## Boosting

Christian Peters January 29, 2021

## What you will know

 $\rightarrow$  The idea behind boosting

## What you will know

 $\rightarrow$  The idea behind boosting

 $\rightarrow$  How to create a strong and efficient learning algorithm

1

## What you will know

ightarrow The idea behind boosting

 $\rightarrow$  How to create a strong and efficient learning algorithm

 $\rightarrow$  What is AdaBoost and why is it so successful?

\_\_\_\_

Let's talk about training a model

#### What we have learned so far...

 $\cdot$  We have to pick a hypothesis class  ${\cal H}$ 

#### What we have learned so far...

- $\cdot$  We have to pick a hypothesis class  ${\cal H}$
- $\cdot$   $\mathcal{H}$  can't be too complex (VC dim needs to be finite)

#### What we have learned so far...

- $\cdot$  We have to pick a hypothesis class  ${\cal H}$
- $\mathcal{H}$  can't be too complex (VC dim needs to be finite)
- · We need enough training data (more than some threshold  $m_{\mathcal{H}}$ )

#### What we have learned so far...

- $\cdot$  We have to pick a hypothesis class  ${\cal H}$
- $\mathcal{H}$  can't be too complex (VC dim needs to be finite)
- · We need enough training data (more than some threshold  $m_{\mathcal{H}}$ )
- Then we use ERM to pick the best  $h \in \mathcal{H}$  that minimizes the empirical error

#### What we have learned so far...

- $\cdot$  We have to pick a hypothesis class  ${\cal H}$
- $\mathcal{H}$  can't be too complex (VC dim needs to be finite)
- · We need enough training data (more than some threshold  $m_{\mathcal{H}}$ )
- Then we use ERM to pick the best  $h \in \mathcal{H}$  that minimizes the empirical error

But there is one problem...

## The problem with ERM

# ERM can be hard.

## The problem with ERM

# ERM can be hard.

- Depending on  $\mathcal{H}$ , the optimization problem can become arbitrarily complex

## The problem with ERM

# ERM can be hard.

- Depending on H, the optimization problem can become arbitrarily complex
- e.g. implementing ERM for halfspaces in the non-separable case is computationally hard (chapter 9)

## ERM can be hard.

- Depending on  $\mathcal{H}$ , the optimization problem can become arbitrarily complex
- e.g. implementing ERM for halfspaces in the non-separable case is computationally hard (chapter 9)
- For many interesting classes, it is infeasible to implement ERM
  - Solving the optimization problem takes forever

# ERM can be hard.

- Depending on  $\mathcal{H}$ , the optimization problem can become arbitrarily complex
- e.g. implementing ERM for halfspaces in the non-separable case is computationally hard (chapter 9)
- · For many interesting classes, it is infeasible to implement ERM
  - Solving the optimization problem takes forever

...so what can we do?

- Problem: Simple classes can be too "weak" to estimate all relationships in the data
  - ightarrow Can lead to underfitting and poor performance

- Problem: Simple classes can be too "weak" to estimate all relationships in the data
  - → Can lead to underfitting and poor performance
- Approximation error is high ( $\rightarrow$  B/C tradeoff)

- Problem: Simple classes can be too "weak" to estimate all relationships in the data
  - → Can lead to underfitting and poor performance
- Approximation error is high ( $\rightarrow$  B/C tradeoff)
- · Still, these classes can be useful for us
  - · If the resulting hypothesis is at least better than random

**Idea:** Use simpler hypothesis classes where ERM isn't hard.

- Problem: Simple classes can be too "weak" to estimate all relationships in the data
  - → Can lead to underfitting and poor performance
- Approximation error is high ( $\rightarrow$  B/C tradeoff)
- · Still, these classes can be useful for us
  - · If the resulting hypothesis is at least better than random

Let's call ERM on a simple class a **weak learner**. We will formally define it later...

Why not combine many weak learners? Can this give us an efficient strong learner?

· This theoretical question is the origin of boosting

- This theoretical question is the origin of boosting
- It was first raised in 1988 by Kearns and Valiant [2]

- · This theoretical question is the origin of boosting
- It was first raised in 1988 by Kearns and Valiant [2]
- The first (practical) answer was given in 1995 by Freund and Schapire [1]
  - $\rightarrow$  It is YES!

- · This theoretical question is the origin of boosting
- It was first raised in 1988 by Kearns and Valiant [2]
- The first (practical) answer was given in 1995 by Freund and Schapire [1]
  - $\rightarrow$  It is YES!
- The result is AdaBoost, a widely popular and award winning algorithm
  - · We will take a look at this later...

### Why not combine many weak learners? Can this give us an efficient strong learner?

- · This theoretical question is the origin of boosting
- It was first raised in 1988 by Kearns and Valiant [2]
- The first (practical) answer was given in 1995 by Freund and Schapire [1]
  - $\rightarrow$  It is YES!
- The result is AdaBoost, a widely popular and award winning algorithm
  - · We will take a look at this later...

But first, let's get back to weak learning.

**Weak Learnability** 

## **Weak Learnability**

Weak Learnability

## AdaBoost

## AdaBoost

AdaBoost

## Conclusion

## Conclusion

Conclusion



### References i



Y. Freund and R. E. Schapire.

A decision-theoretic generalization of on-line learning and an application to boosting.

Journal of Computer and System Sciences, 55(1):119 – 139, 1997.



M. Kearns and L. G. Valiant.

Learning boolean formulae or finite automata is as hard as factoring.

Technical Report TR 14-88, Harvard University Aiken Computation Laboratory, 1988.



S. Shalev-Shwartz and S. Ben-David. Understanding Machine Learning - From Theory to Algorithms. Cambridge University Press, 2014.