

A Probabilistic Method to Predict Classifier Accuracy on Larger Datasets given Small Pilot Data

When a large dataset of labeled images is not available, research projects often have a common trajectory:

- (1) gather a small “pilot” dataset of images and corresponding class labels,
- (2) train classifiers using this available data, and then
- (3) plan to collect an even larger dataset to further improve performance.

When gathering more labeled data is expensive, practitioners face a key decision in step 3: *given that the classifier’s accuracy is $Y\%$ at the current size x , how much better might the model do at $2x$, $10x$, or $50x$ images?*

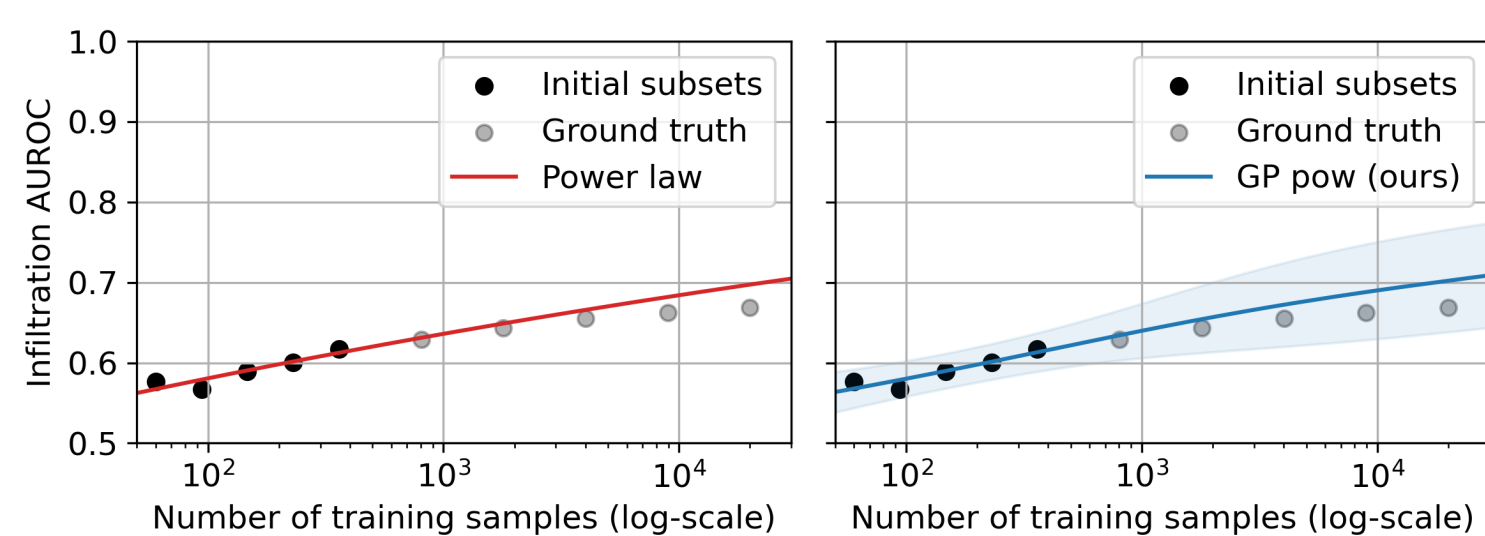


Figure 1: Example learning curves for AUROC of predicting infiltration in chest X-rays. Left: Power law fit with MSE. Right: Our Gaussian process with a power law mean function and 95% confidence interval for uncertainty.

Goals

What: A probabilistic method that can model a *range* of plausible curves to extrapolate classifier accuracy to larger datasets.

Why:

- Recent approaches have focused almost entirely on estimating one single “best-fit” curve.
- Errors are large when extrapolating from small dataset sizes (Rosenfeld et al., 2020; Mahmood et al., 2022).

How:

- A Gaussian process (GP) that can match existing curve-fitting approaches in terms of error while providing additional uncertainty estimates.

Probabilistic Method

GP extrapolation model

$$p(\mathbf{f} | \mathbf{x}) = \mathcal{N}(\mathbf{f} | m(\mathbf{x}), k(\mathbf{x}, \mathbf{x}))$$

$$p(\mathbf{y} | \mathbf{f}, \mathbf{x}) = \prod_{r=1}^R \mathcal{N}(y_r | f_r, \tau^2)$$

Power law mean

$$m^{\text{pow}}(x) = (1 - \varepsilon) - \theta_1 x^{\theta_2}$$

Arctan mean

$$m^{\text{arc}}(x) = \frac{2}{\pi} \arctan\left(\theta_1 \frac{\pi}{2} x + \theta_2\right) - \varepsilon$$

Covariance function

$$k(x, x') = \sigma^2 \exp\left(-\frac{(\log(x) - \log(x'))^2}{2\lambda^2}\right)$$

We pay particular attention to the mean, offering two concrete choices, a power law and an arctan, inspired by the best performing methods from prior work.

