Apache Spark
Machine Learning in Scale

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Disclaimer

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- Understanding WHY

Índice - Debate

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- Machine learning, ¿qué es?
- ¿Qué algoritmos conocéis?
- ¿Qué es la escalabilidad?
- ¿Dónde está el cuello de botella de los algoritmos que conocéis?
- Un cuello de botella típico
- Complejidad

Preguntas para vosotros

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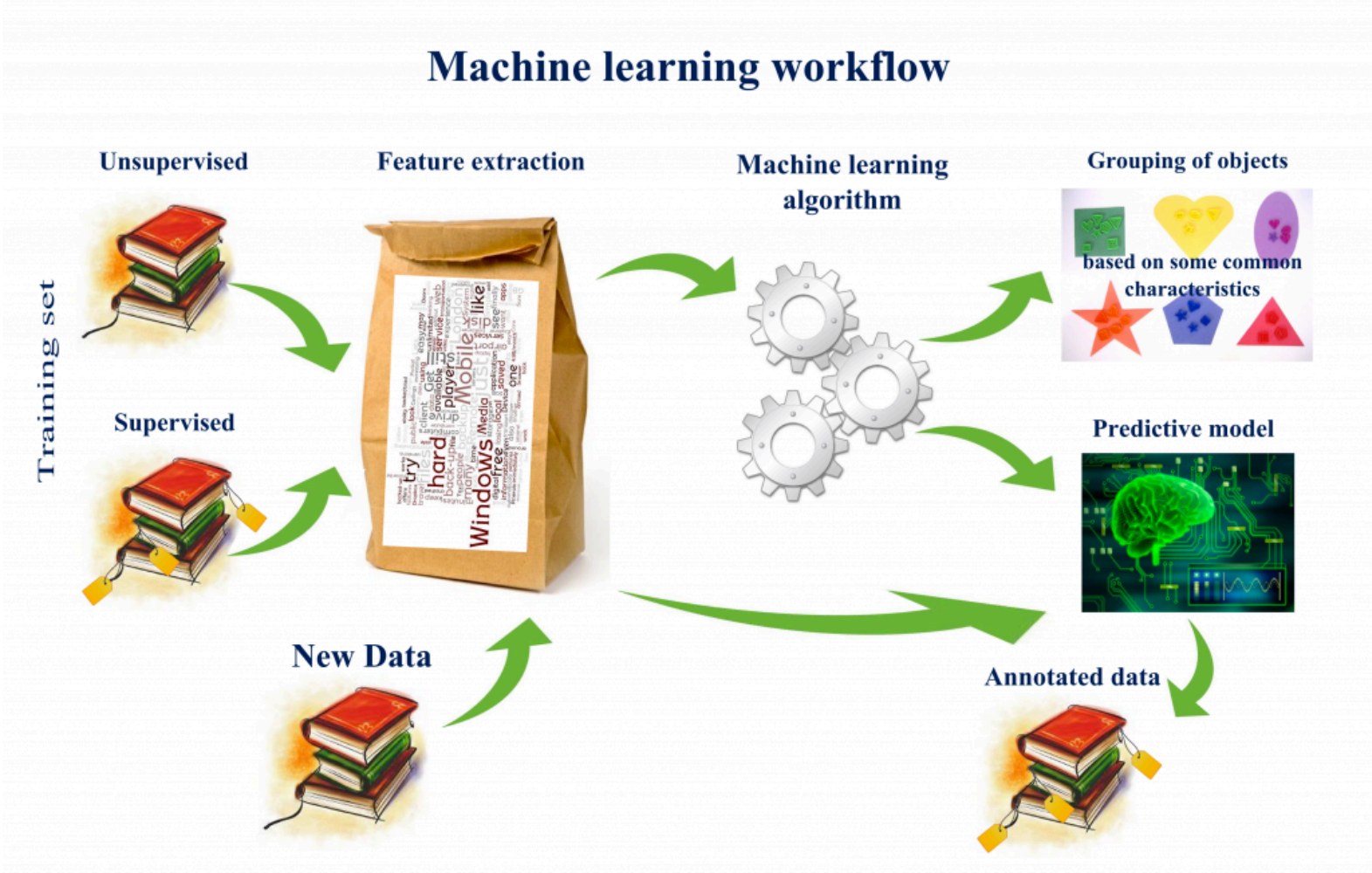
- ¿Qué es Machine Learning?
- ¿Qué algoritmos conocemos?
- ¿Qué es la escalabilidad?
- ¿Dónde está el cuello de botella de los algoritmos que conocéis?

