

# Machine Learning

João Catalão Fernandes, FCUL

Aluno	Nome	Titulo	Dia /hora
	Frederico Henriques	A Comparison between Sentinel-2 and Landsat 8 OLI Satellite Images for Soil Salinity Distribution Mapping Using a Deep Learning Convolutional Neural Network	
	Silvia Mourão	Urban land-use mapping using a deep	
	Diogo Oliveira	Comparison of Machine Learning Methods for Mapping the Stand Characteristics of Temperate Forests Using Multi-Spectral Sentinel-2 Data	
	Gonçalo Mendes	Ship Identification on Satellite Image Using Convolutional Neural Network and Random Forest	
	Sofia Freire	An Integrated CNN Model for Reconstructing and Predicting Land Use/Cover Change: A Case Study of the Baicheng Area, Northeast China	
	Sofia Henriques	Remote sensing approach to simulate the land use/land cover and seasonal land surface temperature change using machine learning algorithms in a fastest-growing megacity of Bangladesh	
	David Pereira	Burned Area Mapping in the Brazilian Savanna Using a One-Class Support Vector Machine Trained by Active Fires	
	Bernardo Rodrigues	High-resolution mapping of forest canopy height using machine learning by coupling ICESat-2 LiDAR with Sentinel-1, Sentinel-2 and Landsat-8 data	
	Nuno Costa	Apresentou no ano passado	
	Renato Miguel Spencer Vaz		
	Alfredo Rafael Rodrigues Bastos		
	Diogo Dias de Oliveira		
	Dajana Dimitrijević		
	Teodor Macan		

# De 1984 a 2020: as imagens que mostram um “Portugal natural ameaçado”

Campos vazios que se transformaram em estufas de agricultura intensiva, milhares de hectares ardidos, construção desordenada junto à costa, a erosão costeira a mudar as praias. Com a nova ferramenta da Google Earth, a associação Zero quis mostrar como a paisagem mudou em 36 anos.

PÚBLICO

21 de Abril de 2021, 19:20

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A associação ambientalista Zero pegou na [nova ferramenta da Google Earth](#) que, em [progressão rápida \(time-lapse\)](#), nos permite ver a evolução de diferentes locais do mundo entre 1984 e 2020. Em Portugal, descobriu espaços profundamente alterados. O impacto do crescimento urbanístico e as marcas de desastres naturais relacionados com as alterações climáticas são visíveis. No Dia da Terra, que se assinala nesta quinta-feira, a selecção da Zero mostra-nos, segundo a própria, “um Portugal natural ameaçado”.

## 1 | Parque Natural do Sudoeste Alentejano e Costa Vicentina

De campos praticamente vazios, a estenderem-se até ao mar, a hectares e hectares de áreas cobertas com o [plástico das estufas](#). Aqui, a paisagem alterou-se radicalmente, com a marca da agricultura intensiva. O que a imagem não mostra, mas a Zero lembra, é que esta mudança foi acompanhada do uso de pesticidas, fertilizantes e de um grande consumo de água, que “põem em causa os valores naturais que deveriam estar salvaguardados”.

## | 1. Ilhas-barreira na Ria Formosa (Algarve)

Este sistema constituído por cinco ilhas e duas penínsulas, na Ria Formosa, no Algarve, está muito vulnerável à [subida do mar](#) e às tempestades oceânicas. Eventos potenciados pelas [alterações climáticas](#), como a subida do nível do mar e intensificação de temporais violentos, colocam em risco estas ilhas, incluindo a de Tavira e Cacela. As ilhas da Ria Formosa são [classificadas](#) como protegidas pelo estatuto de Parque Natural, datado de 1987, e integram da Rede Natura 2000.



DUARTE DRAGO

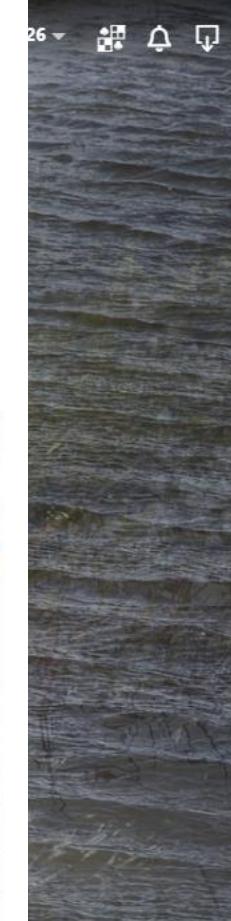
ALTERAÇÕES CLIMÁTICAS

# A destruição silenciosa: ameaçadas em Portugal



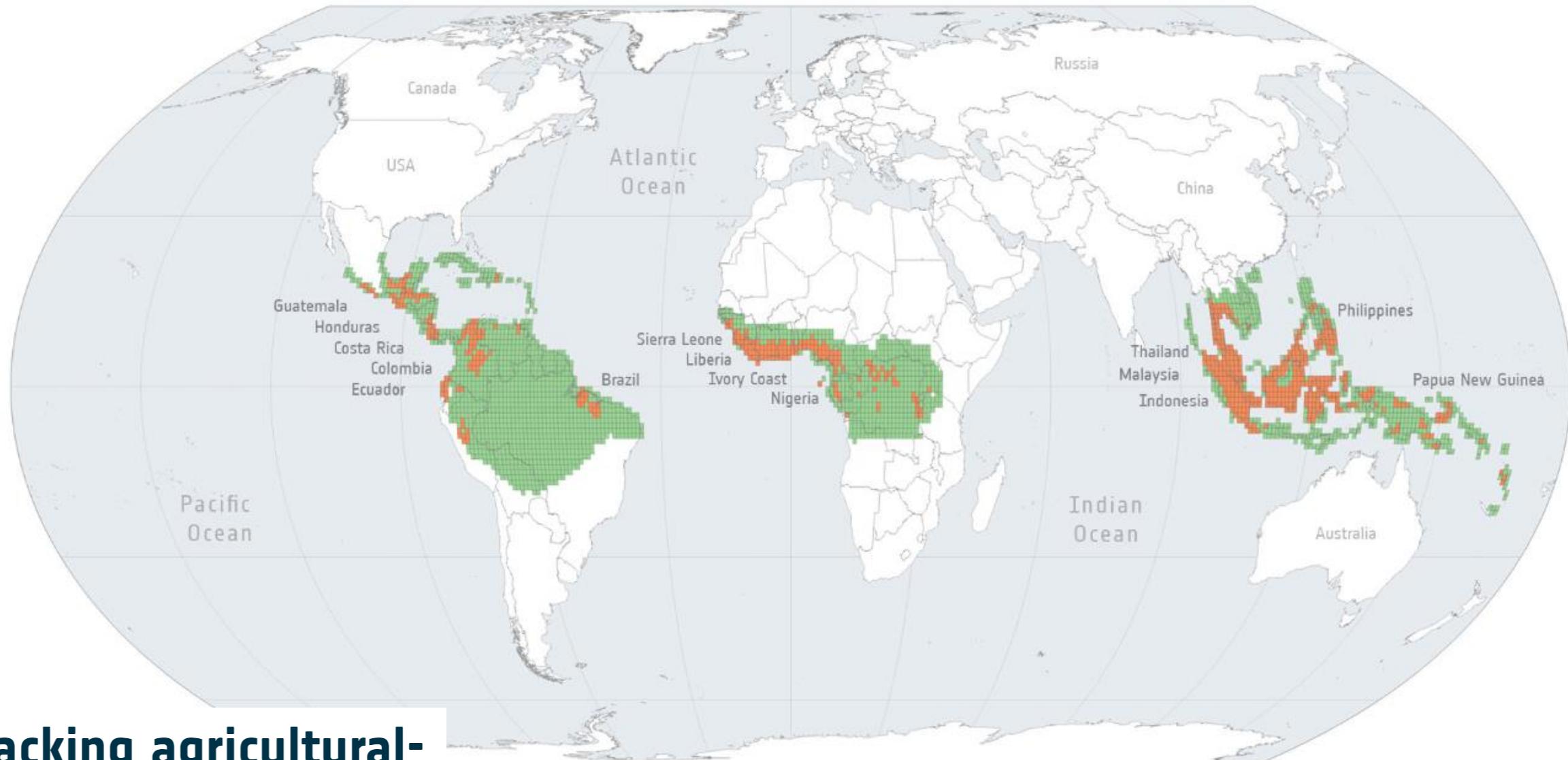
## | 2. Montado de Sobreiro e Azinheira (Alentejo)

As previsões sugerem mudanças muito significativas nas azinheiras, porque estão dependentes de uma certa quantidade de precipitação. Se as chuvas escassearem, as azinheiras “deixam de ter condições de sobreviver” e talvez passem a ser viáveis cada vez mais para norte. “O sobreiro acaba por sofrer *stress* hídrico e pode vir a desaparecer. Isto já está mais ou menos estipulado que poderá acontecer. Este mosaico que nós temos hoje no Alentejo vai ser profundamente afectado pelas alterações climáticas”, afirma Paulo Lucas. Em 2001, foi criado o enquadramento legal que [estabelece](#) as medidas de protecção ao sobreiro e à azinheira.



## | 5. Arrozais da Comporta (Lisboa e Vale do Tejo)

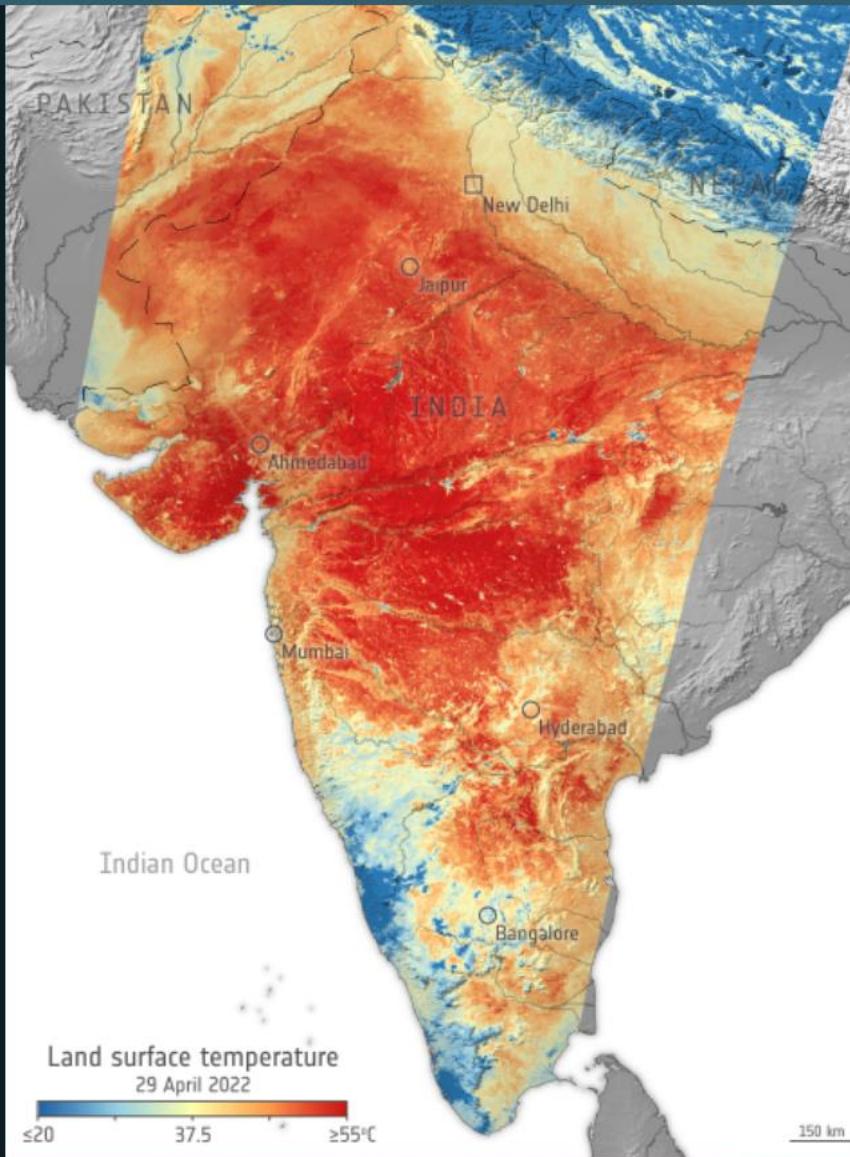
A agricultura que se faz na continuidade dos estuários, muitas vezes até abaixo do nível do mar - como é o caso dos arrozais no estuário do Sado, na península da Comporta - também constitui uma paisagem portuguesa ameaçada. “A intrusão salina vai acabar com este tipo de cultivo mais tarde ou mais cedo. Há áreas que já estão a ser abandonadas. Há inclusivamente zonas que hoje já não são produtivas devido ao sal”, refere Paulo Lucas. Os arrozais [integram](#) a Reserva Natural do Estuário do Sado e a Rede Natura 2000.



# Tracking agricultural-related deforestation

Oil palm plantation distribution grid

- Potential distribution of oil palm plantations
- Detected oil palm plantations

**APPLICATIONS**

## Heatwave across India

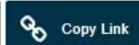
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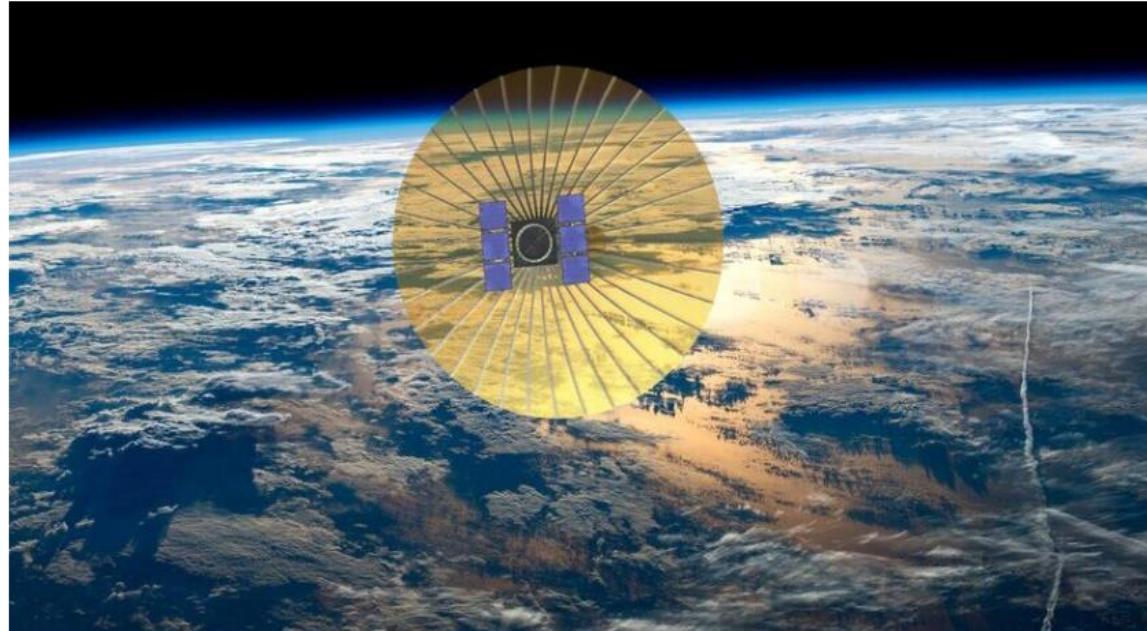
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**RELATED**

India is currently facing a prolonged heatwave, with temperatures exceeding 42°C in numerous cities across the country. This comes just weeks after India recorded its hottest March since the country's meteorological department began its records over 120 years ago. This image, produced using data from the [Copernicus Sentinel-3 mission](#), shows the land surface temperature across most of the nation.

## Umbra advertises SAR imagery with 15-centimeter resolution

by Debra Werner — March 12, 2021



Umbra has a patent for an antenna designed to stow compactly for launch and expand in orbit with a series of ribs attached to a central hub. The antenna is covered in a flexible reflective material. Credit: Umbra

SAN FRANCISCO — Radar satellite startup Umbra plans to capture imagery with a resolution as high as **15 centimeters** per pixel thanks to a Federal Communications Commission license.

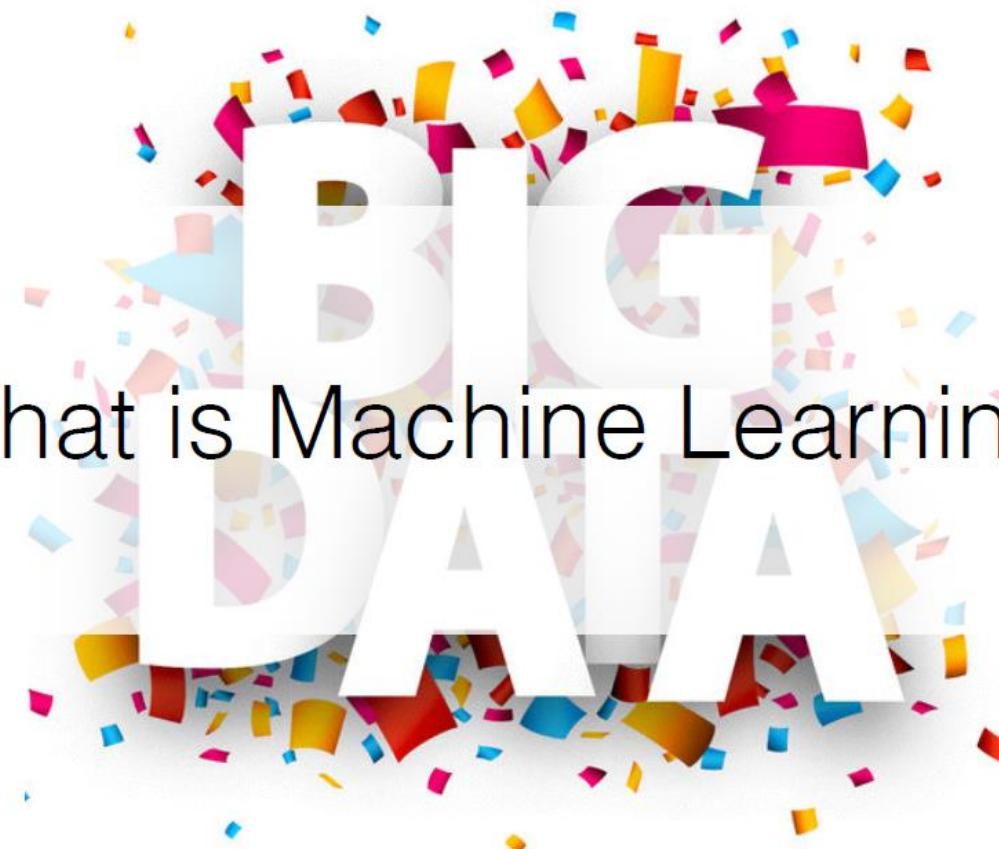
The FCC granted Umbra, a Santa Barbara, California, startup preparing to launch its first X-band synthetic aperture radar (SAR) microsatellite this year, an experimental license in February to operate high-bandwidth SAR using the 1,200 MHz band centered on 9.8 GHz and low-bandwidth SAR with the 600 MHz band centered on 9.6 GHz.

“Bandwidth is the limiting factor in determining slant range resolution, and ultimately ground plane resolution in the cross-track direction,” Dominocielo said by email. “Improvement in resolution is proportional to the amount of bandwidth available for use by the sensor.”

# Tópicos

## 5. Machine Learning

- What is machine learning?
- Bibliography and software
- Tasks for machine learning
- Machine learning models
- Generalization, Overfitting
- k-NN algorithm
- Linear Models
- Decision Trees
- Neural Network
- Convolutional Neural Network



# What is Machine Learning?

Remote sensing multispectral image data, behavioural geography data (person location and trip), transportation network data... BIG DATA of geography.

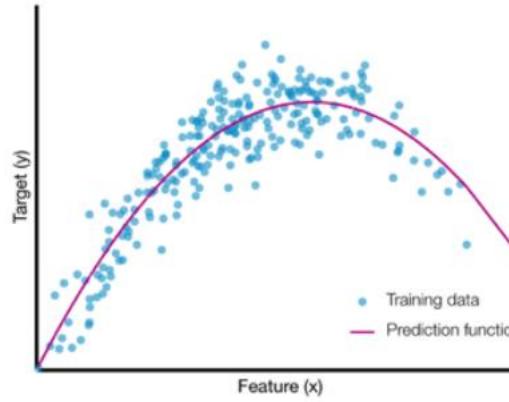
Machine learning is believed to be the powerful tool to explore and analyze the geography big data.

## What is machine learning?

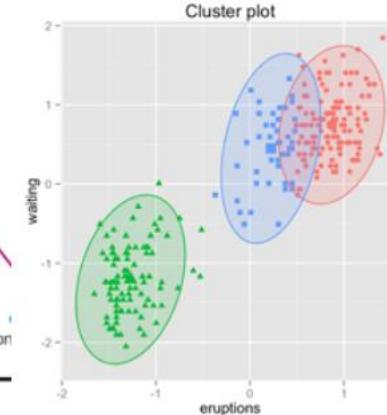
Machine learning evolved from the study of **pattern recognition** and **computational learning theory** in **artificial intelligence (AI)**.

# Machine Learning

“A computer program is said to learn from experience E with respect to some class of tasks T and performance measure P if its performance at tasks in T, as measured by P, improves with experience E” — *T. Michell (1997)*



regression



clustering

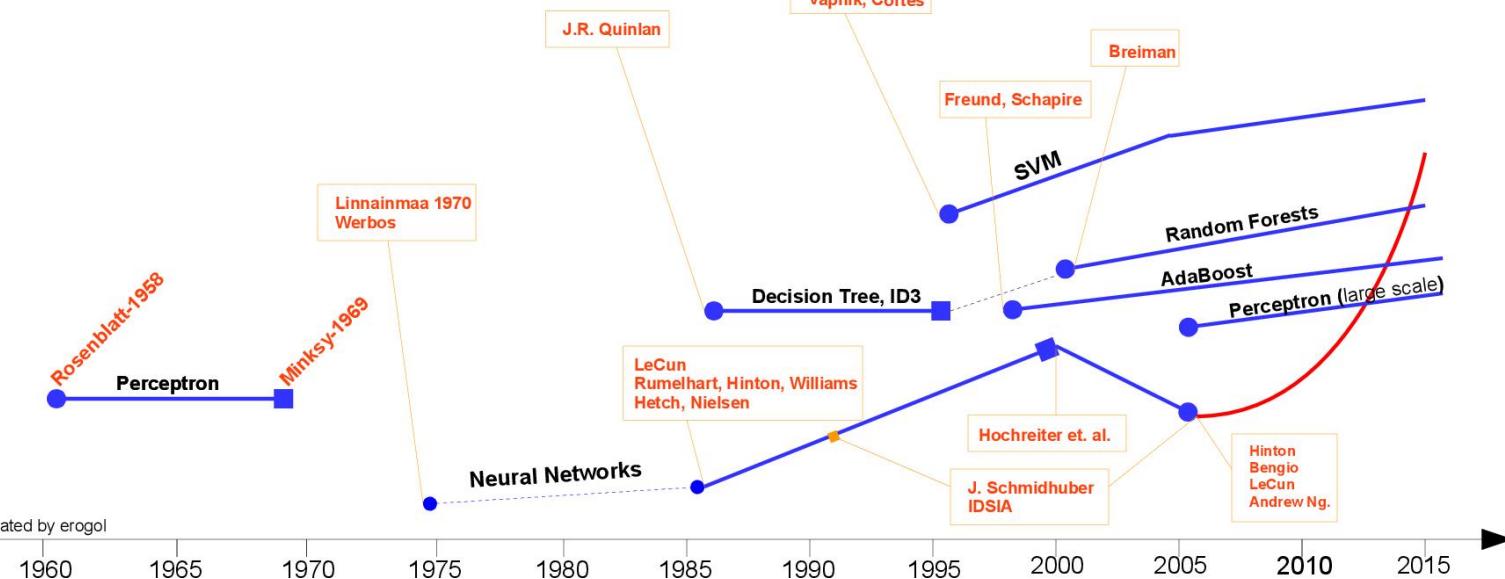


classification

T: Playing checkers  
P: Games won  
E: playing games against itself

## A brief history of machine learning

Subjective Popularity

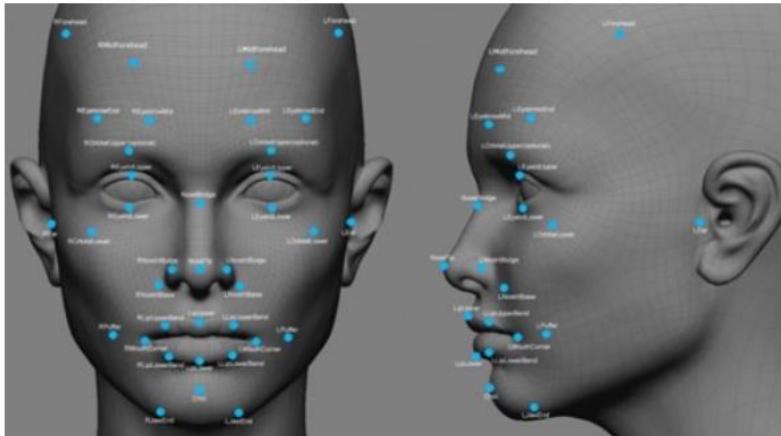


<http://www.erogol.com/wp-content/uploads/2014/05/test.jpg>

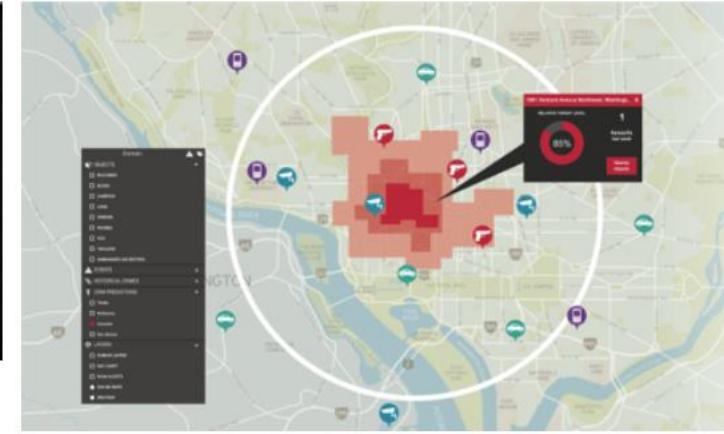
It is all about machine learning...



