

MEDICAL IMAGE COMPUTING (CAP 5937)

LECTURE 5: Pre-Processing Medical Images (III) (MRI Intensity Standardization)

Dr. Ulas Bagci

HEC 221, Center for Research in Computer
Vision (CRCV), University of Central Florida
(UCF), Orlando, FL 32814.

bagci@ucf.edu or bagci@crcv.ucf.edu

Outline

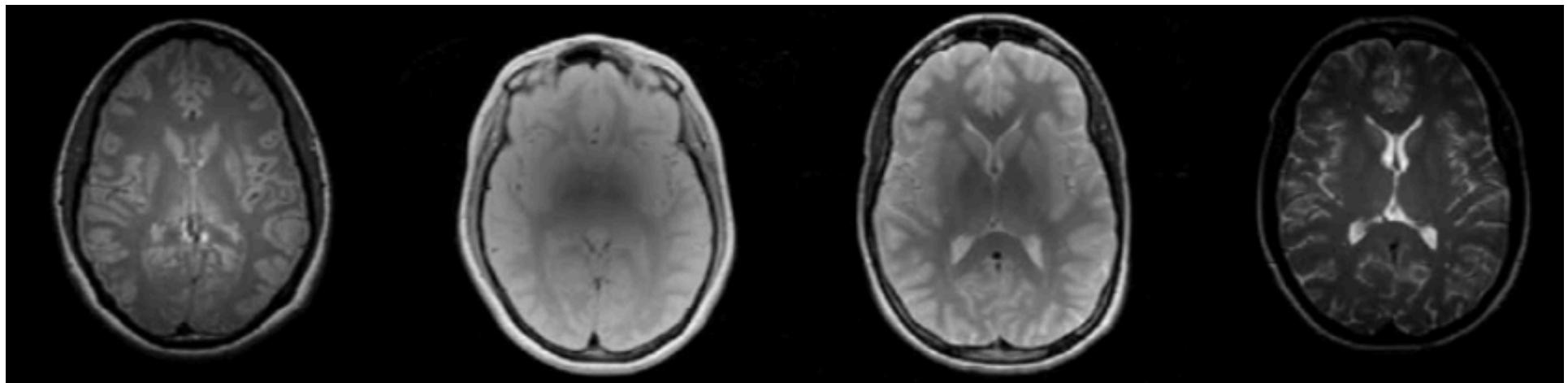
- MR Intensity standardization
- General preprocessing framework for MR images
- Effects of pre-processing on image analysis tasks

MR Intensity Non-Standardness

- Acquisition-to-acquisition signal intensity variations (non-standardness) are inherent in MR images.

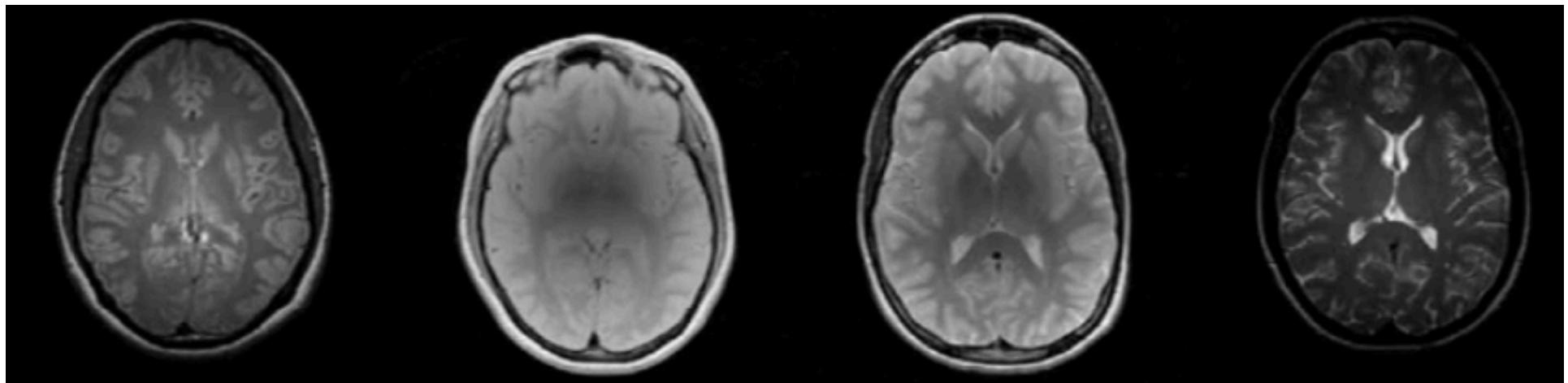
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PD

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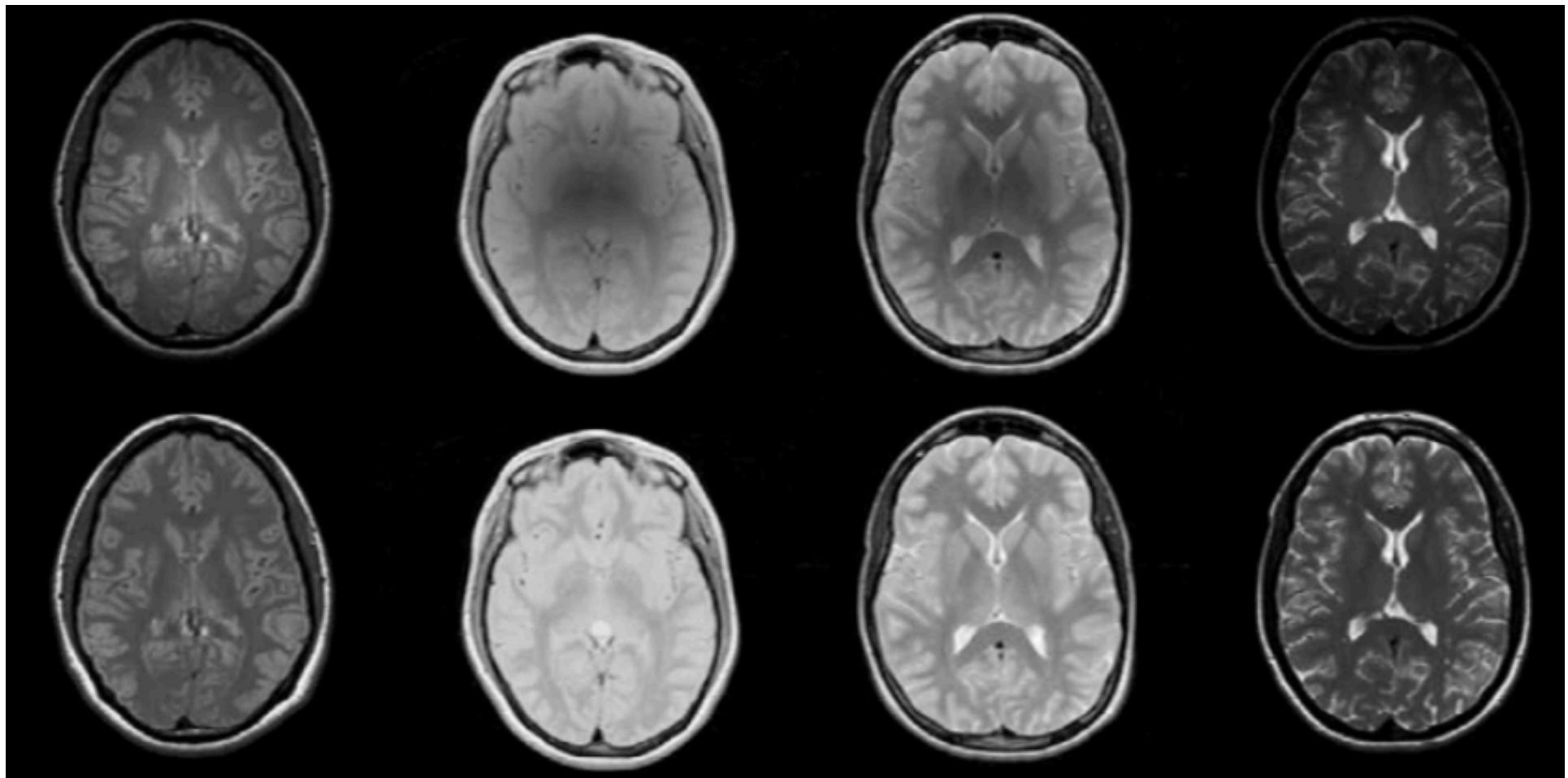
T2

T2



MR Intensity Non-Standardness

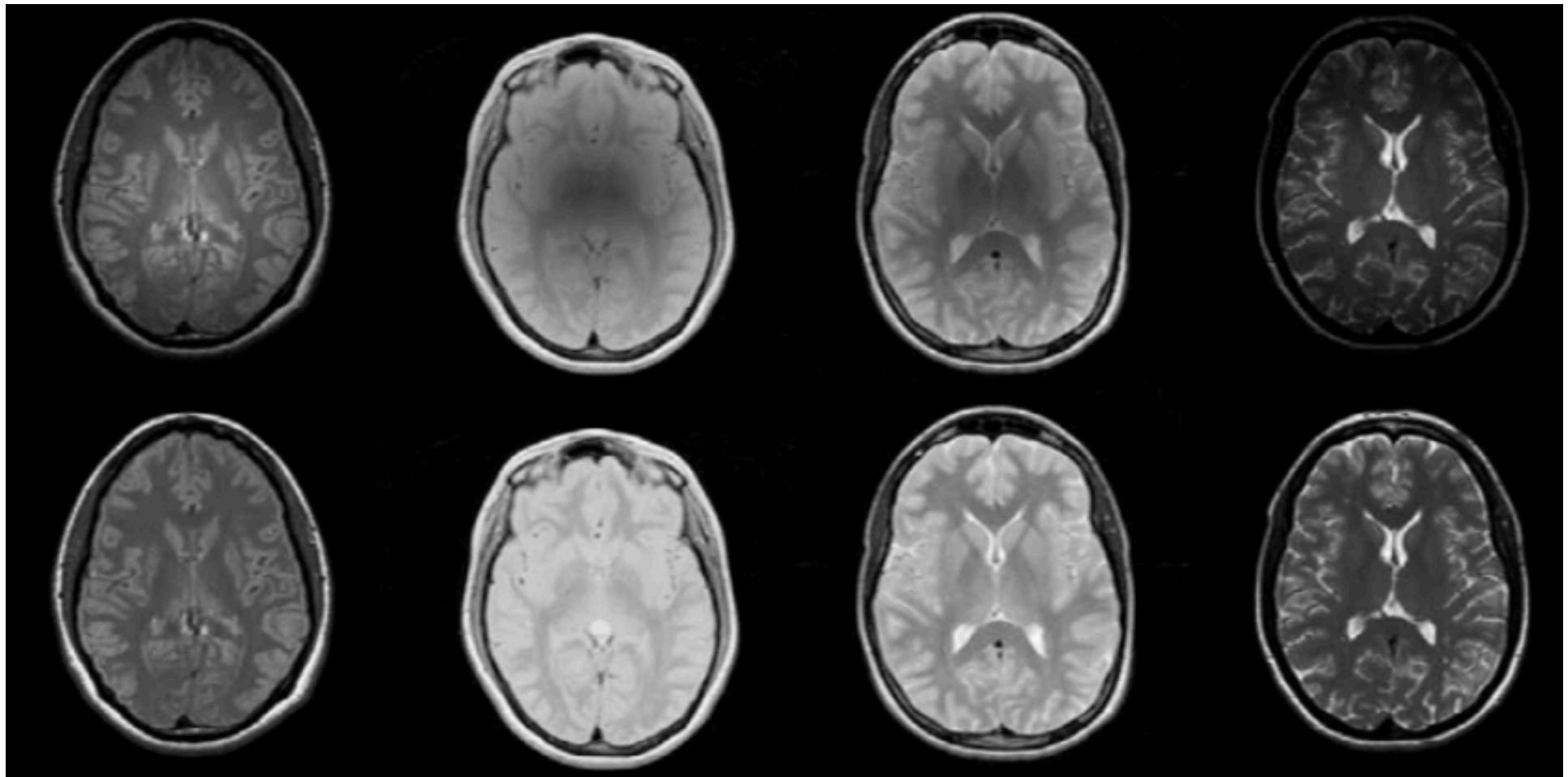
- What is changed?

