



# Deep Learning en Sistemas de Recomendación

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IIC1005 Sistemas Recomendadores

PUC Chile

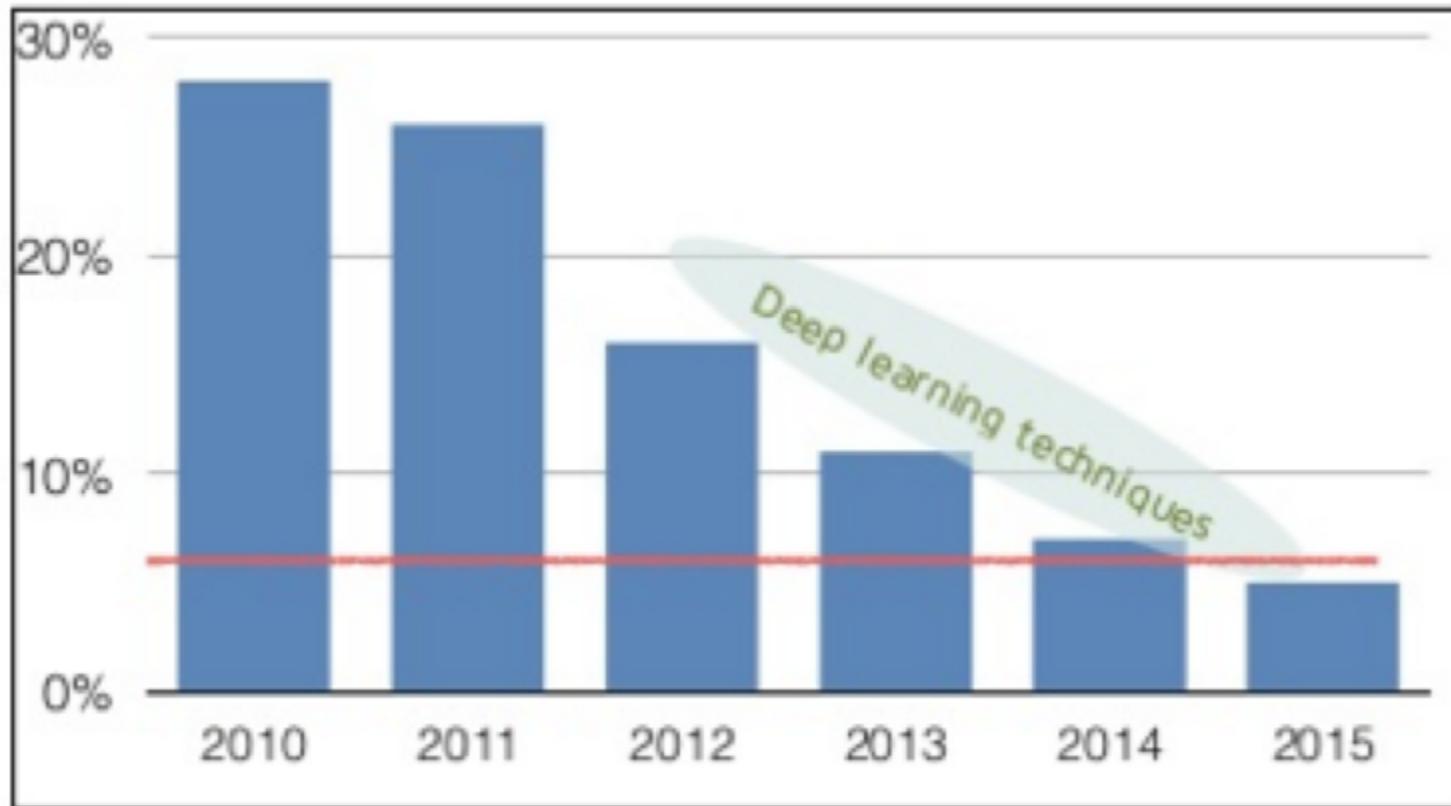
# En esta clase

- Introducción a las redes neuronales artificiales
  - Bases Biológicas
  - Perceptron
  - FeedForward y BackPropagation
- Algunos tipos de arquitecturas de redes neuronales
- Aplicaciones en Sistemas Recomendadores
  - YouTube Recommendations
  - Video Recommendations
  - Recomendación de Productos

# Referencias

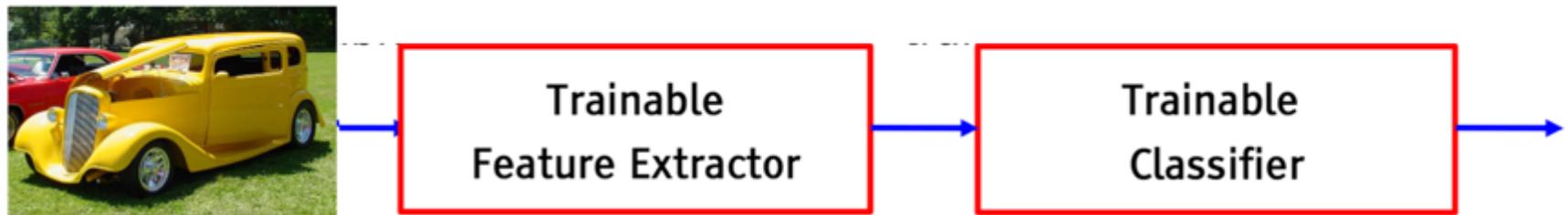
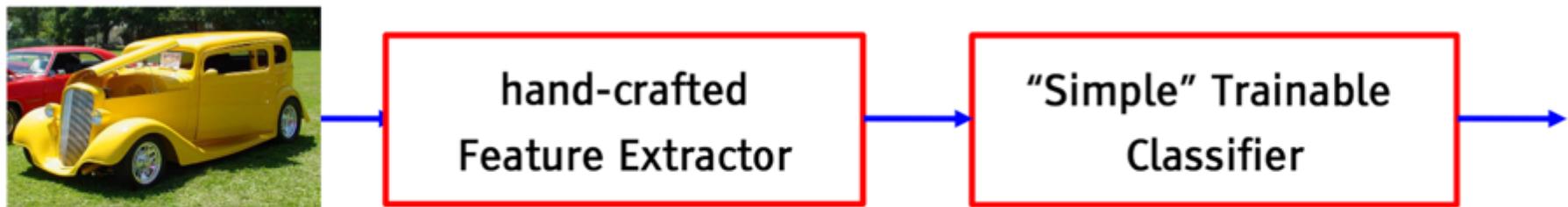
- Estas slides fueron posibles gracias al material que otros investigadores han compartido en línea:
  - Arno Candel  
<http://www.slideshare.net/0xdata/deep-learning-through-examples>
  - Alexandros Karatzoglou
  - <https://www.slideshare.net/kerveros99/deep-learning-for-recommender-systems-recsys2017-tutorial>
  - Balazs Hidasi  
<http://www.slideshare.net/balazshidasi/deep-learning-to-the-rescue-solving-long-standing-problems-of-recommender-systems>
  - Tom Kenter et al.  
[http://nn4ir.com/slides/02\\_Preliminaries.pdf](http://nn4ir.com/slides/02_Preliminaries.pdf)

# ¿Por qué Deep Learning?



ImageNet challenge error rates (red line = human performance)

# ¿Por qué Deep Learning?



# ¿Por qué Deep Learning?

ICH

The New York Times

Godzillium vs. Trumplium: Some Suggestions to Add to the Periodic Table

To Protect Against Zika Virus, Pregnant Women Are Warned About Latin American Trips

THE NEW OLD AI F.T.C.'s Lumen Doesn't End Training Delays

SCIENCE

## Scientists See Promise in Deep-Learning Progr

By JOHN MARKOFF NOV. 23, 2012

BBC

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NEWS

Microsoft Research Global Project

Home Video World UK Business Tech Science Magazine

Forbes / Tech

DEC 29, 2014 @ 11:37 AM 89,471 VIEWS

## Tech 2015: Deep Learning And Machine Intelligence Will Eat The World

'Deep learning' technology inspired by human brain

culture business lifestyle fashion environment tech travel

Androids do dream of electric sheep

nature International weekly journal of science

Home News & Comment Research Careers & Jobs Current Issue

Archive > Volume 518 > Issue 7540 > News > Article

NATURE | NEWS

عرب

## Game-playing software holds lesson: neuroscience

DeepMind computer provides new way to investigate how the bra

Top 20 Stocks for 2016

Google a step closer to developing machines with human-like intell

Algorithms developed by Google designed to encode thoughts, computers with 'common sense' within a decade, says leading AI

# ImageNet: Crowdsourcing a Large Dataset of Image Labels

IM<sup>A</sup>GENET

# Datasets en Computer Vision

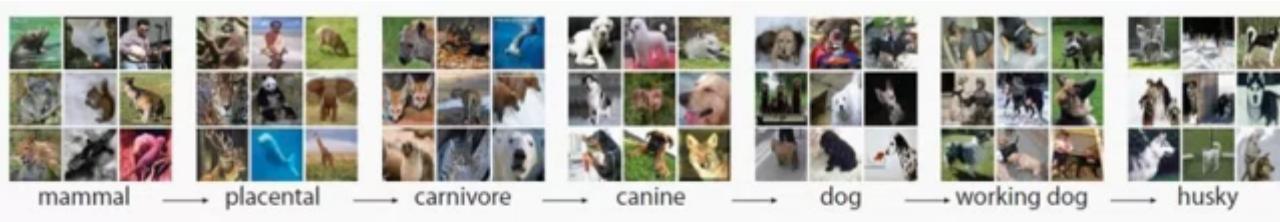
- 1996: faces and cars 14,000 images of 10,000 people
- 1998: MNIST 70,000 images of handwritten digits
- 2004: Caltech 101, 9,146 images of 101 categories
- 2005: PASCAL VOC 20,000 images with 20 classes

# Datasets en Computer Vision

- Imagenet: Presentado in 2009 at CVPR
- Crowdsourced
- 14,197,122 images
- 21,841 categories (non-empty synsets)
- Categories based on WordNet taxonomy

# WordNet

- Wordnet: Miller's project started in 1980 at Princeton, a hierarchy for the English language
- Prof. Fei-Fei Li (then at UIUC and then Princeton), worked on filling WordNet with many images.



- S: (n) [Eskimo dog](#), [husky](#) (breed of heavy-coated Arctic sled dog)
  - [direct hyperonym](#) / [inherited hyperonym](#) / [cister term](#)
  - S: (n) [working dog](#) (any of several breeds of usually large powerful dogs bred to work as draft animals and guard and guide dogs)
  - S: (n) [dog, domestic dog, Canis familiaris](#) (a member of the genus *Canis* (probably descended from the common wolf) that has been domesticated by man since prehistoric times; occurs in many breeds) "the dog barked all night"
  - S: (n) [canine, canid](#) (any of various fissiped mammals with nonretractile claws and typically long muzzles)
  - S: (n) [carnivore](#) (a terrestrial or aquatic flesh-eating mammal) "terrestrial carnivores have four or five clawed digits on each limb"
  - S: (n) [placental, placental mammal, eutherian, eutherian mammal](#) (mammals having a placenta; all mammals except monotremes and marsupials)
  - S: (n) [mammal, mammaliae](#) (any warm-blooded vertebrate having the skin more or less covered with hair; young are born alive except for the small subclass of monotremes and nourished with milk)
  - S: (n) [vertebrate, craniate](#) (animals having a bony or cartilaginous skeleton with a segmented spinal column and a large brain enclosed in a skull or cranium)
  - S: (n) [chordate](#) (any animal of the phylum Chordata having a notochord or spinal column)
  - S: (n) [animal, animate being, beast, brute, creature, fauna](#) (a living organism characterized by voluntary movement)
  - S: (n) [organism, being](#) (a living thing that has (or can develop) the ability to act or function independently)
  - S: (n) [living thing, animate thing](#) (a living (or once living) entity)
  - S: (n) [whole, unit](#) (an assemblage of parts that is regarded as a single entity) "how big is that part compared to the whole?"; "the team is a unit"
  - S: (n) [object, physical object](#) (a tangible and visible entity; an entity that can cast a shadow) "it was full of rackets, balls and other objects"
  - S: (n) [physical entity](#) (an entity that has physical existence)
  - S: (n) [entity](#) (that which is perceived or known or inferred to have its own distinct existence (living or nonliving))

# Crowdsourced

- Amazon Mechanical Turk
- It took 2.5 years to complete. Originally 3.2 million images in 5,247 categories (mammal, vehicle, etc.)

Main Instructions Unsure? Look up in Wikipedia Google [Additional input] No good photos? Have expertise? comments? Click here!

[First time workers please click here for instructions.](#)

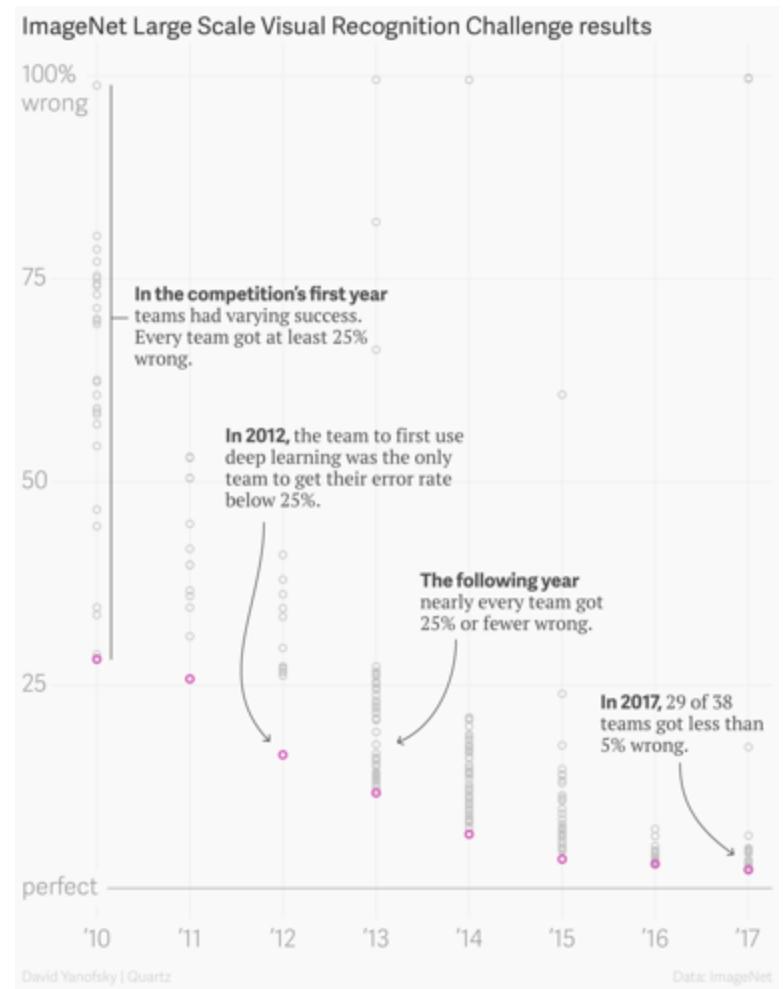
Click on the photos that contain the object or depict the concept of : **delta**: a low triangular area of alluvial deposits where a river divides before entering a larger body of water; "the Mississippi River delta"; "the Nile delta" .(PLEASE READ DEFINITION CAREFULLY)  
Pick as many as possible. **PHOTOS ONLY, NO PAINTINGS, DRAWINGS, etc.** It's OK to have other objects, multiple instances, occlusion or text in the image.  
Do not use back or forward button of your browser. OCCASIONALLY THERE MIGHT BE ADULT OR DISTURBING CONTENT.

Below are the photos you have selected FROM THIS PAGE ONLY (they will be saved when you navigate to other pages). Click to deselect.

what's this? select all deselect all < page 1 of 6 > Submit PREVIEW MODE. TO WORK ON THIS HIT, ACCEPT IT FIRST.

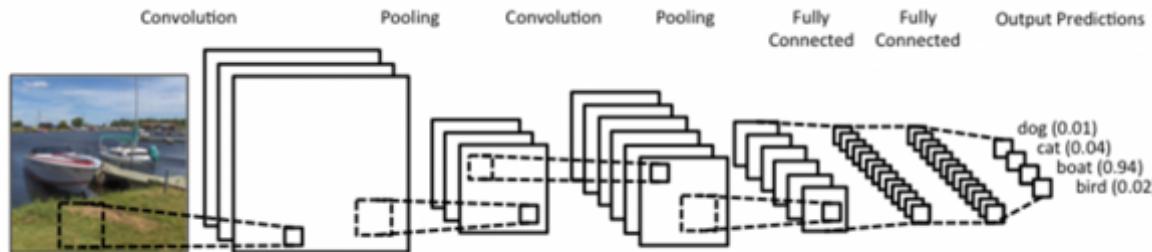
# ImageNet Challenge

- The dataset was used to set a competition for image classification: from 2010 on.
- In 2012 a team used deep learning, got error rate below 25% (Hinton et al.), 10.8 point margin, 41% better than next best.



