



UNIVERSITAT DE  
BARCELONA



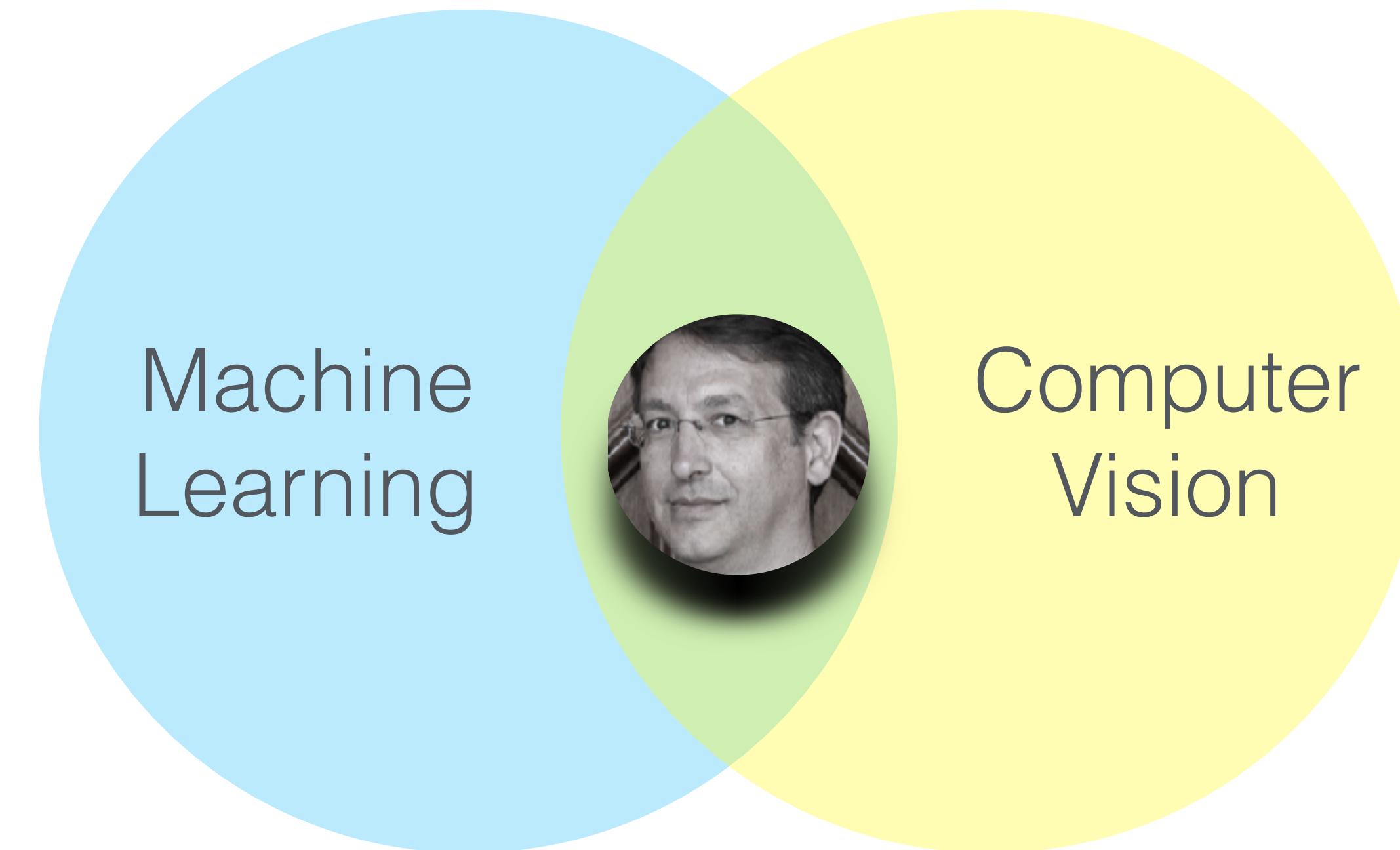
Master on Foundations of Data Science



# Deep Learning

or how to train large and highly complex models with deeply cascaded nonlinearities by using automatic differentiation and several tricks.

Barcelona, 2017



**Jordi Vitrià**

jordi.vitria@ub.edu

Since 2007, I am a Full Professor at Mathematics and Compute Science Department, Universitat de Barcelona. Before that I spent 20 years on the faculty of the Computer Science Department at the Universitat Autònoma de de Barcelona working on Computer Vision and Machine Learning. I am the Director of the DataScience@UB group at UB.

# Course Agenda

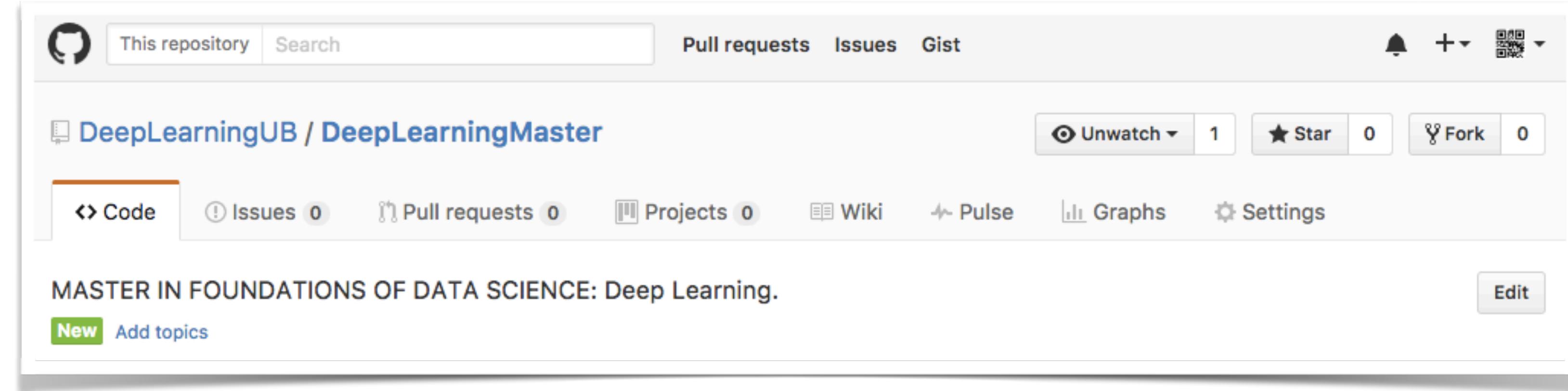
- Introduction to Deep Learning and its applications. Using the Jupyter notebook & Docker. Software stack.
- **Automated differentiation** & Backpropagation. Training a Neural Network from Scratch.
- **Tensorflow** programming model. Dense Neural Networks.
- Tensorflow ecosystem: Keras, tf-contribution.
- **Recurrent Neural Networks I.**
- Recurrent Neural Networks II.
- **Embeddings.**
- Introduction to **Convolutional Neural Networks.**
- Convolutional Neural Networks for Large Scale Learning.
- Invited Session: Microsoft CNTK (tentative).
- Unsupervised Learning I. **Edward.**
- Unsupervised Learning II.
- Wide and Deep Learning.
- DL for Recommenders.
- Reinforcement Learning.



# Deep Learning

# \$\$Hackaton\$\$

# Course Repository



<https://github.com/DeepLearningUB/DeepLearningMaster>

## Grading

Assignment #1: 30%

Assignment #2: 30%

Assignment #3: 40%

Study groups are allowed but we expect students to understand and complete their own assignments and to hand in one assignment per student.

# What

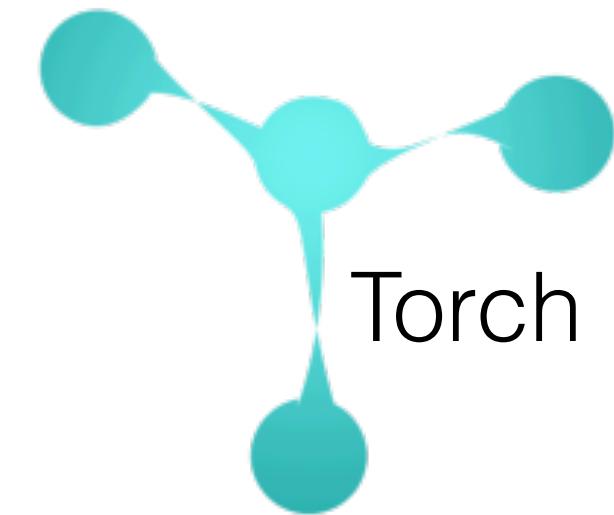
1. Describe how a (deep) neural network works and combine different types of layers and activation functions. **Deep Learning is not magic.**
2. Describe how these models can be applied in computer vision, text analytics, time series analysis, etc. **Deep Learning is not the final machine learning method.**
3. Develop your own models in **Tensorflow** and derivates. **You can train (mid-size) deep models in your laptop.**

