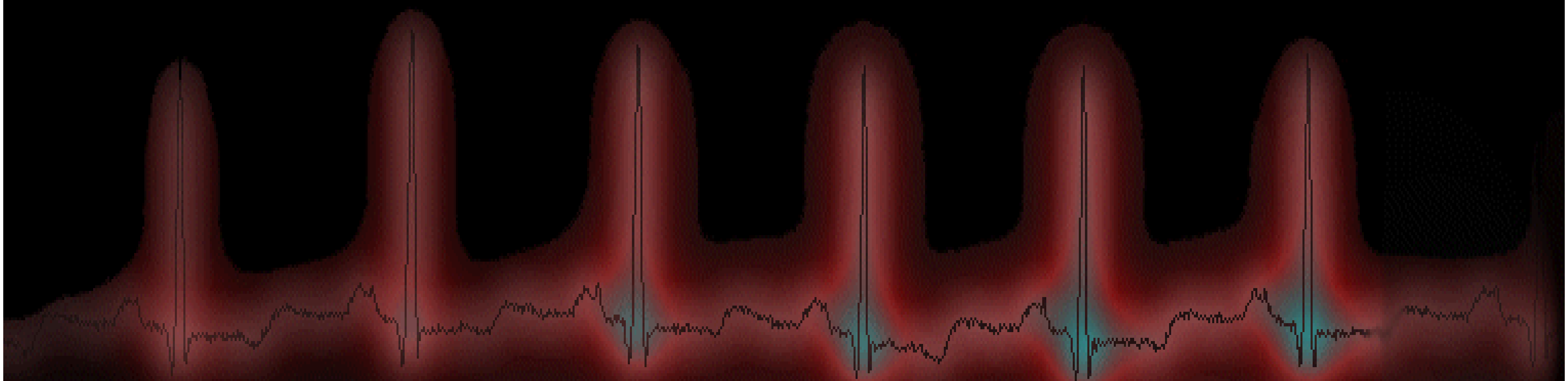
CARDIAC IMAGING FOR INTERVENTIONAL ASSISTANCE



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Outline

INTRODUCTION

- Coronary Heart Disease
- X-ray Fluoroscopy

METHODOLOGY

- Artery Segmentation
- Artery Tracking
- 3D Reconstruction

RESEARCH RESULTS

CONCLUSION

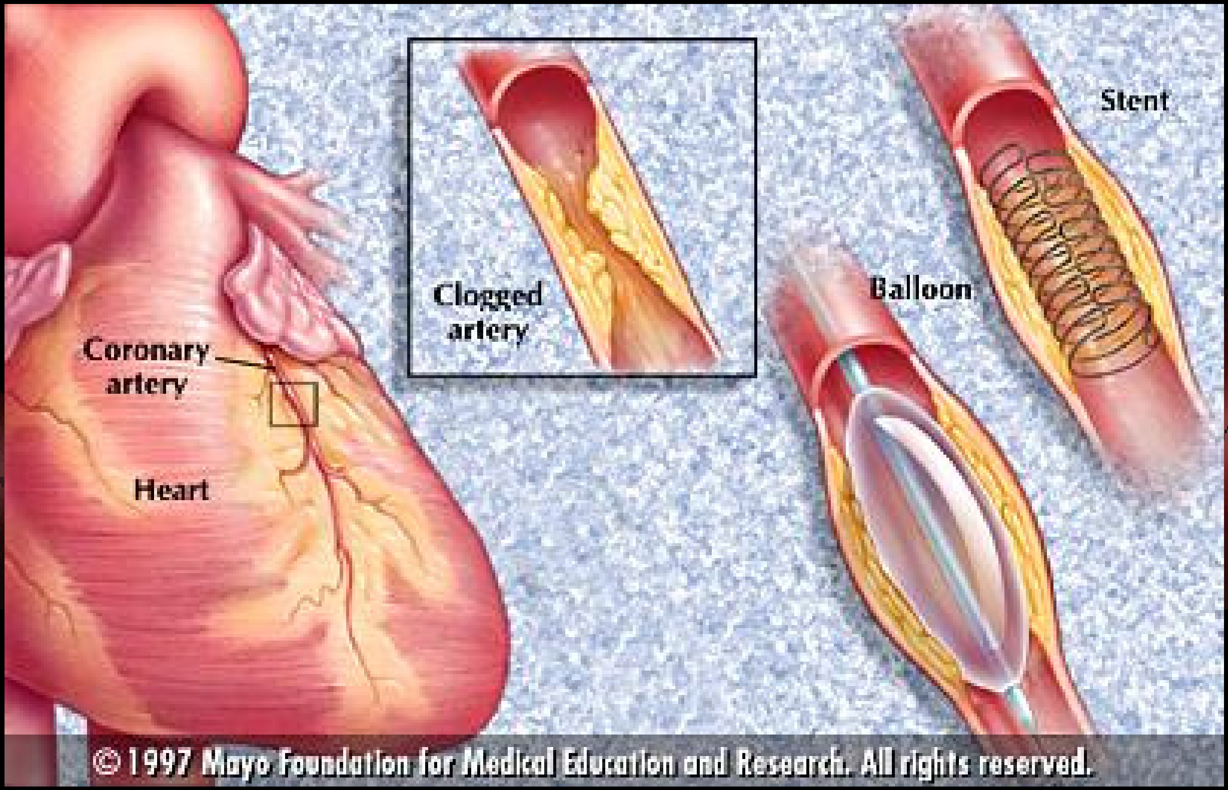
Introduction: Statistics

PREVALENCE

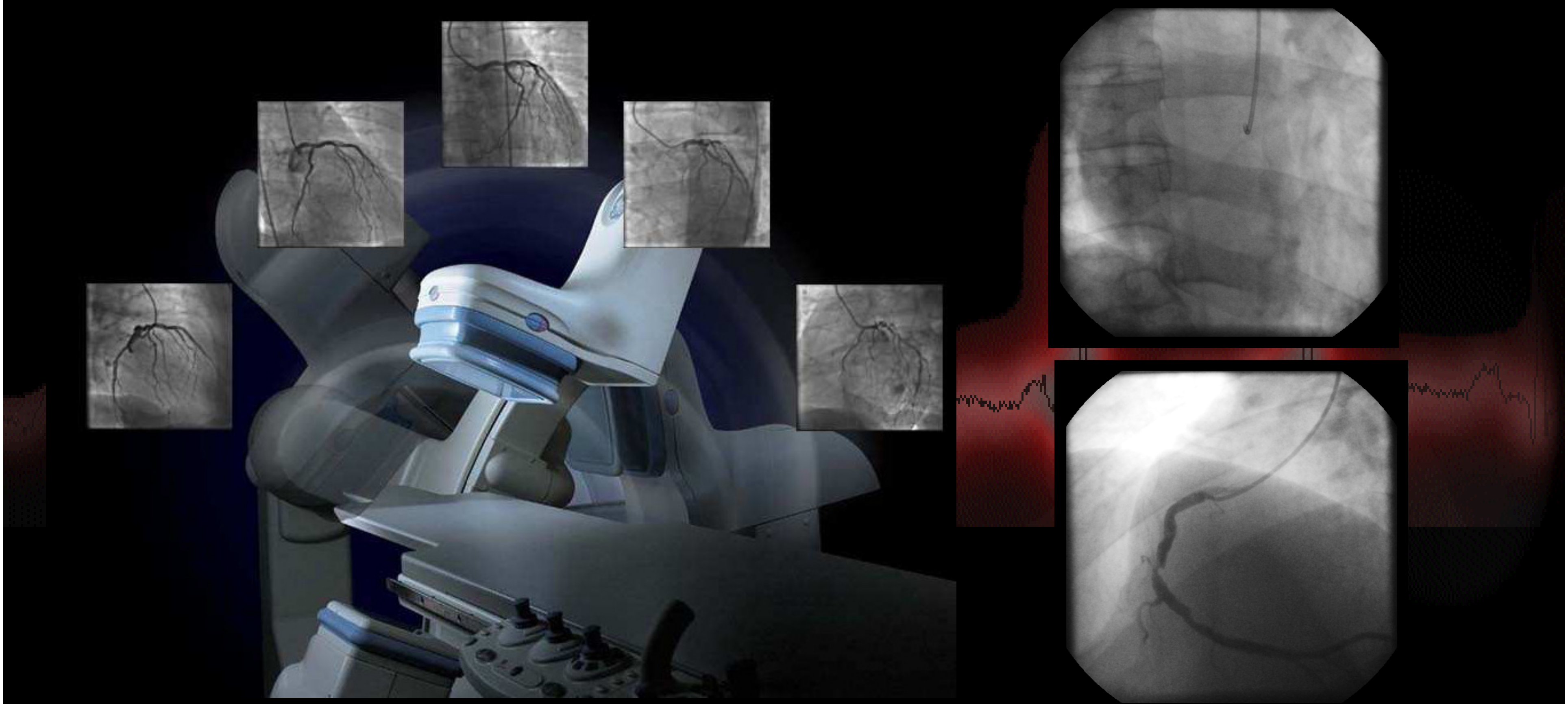
Cardiovascular disease (CVD) is the single leading cause of death in America today.

