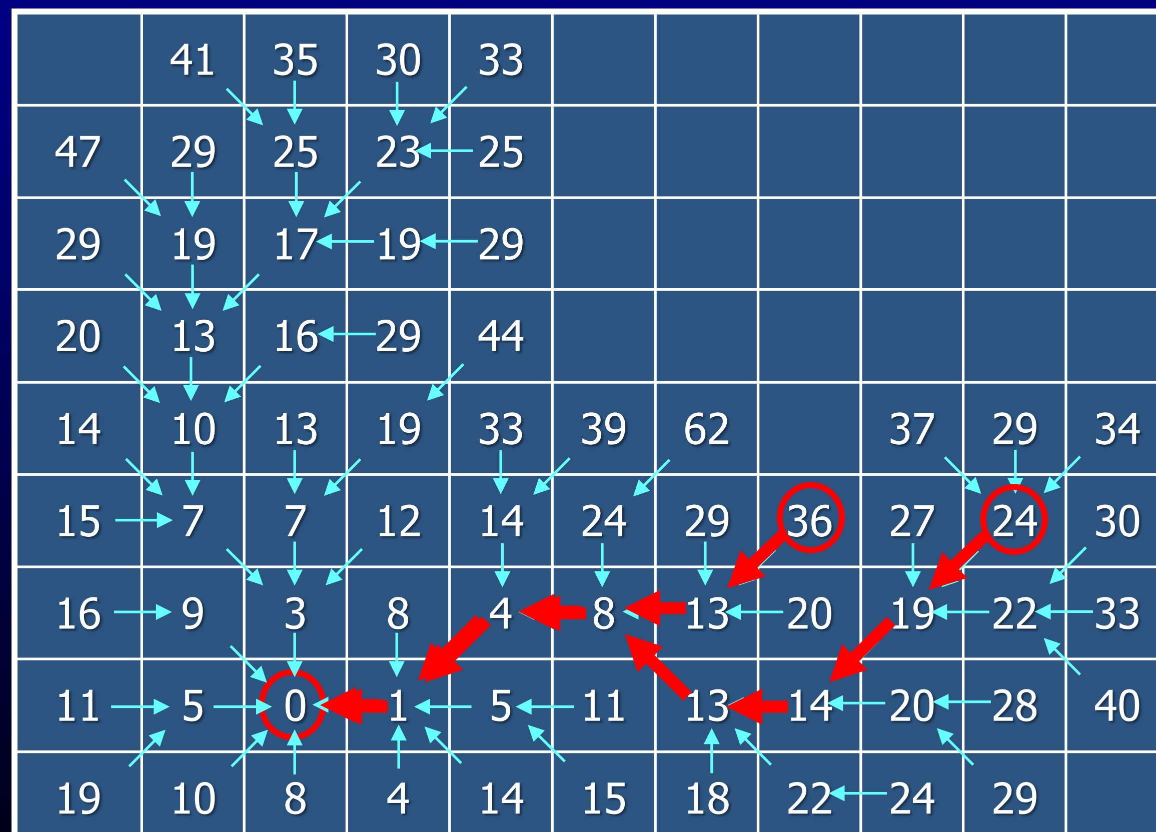
Cost Function:

$$l(p,q) = w_z f_z(q) + w_G f_G(q) + w_D f_D(p,q) + w_{Df} f_{Df}(p,q)$$

Dynamic Graphic Search:

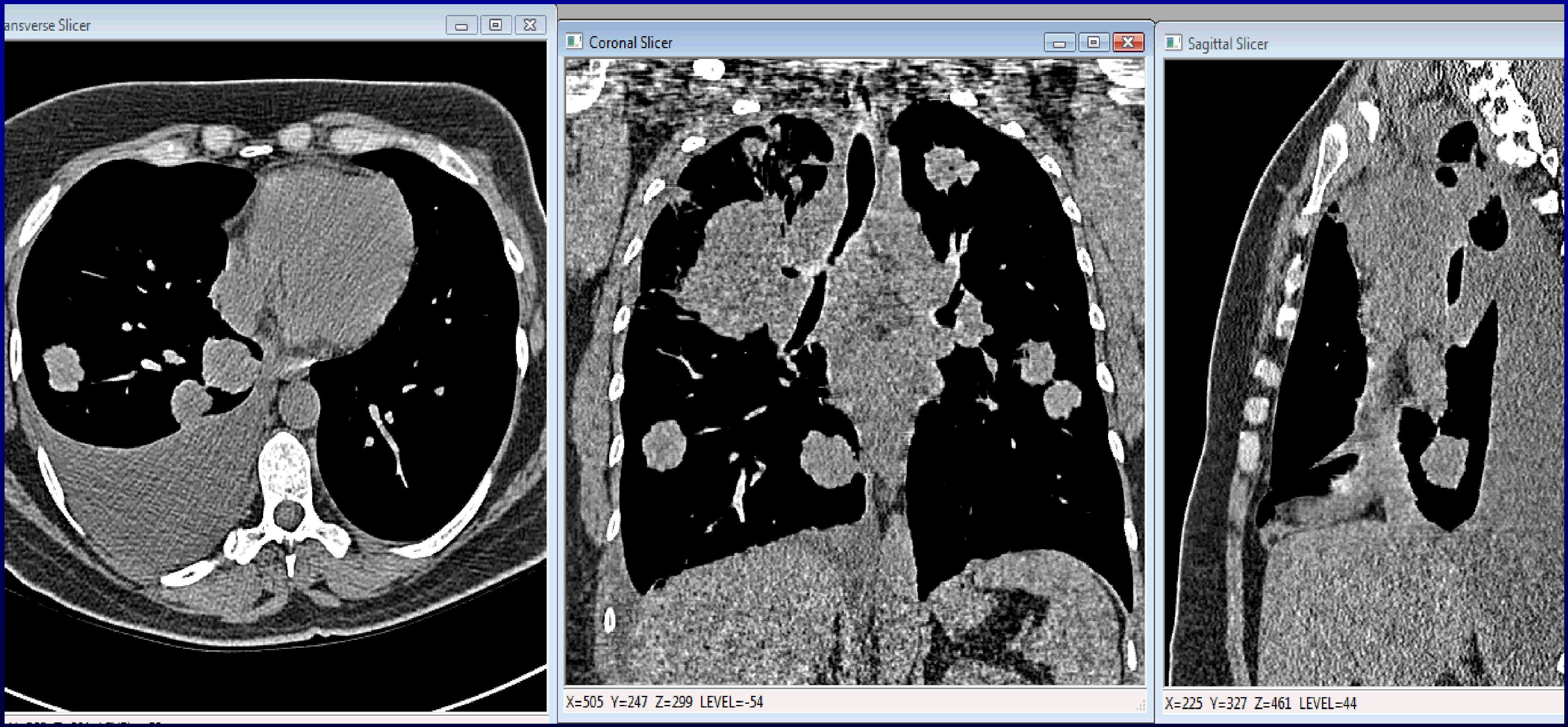
Input:
s
$l(p,r)$
Data Structures:
L
$N(p)$
$e(p)$
$g(p)$
Output
pt
Algorithm:

```
g(s) ← 0; L ← s;
While L ≠ Φ do begin
        pt ← min(L);
        e(p) ← TRUE;

        for each r ∈ N(p) such that ¬e(r) do begin
                gtemp ← g(p) + l(p, r);

                if r ∈ L and gtemp < g(r) then
                        g(r) ← gtemp; pt(r) ← p;
                if r ∉ L then begin
                        g(r) ← gtemp; pt(r) ← p; L ← r;
                end
        end
end
```