# Deep Learning BackEnds



Python, C++  
MultiGPU  
Distributed

Google



Lua  
MultiGPU



theano

Python  
Large amount  
of sample  
code

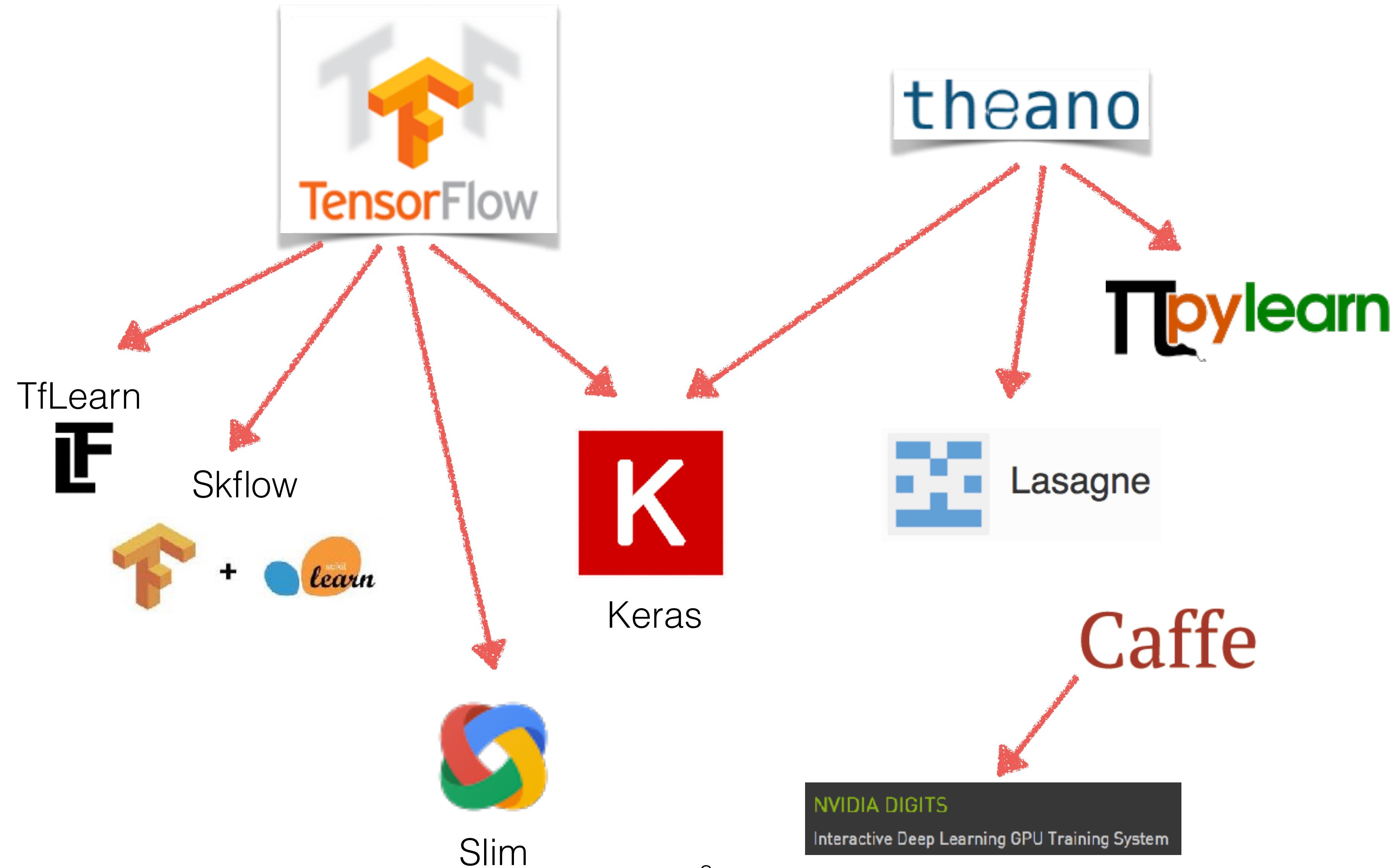
Université de Montréal

Caffe

Python, C++  
MultiGPU

Berkeley  
UNIVERSITY OF CALIFORNIA

# Tools



# Other BackEnds



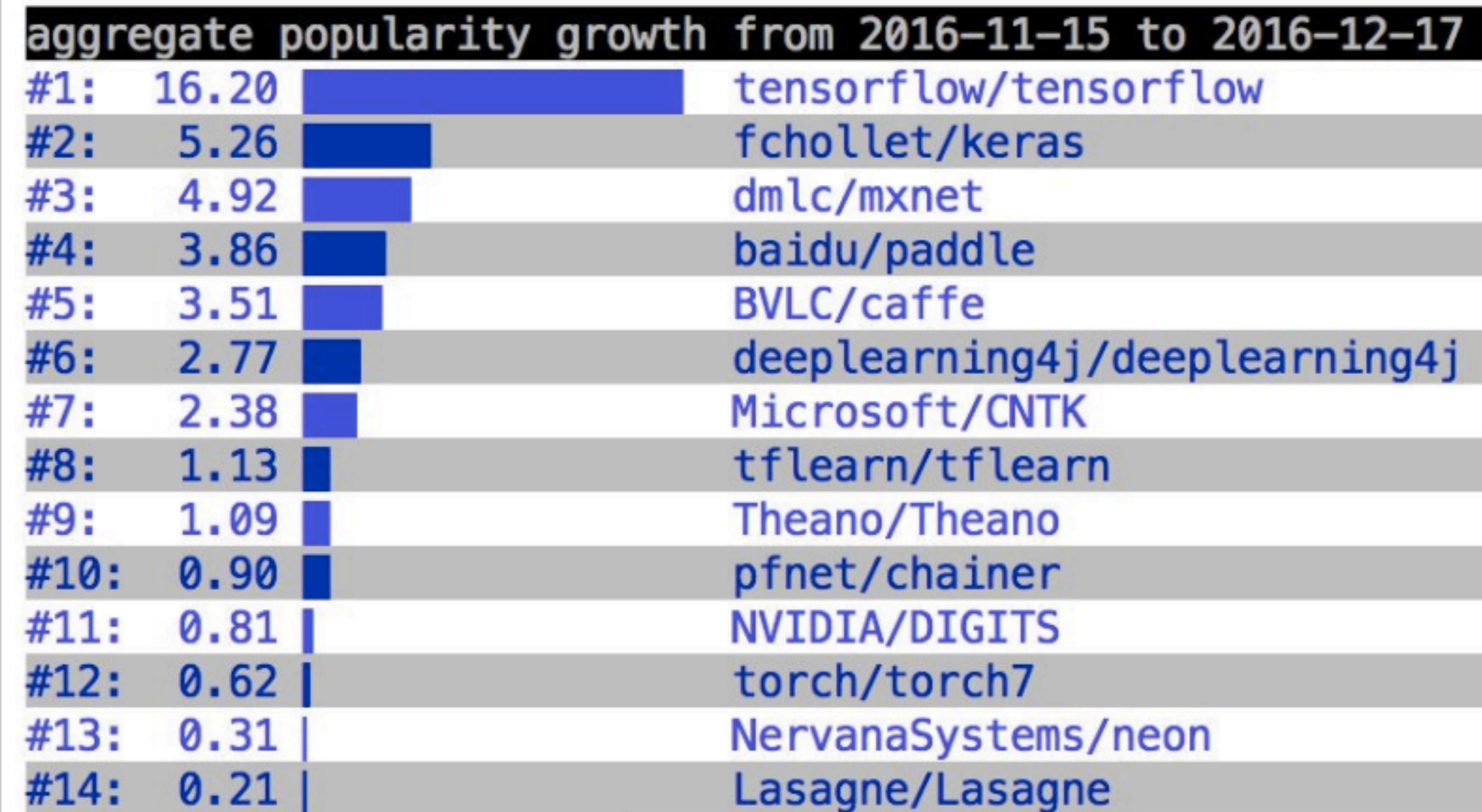
*dmlc*  
**mxnet**



Neon

**DL4J** Deep Learning for Java

 **ConvNetJS**  
Deep Learning in your browser



François Chollet @fchollet · 17 des. 2016

Deep learning frameworks growth over the past month.

◀ 14

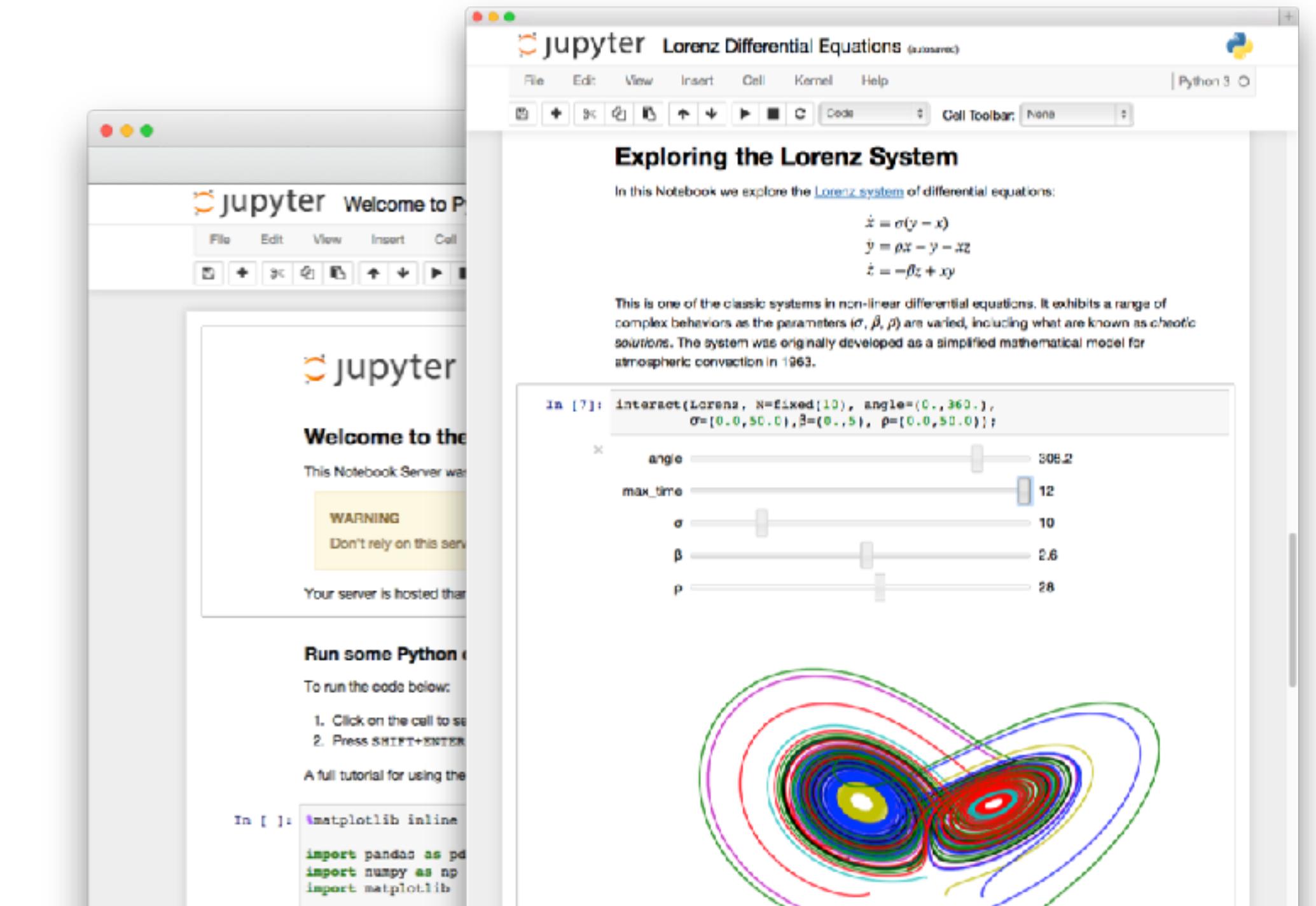
↑ 324



509

# Approach

We will illustrate all contents with Jupyter notebooks, a web application that allows you to create and share documents that contain live code, equations, visualizations and explanatory text.



# Approach



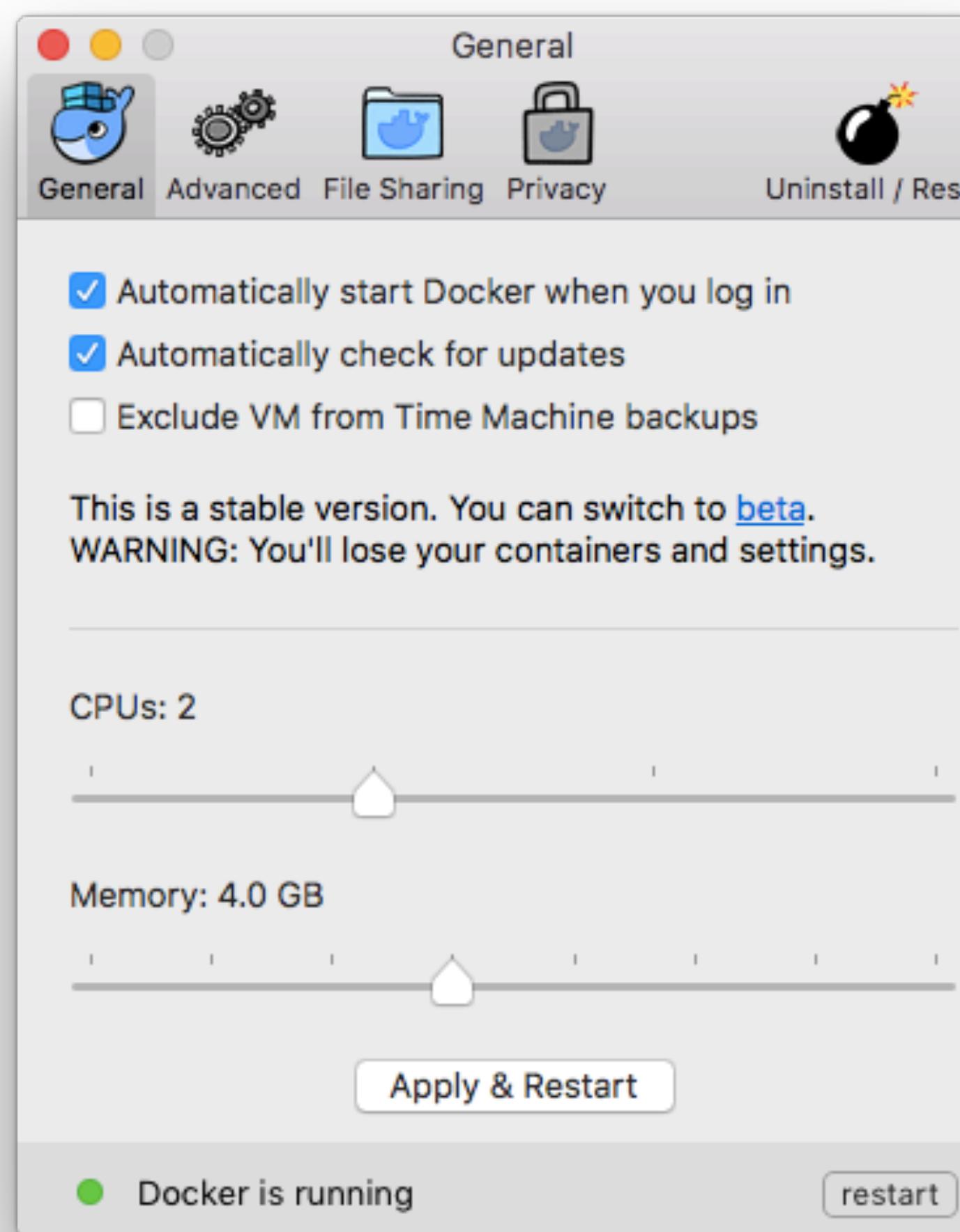
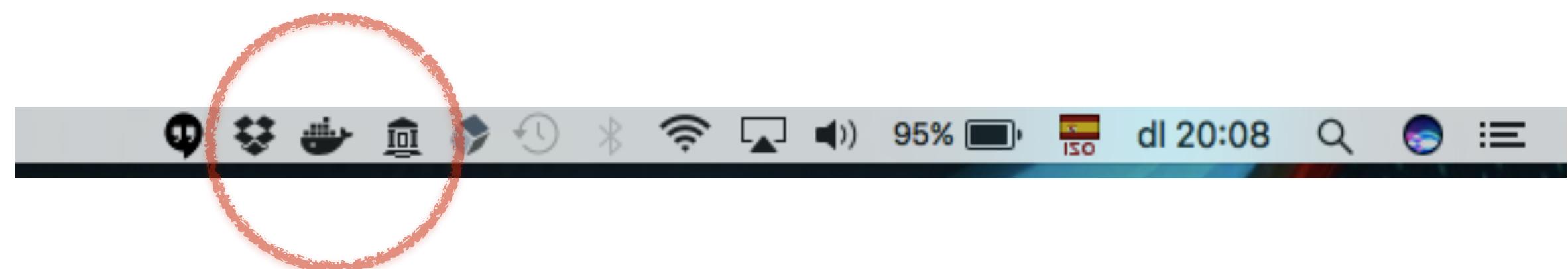
We will use a **Docker Container**.

Docker provides the ability to build a runtime environment that not only remains isolated from other running containers, but also can be deployed to multiple locations in a repeatable way. Docker also uses a text document – a Dockerfile – that contains all the commands to assemble an image, which will meet our need to document the build environment. Finally, Docker's runtime options enable us to attach GPU devices when deploying on remote servers.

## Course Software Installation

The best way to run the course software is to use a **Docker container**. There's full documentation on installing Docker at [docker.com](https://docs.docker.com), but in a few words, the steps are:

- Go to `docs.docker.com` in your browser.
- Step one of the instructions sends you to download Docker.
- Run that downloaded file to install Docker.
- At the end of the install process a whale in the top status bar indicates that Docker is running, and accessible from a terminal.
- Click the whale to get `Preferences`, and other options.
- Open a command-line terminal, and run some Docker commands to verify that Docker is working as expected. Some good commands to try are `docker version` to check that you have the latest release installed, and `docker ps` and `docker run hello-world` to verify that Docker is running.
- By default, Docker is set to use 2 processors. You can increase processing power for the app by setting this to a higher number in `Preferences`, or lower it to have Docker for Mac use fewer computing resources.
- Memory - By default, Docker is set to use 2 GB runtime memory, allocated from the total available memory on your computer. You can increase the RAM on the app to get faster performance by setting this number higher (for example to 3) or lower (to 1) if you want Docker to use less memory.



