Improved 3D Live-Wire Method with Application to 3D CT Chest Image Analysis

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Motivation

- ROI segmentation is important, but difficult
- Manual slice tracing always works
  --but it is time consuming
- Automated segmentation avoids user intervention
  --but it is strongly application dependent
- Semiautomatic methods allow for full user control while reducing human involvement

Prior Work

2D Live Wire:

- Mortensen *et al.* (*IEEE Computers in Cardiology 1992*)
- Mortensen *et al.* (*Graphical Models and Medical Imaging 1998*)
- Falcão *et al.* (*SPIE Medical Imaging 1996*)
- Falcão *et al.* (*Graphical Models and Medical Imaging 1998*)

3D Live Wire:

- Falcão *et al.* (*Medical Image Analysis 2000*)
- Schenk *et al.* (*MICCAI 2000*)
- Salah *et al.* (*Workshop Bildverarbeitung in der Medizin 2005*)
- Hamarneh *et al.* (*SPIE Medical Imaging 2005*)
- König *et al.* (*SPIE Medical Imaging 2005)*

Cost Function

Image Feature	Cost
Laplacian Zero-Crossing	f_Z
Gradient Magnitude	f_G
Gradient Direction	f_D
Secondary Gradient Direction	f_{Df}

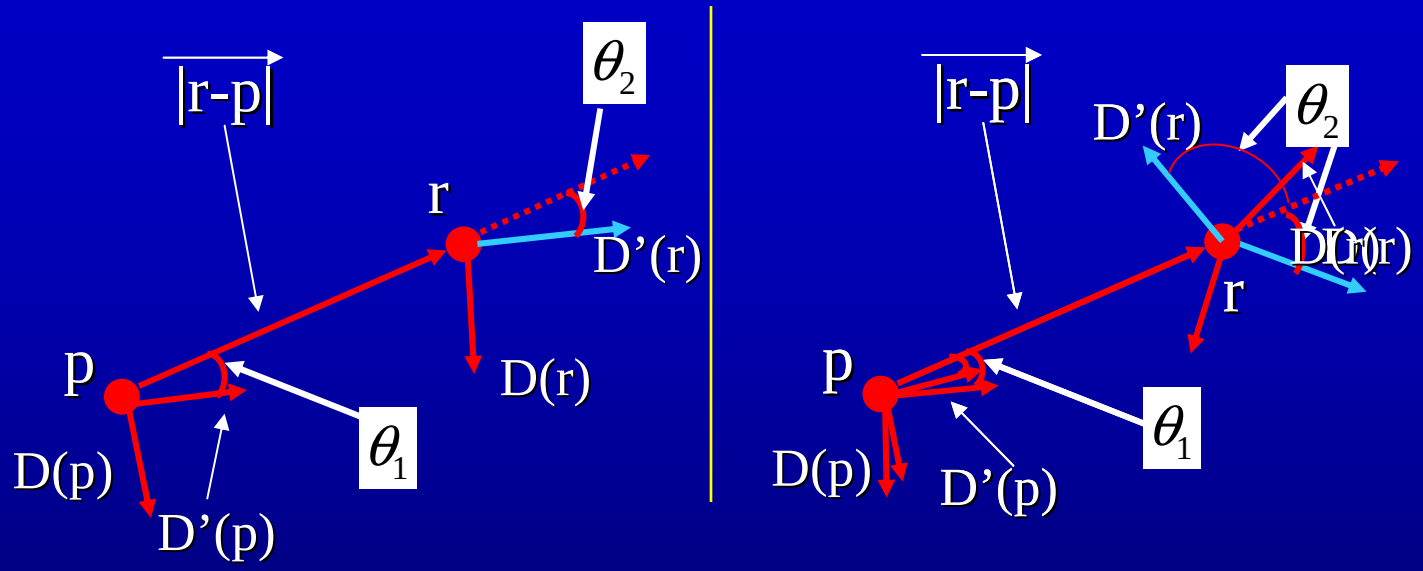
New Cost!

Cost Function:

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

* Three components were derived from *Mortensen 98*

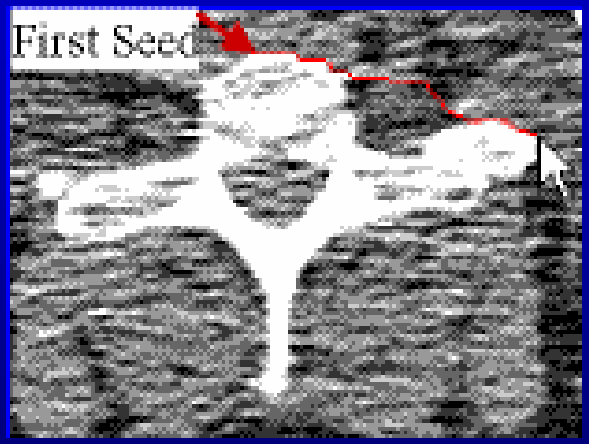
Gradient Direction



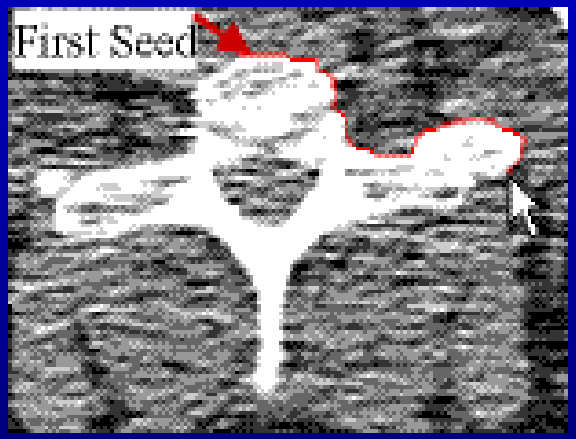
Gradient Direction: $$f_D(p,q) = \frac{2}{3\pi}(\theta_1 + \theta_2)$$