Machine Learning



Source: http://nkonst.com/machine-learning-explained-simple-words/

Machine Learning Algorithms *(sample)*

	Unsupervised	Supervised

Continuous	• Clustering & Dimensionality Reduction
	  ○ SVD
	  ○ PCA
	  ○ K-means
		• Regression
		  ○ Linear
		  ○ Polynomial
		• Decision Trees
		• Random Forests

Categorical	• Association Analysis
	  ○ Apriori
	  ○ FP-Growth
	• Hidden Markov Model
		• Classification
		  ○ KNN
		  ○ Trees
		  ○ Logistic Regression
		  ○ Naive-Bayes
		  ○ SVM

Una visión un poco más amplia

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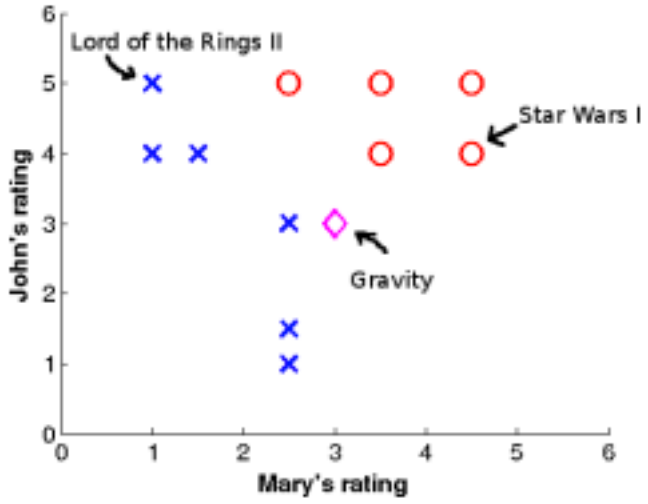
- From: https://cs.stanford.edu/~quocle/tutorial1.pdf

Movie name	Mary's rating	John's rating	I like?
Lord of the Rings II	1	5	No
...	...	...	...
Star Wars I	4.5	4	Yes
Gravity	3	3	?



Función de decisión

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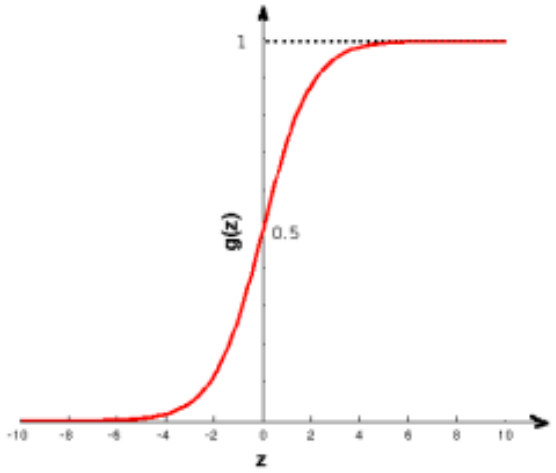
Our decision function can be as simple as a weighted linear combination of Mary's and John's ratings:

$$h(x;\theta,b) = \theta_1 x_1 + \theta_2 x_2 + b, \quad \text{which can also be written as} \quad h(x;\theta,b) = \theta^T x + b \tag{1}$$

A simple way to force h to have values between 0 and 1 is to map it through another function called the sigmoid function, which is bounded between 0 and 1:

$$h(x;\theta,b) = g(\theta^T x + b), \text{ where } g(z) = \frac{1}{1+\exp(-z)}, \tag{2}$$

which graphically should look like this:



The value of function h is now bounded between 0 and 1.

Buscando los coeficientes

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To find the values of θ and b we can try to minimize the following *objective function*, which is the sum of differences between the decision function h and the label y:

$$J(\theta, b) = \left(h(x^{(1)}; \theta, b) - y^{(1)}\right)^2 + \left(h(x^{(2)}; \theta, b) - y^{(2)}\right)^2 + \ldots + \left(h(x^{(m)}; \theta, b) - y^{(m)}\right)^2$$
$$= \sum_{i=1}^{m} \left(h(x^{(i)}; \theta, b) - y^{(i)}\right)^2$$

Stochastic Gradient Descent

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To minimize the above function, we can iterate through the examples and slowly update the parameters θ and b in the direction of minimizing each of the small objective $\left(h(x^{(i)};\theta,b) - y^{(i)}\right)^2$. Concretely, we can update the parameters in the following manner:

$$\theta_1 = \theta_1 - \alpha\Delta\theta_1 \quad (3)$$

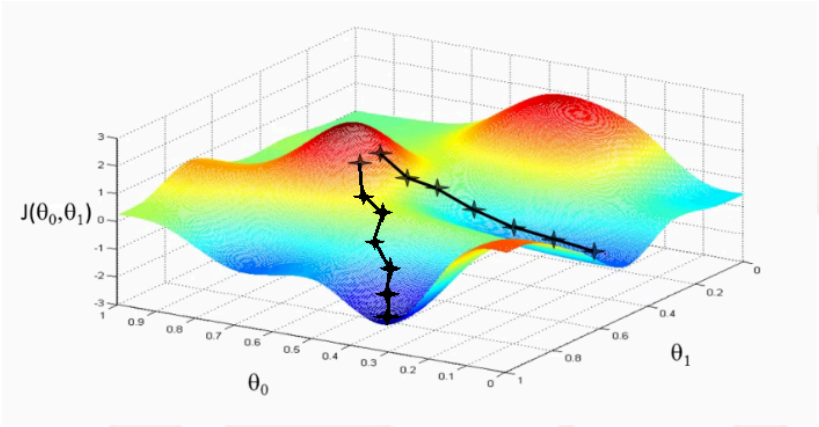
$$\theta_2 = \theta_2 - \alpha\Delta\theta_2 \quad (4)$$

$$b = b - \alpha\Delta b \quad (5)$$

Iterate

Now the question of finding the optimal parameters amounts to finding $\Delta\theta$'s and Δb such that they are in the descent direction. In the following, as our objective function is composed of function of functions, we use the *the chain rule* to compute the derivatives. Remember that the chain rule says that if g is a function of $z(x)$ then its derivative is as follows:

$$\frac{\partial g}{\partial x} = \frac{\partial g}{\partial z}\frac{\partial z}{\partial x}$$



Gráficamente y más simple

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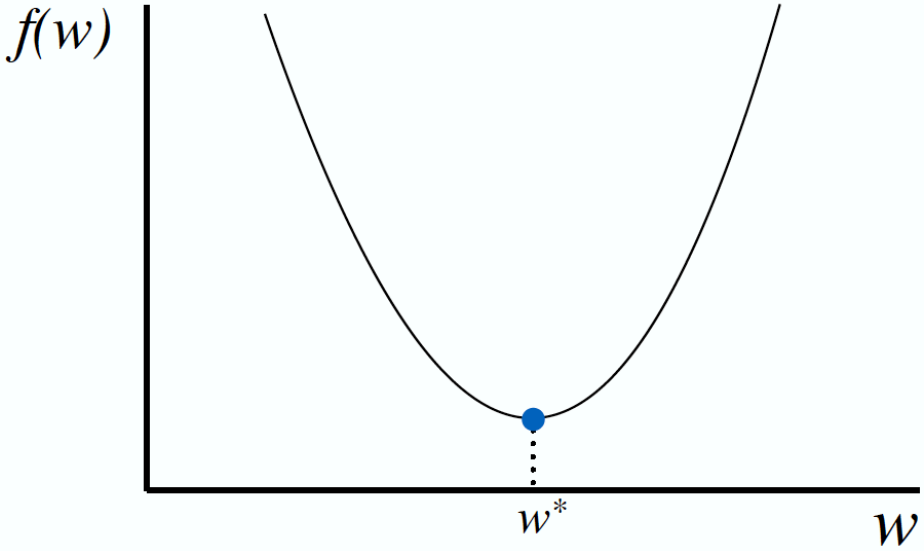
Goal: Find $\mathbf{w}^*$ that minimizes

$$f(\mathbf{w}) = ||\mathbf{X}\mathbf{w} - \mathbf{y}||_2^2$$

- Closed form solution exists
- Gradient Descent is iterative (Intuition: go downhill!)



Scalar objective: $f(w) = ||w\mathbf{x} - \mathbf{y}||_2^2 = \sum_{j=1}^{n} (wx^{(j)} - y^{(j)})^2$

Paso 1

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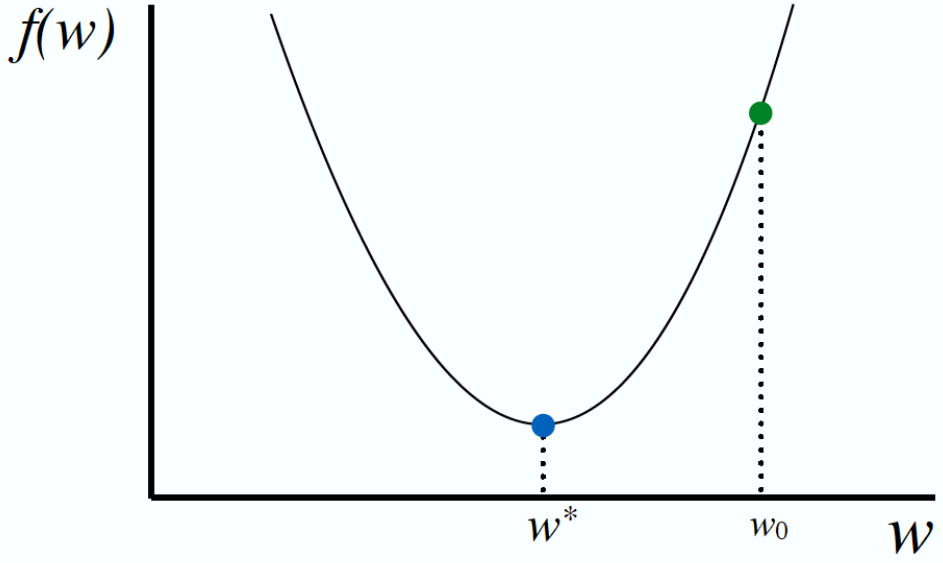
Start at a random point