Once Docker is installed, you can download the image of this course:

- In a terminal, go to your course folder and run (This operation requires a good internet connection; it will take some minutes): `docker pull datascienceub/deepub`
- Run the `deepub` image on your system: `docker run -it -p 8888:8888 -p 6006:6006 -v $(pwd):/notebooks datascienceub/deepub`
- Once these steps have been done, you can check the installation by starting your web browser and introducing this URL: `http://localhost:8888`.
- Open a new Jupyter notebook and execute this instruction in a code cell: `!git clone https://github.com/DeepLearningUB/DeepLearningMaster`

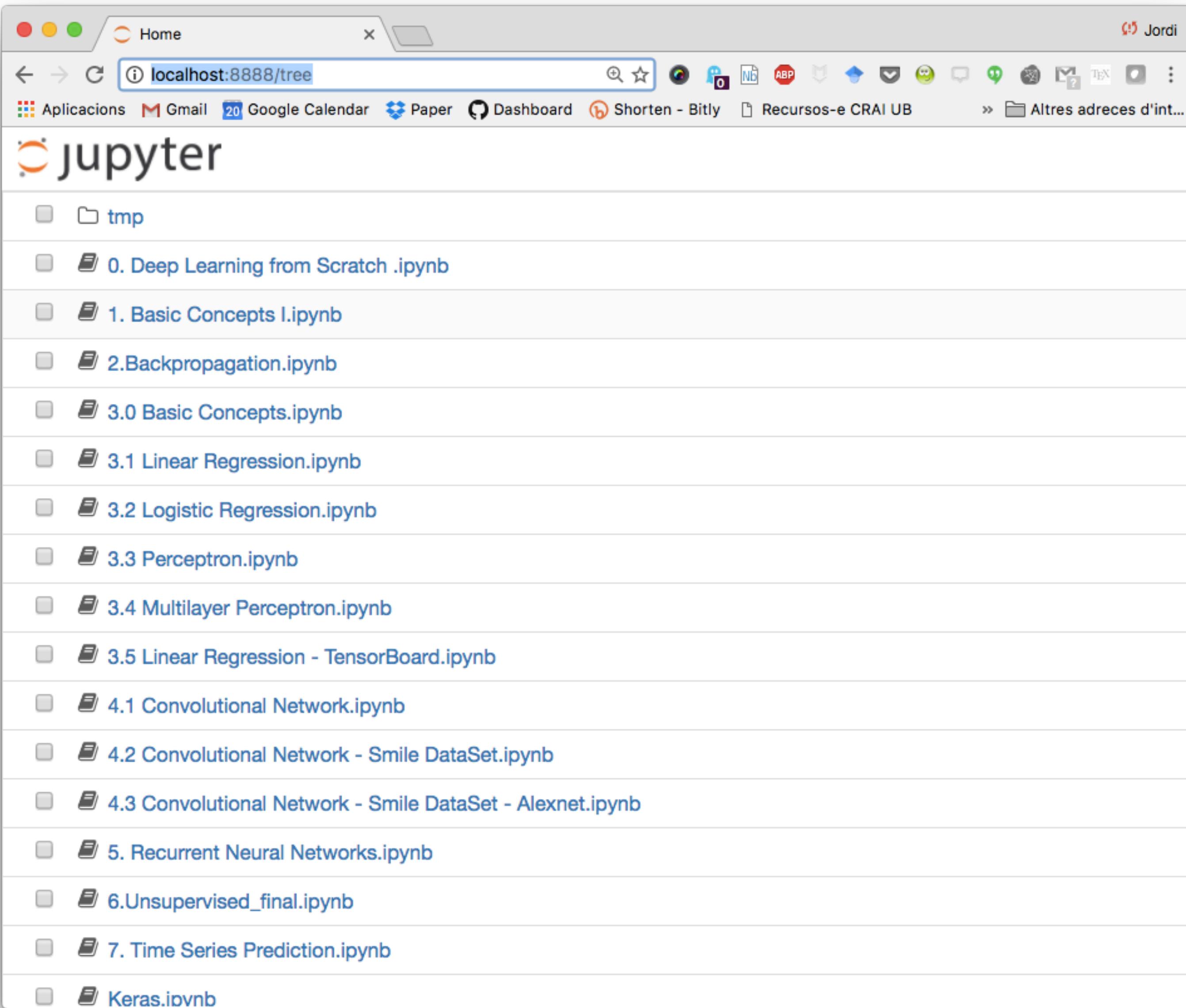
```
jordi — docker pull datascienceub/deepub — 78x28
Last login: Mon Nov 21 20:08:59 on ttys001
[MacBook-Air-de-jordi:~ jordi$ docker pull datascienceub/deepub
Using default tag: latest
latest: Pulling from datascienceub/deepub

6c953ac5d795: Pull complete
3eed5ff20a90: Pull complete
f8419ea7c1b5: Pull complete
51900bc9e720: Pull complete
a3ed95caeb02: Pull complete
ebb77ce6e1c6: Pull complete
c145c1f339f5: Pull complete
9528c5352798: Extracting 68.52 MB
c1f8f4c880d4: Download complete
f5d83de9c678: Download complete
d819f1ec59a0: Download complete
bfc1d5e3de1c: Download complete
182b64c1f020: Download complete
ce321bdf714b: Download complete
ca10bcc60e7c: Download complete
b4fd7a47b122: Download complete
1457c46eff3f: Downloading 25.95 MB/85.36 MB
e52d876fa529: Downloading 6.274 MB/11.73 MB
6076beb51bc0: Download complete
```

```
DeepLearningBBVA2016-master — docker run -it -p 8888:8888 -v ~/Dropbox/Dee...
Last login: Mon Nov 21 20:17:10 on ttys001
[MacBook-Air-de-jordi:~ jordi$ pwd
/Users/jordi
[MacBook-Air-de-jordi:~ jordi$ cd Dropbox/DeepLearningBBVA2016-master/
MacBook-Air-de-jordi:DeepLearningBBVA2016-master jordi$ docker run -it -p 8888:8888
-v /$(pwd):/notebooks datascienceub/deepub
[I 19:18:44.961 NotebookApp] Writing notebook server cookie secret to /root/.local/s
hare/jupyter/runtime/notebook_cookie_secret
[W 19:18:44.975 NotebookApp] WARNING: The notebook server is listening on all IP add
resses and not using encryption. This is not recommended.
[W 19:18:44.975 NotebookApp] WARNING: The notebook server is listening on all IP add
resses and not using authentication. This is highly insecure and not recommended.
[I 19:18:44.982 NotebookApp] Serving notebooks from local directory: /notebooks
[I 19:18:44.982 NotebookApp] 0 active kernels
[I 19:18:44.982 NotebookApp] The Jupyter Notebook is running at: http://[all ip addr
esses on your system]:8888/
[I 19:18:44.983 NotebookApp] Use Control-C to stop this server and shut down all ker
nels (twice to skip confirmation).
```

```
docker run -it -p 8888:8888 -p 6006:6006
-v /$(pwd):/notebooks datascienceub/deepub
```

```
docker run -it -p 8888:8888 -p 6006:6006 -v
C:\jordi\DeepLearningMaster:/notebooks
datascienceub/deepub
```



# THE REVENANT

INSPIRED BY TRUE EVENTS  
JANUARY 8



# Why Deep Learning?



**It's funny!**

**It's not rocket  
science!**

**It's powerful!**



### Historical metaphors of the brain:

Hydraulic (blood cooler, spirits),  
Mechanical (clock, steam machine), ...

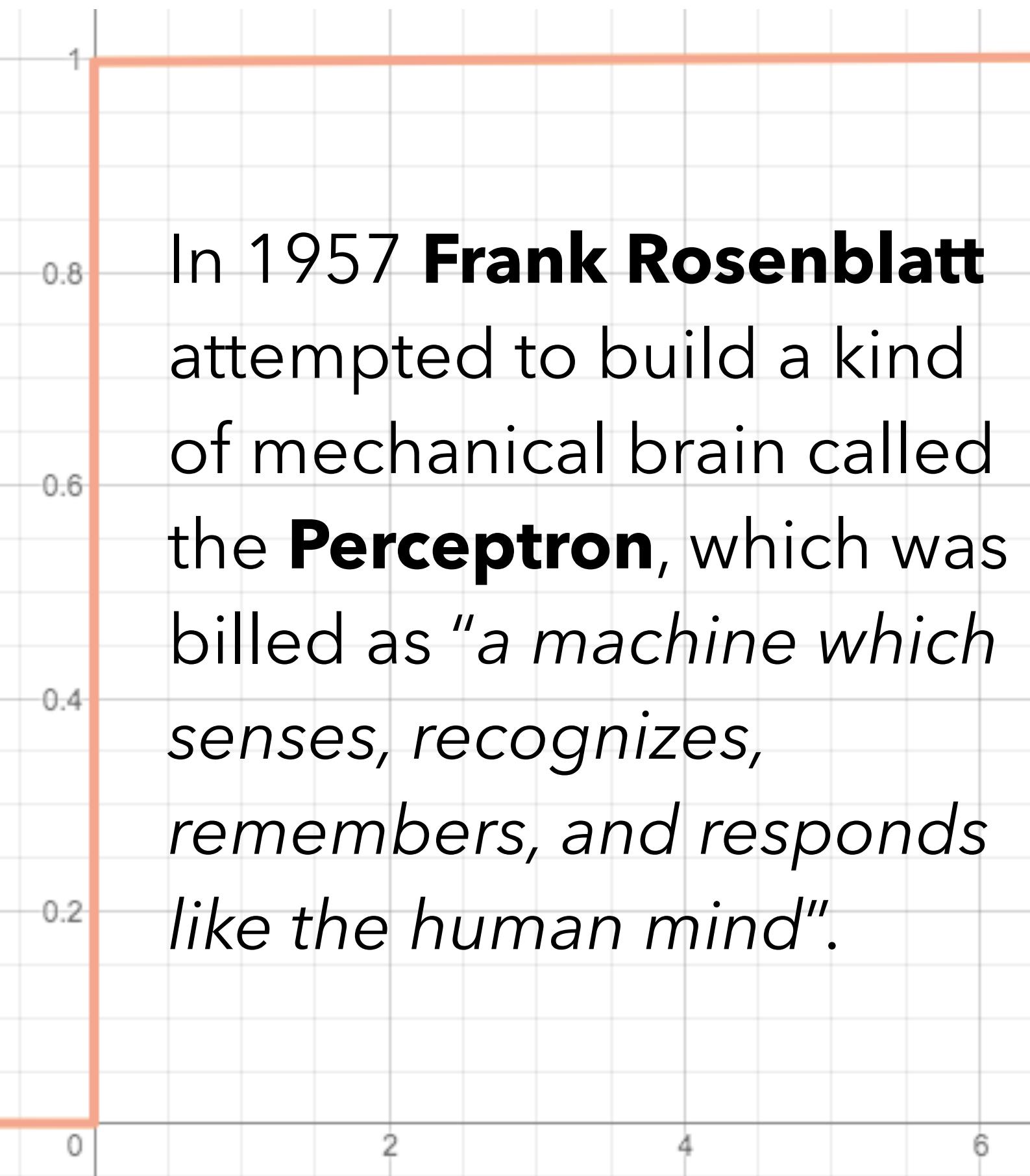


In 1943, neurophysiologist **Warren McCulloch** and mathematician **Walter Pitts** wrote a paper on how neurons might work. In order to describe how neurons in the brain might work, they modeled a simple neural network using **electrical circuits**.



In 1949, Donald **Hebb** wrote *The Organization of Behavior*, a work which pointed out the fact that **neural pathways are strengthened each time they are used**, a concept fundamentally essential to the ways in which humans **learn**.

$$f(x) = \begin{cases} 1 & \text{if } w \cdot x + b > 0 \\ 0 & \text{otherwise} \end{cases}$$