**Intelligent voice assistant**  
<http://www.apple.com/ios/siri/>



**Facial recognition**  
<http://www.face-rec.org/>



**Predictive policing**  
<http://www.predpol.com/>



**Self-driving car**  
<https://www.google.com/selfdrivingcar/>

# How to connect the machine learning with geospatial data?

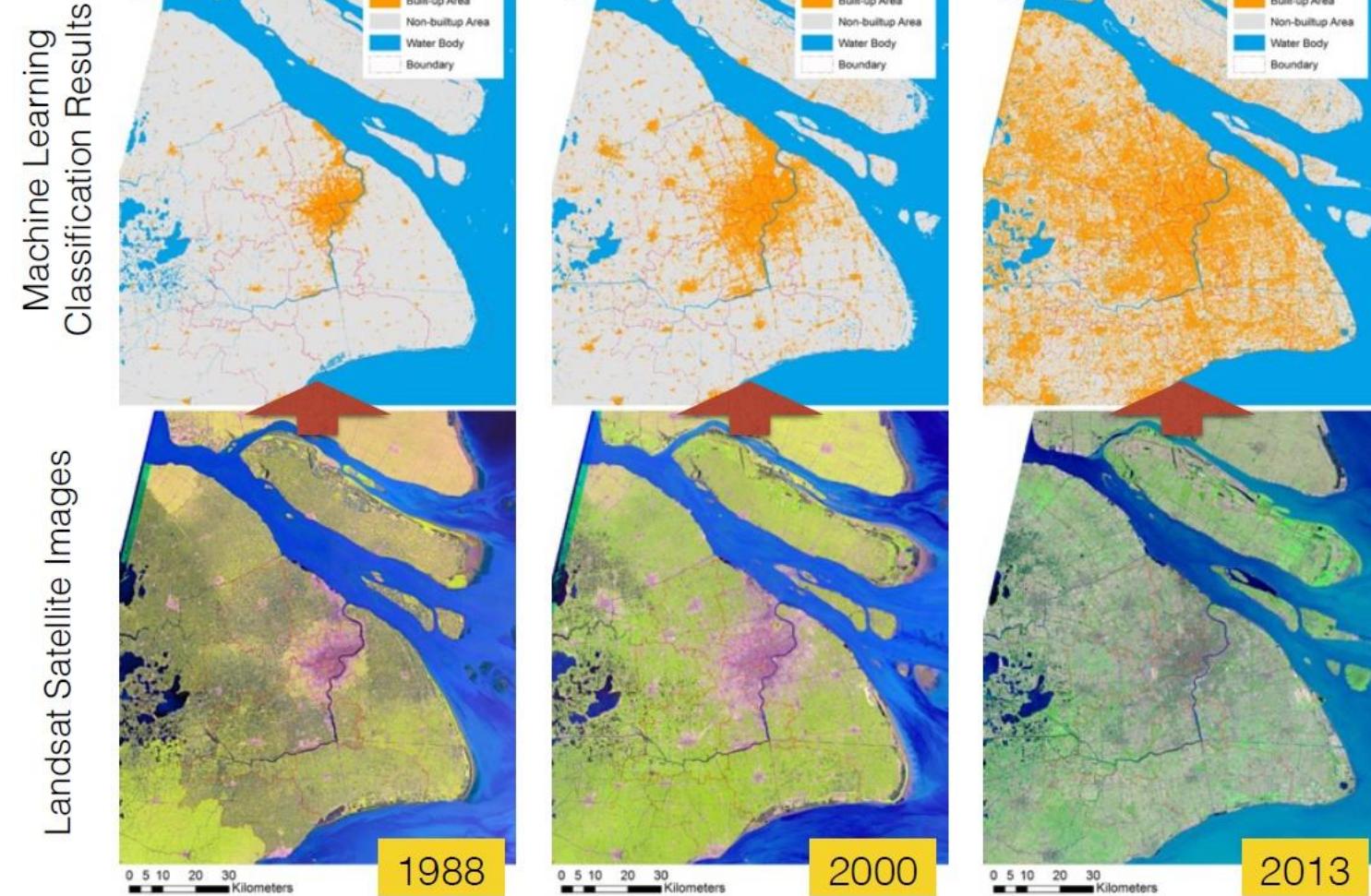
# Geospatial Big Data

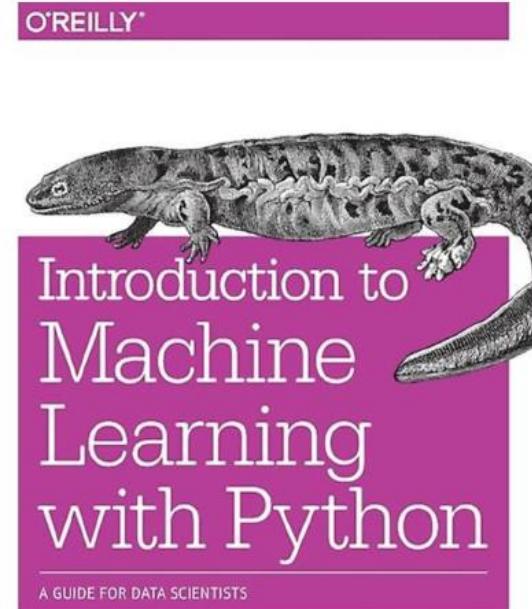
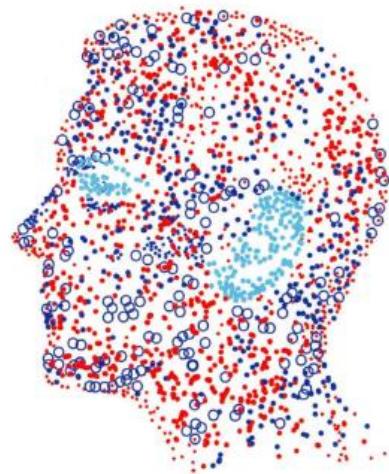
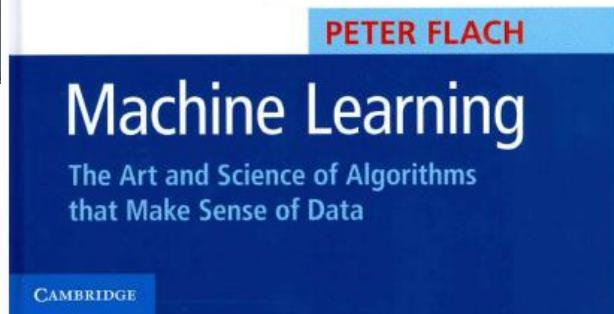
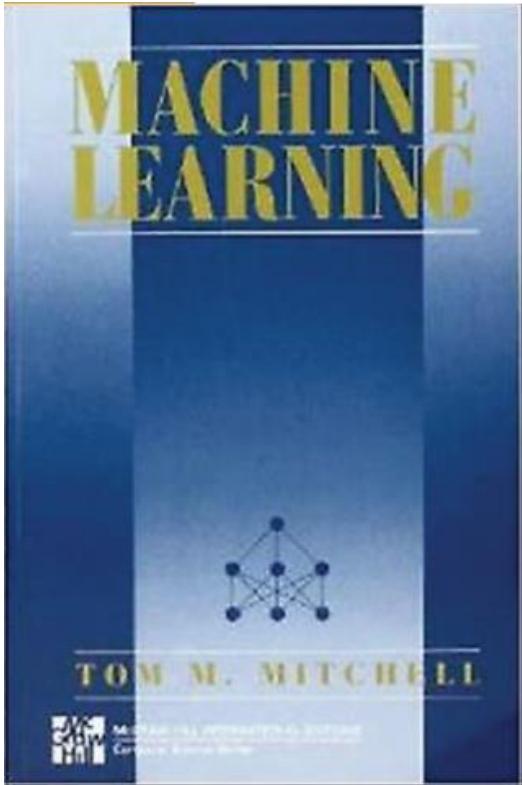
Remote sensing multispectral image data,  
behavioral geography data (person trip),  
transportation network data,



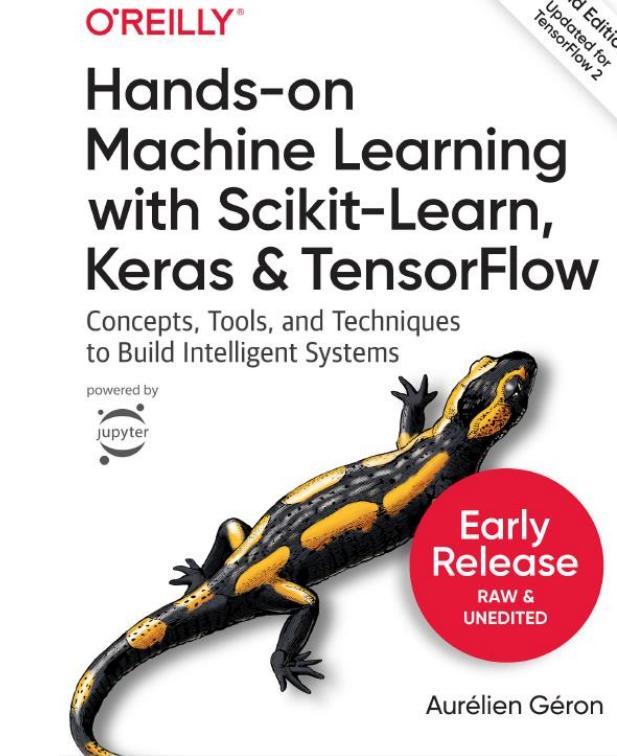
<http://2012.bedreinnovation.dk/aktivitet/data-mining-og-machine-learning-i-praksis>

# Machine Learning in Remote Sensing





Andreas C. Müller & Sarah Guido



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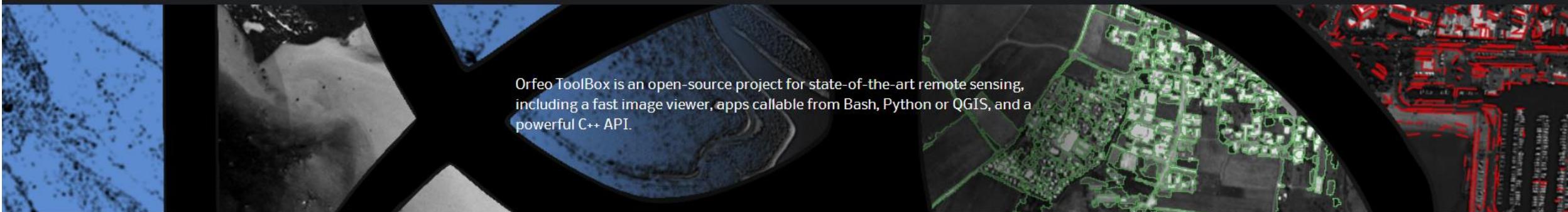


# Orfeo ToolBox

Orfeo ToolBox is not a black box

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Orfeo ToolBox is an open-source project for state-of-the-art remote sensing, including a fast image viewer, apps callable from Bash, Python or QGIS, and a powerful C++ API.



## Open Source processing of remote sensing images

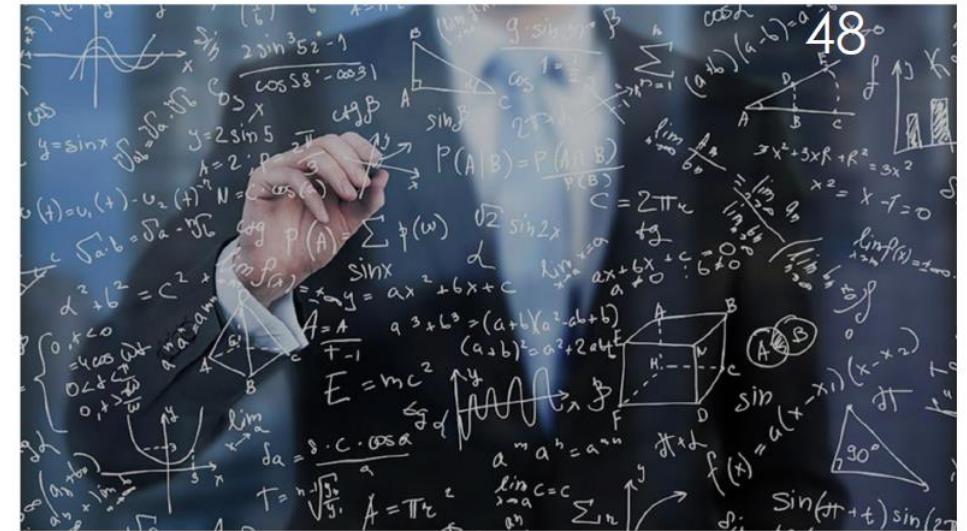
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## List of Common Machine Learning Algorithms

1. Naïve Bayes Classifier Algorithm
2. K Means Clustering Algorithm
3. Support Vector Machine Algorithm
4. Apriori Algorithm
5. Linear Regression
6. Logistic Regression
7. Artificial Neural Networks
8. Random Forests
9. Decision Trees
10. Nearest Neighbours

The 10 Algorithms Machine Learning Engineers Need to Know



1. Linear Regression
2. Logistic Regression
3. Decision Trees
4. SVM (Support Vector Machine)
5. Naive Bayes
6. KNN (K- Nearest Neighbors)
7. K-Means
8. Random Forests
9. Dimensionality Reduction Algorithms
10. Gradient Boosting & AdaBoost

The most common machine learning tasks are *predictive*, in the sense that they concern predicting a target variable from features. .

- ☞ Binary and multi-class classification: categorical target
- ☞ Regression: numerical target
- ☞ Clustering: hidden target

*Descriptive* tasks are concerned with exploiting underlying structure in the data.

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	<i>Predictive model</i>	<i>Descriptive model</i>
<i>Supervised learning</i>	classification, regression	subgroup discovery
<i>Unsupervised learning</i>	predictive clustering	descriptive clustering, association rule discovery

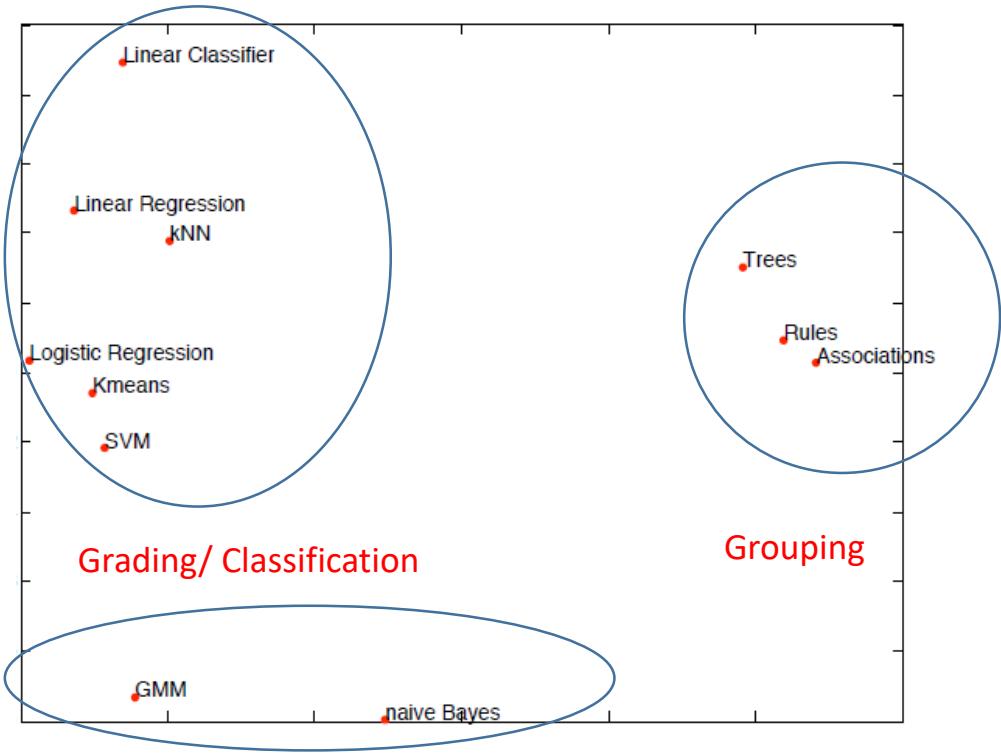
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Machine learning models can be distinguished according to their main intuition:

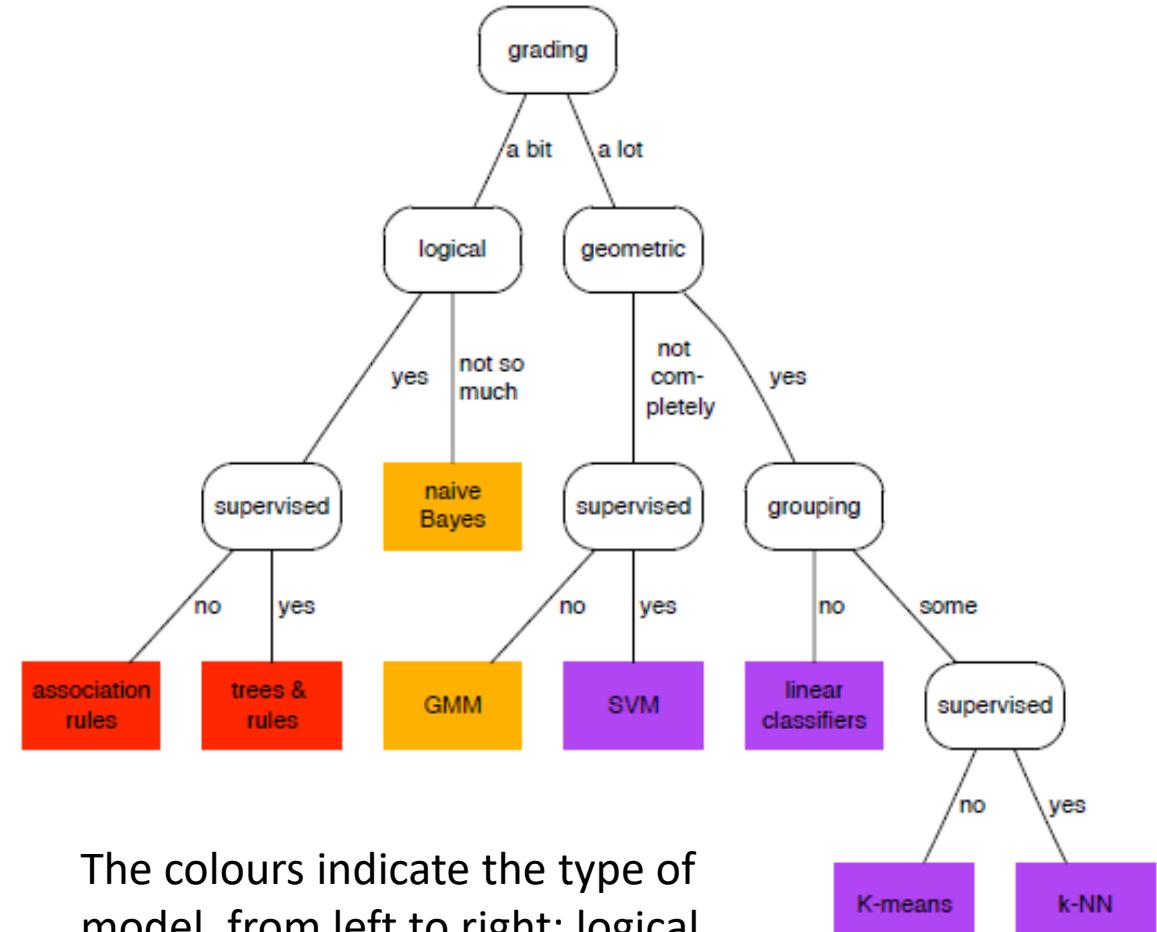
- ☞ *Geometric* models use intuitions from geometry such as separating (hyper-)planes, linear transformations and distance metrics.
- ☞ *Probabilistic* models view learning as a process of reducing uncertainty, modelled by means of probability distributions.
- ☞ *Logical* models are defined in terms of easily interpretable logical expressions.

Alternatively, they can be characterised by their *modus operandi*:

- ☞ *Grouping models* divide the instance space into segments; in each segment a very simple (e.g., constant) model is learned.
- ☞ *Grading models* learn a single, global model over the instance space.



Models that share characteristics are plotted closer together: logical models to the right, geometric models on the top left and probabilistic models on the bottom left. The horizontal dimension roughly ranges from grading models on the left to grouping models on the right.



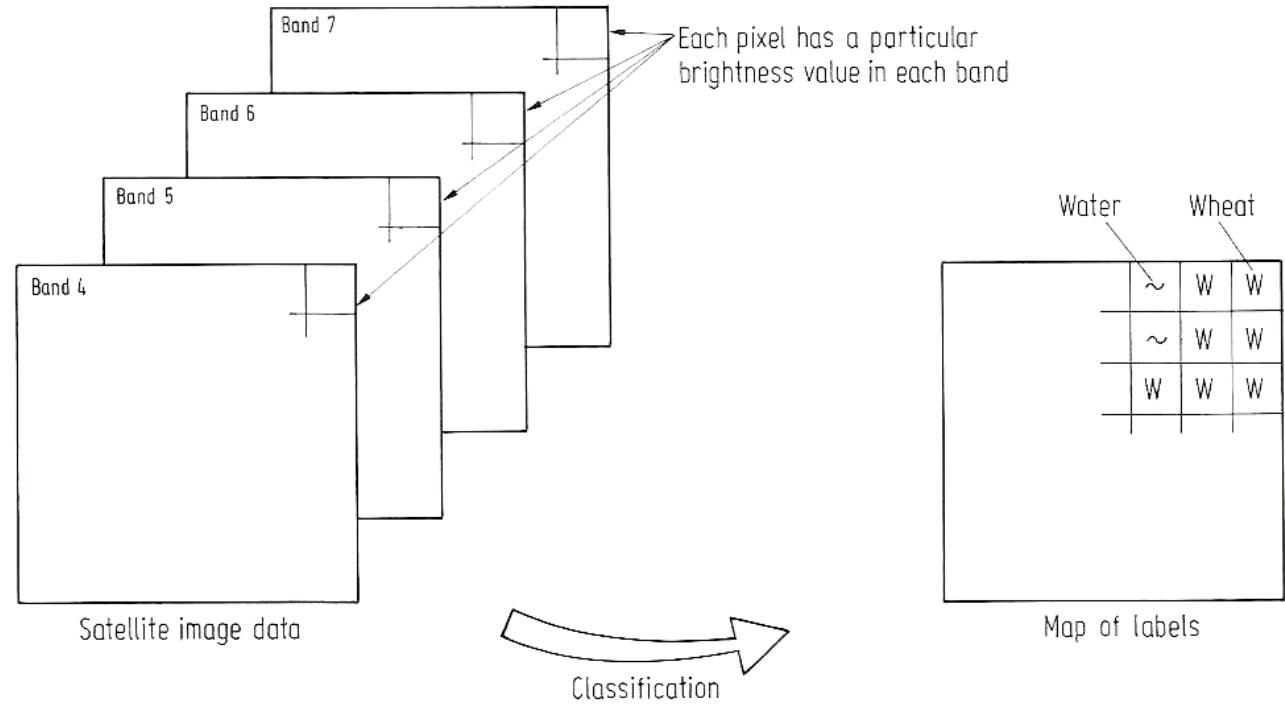
The colours indicate the type of model, from left to right: logical (red), probabilistic (orange) and geometric (purple).

<i>Task</i>	<i>Label space</i>	<i>Output space</i>	<i>Learning problem</i>
Classification	$\mathcal{L} = \mathcal{C}$	$\mathcal{Y} = \mathcal{C}$	learn an approximation $\hat{c} : \mathcal{X} \rightarrow \mathcal{C}$ to the true labelling function $c$
Scoring and ranking	$\mathcal{L} = \mathcal{C}$	$\mathcal{Y} = \mathbb{R}^{ \mathcal{C} }$	learn a model that outputs a score vector over classes
Probability estimation	$\mathcal{L} = \mathcal{C}$	$\mathcal{Y} = [0, 1]^{ \mathcal{C} }$	learn a model that outputs a probability vector over classes
Regression	$\mathcal{L} = \mathbb{R}$	$\mathcal{Y} = \mathbb{R}$	learn an approximation $\hat{f} : \mathcal{X} \rightarrow \mathbb{R}$ to the true labelling function $f$

A *classifier* is a mapping  $\hat{c}: \mathcal{X} \rightarrow \mathcal{C}$ , where  $\mathcal{C} = \{C_1, C_2, \dots, C_k\}$  is a finite and usually small set of *class labels*. We will sometimes also use  $C_i$  to indicate the set of examples of that class.

We use the ‘hat’ to indicate that  $\hat{c}(x)$  function  $c(x)$ . Examples for a classifier instance and  $c(x)$  is the true class by noise).

Learning a classifier involves constructing as closely as possible (and not just one) instance space  $\mathcal{X}$ ).