Mortenson *GMMI* 1998; K. Lu and W.E. Higgins, *SPIE* 2006 and *IJCAR* 2007

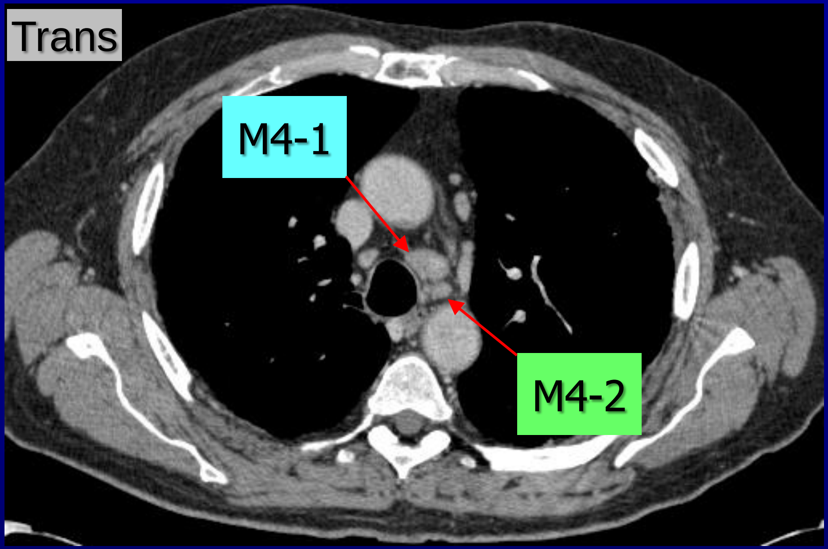
Prior Work

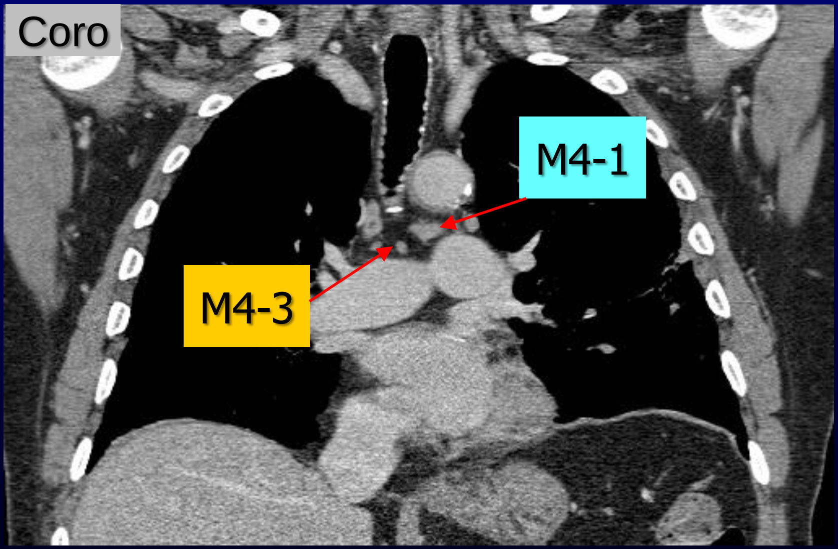


Segment ROI using 3D Live Wire

K. Lu and W.E. Higgins, *SPIE* 2006 and *IJCAR* 2007

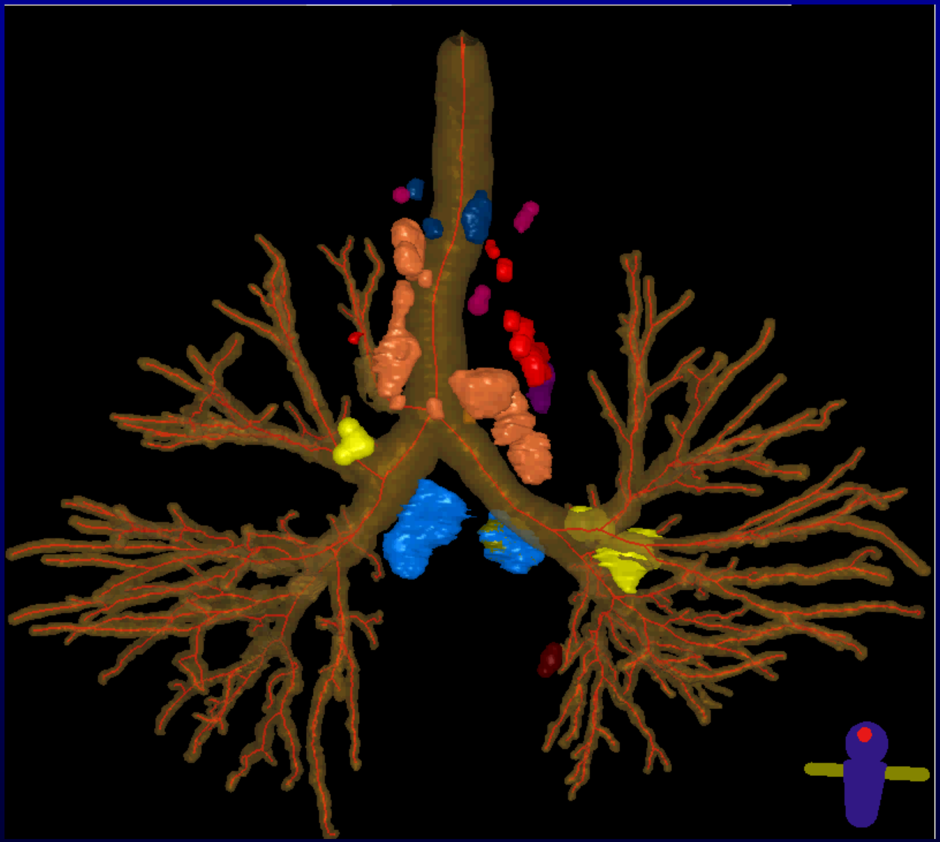
Central-Chest Lymph Nodes in 3D MDCT Image