New Gradient Direction: $$f_{Df}(p,q) = \frac{1}{\pi}(|\theta_1 - \theta_2|)$$

Gradient Direction



Live Wire using old cost



Live wire with new cost f_{Df}

2D Graph-Search Algorithm

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Input:

s	/* Seed pixel */
$l(p, r)$	/* Local cost function for link between "p" and "r" */

Data Structures:

L	/* List of active pixels sorted by total cost(initially empty) */
$N(p)$	/* Neighborhood set of "p"(contains 8 neighbors of pixel "p") */
$e(p)$	/* Boolean function indicating if "p" has been processed */
$g(p)$	/* Total cost function from seed point to pixel "p" */

Output

pt	/* Pointers from each pixel indicating the minimum cost path */

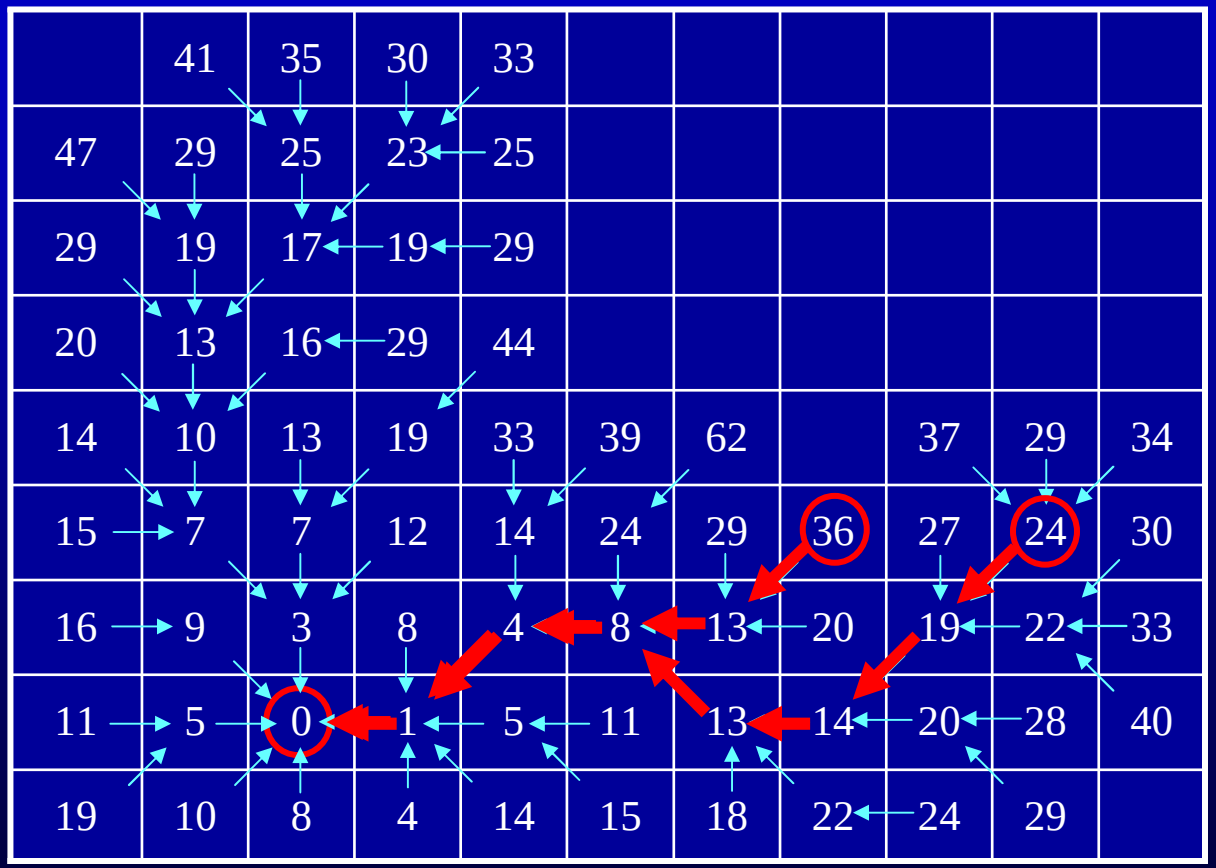
Algorithm:

```
1.  g(s) ← 0; L ← s;                                   /* Initialize active list with zero cost seed pixel */
2.  While L ≠ Φ do begin                               /* While still points to expand */
3.      pt ← min(L);                                   /* remove min cost pixel "p" from active list */
4.      e(p) ← TRUE;                                   /* Mark "p" as processed */
5.
6.      for each r ∈ N(p) such that ¬e(r) do begin
7.          gtemp ← g(p) + l(p, r);                    /* Compute total cost to neighbor */
8.
9.          if r ∈ L and gtemp < g(r) then
10.             g(r) ← gtemp; pt(r) ← p;               /* Update total cost and set back pointer */
11.         if r ∉ L then begin                        /* If neighbor not in list, assign neighbor's */
12.             g(r) ← gtemp; pt(r) ← p; L ← r;         /* total cost, set back pointer and */
13.         end                                        /* place on(or return to) active list */
14.     end
15. end
```

