# High-order local image statistics are used in radiographic judgments of breast density

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## Introduction and Overview

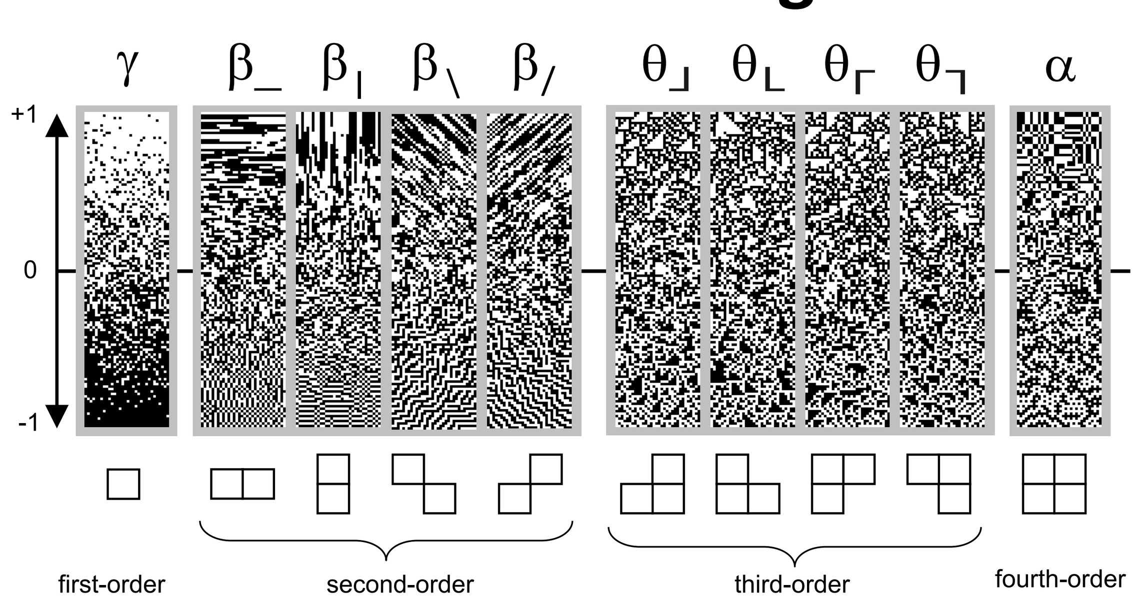
Human observers can use high-order image statistics to discriminate synthetic visual textures. But do they use these statistics for real-world visual tasks?

We addressed this question by analyzing an important clinical judgment: radiologists' ratings of breast density. Determination of breast density is a key factor in breast cancer screening.

We constructed generalized linear models of radiologists' ratings of density based on regressors that either consisted of spectral statistics, or spectral statistics along with local image statistics that captured co-occurrence patterns in pairs, triplets, and quadruplets of neighboring checks.

We found that models that included local image statistics had greater explanatory and predictive power, demonstrating the importance of local image statistics for this real-world visual task.

## Local Image Statistics




For a black-and-white texture, local image statistics describe the configurations of 2x2 neighborhoods via 10 independent parameters, each with a range of -1 to +1. Second-order statistics quantify correlations between pairs checks that are adjacent horizontally, vertically, or diagonally. Third- and fourth-order statistics quantify the parity of checks in regions containing 3 and 4 checks, respectively. The sliders show the effect of varying each statistic in isolation. For a random texture, all statistics have a value of 0.

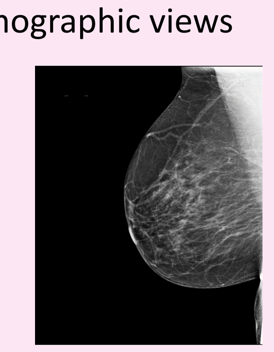
Note that for the images studied here, we binarize at the median, so the first-order statistic is always zero.

