

Putting Bayes to sleep

Wouter M. Koolen

Dimitri Adamskiy

Manfred Warmuth



UNIVERSITY OF CALIFORNIA
SANTA CRUZ



Thursday 30th August, 2012

How
a beautiful and intriguing piece of technology
provides
new insights in existing methods
and
improves the state of the art
in
expert tracking
and
online multitask learning

Point of departure

We are trying to predict a sequence y_1, y_2, \dots

Definition

A **model** issues a prediction each round. We denote the prediction of model m in round t by $P(y_t | y_{<t}, m)$.

Say we have several models $m = 1, \dots, M$.
How to combine their predictions?

Bayesian answer

Place a **prior** $P(m)$ on models. Bayesian **predictive distribution**

$$P(y_t|y_{<t}) = \sum_{m=1}^M P(y_t|y_{<t}, m)P(m|y_{<t})$$

where **posterior distribution** is incrementally updated by

$$P(m|y_{\leq t}) = \frac{P(y_t|y_{<t}, m)P(m|y_{<t})}{P(y_t|y_{<t})}$$

Bayes is **fast**: predict in $\mathcal{O}(M)$ time per round.

Bayes is **good**: regret w.r.t. model m on data $y_{\leq T}$ bounded by

$$\sum_{t=1}^T (-\ln P(y_t|y_{<t}) + \ln P(y_t|y_{<t}, m)) \leq -\ln P(m).$$

Definition (FSSW97,CV09)

A **specialist** may or **may not** issue a prediction.

Prediction $P(y_t|y_{<t}, m)$ only available for **awake** $m \in W_t$.

Say we have several specialists $m = 1, \dots, M$.
How to combine their predictions?

Definition (FSSW97,CV09)

A **specialist** may or **may not** issue a prediction.

Prediction $P(y_t|y_{<t}, m)$ only available for **awake** $m \in W_t$.

Say we have several specialists $m = 1, \dots, M$.

How to combine their predictions?

If we **imagine** a prediction for the sleeping specialists, we can use Bayes

Choice: sleeping specialists predict with Bayesian predictive distribution

That **sounds** circular. Because it **is**. \$%!#?

Bayes for specialists

Place a **prior** $P(m)$ on models. Bayesian **predictive distribution**

$$P(y_t|y_{<t}) = \sum_{m \in W_t} P(y_t|y_{<t}, m)P(m|y_{<t}) + \sum_{m \notin W_t} P(y_t|y_{<t})P(m|y_{<t})$$

Bayes for specialists

Place a **prior** $P(m)$ on models. Bayesian **predictive distribution**

$$P(y_t|y_{<t}) = \sum_{m \in W_t} P(y_t|y_{<t}, m)P(m|y_{<t}) + \sum_{m \notin W_t} P(y_t|y_{<t})P(m|y_{<t})$$

has solution

$$P(y_t|y_{<t}) = \frac{\sum_{m \in W_t} P(y_t|y_{<t}, m)P(m|y_{<t})}{\sum_{m \in W_t} P(m|y_{<t})}.$$

Bayes for specialists

Place a **prior** $P(m)$ on models. Bayesian **predictive distribution**

$$P(y_t|y_{<t}) = \sum_{m \in W_t} P(y_t|y_{<t}, m)P(m|y_{<t}) + \sum_{m \notin W_t} P(y_t|y_{<t})P(m|y_{<t})$$

has solution

$$P(y_t|y_{<t}) = \frac{\sum_{m \in W_t} P(y_t|y_{<t}, m)P(m|y_{<t})}{\sum_{m \in W_t} P(m|y_{<t})}.$$

The **posterior distribution** is incrementally updated by

$$P(m|y_{\leq t}) = \begin{cases} \frac{P(y_t|y_{<t}, m)P(m|y_{<t})}{P(y_t|y_{<t})} & \text{if } m \in W_t, \\ \frac{P(y_t|y_{<t})P(m|y_{<t})}{P(y_t|y_{<t})} = P(m|y_{<t}) & \text{if } m \notin W_t. \end{cases}$$

Bayes is **fast**: predict in $\mathcal{O}(M)$ time per round.

Bayes is **good**: regret w.r.t. model m on data $y_{\leq T}$ bounded by

$$\sum_{t : 1 \leq t \leq T \text{ and } m \in W_t} (-\ln P(y_t|y_{<t}) + \ln P(y_t|y_{<t}, m)) \leq -\ln P(m).$$

The specialists trick

Specialists just a curiosity?