2D graph-search algorithm for the live-wire method

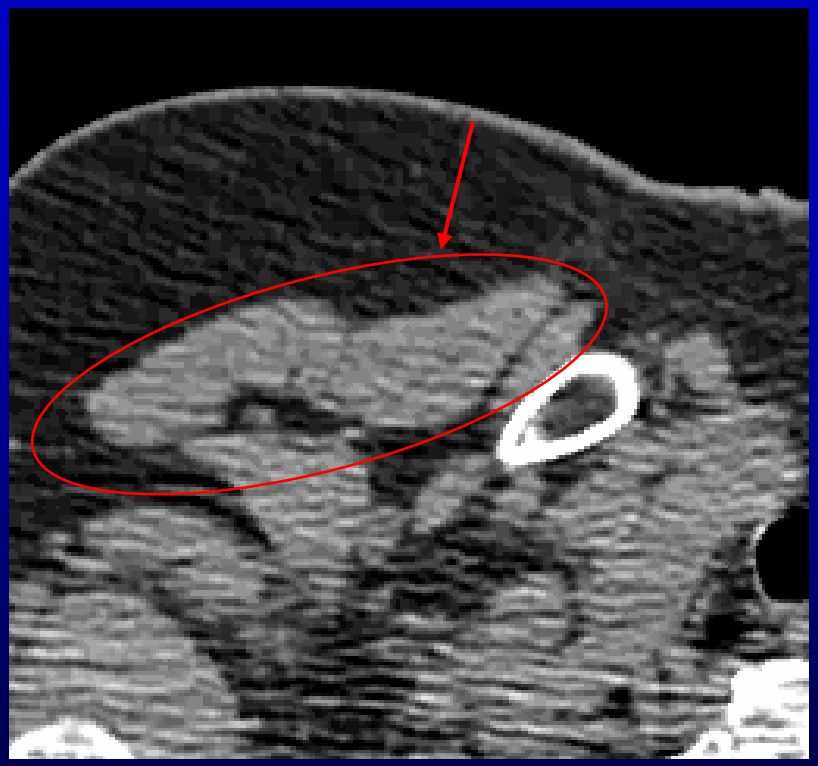
(Modified based on Mortensen 98)