## Image Database and Density Ratings

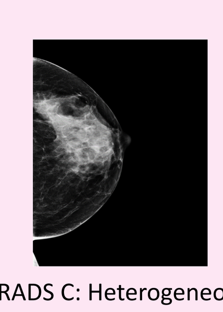
- Image Characteristics
  - Database of de-identified x-ray screening images
  - Full-field digital mammograms (Hologic, Marlborough, MA)
  - 111 patients, 4 standard views per patient (444 images total)
  - Pixel size: 70 microns
  - Area available for analysis: typically > $10^6$ pixels in breast interior
- Patient Characteristics
  - Random sample of University of Pittsburgh Medical Center screening population
  - All images considered normal, with no examples of diagnosed breast cancer
- Breast Density Ratings
  - BIRADS density classification: A: fatty, B: scattered density, C: heterogeneous density, D: dense
  - Ratings made by the radiologist who read the screening exam
- Dependent Variable for Analysis: C or D = "dense", A or B = "not dense"

examples of density categories in standard mammographic views

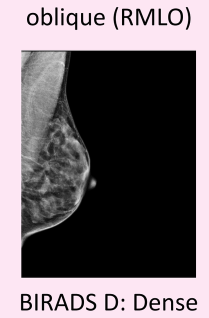
BIRADS A: Fatty
view: right craniocaudal (RCC)



BIRADS B: Scattered
view: right mediolateral oblique (RMLO)



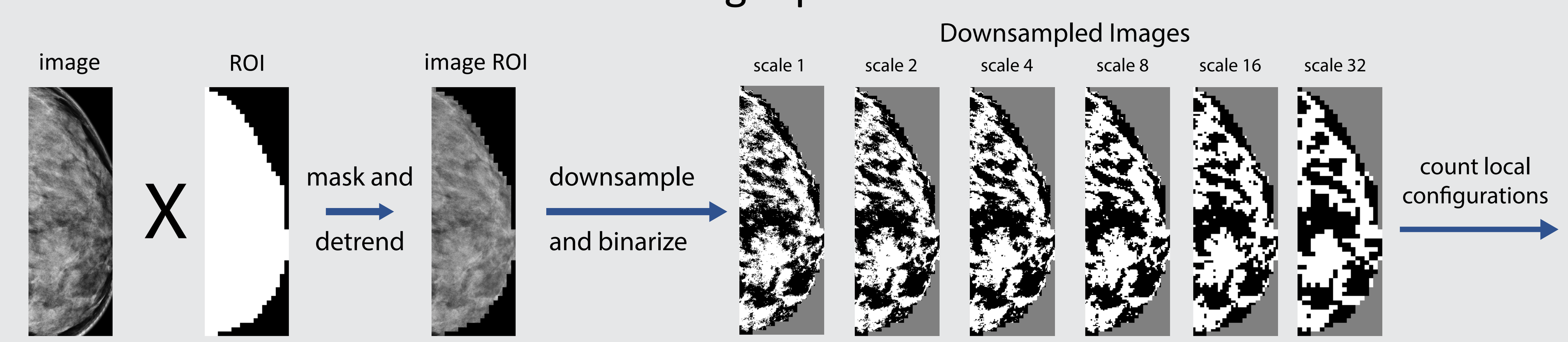
BIRADS C: Heterogeneous
view: left craniocaudal (LCC)



BIRADS D: Dense
view: left mediolateral oblique (LMLO)

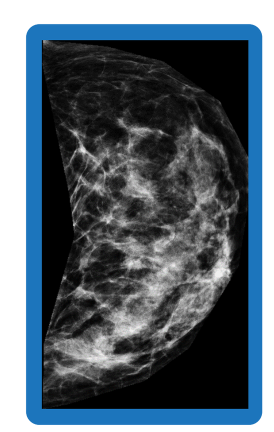
These are example images as viewed by the radiologist. Images demonstrate, in separate patients, the four density ratings and the four standard mammographic views. Skin and chest wall (visible on the oblique views) were excluded from the image analysis.