# Transfer Learning

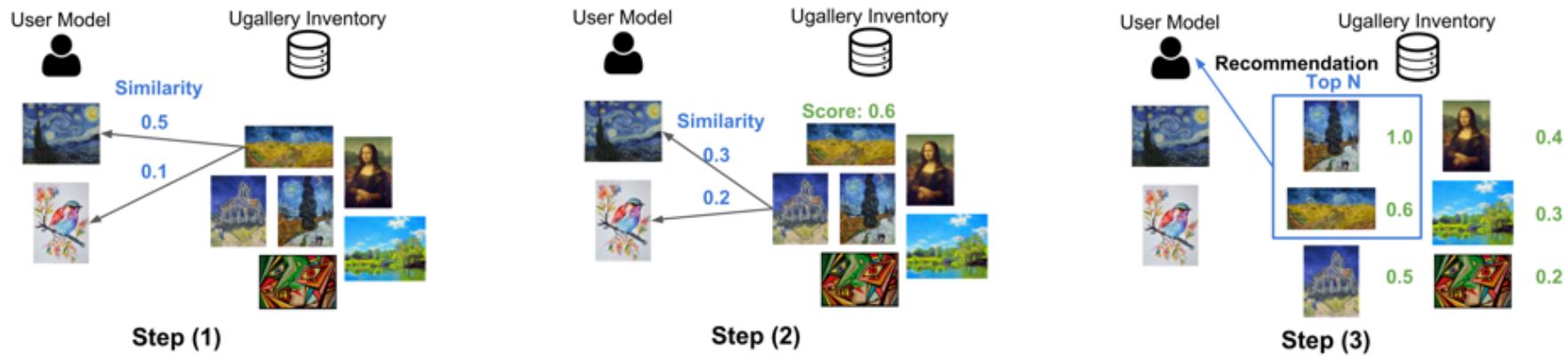
- 2012 model was called AlexNet: a Convolutional Neural Network



- The features learned (fc6, fc7) have been used in other tasks successfully, **allowing to transfer the learning to other tasks.**

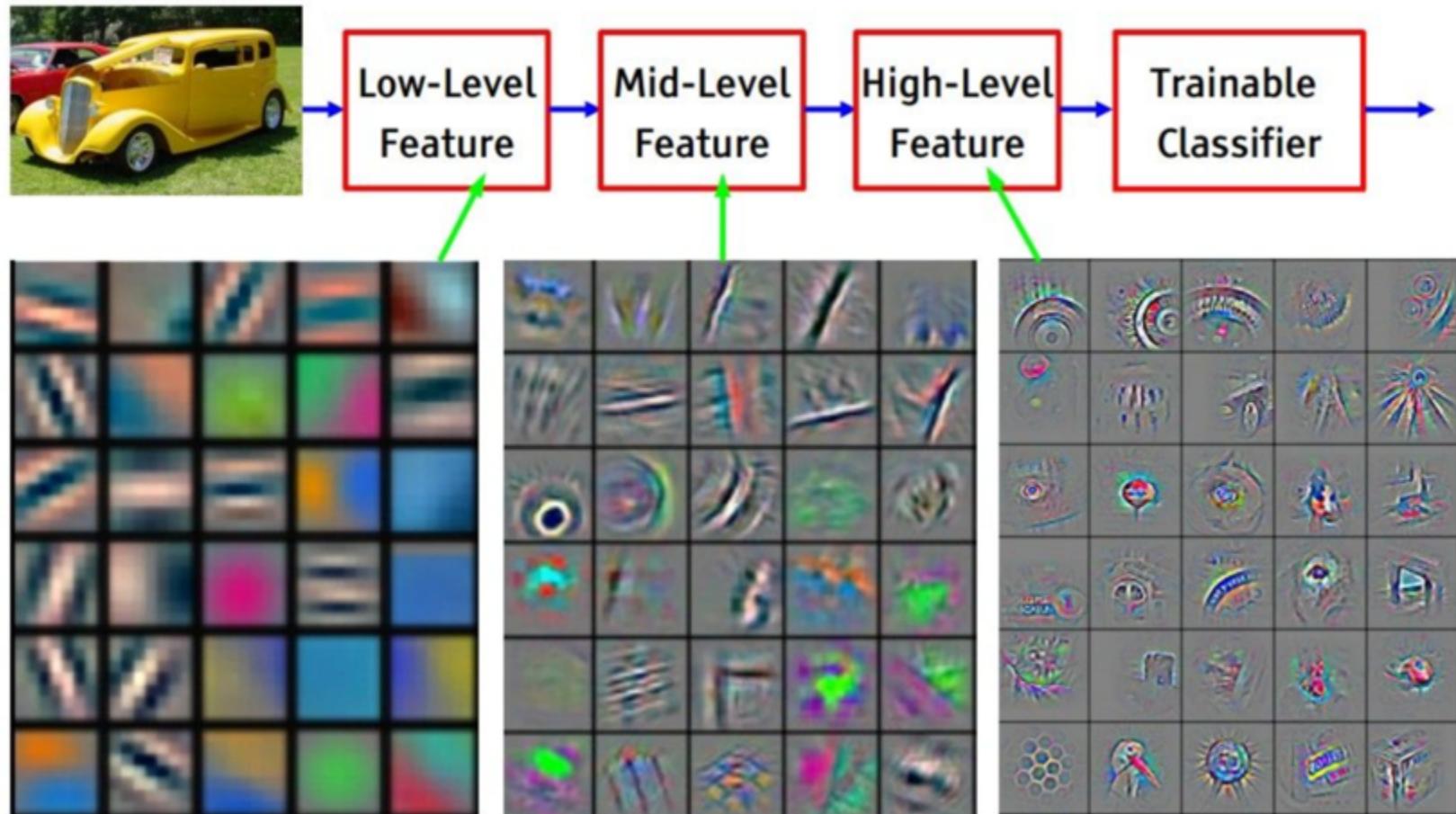
# Un ejemplo: VisRank

- Scoring items based on cosine similarity between user model and item model:



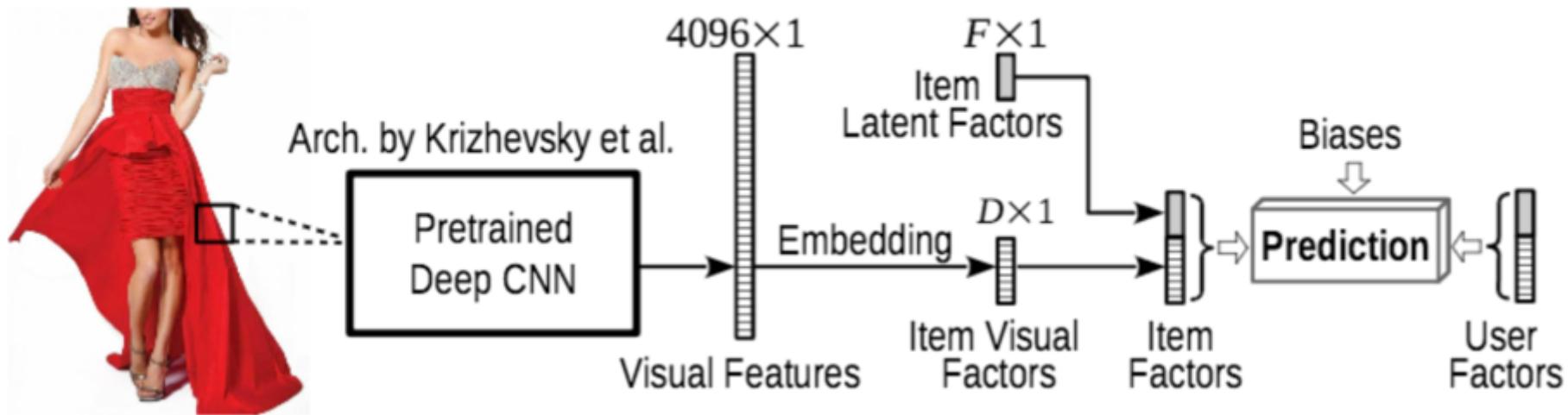
$$sim(V_i, V_j) = \cos(V_i, V_j) = \frac{V_i \cdot V_j}{\|V_i\| \|V_j\|}$$

# CNN



Feature visualization of convolutional net trained on ImageNet from [Zeiler & Fergus 2013]

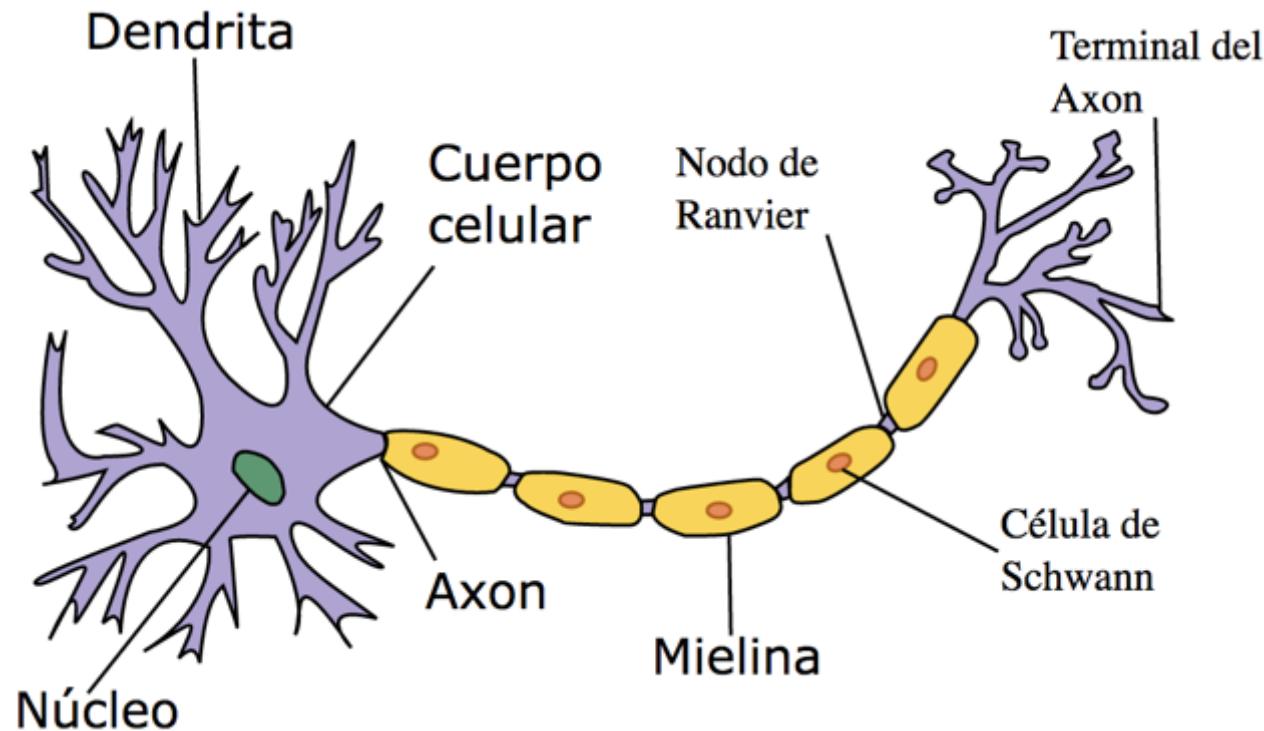
# CNN para Filtrado Colaborativo



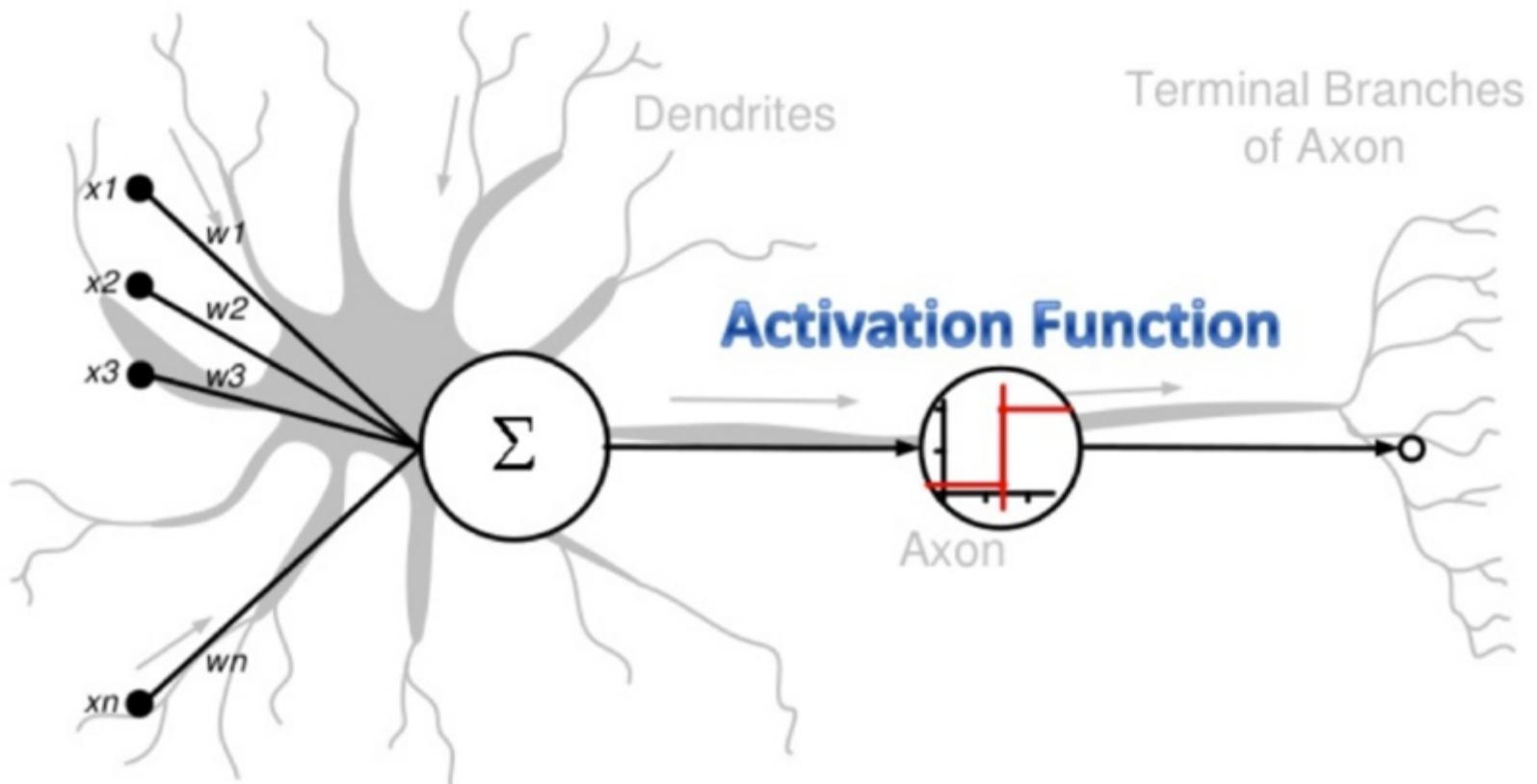
VBPR: Visual Bayesian Personalized Ranking from Implicit Feedback He, et al AAAI 2015

# Bases Biológicas: Neurona

- Tipo de células del sistema nervioso cuya principal función es la excitabilidad eléctrica de su membrana plasmática

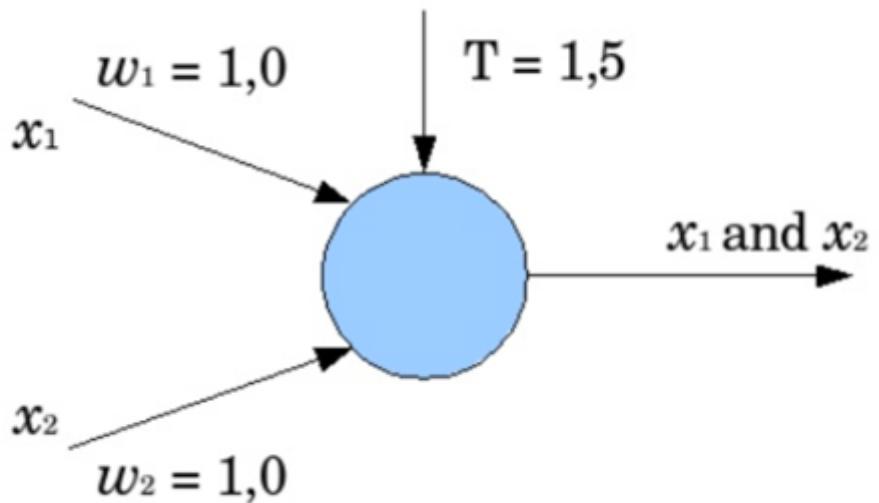
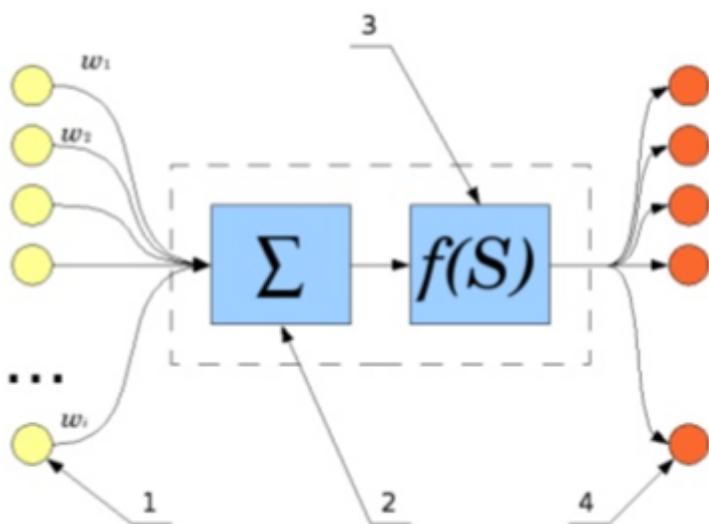


# Redes Neuronales Artificiales



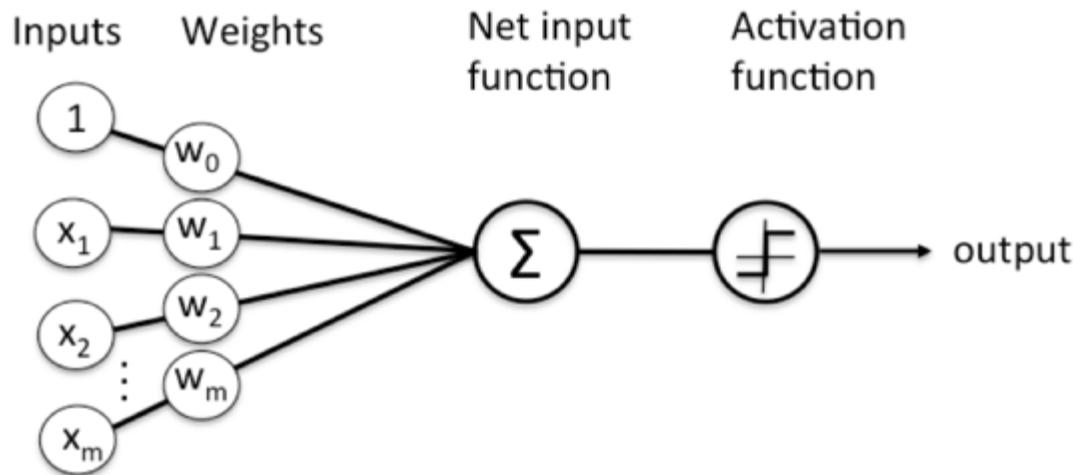
# Redes Neuronales Artificiales

- 1943: McCulloh y Pitts “A Logical Calculus of the Ideas Immanent in Nervous Activity”