Paso 2

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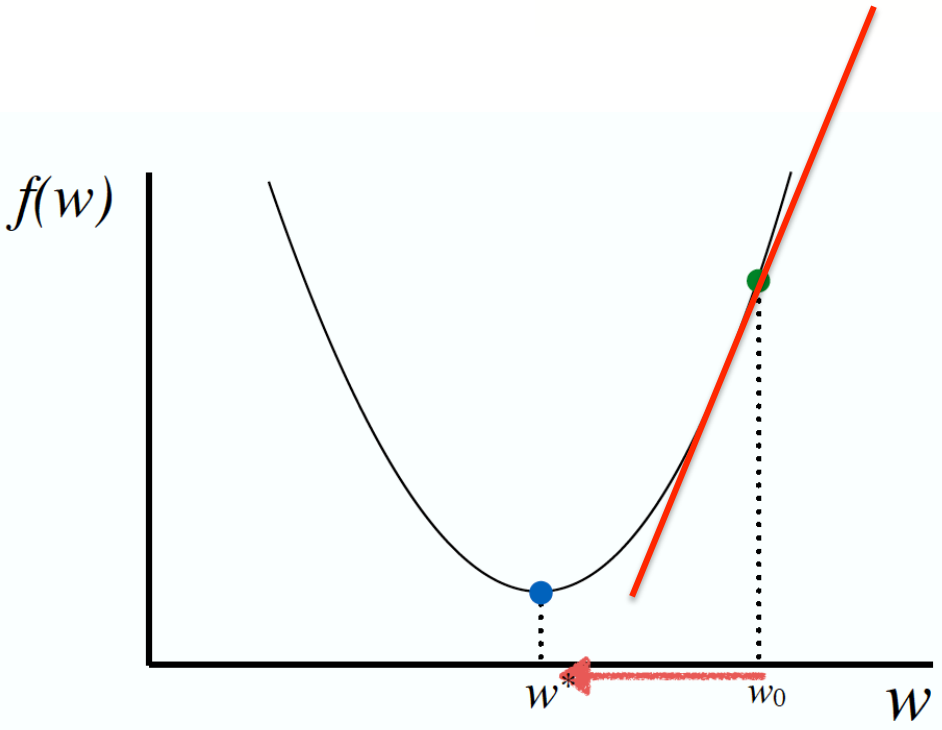
Start at a random point