We make our code and models publicly available at:

github.com/tufts-ml/extrapolating-classifier-accuracy-to-larger-datasets

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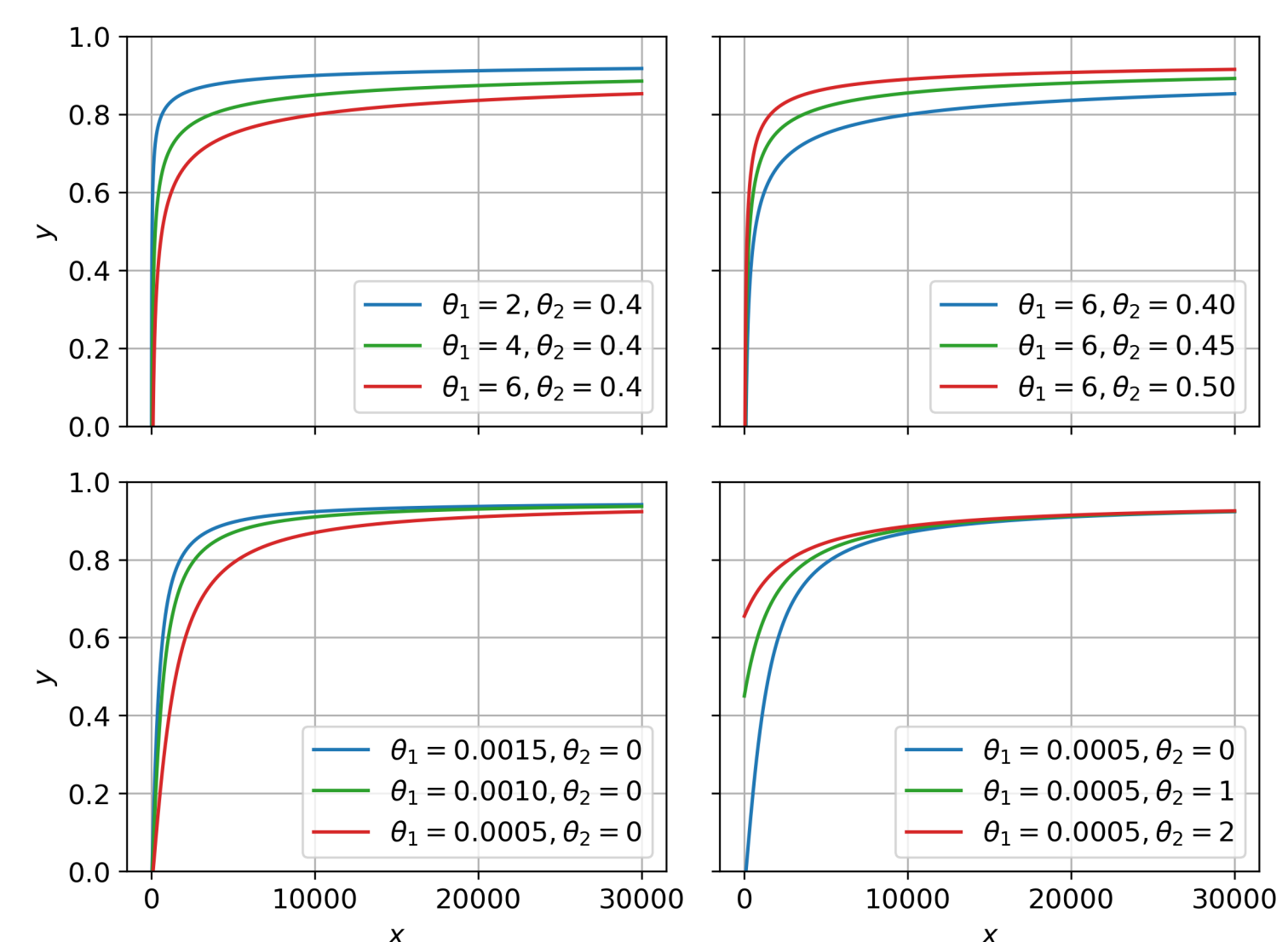


Figure 2: Example varying parameters for the power law (left) and arctan function (right) with $\varepsilon = 0.05$.

Priors

Our GP model has two kinds of parameters. Let $\eta = \{\tau, \sigma, \lambda, \varepsilon\}$ denote the parameters that control *uncertainty* (in the likelihood or the GP covariance function) or *asymptotic behavior* (e.g., ε sets the saturation value of $m(x)$). We develop prior distributions for each parameter in η .