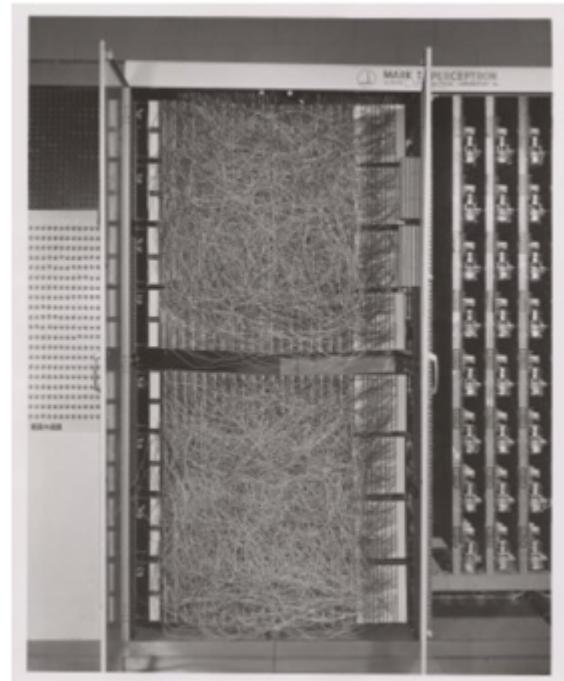
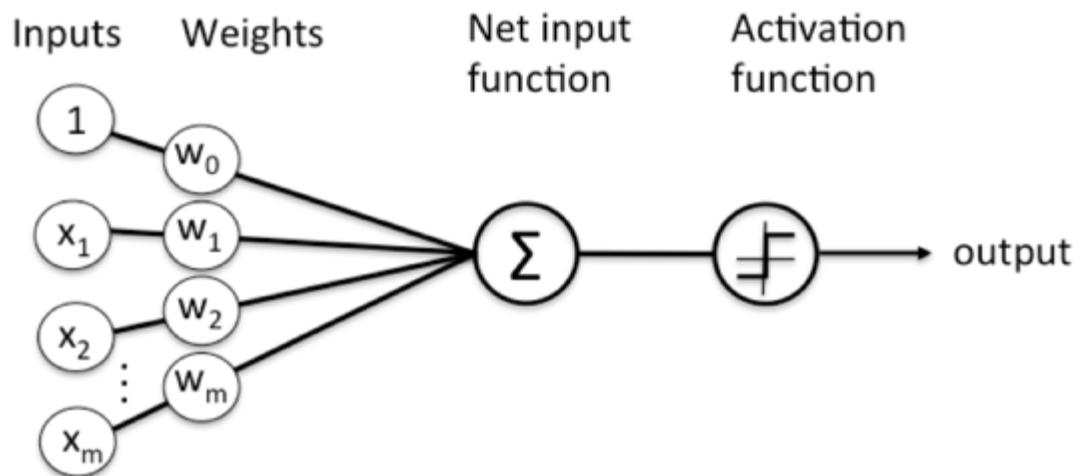
# Perceptron

- 1957: Frank Rosenblatt



# Perceptron

- 1957: Frank Rosenblatt

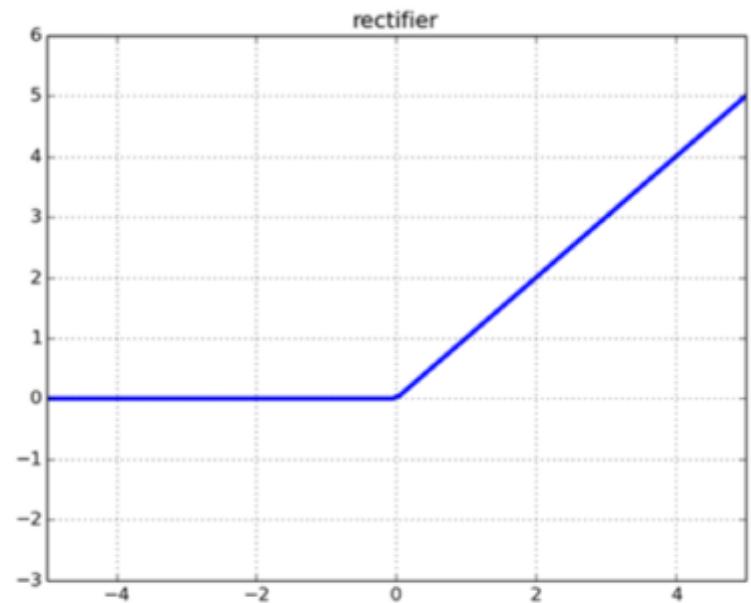
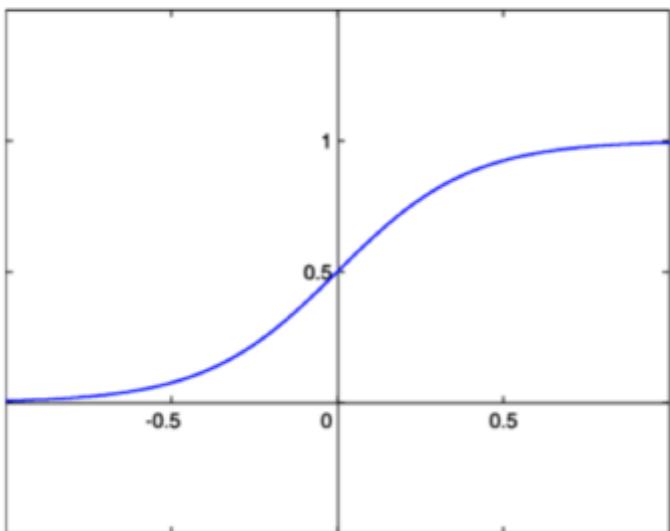


*"[The Perceptron is] the embryo of an electronic computer that [the Navy] expects will be able to walk, talk, see, write, reproduce itself and be conscious of its existence."*

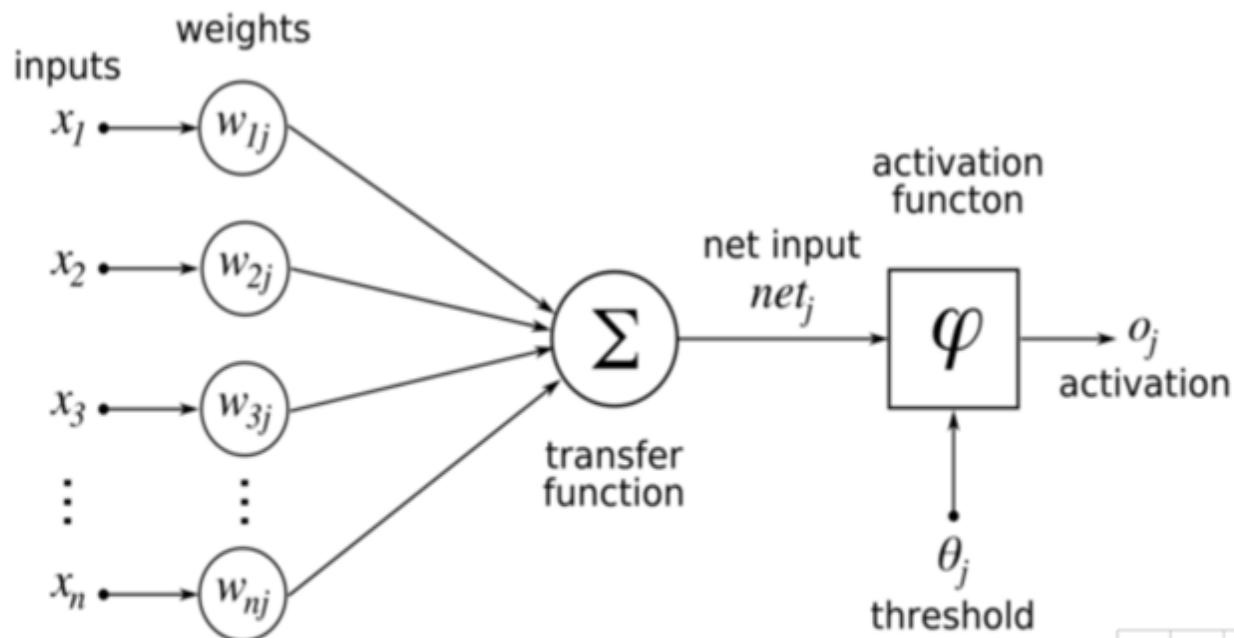
THE NEW YORK TIMES

# Funciones de Activación

- Step, tanh, sigmoid, ReLU (más reciente)

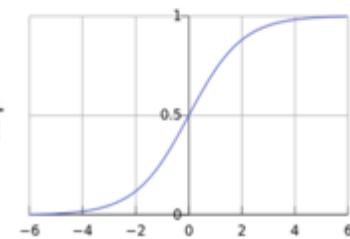


# Perceptron



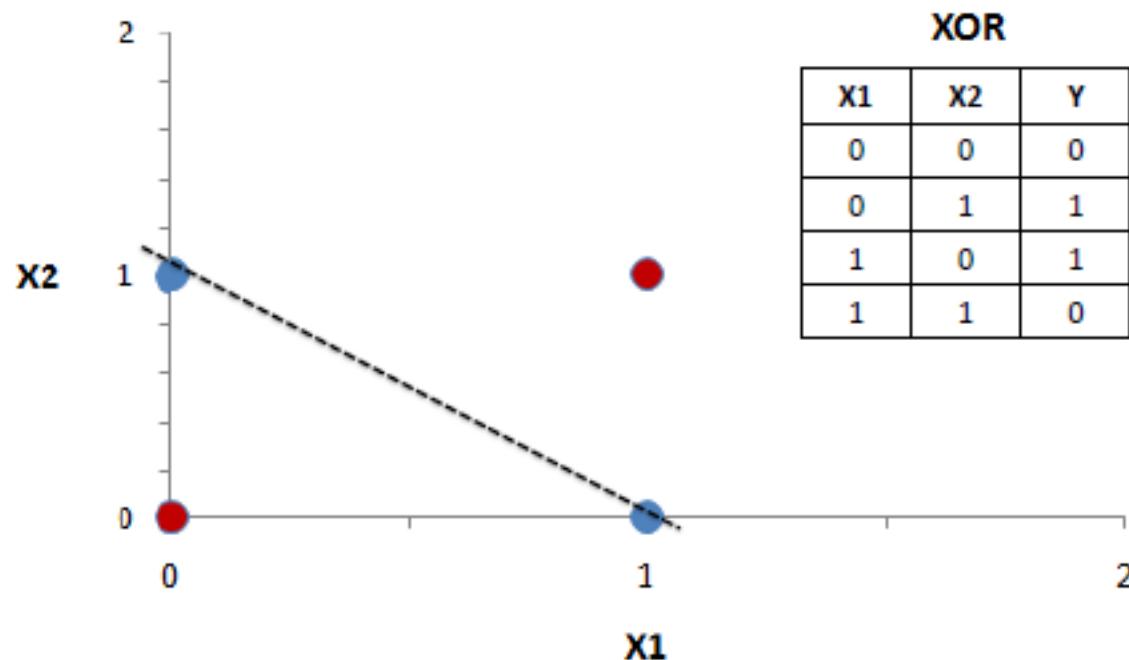
$$P(o_j = 1|x) = \phi \left( \sum_{i=1}^n w_{ij} x_i + \theta_j \right)$$

$$\phi = \frac{1}{1 + e^{-\Sigma}}$$

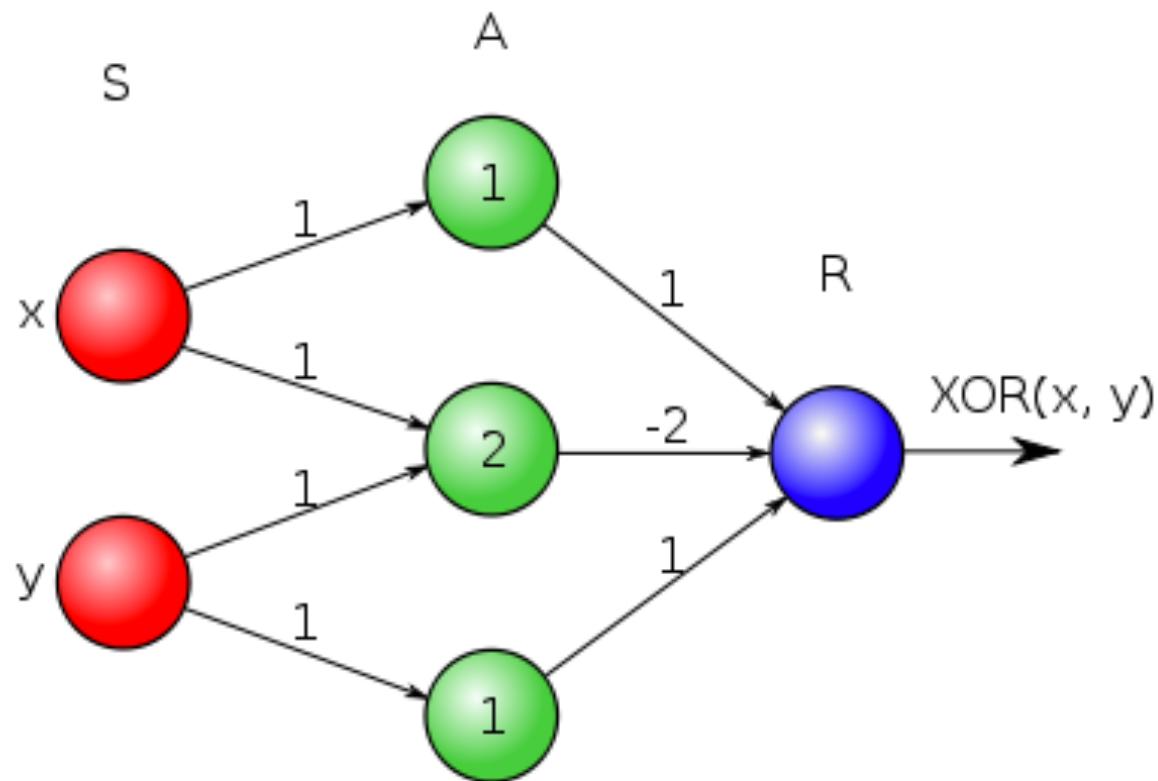


# Limitaciones del Perceptrón

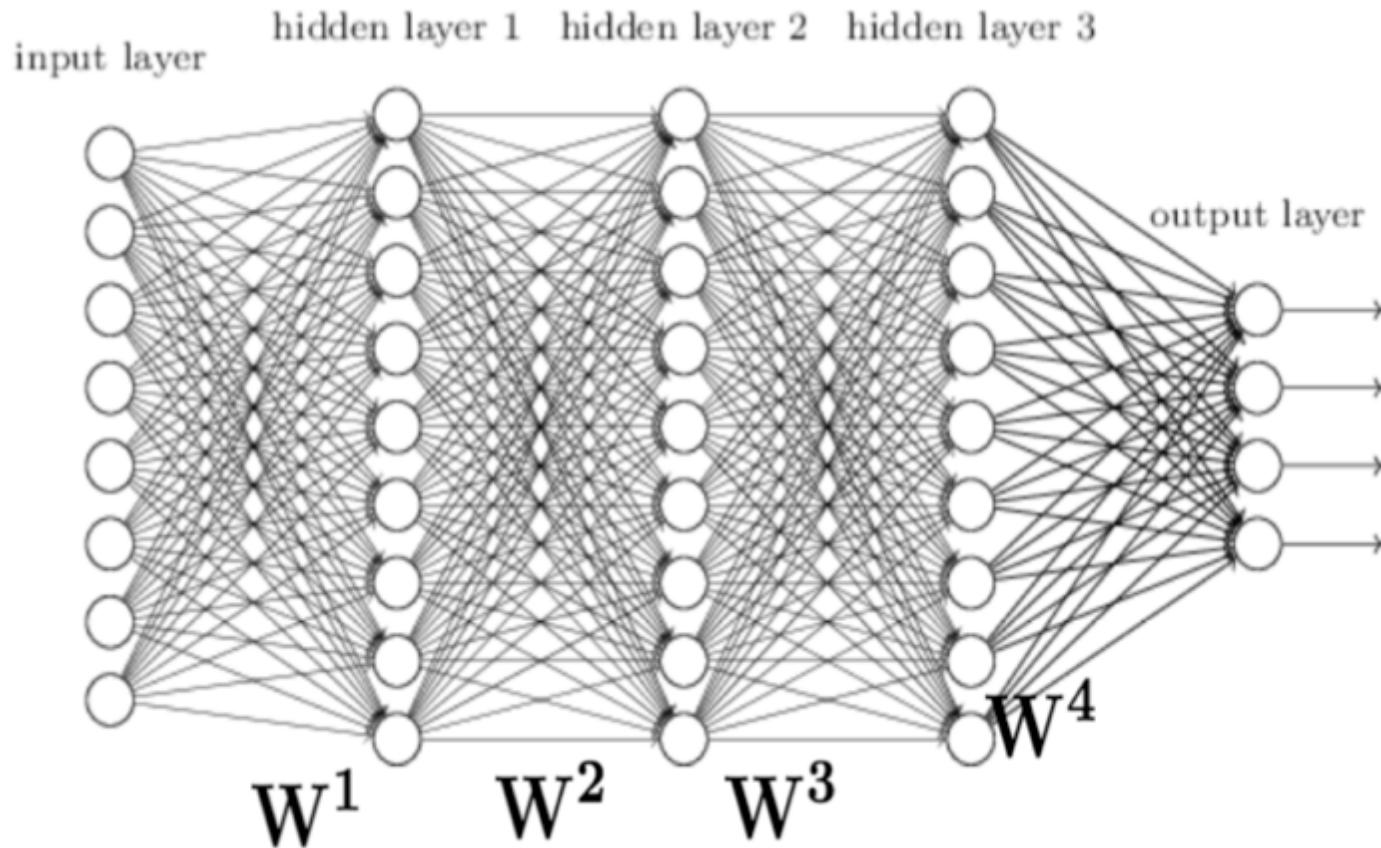
- El perceptrón de una capa es un clasificador lineal
- No puede separar algunas funciones como el XOR