Determine a descent direction



Paso 3

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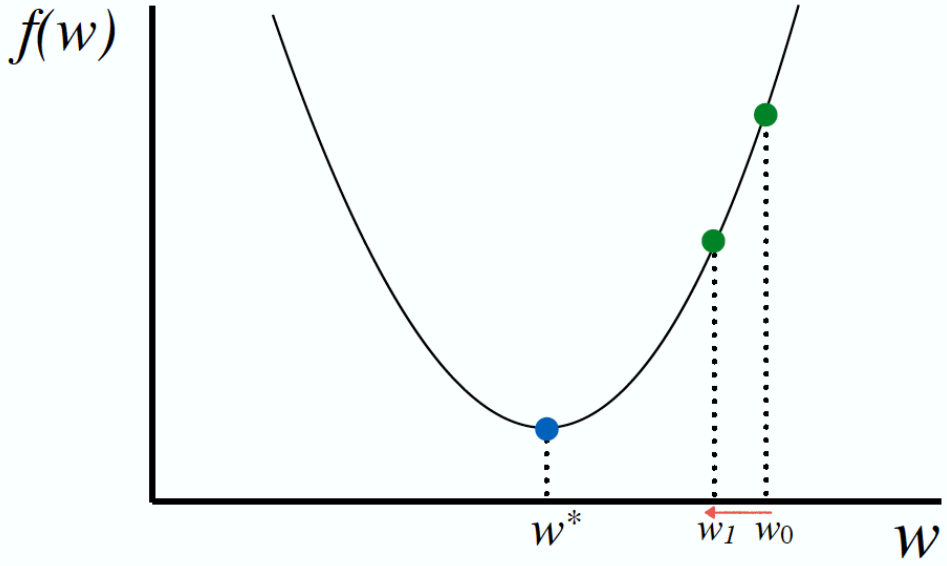
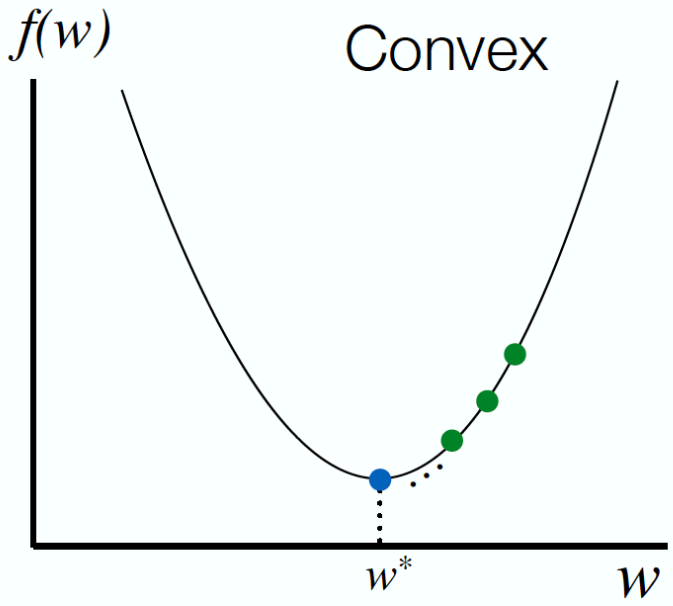
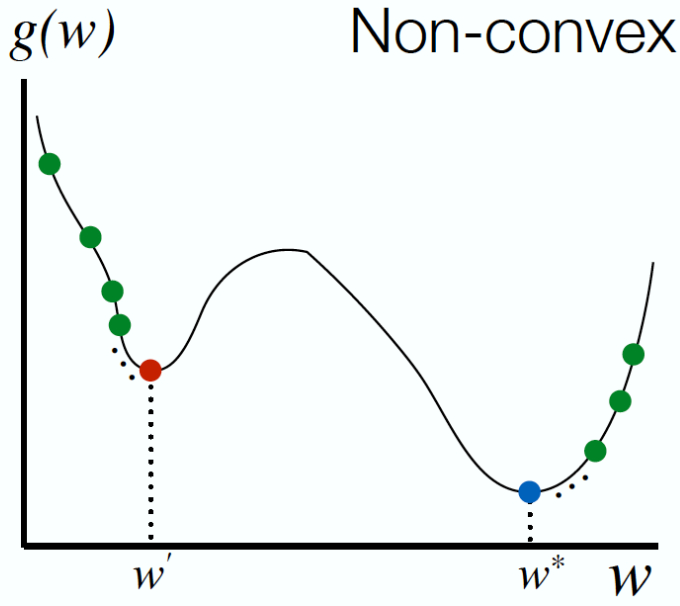
Start at a random point
Repeat
    Determine a descent direction
    Choose a step size
    Update
Until stopping criterion is satisfied



[Nota] Convergencia



Any local minimum is a global minimum



Multiple local minima may exist

Least Squares, Ridge Regression and Logistic Regression are all convex!

Un cuello de botella típico

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- Independientemente del algoritmo que emplees, habrás visto MATRICES, MATRICES, MATRICES
  - Tipos de datos matriciales
  - Productos de matrices
  - Matrices inversas

Multiplying a matrix by its inverse results in the identity matrix

- For an $n \times n$ matrix $\mathbf{A}$, $\mathbf{A}^{-1}$ denotes its inverse (when it exists)
- $\mathbf{A}\mathbf{A}^{-1} = \mathbf{A}^{-1}\mathbf{A} = \mathbf{I}_n$

Only a square matrix (when $n = m$) can have an inverse

Repaso

- ¿Cómo se calcula la matriz inversa?

$$A^{-1} = \frac{1}{|A|} \begin{bmatrix} \begin{vmatrix} a_{22} & a_{23} \\ a_{32} & a_{33} \end{vmatrix} & \begin{vmatrix} a_{13} & a_{12} \\ a_{33} & a_{32} \end{vmatrix} & \begin{vmatrix} a_{12} & a_{13} \\ a_{22} & a_{23} \end{vmatrix} \\ \begin{vmatrix} a_{23} & a_{21} \\ a_{33} & a_{31} \end{vmatrix} & \begin{vmatrix} a_{11} & a_{13} \\ a_{31} & a_{33} \end{vmatrix} & \begin{vmatrix} a_{13} & a_{11} \\ a_{23} & a_{21} \end{vmatrix} \\ \begin{vmatrix} a_{21} & a_{22} \\ a_{31} & a_{32} \end{vmatrix} & \begin{vmatrix} a_{12} & a_{11} \\ a_{32} & a_{31} \end{vmatrix} & \begin{vmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{vmatrix} \end{bmatrix}.$$

¿Dónde aparecen matrices?