Fitting to data via MAP estimation

We optimize the following maximum a-posteriori (MAP) objective to obtain point estimates of θ and η :

$$\hat{\theta}, \hat{\eta} = \underset{\theta, \eta}{\operatorname{argmax}} \log p_{\theta, \eta}(\mathbf{y} | \mathbf{x}) + \log p(\eta)$$

Extrapolation via the predictive posterior

$$p(\mathbf{y}_* | \mathbf{x}_*, \mathbf{y}, \mathbf{x}) = \mathcal{N}(\mathbf{y}_* | \mu, \Sigma),$$

$$\mu = \mathbf{m}_* + \mathbf{K}_*^T (\mathbf{K} + \tau^2 \mathbf{I}_R)^{-1} (\mathbf{y} - \mathbf{m})$$

$$\Sigma = \mathbf{K}_{**} + \tau^2 \mathbf{I}_Q - \mathbf{K}_*^T (\mathbf{K} + \tau^2 \mathbf{I}_R)^{-1} \mathbf{K}_*$$

Results

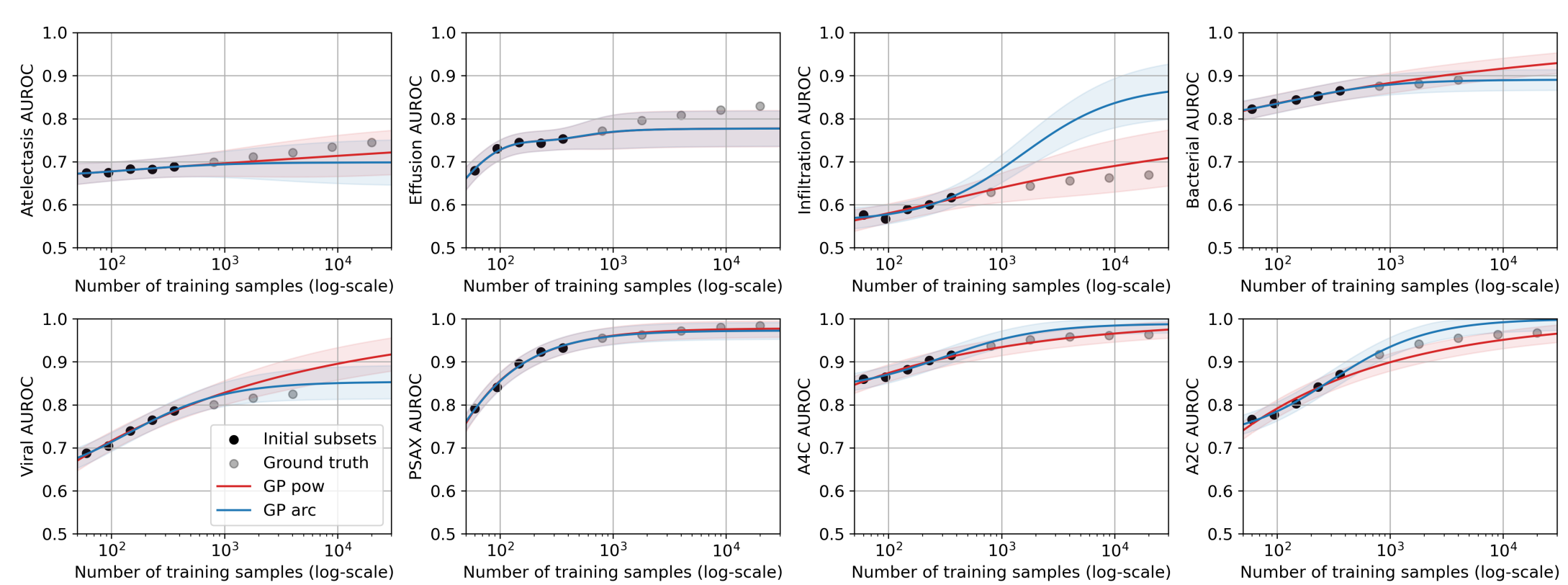


Figure 3: Long-range extrapolation results for AUROC of predicting atelectasis, effusion, and infiltration from the ChestX-ray14 dataset; bacterial and viral pneumonia from the Chest X-Ray dataset; and PSAX, A4C, and A2C from the TMED-2 dataset.

Outlook. We hope our approach provides a useful tool for practitioners in medical imaging and beyond to manage uncertainty when assessing data adequacy.

References

- Rafid Mahmood, James Lucas, David Acuna, Daiqing Li, Jonah Pillion, Jose M. Alvarez, Zhiding Yu, Sanja Fidler, and Marc T. Law. How Much More Data Do I Need? Estimating Requirements for Down-Stream Tasks. *In Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR)*, pages 275–284, 2022.
- Jonathan S Rosenfeld, Amir Rosenfeld, Yonatan Belinkov, and Nir Shavit. A Constructive Prediction of the Generalization Error Across Scales. 2020.