2D Live Wire Introduction



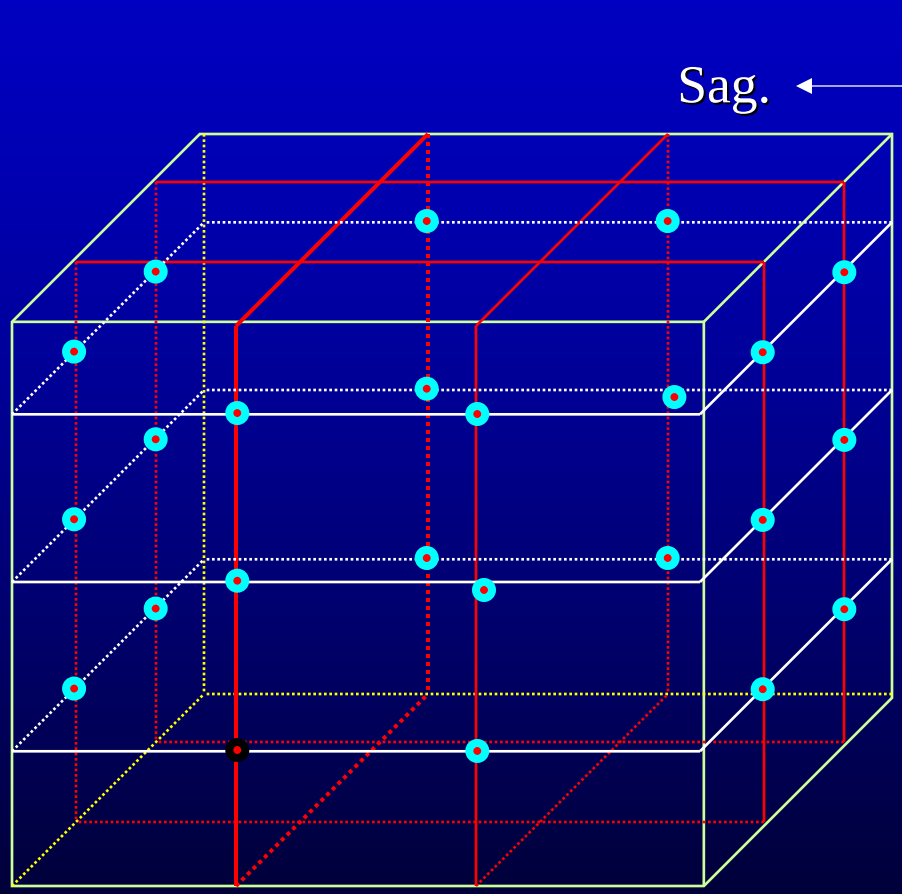
* Derived from *Mortensen 98*

2D Live Wire Example

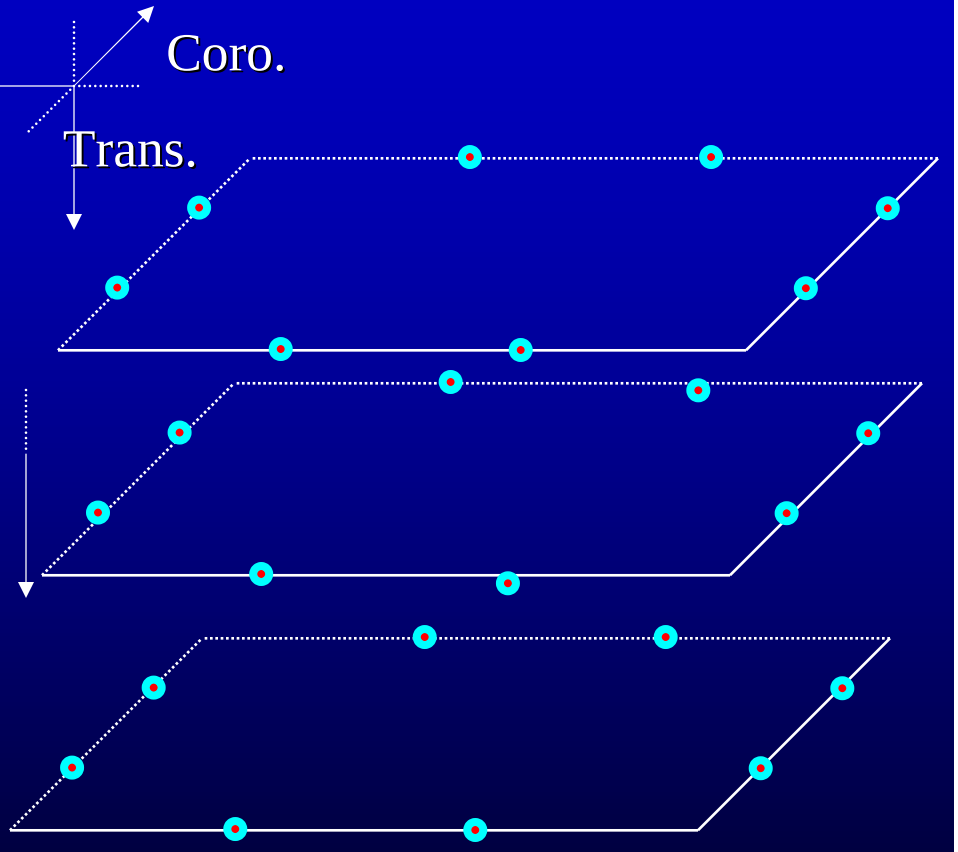


Segment ROI using 2D Live Wire

3D Live Wire

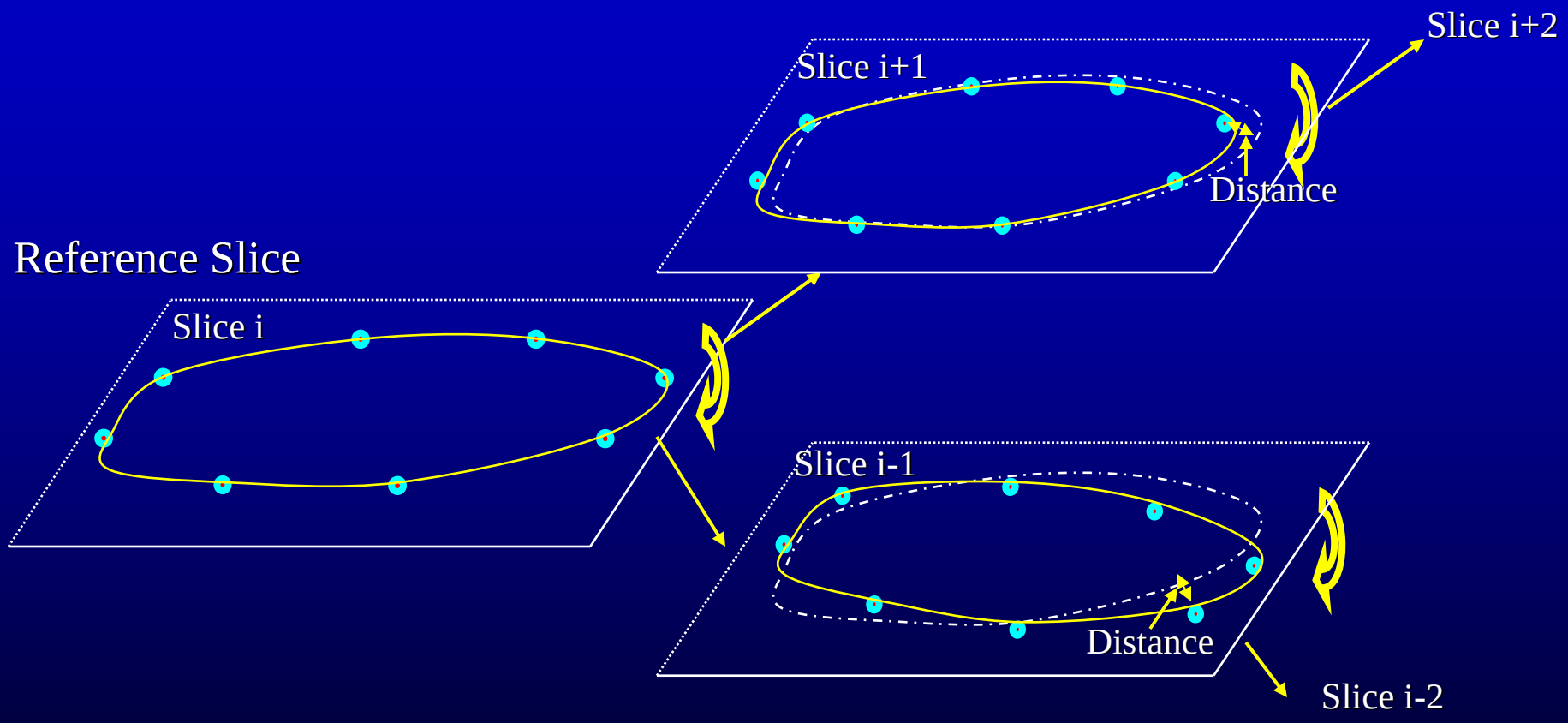


2D live wire on 3 Sagittal slices



Generate 2D live wire on every slice in Trans. direction