# Perceptron con Hidden layers



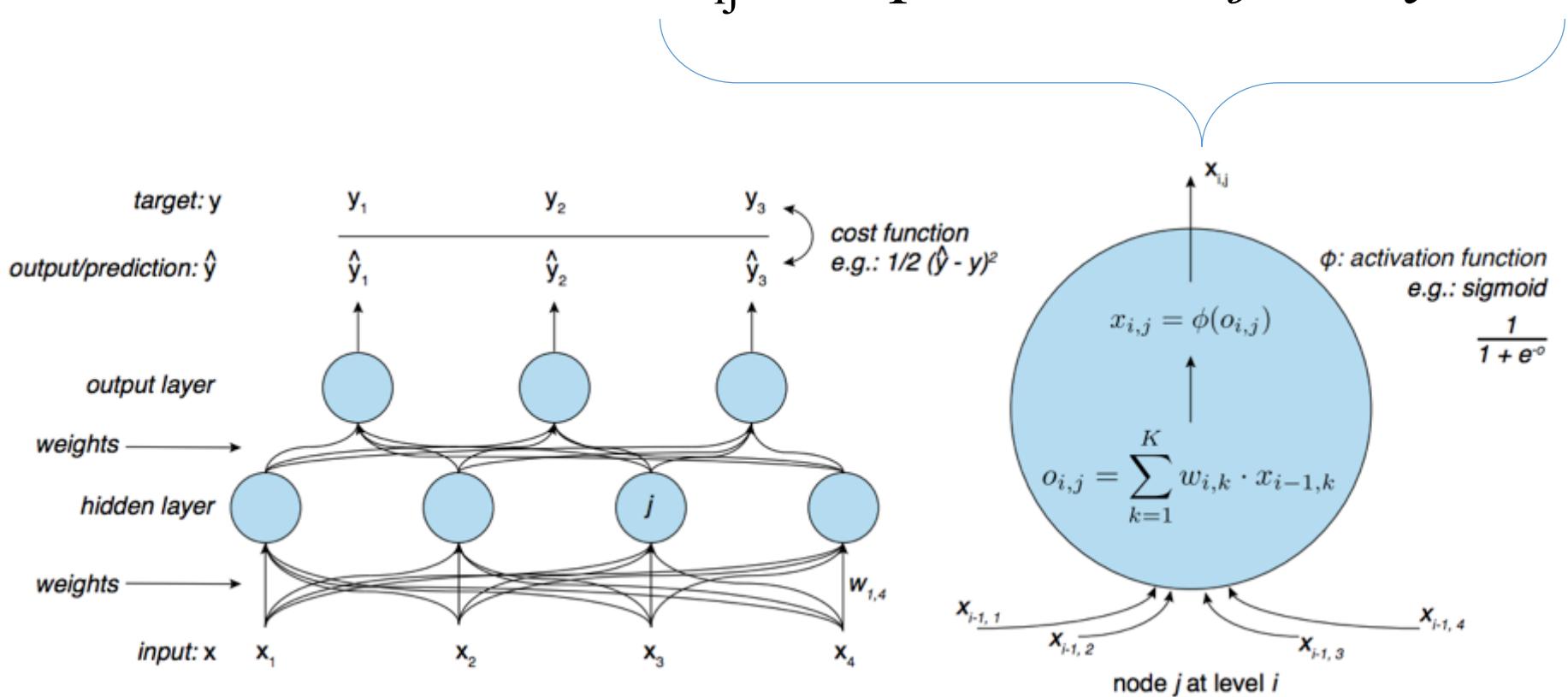
# Redes Feedforward Multilayer



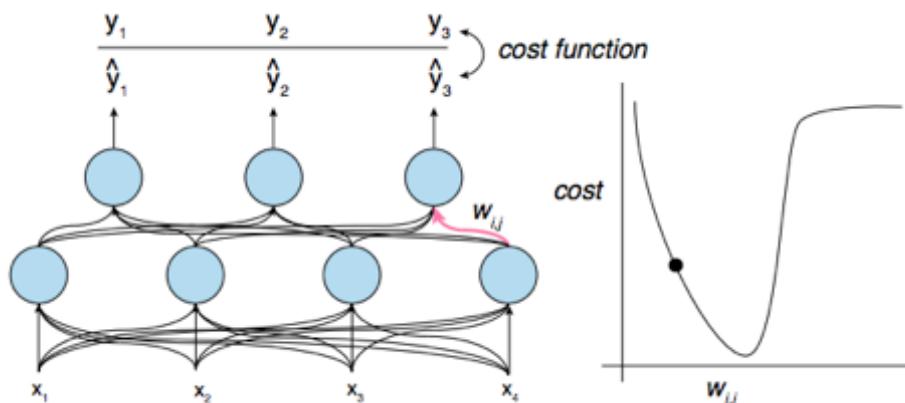
$$F(\mathbf{x}) := \sigma(\dots \mathbf{W}^2 \sigma(\mathbf{W}^1 \mathbf{x}))$$

# Backpropagation: Ejemplo

$x_{ij}$  : output of node  $j$  at layer  $i$



# Backpropagation: Ejemplo



until convergence:

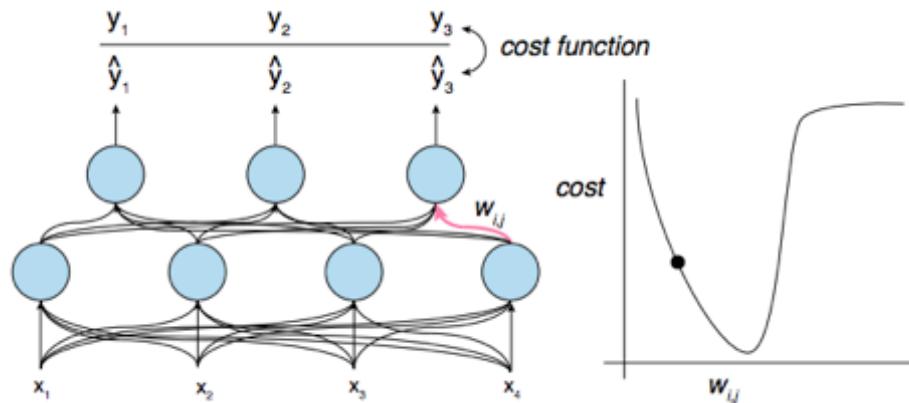
- do a forward pass
- compute the cost/error
- adjust weights ← how??

Adjust every weight  $w_{i,j}$  by:

$$\Delta w_{i,j} = -\alpha \frac{\partial \text{cost}}{\partial w_{i,j}}$$

$\alpha$  is the learning rate.

# Backpropagation: Ejemplo

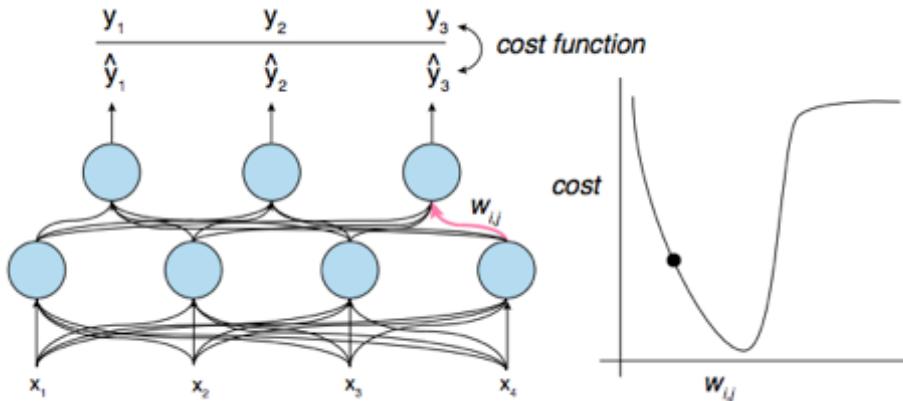


$$\begin{aligned}\Delta w_{i,j} &= -\alpha \frac{\partial \text{cost}}{\partial w_{i,j}} \\ &= -\alpha \frac{\partial \text{cost}}{\partial x_{i,j}} \frac{\partial x_{i,j}}{\partial w_{i,j}} \quad \leftarrow \text{chain rule}\end{aligned}$$

$$\text{cost}(\hat{y}, y) = \frac{1}{2}(y - \hat{y})^2$$

$$\hat{y}_j = x_{i,j} = \phi(o_{i,j})$$

# Backpropagation: Ejemplo



$$\begin{aligned}\Delta w_{i,j} &= -\alpha \frac{\partial cost}{\partial w_{i,j}} \\ &= -\alpha \frac{\partial cost}{\partial x_{i,j}} \frac{\partial x_{i,j}}{\partial w_{i,j}} \\ &= -\alpha \frac{\partial cost}{\partial x_{i,j}} \frac{\partial x_{i,j}}{\partial o_{i,j}} \frac{\partial o_{i,j}}{\partial w_{i,j}} \quad \leftarrow \text{chain rule}\end{aligned}$$

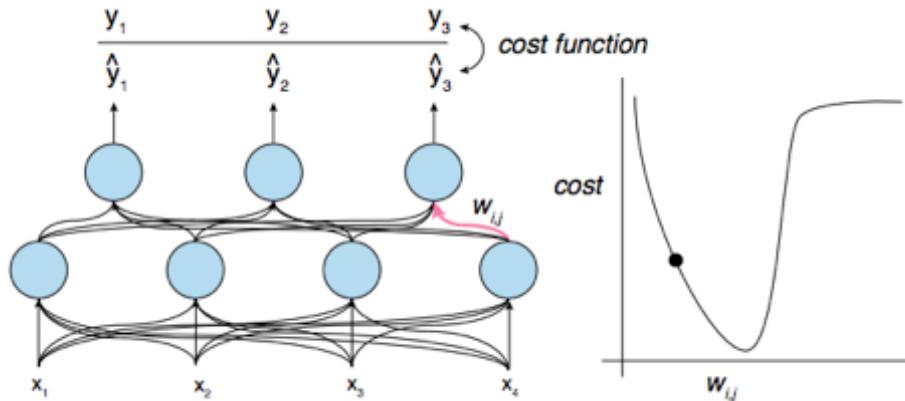
$$cost(\hat{y}, y) = \frac{1}{2}(y - \hat{y})^2$$

$$\hat{y}_j = x_{i,j} = \phi(o_{i,j}), \text{ e.g. } \sigma(o_{i,j})$$

$$x_{i,j} = \sigma(o) = \frac{1}{1 + e^{-o}}$$

$$o_{i,j} = \sum_{k=1}^K w_{i,k} \cdot x_{i-1,k}$$

# Backpropagation: Ejemplo



$$\begin{aligned}\Delta w_{i,j} &= -\alpha \frac{\partial \text{cost}}{\partial w_{i,j}} \\ &= -\alpha \frac{\partial \text{cost}}{\partial x_{i,j}} \frac{\partial x_{i,j}}{\partial w_{i,j}} \\ &= -\alpha \frac{\partial \text{cost}}{\partial x_{i,j}} \frac{\partial x_{i,j}}{\partial o_{i,j}} \frac{\partial o_{i,j}}{\partial w_{i,j}}\end{aligned}$$

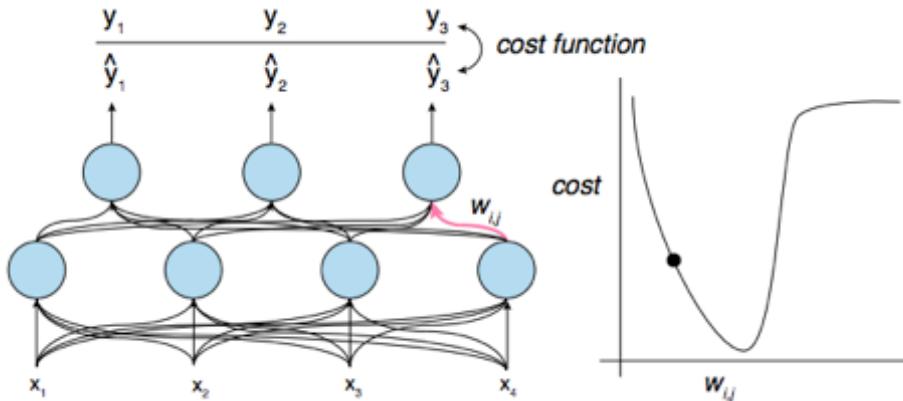
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# Backpropagation: Ejemplo



$$cost(\hat{y}, y) = \frac{1}{2}(y - \hat{y})^2$$

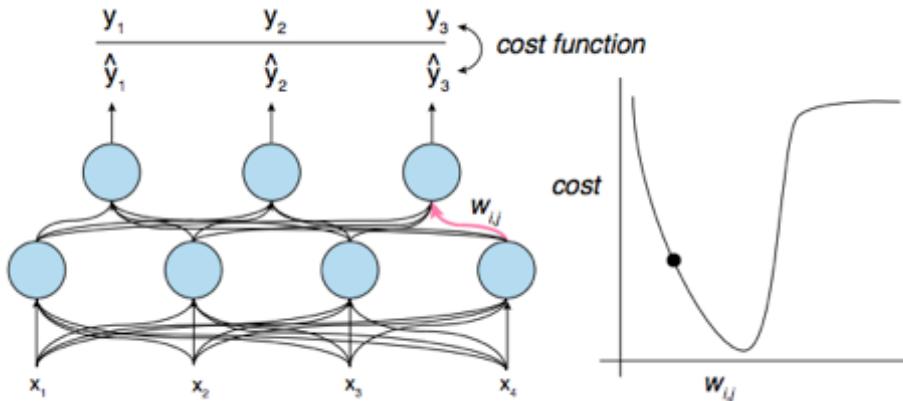
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# Backpropagation: Ejemplo



$$cost(\hat{y}, y) = \frac{1}{2}(y - \hat{y})^2$$

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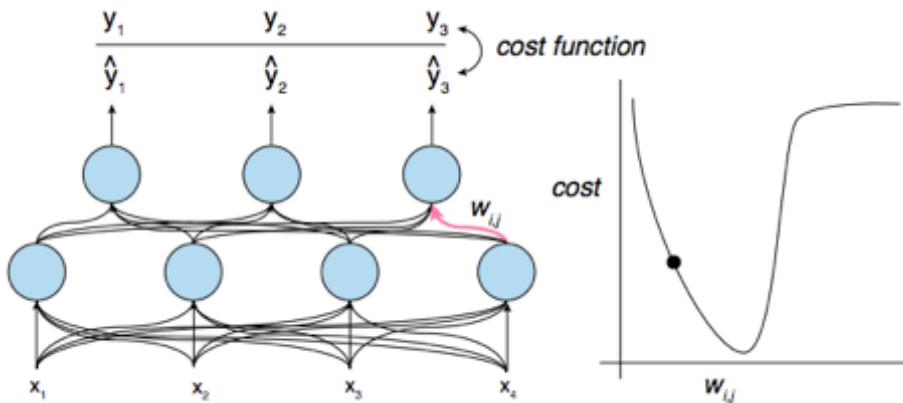
$$x_{i,j} = \sigma(o) = \frac{1}{1 + e^{-o}}$$

$$\boxed{\sigma'(o) = \sigma(o)(1 - \sigma(o))}$$

$$o_{i,j} = \sum_{k=1}^K w_{i,k} \cdot x_{i-1,k}$$

$$\begin{aligned}
 \Delta w_{i,j} &= -\alpha \frac{\partial cost}{\partial w_{i,j}} \\
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 &= -\alpha \frac{\partial cost}{\partial x_{i,j}} \frac{\partial x_{i,j}}{\partial o_{i,j}} \frac{\partial o_{i,j}}{\partial w_{i,j}} \\
 &= -\alpha \frac{\partial cost}{\partial x_{i,j}} \boxed{x_{i,j}(1 - x_{i,j})} \quad \textcolor{red}{x_{i-1,j}}
 \end{aligned}$$

# Backpropagation: Ejemplo



$$cost(\hat{y}, y) = \frac{1}{2}(y - \hat{y})^2$$

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$$x_{i,j} = \sigma(o) = \frac{1}{1 + e^{-o}}$$

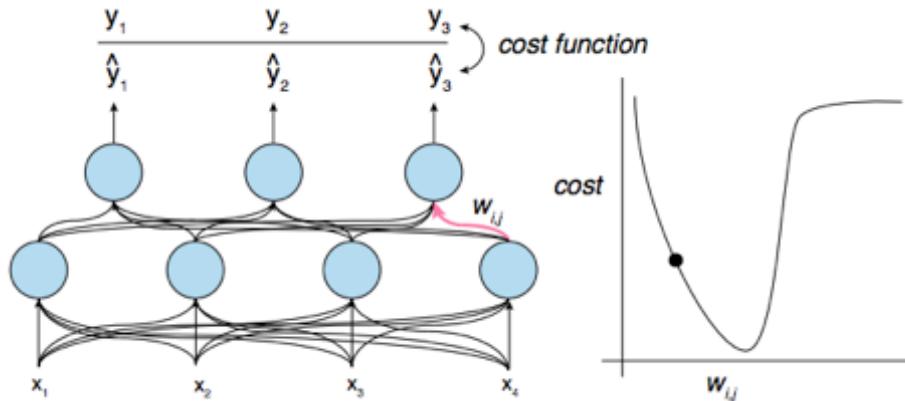
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# Backpropagation: Ejemplo



$$cost(\hat{y}, y) = \frac{1}{2}(y - \hat{y})^2$$

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$$x_{i,j} = \sigma(o) = \frac{1}{1 + e^{-o}}$$

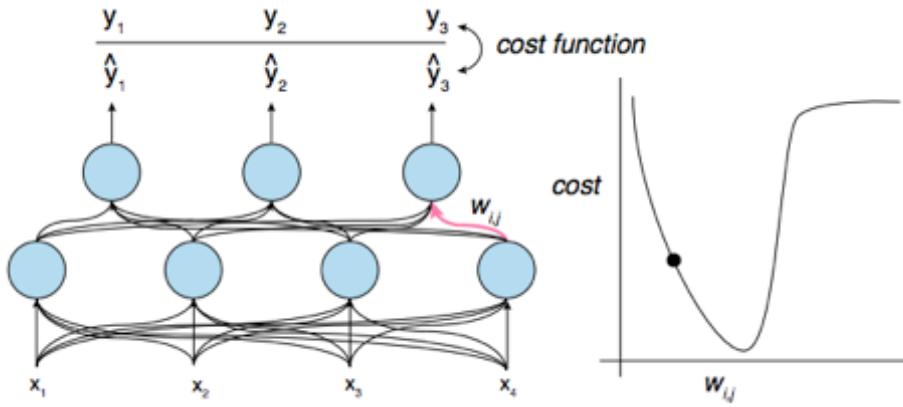
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$$\begin{aligned}g'_{\text{logistic}}(z) &= \frac{\partial}{\partial z} \left( \frac{1}{1+e^{-z}} \right) \\ &= \frac{e^{-z}}{(1+e^{-z})^2} \text{ (chain rule)} \\ &= \frac{1+e^{-z}-1}{(1+e^{-z})^2} \\ &= \frac{1+e^{-z}}{(1+e^{-z})^2} - \left( \frac{1}{1+e^{-z}} \right)^2 \\ &= \frac{1}{(1+e^{-z})} - \left( \frac{1}{1+e^{-z}} \right)^2 \\ &= g_{\text{logistic}}(z) - g_{\text{logistic}}(z)^2 \\ &= g_{\text{logistic}}(z)(1 - g_{\text{logistic}}(z))\end{aligned}$$