It accounted for 452,327 of all deaths in the United States in 2004 and 72,338 in Canada that same year.

Introduction: Atherosclerosis

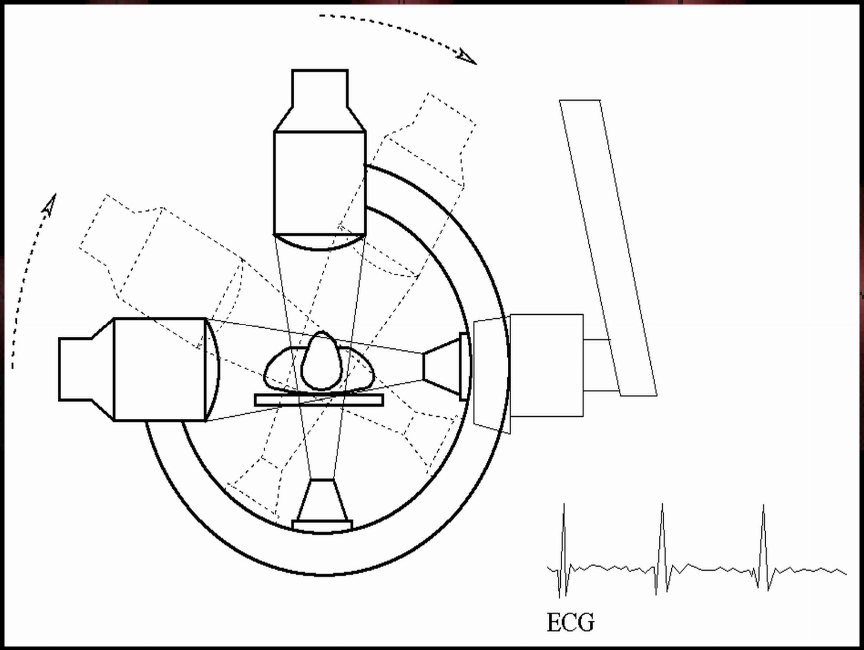


Introduction: Diagnostic imaging



Introduction: X-ray fluoroscopy

Biplane X-ray Fluoroscopy



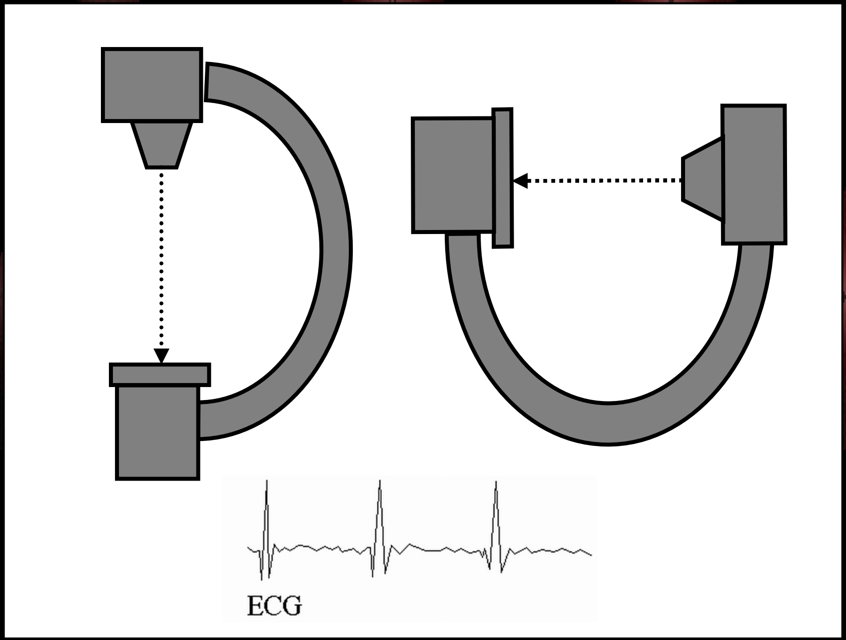
• Two quasi-simultaneous image acquisitions.

• Never used for clinical assistance.

• High costs $$$.

Introduction: X-ray fluoroscopy

2 x Monoplane X-ray Fluoroscopy



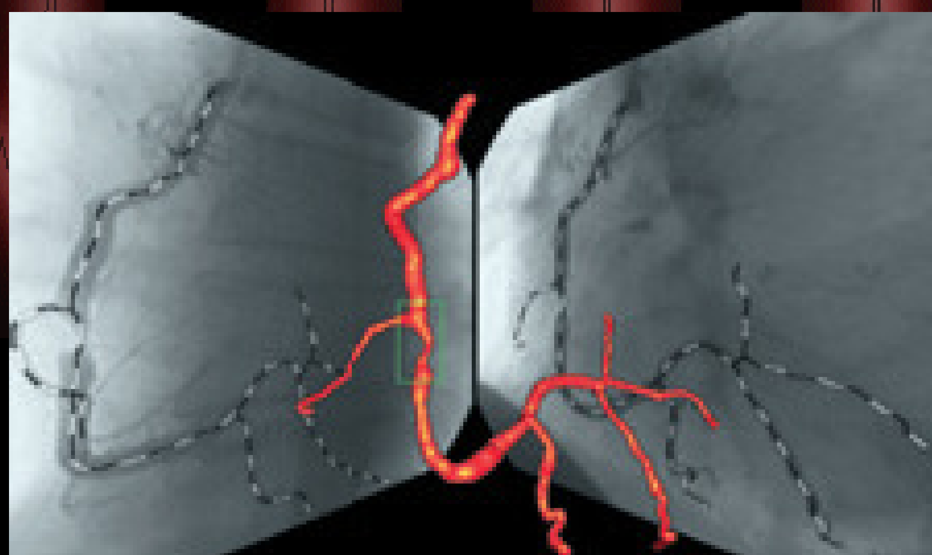
• Two non-simultaneous image acquisitions.

• Artifacts associated with motion + patient respiration.

