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Extreme weather prediction by Support Vector Machine

Statistical Analysis and Application in Climate Research

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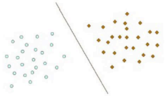

Nov. 2021, UCAS

Contents

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Extreme weather

- Extreme weather is **disastrous** and tends to occur **more frequently**.
- Heat Waves, Drought, Heavy Downpours, Floods, Hurricanes, ...
- By making **better prediction**, we can reduce its loss effectively.

Fig: Extreme weathers

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Method for predicting extreme weather

- There are many ways to predict extreme weather.

Numerical weather prediction (NWP)

- NWP rely on basic **physical laws** and current **weather state**.
- Generally, NWP works fine; But it fails to predict certain **extreme weather** well, e.g. heavy rainfall.
- This may results from **complicated processes** and **multiscale** property.

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Analog method

- Analog method is a **statistical** and **probabilistic** model.
- Based on **similarity of atmospheric conditions** on extreme days.

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Analog method

- Analog method is a **statistical** and **probabilistic** model.
- Based on **similarity of atmospheric conditions** on extreme days.

The key point is how to define "Similarity"?

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To be more specific...

- Assume we have the following knowledge[1].

Date	Temperature at noon (°C)	Weather in the afternoon
2021/8/16	33	Heavy rain
2021/8/17	35	Heavy rain
2021/8/18	28	Sunny
2021/8/19	31	Heavy rain
2021/8/20	26	Sunny

Table: Example data

[1] Fake examples, just for explanation.

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Table: Example data

- We may conclude that an ≥ 30 °C Temp. at noon leads to heavy rain in the afternoon. And we can use this **criterion** to predict heavy rainfall in the afternoon.
- Now we have **large amount** of atmospheric data before extreme weather, how can we develop a **criterion** for prediction?

[1] Fake examples, just for explanation.

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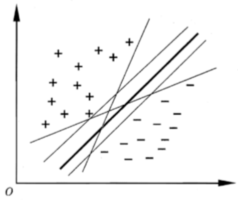
What is SVM?

- Support Vector Machine(SVM), is a **binary classifier**.
- We have labelled data $D = \{(\boldsymbol{x}_1, y_1), \ldots, (\boldsymbol{x}_n, y_n)\}, y_i = \pm 1$.
  - Vector $\boldsymbol{x}_i$ represents **atmospheric conditions**(Temp., Wind, etc.).
  - $y_i = +1, -1$ stands for **extreme** weather and **non-extreme** weather respectively.
- We seek for a hyperplane for **separation** by the sign of y_i.



- For **generalization** purpose, the "center" one is the best.

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How to compute?

We define **Canonical Separating Hyperplane** $\mathcal{H}$, that

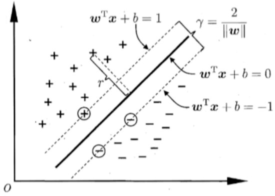
$$\mathcal{H} : \boldsymbol{w}^{\mathrm{T}}\boldsymbol{x} + b = 0 \tag{1}$$

For $\boldsymbol{x}_1$ and $\boldsymbol{x}_2$ which are two **closet** points from each side, they satisfy

$$\boldsymbol{w}^{\mathrm{T}}\boldsymbol{x}_1 + b = 1, \qquad \boldsymbol{w}^{\mathrm{T}}\boldsymbol{x}_2 + b = -1 \tag{2}$$

And the **margin width** γ can be computed as

$$\gamma = \frac{\boldsymbol{w}^{\mathrm{T}}}{\|\boldsymbol{w}\|}(\boldsymbol{x}_1 - \boldsymbol{x}_2) = \frac{2}{\|\boldsymbol{w}\|} \tag{3}$$



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How to compute? The optimization problem.

- Now, as we want to **maximize** margin and the margin directly depends on $\|\boldsymbol{w}\|$, we reach the following optimization problem.

Optimization problem for solving SVM

$$\begin{aligned} &\min \frac{1}{2}\|\boldsymbol{w}\|^2 \\ &s.t. \quad y_i(\boldsymbol{w}^{\mathrm{T}}\boldsymbol{x}_i + b) \geq 1 \end{aligned} \tag{4}$$

- There are many developed **optimization methods** to solve it.

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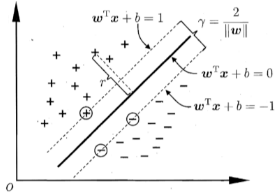
What is support vector?

- It is obvious that, only closet points (e.g. $\boldsymbol{x}_1, \boldsymbol{x}_2$) will affect the result.
- They are called **Support Vectors**, and that is where **Support Vector Machine** comes from.



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Application and Discussion

- Face recognition, text classification, OCR, bioinformatics, ...
- Based on analog methods and SVM, Nayak(2013) developed a **classifier** which predicts **extreme rainfall** in Mumbai 6-48 h ahead, according to corresponding atmosphere conditions.
- They collected extreme rainfall data of Mumbai from 1969 to 2008.
  - The **training set** contains data from 1969 to 1999.
  - The **validation set** contains data from 2000 to 2008.