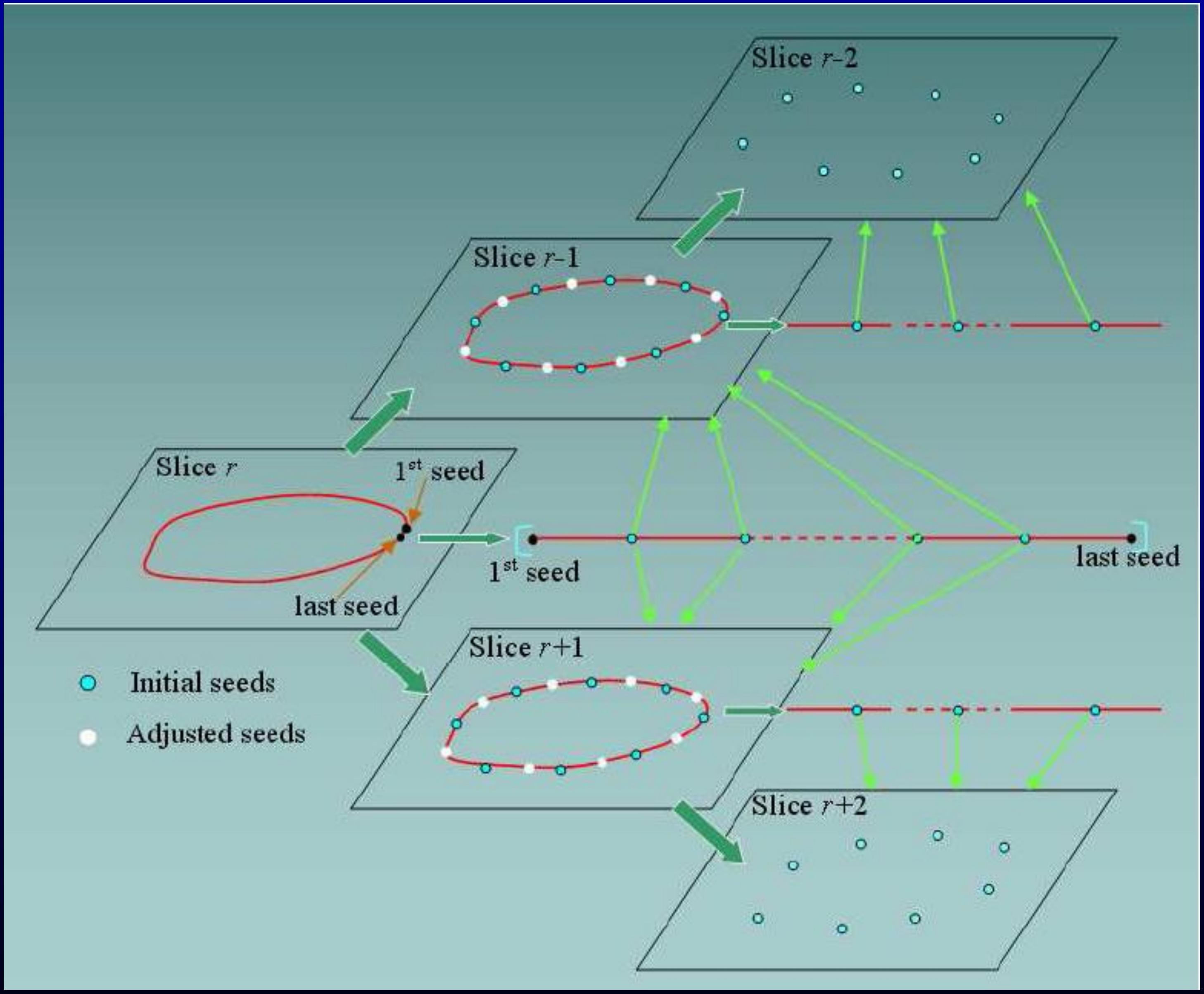
Typical lower paratracheal (M4) lymph nodes

Case IRB20349.3.3



Complete segmentation of central-chest lymph nodes

Single-Section Live Wire



Single-Section Live Wire

Inputs:
i, j — /* Iterators */
n — /* Counter */
r, B_r — /* Reference section index and associated reference boundary */
i_{min}, i_{max} — /* Min and max section indices for running automatic 3D live wire in direction D_{lw} */
$\mathcal{S}_i$ — /* Seed set for section i, defined based on B_{ref} */

Data Structures:
$B_{ref}(i), c_{obj}$ — /* Reference object boundary for section i and its accumulated cost */
$\mathcal{L}_{obj}, N$ — /* List of pixels along $B_{obj}(i)$ and its size. */
T_n, T_{cost} — /* Pixel-number and cost thresholds. By default, $T_n = 16$. */

Output
$B_{obj}(i)$ — /* Final ROI boundary for section i, $i_{min} \le i \le i_{max}$ */

Algorithm:

$i = r + 1$, $k = 1$ — /* Compute 2D boundaries for upper portion of ROI */
$B_{obj} = B_{ref}(i) = B_r$ — /* Use B_r as the reference section for section i */
while $i \le i_{max}$ do
  do
    if $N \le T$ then $n = 4$ — /* Reduce the size of $\mathcal{S}_i$ if N is small enough */
    else $n = 8$
    end
    while $j \le n$ do
      $\mathcal{S}(i) \leftarrow \mathcal{L}_{obj}(j * \frac{N}{n})$ — /* Select pixels evenly along B_{ref} */
    end
    2DLW$(\mathcal{S}_i) \rightarrow B_{obj}(i), c_{obj}$ — /* Connect seeds in $\mathcal{S}_i$ using 2D live wire and output section i's boundary and c_{obj} */
    Update$(\mathcal{L}_{obj}) \rightarrow \mathcal{L}_{obj}$ — /* Add boundary pixels to $\mathcal{L}_{obj}$ starting from the midpoint from the segment between $\mathcal{S}_i(1)$ and $\mathcal{S}_i(1)$ on B_{obj} */
    if $k == 1$ then — /* Record the boundary cost as a reference for next iteration */
      $\tilde{c}_{obj} = c_{obj}$
    end
    $k = k + 1$
  while $|c_{obj} - \tilde{c}_{obj}| > \frac{\tilde{c}_{obj}}{100}$
  if Stopcheck() $\rightarrow$ FALSE then — /* Process next section unless the boundary cost is too small or stopping constraints are met. */
    $i = i + 1$ and $B_{ref}(i) = B_{obj}$
  end
end
$i = r - 1$, $k = 1$ — /* Compute 2D boundaries for lower portion of ROI */
$B_{obj} = B_{ref}(i) = B_r$ — /* Use B_r as the reference section for section i */
while $i \ge i_{min}$ do
  do
    if $N \le T$ then $n = 4$ — /* Reduce the size of $\mathcal{S}_i$ if N is small enough */
      else $n = 4$
    end
    while $j \le n$ do
      $\mathcal{S}(i) \leftarrow \mathcal{L}_{obj}(j * \frac{N}{n})$ — /* Select pixels evenly along B_{ref} */
    end
    2DLW$(\mathcal{S}_i) \rightarrow B_{obj}(i), c_{obj}$ — /* Connect seeds in $\mathcal{S}_i$ using 2D live wire and output section i's boundary and c_{obj} */
    Update$(\mathcal{L}_{obj}) \rightarrow \mathcal{L}_{obj}$ — /* Add boundary pixels to $\mathcal{L}_{obj}$ starting from the mid point from the segment between $\mathcal{S}_i(1)$ and $\mathcal{S}_i(1)$ on B_{obj} */
    if $k == 1$ then
      $\tilde{c}_{obj} = c_{obj}$ — /* Record the boundary cost as a reference for next iteration */
    end
    $k = k + 1$
  while $|c_{obj} - \tilde{c}_{obj}| > \frac{\tilde{c}_{obj}}{100}$
  if Stopcheck() $\rightarrow$ FALSE then — /* Process next section unless the boundary cost is too small or stopping constraints are met. */
    $i = i - 1$ and $B_{ref}(i) = B_{obj}$
  end
end