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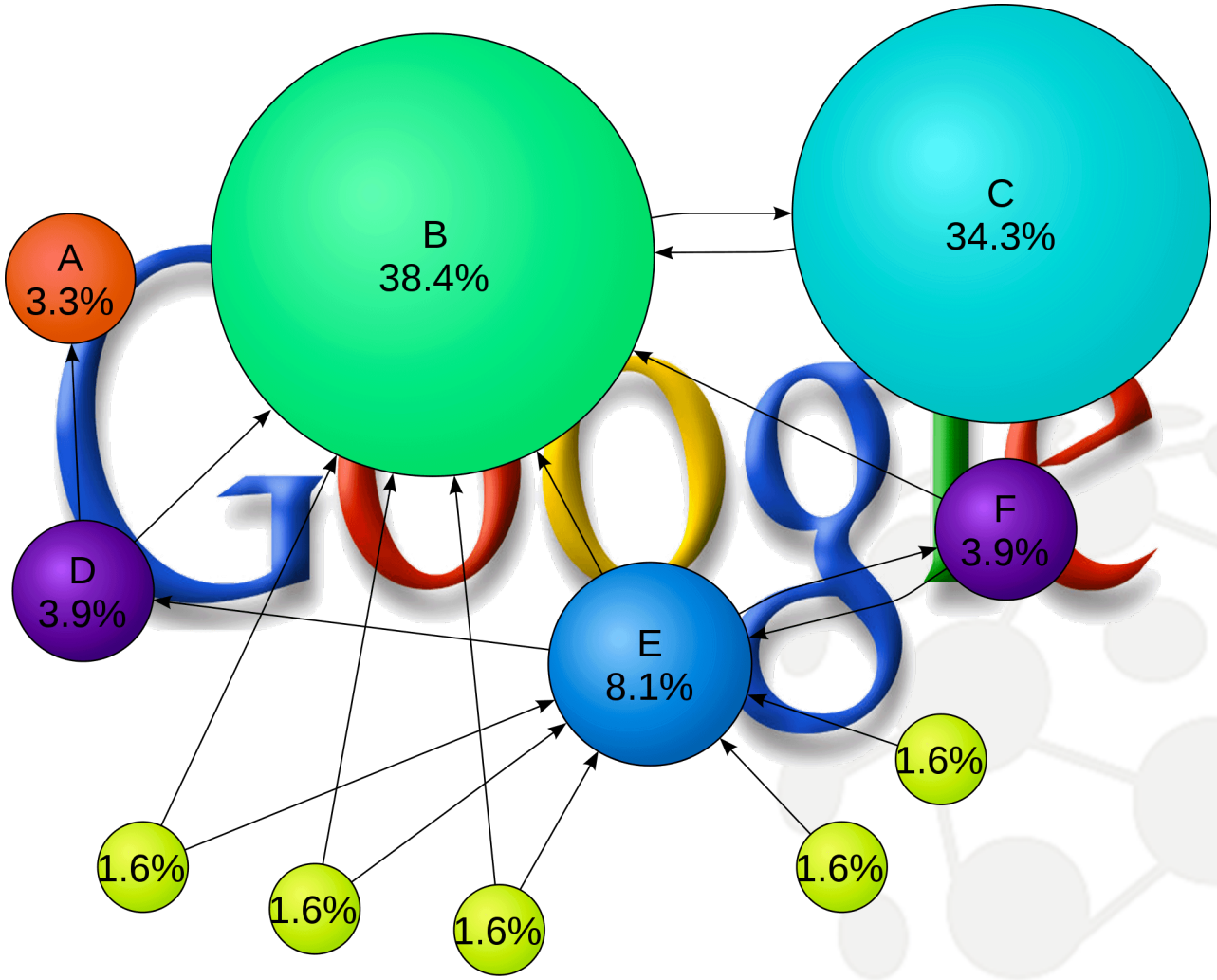
- En cualquier sitio, como una regresión

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ \vdots \\ y_n \end{bmatrix} = \begin{bmatrix} 1 & x_1 & x_1^2 & \dots & x_1^m \\ 1 & x_2 & x_2^2 & \dots & x_2^m \\ 1 & x_3 & x_3^2 & \dots & x_3^m \\ \vdots & \vdots & \vdots & & \vdots \\ 1 & x_n & x_n^2 & \dots & x_n^m \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ \vdots \\ a_m \end{bmatrix} + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \vdots \\ \varepsilon_n \end{bmatrix}$$

