Why does Bagging work?

Why would φ_B be any better than φ?

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Illustration on the regression case:

Suppose (X, Y) drawn from distribution $P_{X,Y}$.
φ predictor trained on $\mathcal{T}$ or any bootstrap sample of $\mathcal{T}$
$\hat{P}_{\mathcal{T}}$ empirical distribution of $\mathcal{T}$
$P_{\mathcal{T}}$ true distribution of $\mathcal{T}$
To simplify notation: $\mathbb{E}_{P_{X,Y}} = \mathbb{E}_{X,Y}$, $\mathbb{E}_{P_{\mathcal{T}}} = \mathbb{E}_{\mathcal{T}}$ and $\mathbb{E}_{\hat{P}_{\mathcal{T}}} = \mathbb{E}_{\hat{\mathcal{T}}}$.
$\varphi_B(\cdot) = \mathbb{E}_{\hat{\mathcal{T}}}(\varphi(\cdot))$ Bagging predictor
$\varphi_A(\cdot) = \mathbb{E}_{\mathcal{T}}(\varphi(\cdot))$ aggregated predictor

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Interpretation: if $\varphi_{\mathcal{T}}$ differs a lot from $\varphi_{\mathcal{T}'}$, then $e - e_A$ is large.

$\Rightarrow$ The highest the variance of φ across training sets $\mathcal{T}$, the more improvement φ_A produces.

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But φ_A is not φ_B. Recall:

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- If φ highly variable w.r.t. $\mathcal{T}$, φ_B improves on φ through aggregation.
- But if φ is rather stable w.r.t. $\mathcal{T}$, $e_A \approx e$ and since φ_B approximates φ_A, e_B might be greater than e.

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Actually, no, it does not always work.
Bagging should be used to transform highly variable predictors φ into a more accurate averaged commitee φ_B.

Examples of φ that Bagging improve:
$\rightarrow$ Trees, Neural Networks.
Examples of φ that Bagging does not improve much (or degrades):
$\rightarrow$ Support Vector Machines, Gaussian Processes.

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Majority vote: $\varphi_B(x) = \arg\max_j \sum_{b=1}^{B} I(\varphi^b(x) = j)$

More drastic conclusions:

- φ unstable w.r.t. $\mathcal{T}$ and reasonable performance $\Rightarrow$ φ_B near optimal.
- φ stable w.r.t. $\mathcal{T}$ $\Rightarrow$ φ_B worse than φ.
- φ poor performance $\Rightarrow$ φ_B worse than φ.