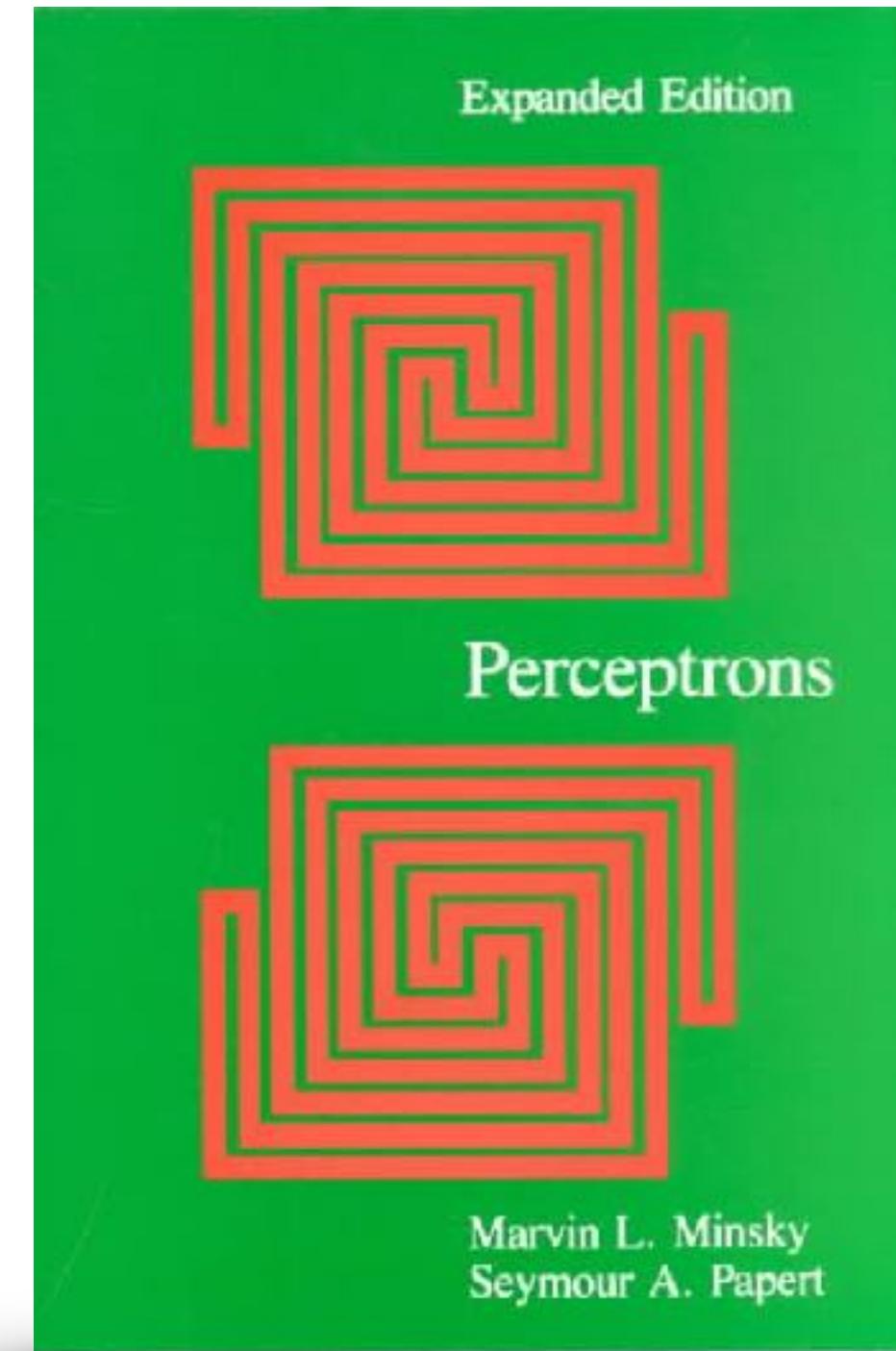
In 1962, **Widrow & Hoff** developed a **learning rule** that examines the value before the weight adjusts it (i.e. 0 or 1) according to the rule:

*Weight Change = (Pre-Weight line value)  
\* (Error / (Number of Inputs)).*

It is based on the idea that **while one active perceptron may have a big error, one can adjust the weight values to distribute it across the network**, or at least to adjacent perceptrons.



A critical book written in 1969 by **Marvin Minsky** and his collaborator **Seymour Papert** showed that Rosenblatt's original system was **painfully limited**, literally blind to some simple logical functions like "exclusive-or".



It is claimed that pessimistic predictions made by the authors were responsible for an erroneous change in the direction of research in AI, concentrating efforts on so-called "symbolic" systems, and contributing to the so-called AI winter. This decision, supposedly, proved to be unfortunate in the 1980s, when new discoveries showed that the prognostics in the book were wrong.

*Source: Wikipedia*

# 70's: First neural network winter





In 1982, interest in the field was renewed. **John Hopfield** of Caltech presented a paper to the National Academy of Sciences. His approach was to create more useful machines by using **bidirectional lines**. Previously, the connections between neurons was only one way.



In 1986, the problem was how to **extend the Widrow-Hoff rule to multiple layers**. Three independent groups of researchers, which included **David E. Rumelhart, Geoffrey E. Hinton** and **Ronald J. Williams**, came up with similar ideas which are now called **back-propagation** networks because it distributes pattern recognition errors throughout the network.



From 1986 to mid 90's new developments arised: convolutional neural networks (**Y.LeCun**), unsupervised learning (**Y.Bengio**), RBM (**G.Hinton**), recurrent networks (**J.Schmidhuber**), etc.

But, by this point **new machine learning methods** had begun to also emerge, and people were again beginning to be skeptical of neural nets since they seemed so intuition-based and since computers were still barely able to meet their computational needs.

90's-00's: Second neural network winter





With the ascent of Support Vector Machines and the **failure of backpropagation**, the early 2000s were a dark time for neural net research.

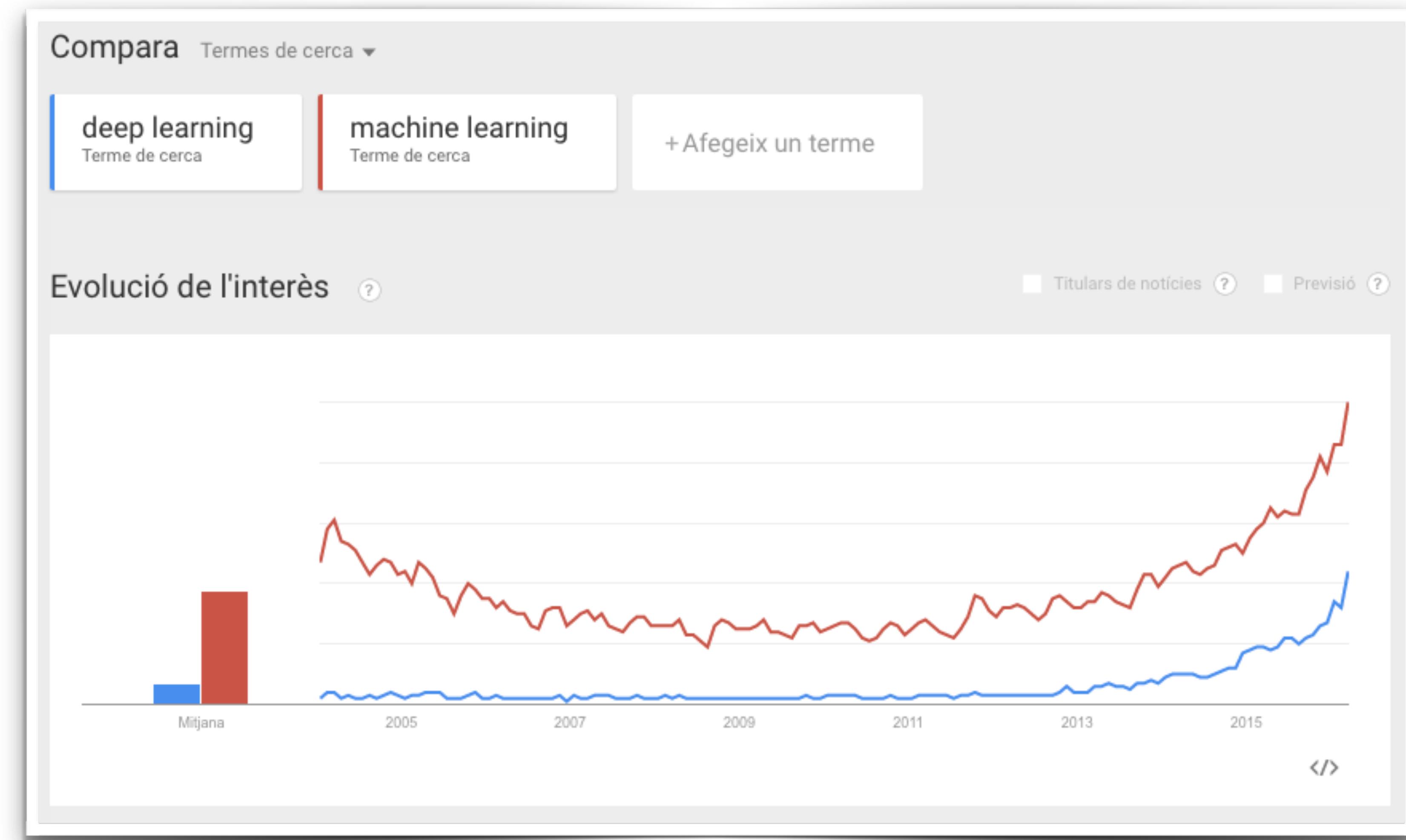


Then, what every researcher must dream of actually happened: G.Hinton, S.Osindero, and Y.W.Teh published a paper in 2006 that was seen as a breakthrough, a breakthrough significant enough to rekindle interest in neural nets: *A fast learning algorithm for **deep** belief nets.*



After that, following Moore's law, computers got dozens of times faster (GPUs) since the slow days of the 90s, making learning with large datasets and many layers much more tractable.

# Neural Networks Reborn



Google Trends



amazon

newegg.com®

MICRO CENTER  
computers & electronics

NVIDIA.

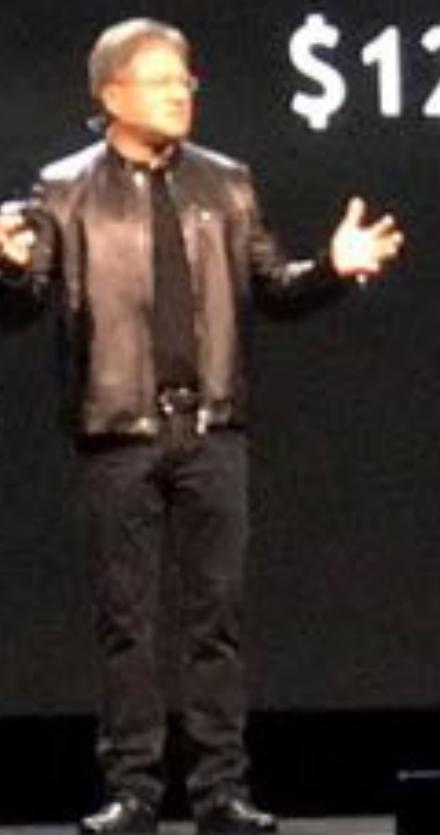


# NVIDIA DGX-1

WORLD'S FIRST  
DEEP LEARNING SUPERCOMPUTER

170TF | "250 servers in-a-box" | [nvidia.com/dgx1](http://nvidia.com/dgx1)

\$129,000



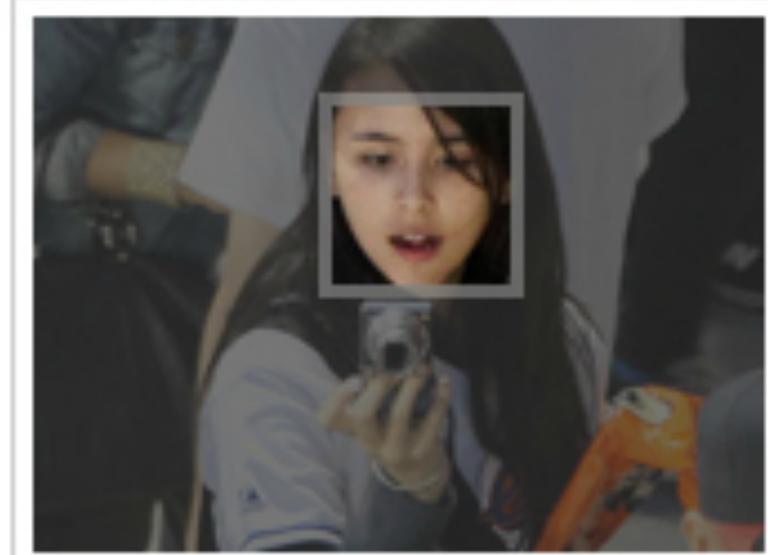
## Definitions

- **Neural Networks (NN)** is a beautiful biologically-inspired programming paradigm which enables a computer to learn from observational data.
- **Deep Learning (DL)** is a powerful set of techniques for learning in neural networks.
- NN and DL currently provide the best solutions to many problems in image recognition, speech recognition, and natural language processing.

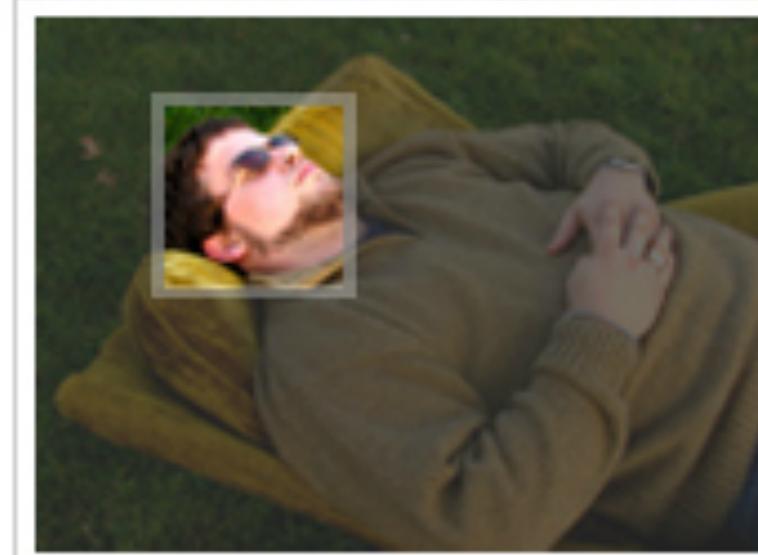
# “Classical” applications: object classification, detection and segmentation.



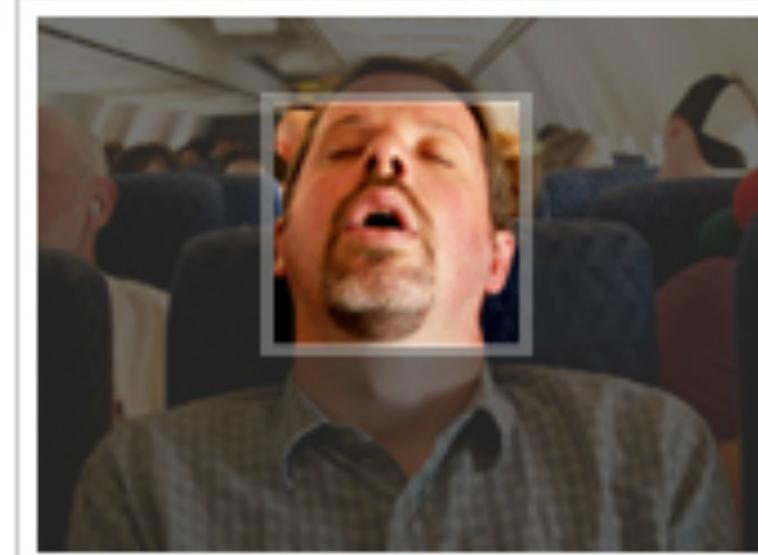
## Face recognition.