Super-Matrices



Y matrices de adyacencia

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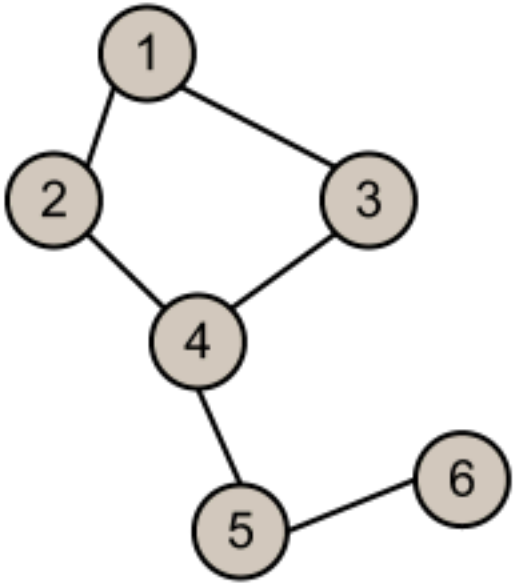
Undirected Graph & Adjacency Matrix



Undirected Graph

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

Adjacency Matrix

¿A cuánto de qué viene este rollo?

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- Tenemos muchos algoritmos que implican un gran número de cálculos e iteraciones
- Empleando un conjunto de datos muy grandes
- Con abstracción matemática en forma matricial
- Y ciertas operaciones con matrices no son nada triviales dependiendo del tamaño de la matrix

Midiendo la complejidad

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Describes how algorithms respond to changes in input size

- Both in terms of processing time and space requirements
- We refer to complexity and Big O notation synonymously

Notation: $f(x) = O(g(x))$

- Can describe an algorithm's time or space complexity

Informal definition: f does not grow faster than g

Formal definition: $|f(x)| \leq C|g(x)| \quad \forall x > N$

Complejidades conocidas

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Matrix inversion of an $n \times n$ matrix

- $O(n^3)$ time complexity to perform inversion
- $O(n^2)$ space complexity to store result

Y ahora sí, la solución…

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Pero no es oro todo lo que reluce

Esto es lo que hay (feb-2017)

- Data types
- Basic statistics
  - summary statistics
  - correlations
  - stratified sampling
  - hypothesis testing
  - streaming significance testing
  - random data generation
- Classification and regression
  - linear models (SVMs, logistic regression, linear regression)
  - naive Bayes
  - decision trees
  - ensembles of trees (Random Forests and Gradient-Boosted Trees)
  - isotonic regression
- Collaborative filtering
  - alternating least squares (ALS)
- Clustering
  - k-means
  - Gaussian mixture
  - power iteration clustering (PIC)
  - latent Dirichlet allocation (LDA)
  - bisecting k-means
  - streaming k-means
- Dimensionality reduction
  - singular value decomposition (SVD)
  - principal component analysis (PCA)
- Feature extraction and transformation
- Frequent pattern mining
  - FP-growth
  - association rules
  - PrefixSpan
- Evaluation metrics
- PMML model export
- Optimization (developer)
  - stochastic gradient descent
  - limited-memory BFGS (L-BFGS)

Lo importante no es la herramienta

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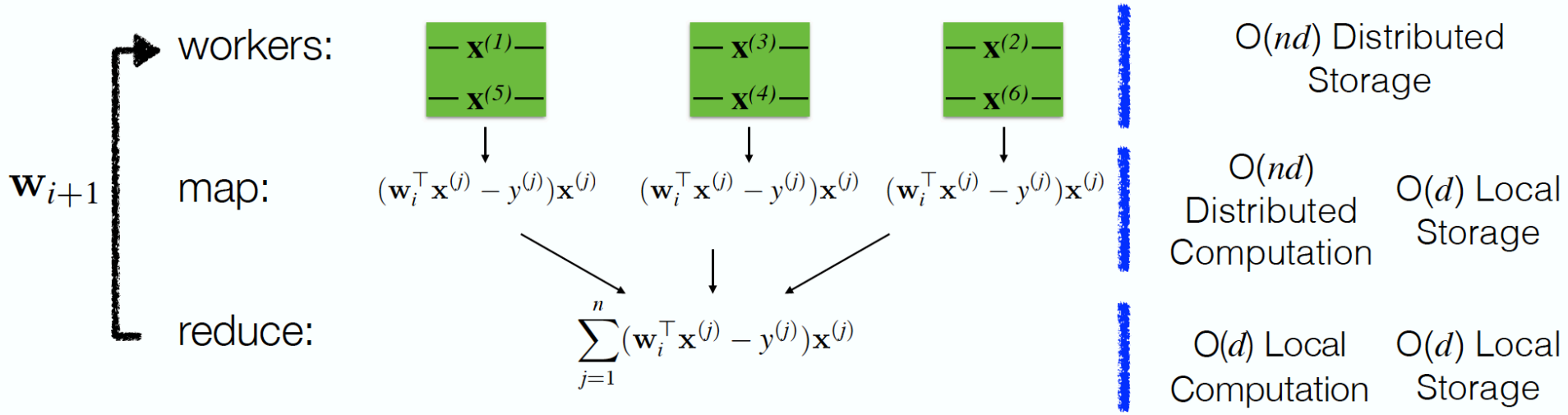
Parallel Gradient Descent for Least Squares