- Adjust working area adaptively
- Refine seed set iteratively
- Terminate iterations when

$$|c_{obj} - \tilde{c}_{obj}| < \frac{\tilde{c}_{obj}}{100};$$

- Terminate 3D process when
  - Section limits reached
  - Boundary costs vary greatly

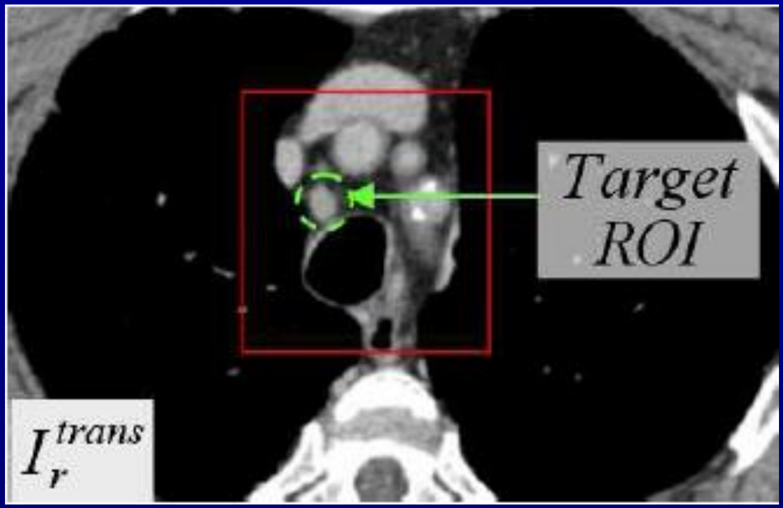
$$|c_{obj} - c_r| > \frac{c_r}{10}.$$

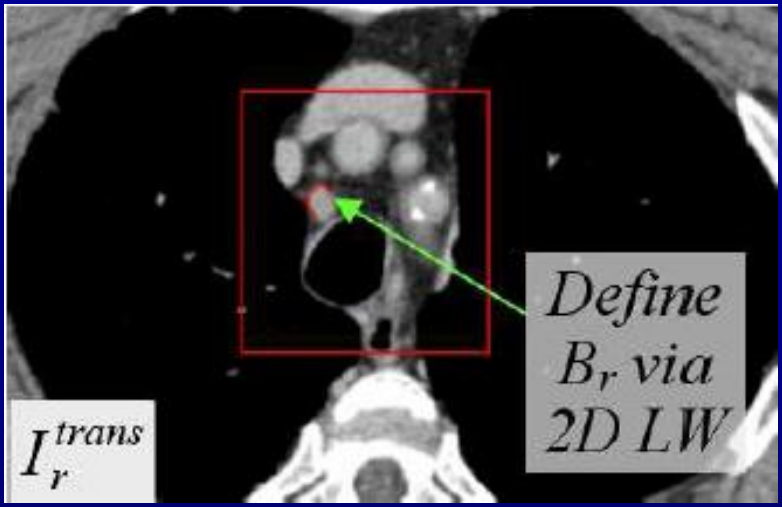
  - Boundary is too small
  - Segmented region is too small
  - Intensity distribution varies greatly