• Point correspondence difficult between 2 non-simultaneous views.

Introduction: Dynamic information

- The dynamic information from the coronary arteries is of great interest to cardiologists and has been attracting increasing attention in cardiac research.



Research Objectives

1. To elaborate a method that aims at the development of a clinical tool for the 2D and 3D visualization and interactive manipulation of the coronary arteries.

2. This potential clinical tool should assist the cardiologists during their angiographic interventions.

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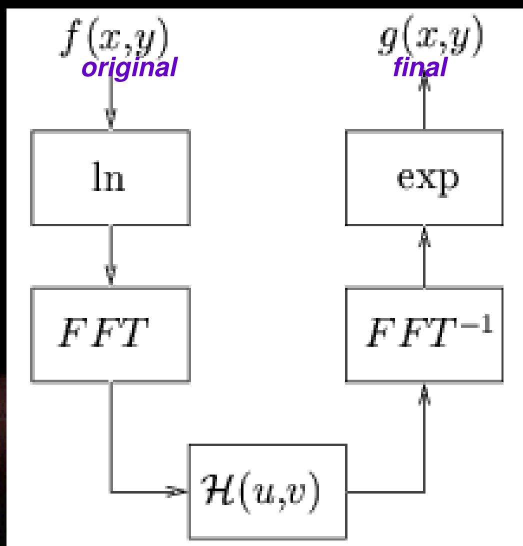
Methodology: 4-Step Filter



1. Homomorphic filter

$$\begin{cases} \partial_t I = \operatorname{div}(D\nabla I) \\ I(\mathbf{x},0) = I(\mathbf{x}) \end{cases}$$

2. Anisotropic Filter

+

$$I_t = -\frac{2}{\pi}\arctan\left(a\,\mathrm{Im}\left(\frac{I}{\theta}\right)\right)\left|\nabla I\right| + \lambda I_{\eta\eta} + \tilde{\lambda} I_{\xi\xi}$$

3. Complex Shock Filter

$$\begin{matrix} 0 & 0 & 1 & 0 & 0 \\ 0 & 1 & 1 & 1 & 0 \\ 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 \end{matrix}$$

4. Morphological Filter

Methodology: Centerline Extraction

Two-click Isotropic Fast Marching Method

• Find optimal path C(*s*): [0,∞ → R^n that minimizes the total cost necessary to travel between starting point ***A*** towards destination point ***B*** in R^n.

• The cost function, τ, will be a function of pixel position, ***x***, therefore the process is termed isotropic.

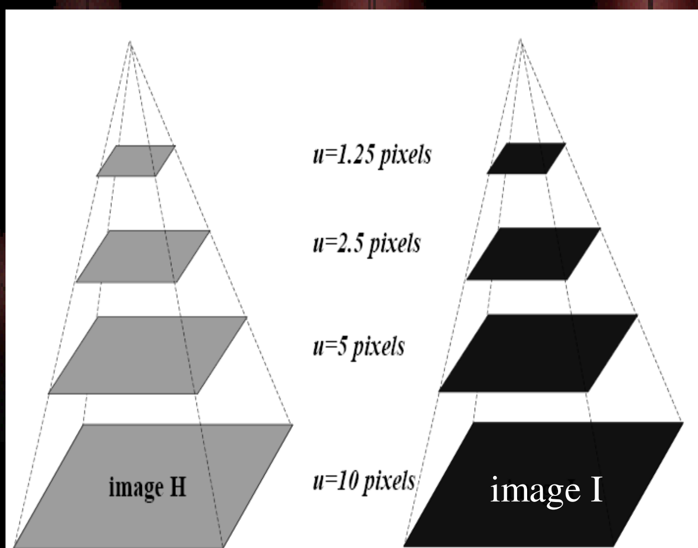
$$U(x) = \min_{C_{Ax}} \int_0^L \tau(C(s))\, ds$$

$$\|\nabla U\| = \tau$$

• The speed of position ***x*** will be defined as: **1/ τ(x),** and equivalent to the inverse of our 4-step image.

Methodology: Temporal Tracking

Estimate Optical Flow displacements [*u*, *v*] of objects using two consecutive images and pyramidal approach.



$$\begin{bmatrix} \Sigma\, wI_x^2 & \Sigma\, wI_xI_y \\ \Sigma\, wI_xI_y & \Sigma\, wI_y^2 \end{bmatrix} \begin{bmatrix} u \\ v \end{bmatrix} = - \begin{bmatrix} \Sigma\, wI_xI_t \\ \Sigma\, wI_yI_t \end{bmatrix}$$

Centerline positions at t=1

\+

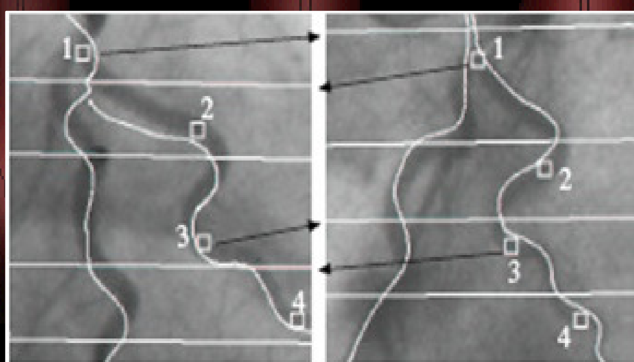
Optical flow displacements

=

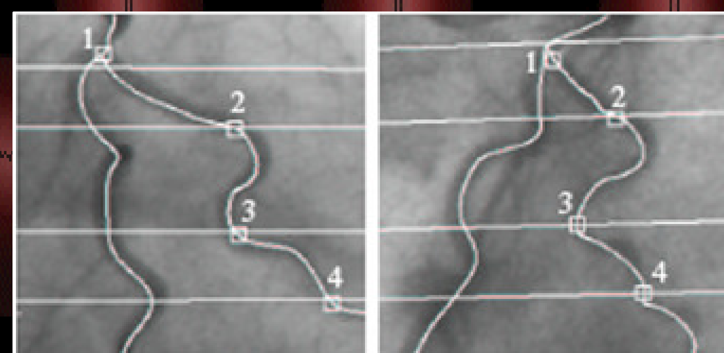
Estimated centerline positions at t=2

Methodology: Temporal Tracking

$$E_{snake} = \int_s \frac{1}{2}(\alpha(s)|v_s|^2 \quad + \quad \beta(s)|v_{ss}|^2) \quad + \quad E_{external}(v(s))ds$$