## Processing Pipeline

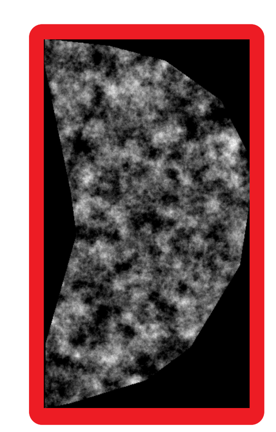



A mask that delineates the interior of the breast was constructed by hand. The texture within this ROI was then quadratically detrended. The result was then downsampled by block-averaging at a range of scales (1x1 to 32 x32 pixels) and then binarized at the median of the ROI. Local image statistics were computed by counting the number of configurations of each 2x2 neighborhood of binarized checks. This generates a set of 9 local image statistics at each of the 6 scales, for each of the original 444 patient images. Along with the spectral slope, spectral intercept, and integrated power spectrum with a bandpass of 0.2 cy/mm to 1.0 cy/mm (Burgess et al., 2001), these statistics serve as independent variables for statistical modeling.

## Local image statistics of mammograms and natural images



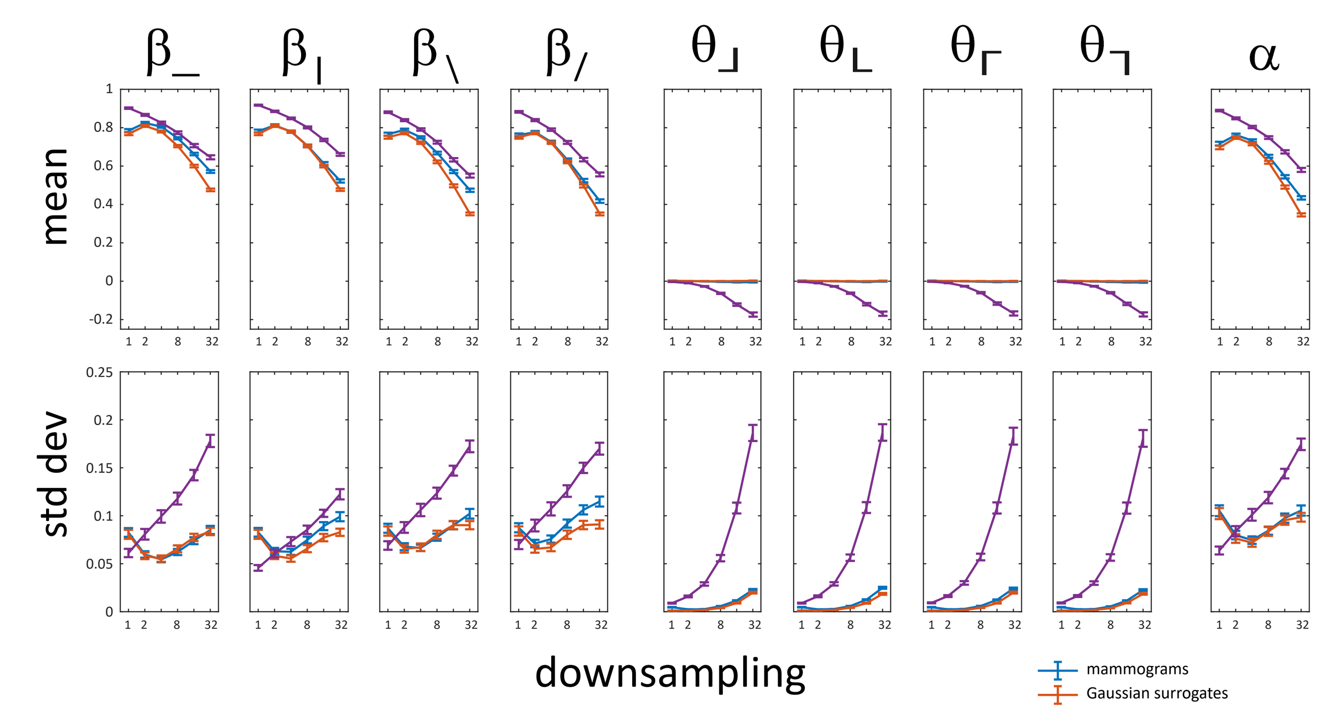
Mammogram
(BIRADS C, LCC view)