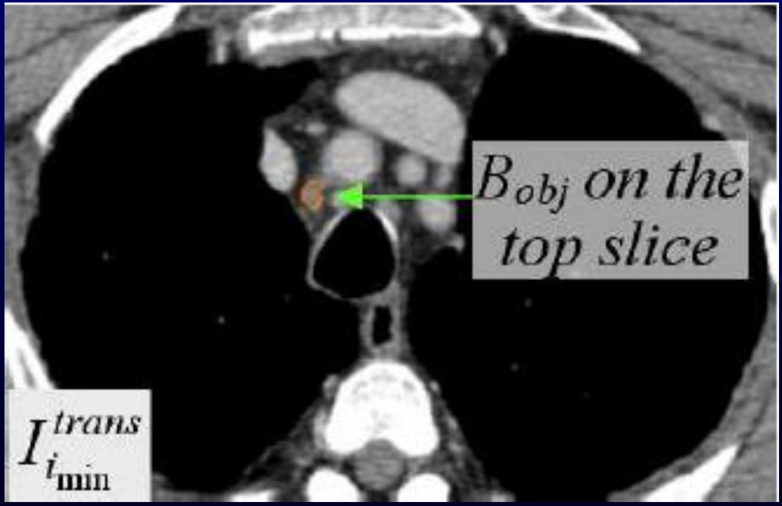
$$N_i^{out} > 0.5 \cdot N_i^{obj}$$

K. Lu, PhD Dissertation 2010

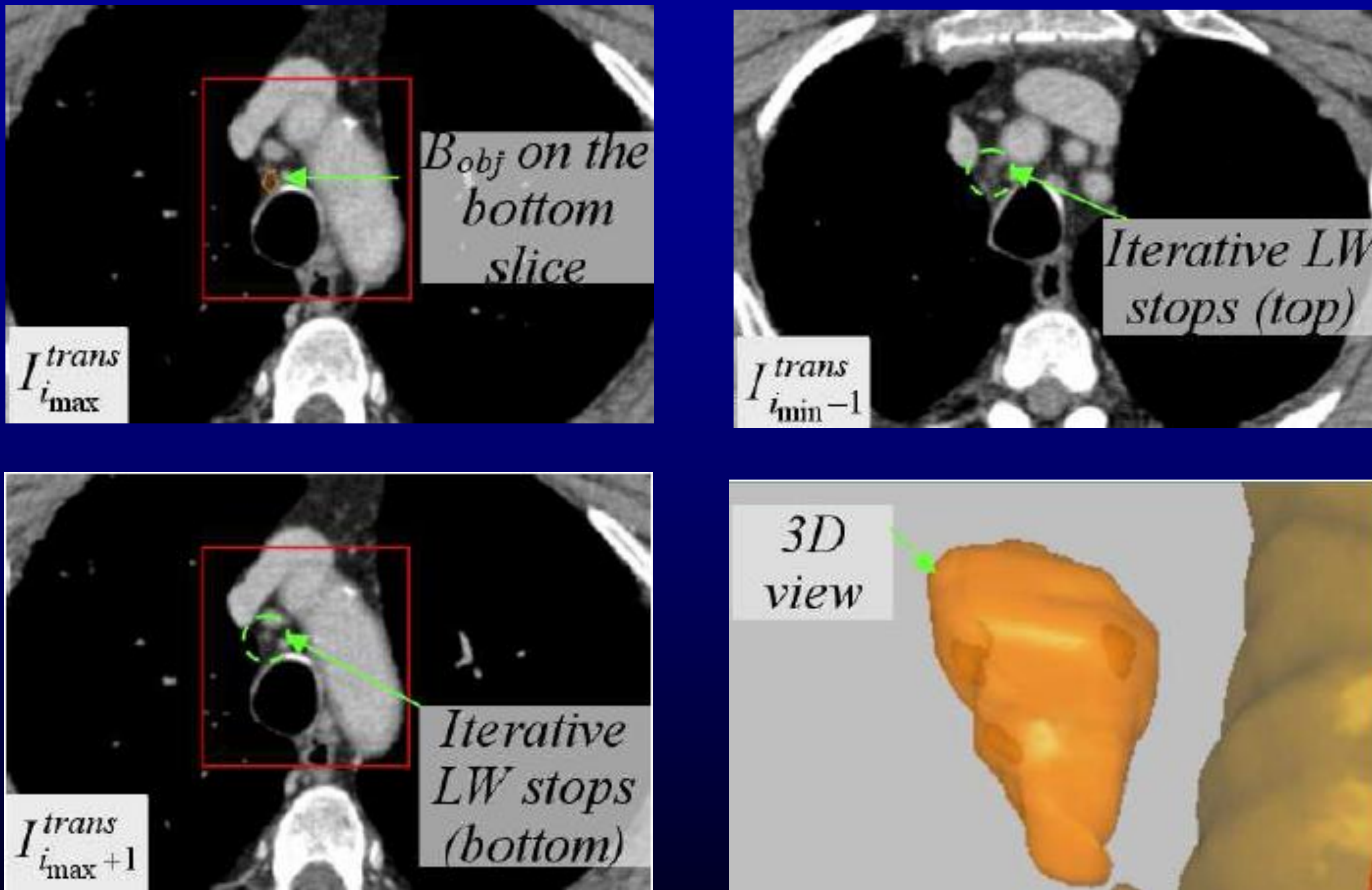
Single-Section Live Wire



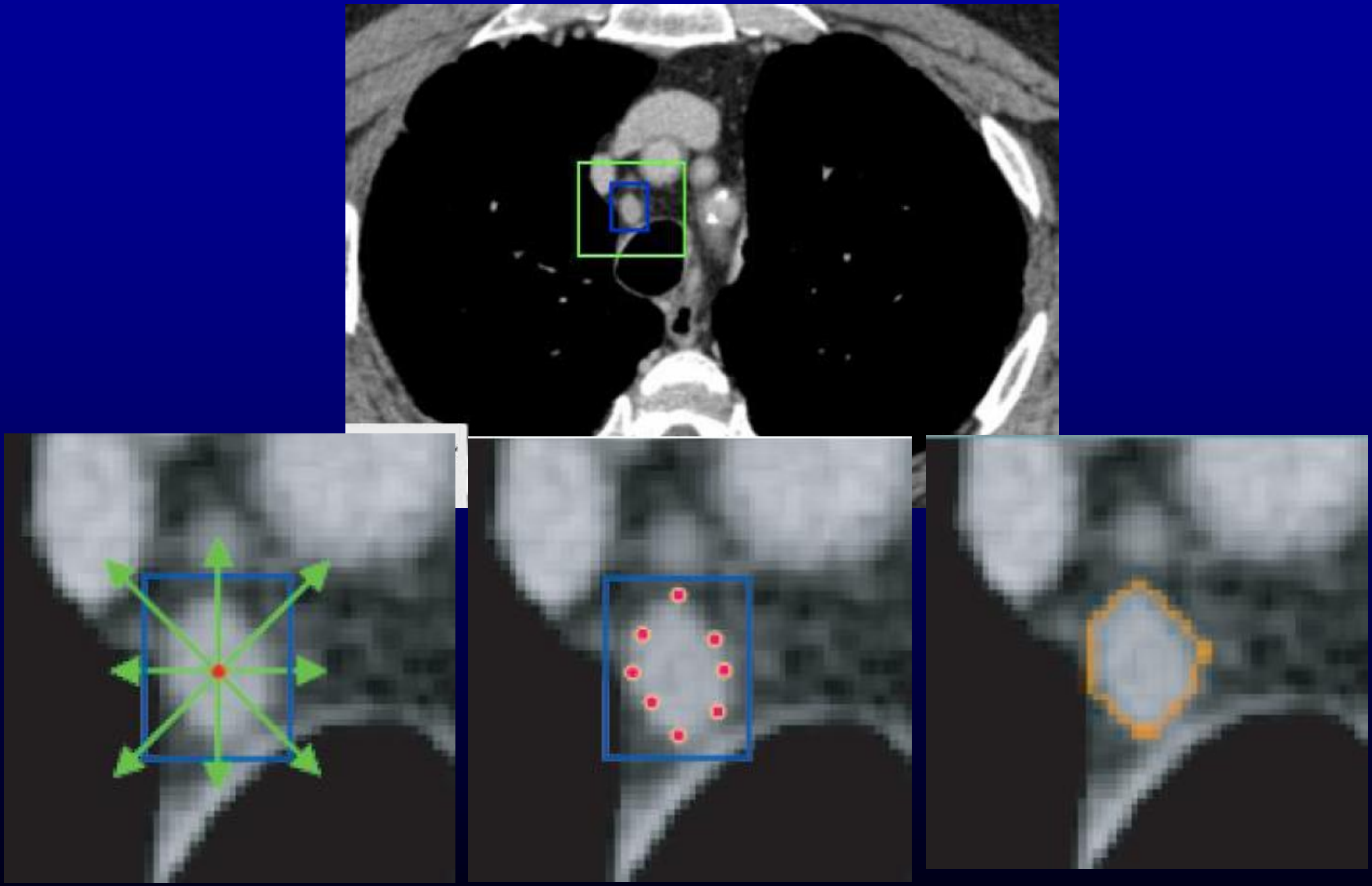




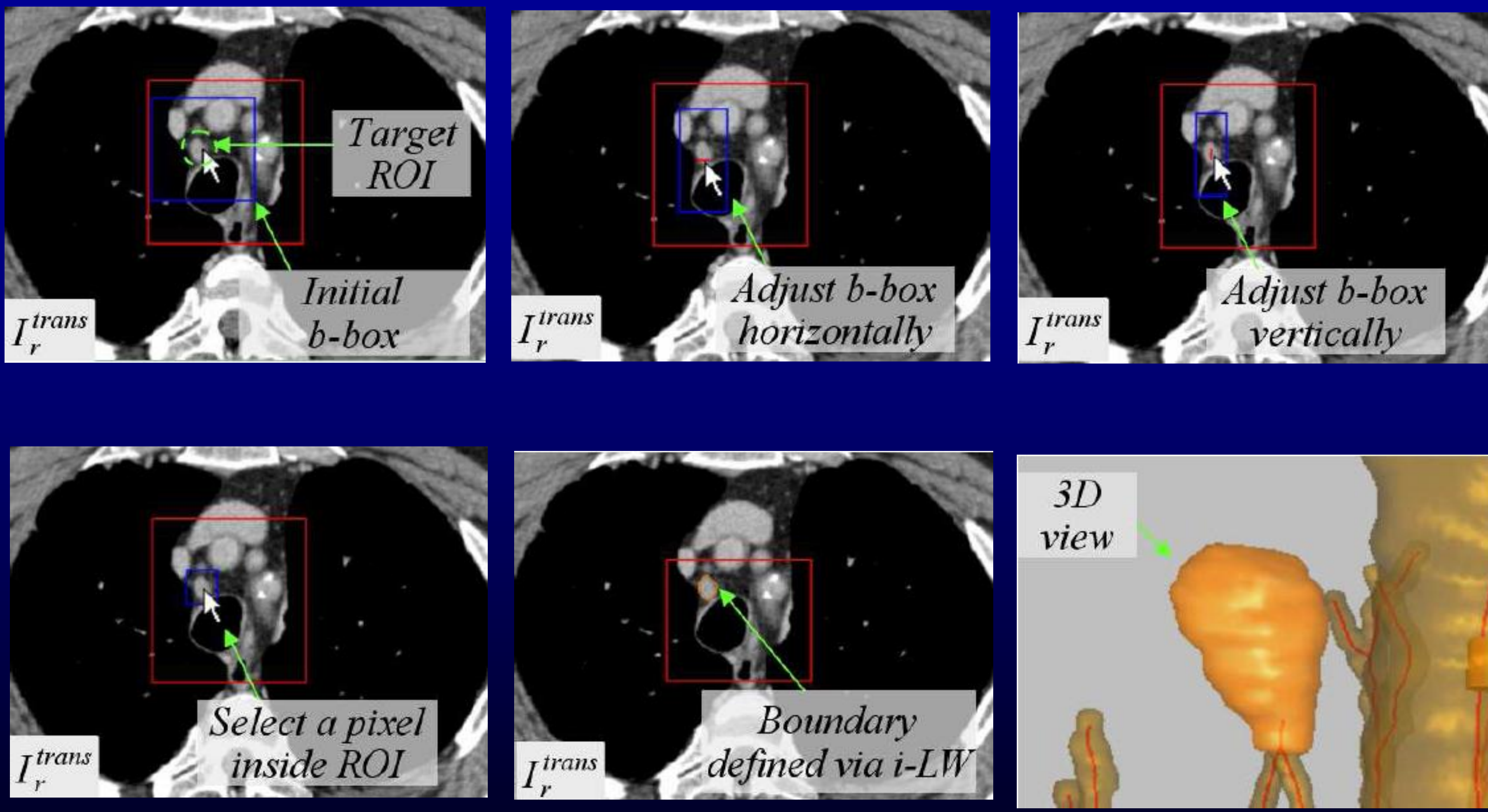
Single-Section Live Wire