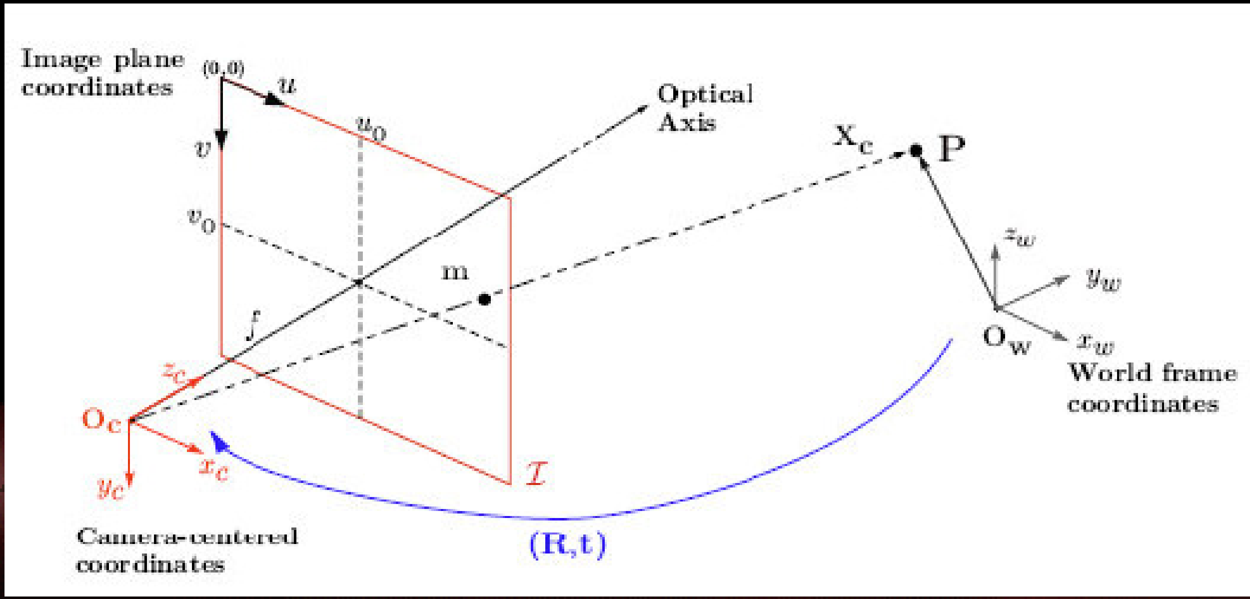


Before convergence



After convergence

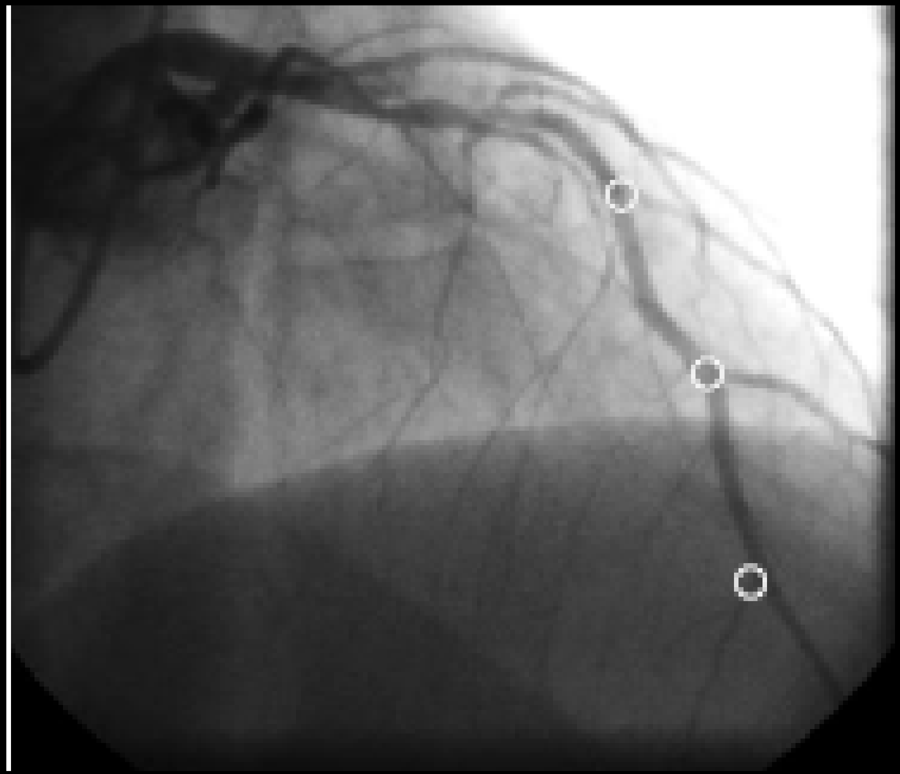
Coordinate Systems



$$P_{mat} = \begin{bmatrix} kf & 0 & u_o \\ 0 & kf & v_o \\ 0 & 0 & 1 \end{bmatrix} \times \left[\begin{array}{ccc|c} r_{11} & r_{12} & r_{13} & t_x \\ r_{21} & r_{22} & r_{23} & t_y \\ r_{31} & r_{32} & r_{33} & t_z \end{array}\right]$$

$$m = P_{mat} P_{world}$$

X-ray Calibration

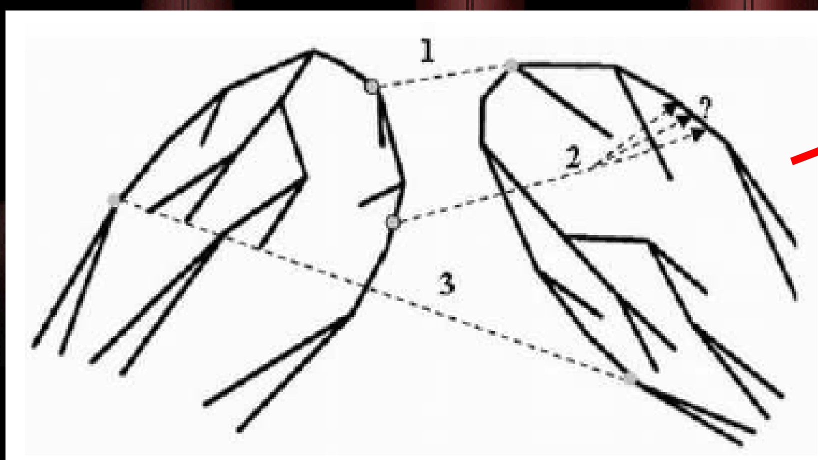


Distance Source to Detector (mm)	"1080"
Intensifier Size (mm)	"178"
Imager Pixel Spacing (mm/pixel)	"0.3704 "
Positioner Primary Angle (degrees)	"-34.0 "
Positioner Secondary Angle (degrees)	" 30 "
Rows (pixels)	"512"
Columns (pixels)	"512"
Window Center (pixels)	"128 "
Window Width (pixels)	"255 "

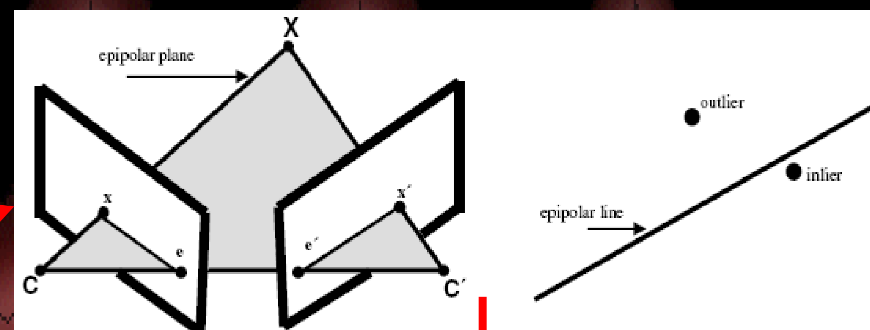
Methodology: Point correspondence

Reconstruction procedure

- X-ray system calibration
- point correspondence between images
- 3D triangulation algorithm