Gaussian Surrogate

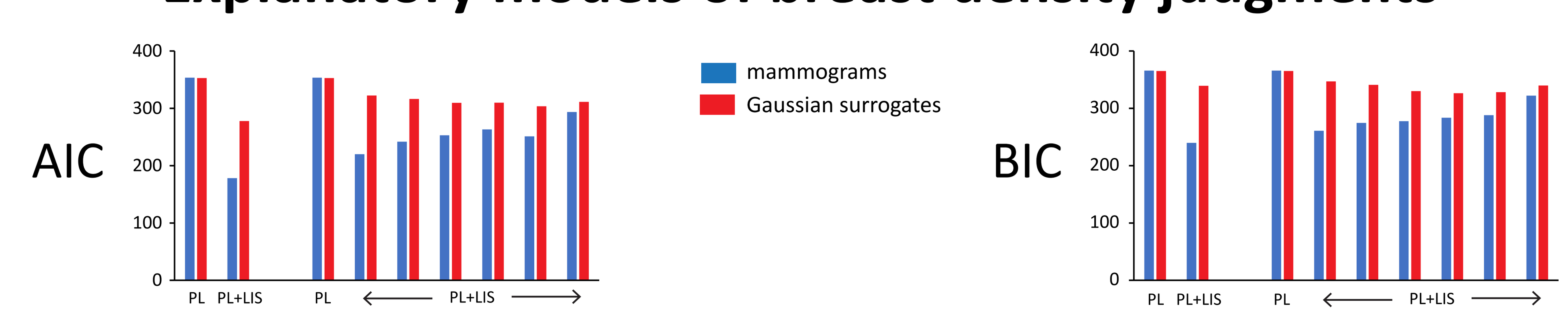
Natural Scene

To assess the role of local image statistics, we created Gaussian surrogate textures with a power spectra that matched each of the image ROI's. The textural difference is apparent.




Local image statistics of mammograms and natural scenes differ greatly. Mammograms and spectrally-matched Gaussian surrogates differ primarily in second-order (β) and fourth-order (α) correlations, and at coarse spatial scales.

## Explanatory models of breast density judgments

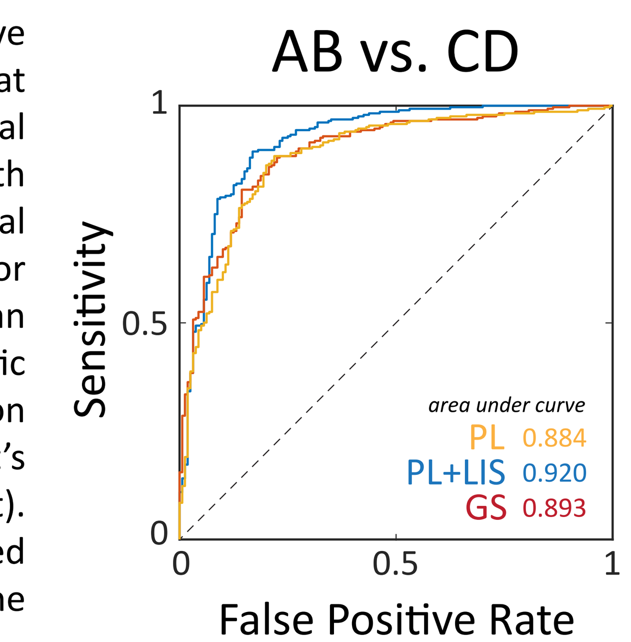



To determine the impact of local image statistics, we compared explanatory models based on power-law spectral statistics alone (PL) with models that also included local image statistics (PL+LIS). We used logistic regression to link image statistics to breast density, considered as a binary variable (0: A and B, 1: C and D). Model quality was assessed via the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC), two ways of balancing the number of model parameters against goodness of fit.