# Backpropagation: Ejemplo



$$\begin{aligned}
 \Delta w_{i,j} &= -\alpha \frac{\partial \text{cost}}{\partial w_{i,j}} \\
 &= -\alpha \frac{\partial \text{cost}}{\partial x_{i,j}} \frac{\partial x_{i,j}}{\partial w_{i,j}} \\
 &= -\alpha \frac{\partial \text{cost}}{\partial x_{i,j}} \frac{\partial x_{i,j}}{\partial o_{i,j}} \frac{\partial o_{i,j}}{\partial w_{i,j}} \\
 &= -\alpha \boxed{y_j - x_{i,j}} x_{i,j} (1 - x_{i,j}) \quad \boxed{x_{i-1,j}}
 \end{aligned}$$

$$\text{cost}(\hat{y}, y) = \frac{1}{2}(y - \hat{y})^2$$

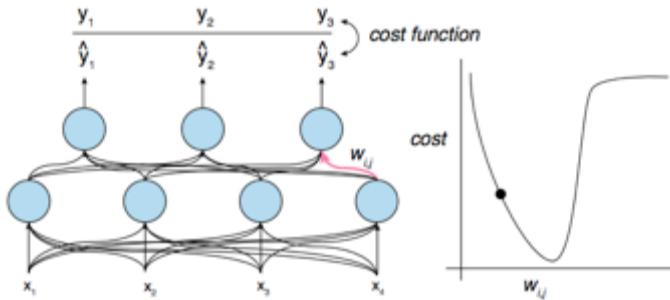
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$$\sigma'(o) = \sigma(o)(1 - \sigma(o))$$

$$o_{i,j} = \sum_{k=1}^K w_{i,k} \cdot x_{i-1,k}$$

# Backpropagation: Ejemplo



$$cost(\hat{y}, y) = \frac{1}{2}(y - \hat{y})^2$$

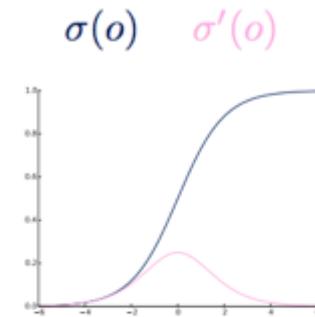
$$\hat{y}_j = x_{i,j} = \phi(o_{i,j}), \text{ e.g. } \sigma(o_{i,j})$$

$$x_{i,j} = \sigma(o) = \frac{1}{1 + e^{-o}}$$

$$\sigma'(o) = \sigma(o)(1 - \sigma(o))$$

$$o_{i,j} = \sum_{k=1}^K w_{i,k} \cdot x_{i-1,k}$$

$$\begin{aligned}
 \Delta w_{i,j} &= -\alpha \frac{\partial cost}{\partial w_{i,j}} \\
 &= -\alpha \frac{\partial cost}{\partial x_{i,j}} \frac{\partial x_{i,j}}{\partial w_{i,j}} \\
 &= -\alpha \frac{\partial cost}{\partial x_{i,j}} \frac{\partial x_{i,j}}{\partial o_{i,j}} \frac{\partial o_{i,j}}{\partial w_{i,j}} \\
 &= -\alpha \frac{y_j - x_{i,j}}{2} x_{i,j}(1 - x_{i,j}) x_{i-1,j} \\
 &= \text{l.rate } cost \quad activation \quad input
 \end{aligned}$$



# Backpropagation: Ejemplo

$$\Delta w_{i,j} = -\alpha \frac{\partial cost}{\partial w_{i,j}}$$

$$= -\alpha \frac{\partial cost}{\partial x_{i,j}} \frac{\partial x_{i,j}}{\partial o_{i,j}} \frac{\partial o_{i,j}}{\partial w_{i,j}}$$

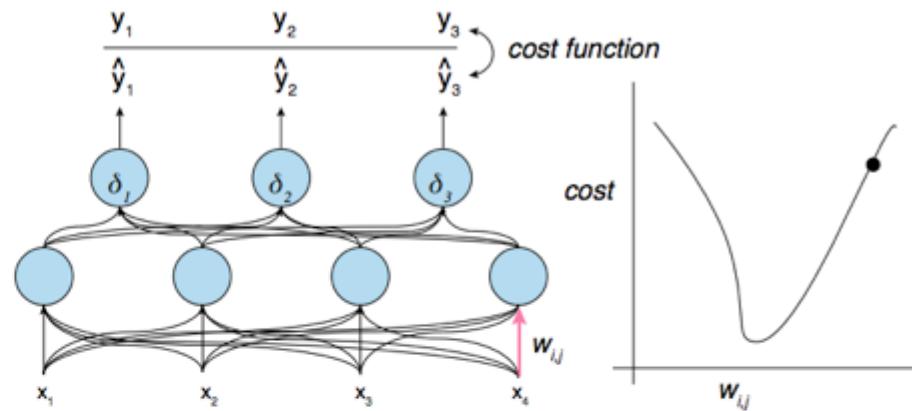
= l.rate *cost activation input*

$$= -\alpha \frac{\partial cost}{\partial x_{i,j}} \frac{\partial x_{i,j}}{\partial o_{i,j}} \frac{\partial o_{i,j}}{\partial w_{i,j}}$$

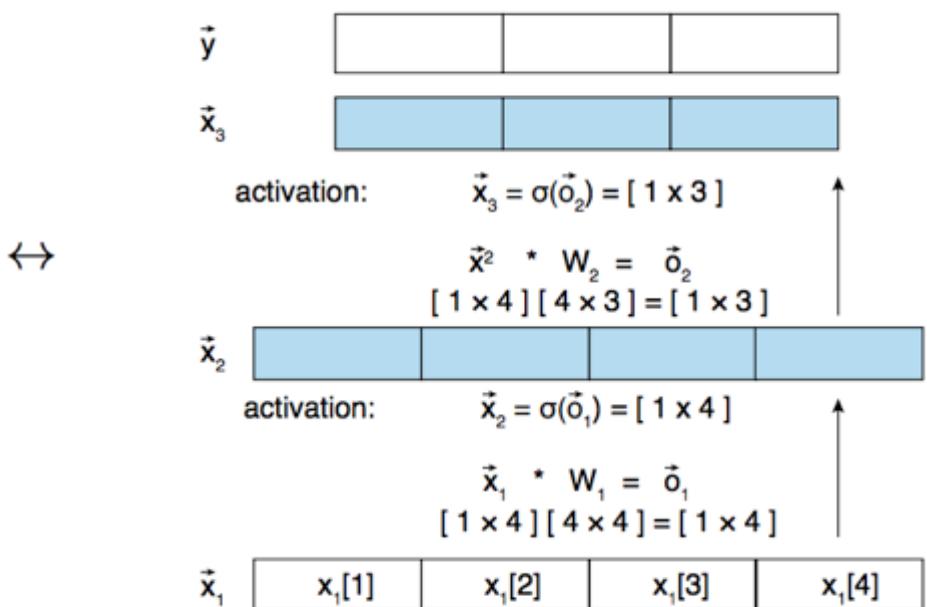
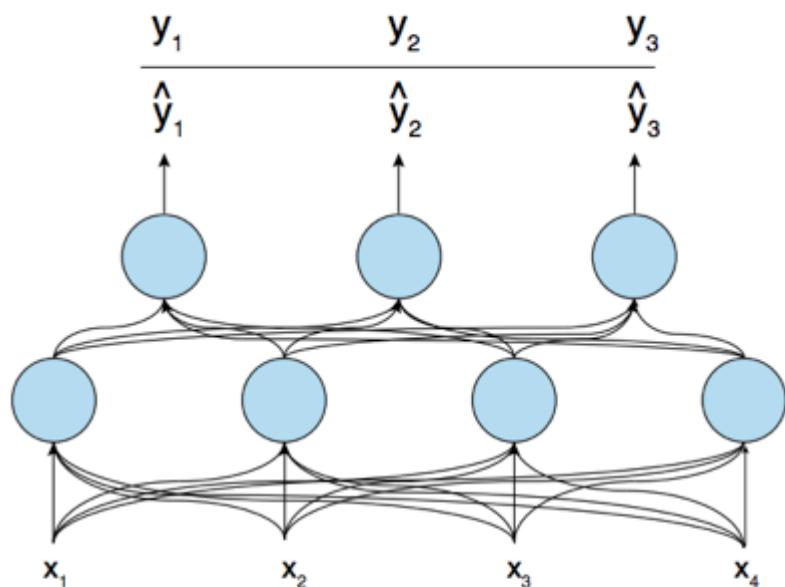
$$= -\alpha \delta_{x_{i-1,j}}$$

$$\delta_{output} = (y_j - x_{i,j}) x_{i,j}(1 - x_{i,j}) \quad \leftarrow \text{previous slide}$$

$$\delta_{hidden} = \left( \sum_{n \in nodes} \delta_n w_{n,j} \right) x_{i,j}(1 - x_{i,j})$$



# Feedforward



# Ahora les puedo contar este chiste...

## Basic Math

$$\begin{pmatrix} A_{11} & A_{12} & \cdots & A_{1m} \\ A_{21} & A_{22} & \cdots & A_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ A_{n1} & A_{n2} & \cdots & A_{nm} \end{pmatrix}$$

## Dangerous Artificial Intelligence

$$\begin{pmatrix} A_{11} & A_{12} & \cdots & A_{1m} \\ A_{21} & A_{22} & \cdots & A_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ A_{n1} & A_{n2} & \cdots & A_{nm} \end{pmatrix} * \begin{pmatrix} A_{11} & A_{12} & \cdots & A_{1m} \\ A_{21} & A_{22} & \cdots & A_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ A_{n1} & A_{n2} & \cdots & A_{nm} \end{pmatrix} * \begin{pmatrix} A_{11} & A_{12} & \cdots & A_{1m} \\ A_{21} & A_{22} & \cdots & A_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ A_{n1} & A_{n2} & \cdots & A_{nm} \end{pmatrix} * \begin{pmatrix} A_{11} & A_{12} & \cdots & A_{1m} \\ A_{21} & A_{22} & \cdots & A_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ A_{n1} & A_{n2} & \cdots & A_{nm} \end{pmatrix}$$

# Ahora les puedo contar este chiste...

## Basic Math

$$\begin{pmatrix} A_{11} & A_{12} & \cdots & A_{1m} \\ A_{21} & A_{22} & \cdots & A_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ A_{n1} & A_{n2} & \cdots & A_{nm} \end{pmatrix}$$

## Dangerous Artificial Intelligence

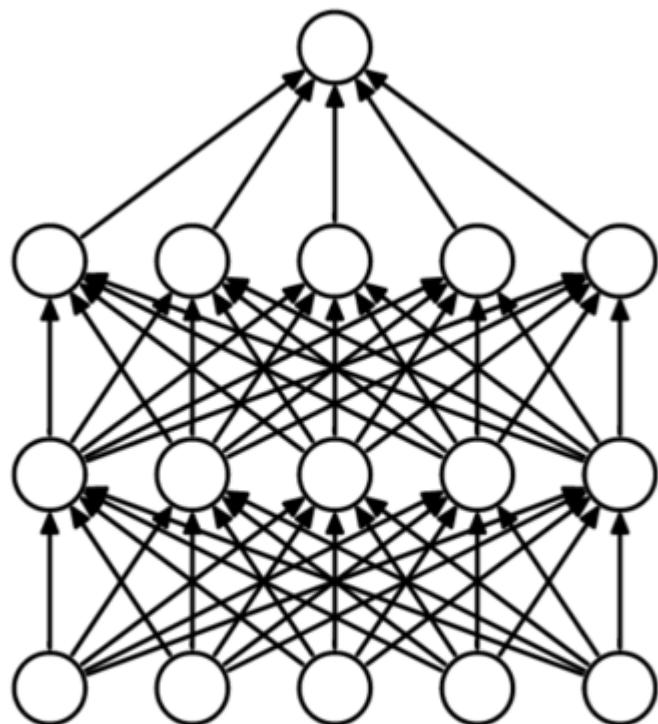
$$\begin{pmatrix} A_{11} & A_{12} & \cdots & A_{1m} \\ A_{21} & A_{22} & \cdots & A_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ A_{n1} & A_{n2} & \cdots & A_{nm} \end{pmatrix} * \begin{pmatrix} A_{11} & A_{12} & \cdots & A_{1m} \\ A_{21} & A_{22} & \cdots & A_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ A_{n1} & A_{n2} & \cdots & A_{nm} \end{pmatrix} * \begin{pmatrix} A_{11} & A_{12} & \cdots & A_{1m} \\ A_{21} & A_{22} & \cdots & A_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ A_{n1} & A_{n2} & \cdots & A_{nm} \end{pmatrix} * \begin{pmatrix} A_{11} & A_{12} & \cdots & A_{1m} \\ A_{21} & A_{22} & \cdots & A_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ A_{n1} & A_{n2} & \cdots & A_{nm} \end{pmatrix}$$



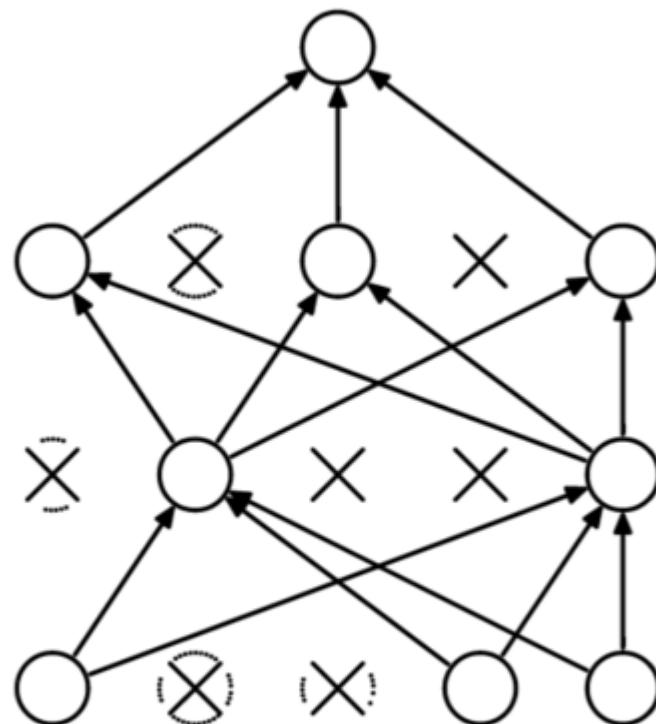
# Otras Arquitecturas y $F(x)$ s

- Dropout
- RLUs
- Autoencoders
- CNN
- RNN

# Dropout



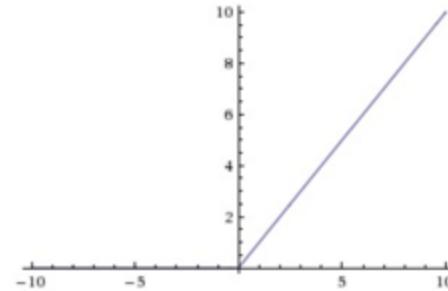
(a) Standard Neural Net



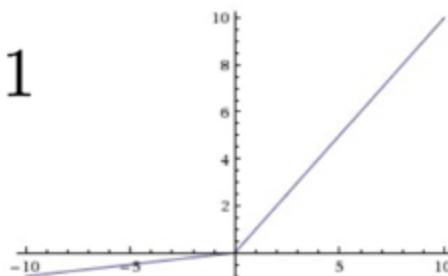
(b) After applying dropout.