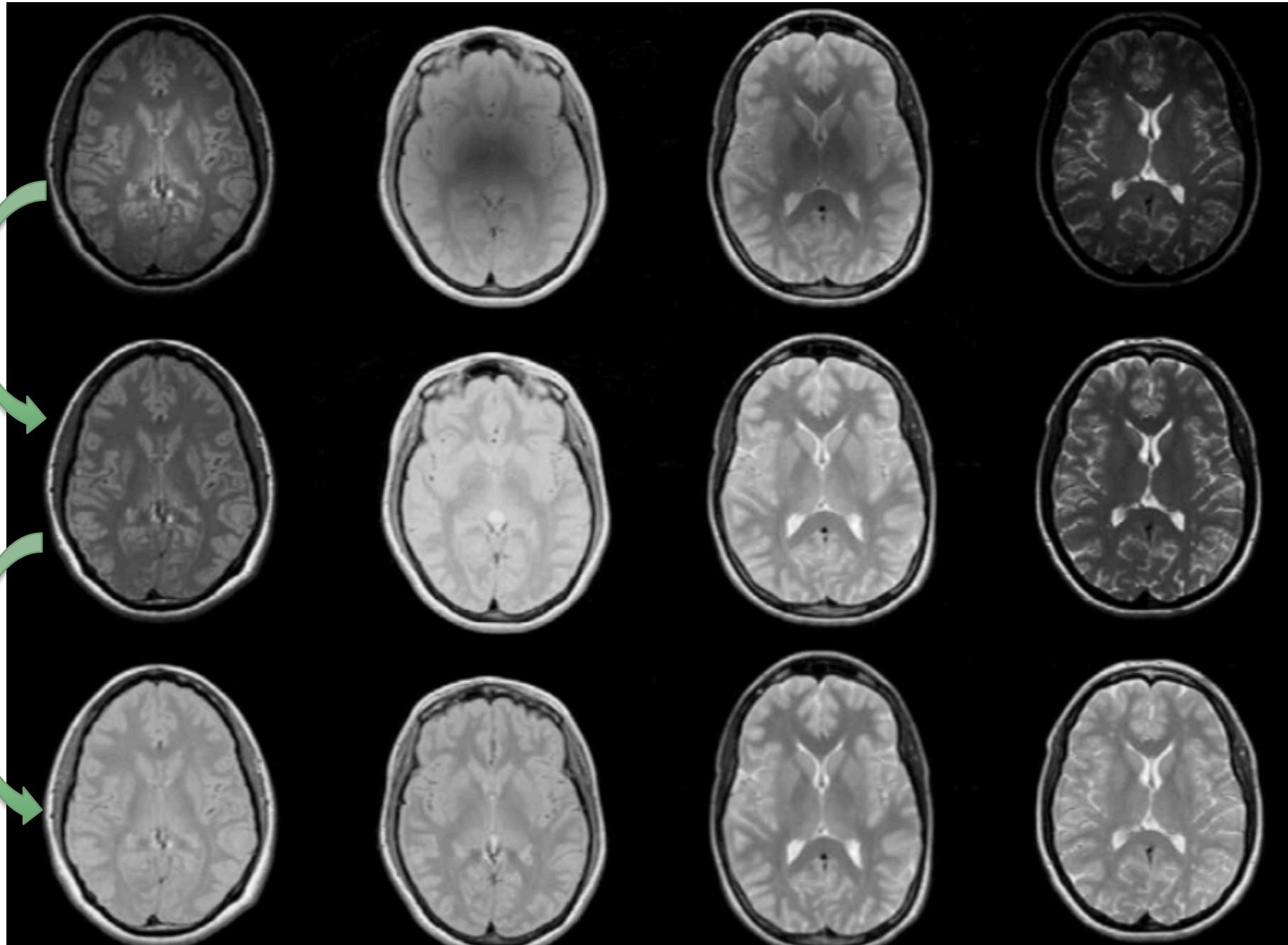




MR Intensity Non-Standardness

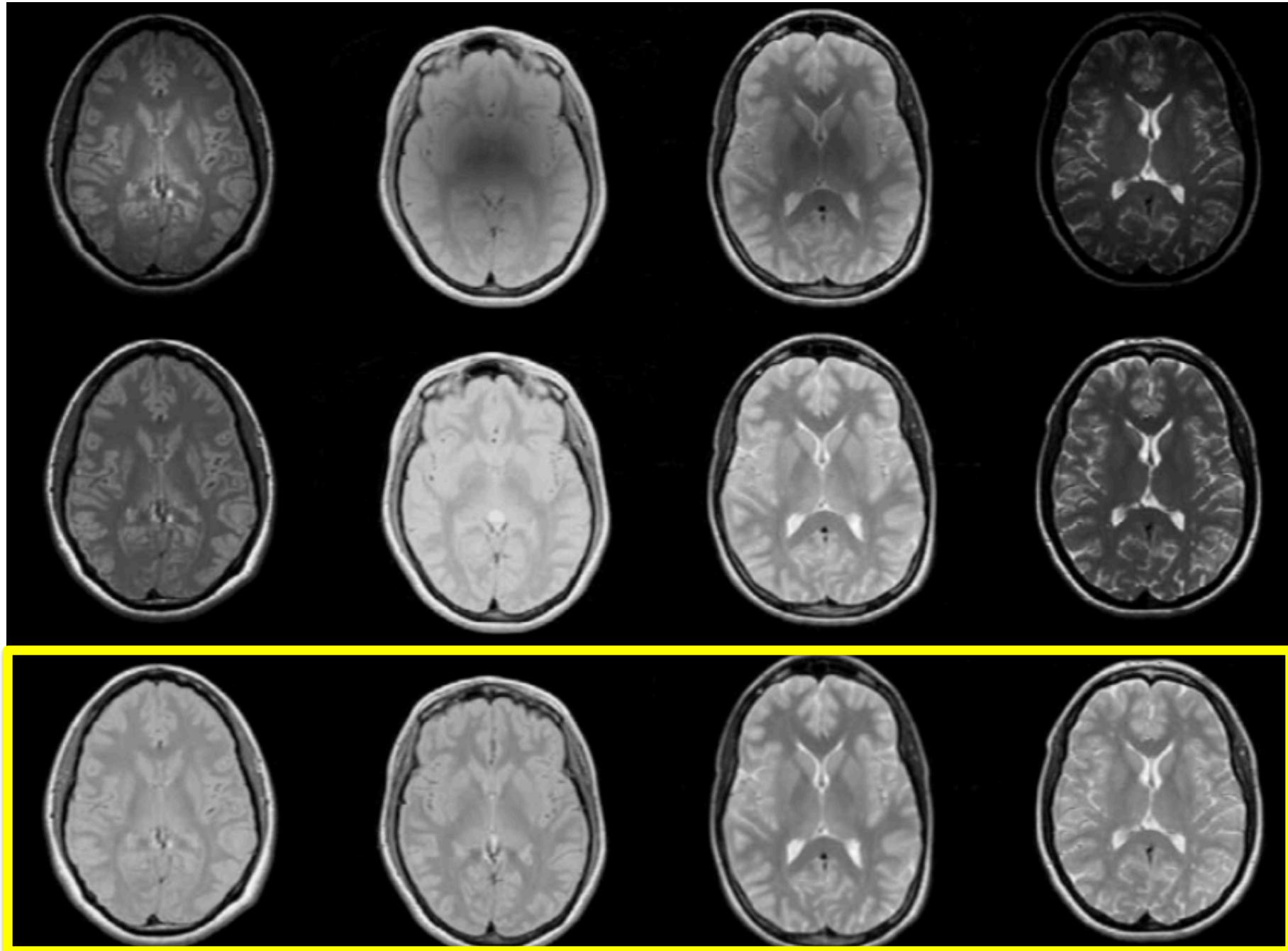
- Intensity inhomogeneity is removed! (N3 or SBC can be used).







Intensities are
standardized!

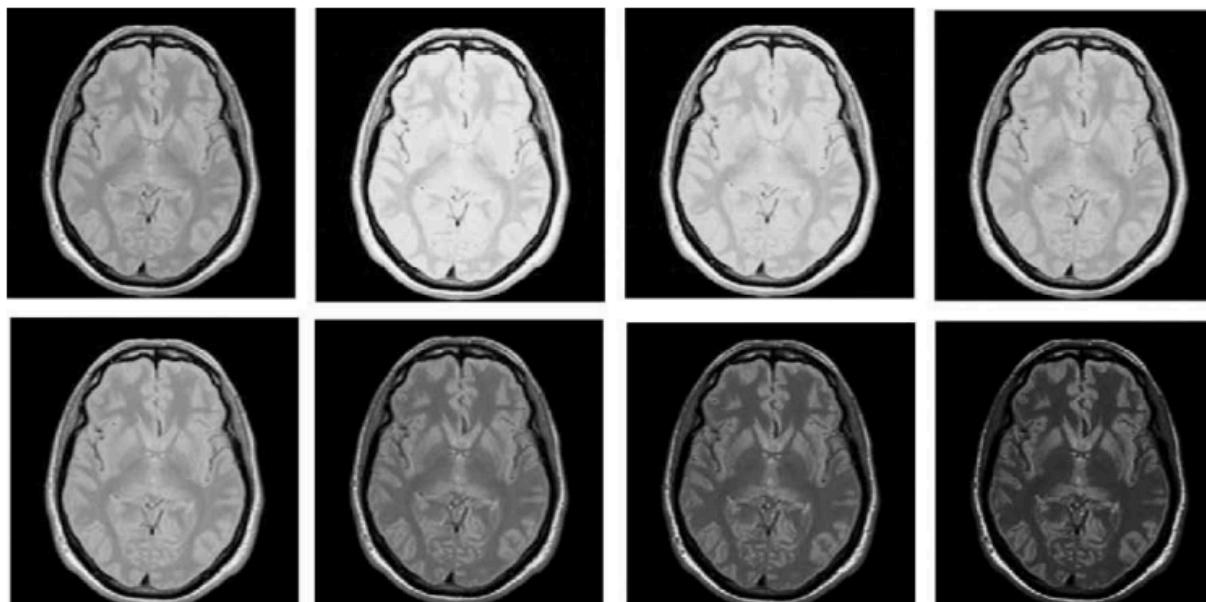


Intensity Non-Standardness

- MR image intensities do not possess a tissue-specific numeric meaning even in images acquired for
 - the same subject,
 - on the same scanner,
 - for the same body region,by using the same pulse sequence

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same brain slice,
same person,
same scanners,
different imaging times,
intensities are significantly
different for the same
Tissue type!

Summary of Problems

- MRI intensities do not have a fixed meaning, even for the same protocol, body region, patient, scanner.

Summary of Problems

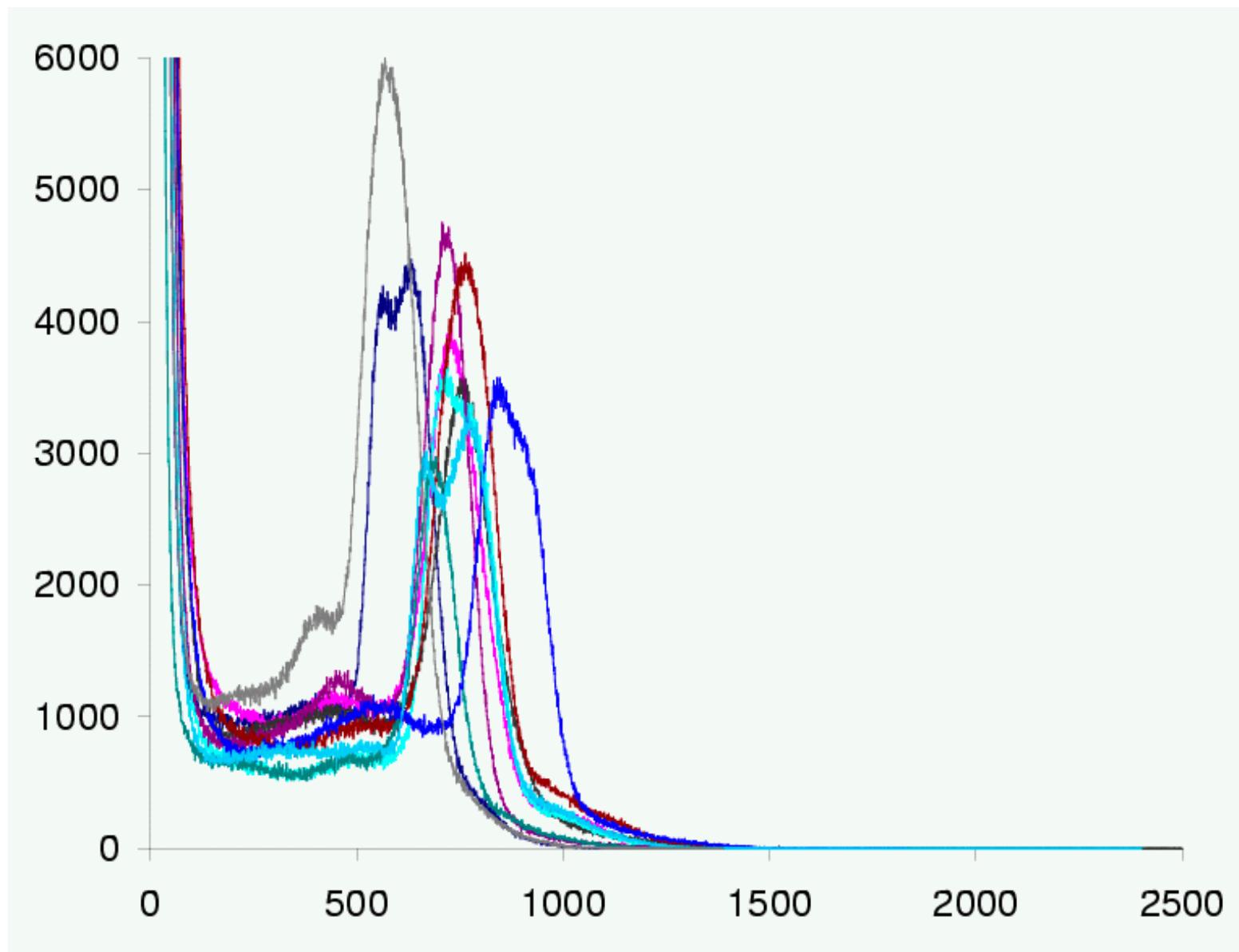
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- Poses problems for image segmentation and analysis

Summary of Problems

- MRI intensities do not have a fixed meaning, even for the same protocol, body region, patient, scanner.
- Poses problems for image segmentation and analysis
- Do you think linear scaling will help? (normalization)?
 - Shifting intensity values linearly to other parts of the histogram?

Summary of Problems

- MRI intensities do not have a fixed meaning, even for the same protocol, body region, patient, scanner.
- Poses problems for image segmentation and analysis
- Simple linear scaling does not help!