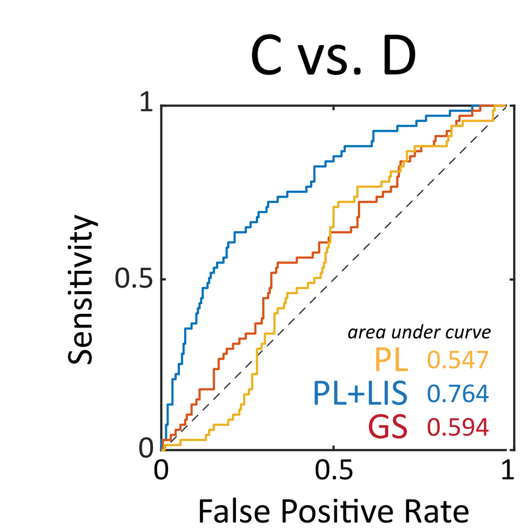
We compared these models when all downsampling scales are included (PL+LIS, left side of each plot), and models that selectively included local image statistics at one scale of downsampling (PL+LIS, right side of each plot). Including local image statistics improved model quality, and this improvement was greater for mammograms than for image statistics calculated from the Gaussian surrogates. This demonstrates a role for local image statistics in radiologists' breast density judgments.

## Predictive performance of models

We compared the predictive performance of models that included power-law spectral statistics alone (PL) with models that also included local image statistics (PL+LIS), for mammograms and Gaussian surrogates (GS), using logistic regression with cross-validation (leaving out one patient's images from the training set). ROC curves were constructed from the logit values of the left-out images.

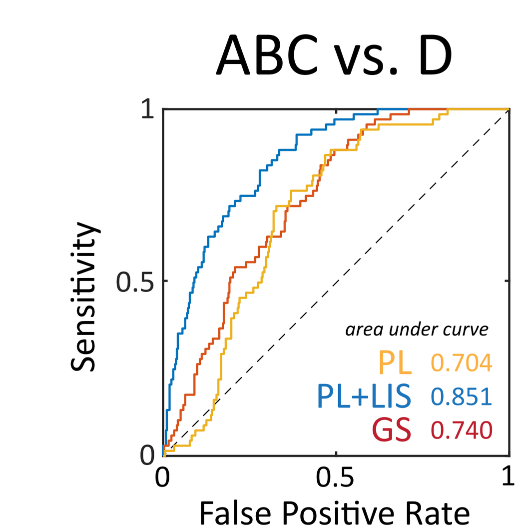



For the mammograms, inclusion of local image statistics increased the area under the ROC curve from 0.884 (power-law statistics alone) to 0.920 (including local image statistics), p=0.08. There was only a minimal improvement if the local image statistics were calculated from Gaussian surrogates (0.884 to 0.893, p=0.31).




As a secondary analysis, we compared predictions for identification of BIRADS-D breasts, within the "dense" category (C vs. D), or among all images (ABC vs. D).

Here, the local image statistics had a greater impact, increasing the area under the curve from 0.547 to 0.764 (p=0.004) for C vs. D and from 0.704 to 0.851 (p=0.006) for ABC vs. D.




## Summary and Conclusions

- Inclusion of local image statistics improves the explanatory power of models of radiologists' judgments of breast density.
  - These statistics capture non-Gaussian aspects of the image.
  - Local image statistics scales up to 16 pixels (1.2 mm) were most relevant.
- Local image statistics are relevant for this clinically-important, real-world visual task.

**References**

Burgess, A.E., Jacobson, F.L, and Judy, P.F. (2001) Human observer detection experiments with mammograms and power-law noise. Med. Phys. 28, 418-437.

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