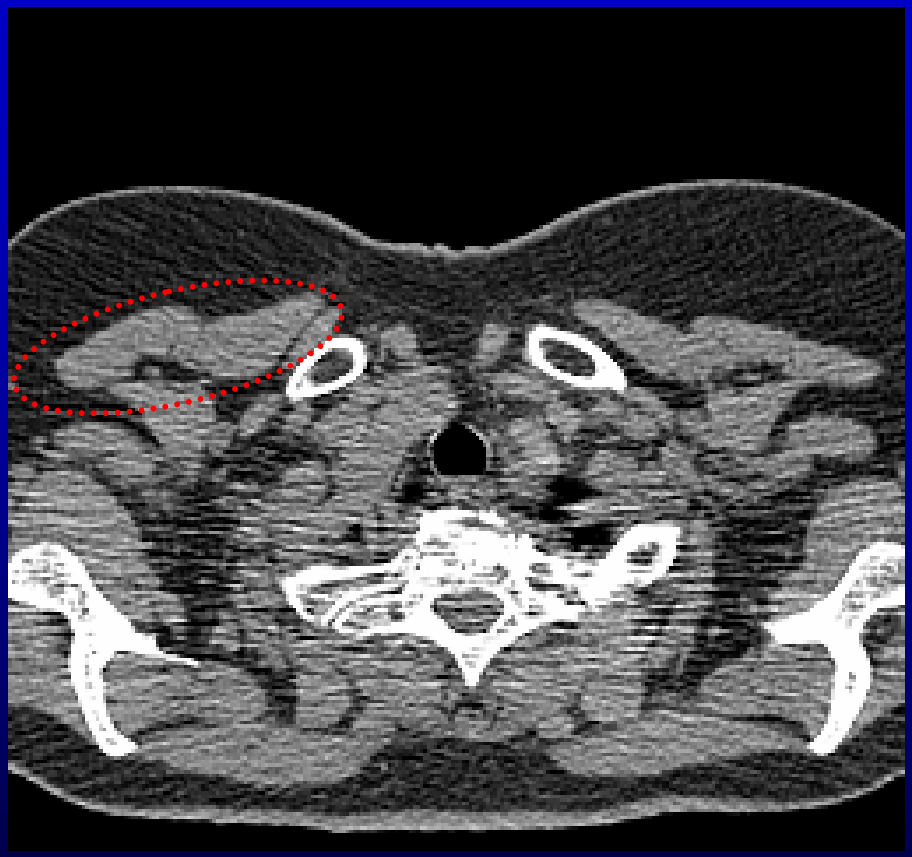
3D Live Wire



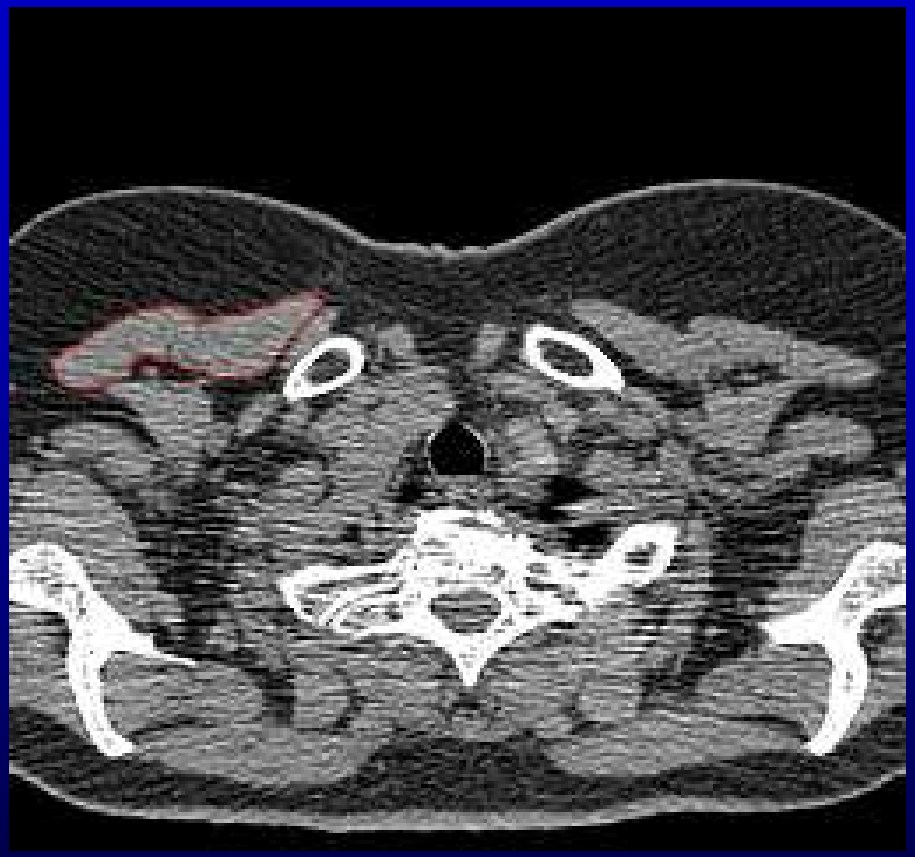
2D live wire on ref. slice

Propagation of live wire

2D Results



2D ROI



Segmentation result

* Three ROIs used in tests

2D Live Wire Evaluation

Three Factors: (derived from *Falcão98, 00*)

