

Bayesian additive regression tree (BART)

- Nonparametric prediction tool
- Ensemble of 'weak learners' that leads to robust out-of-sample predictions
- Dynamically learns important predictors via a sparsity inducing prior

Mathematically, a BART model looks like:

$$Y_i \sim N(\mu_i, \sigma^2)$$
$$\mu_i = \sum_{t=1}^T \sum_{l \in L_t} \psi_{lt} I(x_i \rightsquigarrow (t, l))$$

$I(x_i \rightsquigarrow (t, l)) = 1$ if x_i falls into node (t, l) of tree t .

- An extension of BART for multivariate responses
- Correlation between responses is utilized via shared tree structures
- Variables that predict Y_1 are likely the same variables that predict Y_2 (though the nature of the relationship may be different!)
- Information sharing \Rightarrow better predictions for Y_1 and Y_2

$$Y_i \sim N(\mu_i, \sigma_i^2) \quad (1)$$

$$\delta_i \sim \text{Bernoulli}(\pi_i) \quad (2)$$

- $\begin{pmatrix} \mu_i \\ \pi_i \end{pmatrix}$ modeled jointly using a shared forest model

$$\begin{pmatrix} \mu_i \\ \pi_i \end{pmatrix} = \begin{pmatrix} \sum_{t=1}^T \sum_{l \in L_t} \psi_{lt} I(x_i \rightsquigarrow (t, l)) \\ \sum_{t=1}^T \sum_{l \in L_t} \theta_{lt} I(x_i \rightsquigarrow (t, l)) \end{pmatrix}$$

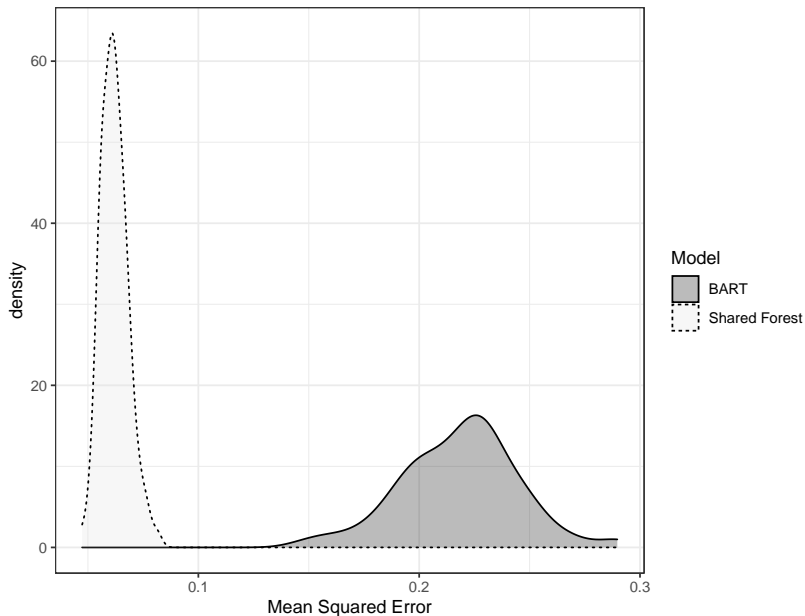
- Likelihood involves two dimensional response: $\{Y_i, \delta_i\}_{i=1}^N$

1 binary, 1 continuous

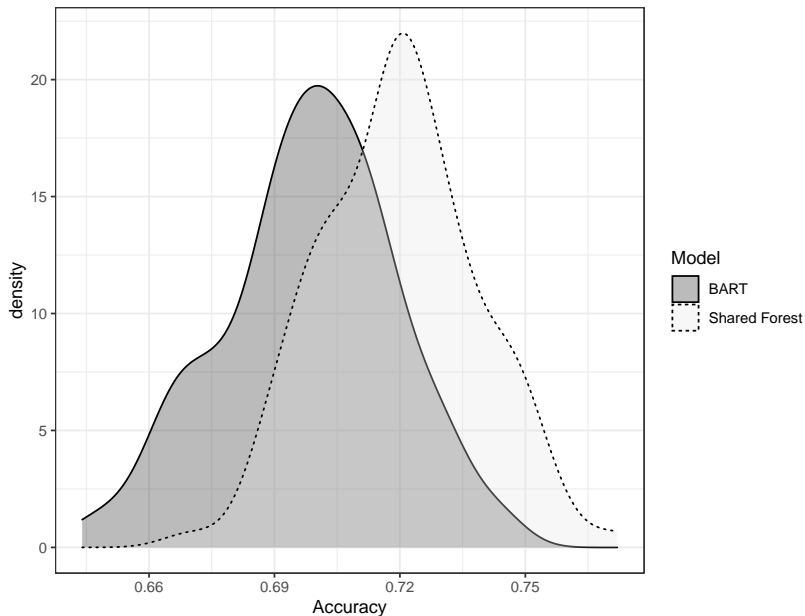
Two quantities may be of interest for prediction