Epipolar Geometry & Fundamental Matrix



RANSAC METHOD

$$s = \left[\frac{\ln(1-\rho)}{\ln(1-(1-\varepsilon)^k)} \right]$$

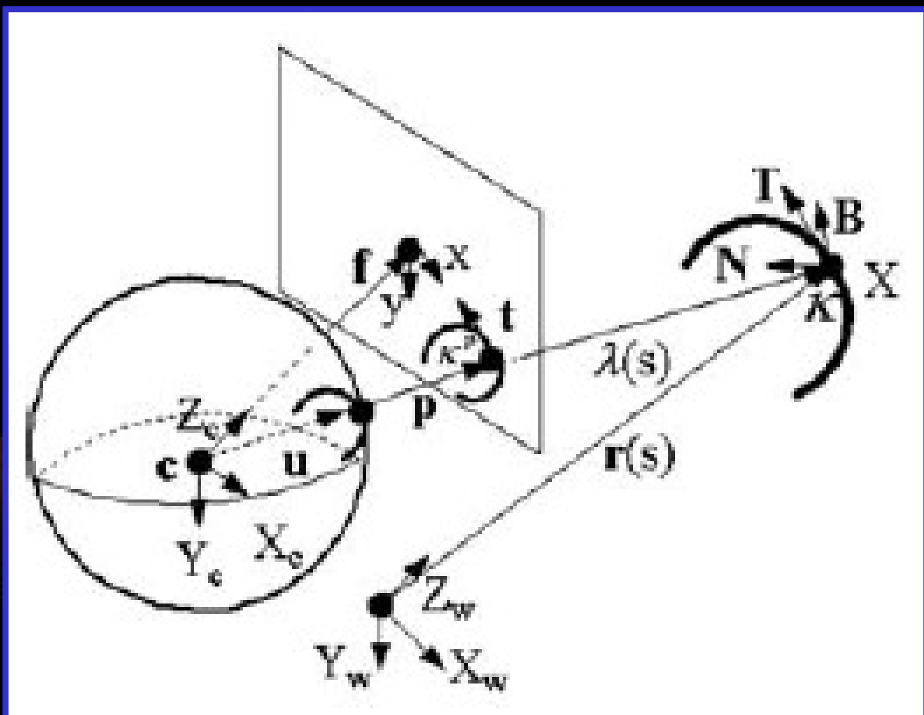
ρ- confidence value

ε- fraction of outliers

k- minimum number of data points

$$\text{Sampson error} = \frac{(x_i^T F_j x_i')^2}{(F_j x_i)_1^2 + (F_j x_i)_2^2 + (F_j^T x_i')_1^2 + (F_j^T x_i')_2^2}$$

Methodology: Point Correspondence



3D space curve, its spherical projection to unit sphere, and its perspective projection to image plane

Cipolla et al. relate the image geodesic curvature to the 3D space curve geometry:

$$\kappa^{g} = \frac{\lambda\kappa(u \times T)\cdot N}{(1-(u\cdot T)^{2})^{3/2}}$$

Use 2D to 3D curvature refinement of RANSAC correspondences for final matches between artery centerlines.

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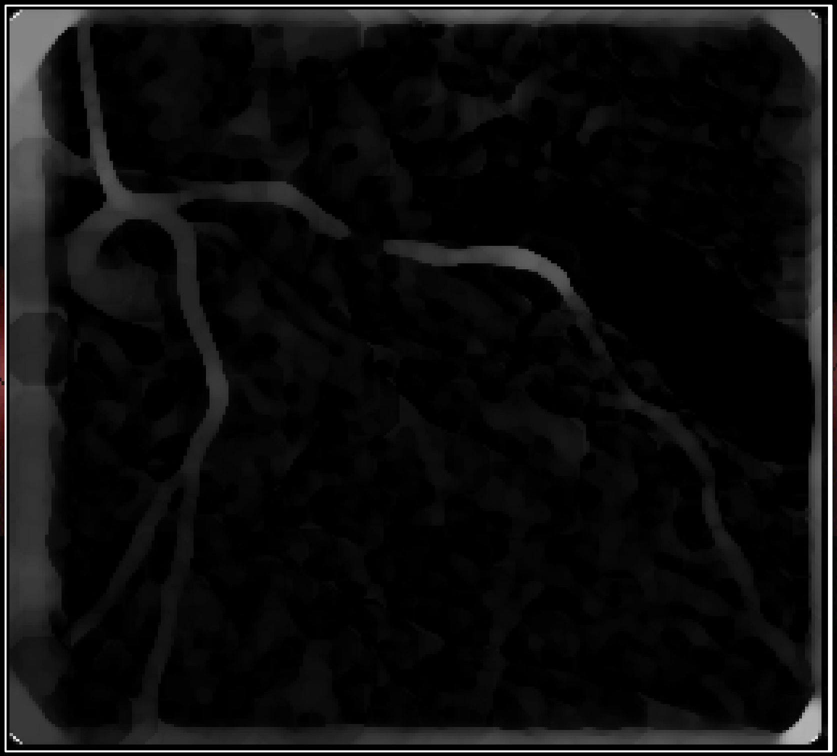
Results: 4-step filter image