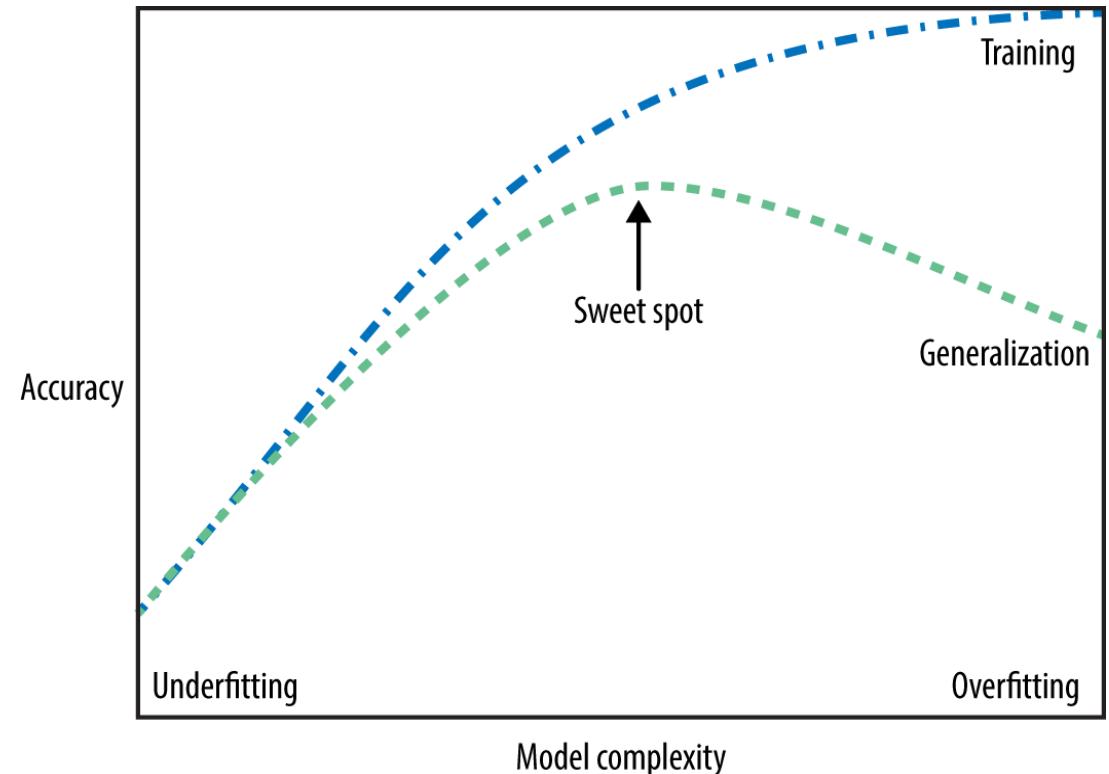


# Generalization, Overfitting, and Underfitting

If a model is able to make accurate predictions on unseen data, we say it is able to **generalize** from the training set to the test set. We want to build a model that is able to generalize as accurately as possible.

**Overfitting** occurs when you fit a model too closely to the particularities of the training set and obtain a model that works well on the training set but is not able to generalize to new data.

Trade-off of model complexity against training and test accuracy

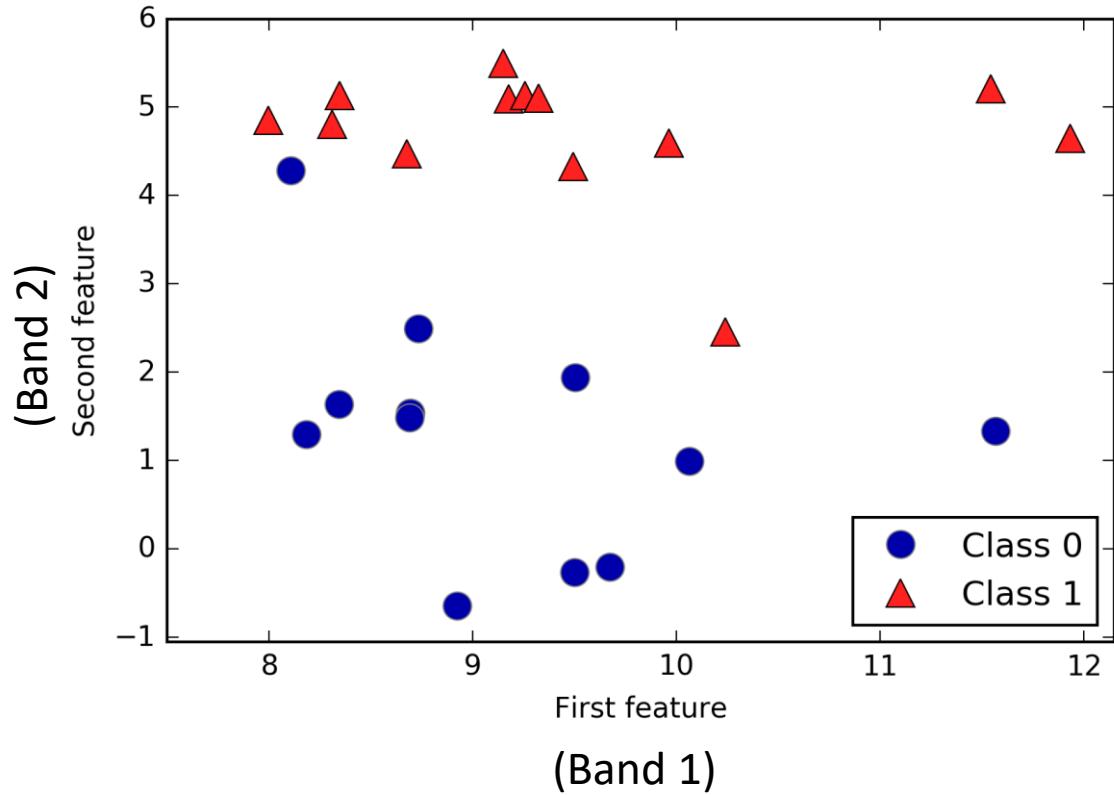


More complex the model => better we will be able to predict on the training data.

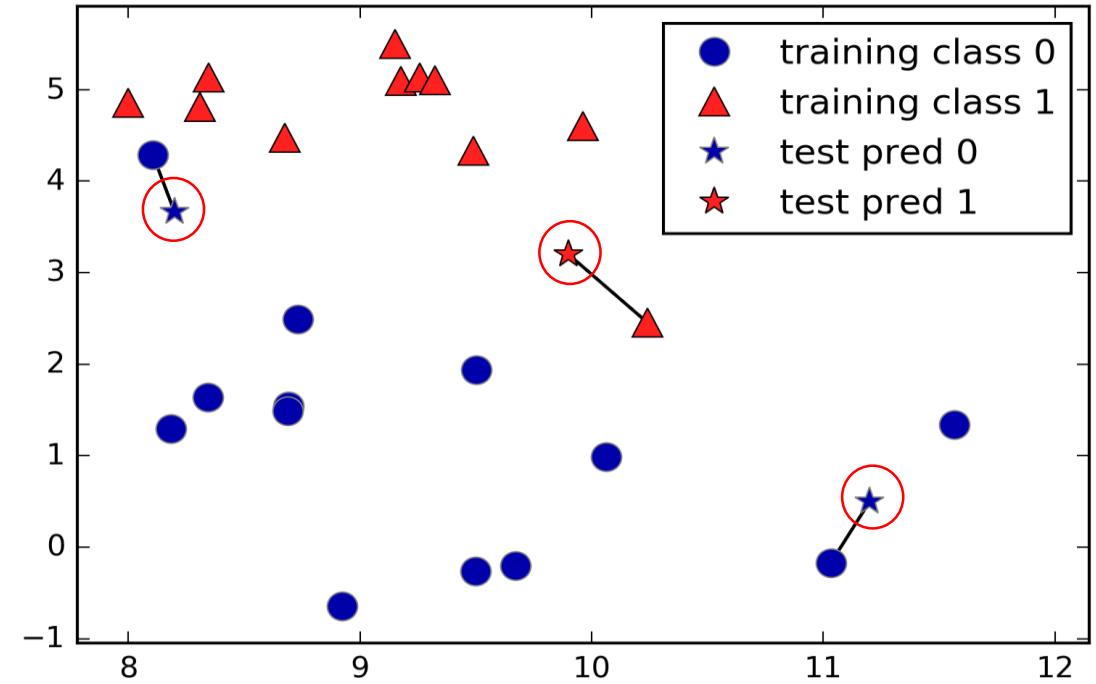
However : Too complex => focusing too much in our training set => not generalize well to new data.

There is a sweet spot in between that will yield the best generalization performance.

Scatter plot of training dataset  
2 bands and 2 classes



Predictions made by the one-nearest-neighbour model on the dataset



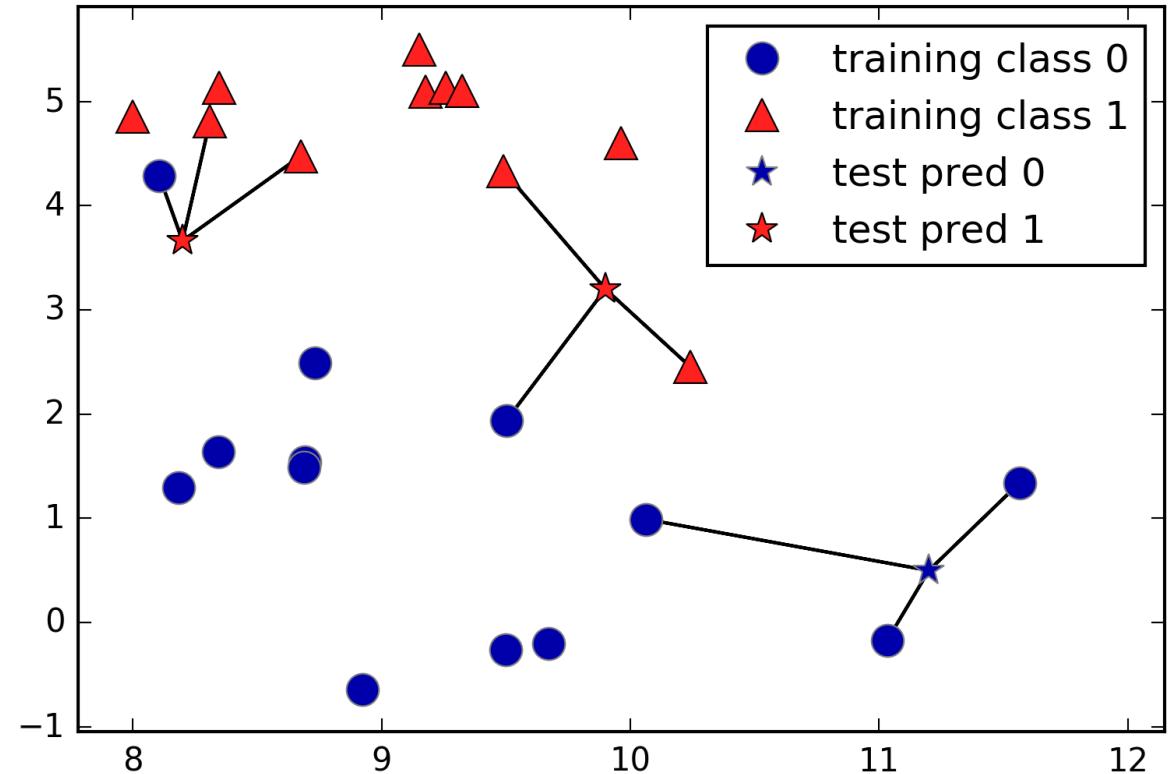
Instead of considering only the closest neighbour, we can also consider an arbitrary number,  $k$ , of neighbours.

This is where the name of the  $k$ -nearest neighbours algorithm comes from.

When considering more than one neighbour, we use voting to assign a label. This means that for each test point, we count how many neighbours belong to class 0 and how many neighbours belong to class 1.

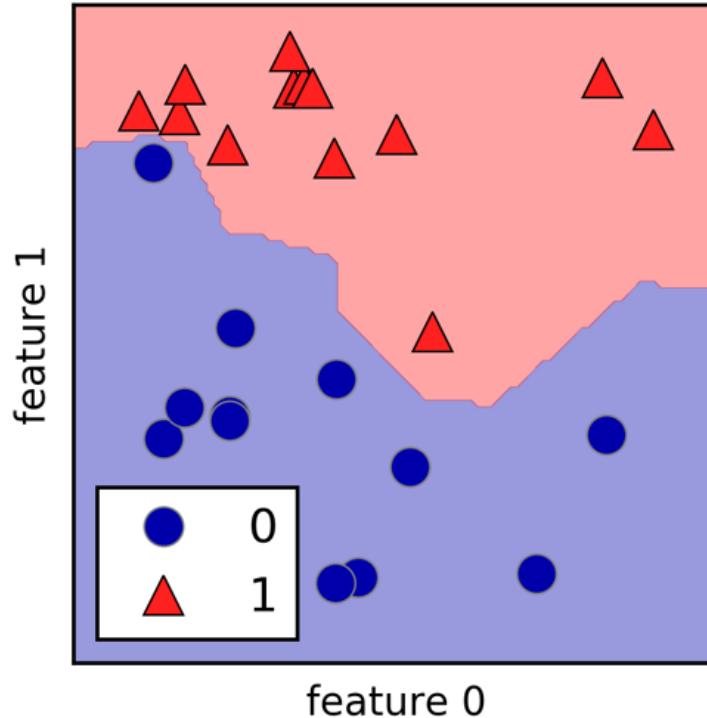
We then assign the class that is more frequent: in other words, the majority class among the  $k$ -nearest neighbours.

Predictions made by the three-nearest-neighbours model on the dataset

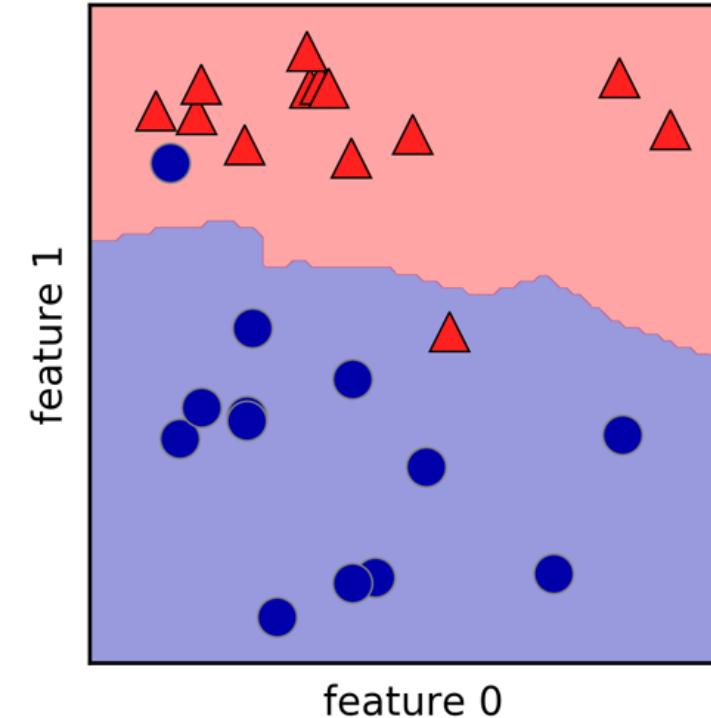


## K-NN (K-Nearest Neighbours)

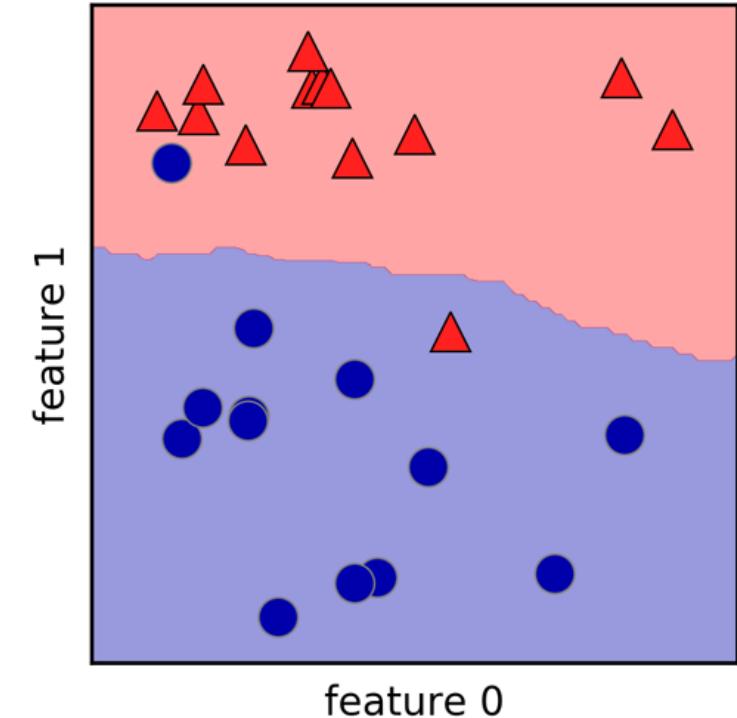
1 neighbor(s)



3 neighbor(s)



9 neighbor(s)



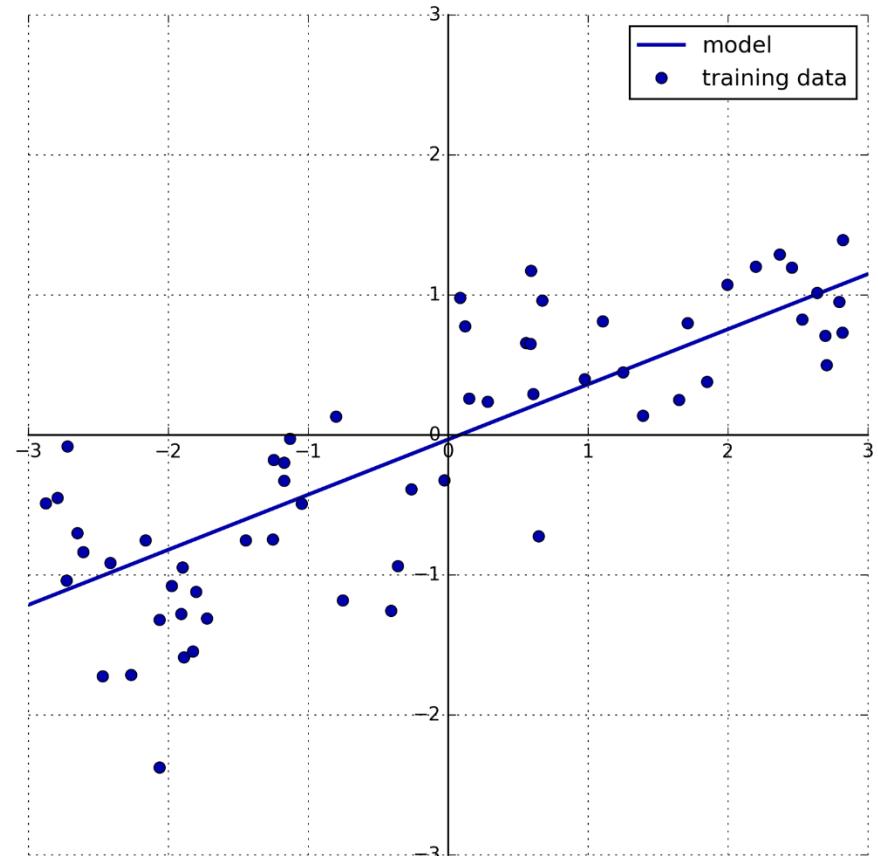
Decision boundaries created by the nearest neighbours model for different values of  $k_{\text{neighbours}}$

Linear models are a class of models that are widely used in practice and have been studied extensively in the last few decades, with roots going back over a hundred years.

Linear models make a prediction using a *linear function* of the input features, which we will explain shortly. For regression:

$$\hat{y} = w[0] * x[0] + w[1] * x[1] + \dots + w[p] * x[p] + b$$

Here,  $x[0]$  to  $x[p]$  denotes the features (in our case, the spectral bands,  $p+1$ ) of a single pixel (or set of pixels),  $w$  and  $b$  are parameters of the model that are learned, and  $\hat{y}$  is the prediction the model makes.

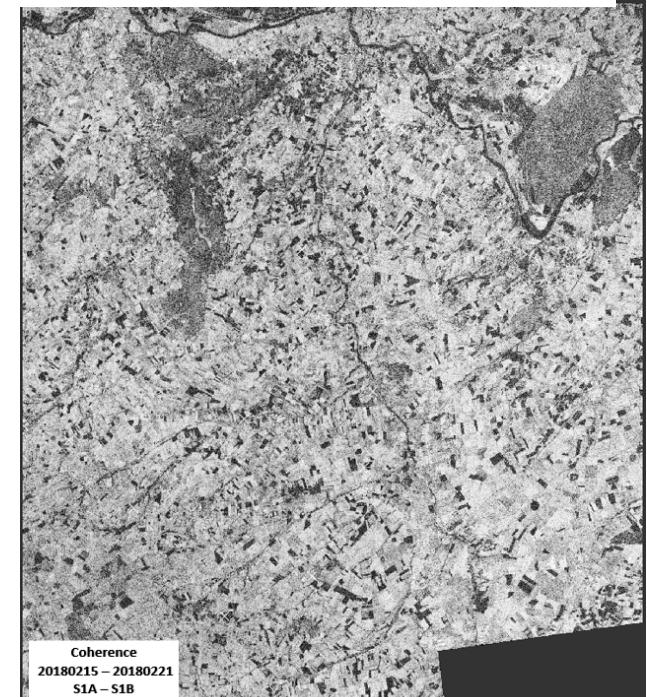
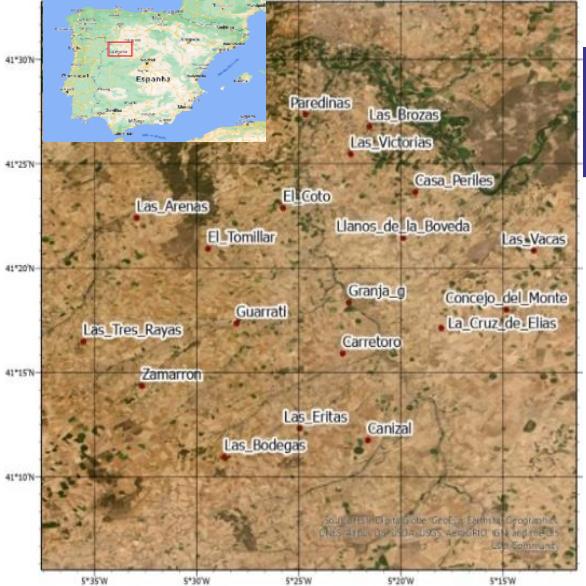


For a dataset with a single feature, this is:

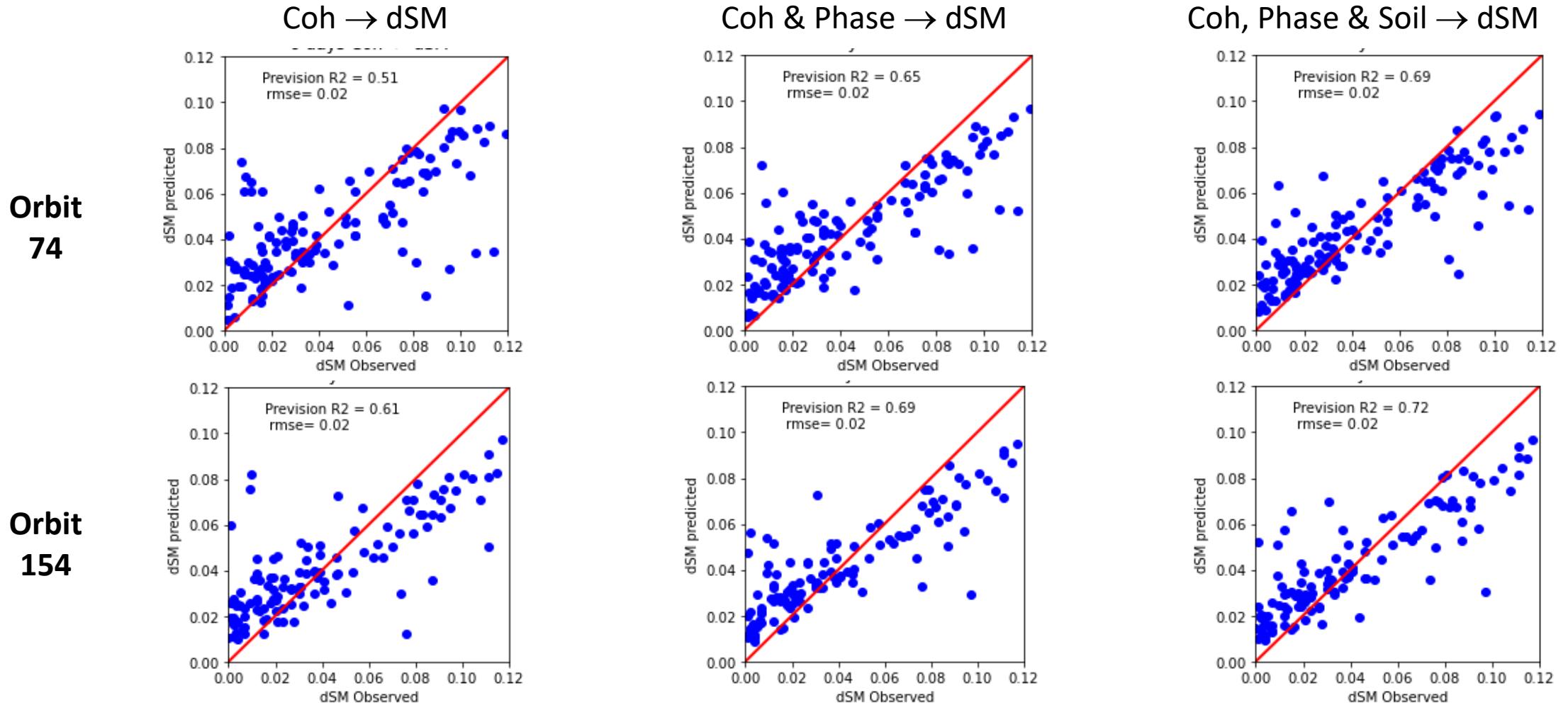
$$\hat{y} = w[0] * x[0] + b$$

## Assess the usefulness of the temporal coherence matrix on the estimation of the soil moisture changes

- Machine Learning Regression Techniques
  - Linear Regression (LR)
  - Random Forest Regressor (RFR)
  - ExtraTree + Bagging Regressor (ETBR)
- Data inputs: InSAR coherence, phase and soil type
- Data output: soil moisture change between two dates



## SM estimation vs SM observation



Linear models are also extensively used for classification.