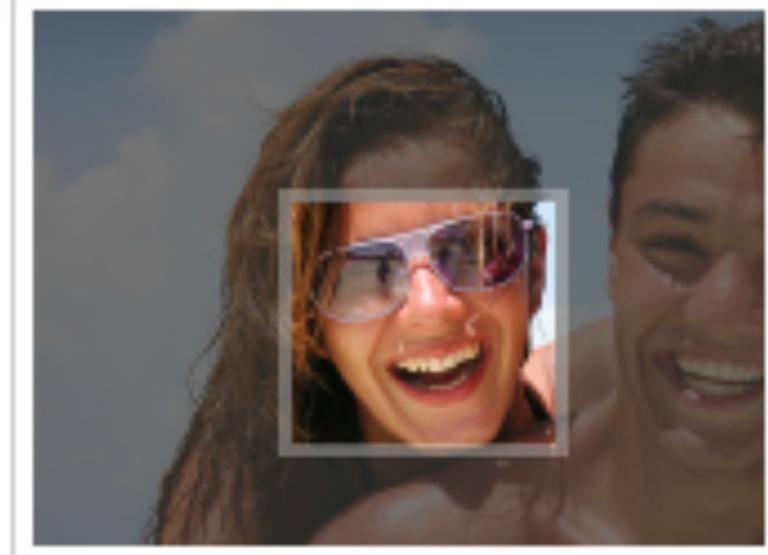
Who is this?



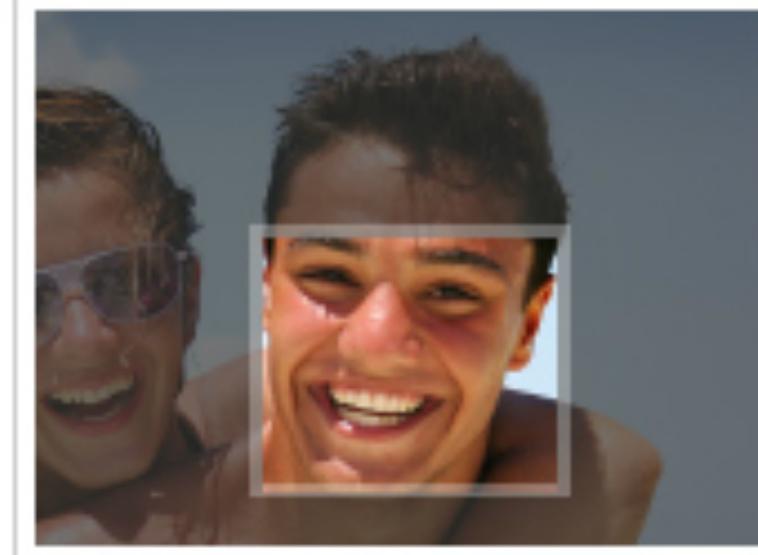
Who is this?



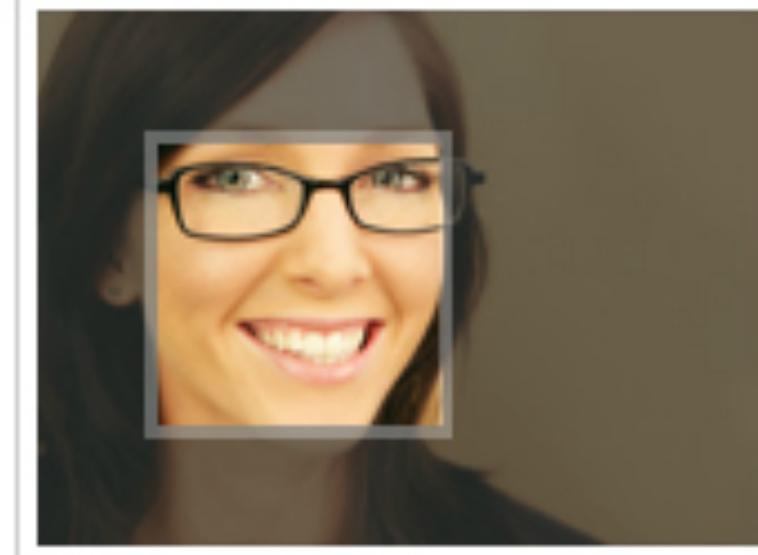
Who is this?



Who is this?



Who is this?



Who is this?

DeepFace (Facebook): Accuracy of 97.35%

# New applications: navigation and mapping.

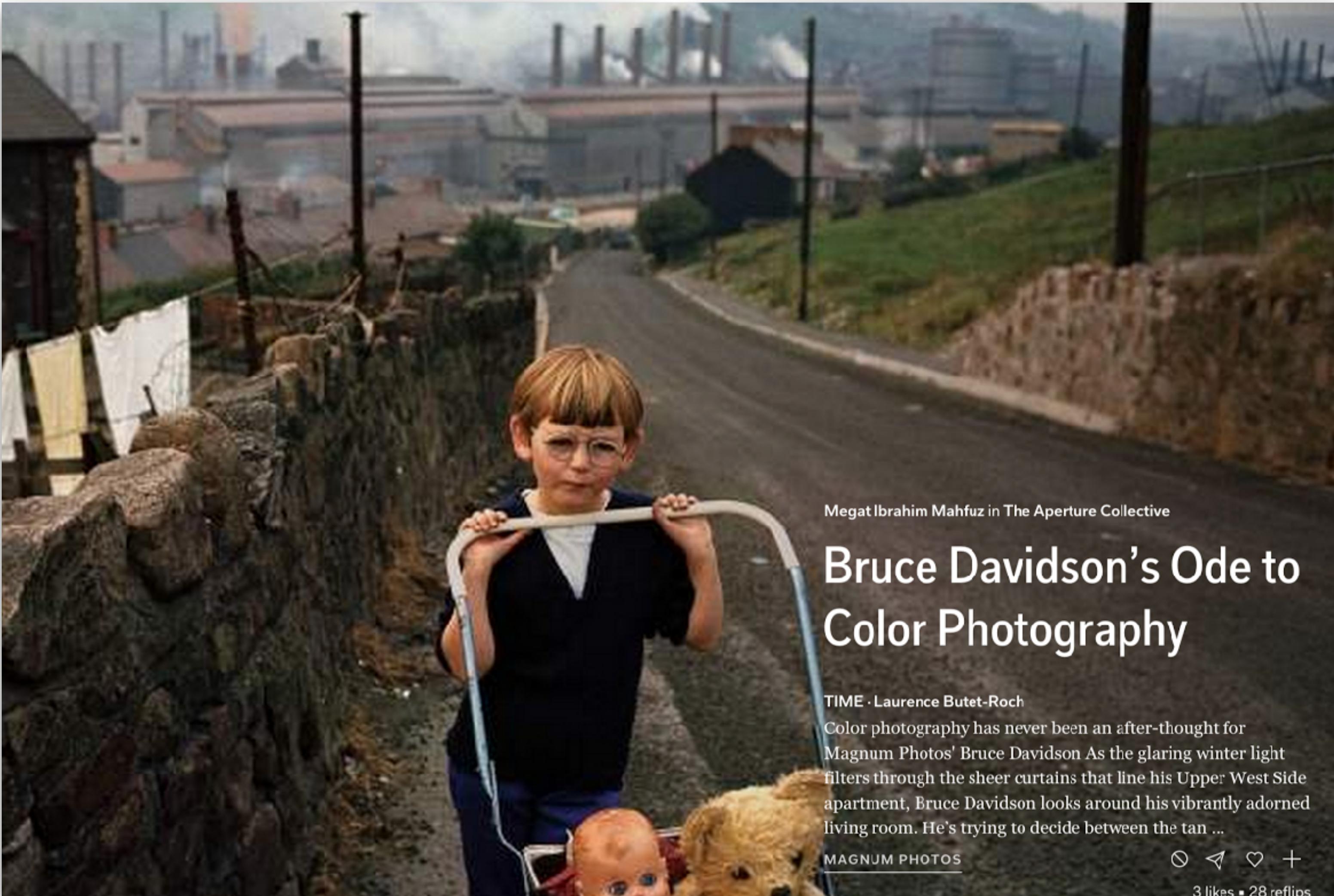


# New applications: Image Upscaling (Flipboard)



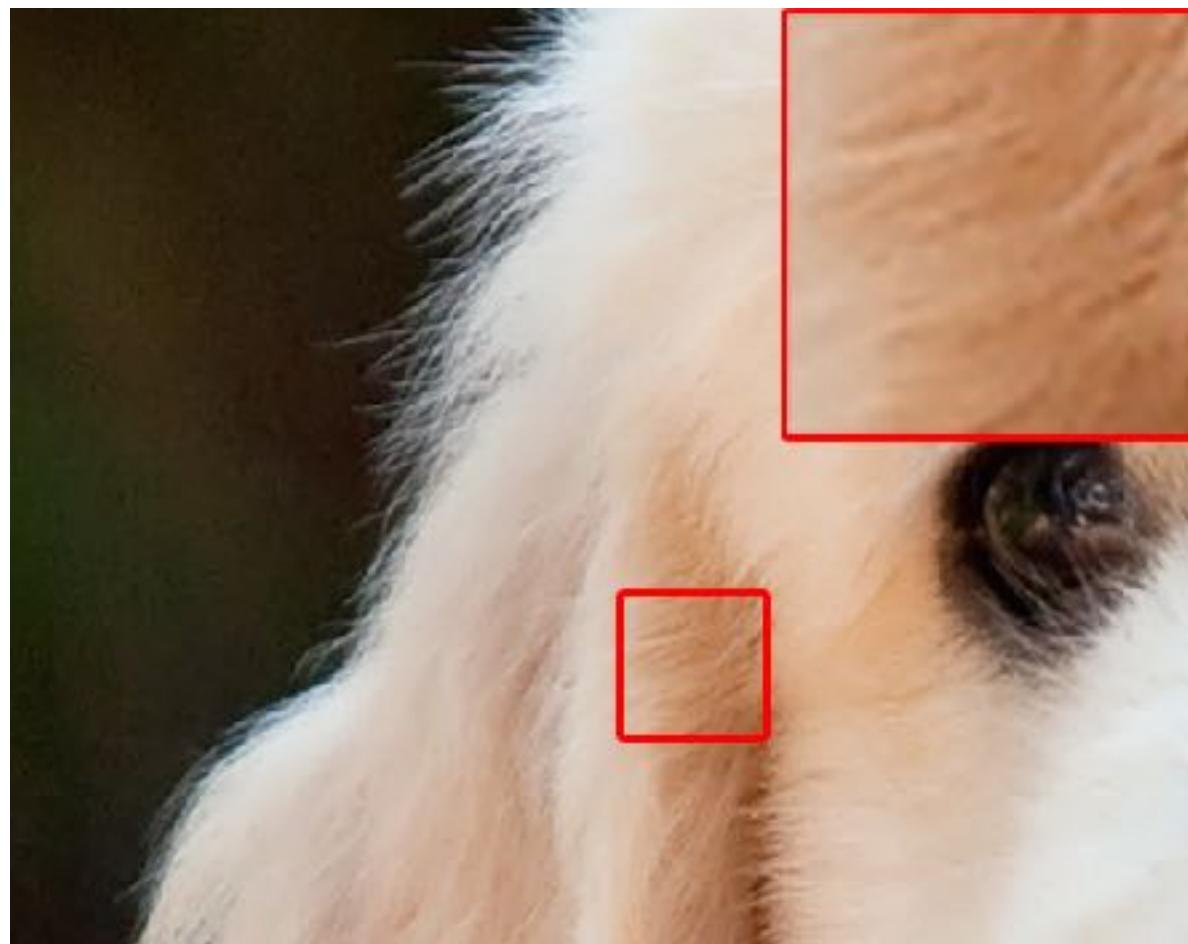
<http://engineering.flipboard.com/2015/05/scaling-convnets/>