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- They collected extreme rainfall data of Mumbai from 1969 to 2008.
  - The **training set** contains data from 1969 to 1999.
  - The **validation set** contains data from 2000 to 2008.
- For better performance, **day** events and **night** events are separately trained.
- Both SVM1 and SVM2 are used for prediction.

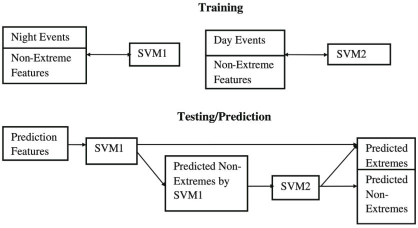

Fig. 4 Flowchart of the two-phase SVM model

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Application and Discussion

- Result:
  - Besides **16 correct** extreme predictions, there are **133 false alarms**. 0 miss.
  - Much better than previous fingerprinting method (**900+ false alarms**).
- Limitations:
  - Region choice: small → **exclude** important factors; large → **less weight**.
  - Lack of data: only 40 yrs and extremes are **rare**.
  - Detailed data: **high-resolution** weather pattern, **Doppler radar data**.

Table 8 Best SVM architecture

SVM1		SVM2	
Kernel function	RBF	Kernel function	Quadratic
Kernel function argument (sigma)	0.8900	Bias	0.9489
Bias	0.3999	Support vectors	45×4
Support vectors	48×32	Optimization method	SMO

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Application and Discussion

- An advantage of SVM is that we know **how predictor works**.
  - E.g. if we find $\boldsymbol{w} = (w^{(1)}, \ldots, w^{(m)}, \ldots, w^{(n)})$ have $w^{(m)} \approx 0$, then it indicates the corresponding variable $x_i^{(m)}$ may not be important. (Why?)
  - The article does not provide it though, which may results from **kernel function** and other difficulties.

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- SVM disadvantages:
  - Cost **great computational effort** for large amount of training data.
  - The selection of kernel function, parameters, etc. is **subjective**.

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- SVM disadvantages:
  - Cost **great computational effort** for large amount of training data.
  - The selection of kernel function, parameters, etc. is **subjective**.

- Open questions:
  - Is it reliable in the future? How can we take **climate change** into account?
  - Should **other factors** be included, like forest area, pollution level, etc.?
  - Can we turn binary classification into **continous** one, which provides rainfall **probability** and **strength** information?
  - How to adapt the method for **other extreme weather** prediction?

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Take Home Message

- Support Vector Machine(SVM) is a **binary classifier** and is trained by solving an **optimization** problem.

- Analog method predicts extreme weather by recognizing **similar weather pattern** ahead.

- After training with historical data, SVM is able to predict extreme weather.

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Tools for SVM

- LIBSVM
  http://www.csie.ntu.edu.tw/~cjlin/libsvm/
- LIBLINEAR
  http://www.csie.ntu.edu.tw/~cjlin/liblinear/
- SVM-light, SVM-perf, SVM-struct
  http://svmlight.joachims.org/svm_struct.html
- Pegasos
  http://www.cs.huji.ac.il/~shais/code/index.html

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Reference I

[1] NAYAK M A, GHOSH S. Prediction of Extreme Rainfall Event Using Weather Pattern Recognition and Support Vector Machine Classifier[J/OL]. Theoretical and Applied Climatology, 2013, 114(3): 583-603(2013-11-01). https://doi.org/10.1007/s00704-013-0867-3. DOI: 10.1007/s00704-013-0867-3.

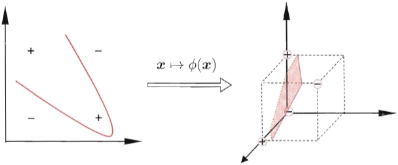
[2] 周志华. 机器学习[M]. 第 1 版. 北京: 清华大学出版社, 2016.

Many thanks to lecture slides from Prof. Lan Yanyan (2019).

THANKS!

Pratical problems and Extensions: Kernel Function

- What if... the data is not **linearly separable**?



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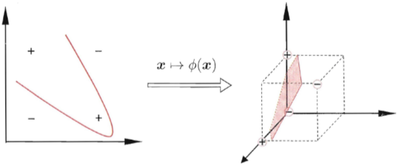

- We can introduce a **function**, which maps data into the **feature space**, where they are separable.

In practice, we only need to deal with $\phi(\boldsymbol{x}_i)^{\mathrm{T}}\phi(\boldsymbol{x}_j)$, and we simply define

$$K(\boldsymbol{x}_i, \boldsymbol{x}_j) = \phi(\boldsymbol{x}_i)^{\mathrm{T}}\phi(\boldsymbol{x}_j) \tag{5}$$

Where K is called **Kernel Function**.