- Efficiency -- Processing time to segment an ROI
- Repeatability --

$$RP_{R2\,jO_mO_kE_nE_l} = 1 - \frac{\left|(B_{R2\,jO_mE_n}) \oplus (B_{R2\,jO_kE_l})\right|}{\left|B_{R2\,jO_mE_n}\right| + \left|B_{R2\,jO_kE_l}\right|}$$

- Accuracy --

$$AC_{R2\,jO_mE_n} = 1 - \frac{\left|(B_{R2\,jO_mE_n}) \oplus (G_{2\,j})\right|}{\left|B_{R2\,jO_mE_n}\right| + \left|G_{2\,j}\right|}$$

2D Live Wire Evaluation

	R_{21}				R_{22}				R_{23}			
	E_1,E_2	E_1,E_3	E_2,E_3	Aver.	E_1,E_2	E_1,E_3	E_2,E_3	Aver.	E_1,E_2	E_1,E_3	E_2,E_3	Aver.
O_1	98.25	97.67	98.01	97.98	99.04	99.55	99.24	99.28	97.86	97.72	98.30	97.96
O_2	99.03	98.82	98.29	98.71	99.27	99.53	99.41	99.40	98.57	98.72	99.34	98.88
O_3	96.84	97.92	97.95	97.57	98.31	98.63	98.99	98.64	99.17	98.51	98.24	98.64
O_4	97.84	97.67	98.19	97.90	96.92	97.37	97.65	97.31	98.09	98.32	98.25	98.22
O_5	97.76	97.78	98.45	98.00	98.58	98.97	98.45	98.67	98.31	97.94	97.32	97.86

Segmentation Reproducibilities

	O_m,O_k $(m \neq k)$										Aver.
	O_1,O_2	O_1,O_3	O_1,O_4	O_1,O_5	O_2,O_3	O_2,O_4	O_2,O_5	O_3,O_4	O_3,O_5	O_4,O_5	
R_{21}	98.02	97.60	97.92	97.79	98.08	97.66	98.32	97.05	98.10	97.73	97.86
R_{22}	99.30	99.03	98.02	98.86	99.01	98.14	99.04	97.74	98.56	97.89	98.45
R_{23}	97.91	98.22	97.96	97.79	97.77	97.81	98.12	98.34	97.87	97.63	98.02

Inter-Operator Segmentation Reproducibilities

2D Live Wire Evaluation

Summary:

	R_{21}	R_{22}	R_{23}
Efficiency	23.4s	13s	18.6s
Repeatability	97.86%	98.57%	98%
Accuracy	98.38%	98.76%	97.68%

Time ratio between manual tracing and 2D live wire:

	R_{21}	R_{22}	R_{23}
2D Live Wire	23.4s	13s	18.6s
Manual Slice Tracing	310s	192s	278s
Time Ratio	13.25	14.77	14.95

* Efficiency comparison based on accuracy higher than 95%

3D Results

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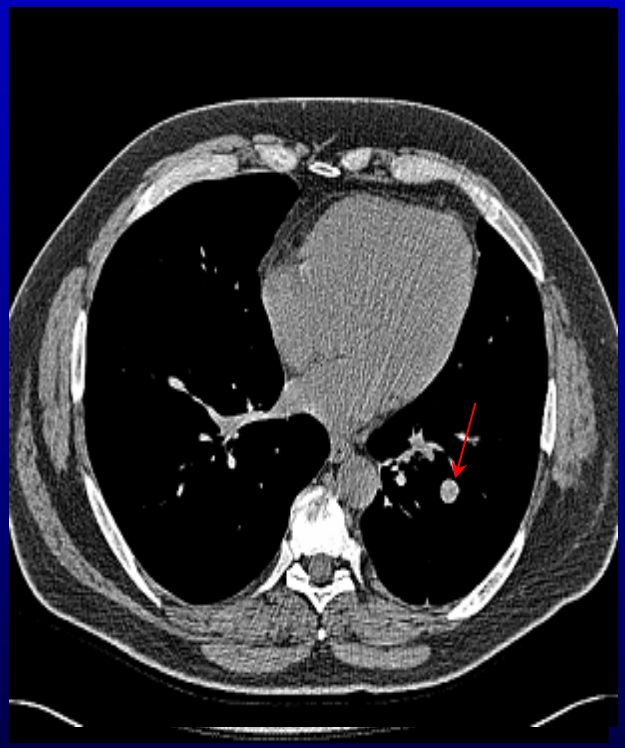
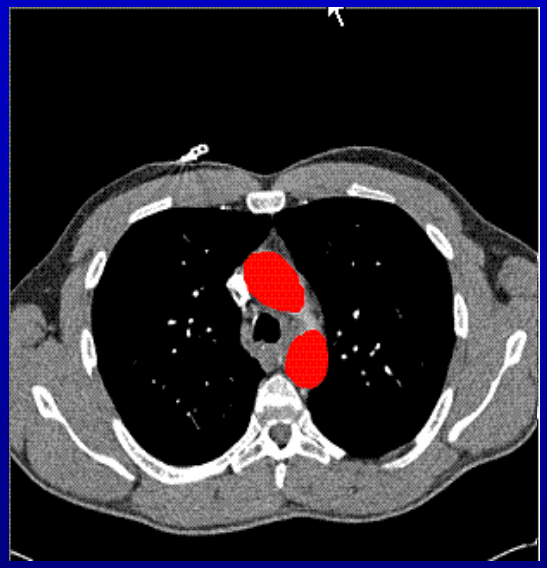
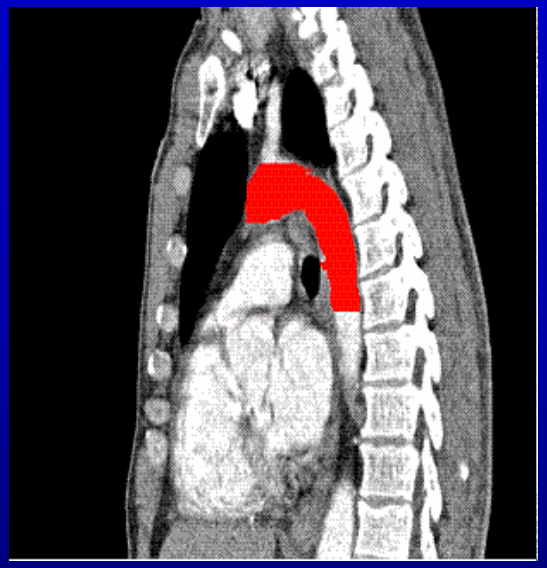
ROI R_{33}