# New applications: Image Upscaling (Flipboard)

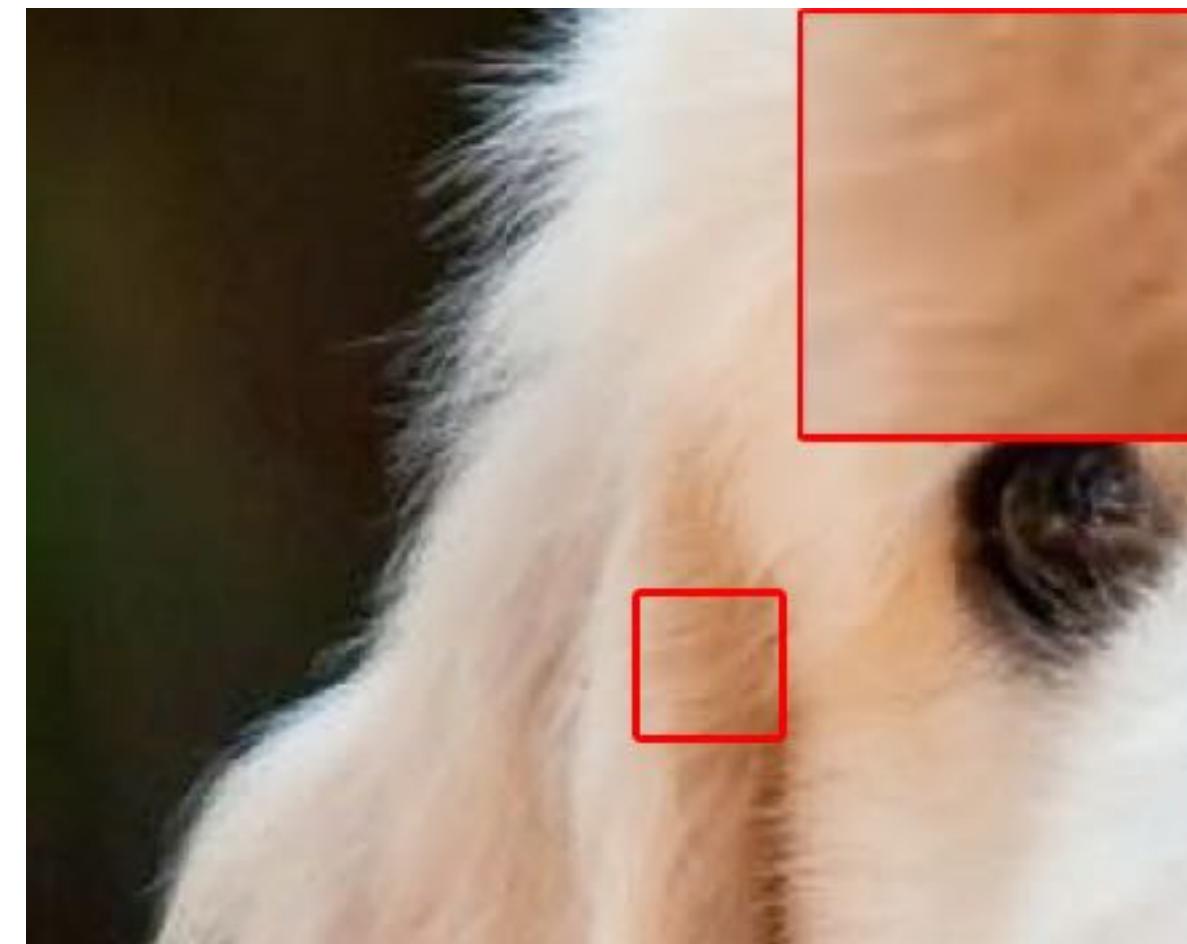


<http://engineering.flipboard.com/2015/05/scaling-convnets/>

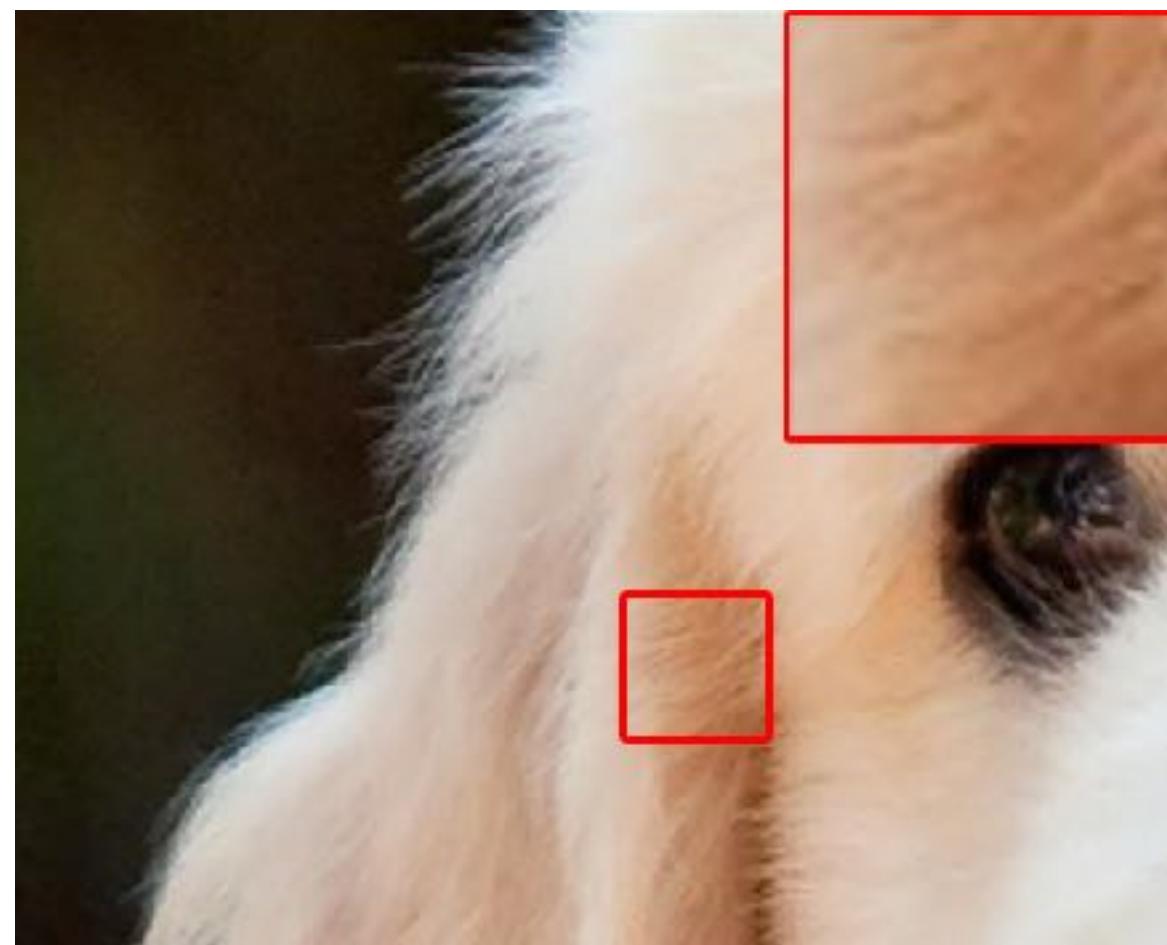
## New applications: Image Upscaling (Flipboard)



Original



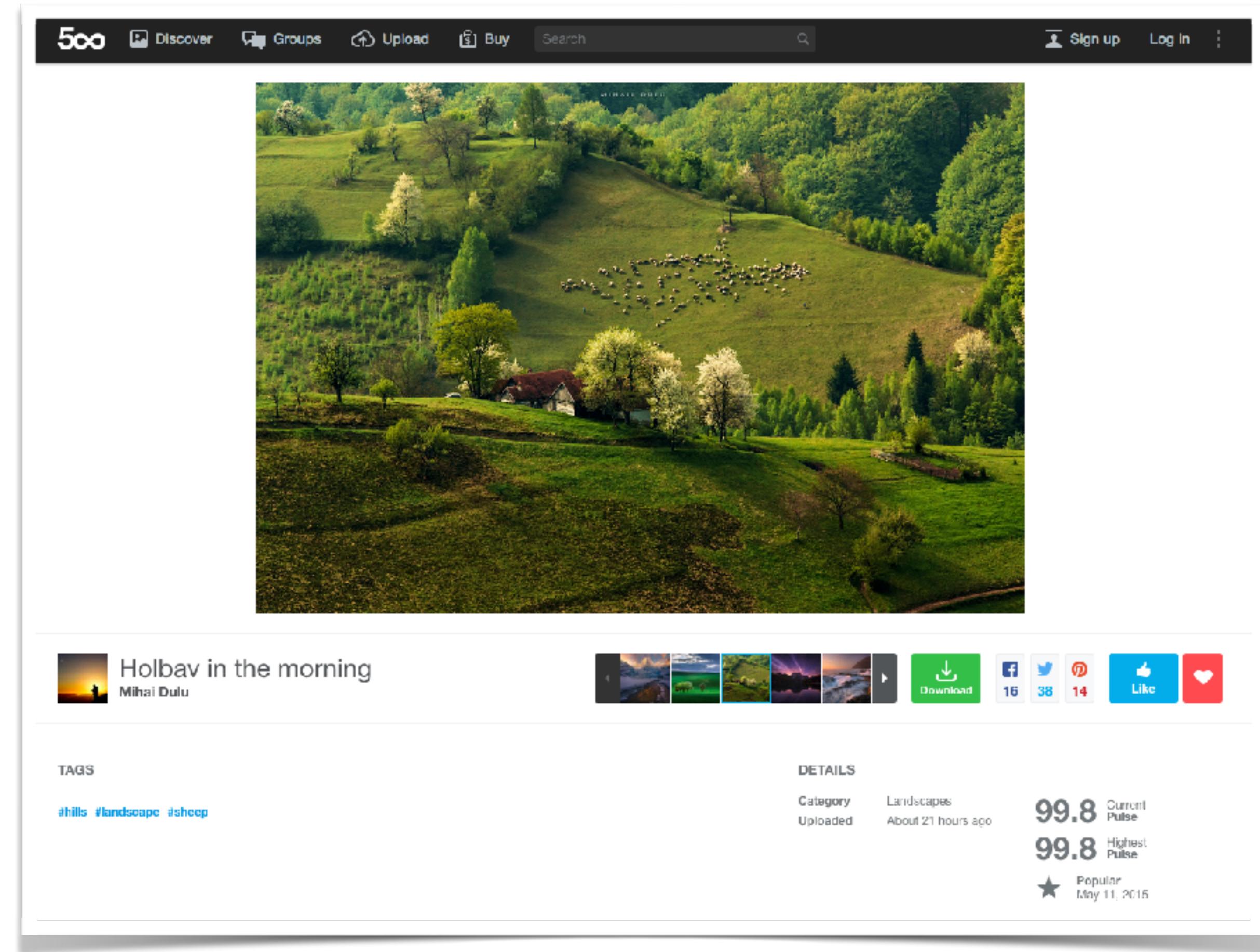
Bicubic



Model

<http://engineering.flipboard.com/2015/05/scaling-convnets/>

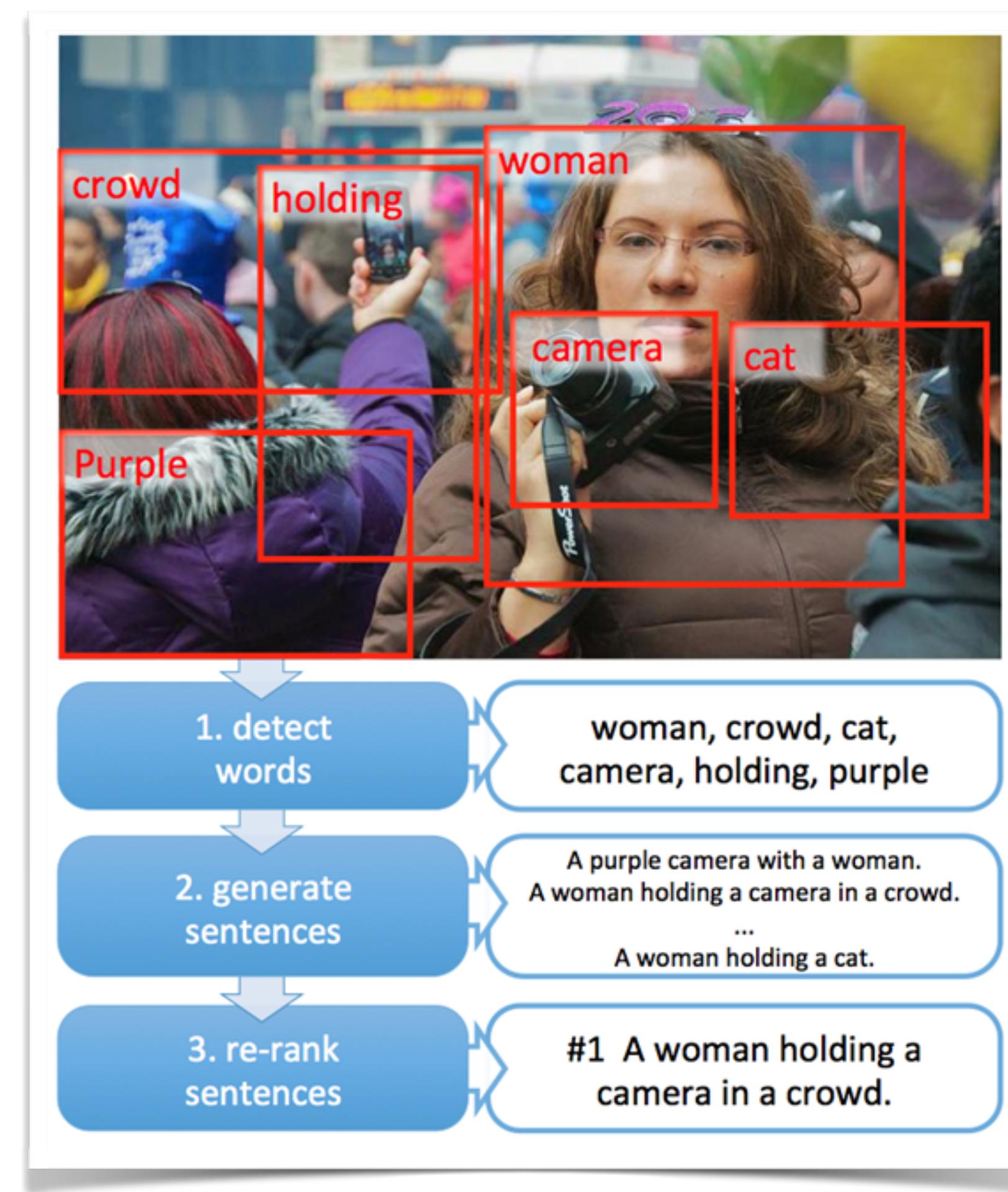
# New applications: Non visual data prediction