# Nuevas Rectified Linear Units

$$\sigma(x) = \max(0, x)$$

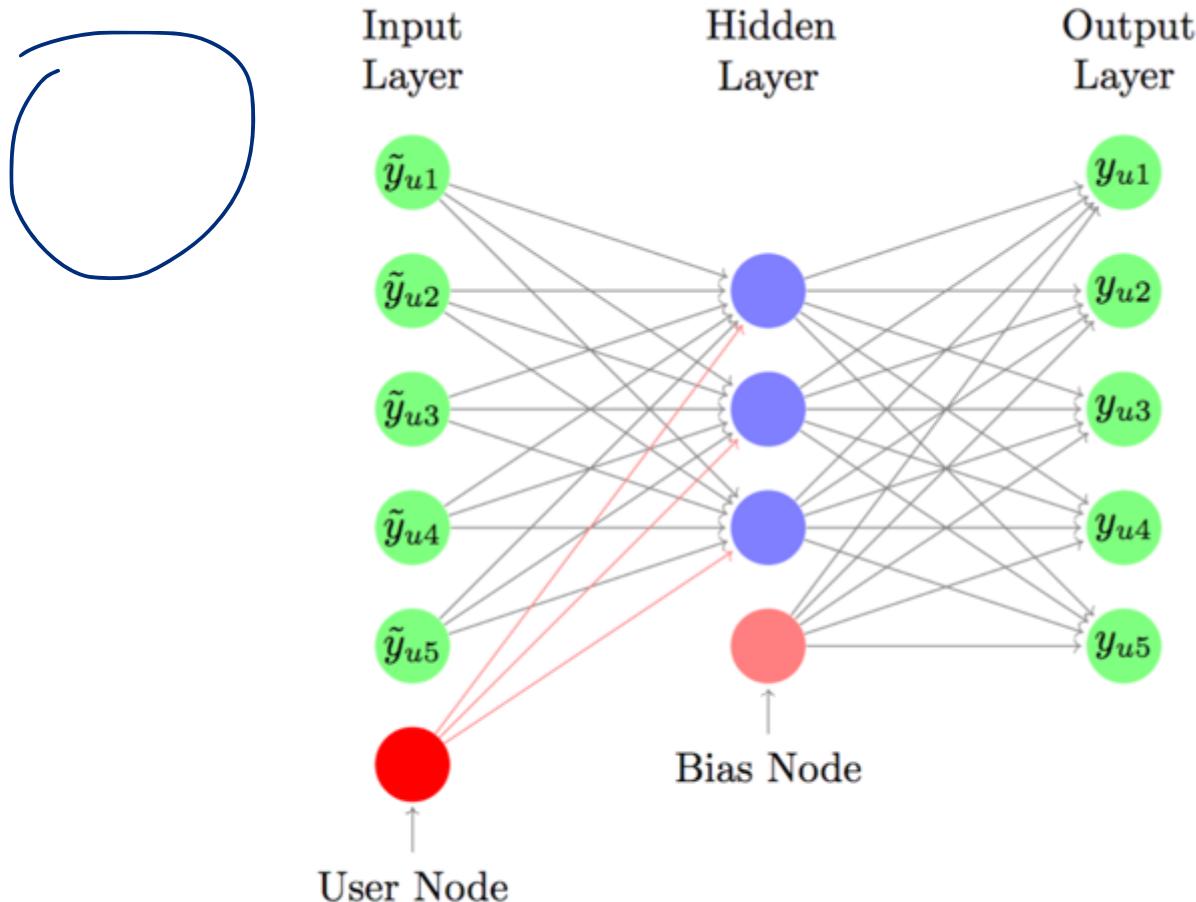


$$\sigma(x) = \max(\alpha x, x) \quad \alpha < 1$$



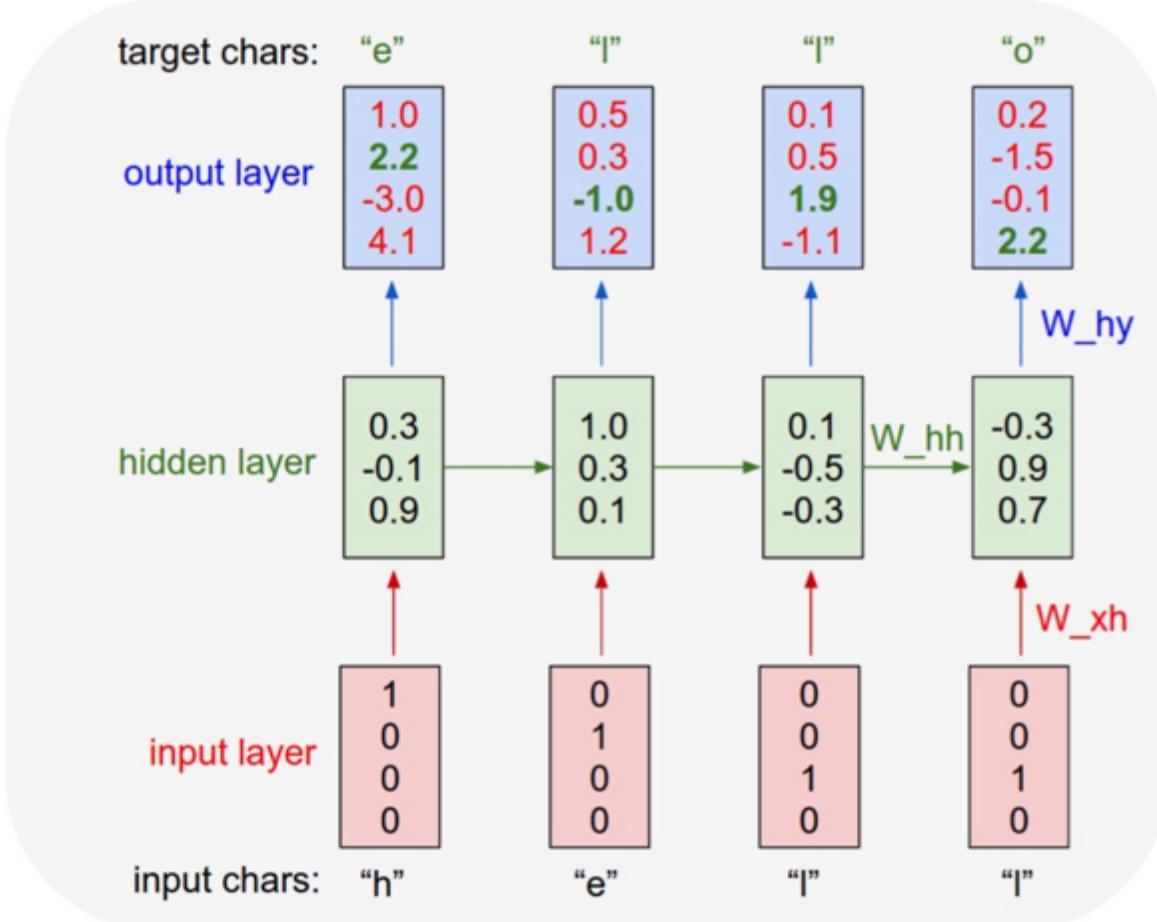
Neuron	MNIST	CIFAR10	NISTP	NORB
<i>Without unsupervised pre-training</i>				
Rectifier	<b>1.43%</b>	<b>50.86%</b>	<b>32.64%</b>	<b>16.40%</b>
Tanh	1.57%	52.62%	36.46%	19.29%
Softplus	1.77%	53.20%	35.48%	17.68%

# Autoencoders



Collaborative Denoising Auto-Encoders for Top-N Recommender Systems Wu et.al. WSDM 2016

# RNN



# Question Answering via RNN

Figure 3: An example story with questions correctly answered by a MemNN. The MemNN was trained on the simulation described in Section 5.2 and had never seen many of these words before, e.g., Bilbo, Frodo and Gollum.

Bilbo travelled to the cave. Gollum dropped the ring there. Bilbo took the ring.  
Bilbo went back to the Shire. Bilbo left the ring there. Frodo got the ring.  
Frodo journeyed to Mount-Doom. Frodo dropped the ring there. Sauron died.  
Frodo went back to the Shire. Bilbo travelled to the Grey-havens. The End.  
Where is the ring? A: Mount-Doom  
Where is Bilbo now? A: Grey-havens  
Where is Frodo now? A: Shire

# Herramientas

- TensorFlow: Python Library (sponsored by Google)
- Pytorch: (sponsored by Facebook)
- Keras: High Level Python Library (Theano & TF as low-level library)
- MXNET: R, Python, Julia
- Theano: Python Library (descontinuada)

# Deep Learning en RecSys

- ¿Cómo se ha usado Deep Learning en RecSys?
- ¿Es este método mejor que Factorización Matricial y otros métods bien establecidos?

# 3 Ejemplos de Deep Learning en ACM RecSys

- ***Ask the GRU: Multi-task Learning for Deep Text Recommendations.*** Trapit Bansal, David Belanger, and Andrew McCallum. 2016
- Este paper usa RNN (redes neuronales recurrentes) con GRUs (gated recurrent units)
- Lo presentaré en Octubre

# Paper 2

- **Meta-Prod2Vec: Product Embeddings Using Side-Information for Recommendation.** Flavian Vasile, Elena Smirnova, and Alexis Conneau. 2016.

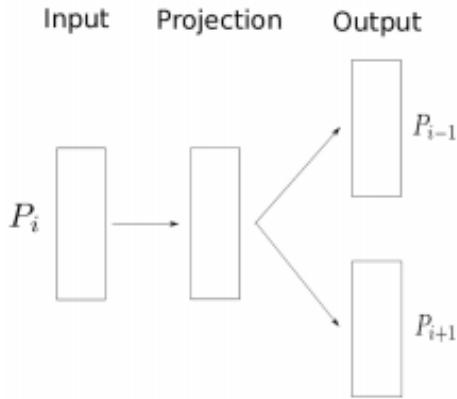


Figure 1: Prod2Vec Neural Net Architecture.

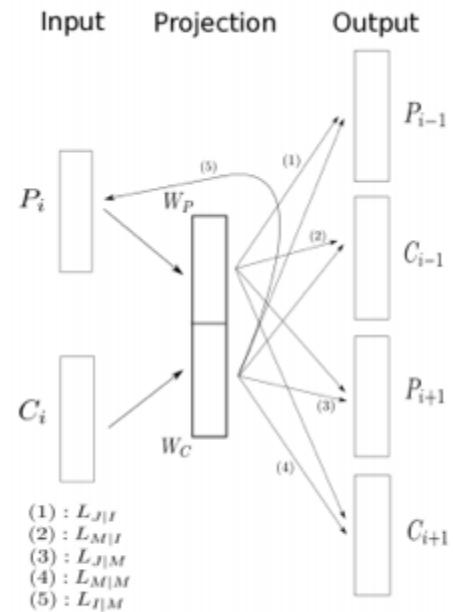
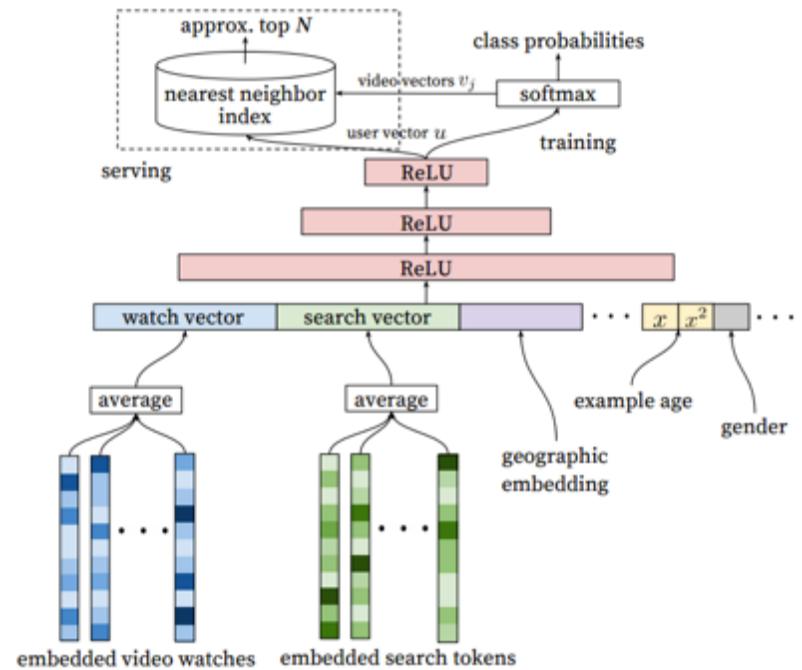


Figure 2: Meta-Prod2Vec Neural Net Architecture.

# Paper 3

- **Deep Neural Networks for YouTube Recommendations.** Paul Covington, Jay Adams, and Emre Sargin. 2016



¿Es mejor que otros métodos De RecSys?

# ¿Es **major** que otros métodos De RecSys?

## **Are We Really Making Much Progress? A Worrying Analysis of Recent Neural Recommendation Approaches**

Maurizio Ferrari Dacrema  
Politecnico di Milano, Italy  
[maurizio.ferrari@polimi.it](mailto:maurizio.ferrari@polimi.it)

Paolo Cremonesi  
Politecnico di Milano, Italy  
[paolo.cremonesi@polimi.it](mailto:paolo.cremonesi@polimi.it)

Dietmar Jannach  
University of Klagenfurt, Austria  
[dietmar.jannach@aau.at](mailto:dietmar.jannach@aau.at)

- Ferrari, M., Cremonesi, P., & Jannach, D. (2019). Are we really making much progress? A worrying analysis of recent neural recommendation approaches. In Proceedings of the ACM Conference on Recommender Systems

# RecSys Deep Learning

- El artículo de Ferrari et al. compara varios métodos en diferentes datasets y bajo las mismas condiciones con otros métodos estado del arte:
  - Neural Collaborative Filtering
  - Collaborative Deep Learning
  - Collaborative Variational Autoencoder for Recommender Systems
  - Variational Autoencoders for Collaborative Filtering

# RecSys Deep Learning CF

- El artículo de Ferrari et al. compara varios métodos en diferentes datasets y bajo las mismas condiciones con otros métodos estado del arte:
  - Neural Collaborative Filtering
  - Collaborative Deep Learning
  - Collaborative Variational Autoencoder for Recommender Systems
  - **Variational Autoencoders for Collaborative Filtering -> Sólo este método lograba vencer consistentemente al resto en diferentes datasets y settings (y por eso fue el que vieron en la ayudantía de ayer)**

# RecSys Deep Learning

- He, X., Liao, L., Zhang, H., Nie, L., Hu, X., & Chua, T. S. (2017). Neural collaborative filtering. In Proceedings of the 26th international conference on world wide web (pp. 173-182).

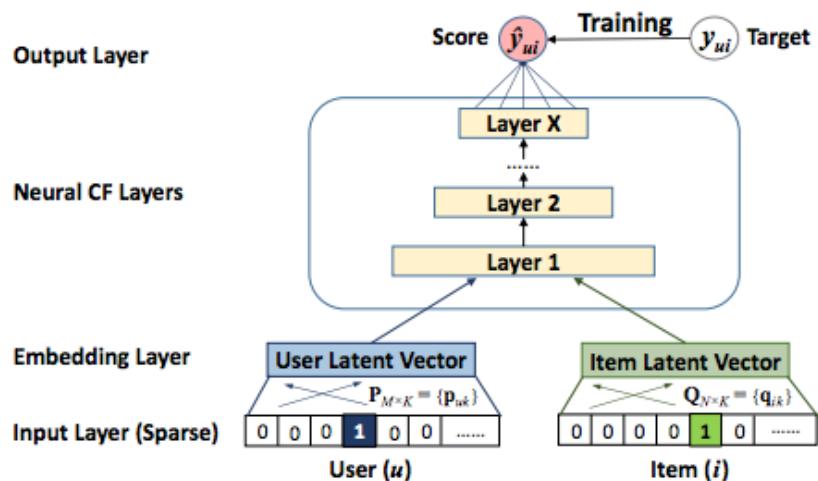


Figure 2: Neural collaborative filtering framework

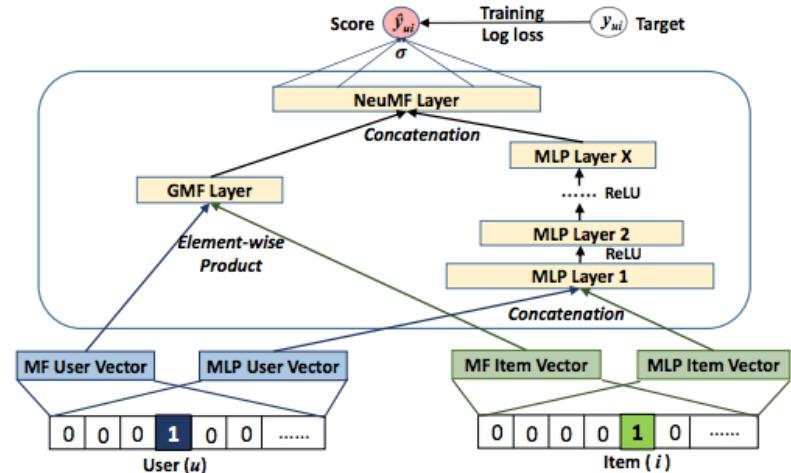


Figure 3: Neural matrix factorization model

# Thanks!

dparra@ing.puc.cl



# Meta-Prod2Vec

- Basado en Word2Vec, donde la función objetivo del embedding se acerca a Shifted Positive PMI (SPMI)

$$PMI_{ij} = \log \left( \frac{X_{ij} \cdot |D|}{X_i X_j} \right)$$

$$SPMI_{ij} = PMI(i, j) - \log k$$

$$\begin{aligned} L_{\text{P2V}} &= L_{J|I}(\theta) \\ &= \sum_{ij} (-X_{ij}^{\text{POS}} \log q_{j|i}(\theta) - (X_i - X_{ij}^{\text{POS}}) \log(1 - q_{j|i}(\theta))) \\ &= \sum_{ij} X_i (-p_{j|i} \log q_{j|i}(\theta) - p_{\neg j|i} \log q_{\neg j|i}(\theta)) \\ &= \sum_i X_i H(p_{\cdot|i}, q_{\cdot|i}(\theta)). \end{aligned}$$

- Función de pérdida Meta-Prod2Vec

$$L_{MP2V} = L_{J|I} + \lambda \times (L_{M|I} + L_{J|M} + L_{M|M} + L_{I|M})$$

# Meta-Prod2Vec

- Resultados

Method	HR@10	NDCG@10	HR@20	NDCG@20
BestOf	0.0003 (0.0002;0.0003)	0.001 (0.001;0.001)	0.0003 (0.0002;0.0003)	0.002 (0.002;0.002)
CoCounts	0.0248 (0.0245;0.0251)	0.122 (0.121;0.123)	0.0160 (0.0158;0.0161)	0.141 (0.139;0.142)
Prod2Vec	0.0170 (0.0168;0.0171)	0.105 (0.103;0.106)	0.0101 (0.0100;0.0102)	0.113 (0.112;0.115)
Meta-Prod2Vec	0.0191 (0.0189;0.0194)	0.110 (0.108;0.113)	0.0124 (0.0123;0.0126)	0.125 (0.123;0.126)
Mix(Prod2Vec,CoCounts)	0.0273 (0.027;0.0276)	0.140 (0.139;0.141)	0.0158 (0.0157;0.0160)	0.152 (0.151;0.153)
Mix(Meta-Prod2Vec,CoCounts)	<b>0.0292</b> (0.0288;0.0297)	<b>0.144</b> (0.142;0.145)	<b>0.0180</b> (0.0178;0.0182)	<b>0.161</b> (0.160;0.162)

Table 1: Comparison of recommendation performance of Meta-Prod2Vec and competing models in terms of HitRate and NDCG.

Method	Pair freq=0	Pair freq<3
BestOf	0.0002	0.0002
CoCounts	0.0000	0.0197
Prod2Vec	0.0003	0.0078
Meta-Prod2Vec	<b>0.0013</b>	0.0198
Mix(Prod2Vec,CoCounts)	0.0002	0.0200
Mix(Meta-Prod2Vec,CoCounts)	0.0007	<b>0.0291</b>

Table 2: Recommendation accuracy (HR@20) in cold-start regime as a function of training frequency of the pair (*query item, next item*).

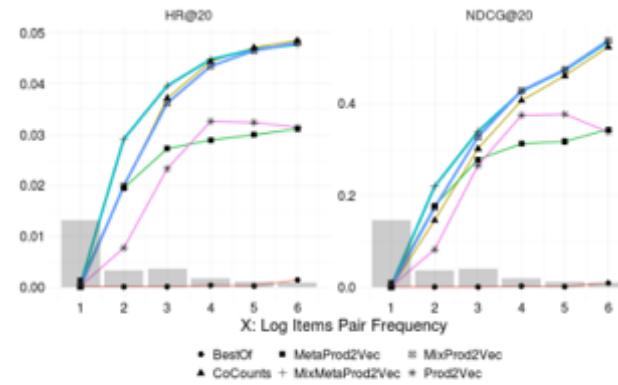


Figure 4: Cold-start improvements on the query and next item pairs.