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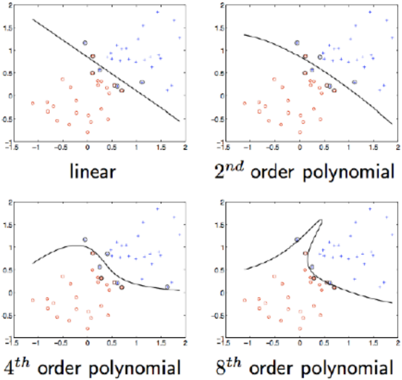
Pratical problems and Extensions: Kernel Function

The choice of K requires experience and attempts.

Type	Formula
Linear	$\boldsymbol{x}_i^{\mathrm{T}}\boldsymbol{x}_j$
Polynomial	$(\boldsymbol{x}_i^{\mathrm{T}}\boldsymbol{x}_j)^q$
Gaussian	$\exp(-\lVert\boldsymbol{x}_i-\boldsymbol{x}_j\rVert^2/2\sigma^2)$
Laplace	$\exp(-\lVert\boldsymbol{x}_i-\boldsymbol{x}_j\rVert/\sigma)$
Sigmoid	$\tanh(\beta\boldsymbol{x}_i^{\mathrm{T}}\boldsymbol{x}_j+\theta)$

Table: Common Kernel Functions



From Tommi Jaakkola, MIT CSAIL

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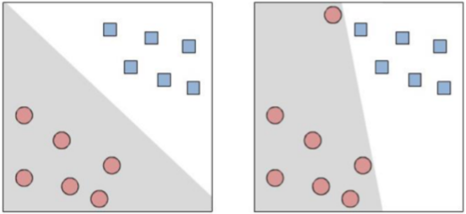
Pratical problems and Extensions: Soft margin

- What if... there is noise or **outliers** in the data?



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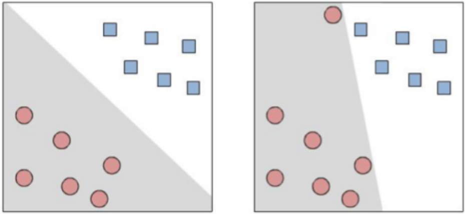

- For **generalization** purpose, we may want a separation that is not so **strict**.
- So we can relax the constraint a little.

$$y_i(\boldsymbol{w}^{\mathrm{T}}\boldsymbol{x}_i + b) \geq 1 \quad \rightarrow \quad y_i(\boldsymbol{w}^{\mathrm{T}}\boldsymbol{x}_i + b) \geq 1 - \xi_i \tag{6}$$

- Where $\xi_i > 0$ represents the **error**.

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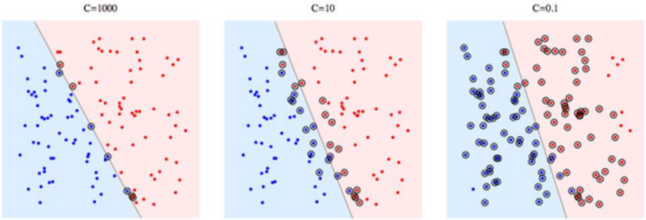
Pratical problems and Extensions: Soft margin

- On the other hand, we don't want the error to be **too large**, thus the goal is reformulated as

$$\min \frac{1}{2}\|w\|^2 \quad \rightarrow \quad \min \left(\frac{1}{2}\|w\|^2 + C \sum_{i=1}^{n} \xi_i \right) \tag{7}$$

- Where parameter C measures the tradeoff between **margin maximization** and **training error minimization**.
- Now we can solve the new **optimization problem**.



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Backup: AFM method

- Anomaly frequency method(AFM) is an efficient technique in extracting the **features** which discriminate extreme events and non-extreme events.
- For a variable, those grid points are selected as feature grid points which have a very **high frequency** of extreme anomalies.

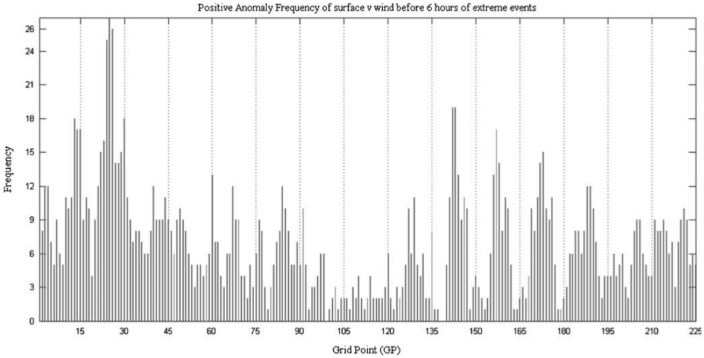

Fig. 3 Frequency of high positive anomaly of V-wind velocity at the surface level, at different grid points, 6 h before the extreme events. Fifty extreme events are considered for this

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Backup: Fingerprinting approach drawbacks

1. The fingerprints identified by the approach may also be present on a **non-extreme** day, which may result in false alarms.
2. There may be **multiple numbers of weather patterns**, which may result in extreme events; however, the fingerprinting approach considers only one fingerprint.