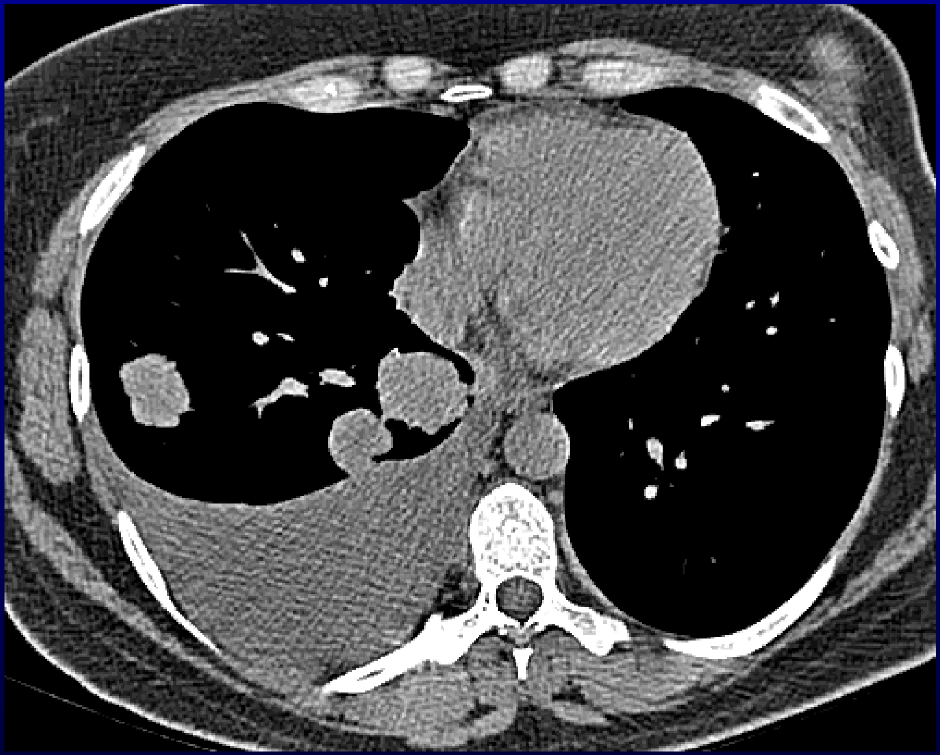
Single-Click Live Wire



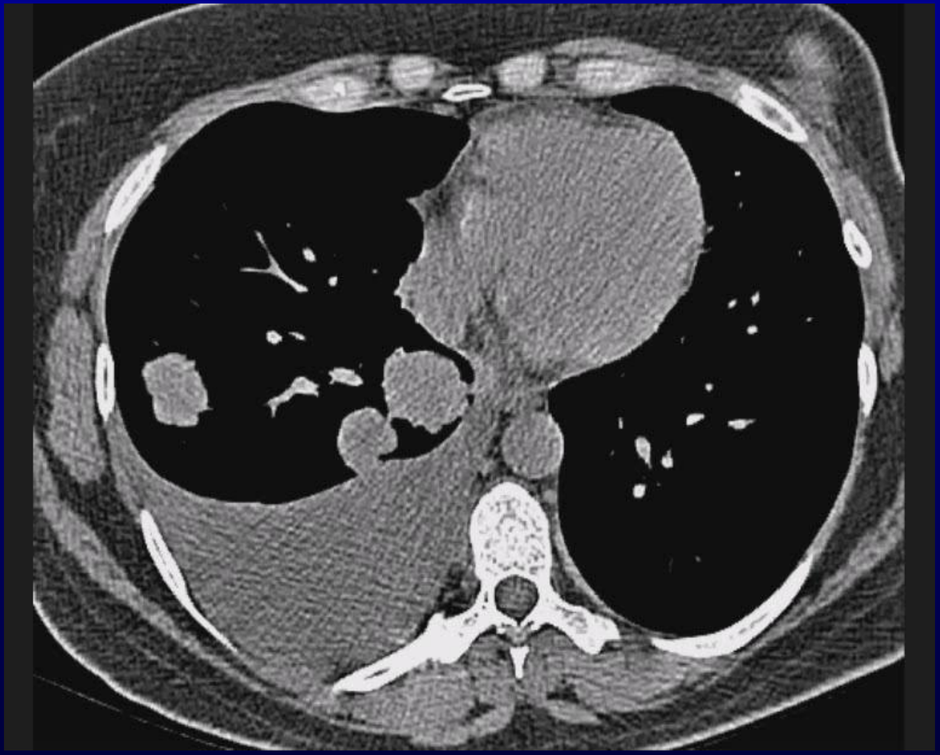
Single-Click Live Wire



Single-Section and Single-Click LW



Single-Section



Single-Click

Lu, PhD Dissertation 2010 and K. Lu and W.E. Higgins *Computer in Biology and Medicine* (in submission)