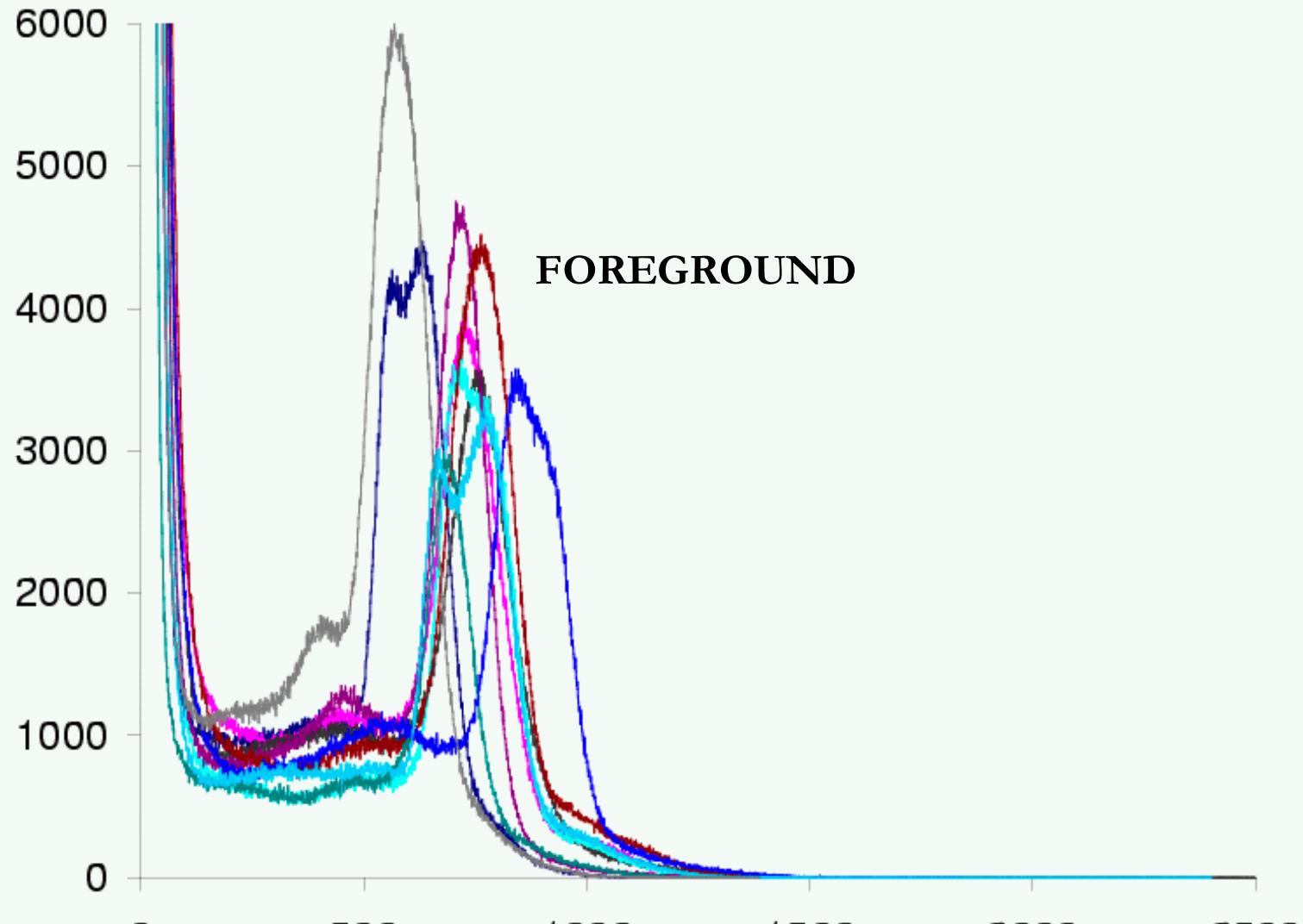
ORIGINAL
HISTOGRAMS

Credit: L. Nyul



BACKGROUND

FOREGROUND



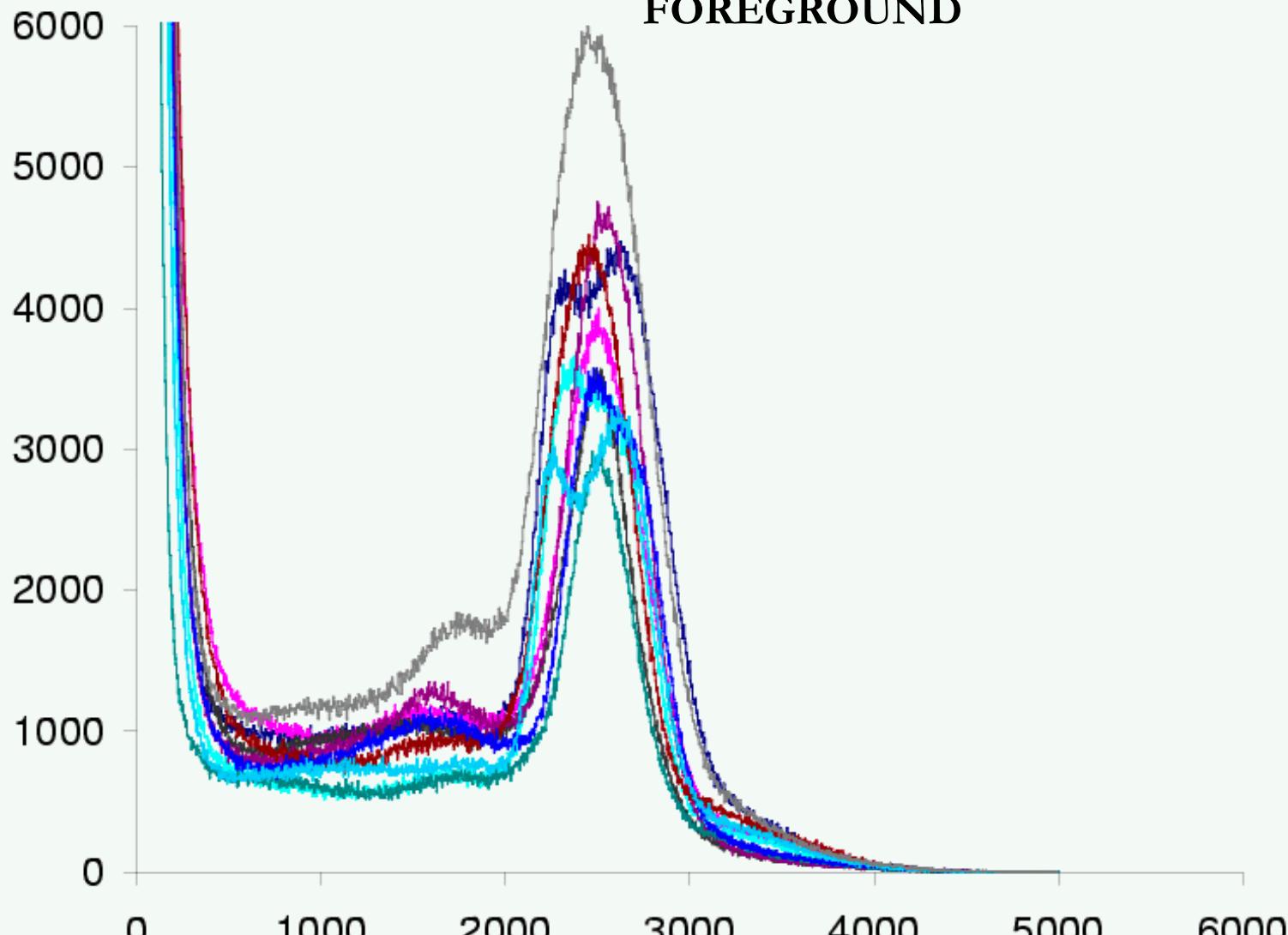
10 Different
PD studies

ORIGINAL
HISTOGRAMS



BACKGROUND

FOREGROUND

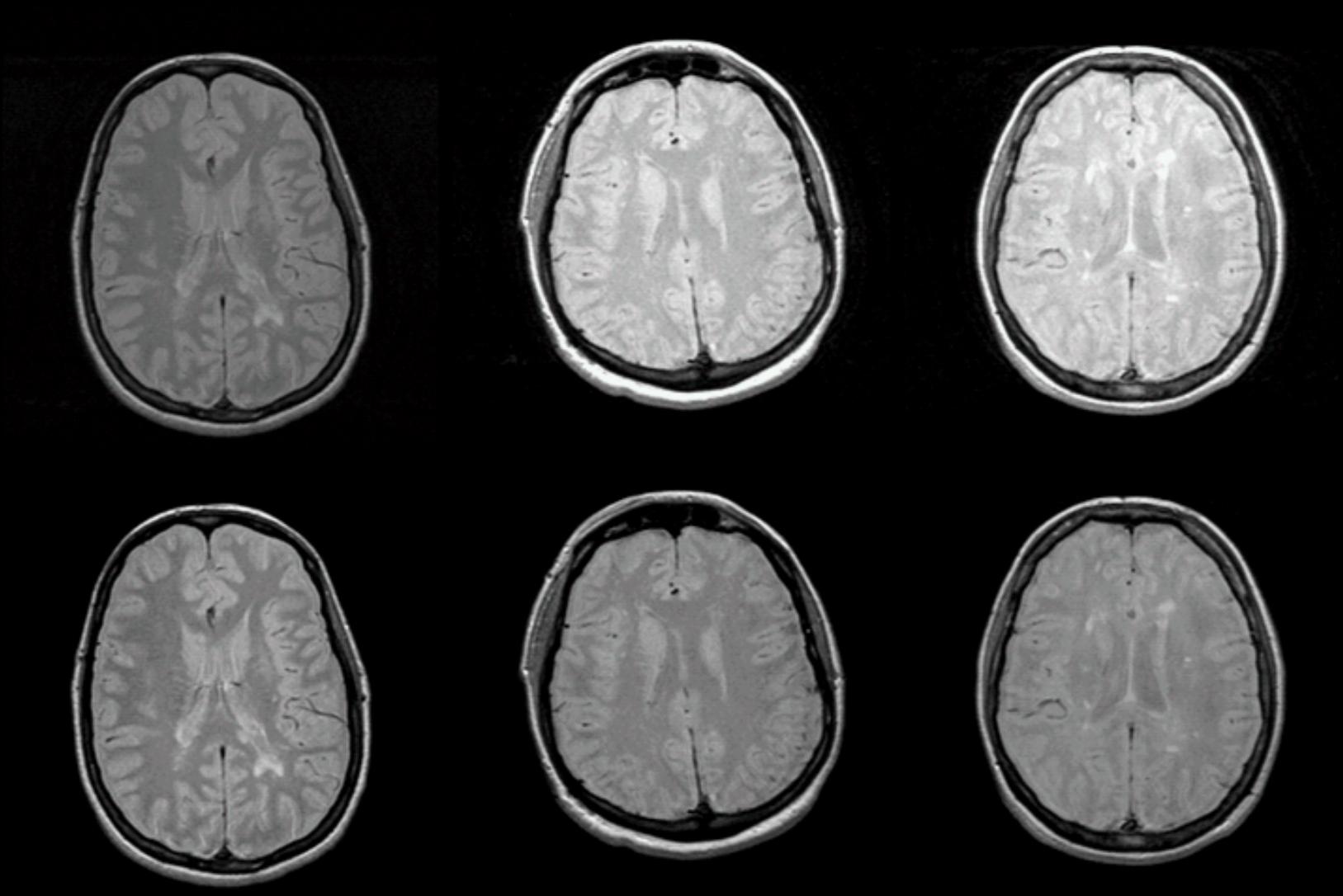


10 Different
PD studies

ORIGINAL
HISTOGRAMS



Original
Gray Scale



After Intensity
Standardization

Credit: L. Nyul



How to Standardize MRI Intensities?

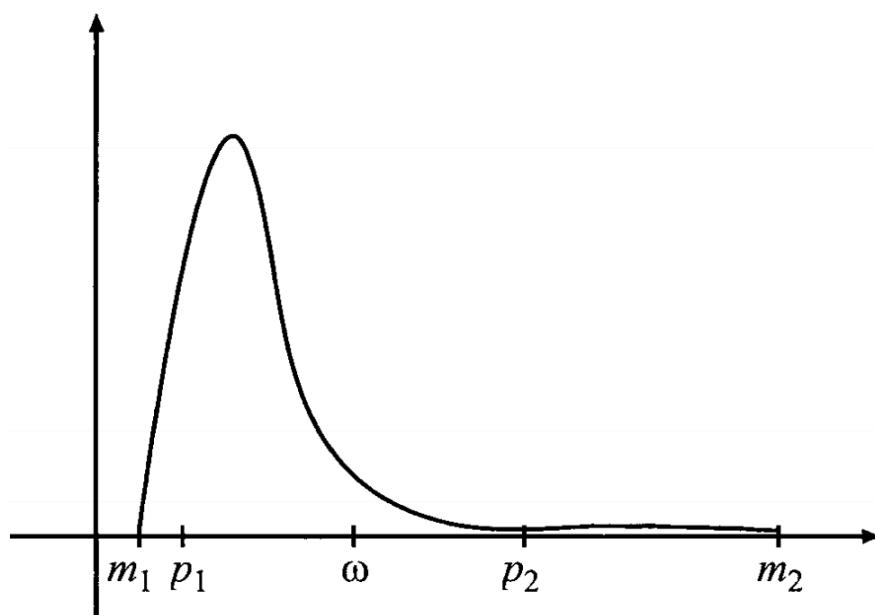
How to Standardize MRI Intensities?

- Histogram

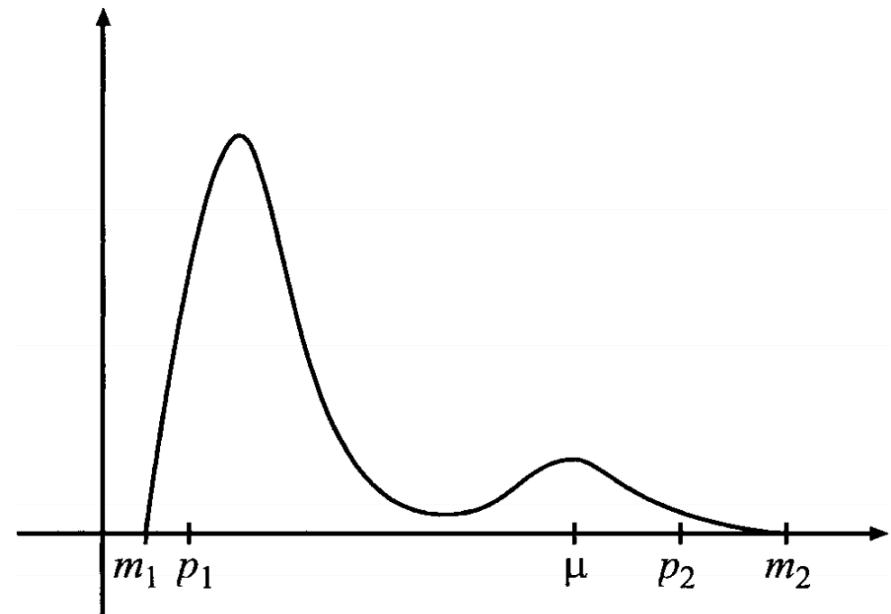


How to Standardize MRI Intensities?

- Histogram



Mono-modal

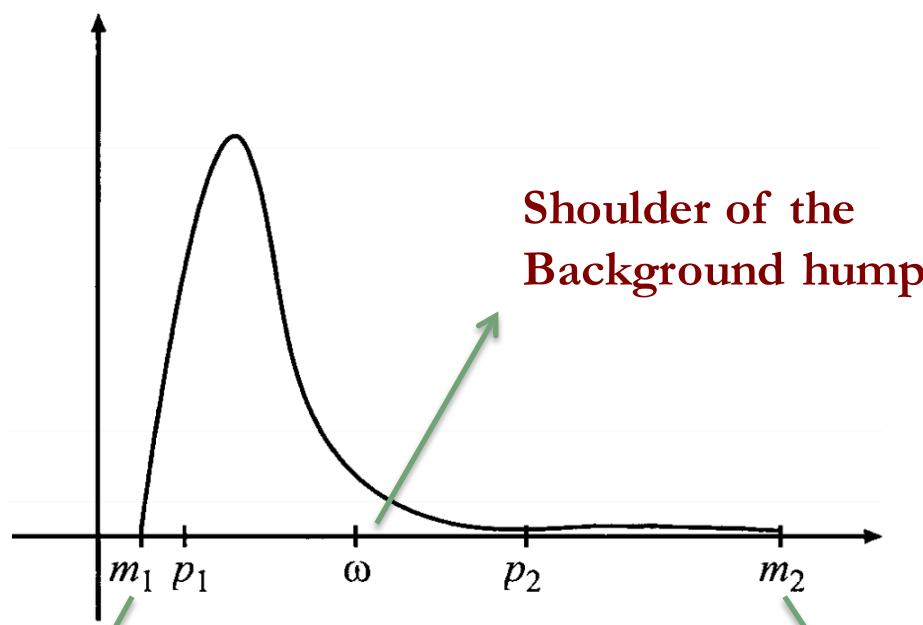


Bi-modal



How to Standardize MRI Intensities?

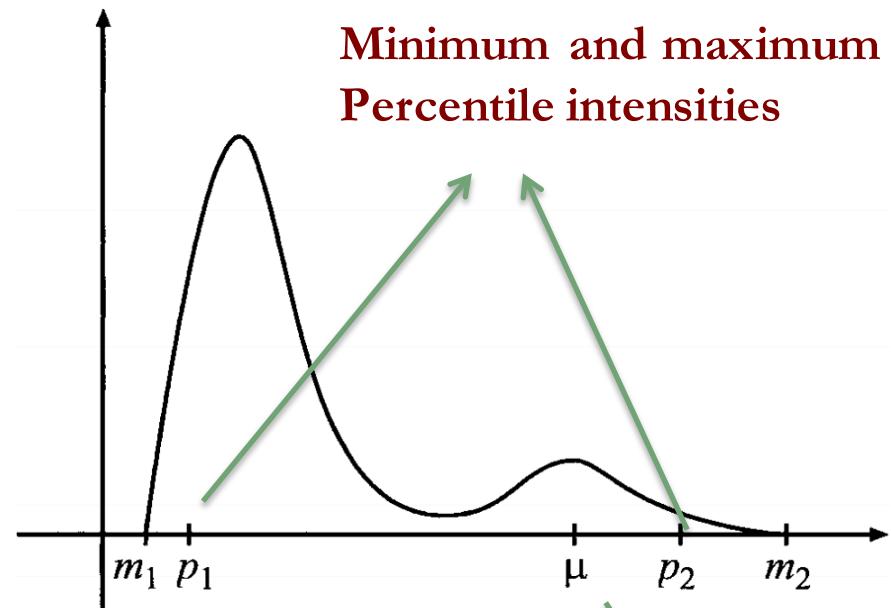
- Histogram



Mono-modal

Minimum intensity

Maximum intensity



Bi-modal

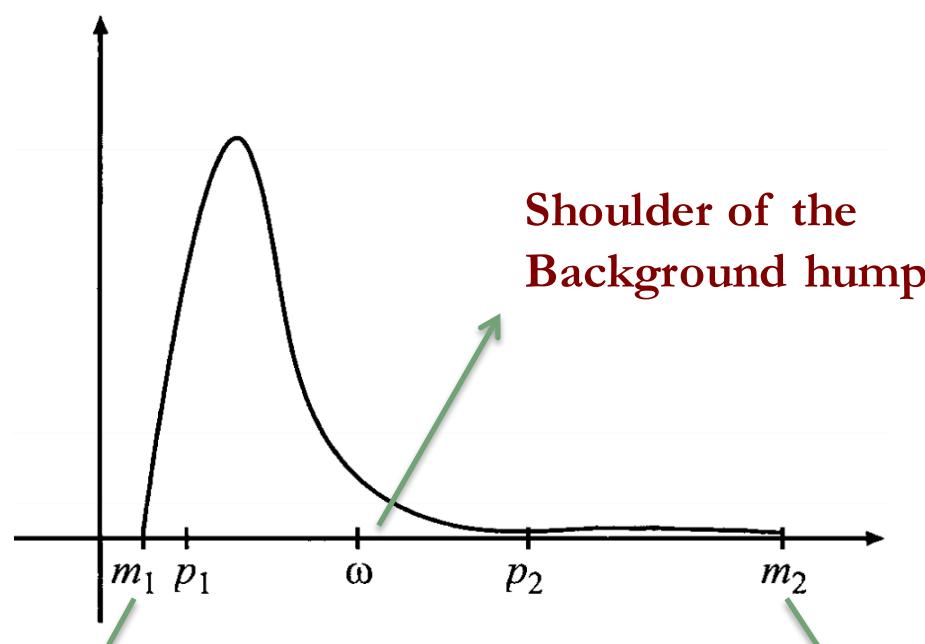
Second mode
Of the histogram

Minimum and maximum
Percentile intensities



How to Standardize MRI Intensities?