## What is Pulse?

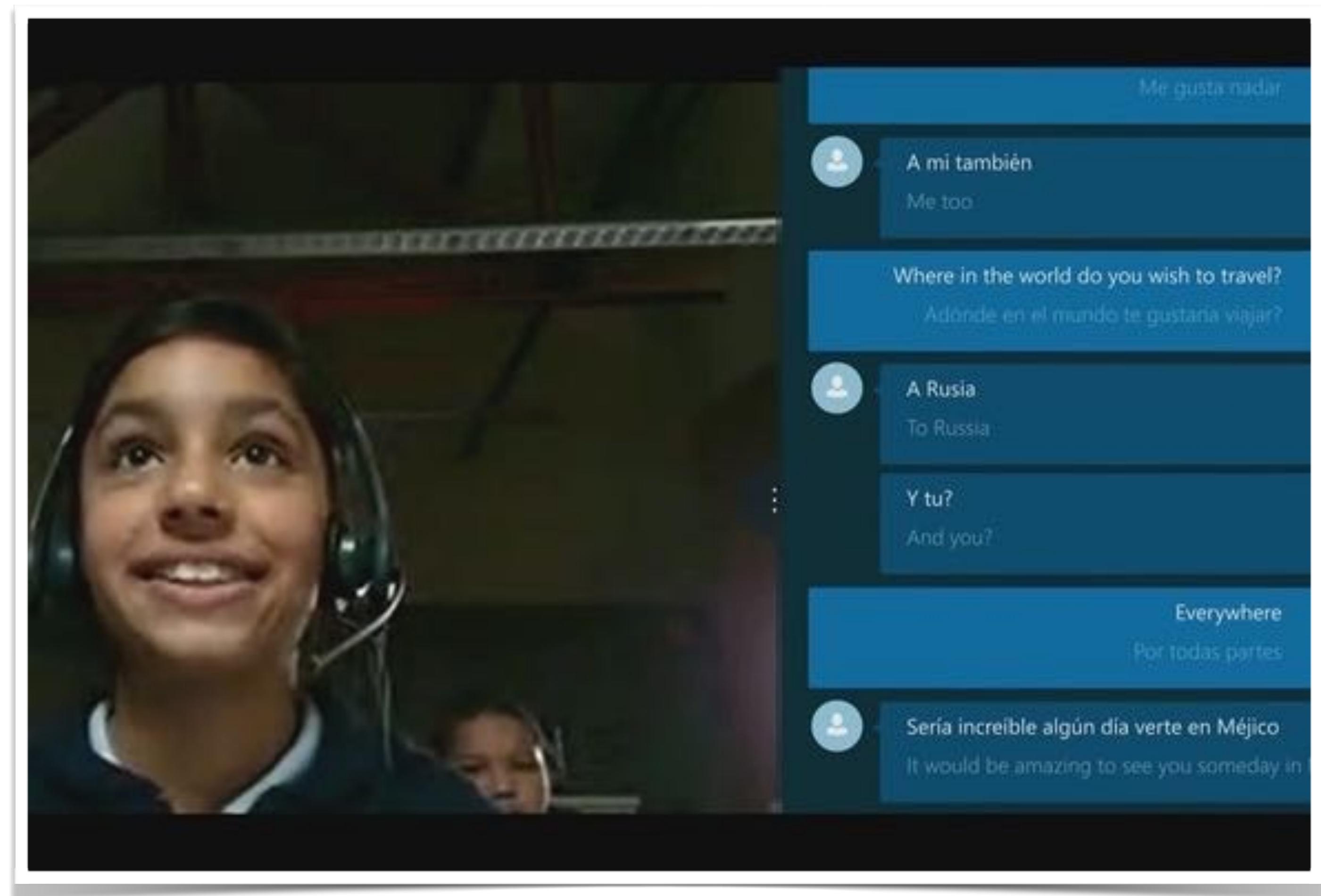
Pulse is a score out of 100 points that measures how **popular** a photo is. Pulse is calculated by an algorithm, which is unique to 500px and is based on votes (Likes & Favorites) on your photo from the community. The Pulse algorithm was designed to promote daily exposure of new photographs and photographers. It is not necessarily a measure of photograph's quality.

# New applications: Automatic Image Captioning

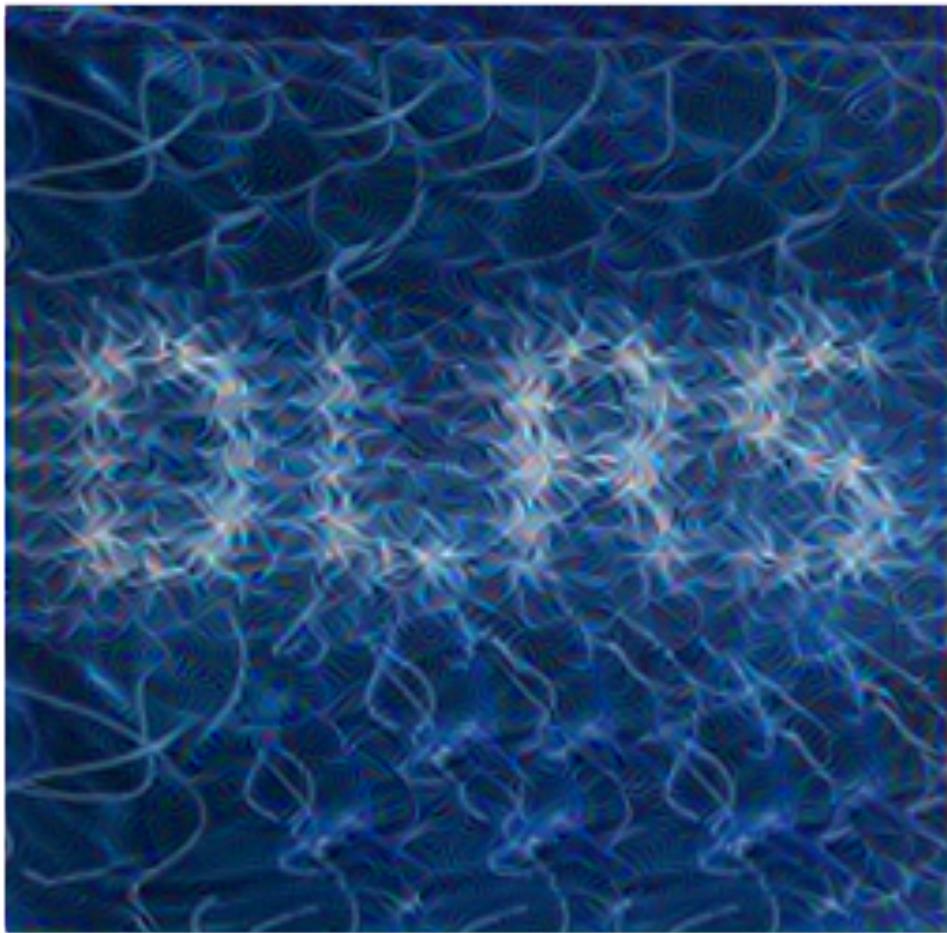


<http://blogs.technet.com/b/machinelearning/archive/2014/11/18/rapid-progress-in-automatic-image-captioning.aspx>

# Speech translation



# Recommenders



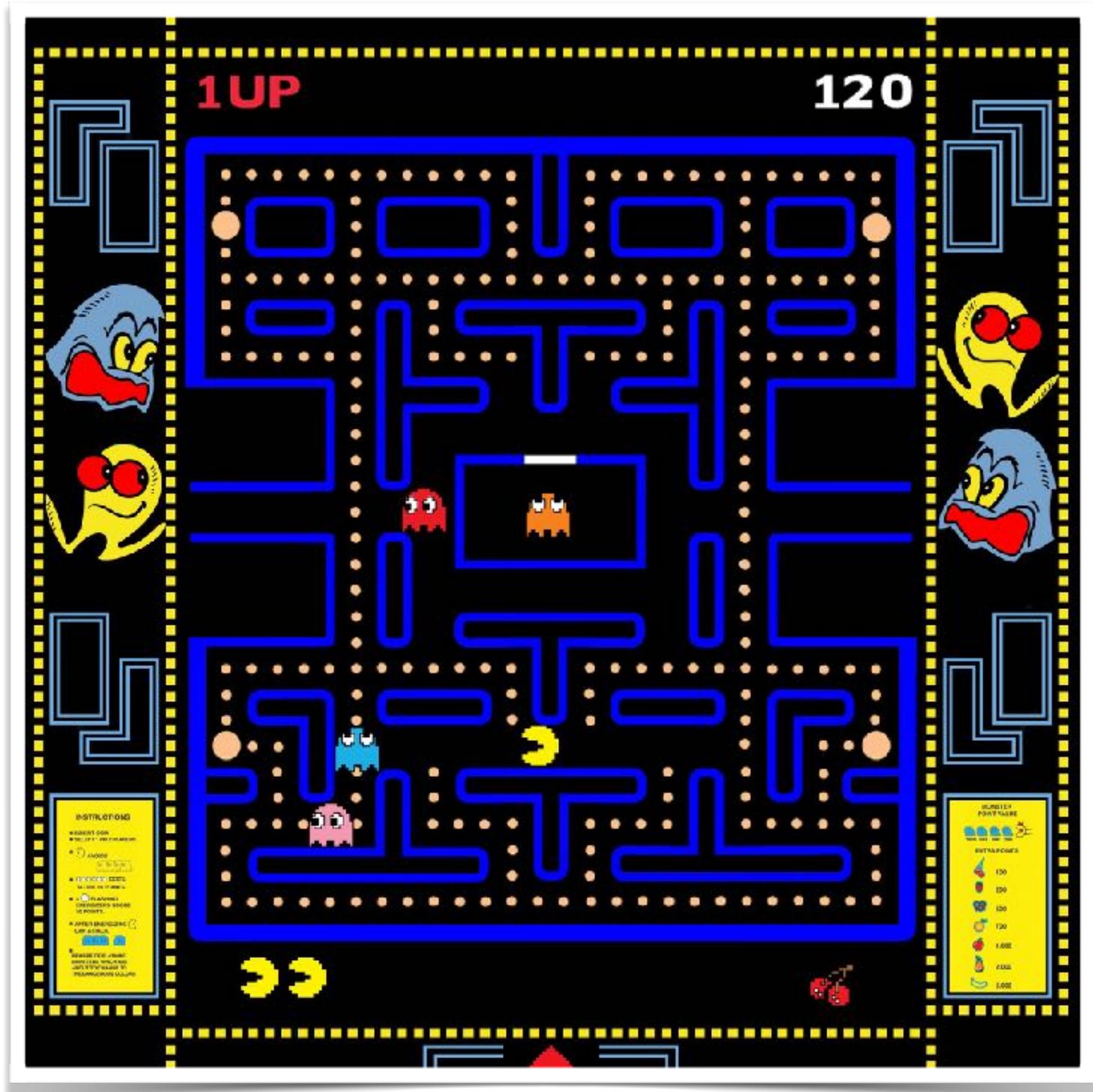
## 1st Workshop on Deep Learning for Recommender Systems

in conjunction with RecSys 2016  
15 September 2016, Boston, USA

# Music Generation

The screenshot shows a SoundCloud profile for an AI entity named 'deepjazz'. The profile picture is a white circle containing a stylized 'dj' logo. The bio reads: 'I'm an AI built to make Jazz' and 'Princeton, United States'. The profile has 104 followers, 1 following, and 6 tracks. It features a track titled 'deepjazz on Metheny' from 14 days ago, categorized as '#Electronic', which has 0:33 duration. Below are three other tracks: '1 deepjazz On Metheny ... 1 Epoch' (6,142 plays), '2 deepjazz On Metheny ... 16 Epochs' (3,452 plays), and '3 deepjazz On Metheny ... 32 Epochs' (1,908 plays). The SoundCloud header includes a search bar, 'Sign in' and 'Create account' buttons, and an 'Upload' option.

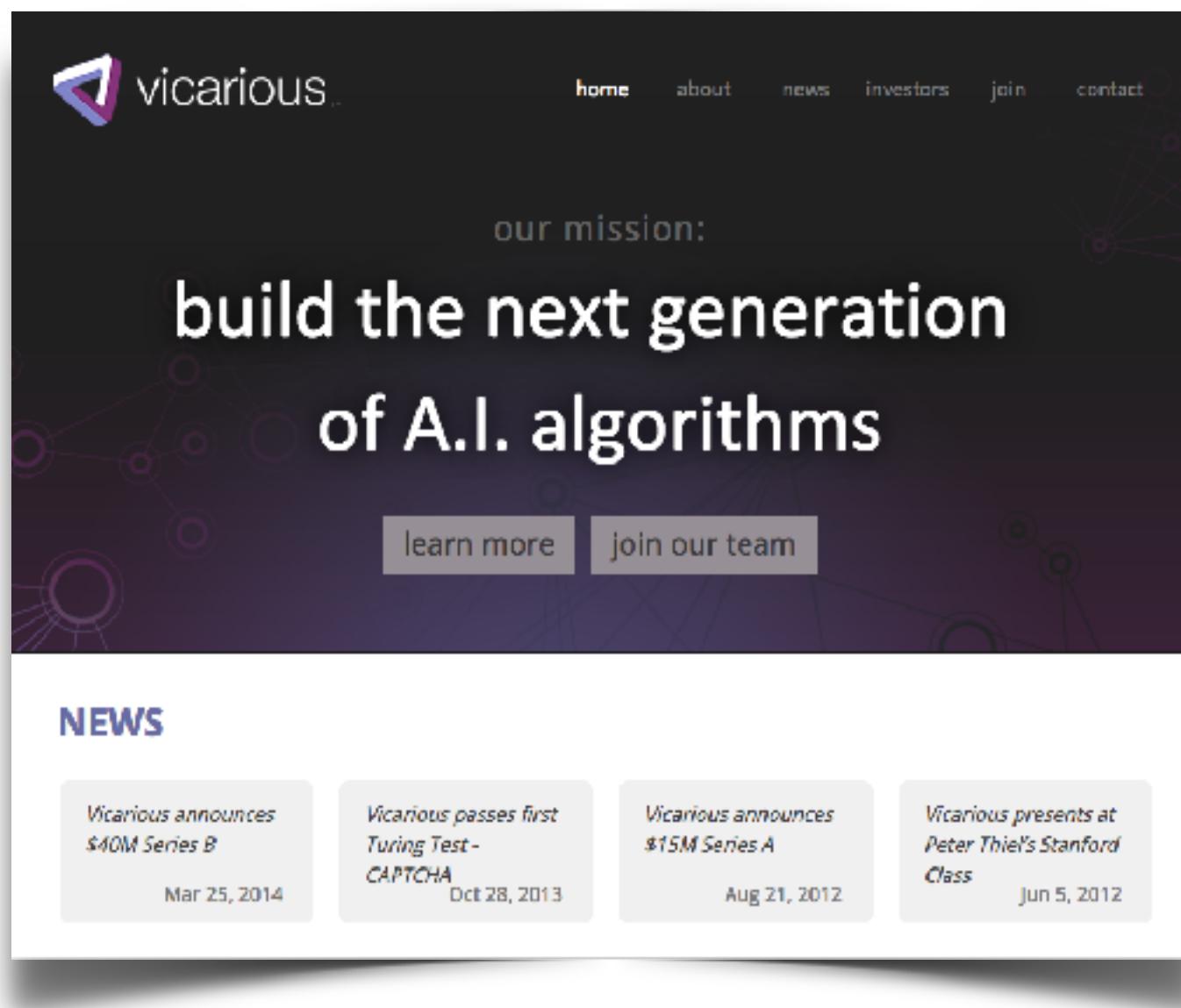
# Reinforcement learning.