Performance Evaluation

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MDCT Data:

Case	Voxel Dim.(mm)			# of slice in scan	Contrast-Enhanced	Observer $\mathcal{O}$	Scan ID
	ΔX	ΔY	ΔZ				
21405_64	0.64	0.64	0.5	702	N	$\mathcal{O}_1$	1
20349_3_3	0.72	0.72	0.5	578	N	$\mathcal{O}_1$	2
20349_3_15	0.68	0.68	0.5	757	N	$\mathcal{O}_1, \mathcal{O}_2$	3
20349_3_27	0.67	0.67	0.5	752	Y	$\mathcal{O}_1$	4
21405_67	0.69	0.69	0.5	716	N	$\mathcal{O}_1, \mathcal{O}_2$	5

Computer - Dell Precision 650 workstation:

- Dual Intel Xeon 3.2GHz, 3GB RAM, Windows XP

Results

Method	Single-Section	Single-Click
Number of Nodes	50	
Success Rate	90 % (45/50)	80% (40/50)
Accuracy	81±7%	79±8%
Inter-Trial Reproducibility	88±7%	86±9%
Processing Time	16±4s	20±5s

Segmented Nodes:

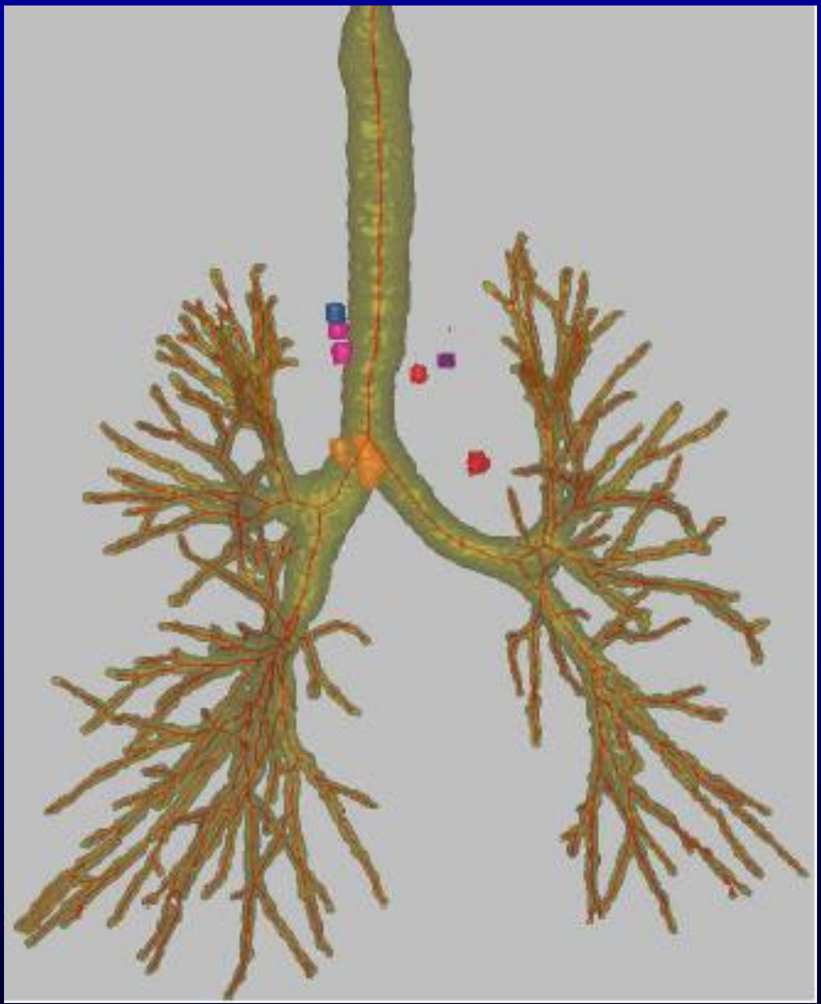
- Short-Axis Length: 5.8±1.5 mm
- Long-Axis Length: 11±4.0 mm
- Volume: 256±210 mm^3
- Number of Voxels: 1089±861

Comparison of Two Observers

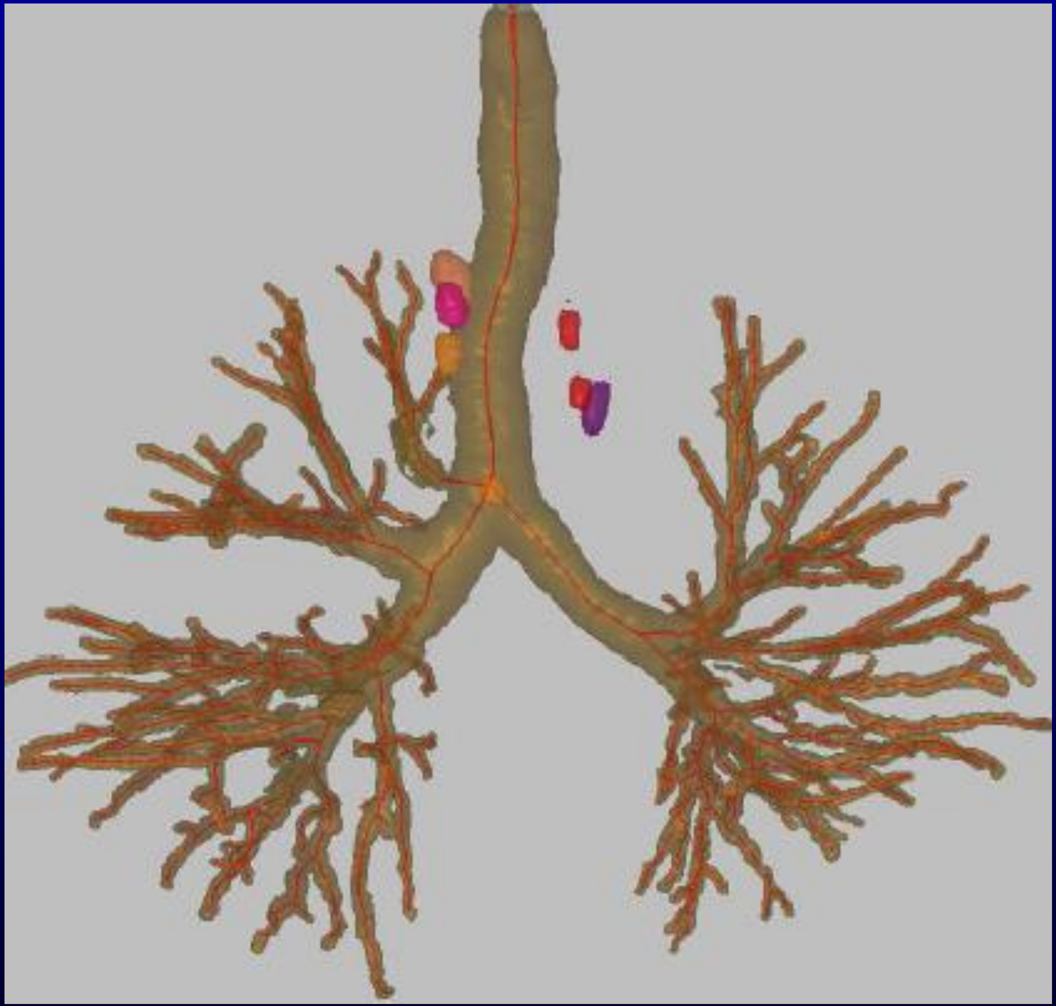
	20349.3.15		21405.67	
	O_1	O_2	O_1	O_2
Accuracy	83%	80%	78%	79%
Reproducibility	87%	88%	89%	85%
Processing Time	16s	20s	19s	22s