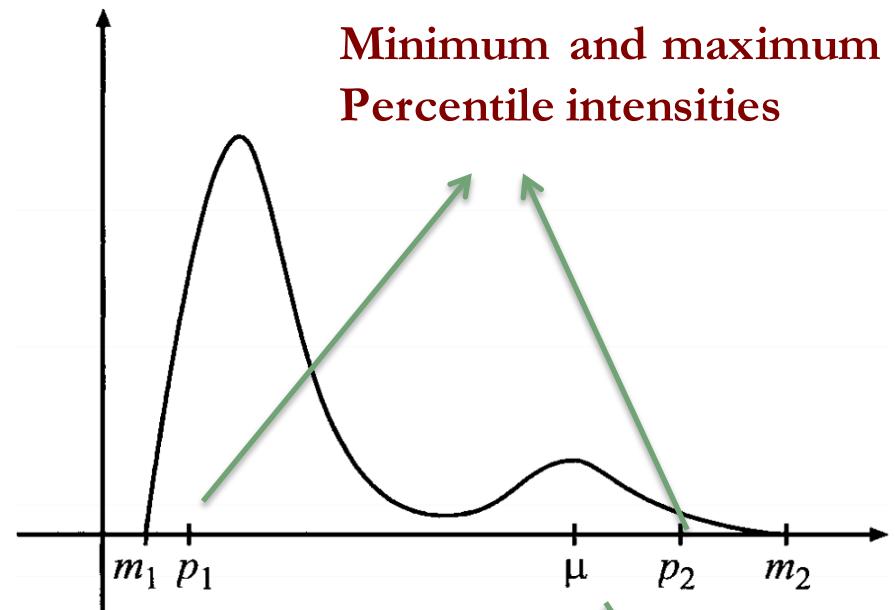
- Histogram



Mono-modal

Minimum intensity

Minimum and maximum Percentile intensities



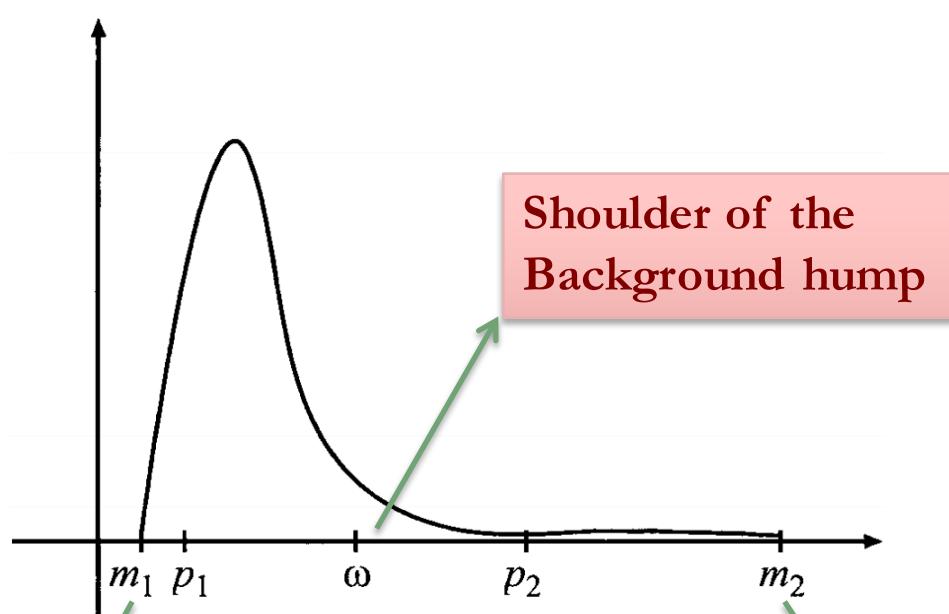
Bi-modal

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How to Standardize MRI Intensities?

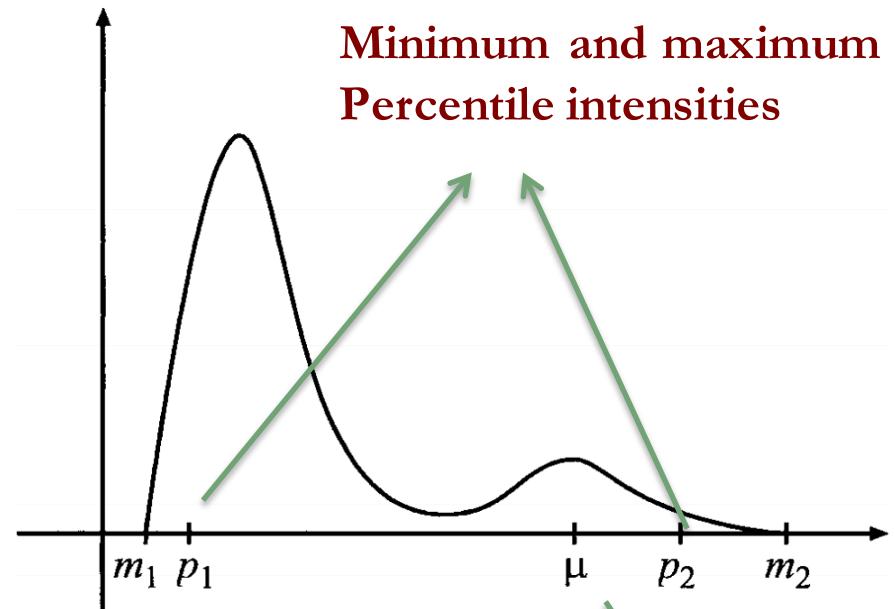
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Mono-modal

Minimum intensity

Maximum intensity



Bi-modal

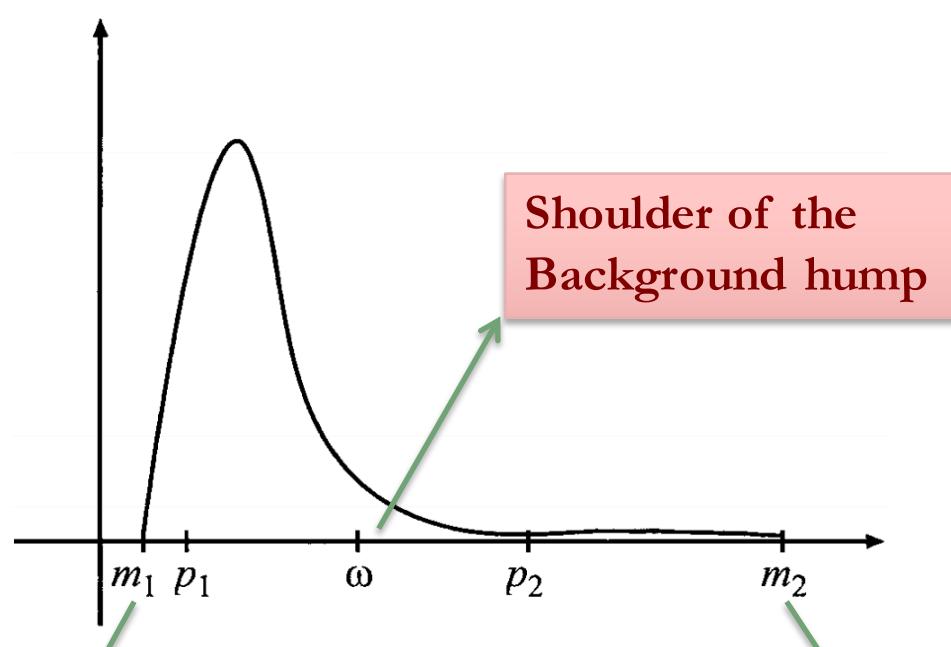
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Minimum and maximum
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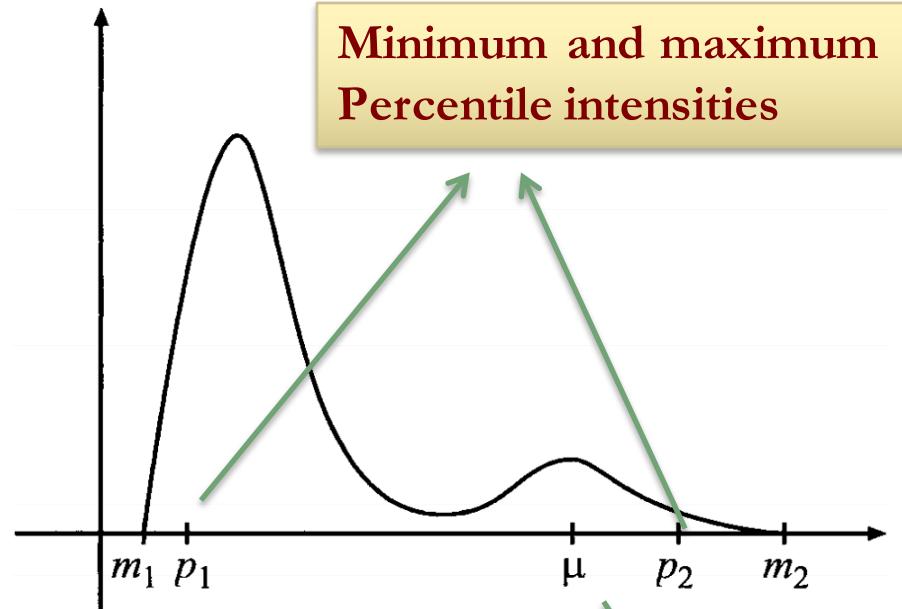
- Histogram



Mono-modal

Minimum intensity

Maximum intensity



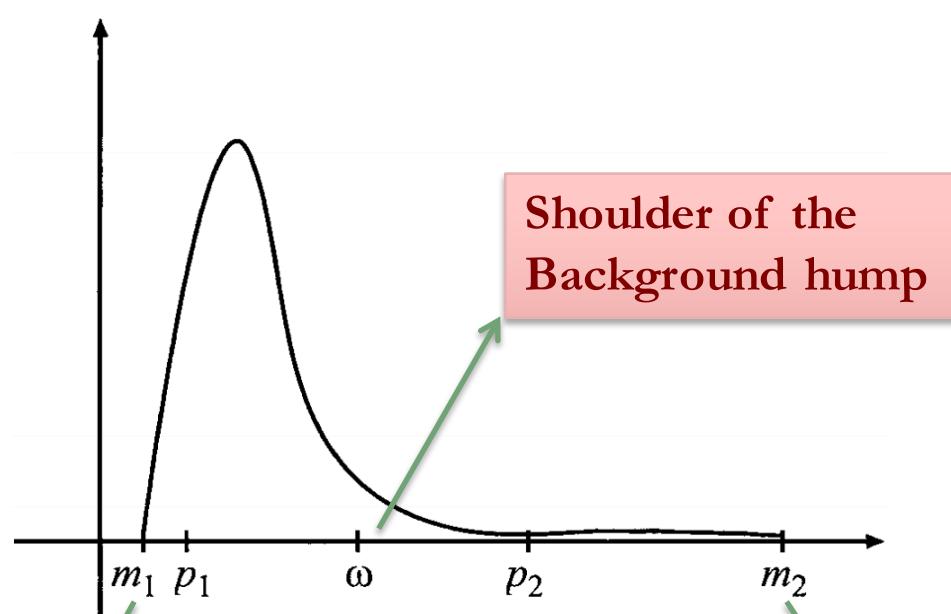
Bi-modal

Second mode
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How to Standardize MRI Intensities?