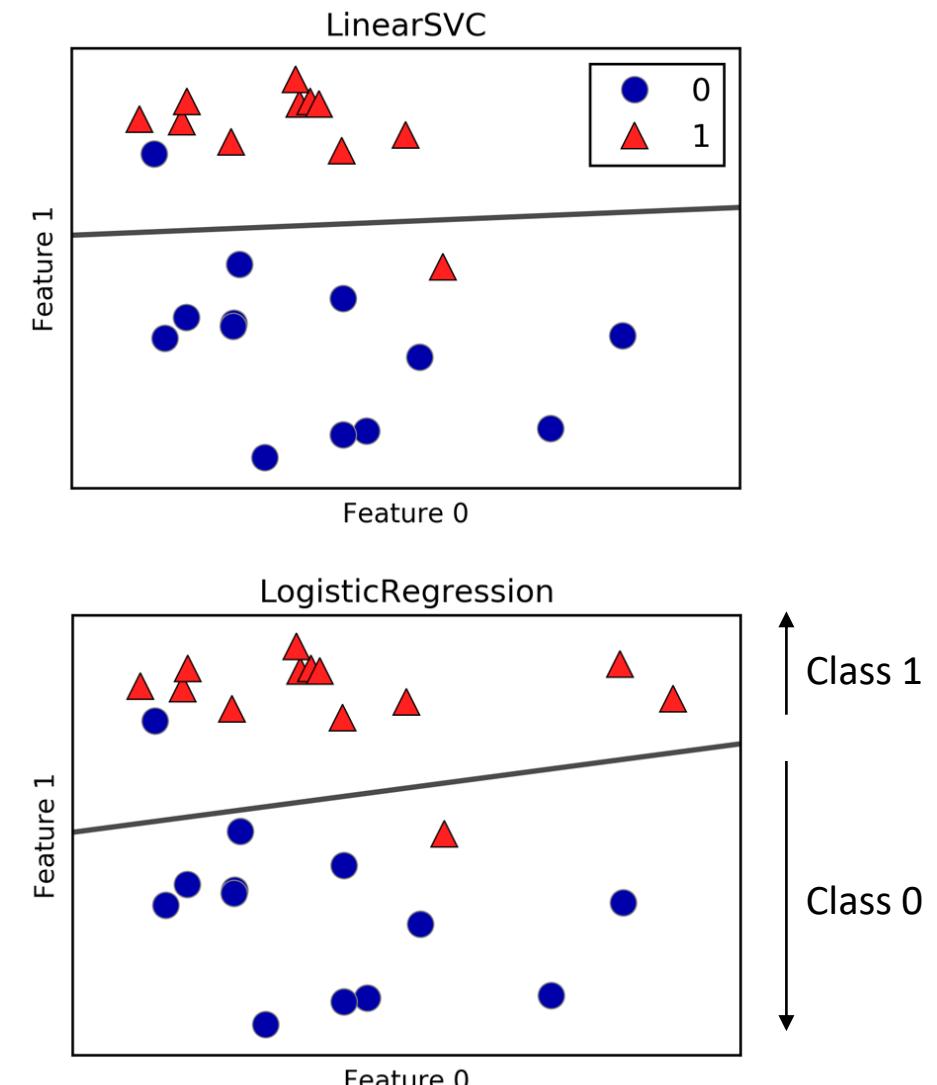
In this case, a prediction is made using the following formula:

$$\hat{y} = w[0] * x[0] + w[1] * x[1] + \dots + w[p] * x[p] + b > 0$$

The formula looks very similar to the one for linear regression, but instead of just returning the weighted sum of the features, we threshold the predicted value at zero.

If the function is smaller than zero, we predict the class  $-1$ ; if it is larger than zero, we predict the class  $+1$ .

This prediction rule is common to all linear models for classification. Again, there are many different ways to find the coefficients ( $w$ ) and the intercept ( $b$ ).



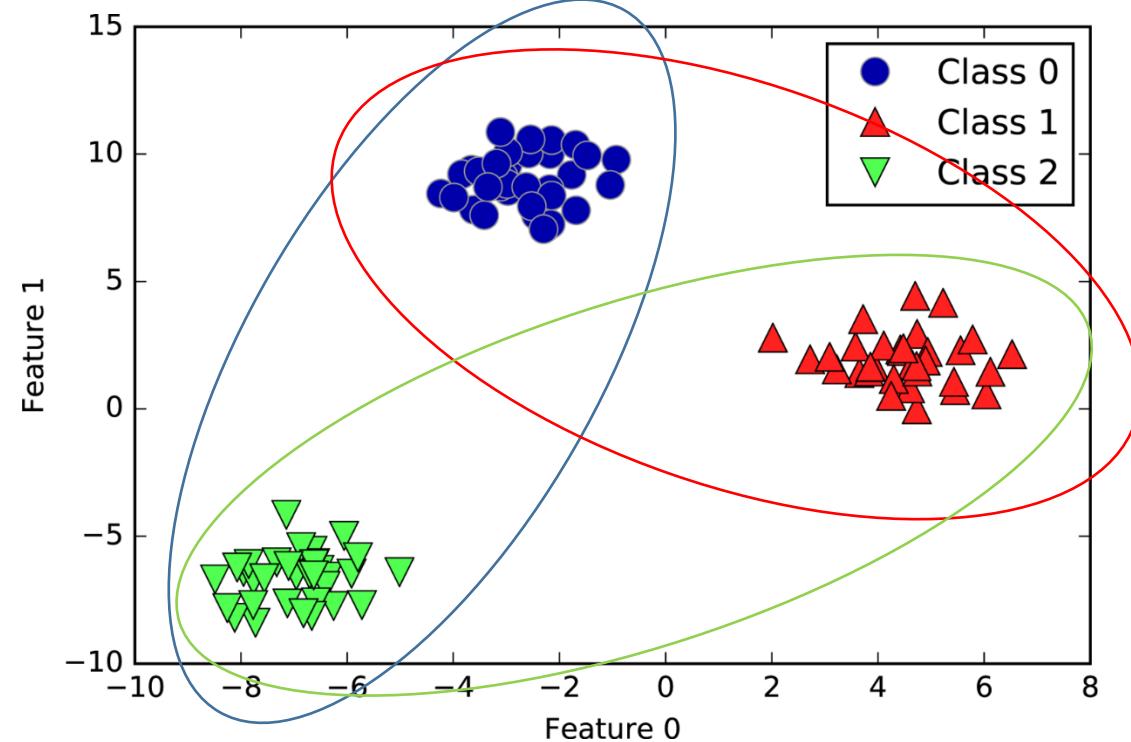
A common technique to extend a binary classification algorithm to a multiclass classification algorithm is the **one-vs.-rest approach**.

In the **one-vs.-rest** approach, a binary model is learned for each class that tries to separate that class from all of the other classes, resulting in as many binary models as there are classes.

Having one binary classifier per class results in having one vector of coefficients ( $w$ ) and one intercept ( $b$ ) for each class.

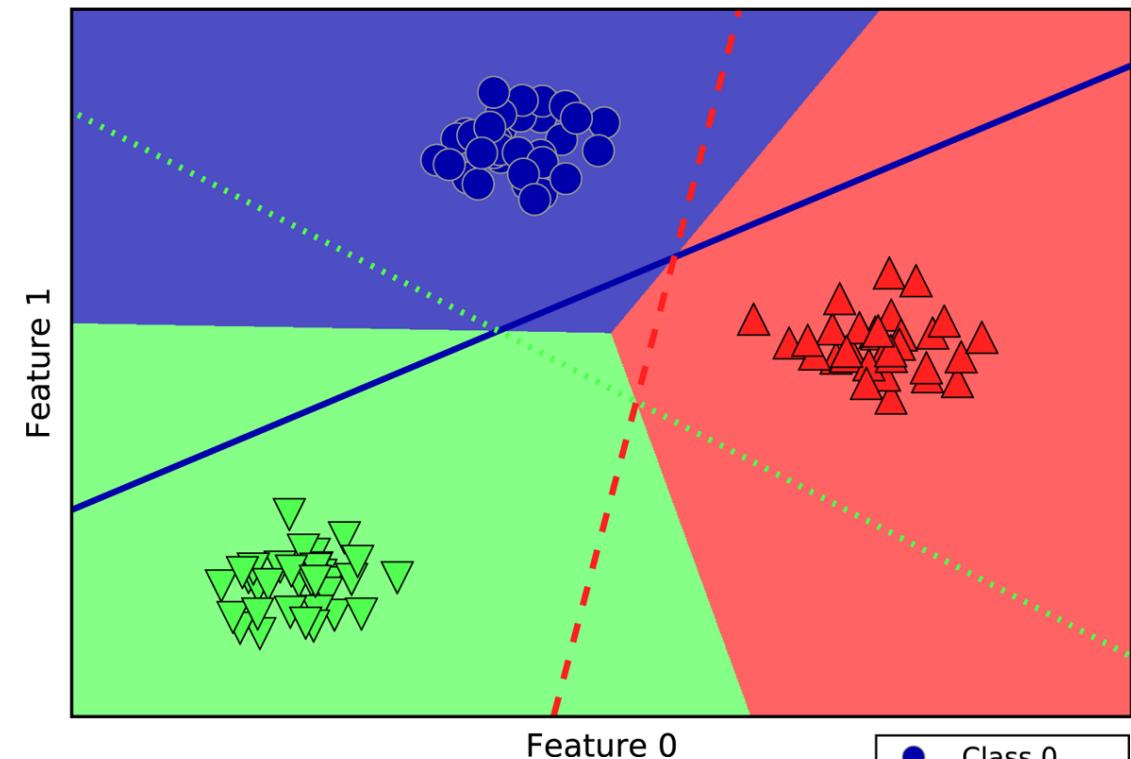
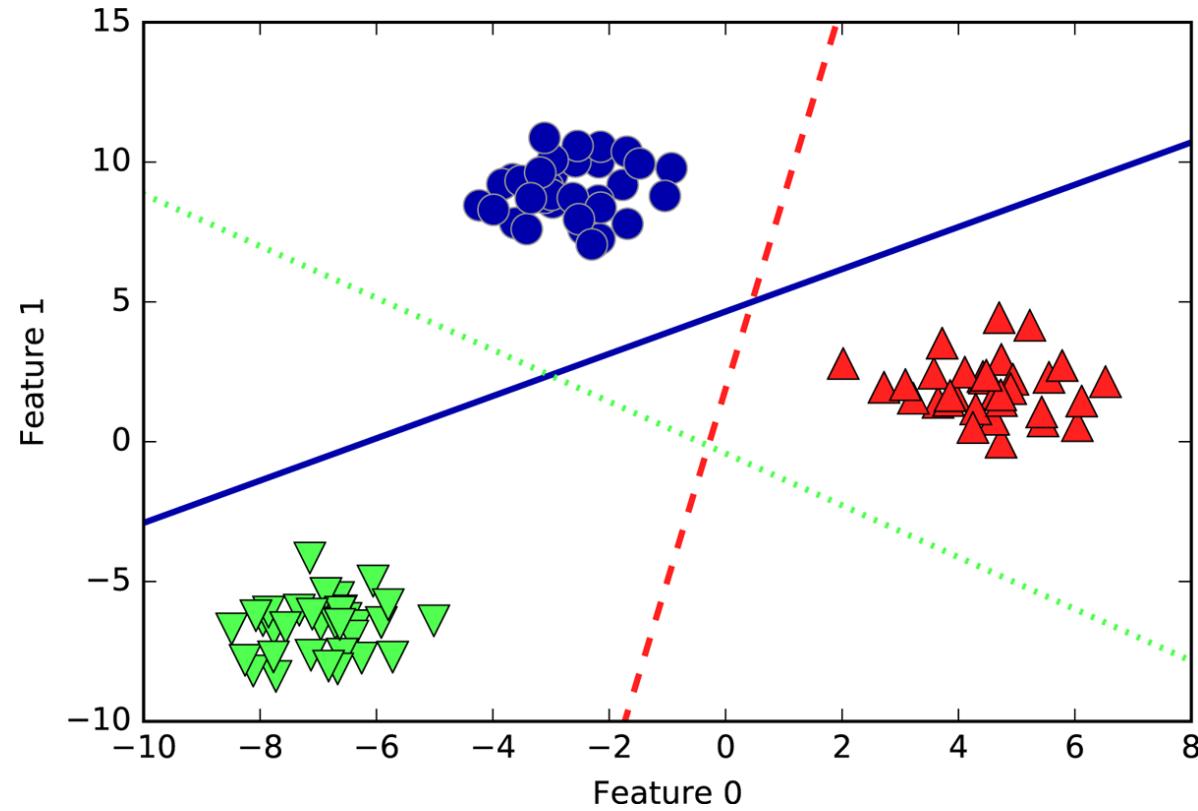
The class for which the result of the classification confidence formula given here is highest is the assigned class label:

$$w[0] * x[0] + w[1] * x[1] + \dots + w[p] * x[p] + b$$



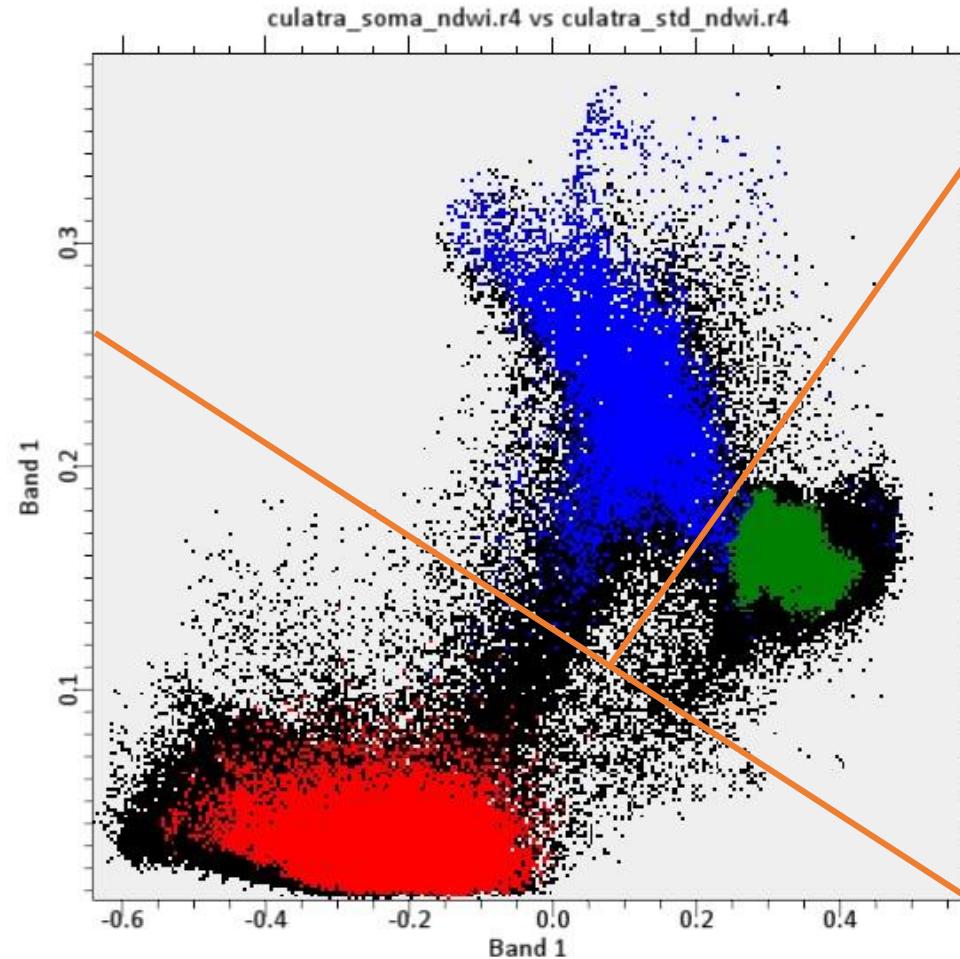
The classifier that has the highest score on its single class “wins,” and this class label is returned as the prediction.

Multiclass decision boundaries derived from the three one-vs.-rest classifiers



- Class 0
- ▲ Class 1
- ▼ Class 2
- Line class 0
- ▲ Line class 1
- ▼ Line class 2

Blue: water  
Red: Land  
Green: intertidal

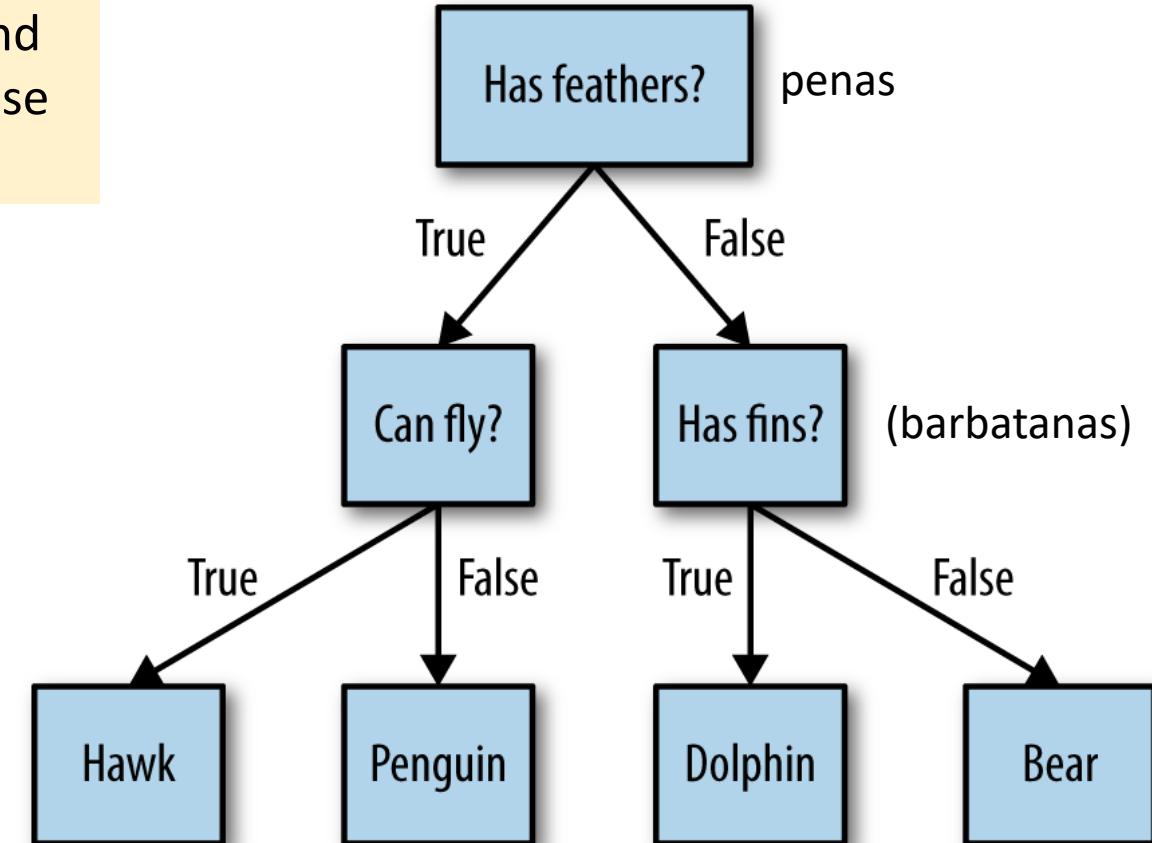


Decision trees are widely used models for classification and regression tasks. Essentially, they learn a hierarchy of if/else questions, leading to a decision.

Imagine you want to distinguish between the following four animals:

bears, hawks, penguins, and dolphins.

Your goal is to get to the right answer by asking as few if/else questions as possible.



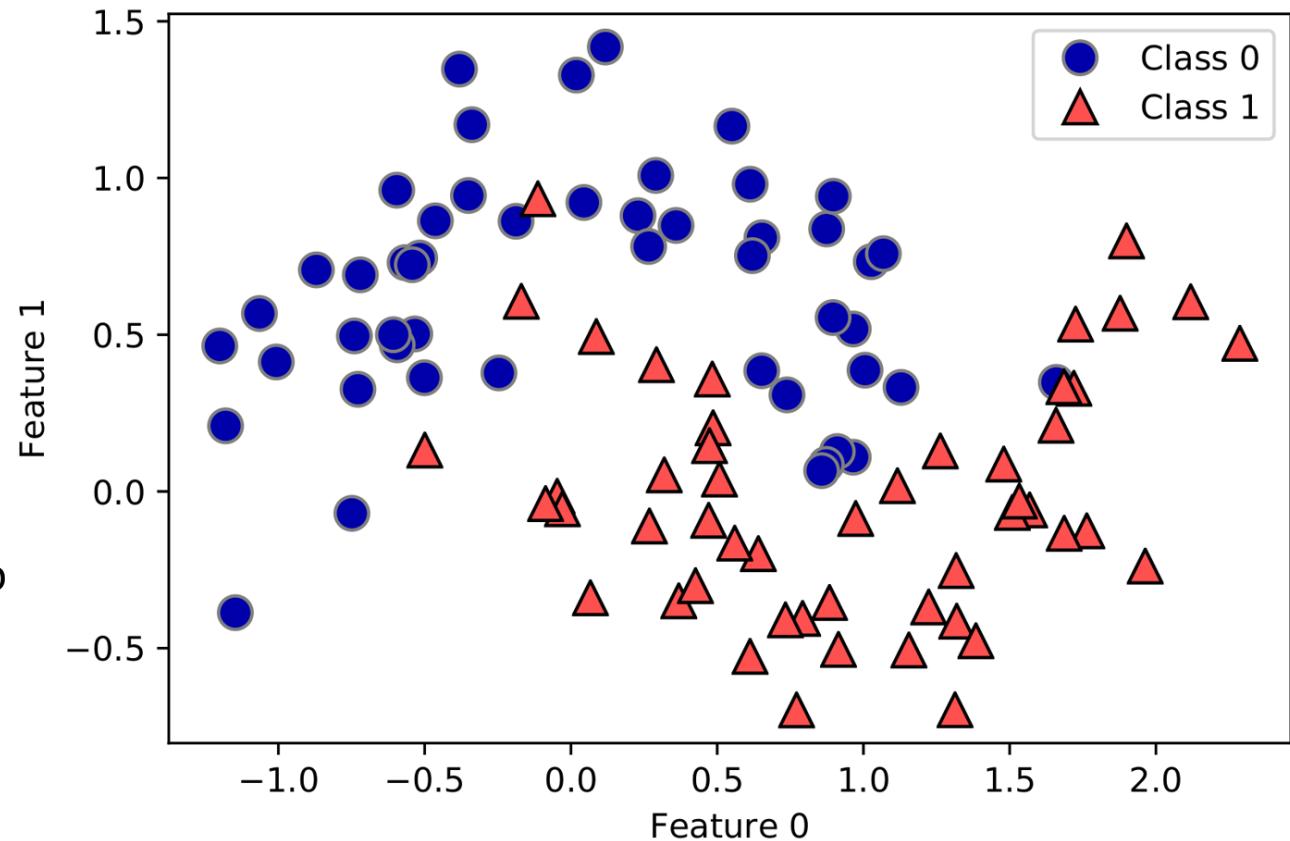
In this illustration, each node in the tree either represents a question or a terminal node (also called a *leaf*) that contains the answer. The edges connect the answers to a question with the next question you would ask.

Learning a decision tree means learning the sequence of **if/else** questions that gets us to the true answer most quickly.

In the machine learning setting, these questions are called **tests** (not to be confused with the test set, which is the data we use to test to see how generalizable our model is).

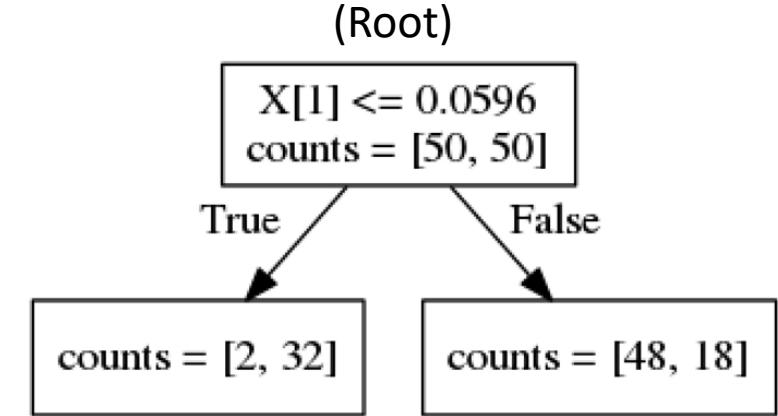
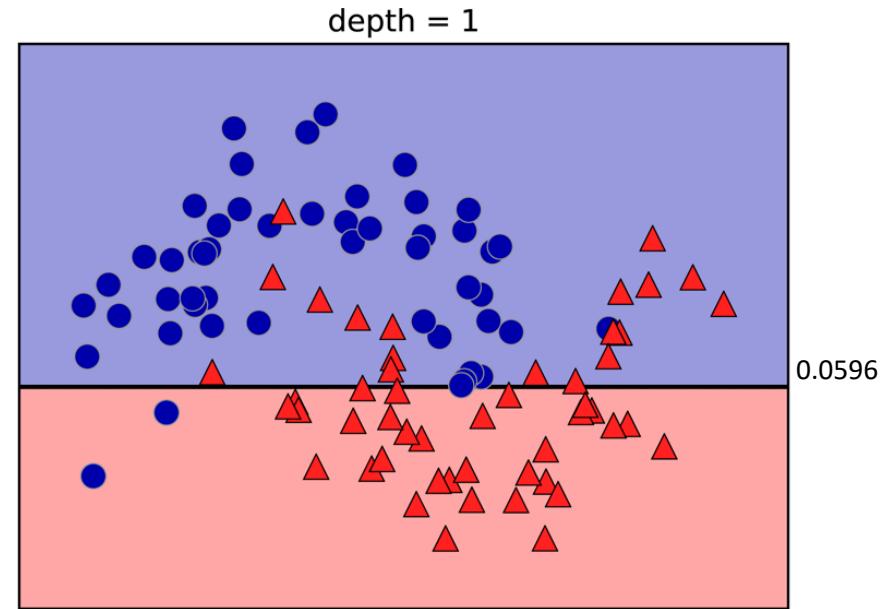
Usually data does not come in the form of binary yes/no features as in the animal example, but is instead represented as continuous features such as in the 2D dataset shown in figure.

The tests that are used on continuous data are of the form “Is feature  $i$  larger than value  $a$ ?”