# Ask the GRU...

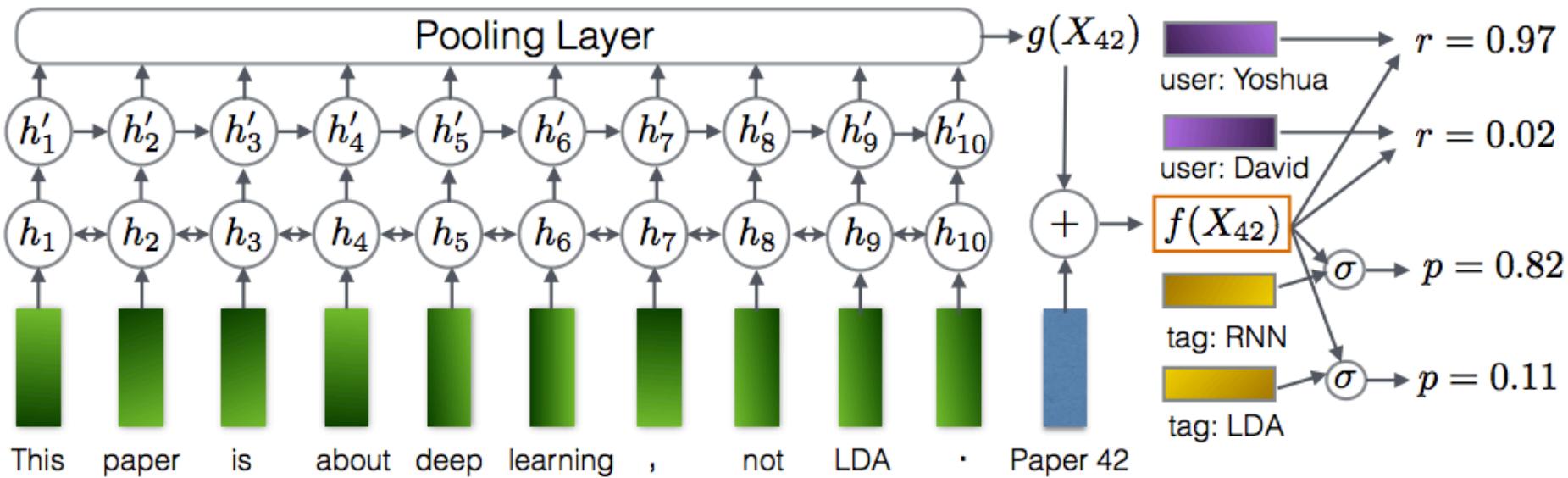


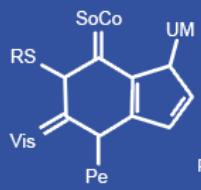
Figure 1: Proposed architecture for text item recommendation. Rectangular boxes represent embeddings. Two layers of RNN with GRU are used, where the first layer is a bi-directional RNN. The output of all the hidden units at the second layer is pooled to produce a text encoding which is combined with an item-specific embedding to produce the final representation  $f(X)$ . Users and tags are also represented by embeddings, which are combined with the item representation to do tag prediction and recommendation.

# Ask the GRU ...

- Citeulike-a consists of 5551 users, 16980 papers and 3629 tags with a total of 204,987 user-item likes.
- Citeulike-t [5] consists of 5219 users, 25975 papers and 4222 tags with a total of 134,860 user-item likes.
- Note Citeulike-t is much more sparse (99.90%) than Citeulike-a (99.78%).

**Table 1: % Recall@50 for all the methods (higher is better).**

	Citeulike-a			Citeulike-t		
	Warm Start	Cold Start	Tag Prediction	Warm Start	Cold Start	Tag Prediction
GRU-MTL	<b>38.33</b>	<b>49.76</b>	<b>60.52</b>	45.60	<b>51.22</b>	<b>62.32</b>
GRU	36.87	46.16	—	42.59	47.59	—
CTR-MTL	35.51	39.87	48.95	<b>46.82</b>	34.98	46.66
CTR	31.10	39.00	—	40.44	33.74	—
Embed-MTL	36.64	41.71	60.36	43.02	38.16	62.29
Embed	33.95	38.53	—	37.98	35.85	—



SoCVis

PUC SOCIAL COMPUTING & VISUALIZATION GROUP



# Transfer Big Data Learning to Smaller Artwork Recommender System

Pablo Messina & Vicente Dominguez, Master Students

Denis Parra, Assistant Professor

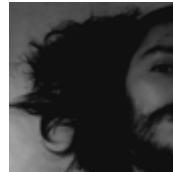
CS Department

School of Engineering

Pontificia Universidad Católica de Chile

# All people involved (apart from me)

- Pablo Messina & Vicente Dominguez



- Christoph Trattner, Modul U., Austria



- Alvaro Soto & Domingo Mery, PUC Chile



# Artwork Recommendation

- Online artwork market: Growing since 2008, despite global crises!
  - In 2011, art received \$11.57 billion in total global annual revenue, over \$2 billion versus 2010 (\*forbes)
- Previous recommendation projects date for as long as 2007, such as the CHIP project to recommend paintings from Rijksmuseum.
- Little use of recent advances in Deep Neural Networks for Computer Vision.

[forbes] The World's Strongest Economy? the Global Art Market. <https://www.forbes.com/sites/abigailesman/2012/02/29/the-worlds-strongest-economy-the-global-art-market/> (2012)

# Our research

- Art catalogues rely heavily on manual curation.
- Do manually-curated features work better than automatically obtained features (visual) ?
- Among the visual approaches, do DNN features perform better than EVF?
  - DNN : Deep Neural Networks
  - EVF : Explicit Visual Features

# Data: UGallery

- Online Artwork Store, based on CA, USA.
- Mostly sales one-of-a-kind physical artwork.

**Orientation**

- Horizontal (496)
- Vertical (162)
- Square (145)

**Size**

Height: 0"- 18"  
 60"+

Width: 0"- 45"  
 60+

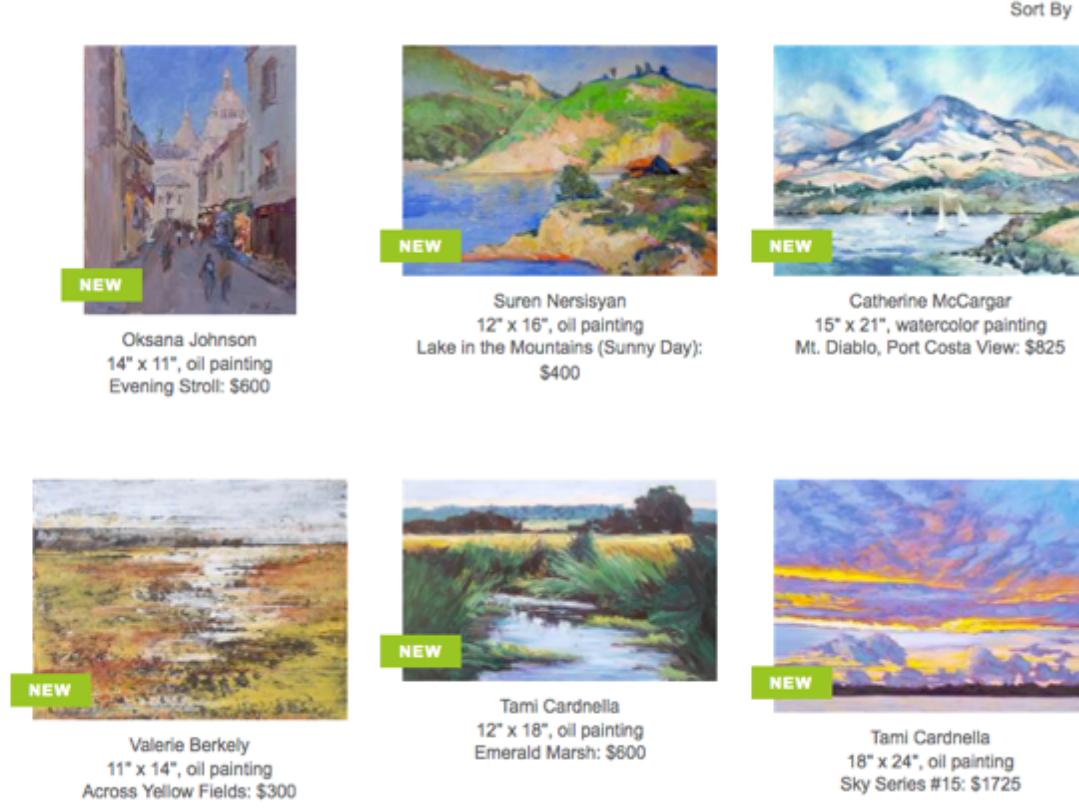
**Medium**

- Oil Painting (537)
- Acrylic Painting (125)
- Watercolor Painting (116)
- Drawing Artwork (10)
- Mixed Media Artwork (8)
- Other Media (6)
- Photography (1)

**Style**

**Color**

**Price**

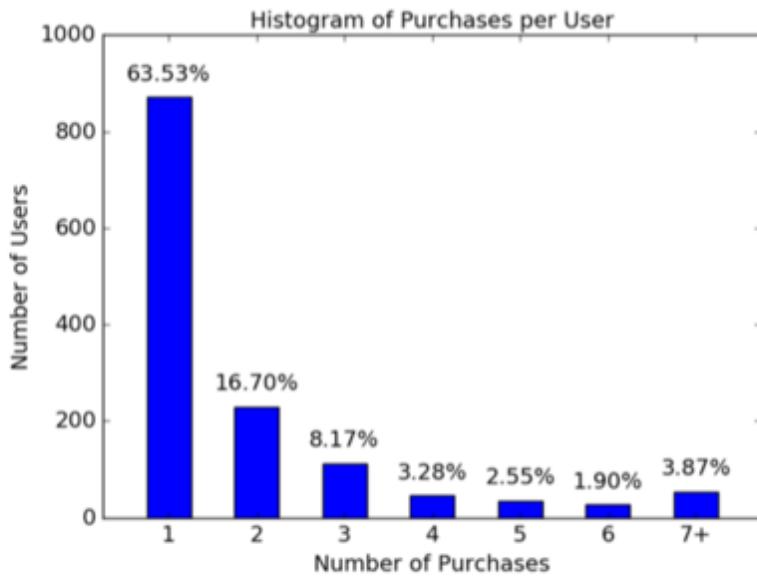


# UGallery Data: Metadata

Attribute	Type	Attribute Values
Color	Nominal	B&W, Beige, Black, Blue, Brown, Dark Blue, Dark Green, Dark Red, Green, Grey, Orange, Pink, Purple, Red, Turquoise, Violet, White, Yellow
Subject	Nominal	Animals, Architecture, Cuisine, Fantasy, Fashion, Flora, Landscape, Nature, Nudes, People, Religion, Seascapes, Sports, Still Life, Travel, Western
Style	Nominal	Abstract, Classical, Expressionism, Impressionism, Minimalism, Modern , Non-representational, Pop, Primitive, Realism, Representational, Street Art, Street Photography, Surrealism, Vintage
Medium	Nominal	Acrylic Painting, Ceramic Artwork, Chalk Drawing, Charcoal Drawing, Colored Pencil, Digital Printmaking, Drawing Artwork, Encaustic Artwork, Gouache Painting, Ink Artwork, Marker Artwork, Mixed Media Artwork, Oil Painting, Other Media, Pastel Artwork, Pencil Drawing, Photography, Printmaking, Sculpture, Watercolor
Energy	Ordinal	Calm, Neutral, Energetic
Seriousness	Ordinal	Playful, Neutral, Serious
Warmness	Ordinal	Warm, Neutral, Cool
Purpose	Ordinal	Decorative, Neutral, Thought-Provoking
Complexity	Ordinal	Simple, Neutral, Complex
Formality	Ordinal	Formal, Neutral, Informal
Age Perception	Ordinal	Young, Neutral, Old

# Data II

- 1,371 users / 3,940 items / 2,846 transactions



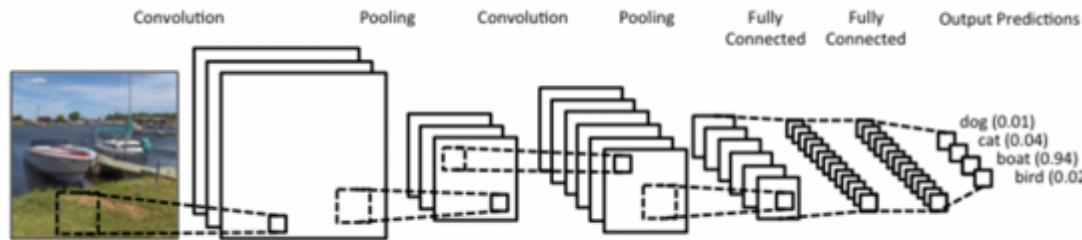
**Table 1:** Statistics of attributes present and absent for each artwork in *UGallery* dataset.

	color	style	subject	mood	medium
present	3,391	646	578	1,550	3,490
absent	99	2,844	2,912	1,940	0

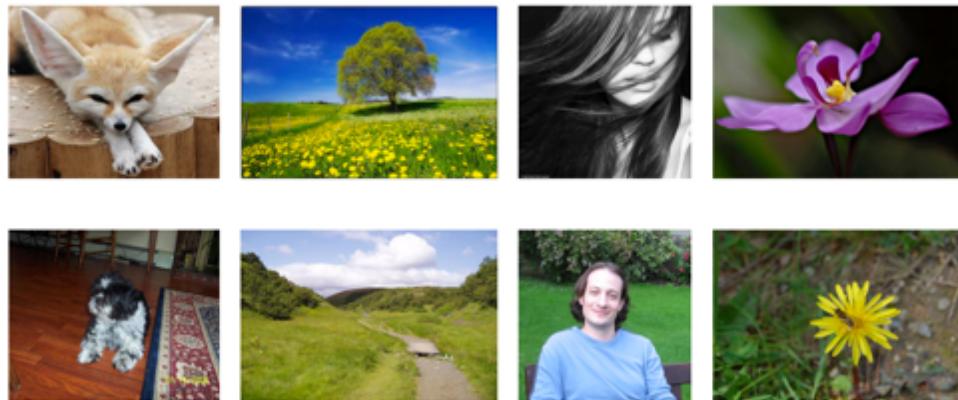
**Figure 2: Distribution of purchases per user. It resembles the typical skewed behavior in online websites.**

# Visual Features

- (DNN) Deep Neural Networks

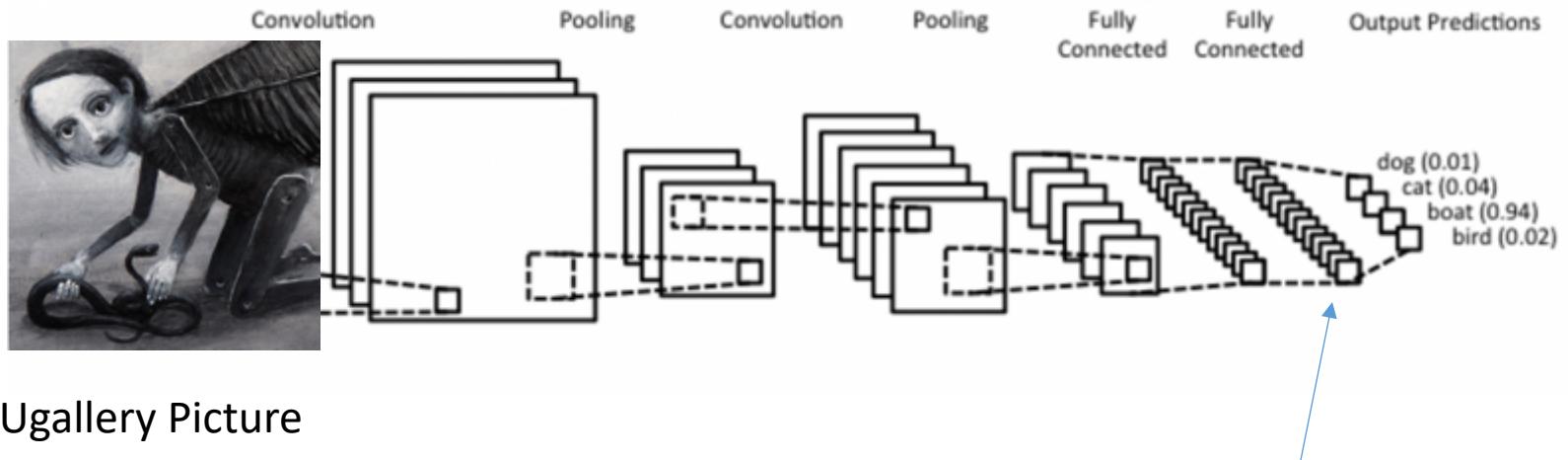


- (EVF) Attractiveness-based



# UGallery Data: DNN Visual Features

- AlexNet network, pre-trained with 1,000 classes (ImageNet dataset)



# UGallery Data: Visual Features

- Average brightness,
- Saturation,
- Sharpness,
- Entropy,
- RGB-contrast,
- Colorfulness,
- Naturalness

*Jose San Pedro and Stefan Siersdorfer.  
2009.*

*Ranking and Classifying Attractiveness of  
Photos in Folksonomies.*

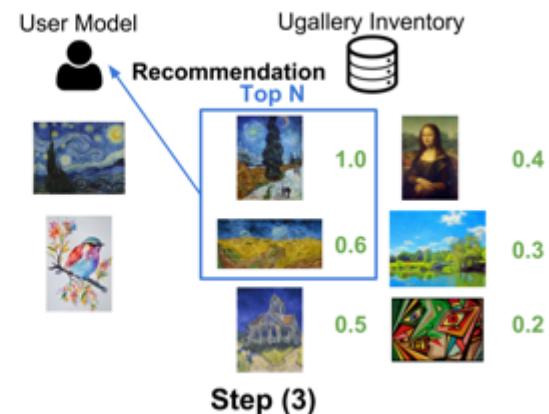
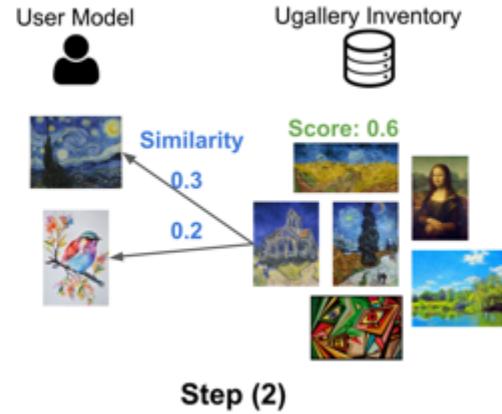
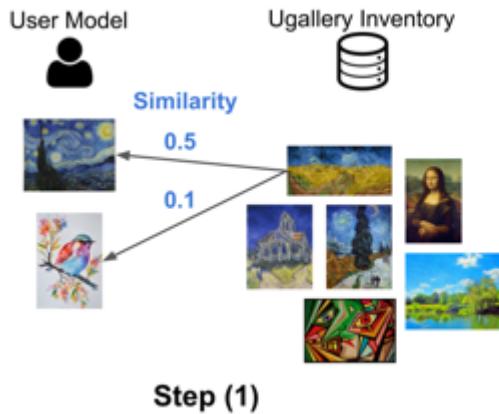
*In Proceedings of the 18th International  
Conference on World Wide Web (WWW  
'09).*

# Ugallery: All Features

- Most Popular Attribute Value (MPAV): A Non-personalized metadata-based method,
- Personalized MPAV (PMPAV): Personalized version of MPAV.
- Favorite Artist (FA): Analog to PMPAV, but recommends artworks based on the user's favorite artist.
- DNN.
- EVF.
- Price Based (Price).
- Hybrid Recommendation (Hybrid): A hybrid recommender based on a combination of metadata attributes and visual features.