- Histogram

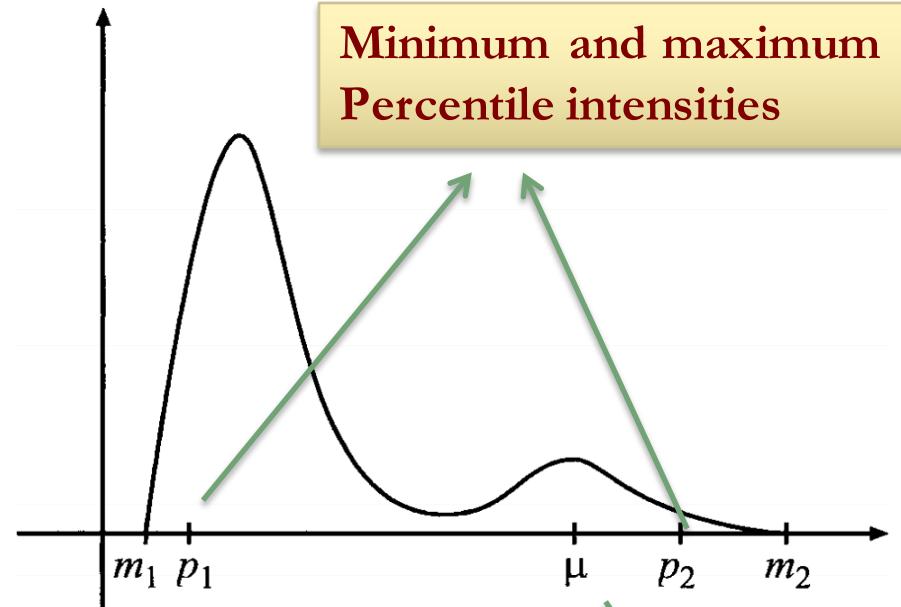


Mono-modal

Minimum intensity

Shoulder of the
Background hump

Maximum
intensity



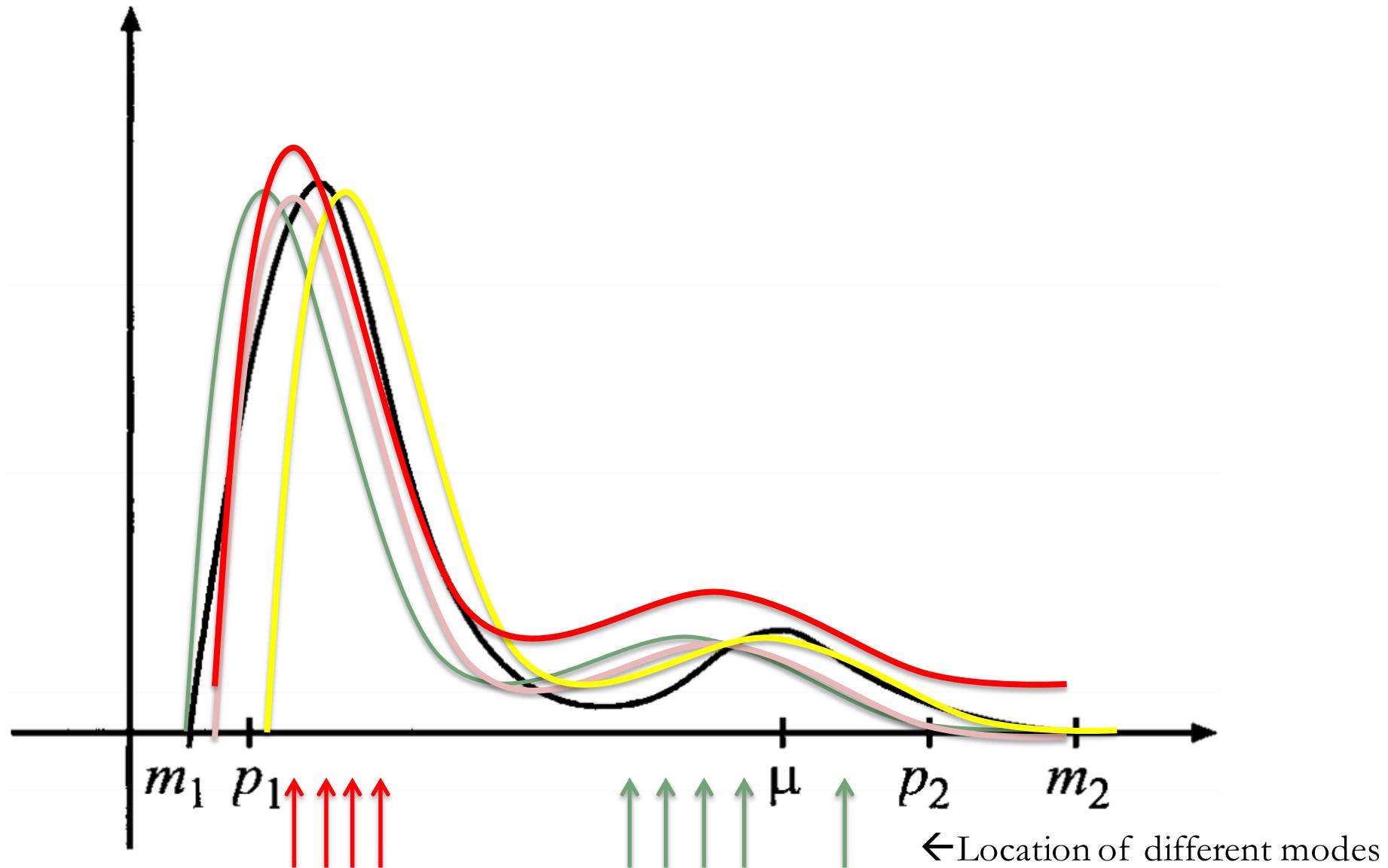
Bi-modal

Minimum and maximum
Percentile intensities

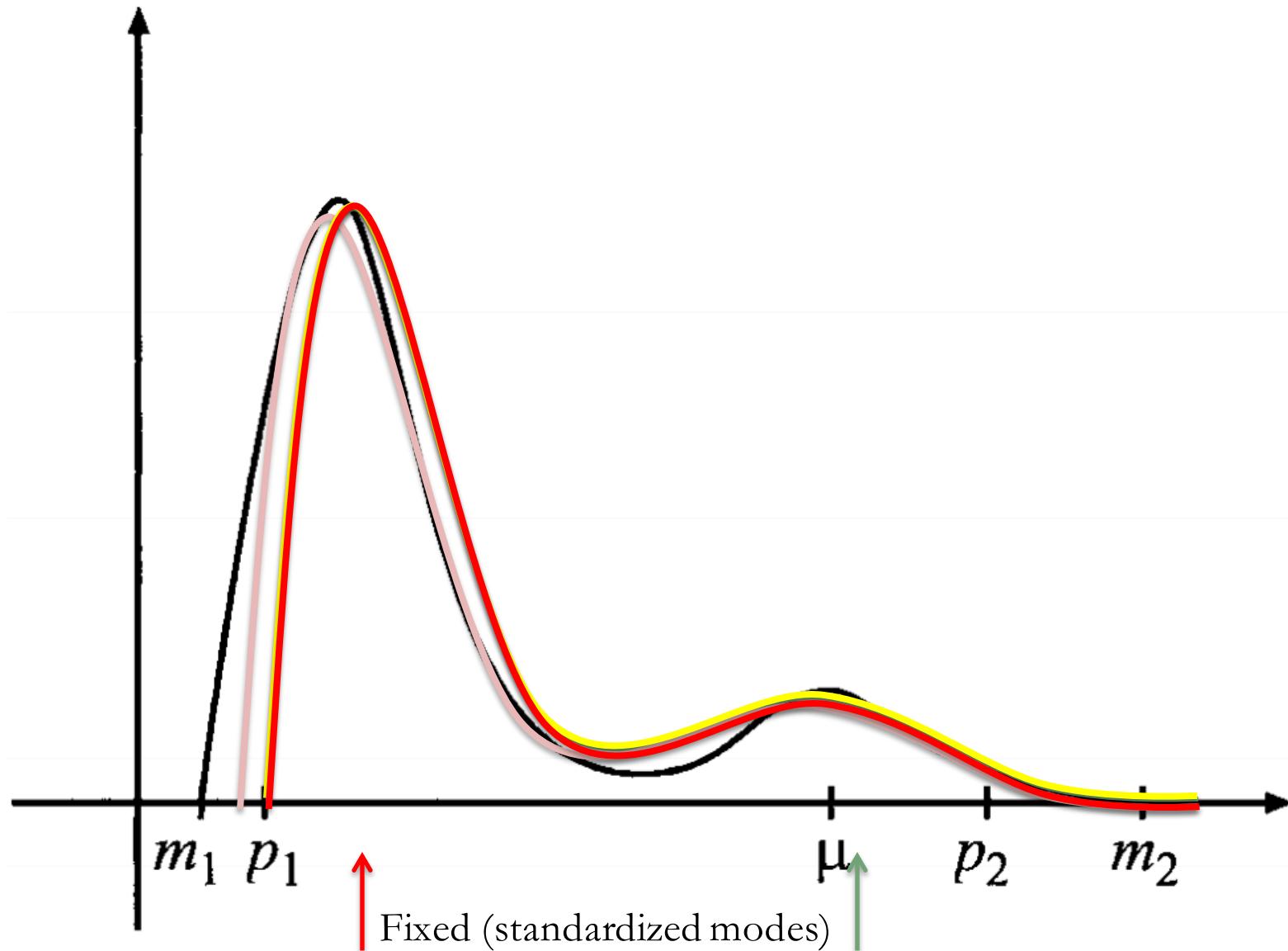
Second mode
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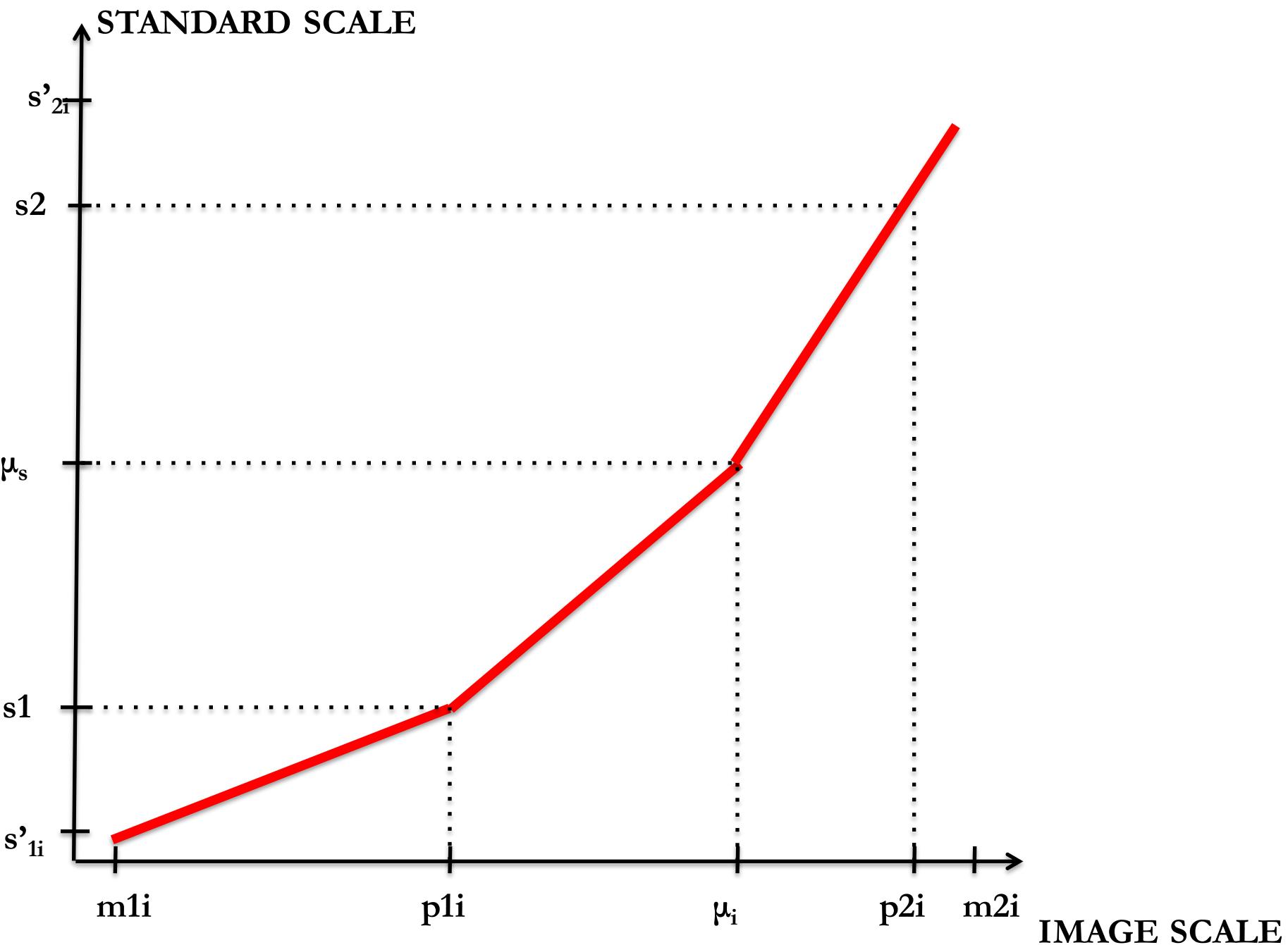


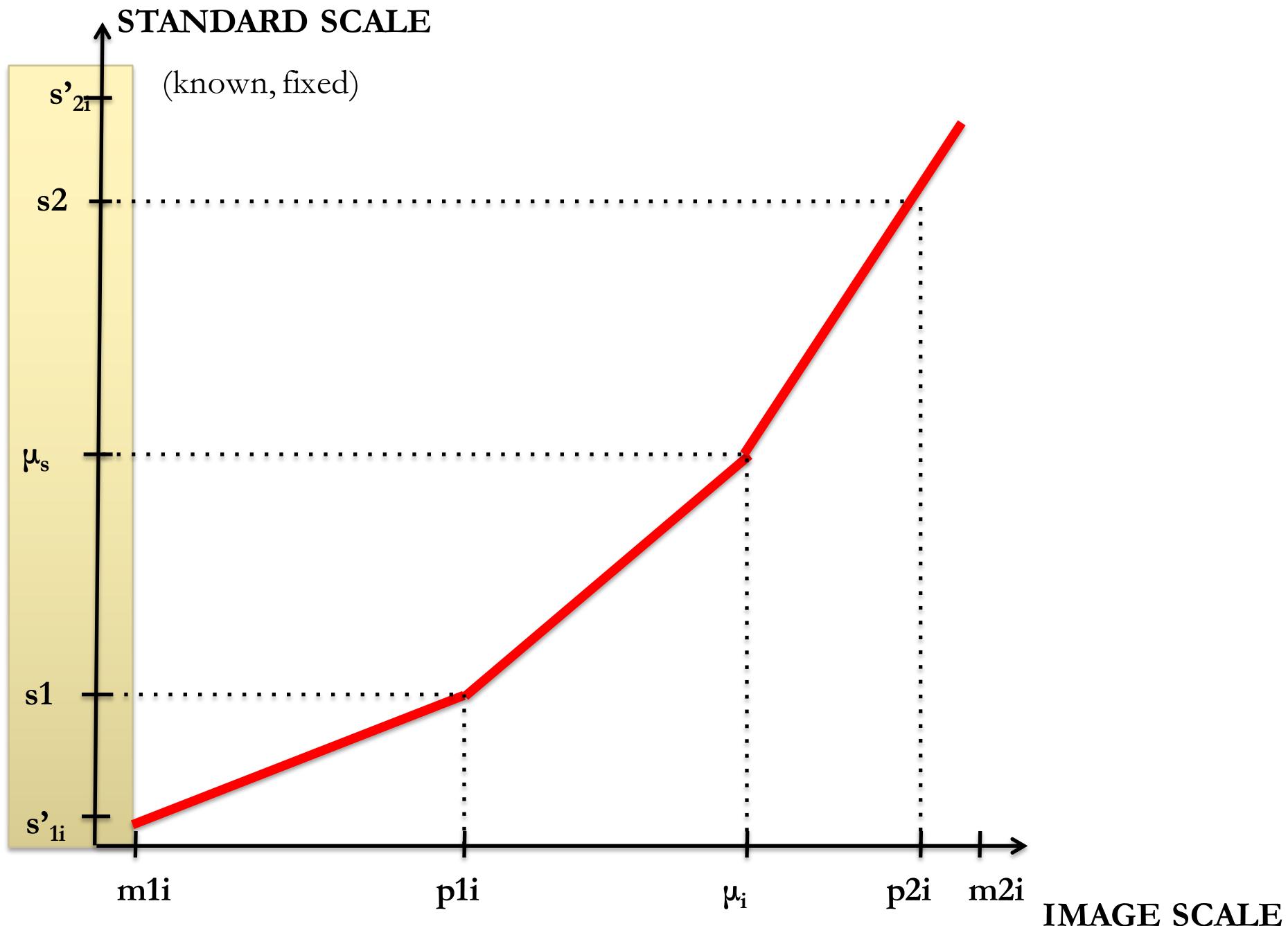
Map background and foreground into the fixed intensity regions!