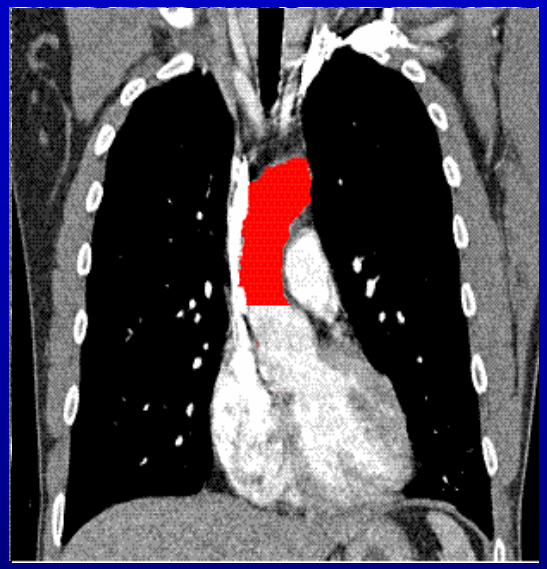


* Three 3D ROIs used in tests

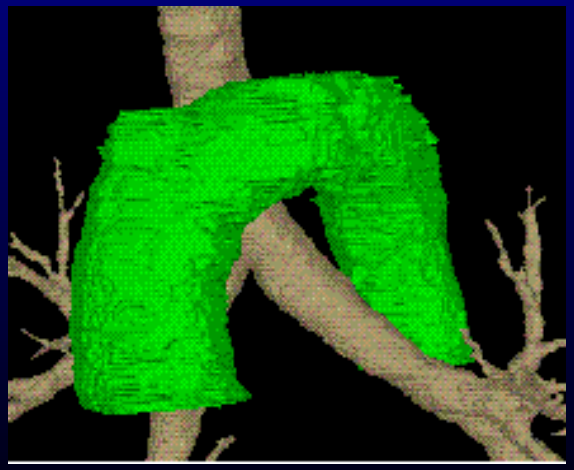
3D Results







R_{33}



3D Segmentation Results

3D Live Wire Evaluation

Summary:

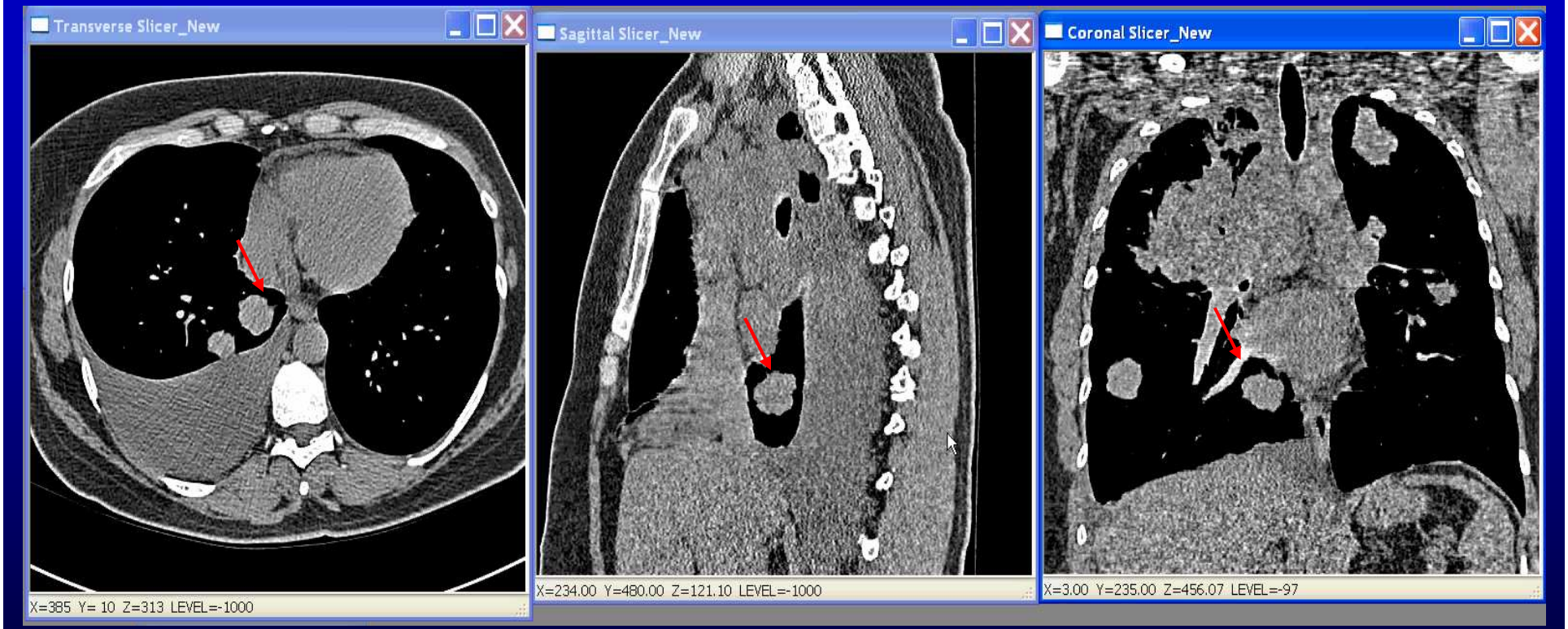
	R_{31}	R_{32}	R_{33}
Efficiency	34s	95s	8m9s
Repeatability	97.64%	97.88%	96.87%
Accuracy	98.08%	98.12%	97.16%

