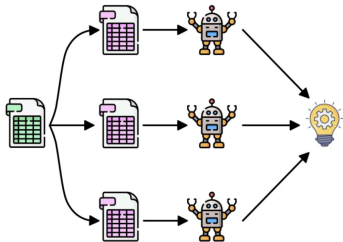


# Introduction to Machine Learning

## Random Forest Bagging Ensembles

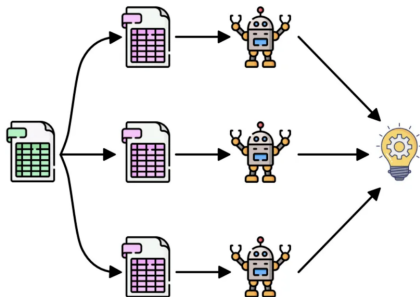


### Learning goals

- Understand idea of bagging
- Be able to explain the connection between bagging and bootstrap
- Understand why bagging improves predictive performance

# BAGGING

- Bagging is short for **B**ootstrap **A**ggregation
- **Ensemble method**, combines models into large “meta-model”; ensembles usually better than single **base learner**
- Homogeneous ensembles always use same BL class (e.g. CART), heterogeneous ensembles can use different classes
- Bagging is homogeneous







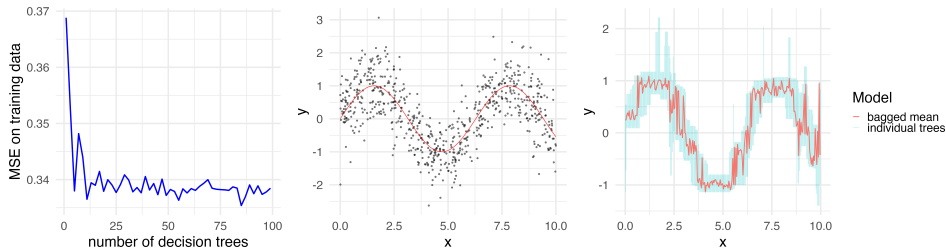
## BAGGING PSEUDO CODE

## Bagging algorithm: Training

- 1: **Input:** Obs.  $\mathbf{x}$ , trained BLs  $\hat{b}^{[m]}$  (as scores  $\hat{f}^{[m]}$ , hard labels  $\hat{h}^{[m]}$  or probs  $\hat{\pi}^{[m]}$ )
- 2: Aggregate/Average predictions

# WHY/WHEN DOES BAGGING HELP?

- Bagging reduces the variability of predictions by averaging the outcomes from multiple BL models
- It is particularly effective when the errors of a BL are mainly due to (random) variability rather than systematic issues



- Increasing **nr. of BLs** improves performance, up to a point, optimal ensemble size depends on inducer and data distribution

# MINI BENCHMARK

Bagged ensembles with 100 BLs each on spam:

Bagging seems especially helpful for less stable learners like CART