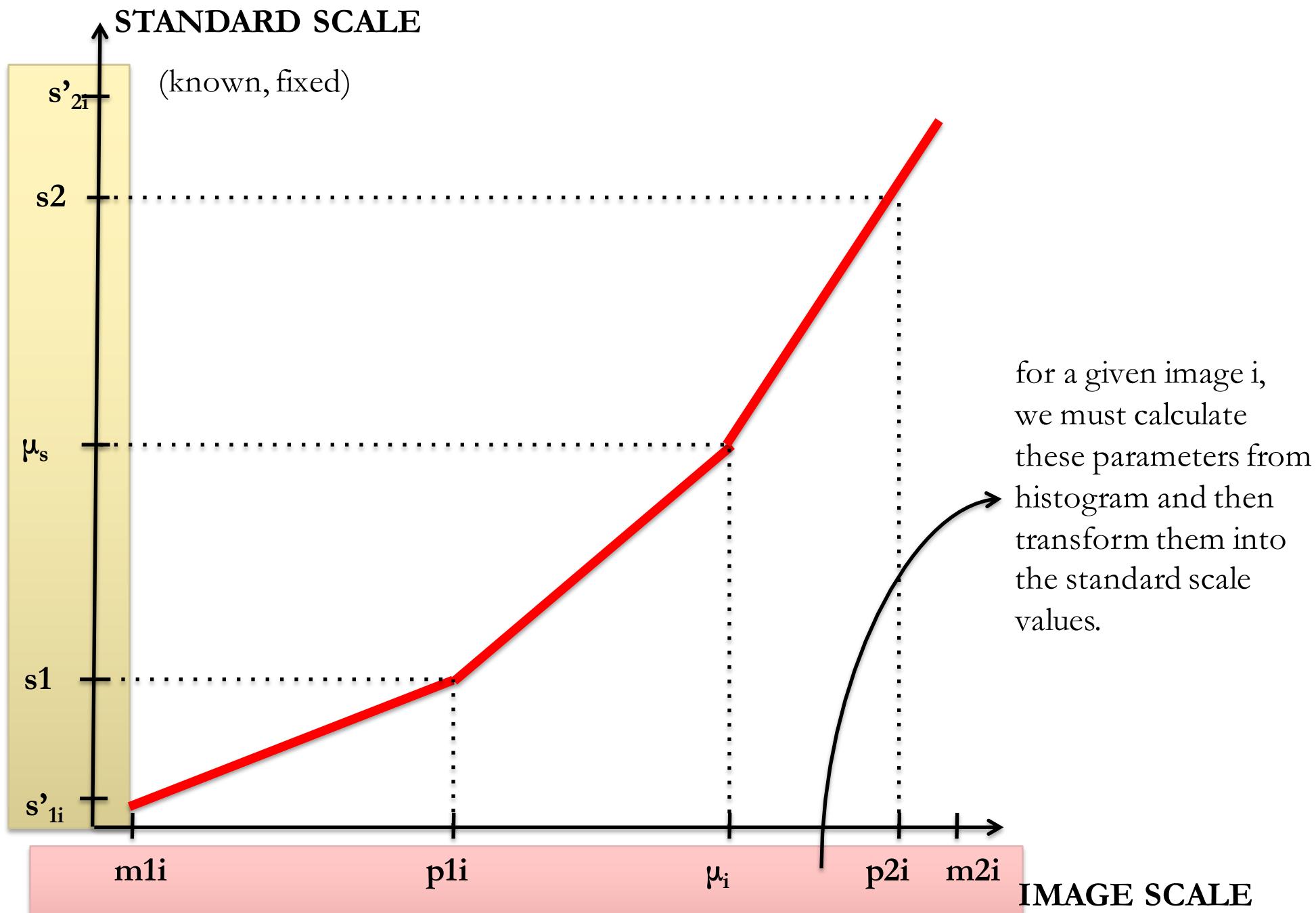


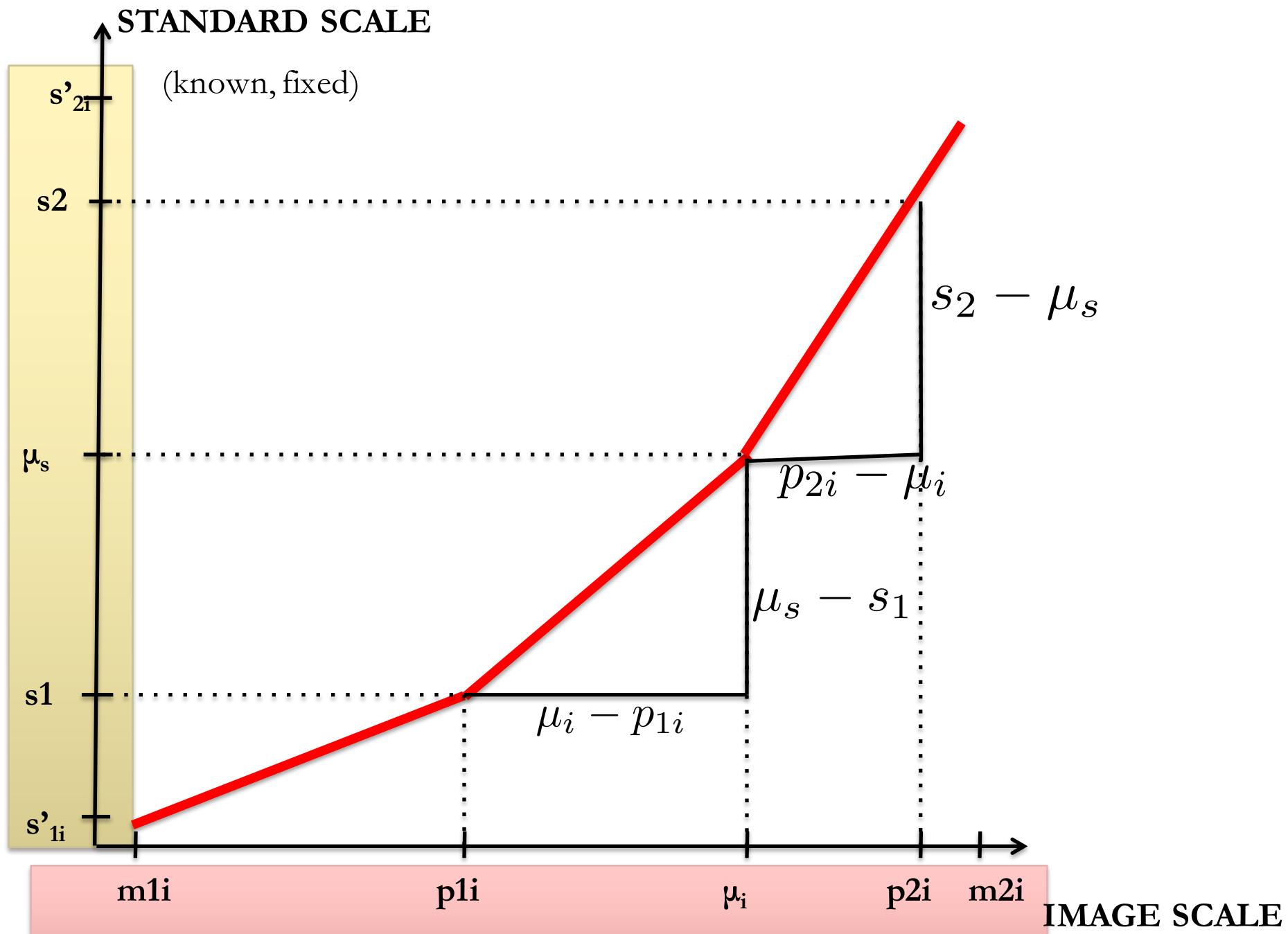
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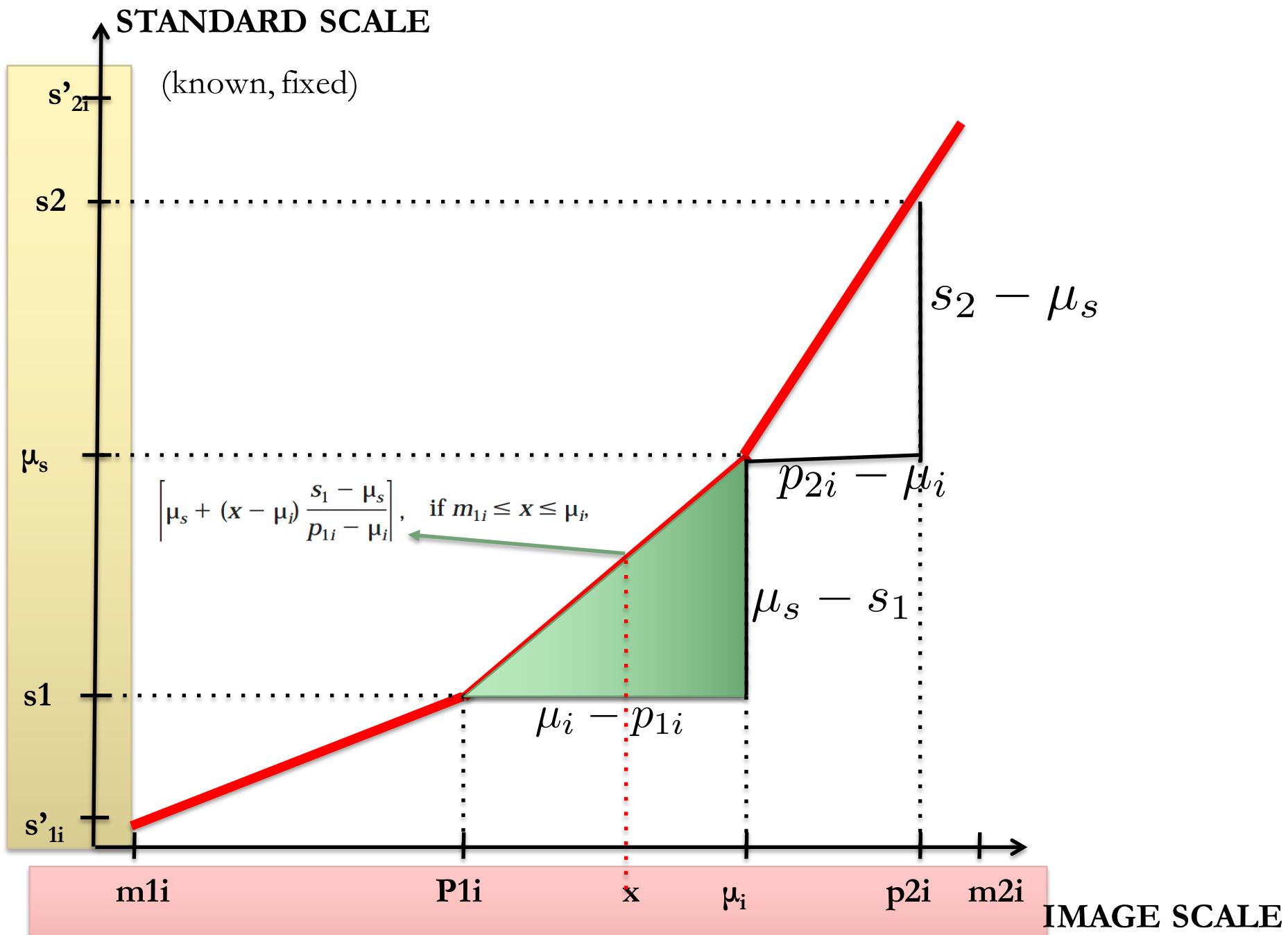


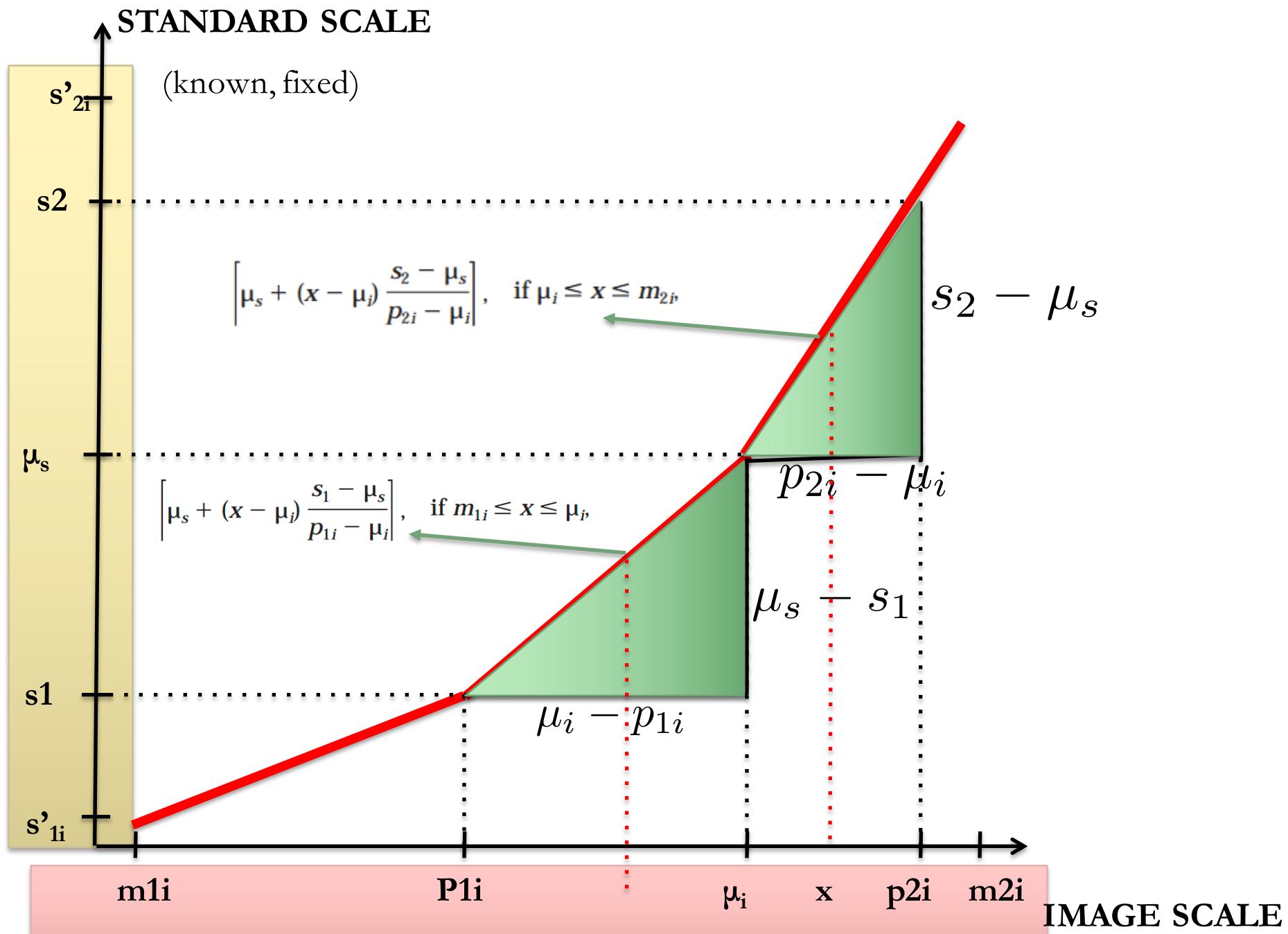










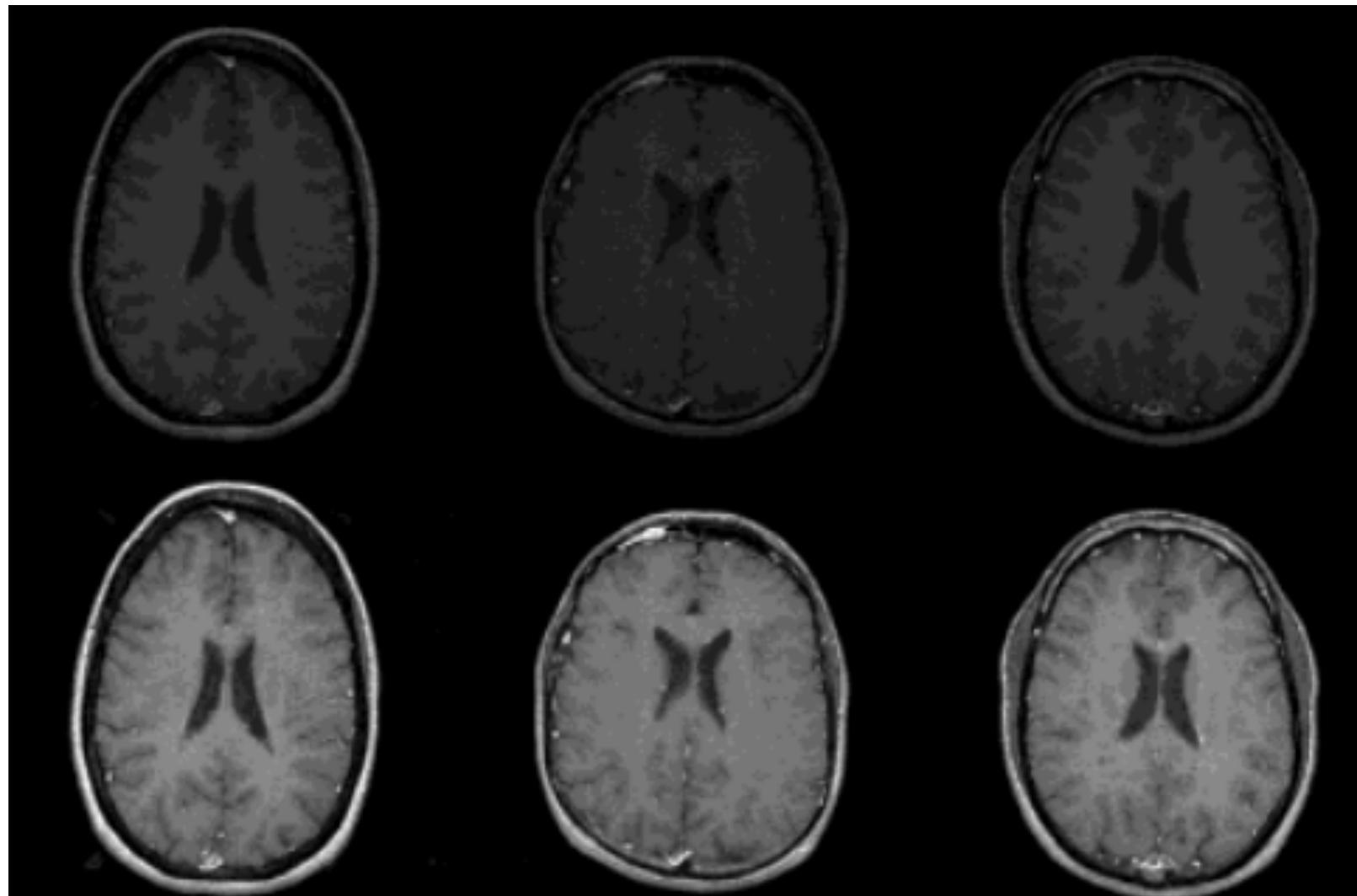


Intensity Mapping Function

$$\tau_{\mathcal{V}_i}(x) \begin{cases} \left[\mu_s + (x - \mu_i) \frac{s_1 - \mu_s}{P_{1i} - \mu_i} \right], & \text{if } m_{1i} \leq x \leq \mu_i, \\ \left[\mu_s + (x - \mu_i) \frac{s_2 - \mu_s}{P_{2i} - \mu_i} \right], & \text{if } \mu_i \leq x \leq m_{2i}, \end{cases}$$