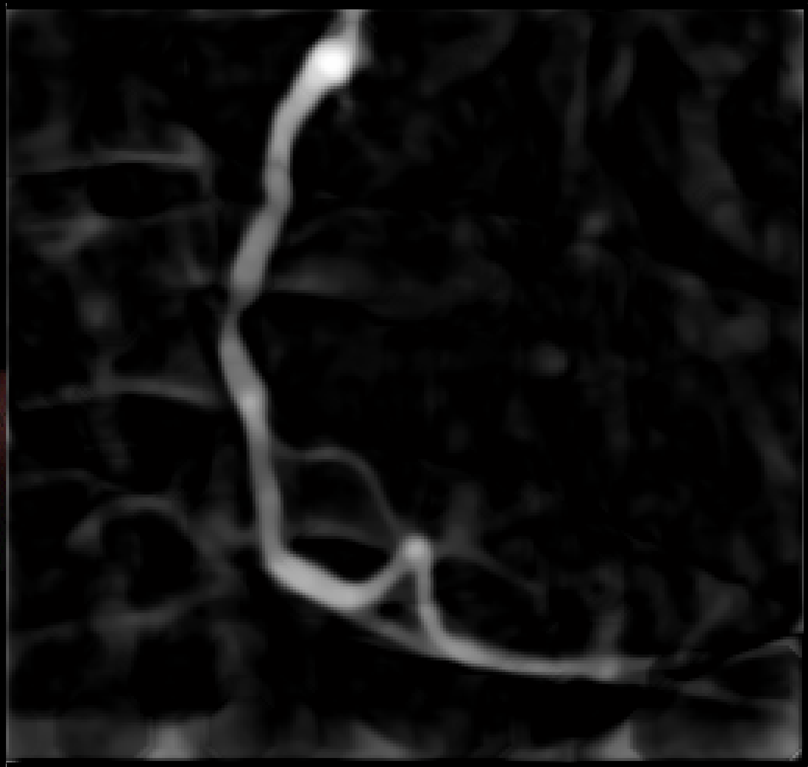
Coronary Artery Enhancement

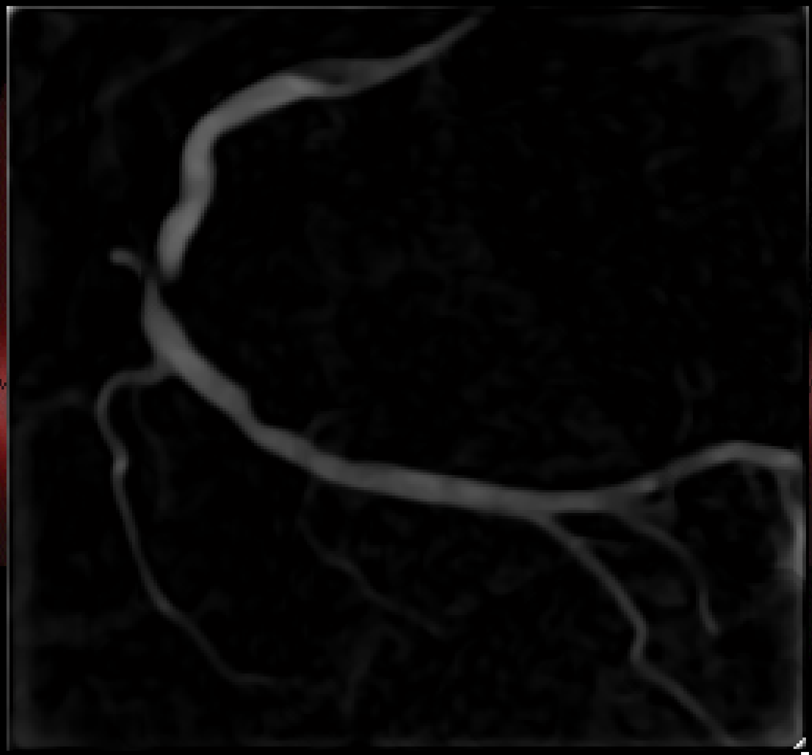
Diastole Coronary Image



4-Step Filter

Results: 4-step filter image

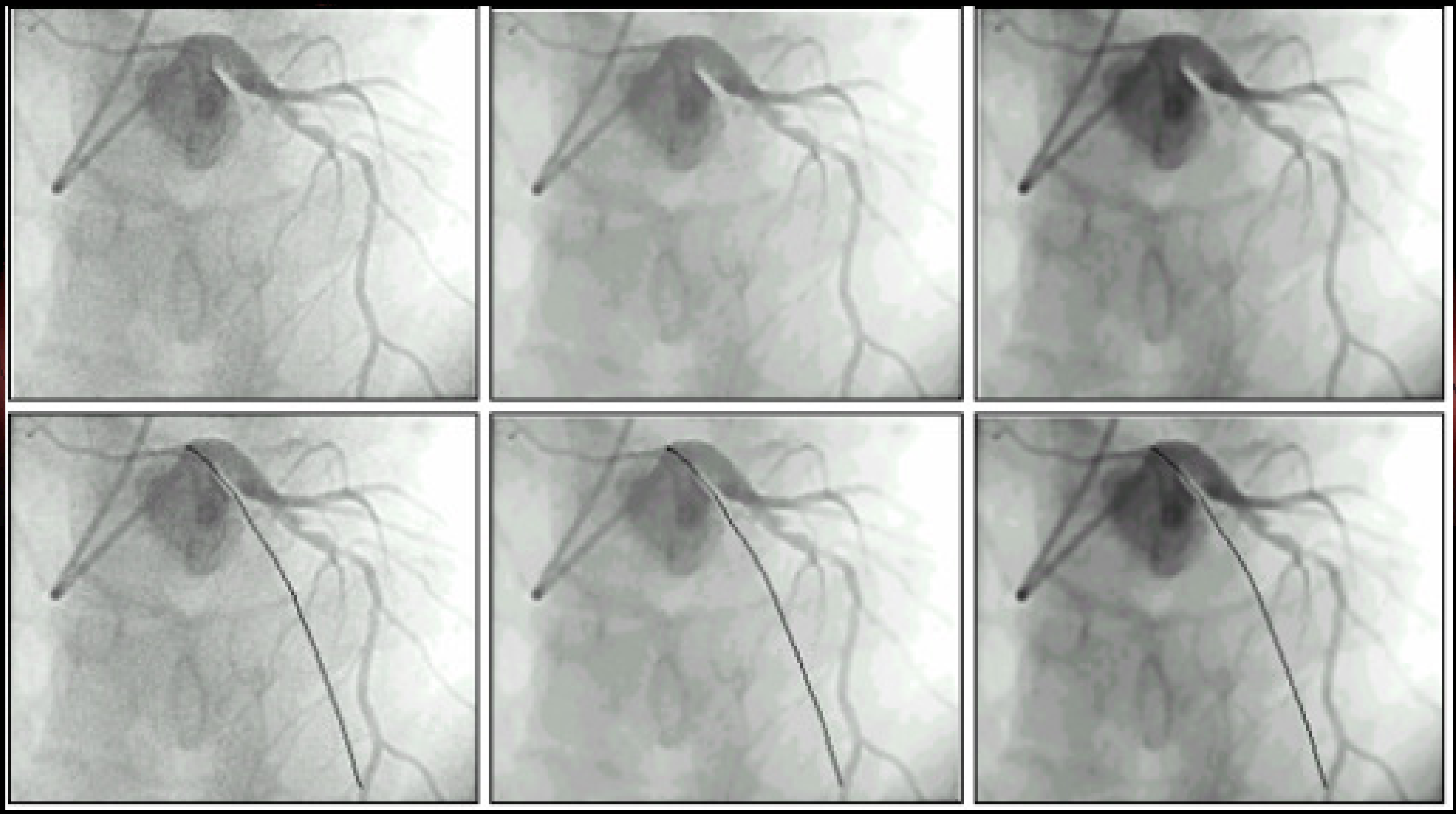




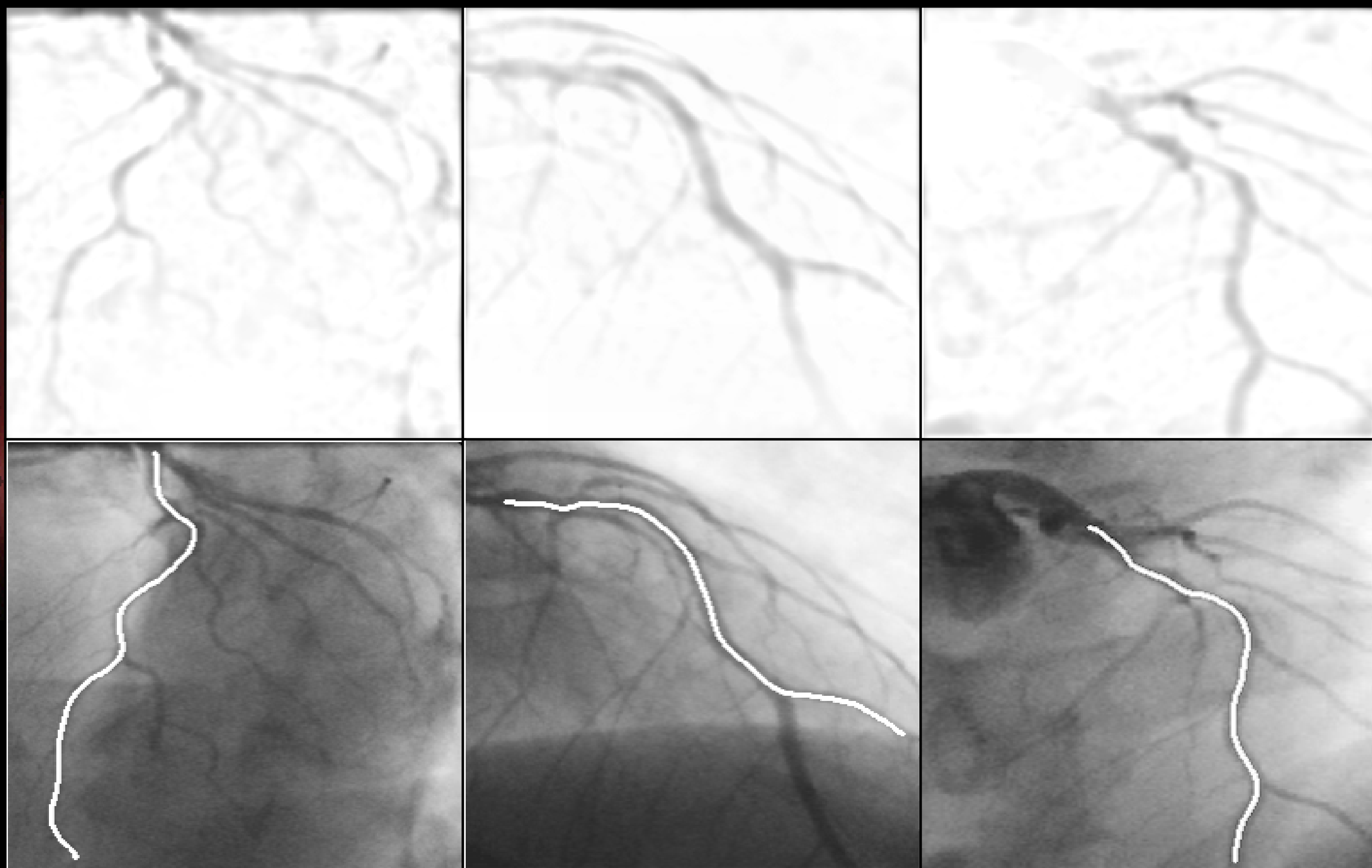
… other examples of 4-step filter image enhancement