The specialists trick

Specialists just a curiosity?

Specialists trick:

- Start with input **models**
- Create many derived **virtual specialists**
 - Control how they predict
 - Control when they are awake
- Run Bayes on all these specialists
- Carefully choose prior
 - Low regret w.r.t. class of intricate combinations of input models.
 - Fast execution. Bayes on specialists **collapses**

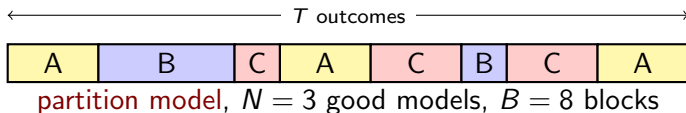
Application 1: Freund's Problem

In practice:

- Large number M of models
- Some are good some of the time
- Most are bad all the time

We do not know in advance **which** models will be useful **when**.

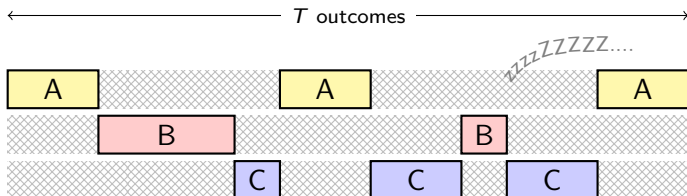
Goal: compare favourably on data $y_{\leq T}$ with the best alternation of $N \ll M$ models with $B \ll T$ blocks.



Bayesian reflex: average all **partition models**. **NP hard**.

Application 1: sleeping solution

Create **partition specialists**

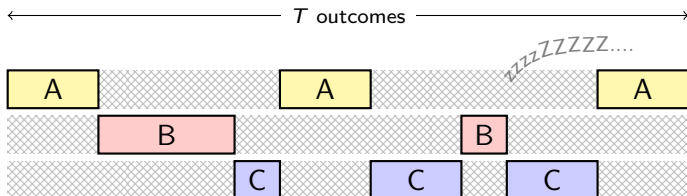


Bayes is **fast**: $\mathcal{O}(M)$ time per trial, $\mathcal{O}(M)$ space

Bayes is **good**: regret close to information-theoretic lower bound

Application 1: sleeping solution

Create **partition specialists**



Bayes is **fast**: $\mathcal{O}(M)$ time per trial, $\mathcal{O}(M)$ space

Bayes is **good**: regret close to information-theoretic lower bound

- Bayesian interpretation for Mixing Past Posteriors
- Faster algorithm
- Slightly improved regret bound
- Explain mysterious factor 2

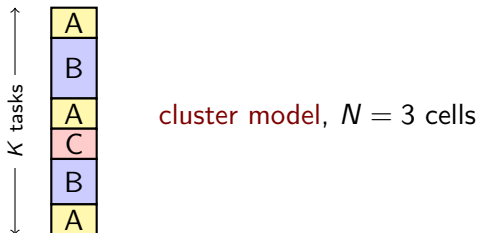
Application 2: online multitask learning

In practice:

- Large number M of models
- Data y_1, y_2, \dots from K interleaved tasks
- Observe task label $\kappa_1, \kappa_2, \dots$ before prediction

We do not know in advance **which** tasks are **similar**.

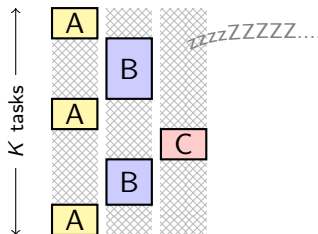
Goal: Compare favourably to best clustering of task with $N \ll K$ cells



Bayesian reflex: average all **cluster models**. **NP hard**.

Application 2: sleeping solution

Create **cluster specialists**



Bayes is **fast**: $\mathcal{O}(M)$ time per trial, $\mathcal{O}(MK)$ space

Bayes is **good**: regret close to information-theoretic lower bound

- Intriguing algorithm
- Regret independent of task switch count

The **specialists trick**

- NP-hard offline problem
- Ditch Bayes on **coordinated** comparator models
- Instead create **uncoordinated** virtual specialists
- Craft prior so that
 - Bayes collapses (efficient emulation)
 - Small regret

The **specialists trick**

- NP-hard offline problem
- Ditch Bayes on **coordinated** comparator models
- Instead create **uncoordinated** virtual specialists
- Craft prior so that
 - Bayes collapses (efficient emulation)
 - Small regret

Thank you!