- ① $E(\delta^*, y^* | x)$, where * indicates those observations come from a test / hold-out sample
 - ex) Predict salary of individual, conditional on cellular traits x_i
 - ex) Predict gender of individual, conditional on cellular traits x_i
- ② $E(y^* | \delta)$
 - ex) Predict mean salary of females (avg. across traits observed for females)

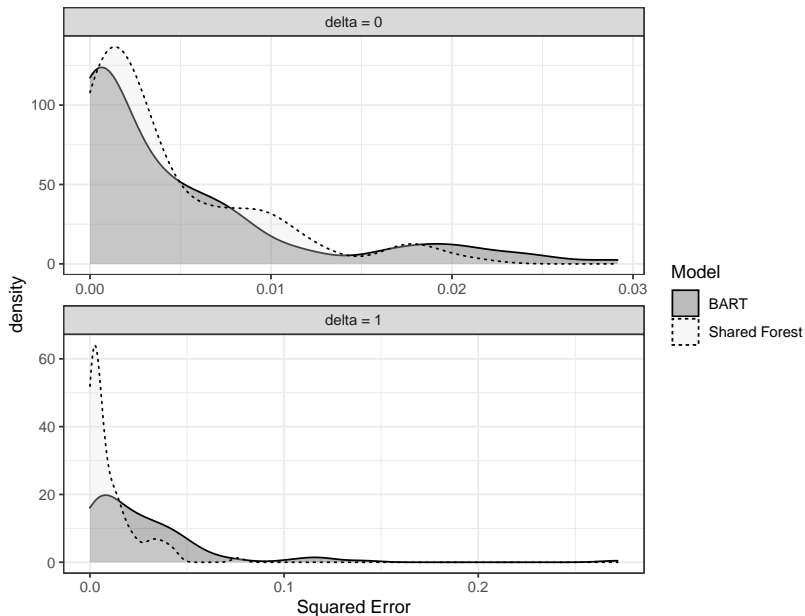
Predicting Individual Y^*



Predicting Individual δ^*



Predicting $E(Y^* | \delta^*)$



Predicting $E(Y^* | \delta^*)$

δ	Model	MSE	L_bound	U_bound
0	BART	0.004875	0.000004	0.023207
0	Shared Forest	0.004330	0.000007	0.017697
1	BART	0.028464	0.000042	0.119264
1	Shared Forest	0.010399	0.000011	0.041591

Table: Mean of the squared errors (across simulations) comparing the true $E(Y^* | \delta^*)$ to the estimated $\hat{E}(Y^* | \hat{\delta})$.

2 binary responses

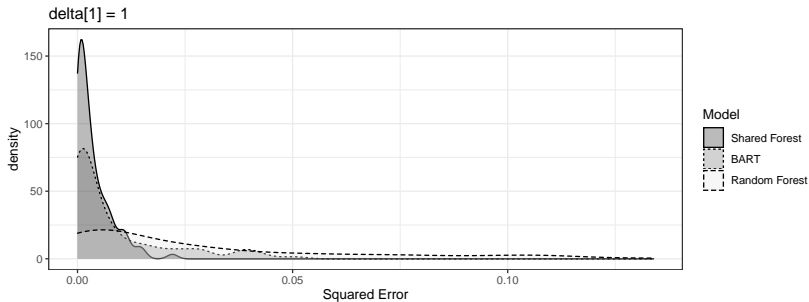
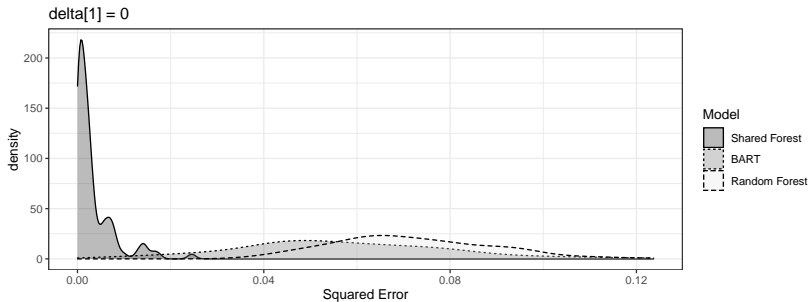
The model structure is the same as described before; however, the likelihood reflects that:

$$\delta_{1i} \sim \text{Bernoulli}(\pi_{1i}) \quad (3)$$

$$\delta_{2i} \sim \text{Bernoulli}(\pi_{2i}) \quad (4)$$

As before, the tree structures will be built using information shared between δ_1 and δ_2 , while the location parameters are estimated separately.

Predicting $E(\delta_2^* | \delta_1^*)$



2 binary responses

In this context, we are interested in predicting $P(\delta_2^* = 1 \mid \delta_1^*)$.

ex) Probability a randomly selected female is employed.
($\delta_1 = \text{gender}$, $\delta_2 = \text{employment}$)