Time ratio between 3D live wire and 2D live wire / manual slice tracing:

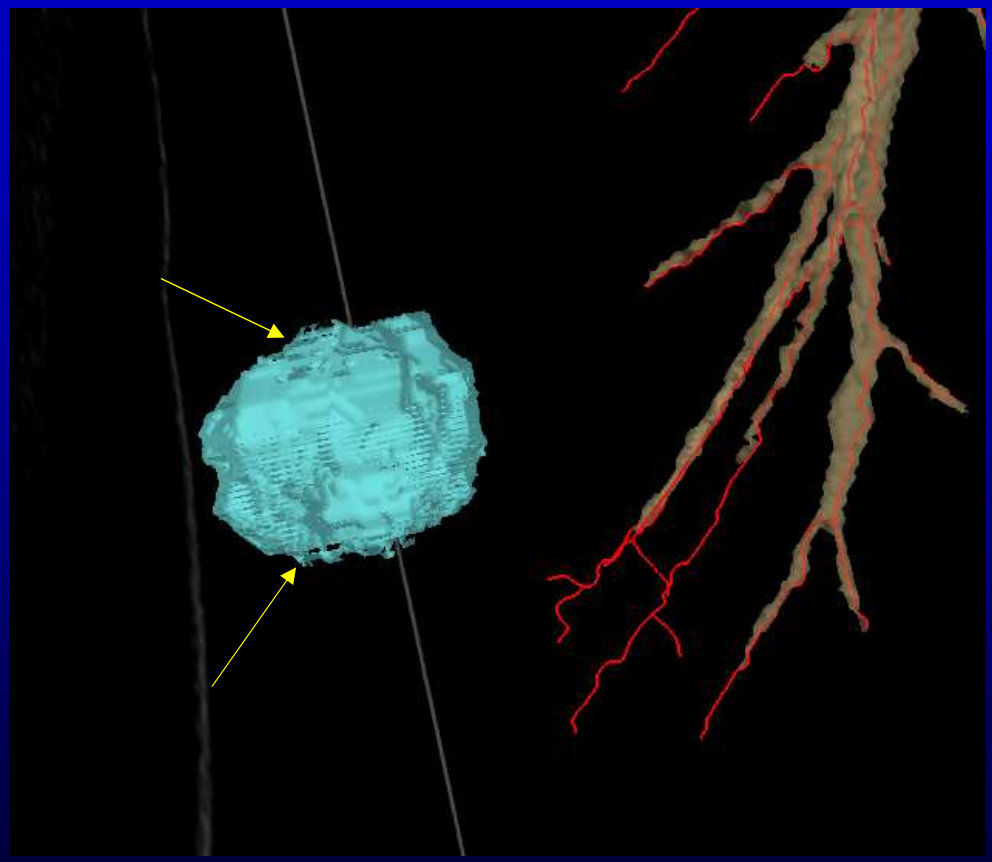
	R_{21}	R_{22}	R_{23}
2D LW vs. 3D LW	7.2	8.4	9.9
Manual vs. 3D LW	28	56	41

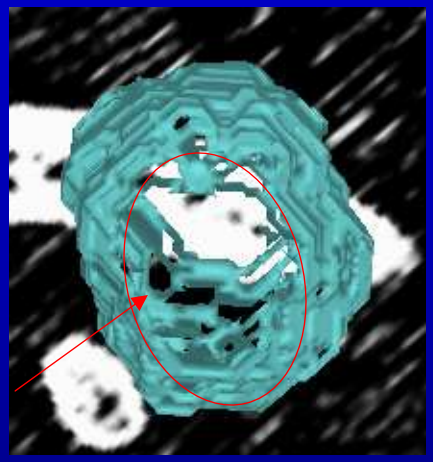
* Efficiency comparison based on accuracy higher than 90%

3D Live Wire Example

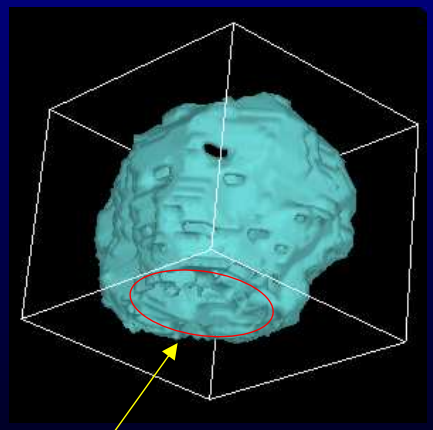


Comments on 3D Live Wire





Top view



Bottom view

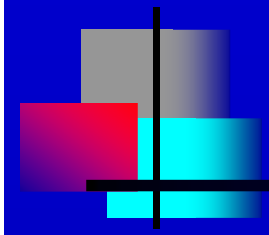
Summary

2D Live Wire:

- Introduce new gradient direction cost
- 2D live wire works very well

3D Live Wire:

- Reliable and efficient



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Thanks!