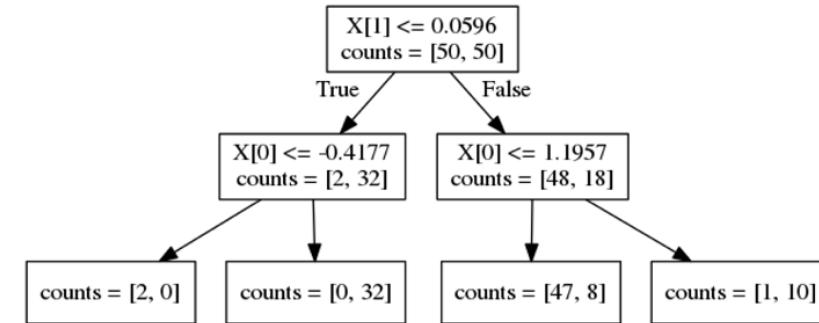
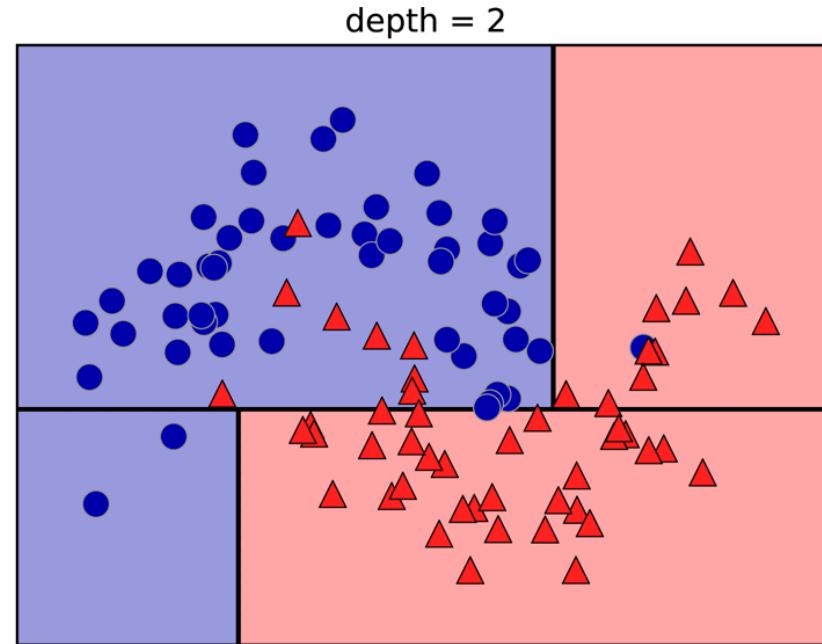
Two-moons dataset on which the decision tree will be built

To build a tree, the algorithm searches over all possible tests and finds the one that is most informative about the target variable.

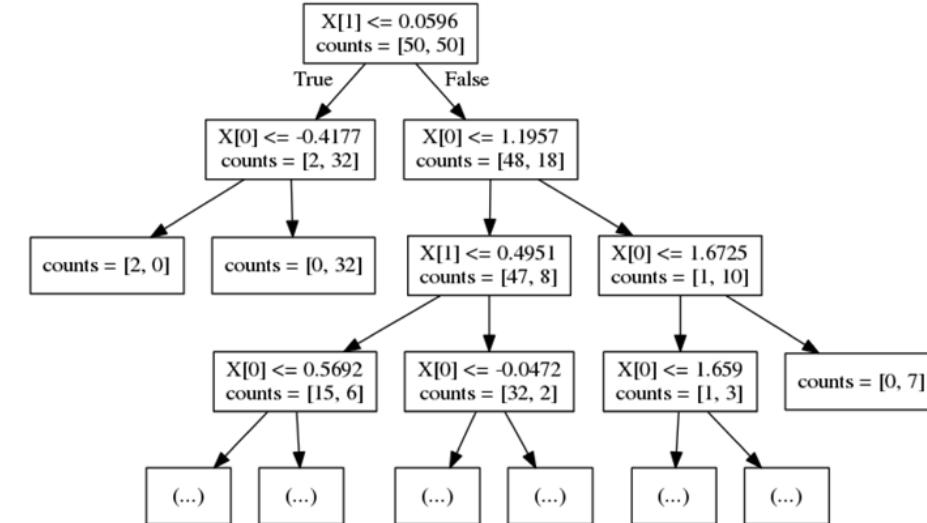
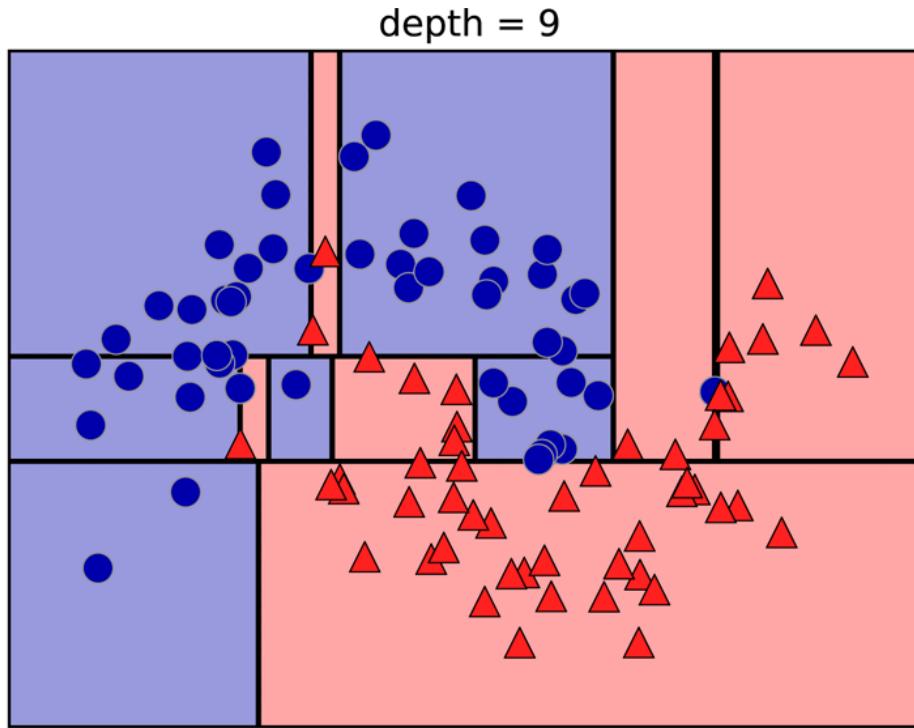


Splitting the dataset horizontally at  $x[1]=0.0596$  yields the most information; it best separates the points in class 0 from the points in class 1. The top node, also called the *root*, represents the whole dataset, consisting of 50 points belonging to class 0 and 50 points belonging to class 1. The split is done by testing whether  $x[1] \leq 0.0596$ , indicated by a black line. If the test is true, a point is assigned to the left node, which contains 2 points belonging to class 0 and 32 points belonging to class 1.

Even though the first split did a good job of separating the two classes, the bottom region still contains points belonging to class 0, and the top region still contains points belonging to class 1. We can build a more accurate model by repeating the process of looking for the best test in both regions.



This recursive process yields a binary tree of decisions, with each node containing a test.

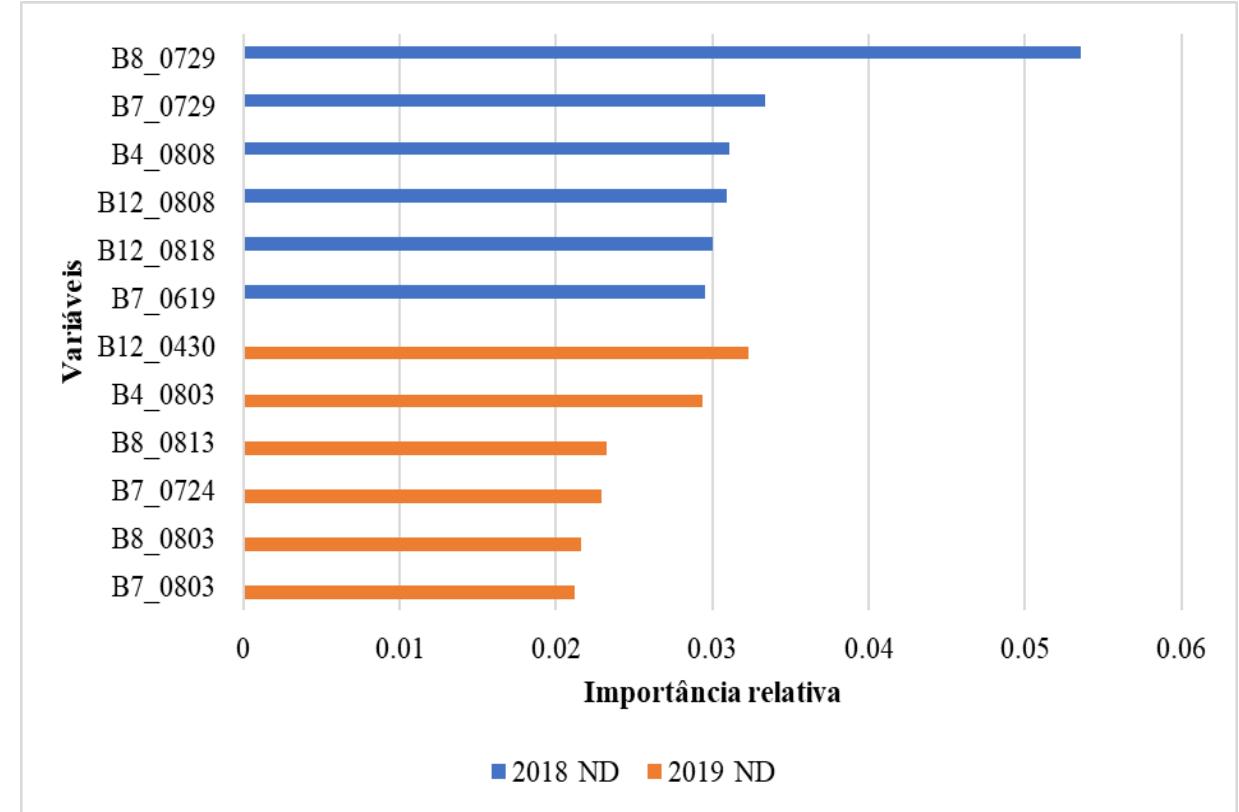


Typically, building a tree as described here and continuing until all leaves are pure leads to models that are very complex and highly overfit to the training data. The presence of pure leaves mean that a tree is 100% accurate on the training set; each data point in the training set is in a leaf that has the correct majority class.

Instead of looking at the whole tree, there are some useful properties that we can derive to summarize the workings of the tree.

The most commonly used summary is ***feature importance***, which rates how important each feature is for the decision a tree makes.

It is a number between 0 and 1 for each feature, where 0 means “not used at all” and 1 means “perfectly predicts the target.”

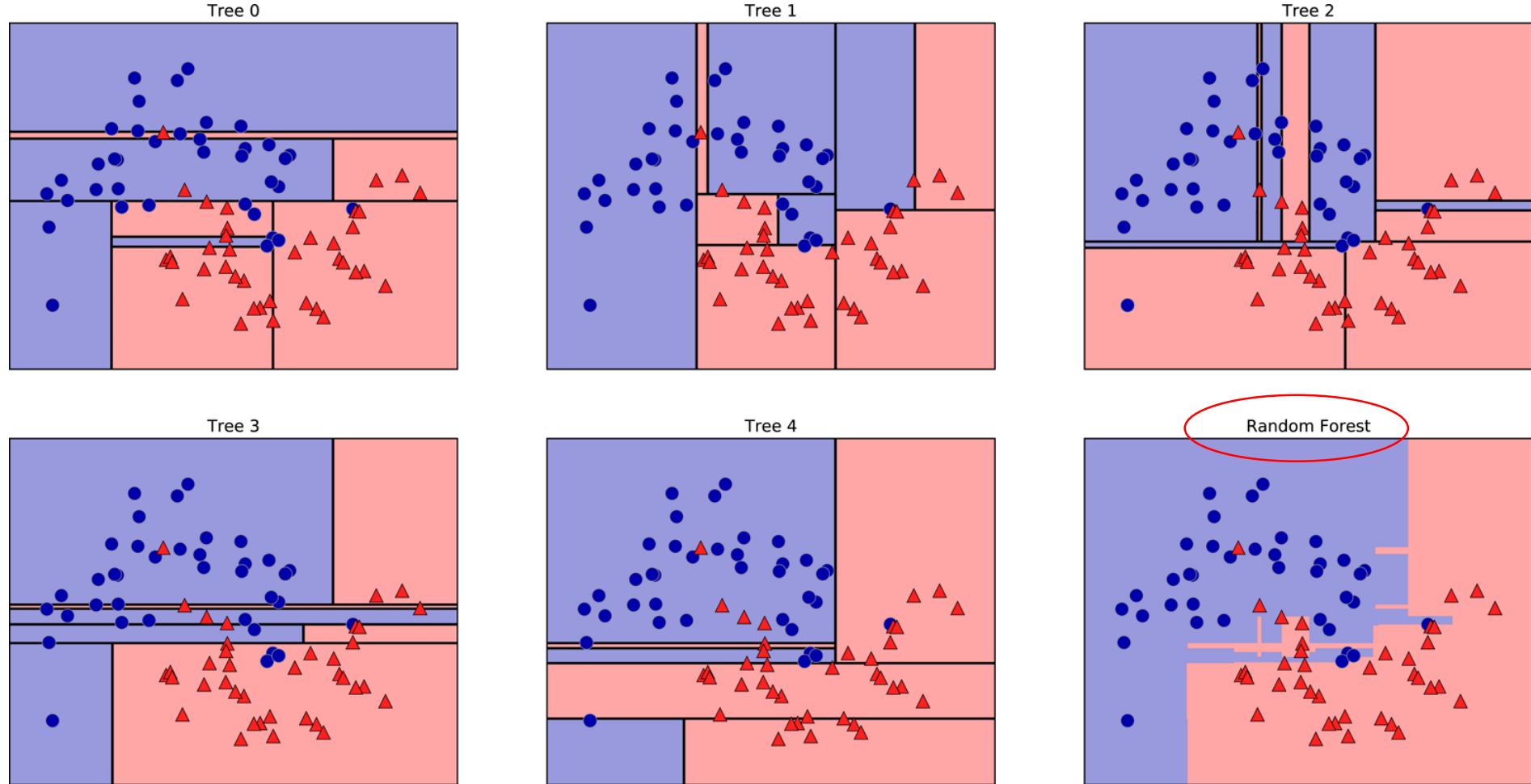


Importância relativa das variáveis na classificação com RF para dados de 2018 (a azul) e de 2019 (a laranja). As denominações das variáveis dizem respeito à banda, mês e dia de aquisição da imagem, respetivamente.

# Ensembles of decision trees

The Random Forest overfits less than any of the trees individually

In any real application, we would use many more trees (often hundreds or thousands), leading to even smoother boundaries.



Decision boundaries found by five randomized decision trees and the decision boundary obtained by averaging their predicted probabilities

Multilayer perceptrons (MLPs) are also known as feed-forward neural networks, or sometimes just **neural networks**.

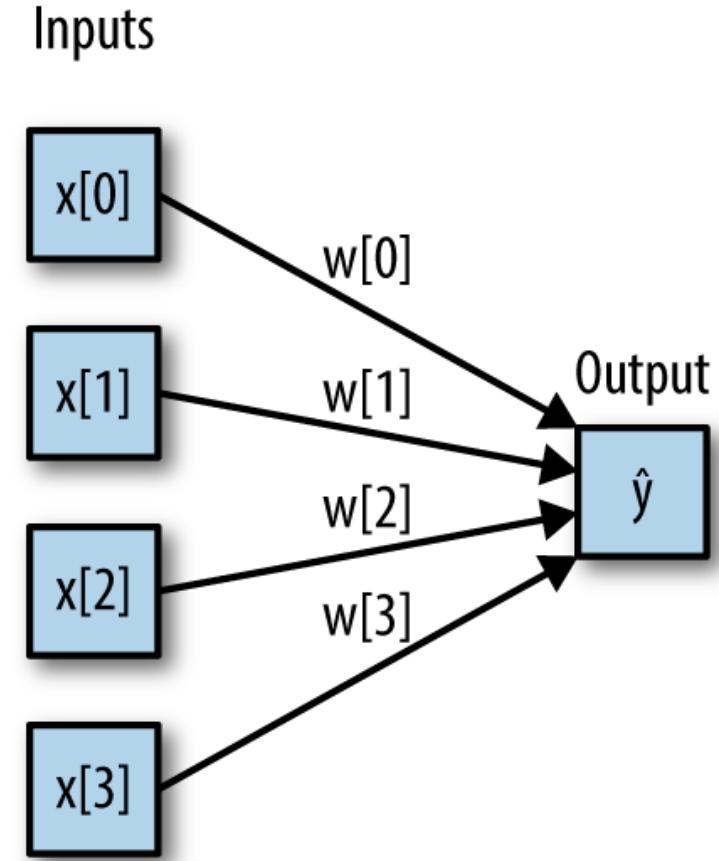
MLPs can be viewed as generalizations of linear models that perform multiple stages of processing to come to a decision.

Remember that the prediction by a linear regressor is given as:

$$\hat{y} = w[0] * x[0] + w[1] * x[1] + \dots + w[p] * x[p] + b$$

in plain English,  $\hat{y}$  is a weighted sum of the input features  $x[0]$  to  $x[p]$  (our spectral bands), weighted by the learned coefficients  $w[0]$  to  $w[p]$ .

(“deep learning” are a revival of the neural networks tailored very carefully to a specific use case)

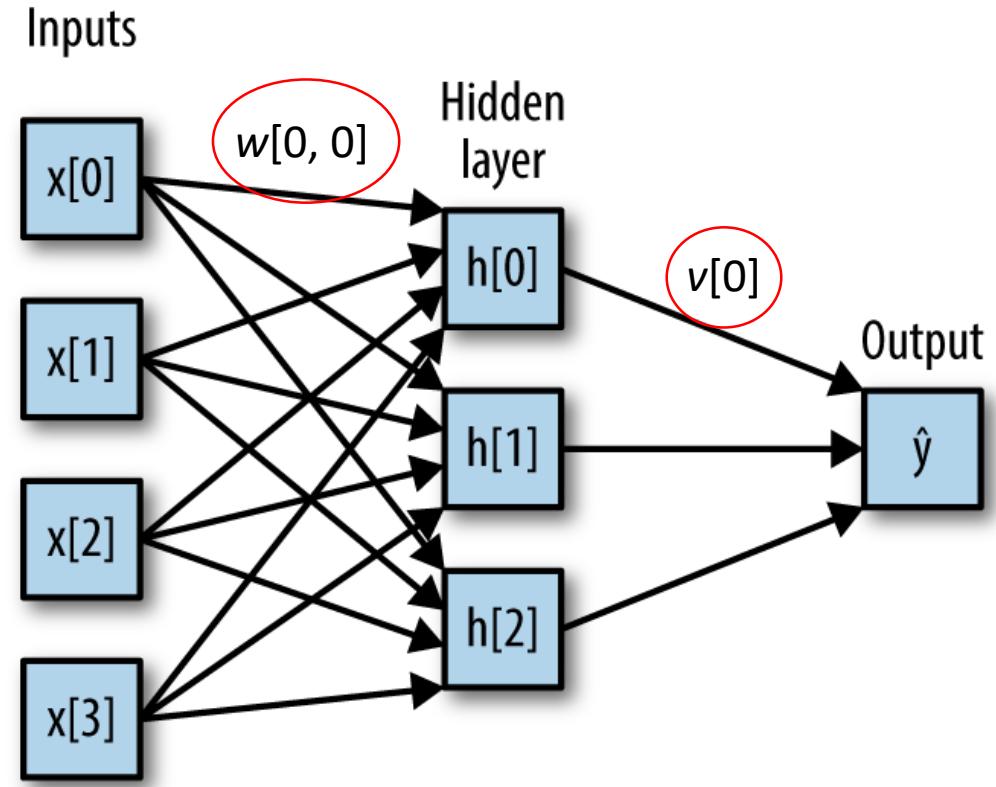


Here, each node on the left represents an input feature, the connecting lines represent the learned coefficients, and the node on the right represents the output, which is a weighted sum of the inputs.

In an MLP this process of computing weighted sums is repeated multiple times,

first computing **hidden units** that represent an intermediate processing step, which are again combined using weighted sums to yield the final result.

*Multilayer perceptron with a single hidden layer*

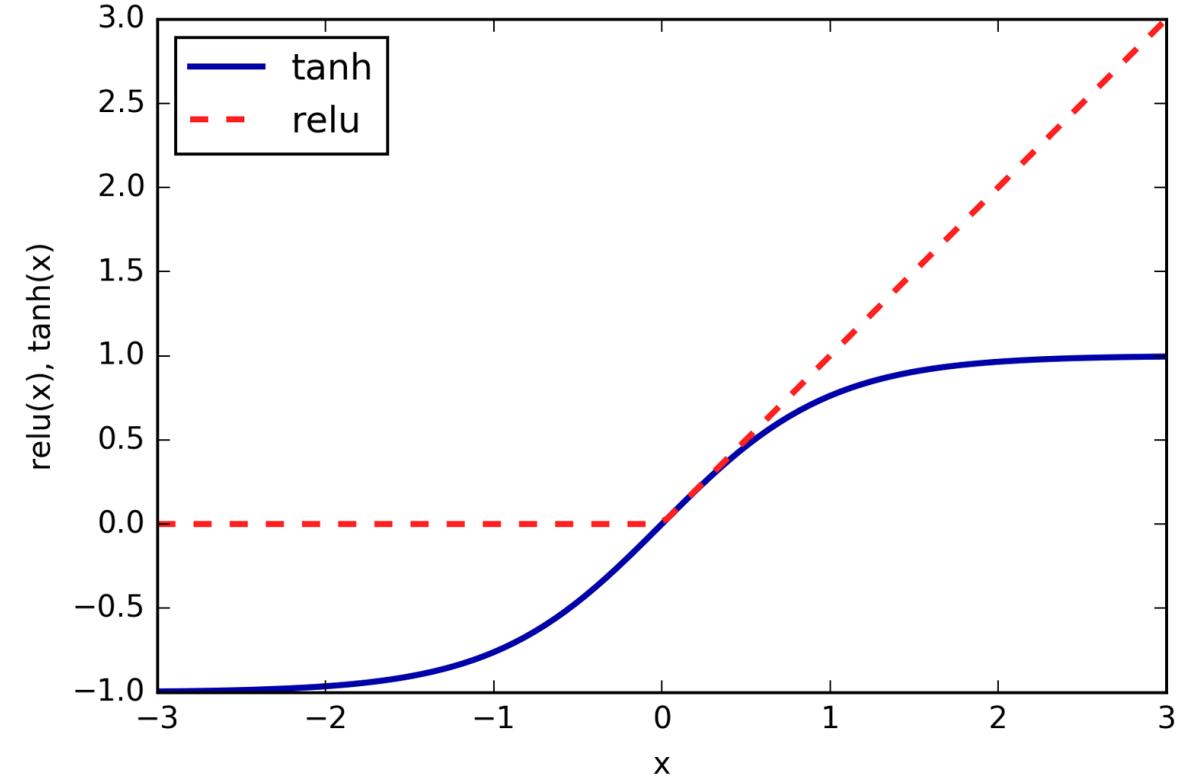


This model has a lot more coefficients (also called weights) to learn: there is one between every input and every hidden unit (which make up the hidden layer), and one between every unit in the hidden layer and the output.

Computing a series of weighted sums is mathematically the same as computing just one weighted sum, so to make this model truly more powerful than a linear model, we need one extra trick.

After computing a weighted sum for each hidden unit, a nonlinear function is applied to the result—usually the *rectifying nonlinearity* (also known as rectified linear unit or *relu*) or the *tangens hyperbolicus* (*tanh*).

The result of this function is then used in the weighted sum that computes the output,  $\hat{y}$ .



$$h[0] = \tanh(w[0, 0] * x[0] + w[1, 0] * x[1] + w[2, 0] * x[2] + w[3, 0] * x[3] + b[0])$$

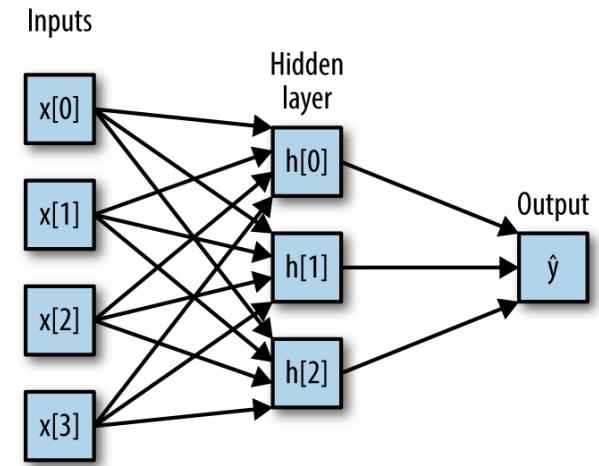
For the small neural network the full formula for computing  $\hat{y}$  in the case of regression would be (when using a tanh nonlinearity):

$$h[0] = \tanh(w[0, 0] * x[0] + w[1, 0] * x[1] + w[2, 0] * x[2] + w[3, 0] * x[3] + b[0])$$

$$h[1] = \tanh(w[0, 1] * x[0] + w[1, 1] * x[1] + w[2, 1] * x[2] + w[3, 1] * x[3] + b[1])$$

$$h[2] = \tanh(w[0, 2] * x[0] + w[1, 2] * x[1] + w[2, 2] * x[2] + w[3, 2] * x[3] + b[2])$$

$$\hat{y} = v[0] * h[0] + v[1] * h[1] + v[2] * h[2] + b$$



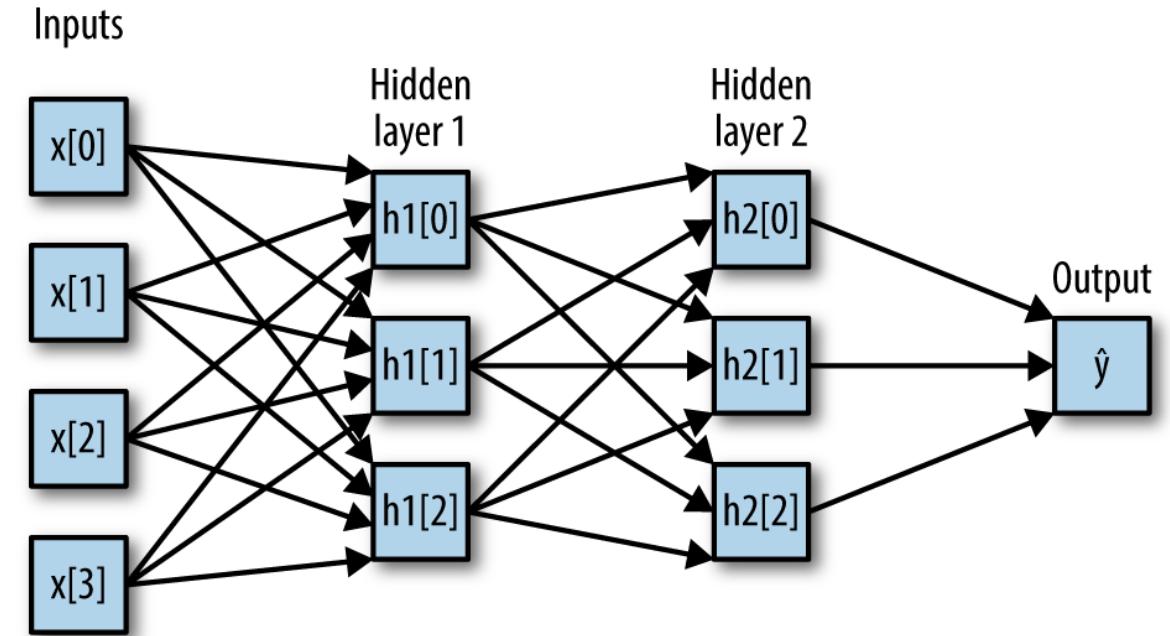
Here,  $w$  are the weights between the input  $x$  and the hidden layer  $h$ , and  $v$  are the weights between the hidden layer  $h$  and the output  $\hat{y}$ . The weights  $v$  and  $w$  are learned from data,  $x$  are the input features,  $\hat{y}$  is the computed output, and  $h$  are intermediate computations.