Standardized Intensity Mapping T1-MRI

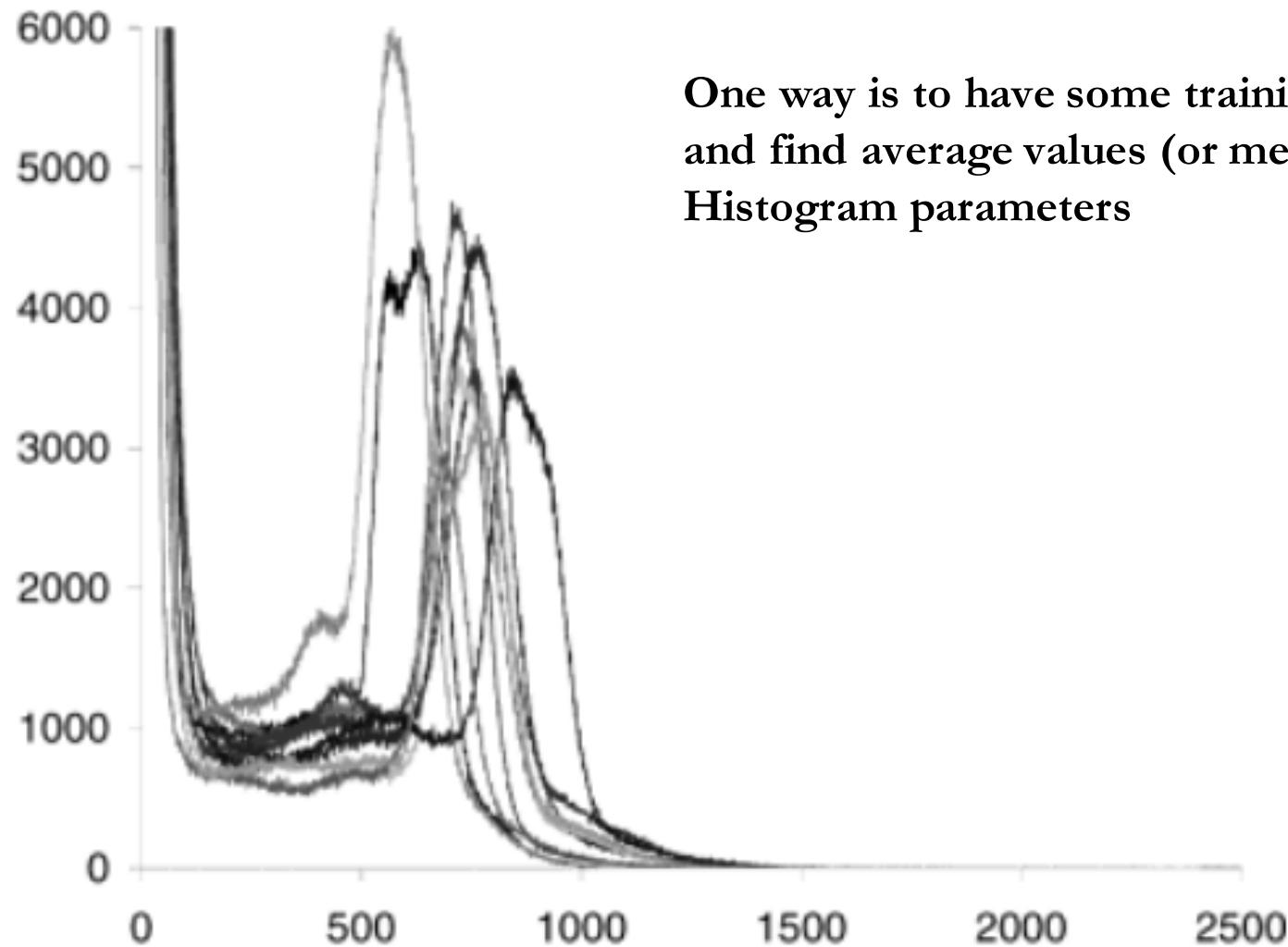
Original Scale



Standard Scale



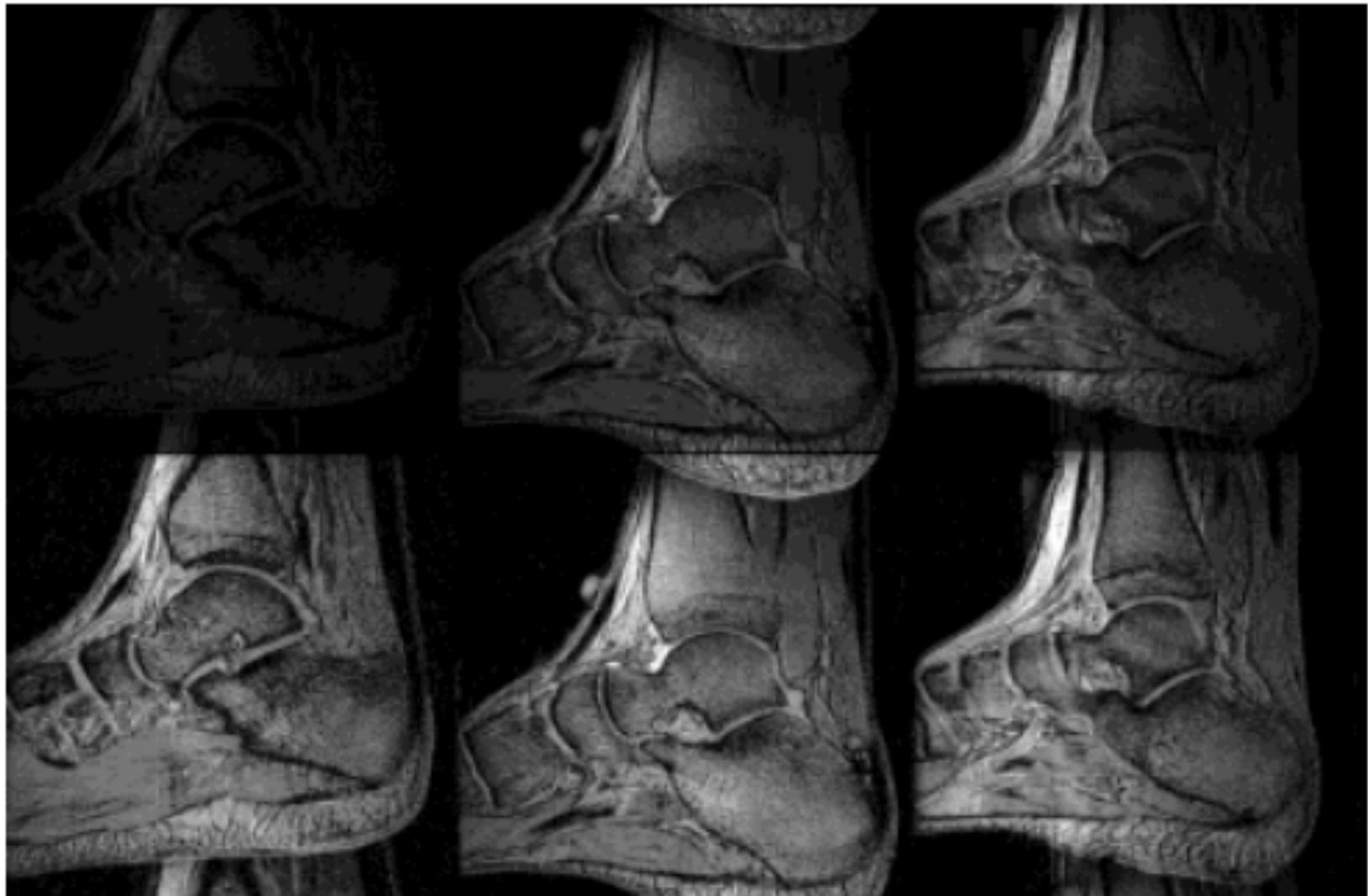
How to determine standardized parameters?



One way is to have some training images,
and find average values (or median) for
Histogram parameters

Foot MRI Intensity Standardization

Original Scale

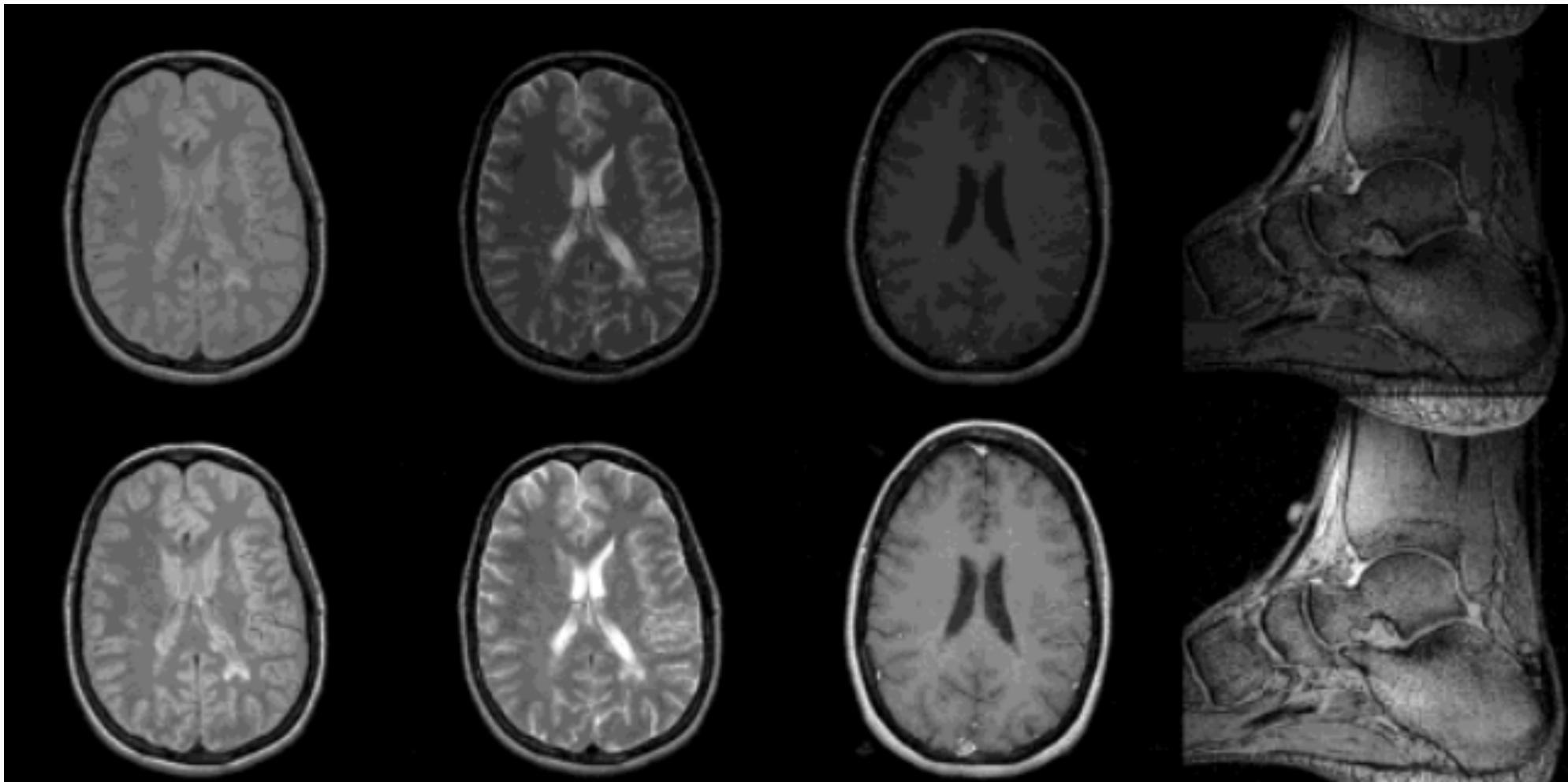


Standard Scale

Different Body region, MR Modality, and Subjects for Training?



