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NON-LOCAL OPERATIONAL ANISOTROPIC DIFFUSION FILTER

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Medical Image Filtering

- Remove high-frequency noise;
- Preserve signal;
- Do not insert artifacts;

- Anisotropic Diffusion Filters

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Filtering Generations

1) Local and isotropic
   - Gaussian, median
2) Local and anisotropic
   - Bilateral and diffusion
3) Non-local and anisotropic
   - NLM, BM3D

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Anisotropic Diffusion Filter

- Iterative process simulating thermal energy flow.

$$I_s^{t+1} \approx I_s^t + \frac{\lambda}{|\eta_s|} \sum_{p \in \eta_s} g(\nabla I_{s,p}^t, \gamma) \nabla I_{s,p}^t$$

  - I_s^t – intensity of pixel *s* in instant *t*
  - λ – diffusion rate scalar
  - γ – smoothing strength
  - η_s – pixels adjacent to *s*
  - $\nabla I_{s,p}^t$ or *x* – magnitude of intensity directional gradient from *s* to *p*
  - g( ) – edge stopping function

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Edge Stopping Functions

$$I_s^{t+1} \approx I_s^t + \frac{\lambda}{|\eta_s|} \sum_{p \in \eta_s} g(\nabla I_{s,p}^t, \gamma) \nabla I_{s,p}^t$$

Let $\gamma = \lambda / |\eta_s|$

$$g(x, \gamma) = exp\left(-x^2 / 2\gamma^2\right)$$

$$g(x, \gamma) = \left[1 + (x/\gamma)^2\right]^{-1}$$

$$g(x, \gamma) = \begin{cases} \left[1 - (x^2/5\gamma^2)\right]^2 & |x| \leq \gamma\sqrt{5} \\ 0, & \text{otherwise} \end{cases}$$

(Tukey's Function - Black et al. 1998)

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Third Generation Diffusion Filters

- Trivial extensions with no parametric evaluation:
  - M Yang et al., *Non-local means theory based Perona-Malik model for image denosing*" - Neurocomputing, vol. 120, pp. 262–267, 2013.
    - Original edge-stopping function.
  - J Yuan, *Improved anisotropic diffusion equation based on new non-local information scheme for image denoising*- IET Computer Vision, vol. 9, no. 6, pp. 864–870, 2015.
    - Tukey's stopping function.
    - Computes adjacent patches on each iteration.

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Optimal Non-Local Anisotropic Diffusion Filter

$$I_s^{t+1} \approx I_s^t + \frac{1}{|H_s|} \sum_{p \in H_s} \frac{g(\nabla I_{s,p}^t, \gamma)}{d_{s,t}} \nabla I_{s,p}^t$$

- H_s – Local and Non-local adjacency.
- $d_{s,t}$ – distance between pixels s and t.
  - Non-local adjacency is treated as a new dimension.
  - Local and non-local dimensions may be weighted differently.
  - Distance weight eliminates λ parameter.

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- Parameter estimation:
  - Initial γ
    - 5% high threshold of the sum of directional gradients
    - $G_s = \sum_{p \in \eta_s} I_s - I_p$
  - Stopping criteria
    - $\gamma^t \leq \varepsilon\, I^M$
      - I^M is the maximum image intensity.
      - ε=0.01 in our experiments.

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- New parameters:
  - γ-reduction rate or conservativeness (Rγ)
  - Non-local similar patch search radius (SR)
  - Non-local patch radius (PR)
  - Non-local dimension distance unit (PD)
  - Number of non-local patches (#P)

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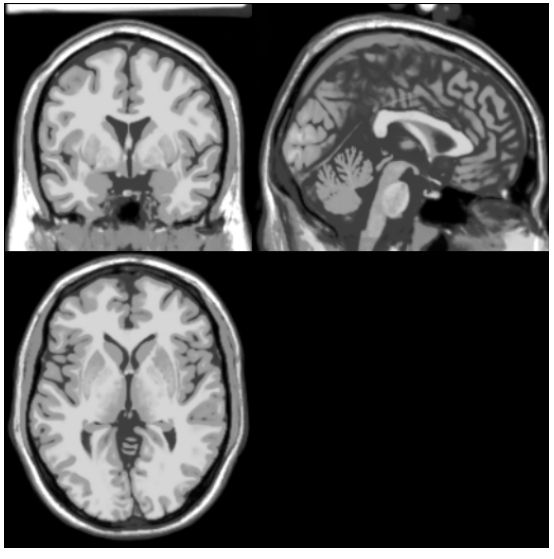
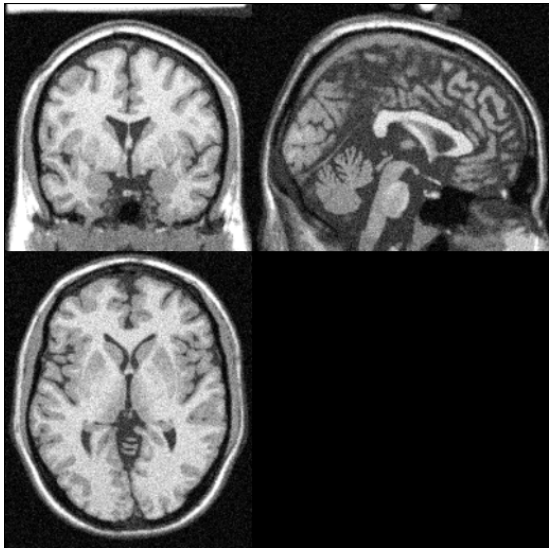
Parameter Estimation