→ Operator Independent

Example Lymph Node Segmentations



21405.64



20349.3.3

* Segmentable nodes: both observers and both methods

Summary

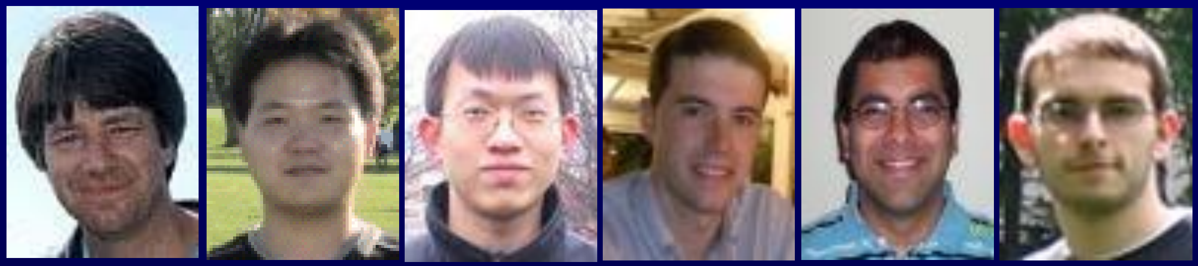
Single-Section and Single-Click Live Wire

- Reduce human interaction
- Efficient and reliable
- Operator independent
- Can handle typical lymph nodes and other ROIs
  - 90%   Single-Section
  - 80%   Single-Click

Acknowledgments

- NIH NCI grant #R01-CA074325
- Pinyo Taeprasartsit - experiment participant

The Multidimensional Imaging Processing Lab at Penn State



Thanks!

Single-Section and Single-Click LW Evaluation

PENNSTATE 1855

Lymph node #: 50

Succ. Seg. : M_1-45 (90%) M_2-40 (80%)

Accuracy: >80%

Inter-trial Reprod.: >85%

Lymph Node	Processing Time (Second)				Axis Length (mm)		Volume	# of Voxel
	$\mathcal{M}_1, \mathcal{E}_1$	$\mathcal{M}_1, \mathcal{E}_2$	$\mathcal{M}_2, \mathcal{E}_1$	$\mathcal{M}_2, \mathcal{E}_2$	Short	Long	(mm^3)	in Lymph Node
μ	15	17	19	20	5.8	10.5	255.6	1089
σ	3.9	4.5	5.1	5.1	1.5	4.0	209.6	861.1
Min	7	9	7	9	3.7	5.5	63	273
Max	28	30	29	35	10.7	20.1	970	3796

	$a(\mathcal{M}_1, \mathcal{E}_1)$	$a(\mathcal{M}_1, \mathcal{E}_2)$	$r(\mathcal{M}_1, \mathcal{E}_1, \mathcal{E}_2)$	$a(\mathcal{M}_2, \mathcal{E}_1)$	$a(\mathcal{M}_2, \mathcal{E}_2)$	$r(\mathcal{M}_2, \mathcal{E}_1, \mathcal{E}_2)$
μ	81	81	88	79	79	86
σ	6.8	6.5	6.7	7.6	8.2	8.5
Min	62	69	66	63	54	60
Max	95	97	98	93	92	99

M_1, M_2:Single-section and single-click LW; ε_1, ε_2: Trials; a(M_i, ε_j): accuracy; r(M_i, ε_j, ε_k): reproducibility

Single-Section and Single-Click LW Evaluation

	Processing Time (Second)			
	$\mathcal{M}_1, \mathcal{E}_1$	$\mathcal{M}_1, \mathcal{E}_2$	$\mathcal{M}_2, \mathcal{E}_1$	$\mathcal{M}_2, \mathcal{E}_2$
$\mu_{\text{Scan3},\mathcal{O}_1}$	15	14	17	19
$\mu_{\text{Scan3},\mathcal{O}_2}$	16	19	20	21
$\mu_{\text{Scan5},\mathcal{O}_1}$	19	20	19	20
$\mu_{\text{Scan5},\mathcal{O}_2}$	15	18	26	27
Overall	15	17	19	20

	Accuracy and Reproducibility (%)					
	$a(\mathcal{M}_1,\mathcal{E}_1)$	$a(\mathcal{M}_1,\mathcal{E}_2)$	$r(\mathcal{M}_1,\mathcal{E}_1,\mathcal{E}_2)$	$a(\mathcal{M}_2,\mathcal{E}_1)$	$a(\mathcal{M}_2,\mathcal{E}_2)$	$r(\mathcal{M}_2,\mathcal{E}_1,\mathcal{E}_2)$
$\mu_{\text{Scan3},\mathcal{O}_1}$	84.3	85.5	88.5	81.2	80.5	85.6
$\mu_{\text{Scan3},\mathcal{O}_2}$	78.3	78.5	82.9	79.5	78.2	86.2
$\mu_{\text{Scan5},\mathcal{O}_1}$	78.8	79.1	91.8	76.3	77.1	85.6
$\mu_{\text{Scan5},\mathcal{O}_2}$	80.9	81.1	89.8	77.1	80.1	85.2
Overall	80.7	81.2	88.3	79.2	79.3	85.6

M_1, M_2:Single-section and single-click LW; ε_1, ε_2: Trials; a(M_i, ε_j): accuracy; r(M_i, ε_j, ε_k): reproducibility