Results: 4-step filter image

- Failure of incorrect cost image for centerline extraction

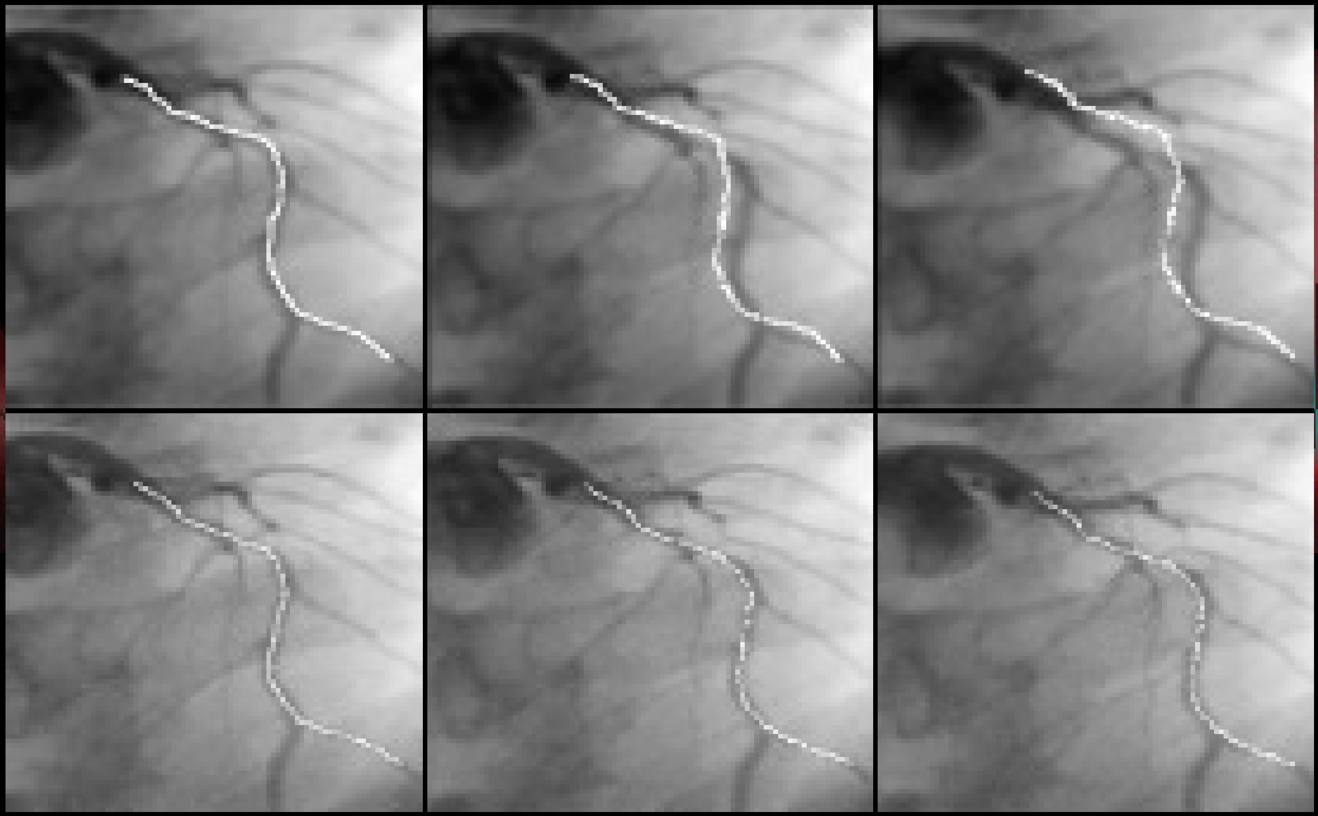


Results: Image enhancement and centerline extraction



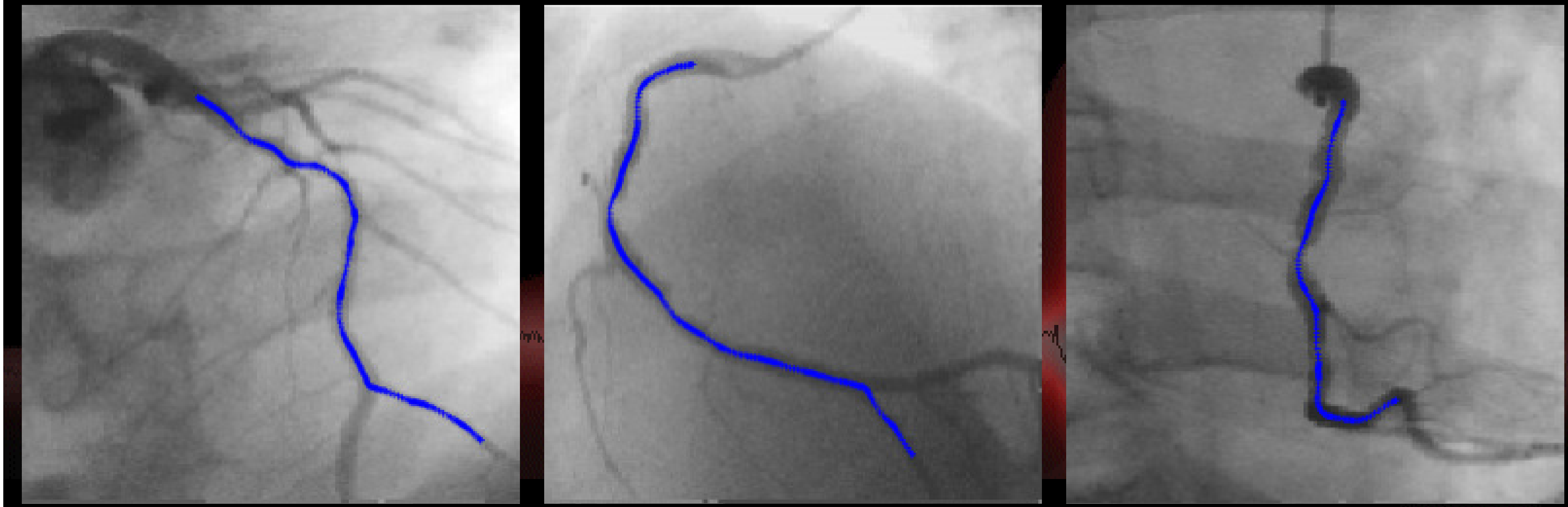
Results: temporal tracking

- Classical vs Pyramidal Optical Flow Evaluation



Estimated motion is more precise using multi-resolution approach.