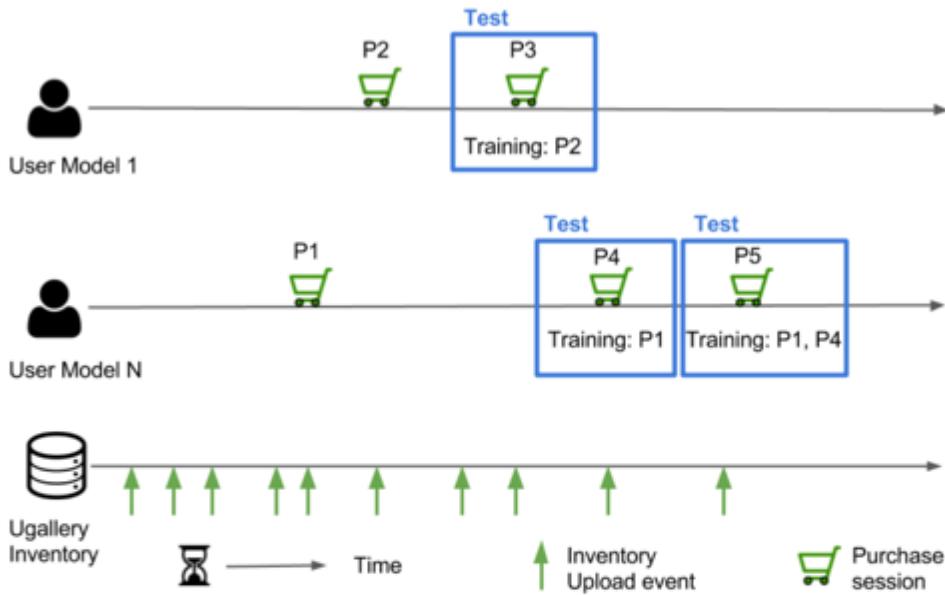
# Ugallery: Making Recommendations

- Scoring items based on cosine similarity between user model and item model:



$$sim(V_i, V_j) = \cos(V_i, V_j) = \frac{V_i \cdot V_j}{\|V_i\| \|V_j\|}$$

# Evaluation: Based on Transactions



**Figure 3: Evaluation procedure.** Each surrounding box represents a test, where we predict the items of the purchase session. In the figure, we predict which artworks bought User 1 in purchase P3. ‘Training:P2’ means we used items from purchase session P2 to train the model.

# Results I: Metadata Personalization

**Table 3: Recall@k, Diversity, and Coverage for MPAV and PMPAV by attribute. The best results are highlighted in bold.**

Attribute	r@5	r@10	diversity	user cov.	sess. cov.
MPAV - Most Pop. Attr. Value					
Color	<b>.0108</b>	<b>.0223</b>	.6218	<b>.9993</b>	<b>.9995</b>
Medium	.0095	.0199	.6706	<b>.9993</b>	<b>.9995</b>
Style	.0083	.0164	<b>.7055</b>	<b>.9993</b>	<b>.9995</b>
Subject	.0060	.0139	.6881	<b>.9993</b>	<b>.9995</b>
Mood	.0089	.0177	.5724	<b>.9993</b>	<b>.9995</b>
All Combined	.0099	.0198	.6683	<b>.9993</b>	<b>.9995</b>
PMPAV - Personalized Most Pop. Attr. Value					
Color	.0166	.0351	.6574	.2619	.3570
Medium	.0184	.0336	.6774	<b>.2640</b>	<b>.3593</b>
Style	<b>.0280</b>	<b>.0494</b>	.7127	.0766	.1168
Subject	.0125	.0236	.6897	.0890	.1407
Mood	.0159	.0270	.6967	.1327	.1822
All Combined	.0148	.0285	.6863	<b>.2640</b>	<b>.3593</b>

# Results II : EVF

- Contrast & Entropy (+)
- Colorfulness (-)

name	ndcg@5	ndcg@10	rec@5	rec@10	prec@5	prec@10
EVF (all features)	.0344	.0459	.0547	.0885	.0127	.0111
EVF (all, except LBP)	.0370	.0453	.0585	.0826	.0152	.0109
EVF (LBP)	.0292	.0388	.0431	.0715	.0103	.0085
EVF (brightness)	.0048	.0083	.0080	.0186	.0035	.0031
EVF (colorfulness)	.0020	.0052	.0033	.0126	.0008	.0017
EVF (contrast)	.0079	.0102	.0149	.0220	.0033	.0025
EVF (entropy)	.0088	.0098	.0110	.0137	.0026	.0019
EVF (naturalness)	.0062	.0110	.0108	.0248	.0026	.0032
EVF (saturation)	.0055	.0084	.0096	.0187	.0021	.0020
EVF (sharpness)	.0063	.0085	.0117	.0178	.0024	.0021

# Results III : Altogether

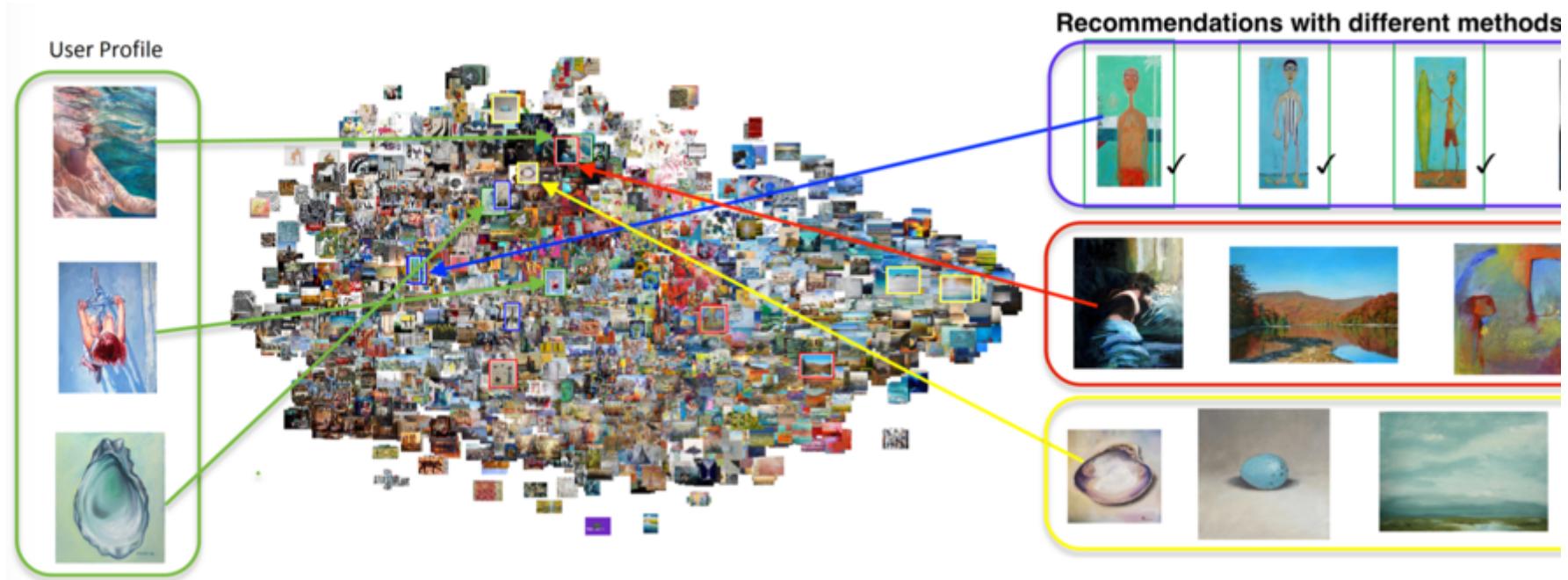
Group	Method	nD@5	nD@10	r@5	r@10	p@5	p@10	f1@5	f1@10
G4*	Hyb <sub>1</sub> (FA+DNN+EVF+Price)	.1367▼♦	.1569▼♦□	.1768▼♦	.2368▼♦	.0425▼♦	.0287▼♦	.0663▼♦	.0501▼
G4*	Hyb <sub>2</sub> (FA+DNN)	.1342▼♦	.1526▼♦□	.1716▼♦	.2251▼♦	.0420▼♦	.0283▼♦	.0651▼♦	.0490▼
G4*	Hyb <sub>3</sub> (FA+EVF)	.1282▼♦	.1439▼♦	.1780▼♦	.2252▼♦	.0420▼♦	.0272▼♦	.0659▼♦	.0474▼
G4*	Hyb <sub>4</sub> (FA+Price)	.1322▼♦	.1441▼♦	.1780▼♦	.2139▼♦	.0435▼♦	.0263▼	.0672▼♦	.0456▼
G3	FA	.1132▼□	.1270▼□	.1591▼♦□	.2039▼□	.0385▼□	.0252▼□	.0596▼□	.0436▼□
G3	Price	.0239	.0293	.0366	.0527	.0083	.0065	.0131	.0112
G2*	DNN	.0810▼♦	.0968▼♦	.1052▼	.1525▼♦	.0269▼	.0195▼♦	.0415▼	.0338▼♦
G2*	EVF	.0370▼	.0453▼	.0585▼	.0826▼	.0152▼	.0109▼	.0233▼	.0188▼
G1▼	PMPAV (Color)	.0097▼	.0167▼	.0166▼	.0351▼	.0039▼	.0042▼	.0061▼	.0073▼
G1▼	MPAV (Color)	.0067	.0106	.0108	.0223	.0029	.0029	.0043	.0049

Statistical significance using multiple pairwise t-tests with Bonferroni correction,  $\alpha_{bonf} = \alpha/n = 0.05/45 = .001$

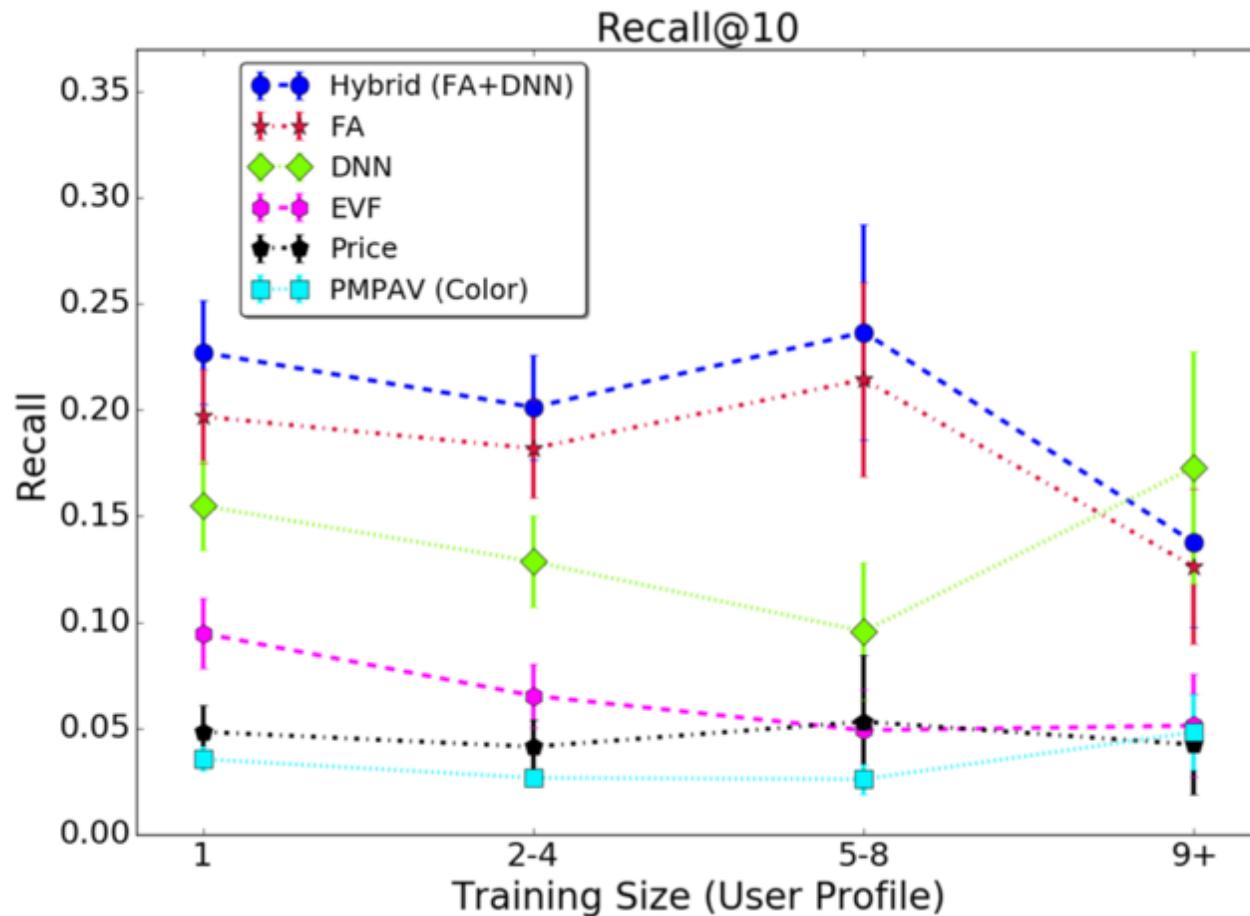
# DNN Embedding



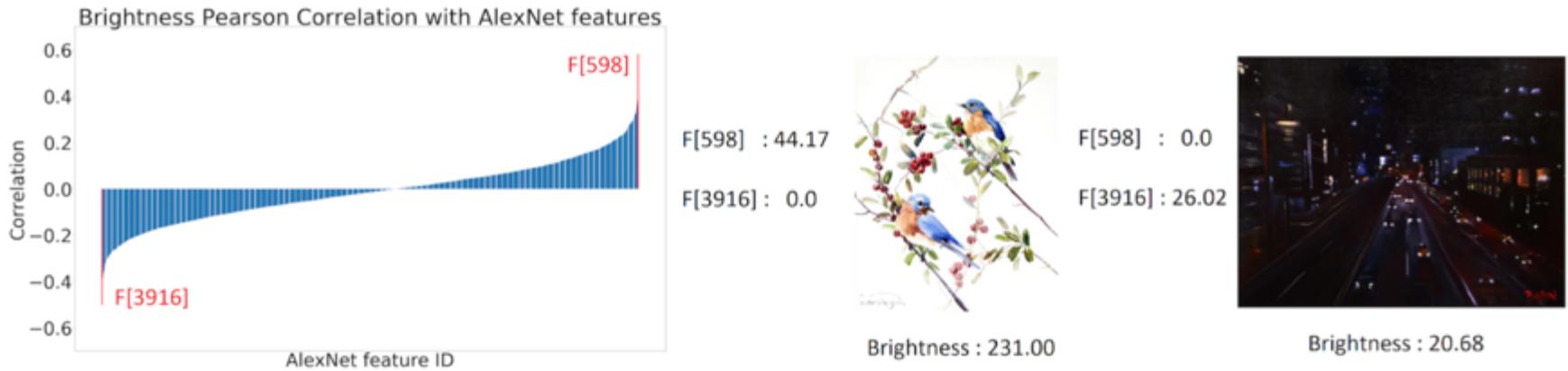
# DNN Embedding and other methods



# Discussion: Profile Size



# Explanability: DNN vs. EVF?



Visual feature	$\max(\text{corr.})$	$\text{index}(F_{\max})$	$\min(\text{corr.})$	$\text{index}(F_{\min})$
brightness	<b>0.5815</b>	598	<b>-0.5020</b>	3916
sharpness	0.4682	4095	-0.3668	1025
saturation	0.3645	445	-0.5019	2370
colorfulness	0.3034	1014	-0.3383	2410
entropy	0.3410	286	-0.4369	3499
contrast	0.3941	469	-0.2799	3761
naturalness	0.0852	2626	-0.0256	2499

# Evaluation with 7 experts

- Results are consistent with our off-line analysis.
- Further research is conducted now in the intersection of explainability and recommendations.

User Name  
dummy1

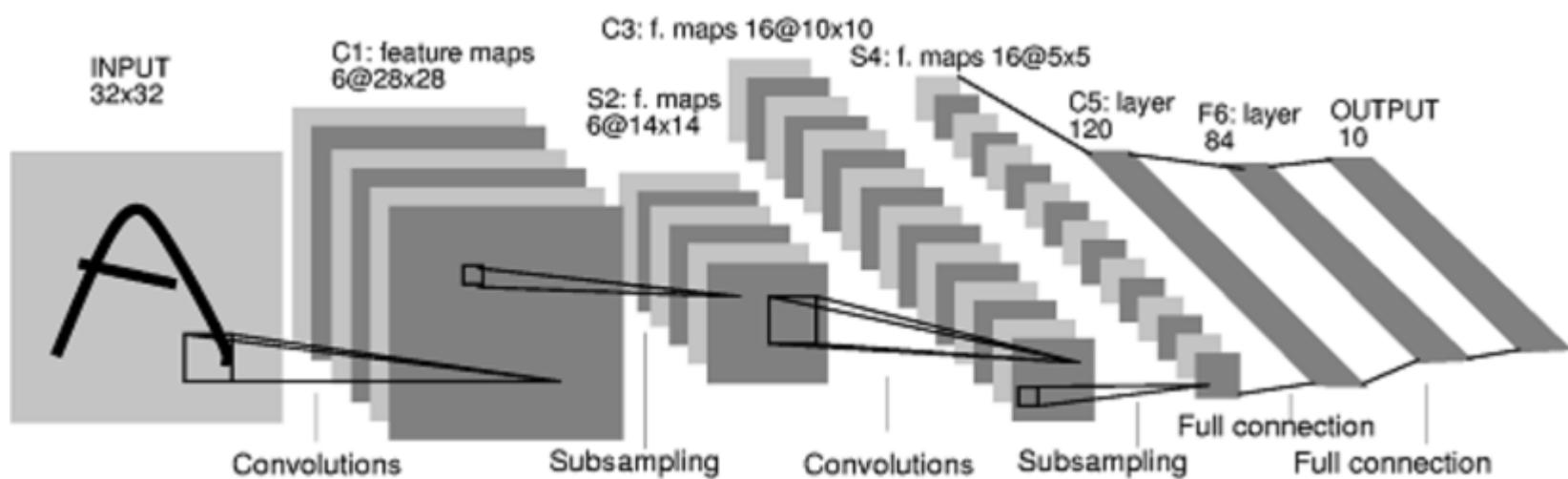
Profile Mode  
Likes

dummy1's profile

Liked Artworks

(9/10) - DNN+EVF/@10_dnn(avgsimt op2-cosine)_evf(maxsim-cosine)_betas(0.50,0.50).json	(9/10) - EVF/@10_max-cos-sim.json
Successfully rated! ★★★★★	Successfully rated! ★★★★★
Successfully rated! ★★★★★	Successfully rated! ★★★★★
Successfully rated! ★★★★★	Successfully rated! ★★★★★

# CNN



# Future Work

- Implementing a more sophisticated way to make the recommendations (BPR, FM + dimensionality reduction)
- Conduct a user study (with Ugallery customers).
- Implementing an interface to produce the visualizations.