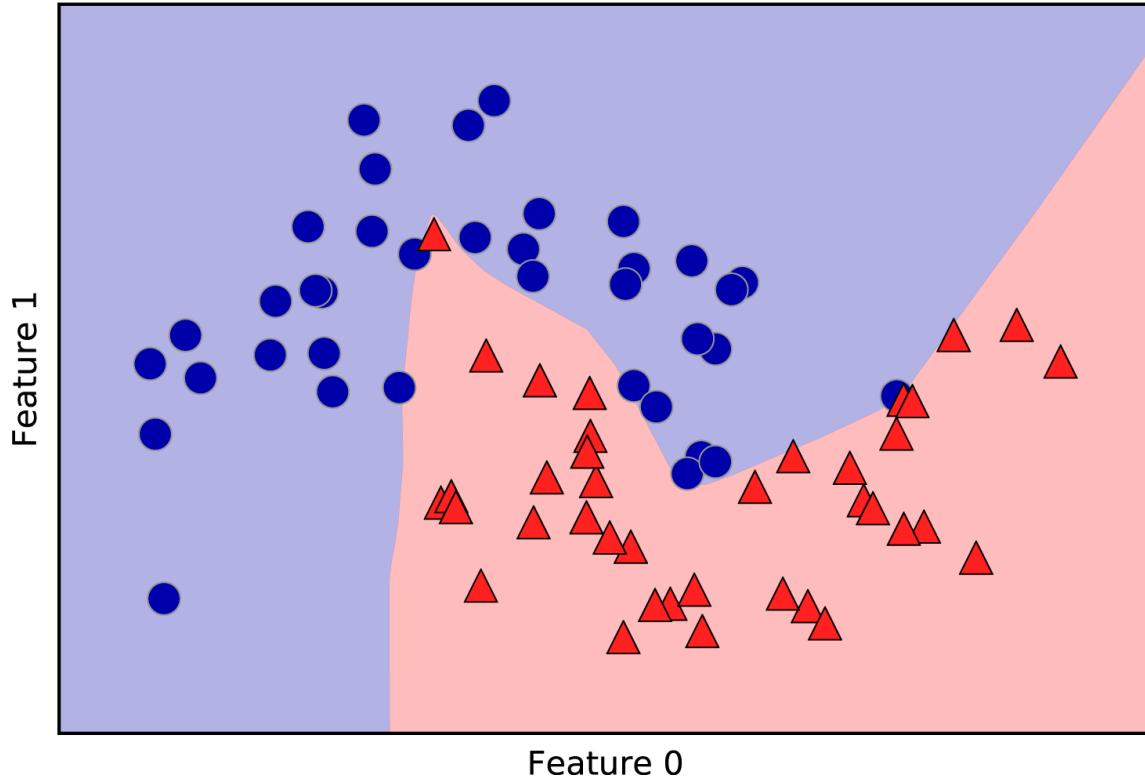
1 pixel = 19 weights  
we know  $(x, y)$  for a sample of pixels

An important parameter that needs to be set by the user is the number of nodes in the hidden layer.

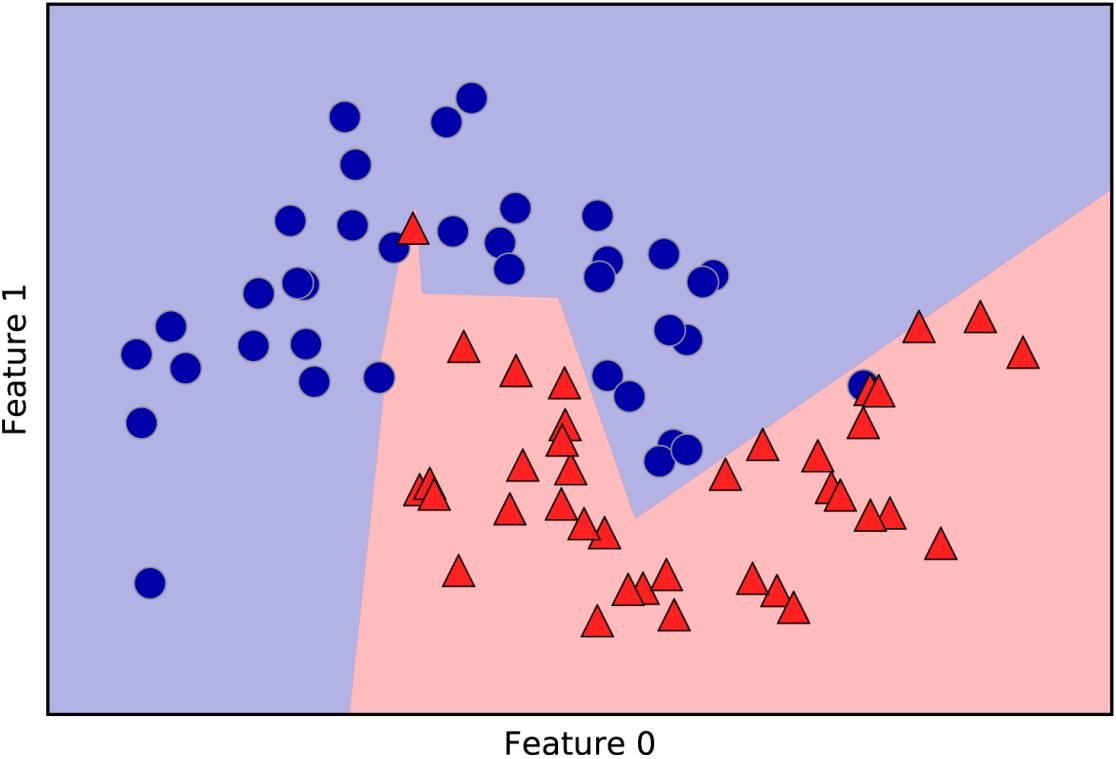
This can be as small as 10 for very small or simple datasets and as big as 10,000 for very complex data.

Having large neural networks made up of many of these layers of computation is what inspired the term “**deep learning**.”

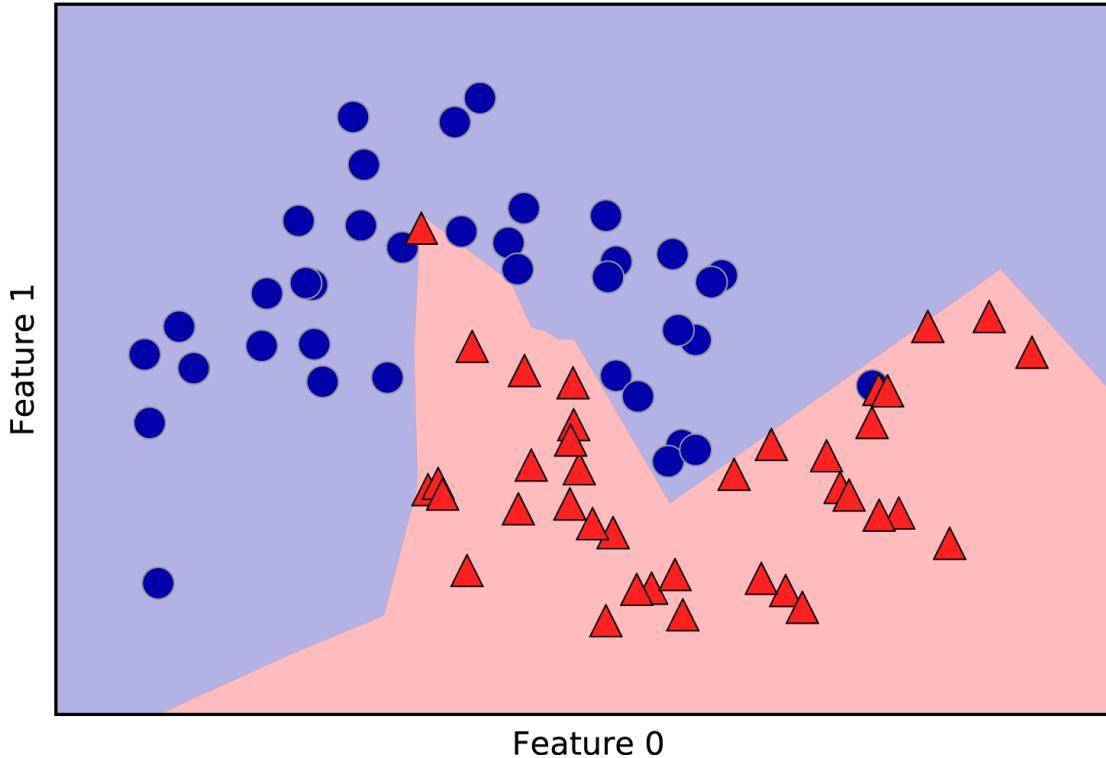




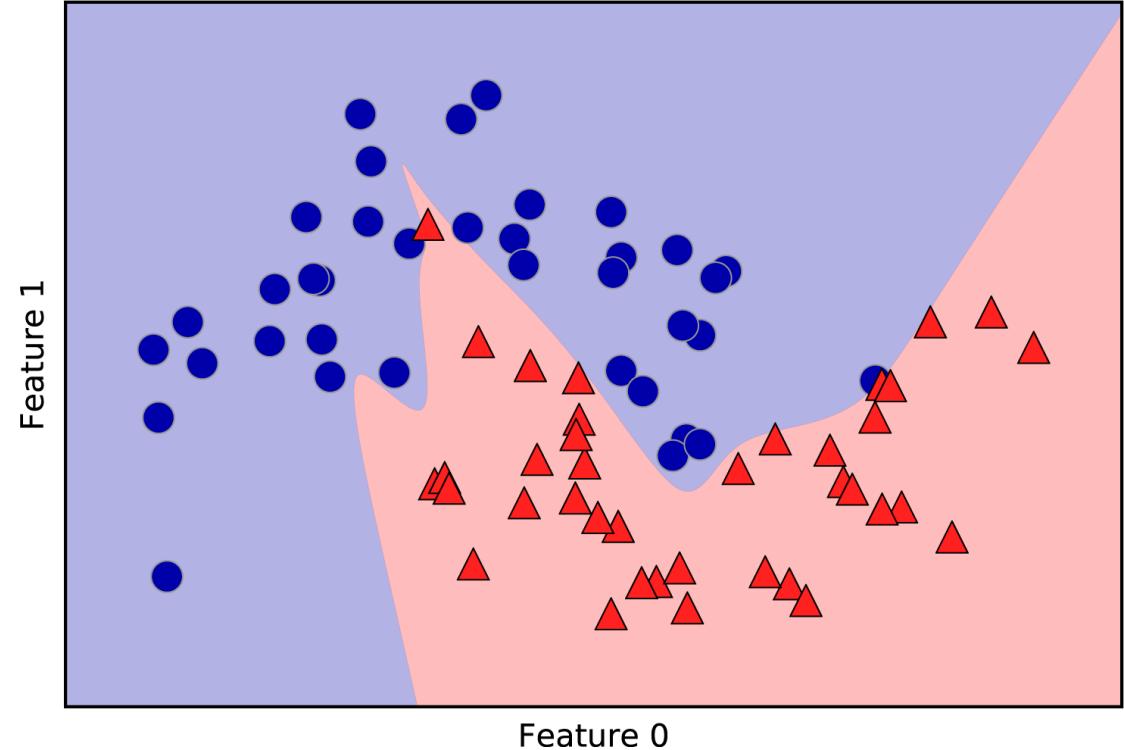
Decision boundary learned by a neural network  
with 100 hidden units on the two\_moons dataset



Decision boundary learned by a neural network  
with 10 hidden units on the two\_moons dataset



Decision boundary learned using 2 hidden layers with 10 hidden units each, with rect activation function

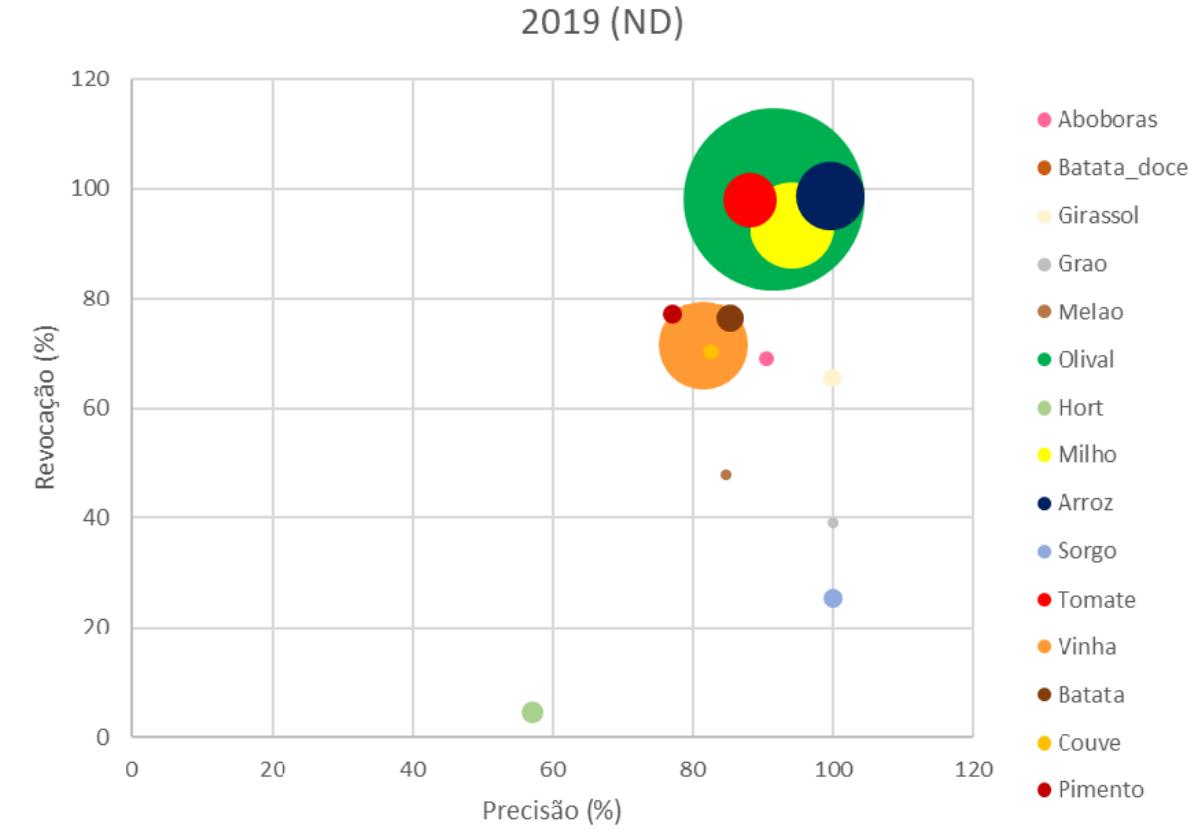
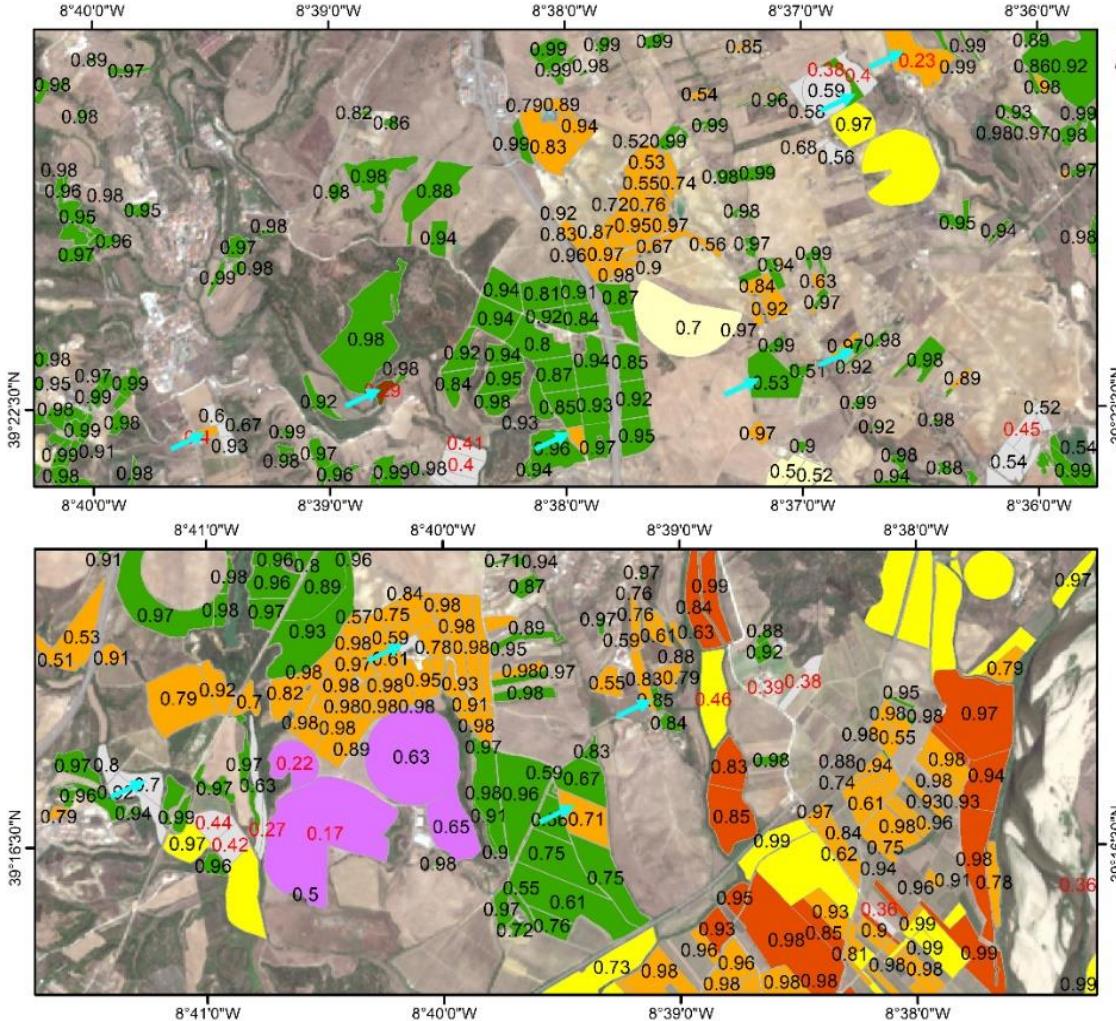


Decision boundary learned using 2 hidden layers with 10 hidden units each, with tanh activation function

A quick summary of when to use each model:

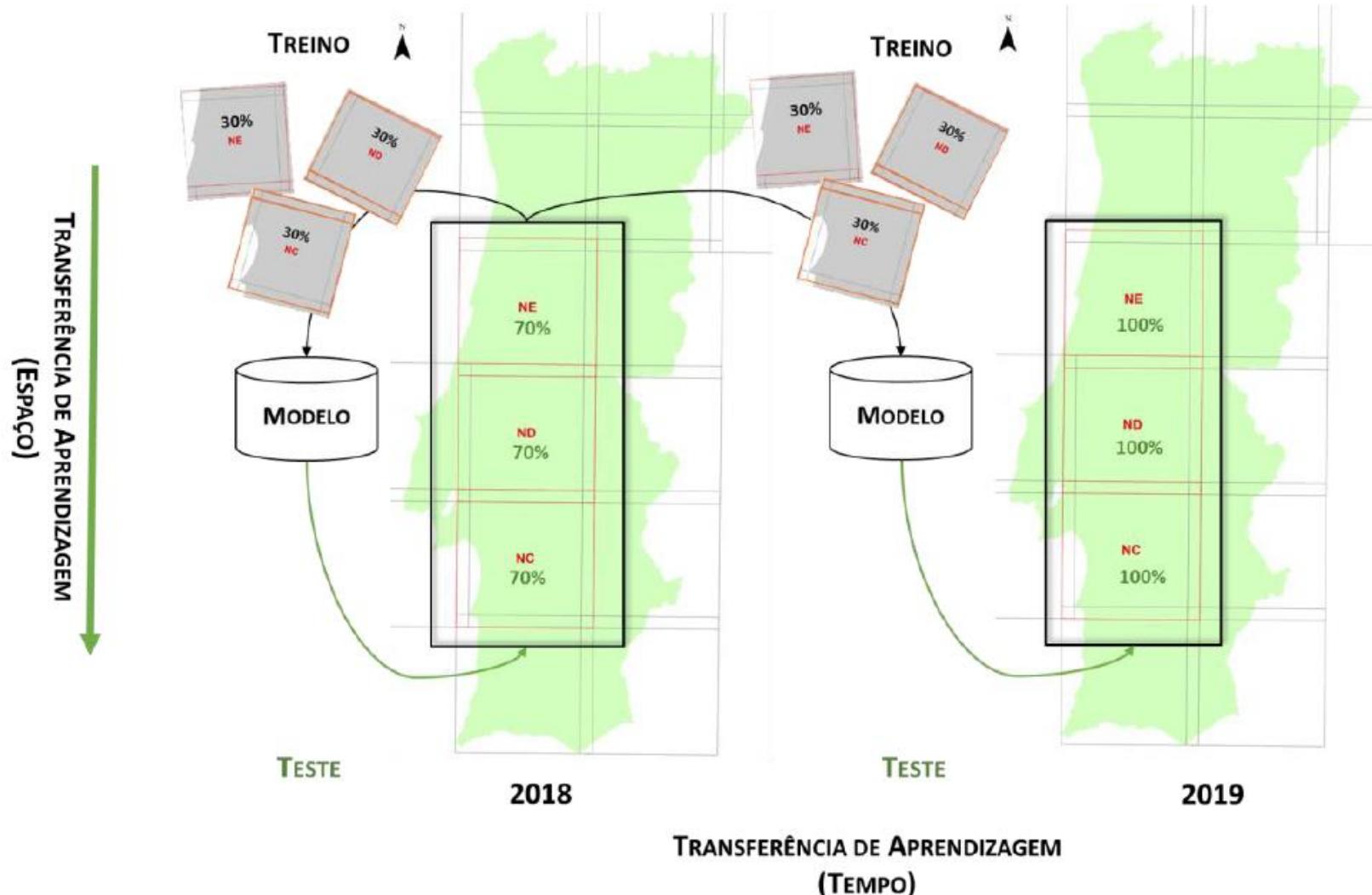
Algorithm	Characteristics
Nearest neighbors	For small datasets, good as a baseline, easy to explain.
Decision trees	Very fast, don't need scaling of the data, can be visualized and easily explained.
Random forests	Nearly always perform better than a single decision tree, very robust and powerful. Don't need scaling of data. Not good for very high-dimensional sparse data.
Support vector machines	Powerful for medium-sized datasets of features with similar meaning. Require scaling of data, sensitive to parameters.
Neural networks	Can build very complex models, particularly for large datasets. Sensitive to scaling of the data and to the choice of parameters. Large models need a long time to train.