Temporal Tracking



-The average tracking time in 1 cardiac cycle is approximately 15mins/frame, including image preprocessing using Matlab.

- 35 of 38 coronary frames were tracked correctly.

Results: optimal point correspondence

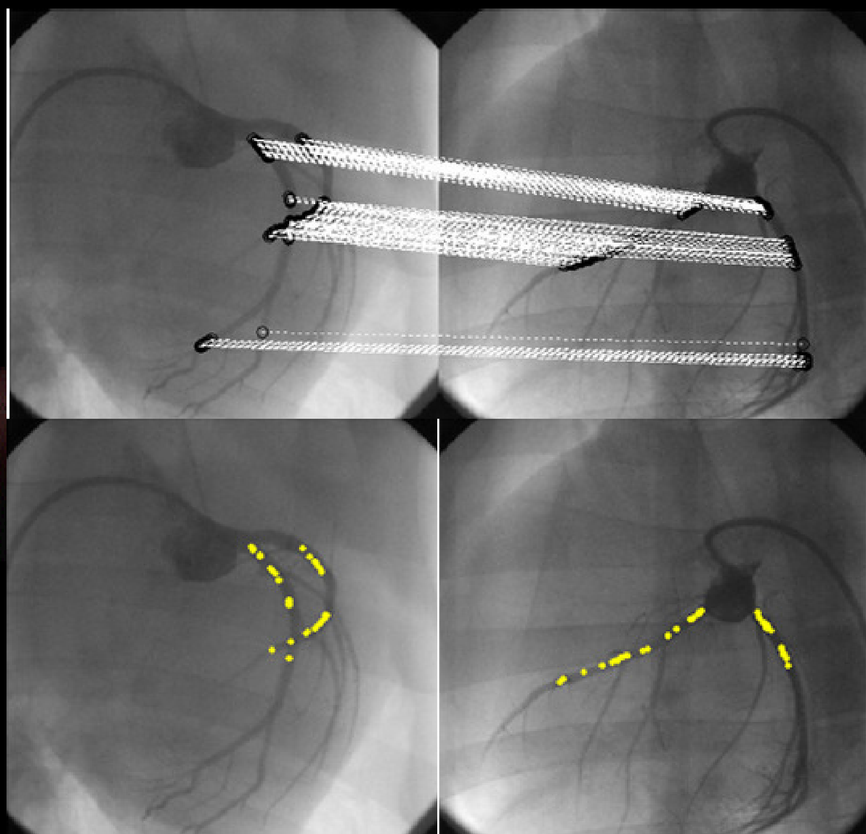
- Synthetic Validation on 5 biplane datasets of 3D helix and its 2D projections

PA/LAT Simulation

	RANSAC			CURVATURE CONSTRAINT		
	# of candidates	Residual	Sampson error	# of candidates	Residual	Sampson error
Image Pair #1						
Inlier distance: 1 pixel	390	0.561	0.140	60	0.399	0.098
Inlier distance: 1.5 pixels	548	1.270	0.316	62	0.955	0.236
Inlier distance: 2 pixels	695	2.268	0.565	97	2.142	0.533
Image Pair #2						
Inlier distance: 1 pixel	422	0.609	0.151	46	0.406	0.101
Inlier distance: 1.5 pixels	572	1.370	0.341	72	1.292	0.321
Inlier distance: 2 pixels	655	2.240	0.554	112	2.015	0.500
Image Pair #3						
Inlier distance: 1 pixel	424	0.654	0.163	49	0.624	0.154
Inlier distance: 1.5 pixels	528	1.451	0.362	76	1.275	0.317
Inlier distance: 2 pixels	736	2.288	0.569	82	2.037	0.505
Image Pair #4						
Inlier distance: 1 pixel	402	0.603	0.150	51	0.444	0.111
Inlier distance: 1.5 pixels	565	1.407	0.350	81	1.009	0.249
Inlier distance: 2 pixels	697	2.338	0.583	100	1.963	0.487
Image Pair #5						
Inlier distance: 1 pixel	385	0.651	0.162	41	0.520	0.129
Inlier distance: 1.5 pixels	559	1.458	0.363	70	0.830	0.207
Inlier distance: 2 pixels	675	2.527	0.626	86	1.738	0.430

Results: optimal point correspondence

- Clinical Validation using RANSAC and our approach

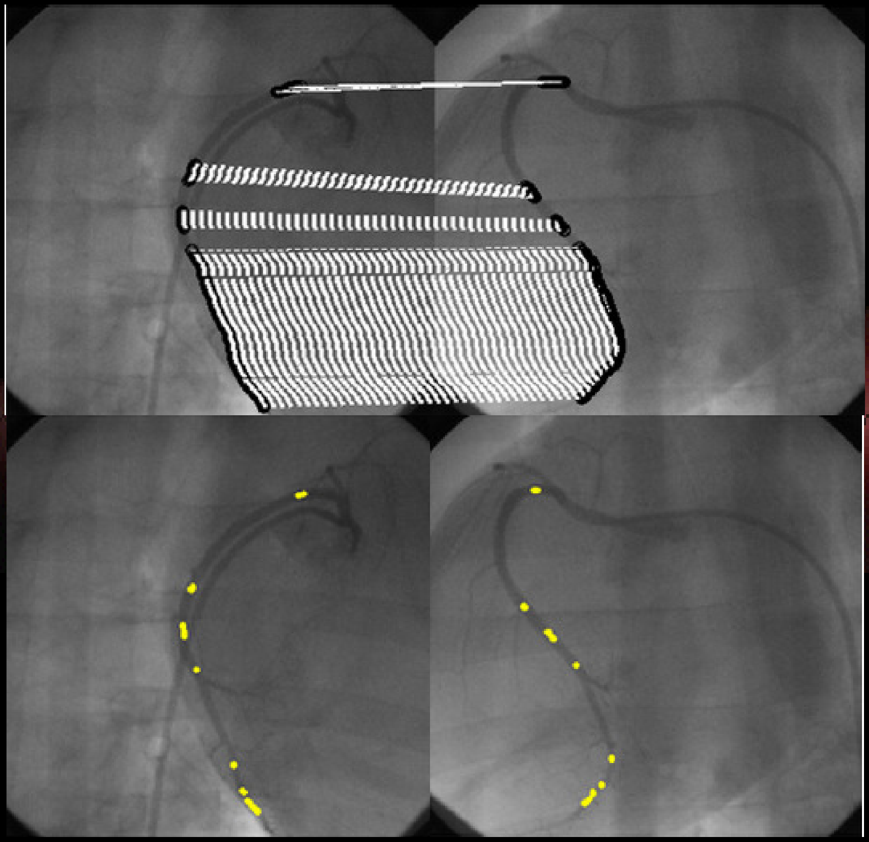


DATASET #1

3D Retroprojection results onto images improve from 2.4 mm to 1.9 mm using geometric constraint

Results: optimal point correspondence

- Clinical Validation using RANSAC and our approach



DATASET #2

3D Retroprojection results onto images improve from 1.6 mm to 1.4 mm using geometric constraint

Conclusion

- Target algorithms that will assist cardiologists concurrently during interventions.
- Use only spatial information contained in X-ray sequences to produce a 3D reconstruction of the coronary arteries.
- Point correspondence is optimized using a novel curvature constraint and improves final 3D reconstruction accuracy.
- Algorithms were validated synthetically and on clinical datasets.

QUESTIONS