- BrainWeb Phantom
  - Weighted Anisotropic Diffusion Filter – WADF (local)





yR	IQI	MSE	PSNR
$0.16y^{t-1}$	0.990	3.74	27.6
$0.32y^{t-1}$	0.995	2.99	28.8
$0.48y^{t-1}$	0.996	2.84	29.1
$0.64y^{t-1}$	**0.997**	2.79	29.2
$0.80y^{t-1}$	0.995	**2.78**	**29.3**
$0.96y^{t-1}$	0.994	2.80	29.2

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Parameter Estimation

- BrainWeb Phantom
  - Non-Local Weighted Anisotropic Diffusion Filter – NL-WADF

SR	PR	PD	#R	yR	IQI	MSE	PSNR
2.0	1.1	0.5	2	$0.32\gamma^{t-1}$	**0.997**	2.72	**29.5**
4.0	1.1	0.5	2	$0.32\gamma^{t-1}$	**0.997**	**2.71**	**29.5**
2.0	1.9	2.0	1	$0.64\gamma^{t-1}$	**0.997**	2.79	29.2
3.0	1.9	0.5	1	$0.64\gamma^{t-1}$	**0.997**	2.78	29.2
4.0	1.9	1.0	2	$0.64\gamma^{t-1}$	**0.997**	2.79	29.2

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Quantitative Evaluation

- BrainWeb Phantom
  - Comparing NL-WADF with other non-local filters:

	IQI			MSE			PSNR		
Noise level	5%	7%	9%	5%	7%	9%	5%	7%	9%
NL-WADF	0.974	0.993	0.971	23.5K	47,0K	110K	28.5	25.2	21.8
NLM-3D	**1.002**	0.970	0.963	**21.0K**	**38.5K**	**101K**	**29.0**	**26.4**	**22.2**
BM4D	0.973	**1.000**	**0.975**	21.7K	44.0K	104K	28.9	25.8	22.1

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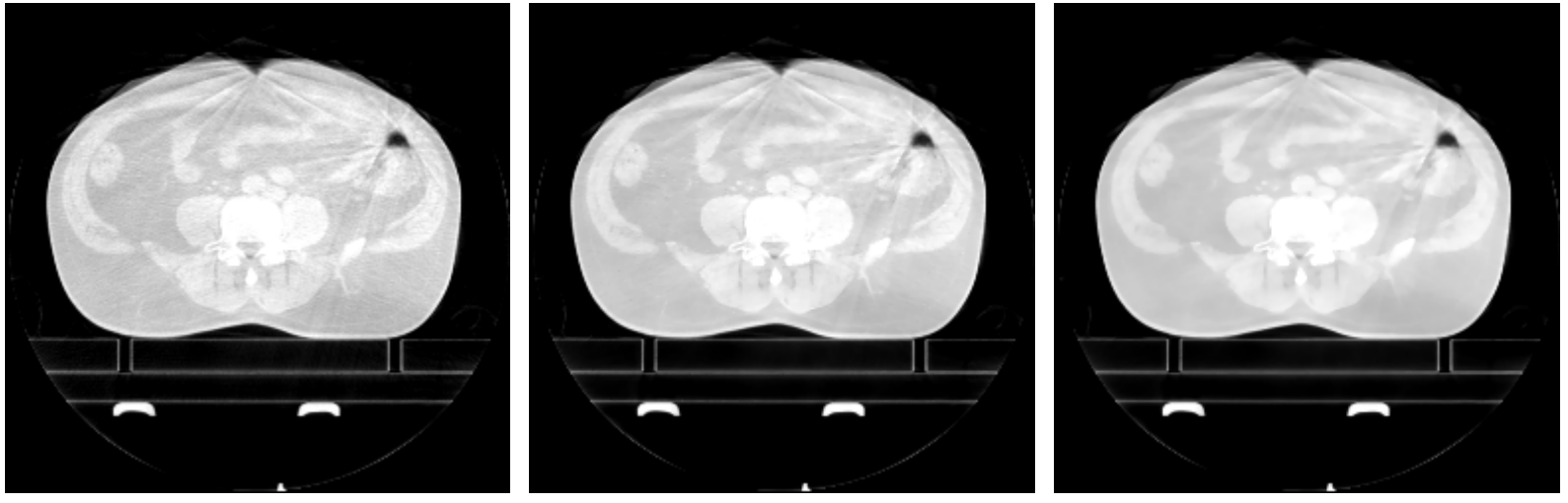
Qualitative Evaluation

- CBCT/kV radiotherapy images.



γ^0	$0.2\sigma_{Gs}$	$0.4\sigma_{Gs}$	$0.6\sigma_{Gs}$	$0.8\sigma_{Gs}$	σ_{Gs}
Score	4.9	5.0	4.9	4.9	4.8

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Thank you!

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