Vector Update: $\mathbf{w}_{i+1} = \mathbf{w}_i - \alpha_i \sum_{j=1}^{n} (\mathbf{w}_i^\top \mathbf{x}^{(j)} - y^{(j)}) \mathbf{x}^{(j)}$

Compute summands in parallel!
note: workers must all have $\mathbf{w}_i$

Example: n = 6; 3 workers



Tampoco es tan difícil

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```
for i in range(numIters):
    alpha_i = alpha / (n * np.sqrt(i+1))
    gradient = train.map(lambda lp: gradientSummand(w, lp))
                    .sum()
    w -= alpha_i * gradient
return w
```

A tener en cuenta

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1. Combina cálculo en “memoria” con cálculo paralelo para reducir el coste de comunicaciones
2. Minimiza las comunicaciones
3. Reduce las iteraciones

Resumen

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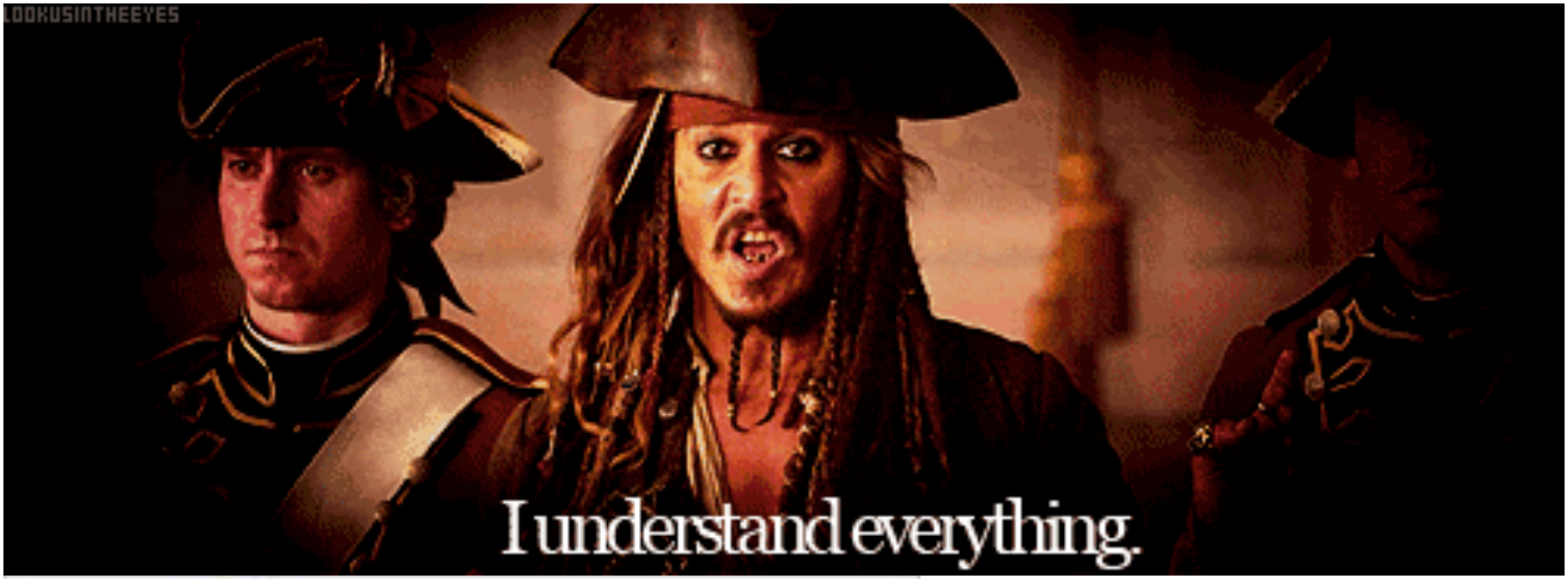
- Casi todos los algoritmos constan de fases interativas
- Además, suelen necesitar cálculo matricial
- Todo ello hace que, con volúmenes de datos medianamente grandes, tengamos problemas de procesamiento
- Pero Spark MLlib está aquí para ayudarnos
- La programación en paralelo no es cuestión trivial y debe considerarse ciertas precauciones


I understand everything.


im so sick of not being understood!
what do you mean?


"HAVE I MADE MYSELF UNDERSTOOD?"
May