Different Body region, MR Modality, and Subjects for Training? (mixed training)



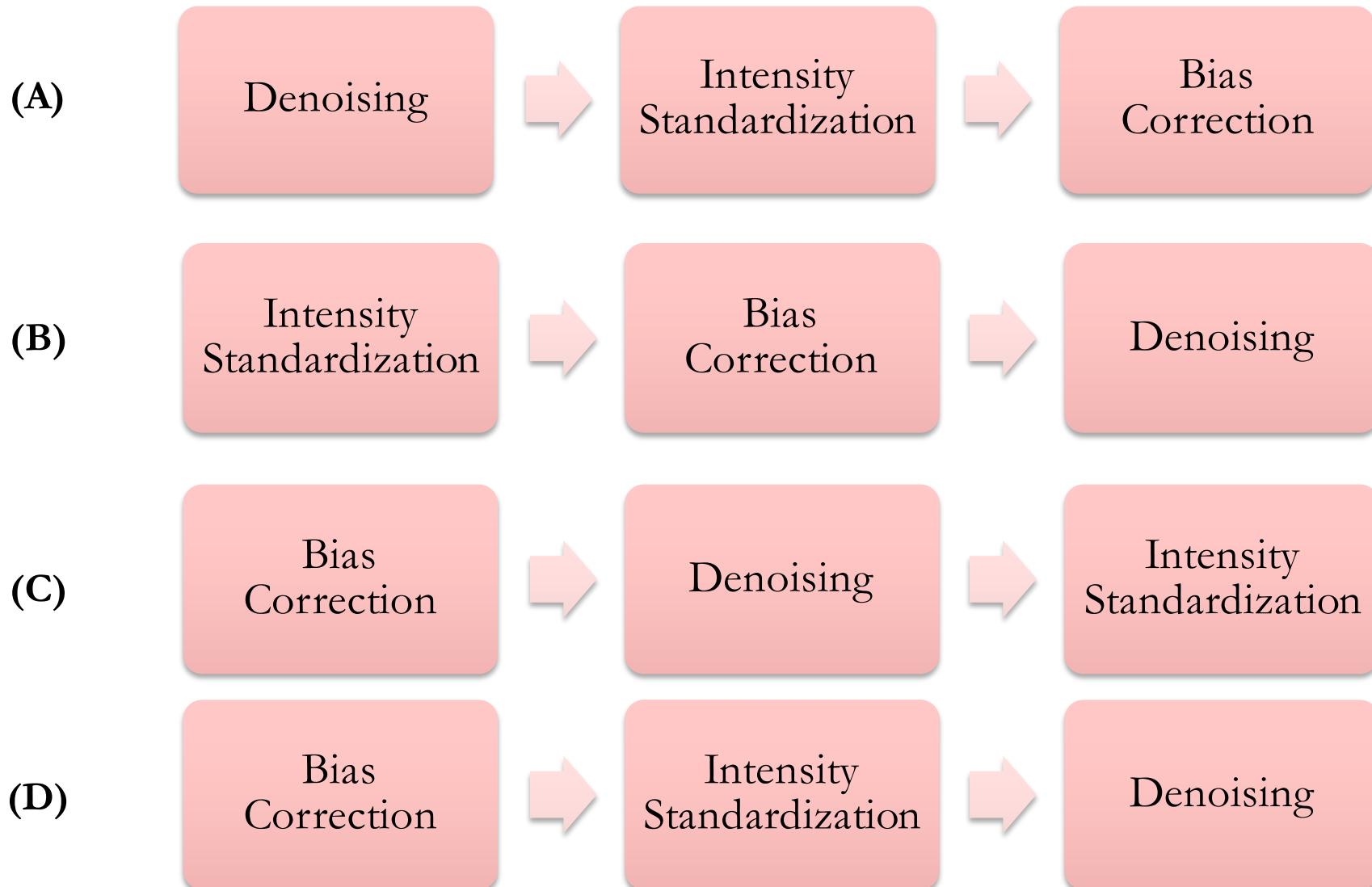
Quantitative Comparisons

Mean and Standard Deviation of Normalized Mean Squared Differences (NMSD) Before and After Standardization for 15 Pairs of Studies and for Three Different Protocols

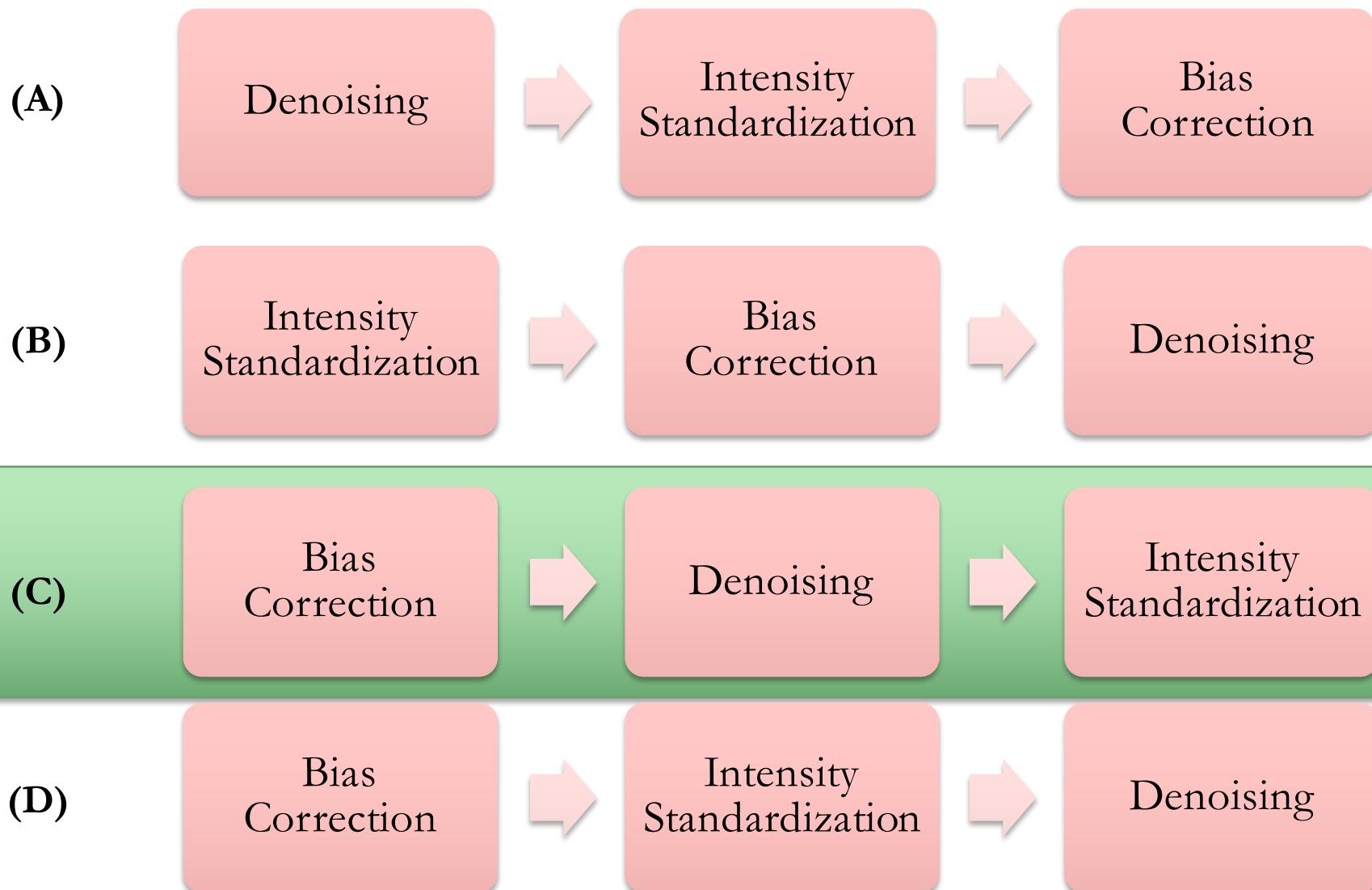
	FSE Pd		FSE T ₂		T ₁ E	
	Mean	SD	Mean	SD	Mean	SD
Before	0.0099	0.0094	0.0093	0.0085	0.0025	0.0018
After	0.0039	0.0055	0.0036	0.0050	0.0020	0.0018
P-value		0.0094		0.0036		0.0450

Each pair represents the studies obtained for the same patient at two time instances. The *P*-values of paired *t*-tests are also shown.

Interplay between Denoising, Bias Correction, and Intensity Standardization ?



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Effects of Intensity Standardization on Image Registration

- The results from literature (**Bagci PRL 2010**) imply that the accuracy of image registration not only depends on spatial and geometric similarity but also on the similarity of the intensity values for the same tissues in different images

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Comparison of methods for Accuracy. The Goodness values γ are listed. Type of non-standardness are indicated by $\bar{\psi}_1, \dots, \bar{\psi}_7$, and the type of affine deformations are indicated by small, medium, and large in the columns.

Type of non-standardness	Small	Medium	Large	Total
$\bar{\psi}_1$	1	0.8222	0.6562	0.7811
$\bar{\psi}_2$	0.9400	0.8305	0.6167	0.7716
$\bar{\psi}_3$	0.9369	0.7751	0.6309	0.7651
$\bar{\psi}_4$	0.9318	0.7004	0.6048	0.7565
$\bar{\psi}_5$	0.8806	0.6004	0.5622	0.6254
$\bar{\psi}_6$	0.7565	0.5511	0.5341	0.5881
$\bar{\psi}_7$	0.7447	0.5901	0.5051	0.5819

Effects of Intensity Standardization on Image Segmentation

- **Recap:** Segmentation is to extract object information from image.
- For instance, extraction white matter tissue from MRI, identifying the boundaries of lung from CT,

Effects of Intensity Standardization on Image Segmentation

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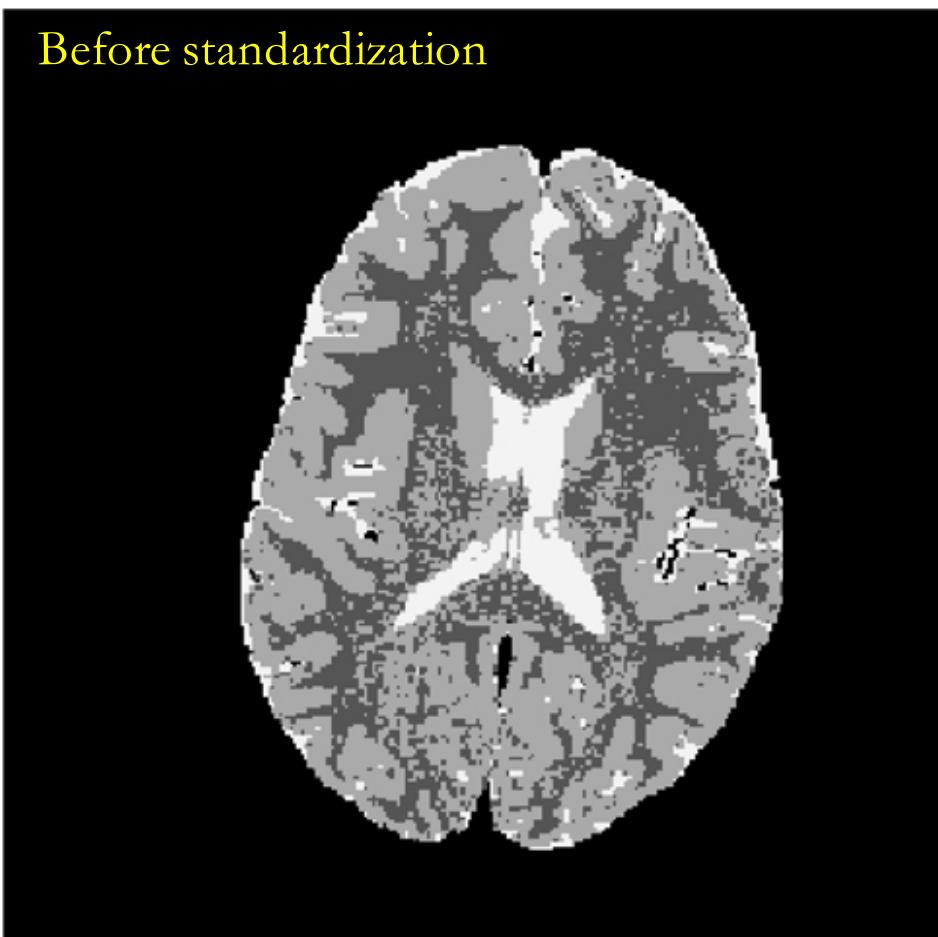
The procedure for segmenting the brain tissues consists of the following steps.

- (S1). Correcting for RF field inhomogeneity.
- (S2). Standardizing MRI scene intensities.
- (S3). Training to estimate parameters of the segmentation method.
- (S4). Creating brain intracranial mask.
- (S5). Estimating tissue membership values.
- (S6). Segmenting brain tissue regions.

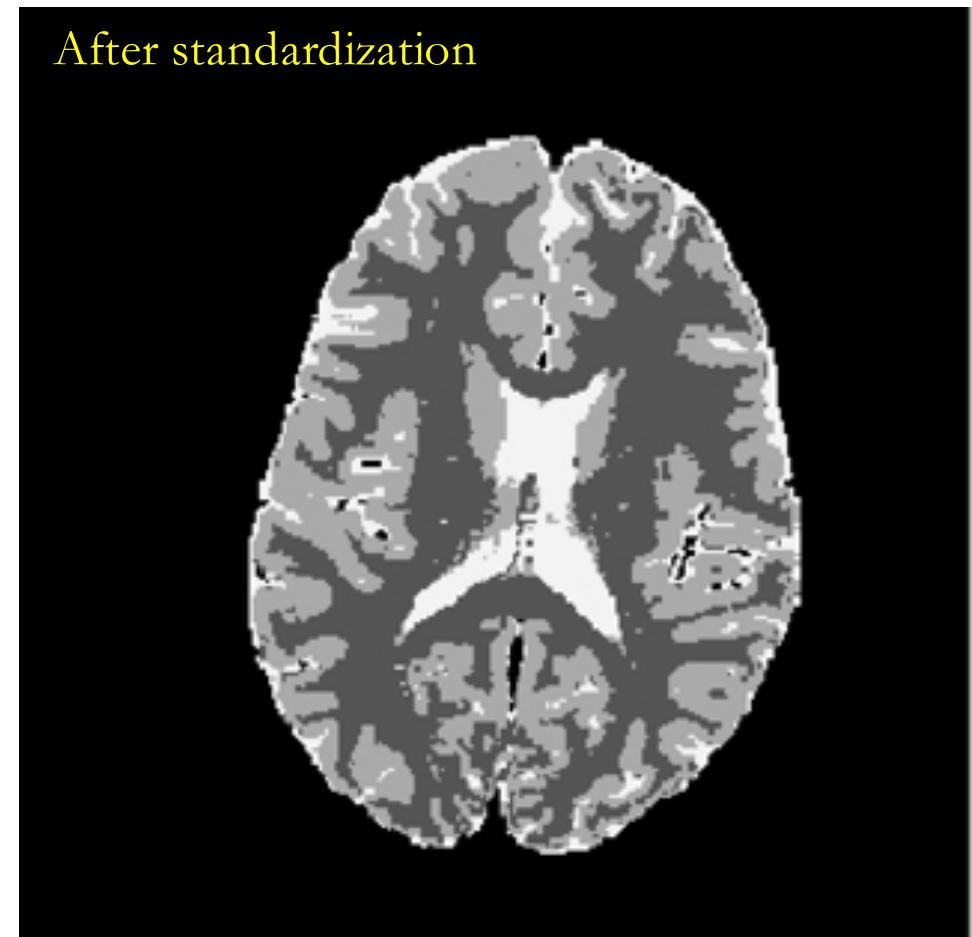
Effects of Intensity Standardization on Image Segmentation

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Before standardization



After standardization



Effects of Intensity Standardization on Anatomy Recognition (Localization/Initialization)

- Bagci et al TMI 2012 showed that object localization is affected from intensity non-standardness.

	Ψ_0	Ψ_1	Ψ_2	Ψ_3	Ψ_4	Ψ_5	Ψ_6	Ψ_7
MOE in x (deg)	0.0292	0.0925	0.0898	0.0615	0.0846	0.0869	0.1945	0.2094
SD in x (deg)	0.7088	0.7399	0.7321	0.7638	0.7684	0.7693	0.7562	0.7303
MOE in y (deg)	0.3576	0.3426	0.3840	0.3858	0.3899	0.3846	0.3528	0.3839
SD in y (deg)	2.0739	2.1311	2.2962	2.3018	2.3970	2.5217	2.3428	2.3060
MOE in z (deg)	0.0209	0.0264	0.0236	0.0341	0.0550	0.0266	0.0984	0.1157
SD in z (deg)	9.4049	9.7597	9.7541	9.7741	9.7796	9.7823	9.7324	9.7051
MTE in mm	2.1004	2.4500	2.5701	2.9700	3.4050	3.2000	3.6606	3.5709
SD in Trans. (in mm)	4.2247	4.2549	4.3690	4.2783	4.4600	4.5811	8.0536	9.7181

- MOE: mean orientation error
- SD: standard deviation
- MTE: mean translation error
- 1...7, increasing order of standardness

Summary

- Intensity non-standardness is inherent in MRI
 - Must standardize
- Intensity standardization + inhomogeneity correction + denoising need to be handled prior to image analysis
- Intensity non-standardness affects
 - Perception/qualitative analysis
 - Image analysis/quantification
 - Segmentation
 - Registration
 - Recognition/localization

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PROGRAMMING ASSIGNMENT 1 IS AVAILABLE THIS WEEK !!!

References and Slide Credits

- Jayaram K. Udupa, MIPG of University of Pennsylvania, PA.
- P. Suetens, Fundamentals of Medical Imaging, Cambridge Univ. Press.
- N. Bryan, Intro. to the science of medical imaging, Cambridge Univ. Press.
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