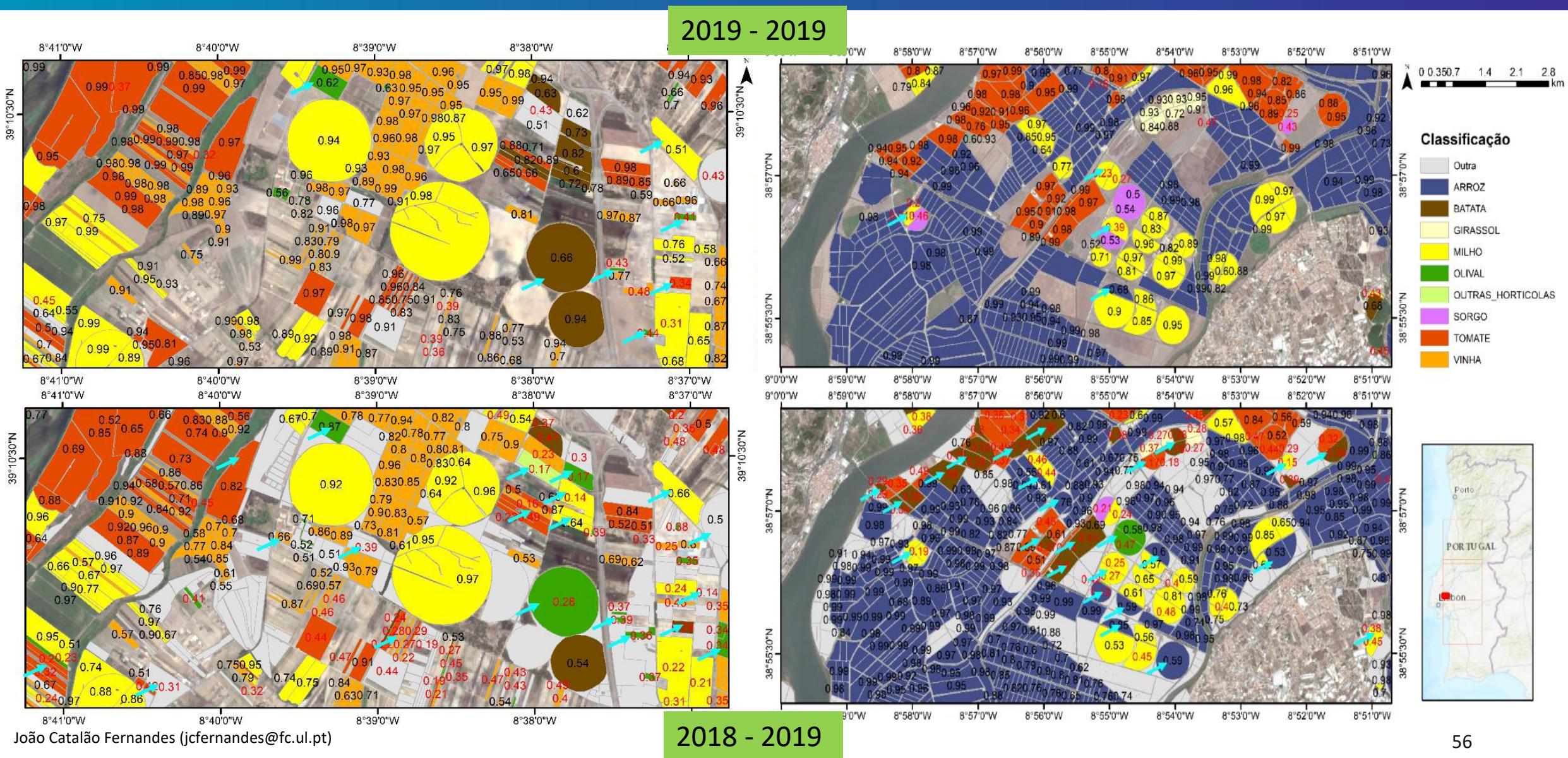
## Classification using Random Forest algorithm



A dimensão dos círculos ilustra a frequência de cada classe nos dados.

Inês Silva (2020)





# Convolutional Neural Network

David H. Hubel and Torsten Wiesel performed a series of experiments on cats in **1958** and **1959** (and a few years later on monkeys), giving crucial insights on the structure of the visual cortex.

The authors showed that some neurons react only to images of horizontal lines, while others react only to lines with different orientations.

These observations led to the idea that the higher-level neurons are based on the outputs of neighboring lower-level neurons.

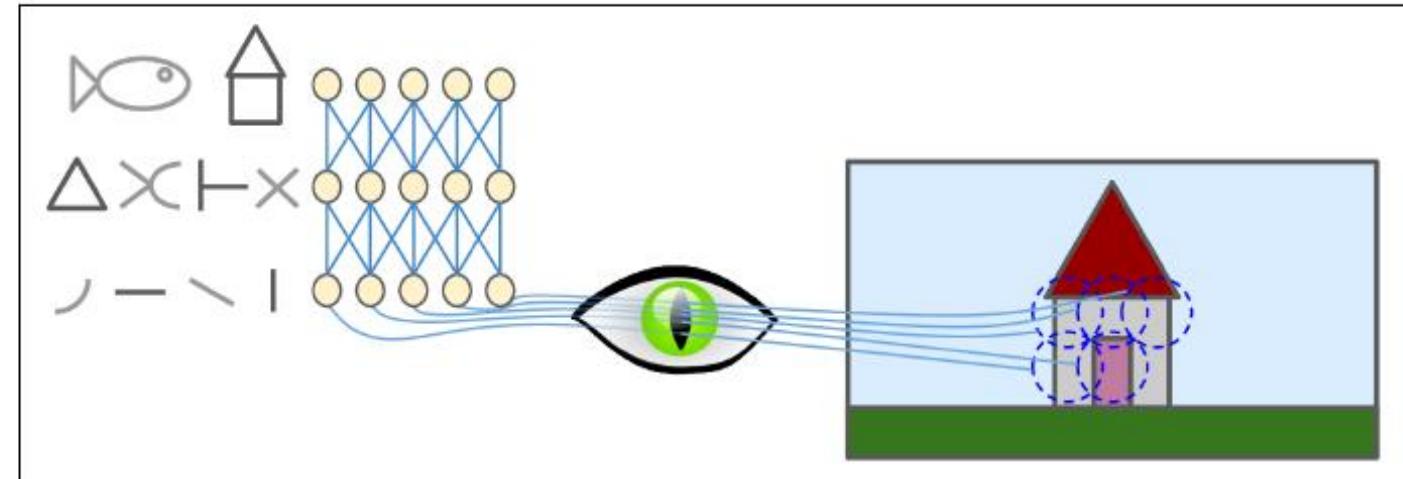


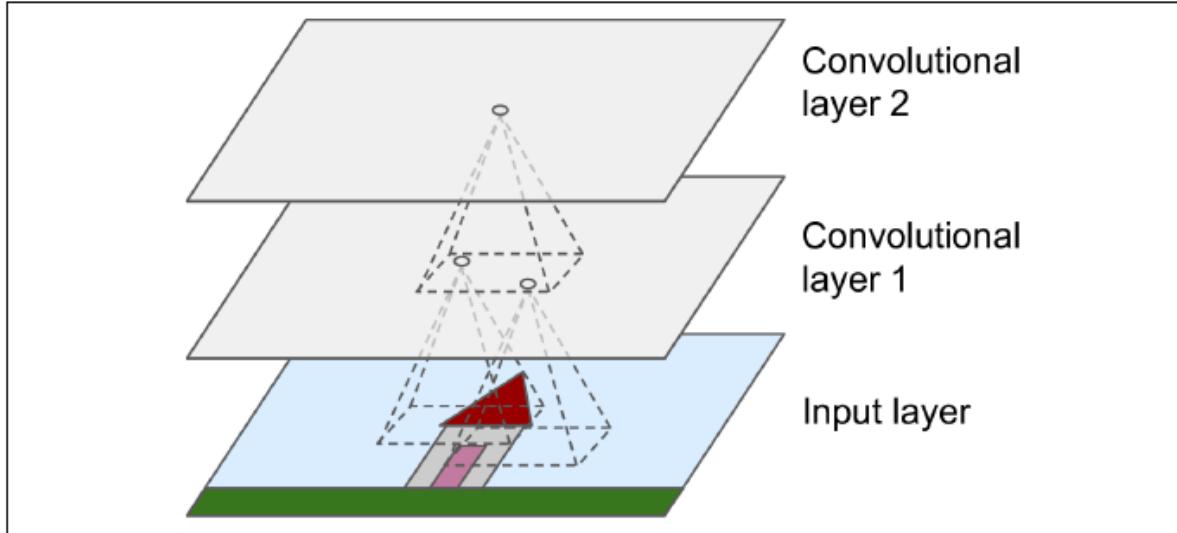
Figure 14-1. Local receptive fields in the visual cortex

These studies of the visual cortex inspired the **neocognitron**, introduced in **1980**, which gradually evolved into what we now call **convolutional neural networks**.

An important milestone was a **1998 paper** by Yann LeCun, Leon Bottou, Yoshua Bengio, and Patrick Haffner, which introduced the famous *LeNet-5* architecture, widely used to recognize handwritten check numbers.

## Convolutional Neural Network

*CNN layers with rectangular local receptive fields*

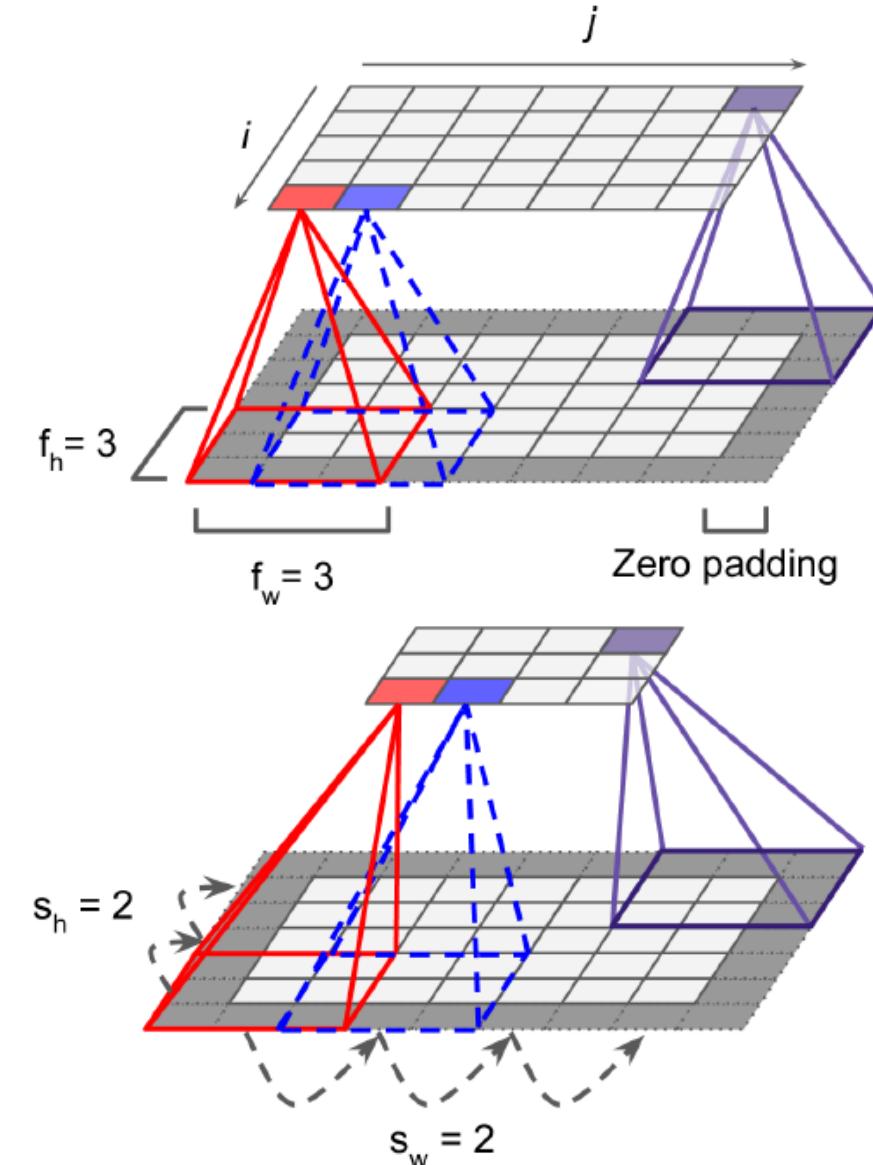


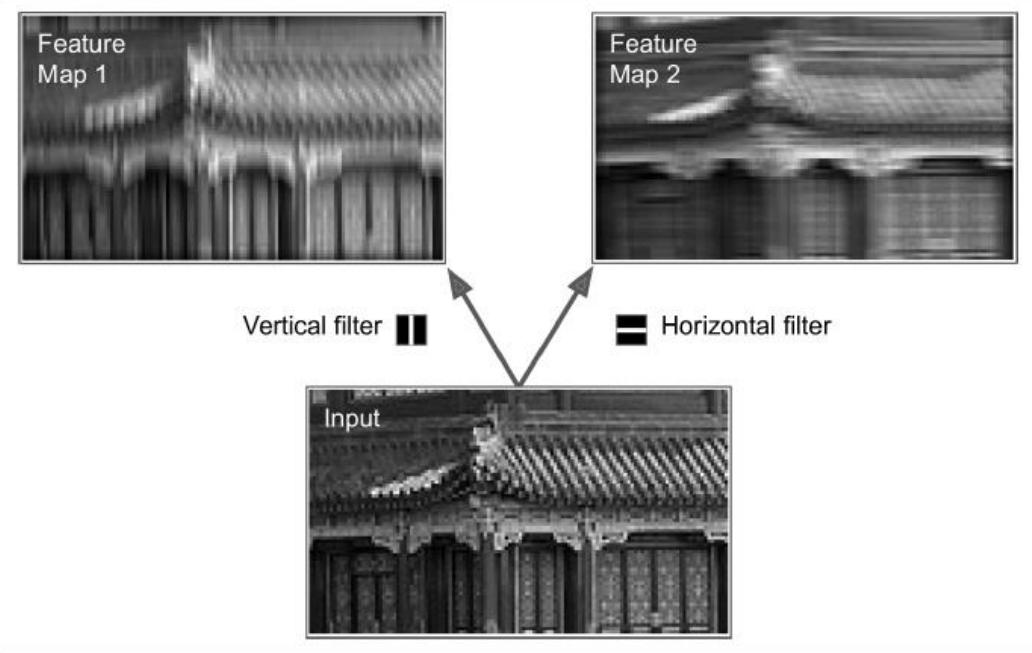
A neuron located in position  $(i,j)$  in the upper layer is connected to the outputs of the neurons in the previous layer located in

Rows:  $[i \times sh \text{ to } i \times sh + fh - 1]$

Column:  $[j \times sw \text{ to } j \times sw + fw - 1]$ ,

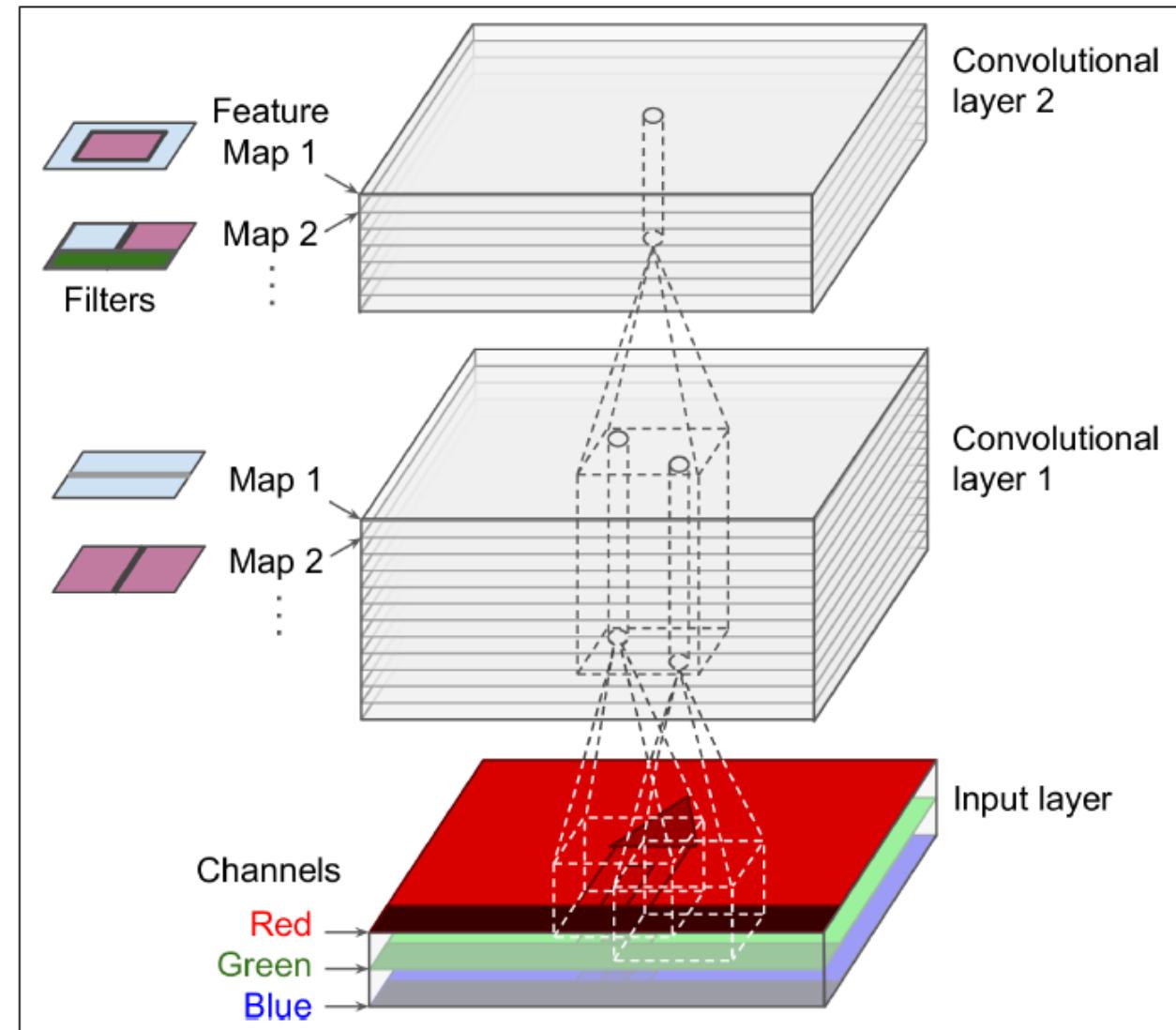
where  $sh$  and  $sw$  are the vertical and horizontal strides.



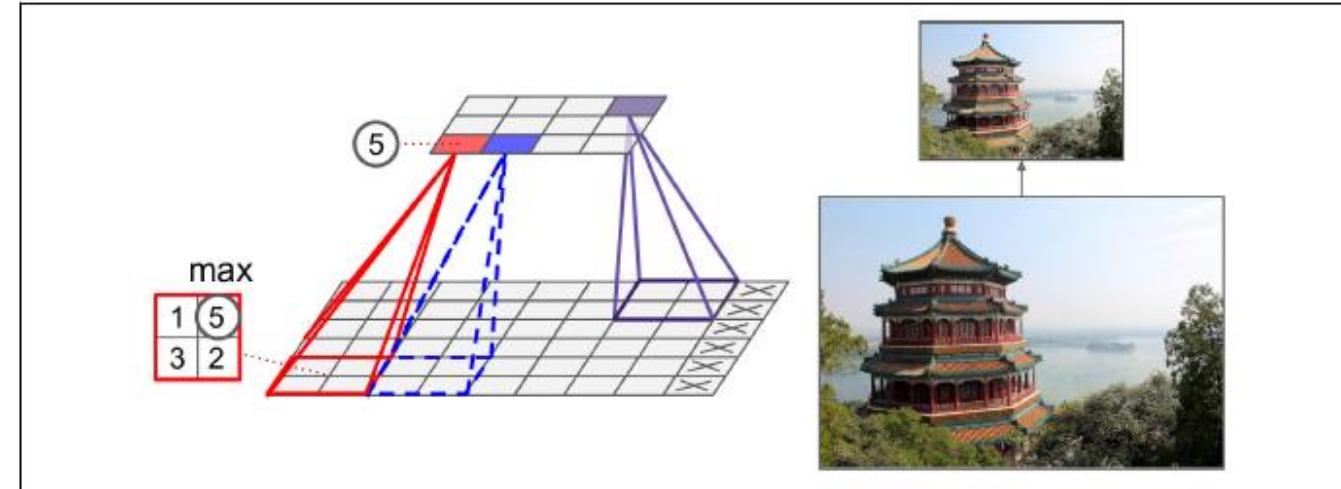


Aplicação de um filtro vertical e um filtro horizontal

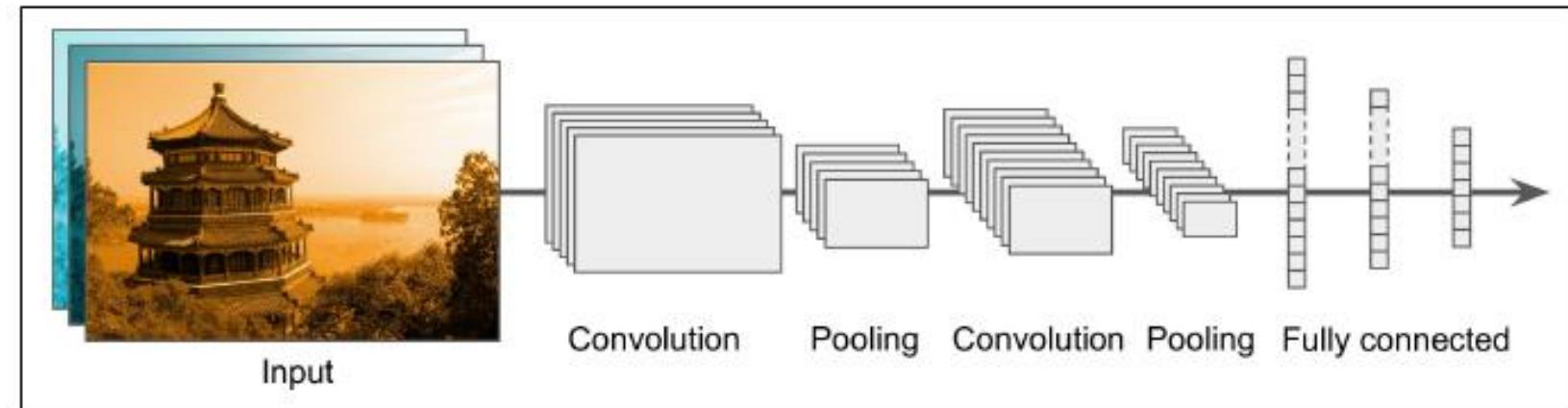
Aplicação de múltiplos filtros em cada layer



*Max pooling layer ( $2 \times 2$  pooling kernel, stride 2, no padding)*



*Typical CNN architecture*



## INPUT Image (RGB)

0	0	0	0	0	0	0	0
0	5	4	5	7	0		
0	3	2	3	1	0		
0	1	5	3	3	0		
0	6	1	7	1	0		
0	0	0	0	0	0		
0	0	0	0	0	0		
0	0	0	0	0	0		

0	0	0	0	0	0	0
0	5	5	5	3	0	
0	7	5	2	3	0	
0	0	6	3	1	0	
0	0	0	0	1	0	
0	0	0	0	0	0	
0	0	0	0	0	0	

0	1	2	4	4	0	
0	5	3	2	6	0	
0	4	0	2	0	0	
0	6	3	7	4	0	
0	0	0	0	0	0	
0	0	0	0	0	0	
0	0	0	0	0	0	

## Zero Padding

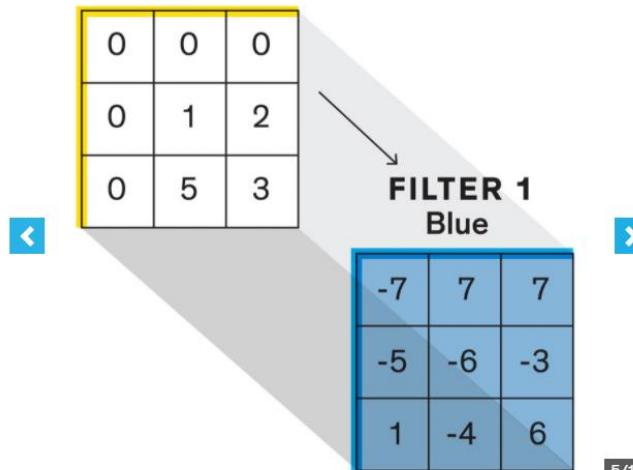
0	0	0	0	0	0	0
0	5	4	5	7	0	
0	3	2	3	1	0	
0	1	5	3	3	0	
0	6	1	7	1	0	
0	0	0	0	0	0	
0	0	0	0	0	0	

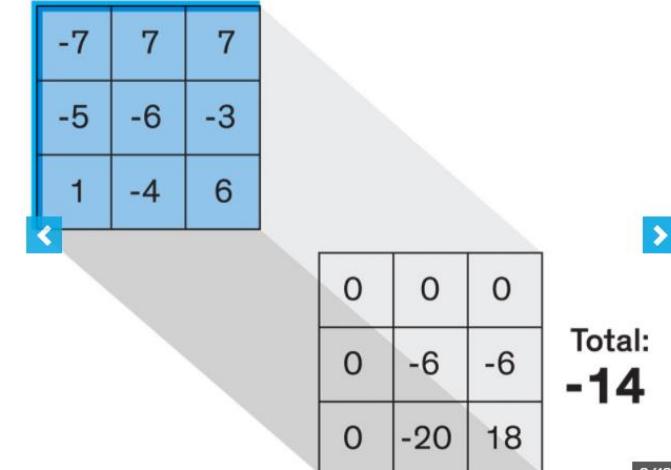
0	0	0	0	0	0	0
0	5	5	5	3	0	
0	7	5	2	3	0	
0	0	6	3	1	0	
0	0	0	0	1	0	
0	0	0	0	0	0	
0	0	0	0	0	0	

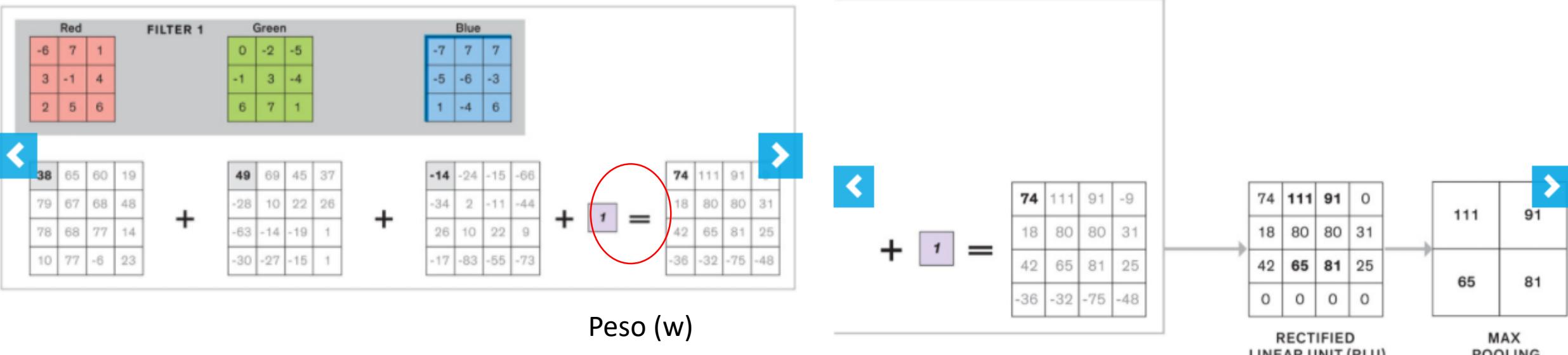
0	1	2	4	4	0	
0	5	3	2	6	0	
0	4	0	2	0	0	
0	6	3	7	4	0	
0	0	0	0	0	0	
0	0	0	0	0	0	
0	0	0	0	0	0	



A filter performs simple calculations, multiplying its own number values by the pixel values in the first chunk. The filter looks for a particular feature in the image—perhaps an angled line or a certain gradation of color—as represented by pixel values.



The resulting products for the first chunk are summed up, and the total is put down in one cell of a grid (see next slide). Then the filter moves over one pixel to the right and looks at the next 3-by-3 chunk.



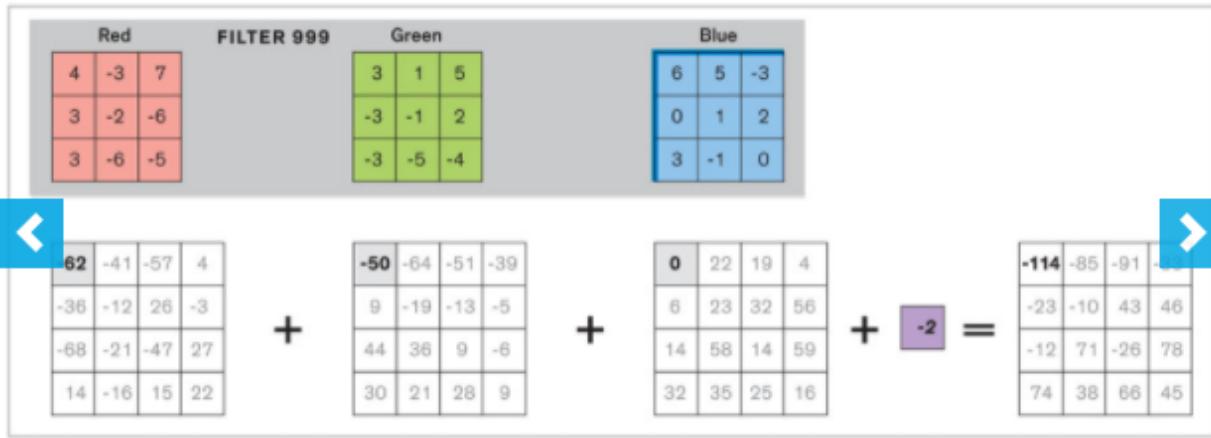
Peso (w)

7/12

One chunk at a time, the filter scans the image to fill in grids for the red, green, and blue channels. Then the grid cells are summed up along with a number called the weight, which represents the importance of this filter for the final output. This produces a new grid with the final sums.

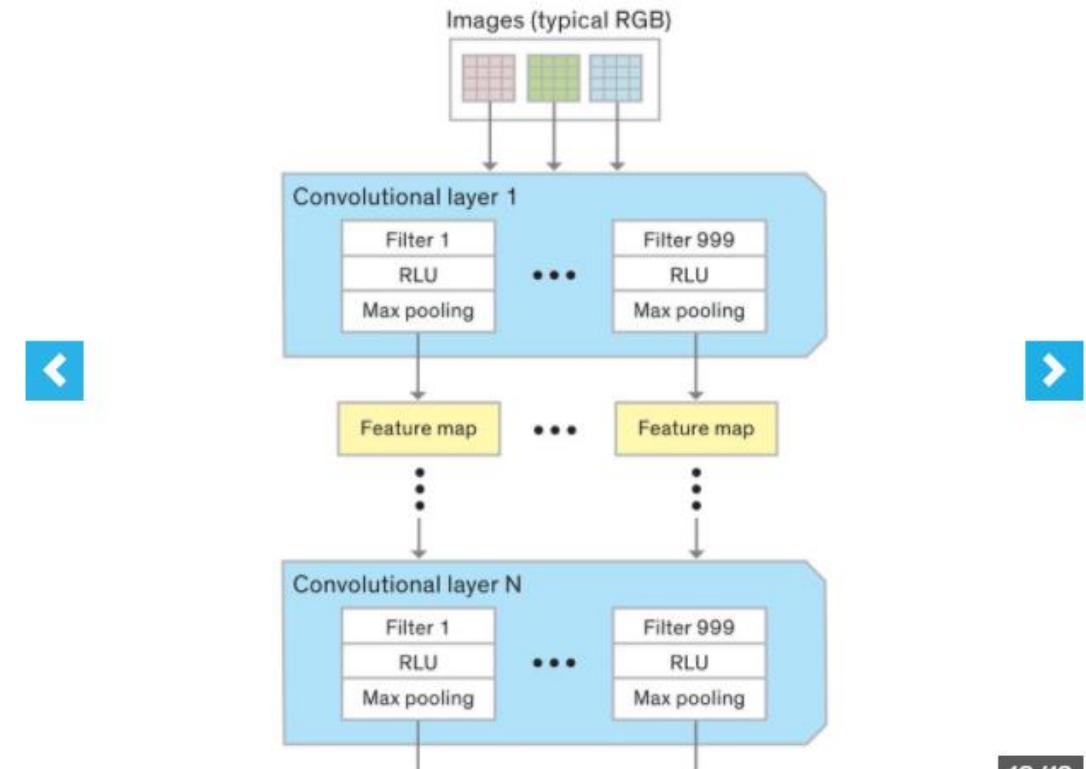
Two more simple steps finish this filter's work. In the rectified linear unit (RLU) step, the negative numbers among the sums are replaced by zeros. In the max pooling step, the highest value in each two-by-two chunk is selected. The end result is a simple set of numbers called a feature map.

8/12



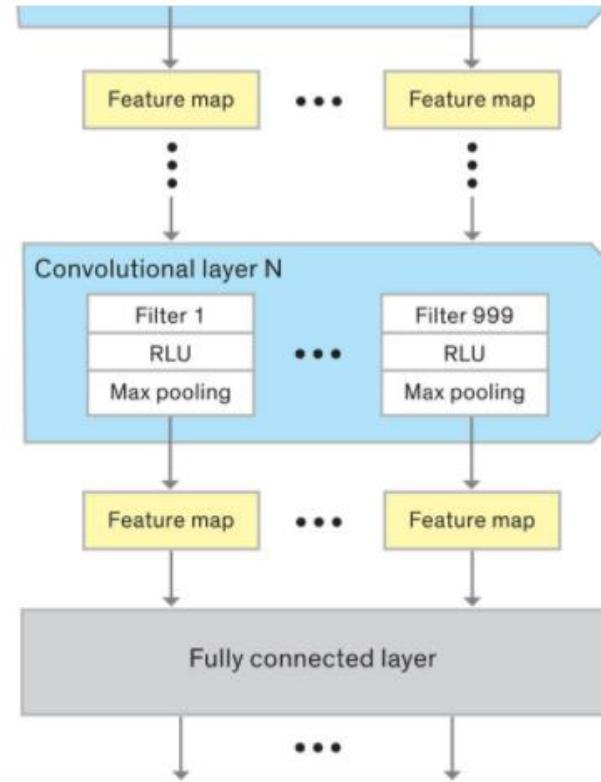
9/12

A typical CNN may have hundreds of filters in each convolutional layer. Each filter performs its simple calculations and feeds its filter map forward to all the filters in the next convolutional layer. Those filters examine the feature maps in the same chunk-by-chunk way.

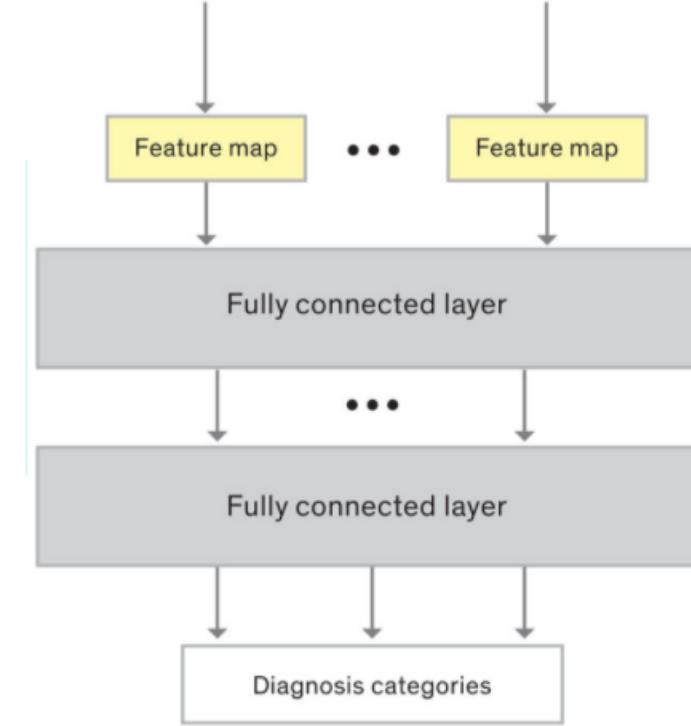


For each digital image, a CNN uses many convolutional layers, each packed with many filters.

10/12



Finally, the last convolutional layer outputs all of its feature maps to a "fully connected" layer, which examines the maps in their entirety (instead of doing chunk-by-chunk scans).



uses several fully connected layers to make a final determination about the patient. For example, does the image show a healthy cervix or a cancerous one? Once the AI has run through all the images and made all its assessments, it checks its accuracy. In the next run, it will choose a different combination of filters and weights and see if its accuracy improves.

12/12

<https://spectrum.ieee.org/biomedical/devices/ai-medicine-comes-to-africas-rural-clinics>

# LeNet-5

The **LeNet-5 architecture** is the most widely known CNN architecture. It was created by Yann LeCun in 1998 and widely used for handwritten digit recognition

Layer	Type	Maps	Size	Kernel size	Stride	Activation
Out	Fully Connected	–	10	–	–	RBF
F6	Fully Connected	–	84	–	–	tanh
C5	Convolution	120	1 × 1	5 × 5	1	tanh
S4	Avg Pooling	16	5 × 5	2 × 2	2	tanh
C3	Convolution	16	10 × 10	5 × 5	1	tanh
S2	Avg Pooling	6	14 × 14	2 × 2	2	tanh
C1	Convolution	6	28 × 28	5 × 5	1	tanh
In	Input	1	32 × 32	–	–	–

# AlexNet

The **AlexNet CNN architecture** was developed by Alex Krizhevsky, Ilya Sutskever, and Geoffrey Hinton.

It is quite similar to LeNet-5, only much larger and deeper, and it was the first to stack convolutional layers directly on top of each other, instead of stacking a pooling layer on top of each convolutional layer.

Layer	Type	Maps	Size	Kernel size	Stride	Padding	Activation
Out	Fully Connected	–	1,000	–	–	–	Softmax
F9	Fully Connected	–	4,096	–	–	–	ReLU
F8	Fully Connected	–	4,096	–	–	–	ReLU
C7	Convolution	256	13 × 13	3 × 3	1	SAME	ReLU
C6	Convolution	384	13 × 13	3 × 3	1	SAME	ReLU
C5	Convolution	384	13 × 13	3 × 3	1	SAME	ReLU
S4	Max Pooling	256	13 × 13	3 × 3	2	VALID	–
C3	Convolution	256	27 × 27	5 × 5	1	SAME	ReLU
S2	Max Pooling	96	27 × 27	3 × 3	2	VALID	–
C1	Convolution	96	55 × 55	11 × 11	4	VALID	ReLU
In	Input	3 (RGB)	227 × 227	–	–	–	–

## Outras Arquiteturas:

GoogLeNet

VGGNet

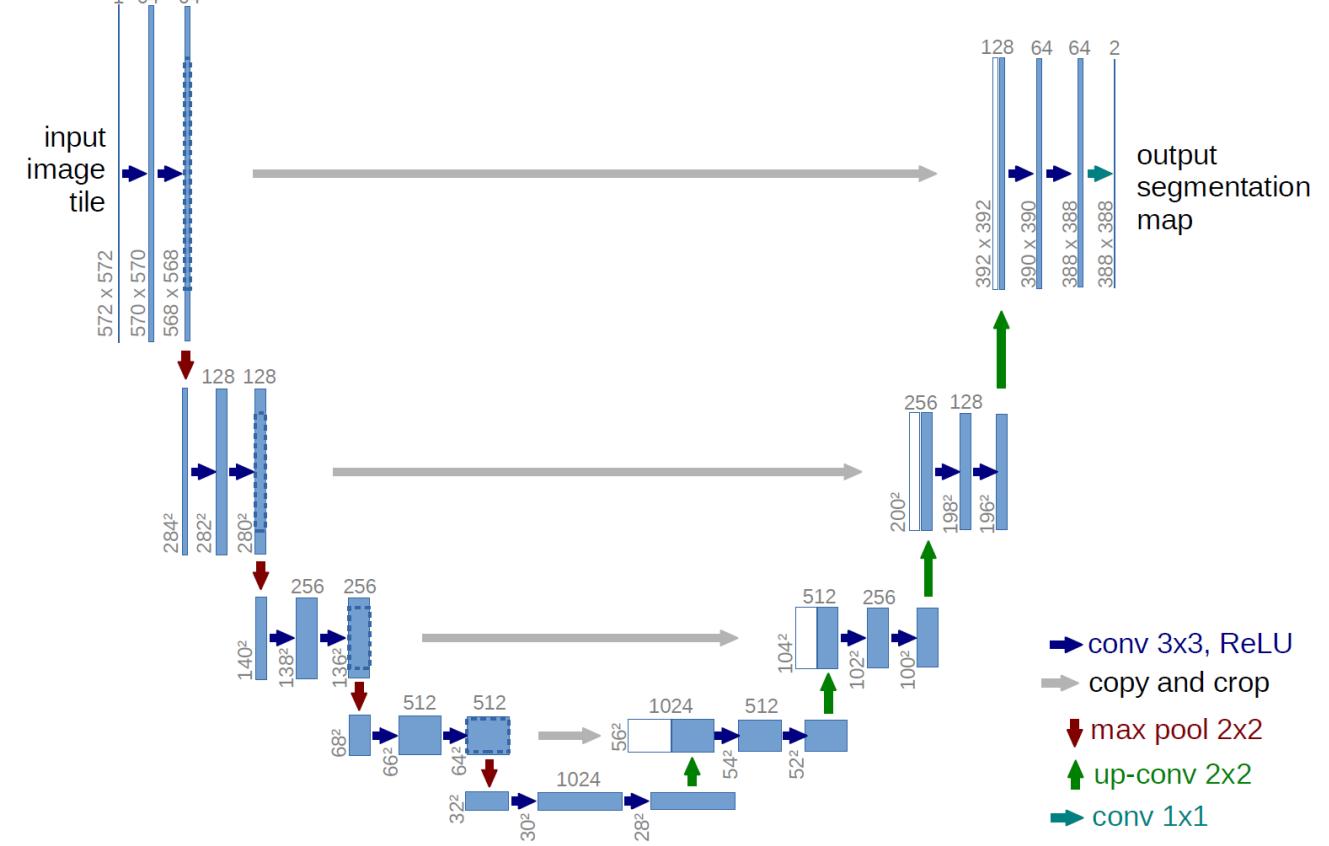
ResNet

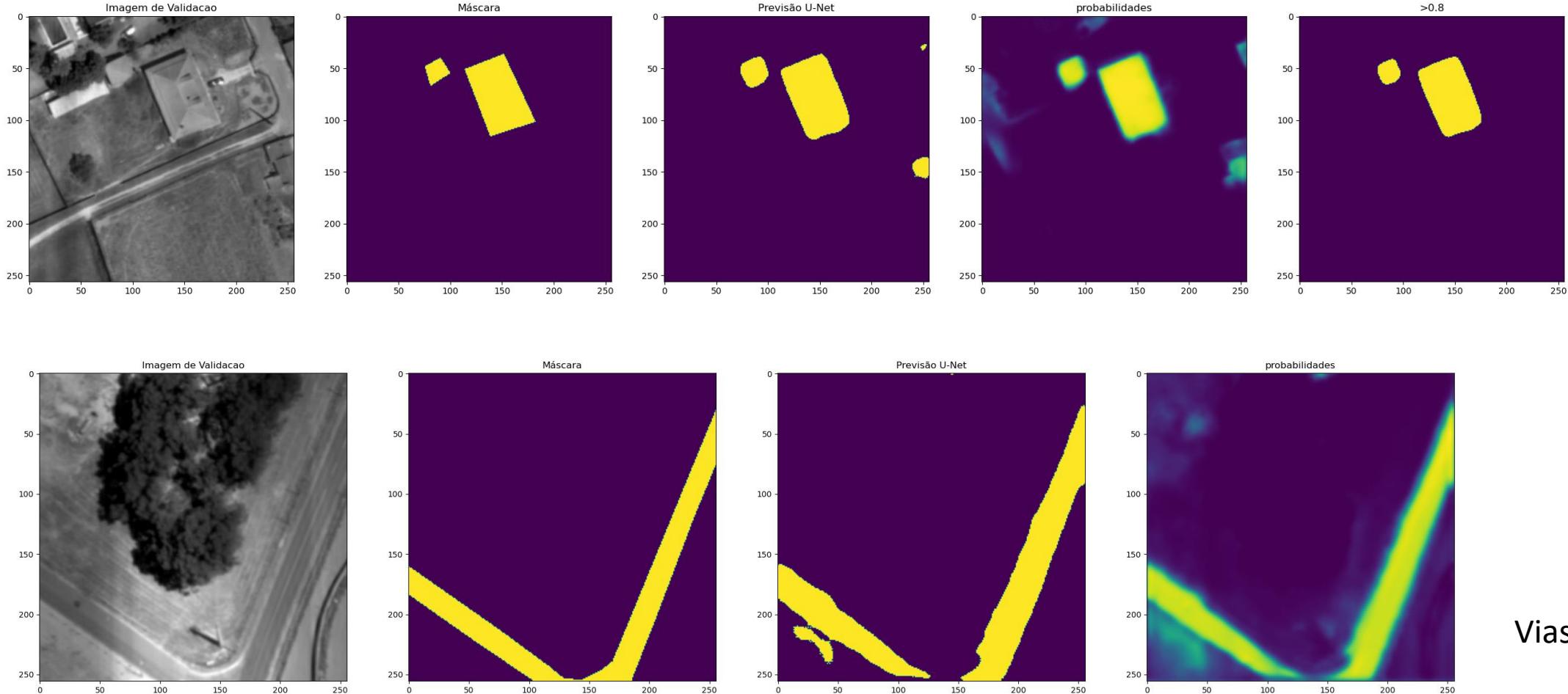
Xception (variante da GoogLeNet)

SENet

Desenvolvidas nos ultimos 5 anos

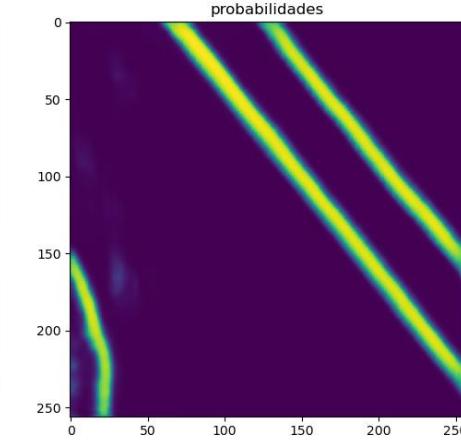
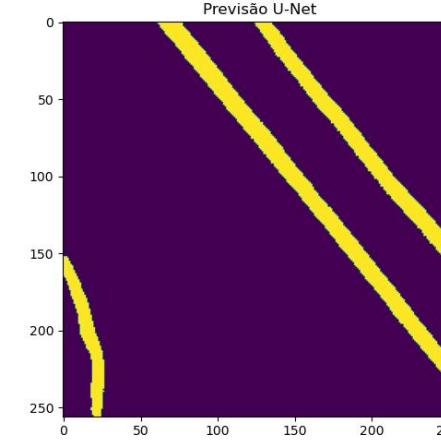
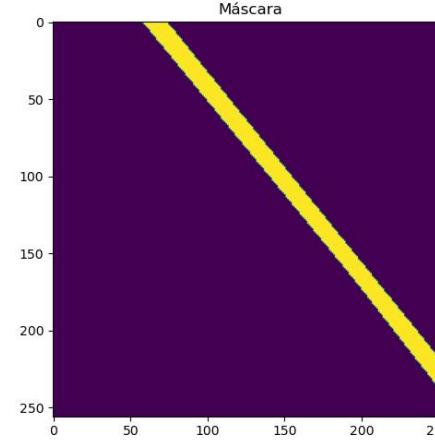
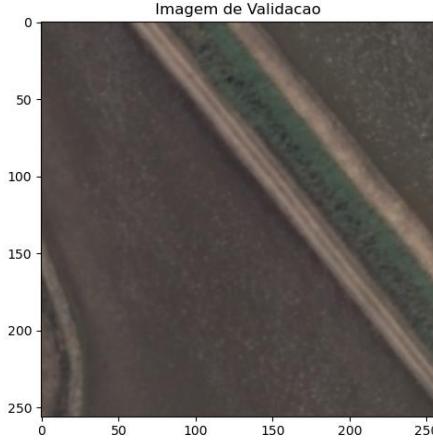
## U-Net (Olaf Ronneberger, 2015)



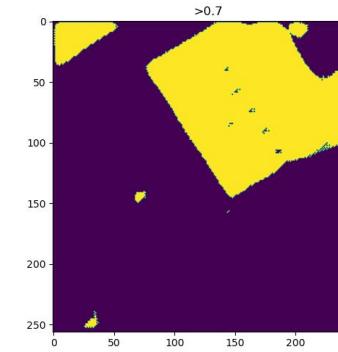
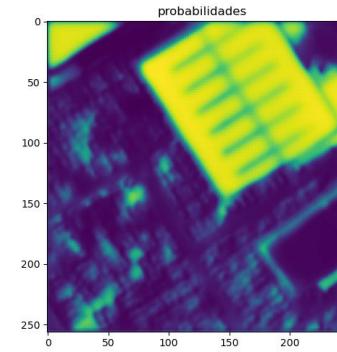
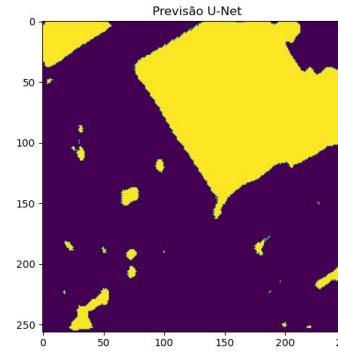
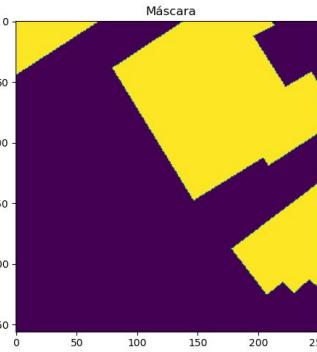
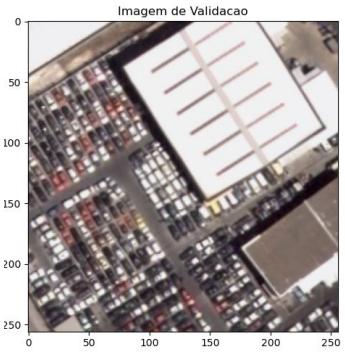


Vias

João Sacadura, 2021



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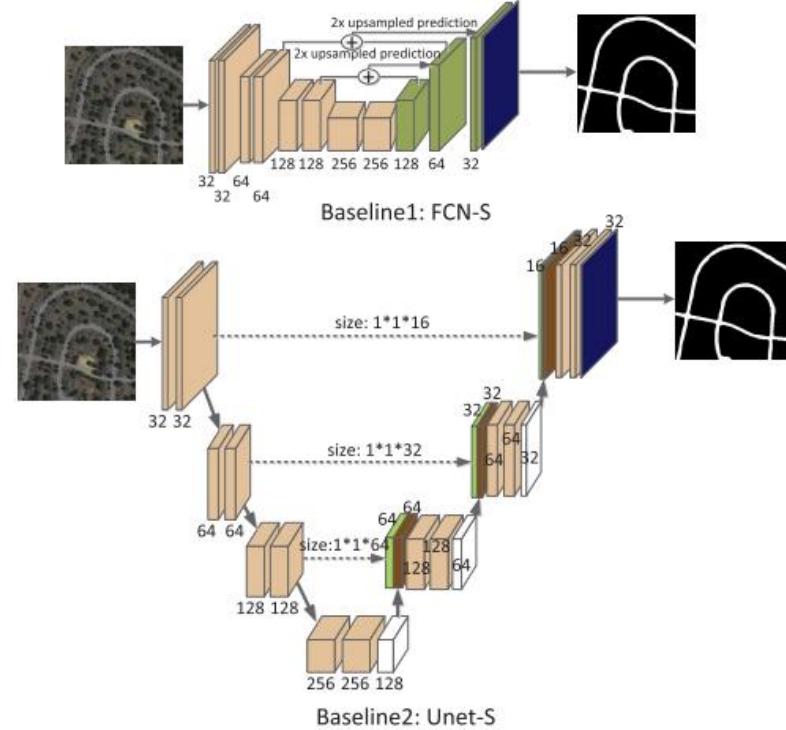


Fig. 3. Architecture of two baseline networks. In FCN-S, feature maps summation and  $2 \times$  upsampled prediction are utilized. In Unet-S, concat layer is employed to concatenate two groups of feature maps. The dotted line represents convolution operation with  $1 \times 1$  kernel.

Automatic road detection and centerline extraction via cascaded end-to-end convolutional neural network,” IEEE Transactions on Geoscience and Remote Sensing, vol. 55, no. 6, pp. 3322–3337, 2017.

Compared with the conventional multilayer perceptron (MLP), which only consists of fully connected layers, the convolutional network has less parameters due to its local connectivity characteristic.

For example, for a  $300 \times 300$  image, we assume that there are ten hidden neurons. There are  $300 \times 300 \times 10 = 900\,000$  weight parameters for MLP.

In convolutional network, if we use  $10 \times 10$  local connectivity pattern, the number of weight parameters is  $10 \times 10 \times 10 = 1000$ .