Go



# Start Ups

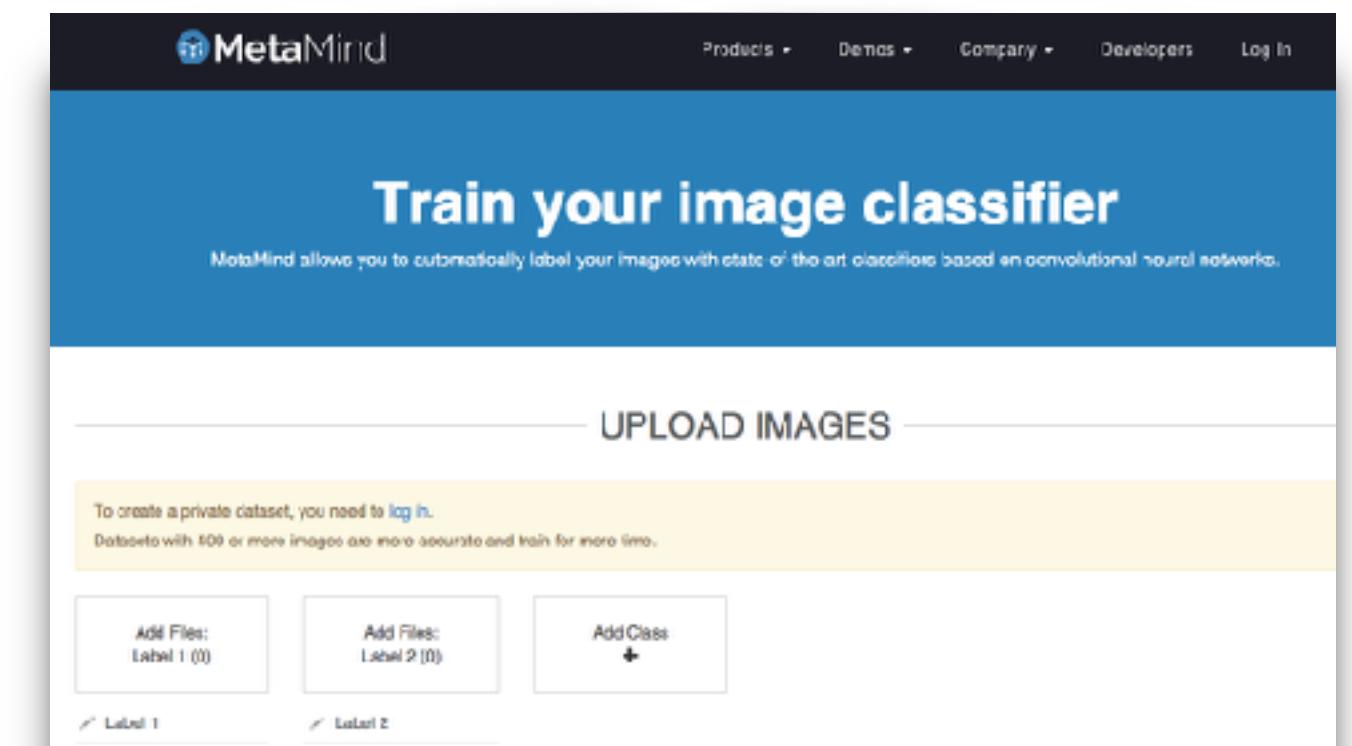


The homepage of Vicarious features a dark background with a network of nodes and connections. At the top, there's a navigation bar with links to home, about, news, investors, join, and contact. Below the navigation, the text "our mission: build the next generation of A.I. algorithms" is prominently displayed. There are two buttons at the bottom: "learn more" and "join our team". On the left side, there's a section titled "NEWS" with four news items:

- Vicarious announces \$40M Series B - Mar 25, 2014
- Vicarious passes first Turing Test - CAPTCHA - Oct 28, 2013
- Vicarious announces \$15M Series A - Aug 21, 2012
- Vicarious presents at Peter Thiel's Stanford Class - Jun 5, 2012



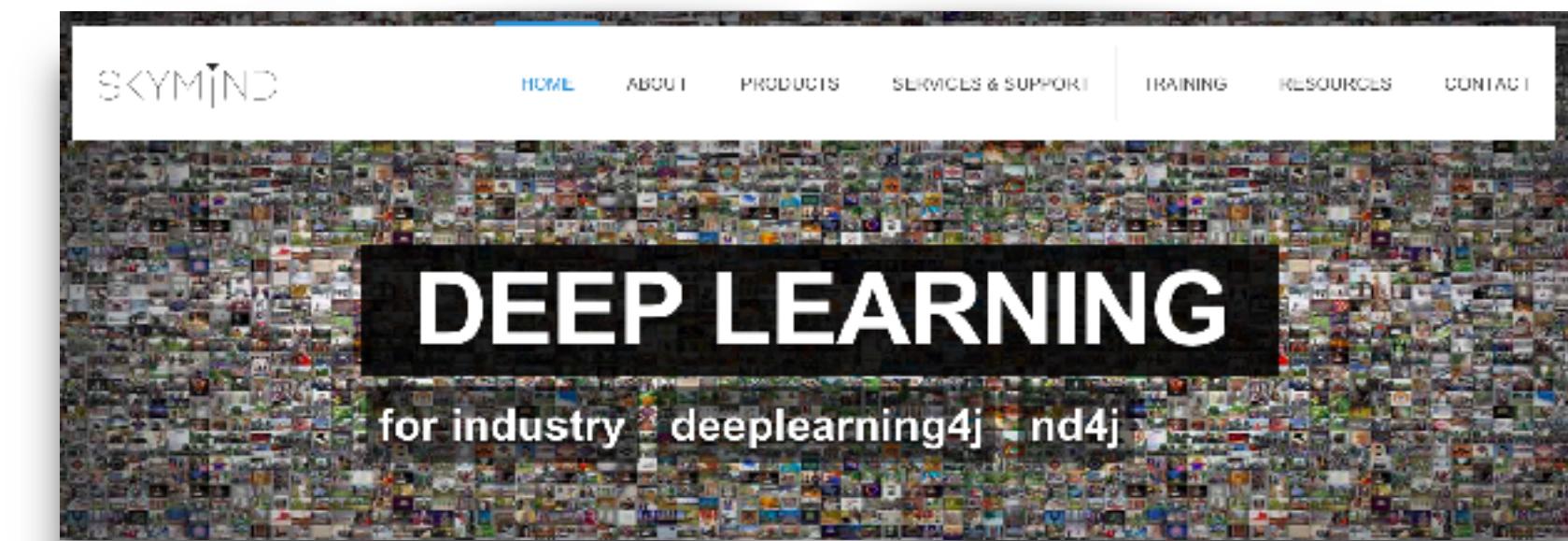
The homepage of Dato features a dark blue header with the Dato logo and a "DOWNLOAD" button. Below the header, the text "MACHINE LEARNING that scales with your business" is displayed. There are three main sections: "Ultra-Fast Data Analytics", "Best-In-Class Predictive Modeling", and "Production-Ready Data Science". Each section has a brief description and a downward arrow icon.



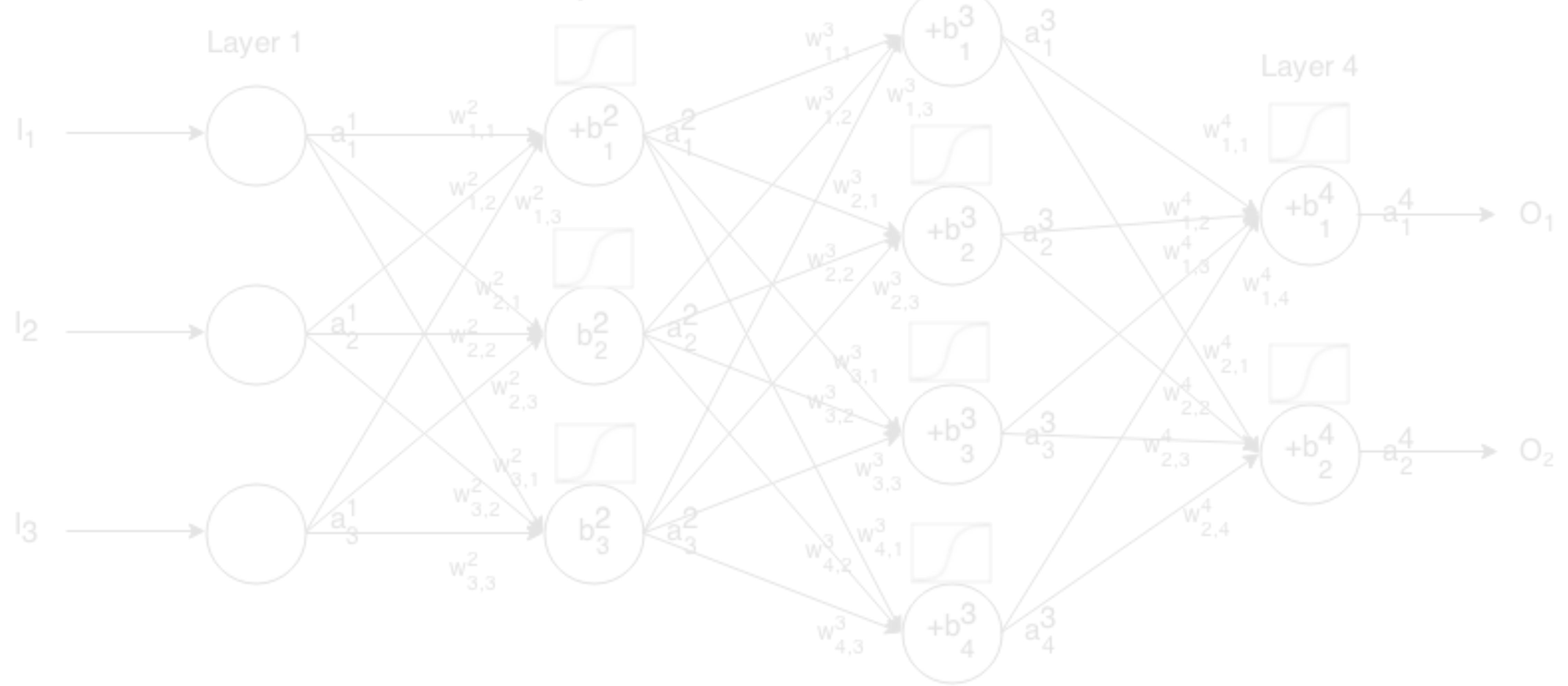
The homepage of MetaMind has a dark blue header with a "MetaMind" logo and a "Log In" button. Below the header, the text "Train your image classifier" is displayed. A subtext states: "MetaMind allows you to automatically label your images with state-of-the-art classifications based on convolutional neural networks." The main area is titled "UPLOAD IMAGES" and includes instructions: "To create a private dataset, you need to log in. Datasets with 100 or more images are more accurate and train for longer." There are three input fields: "Add Files: Label 1 (0)", "Add Files: Label 2 (0)", and "Add Class +".



The homepage of Clarifai features a large image of a mountain landscape. At the top, there's a navigation bar with links to ABOUT, TECHNOLOGY, API, NEWS, BLOG, JOBS, and CONTACT. The Clarifai logo is prominently displayed. Below the navigation, the text "Bring the future into focus with our world class visual recognition system" is displayed. There are two main news articles: "Image recognition: Consumer products will drive enterprise breakthroughs" by HANNAH KASTMAN, BOSTON, NOV 14 and "Machines Finally Match Monkeys in Key Image Recognition Test" by ROBERT McLELLAN, WIRE, NOV 14. At the bottom, there are two buttons: "TRY IT NOW" and "API SIGN UP".



The homepage of Skymind features a large image of a collage of small images. At the top, there's a navigation bar with links to HOME, ABOUT, PRODUCTS, SERVICES & SUPPORT, TRAINING, RESOURCES, and CONTACT. The word "SKYMIN" is written vertically on the left. Below the navigation, the text "DEEP LEARNING" is displayed in large letters. A subtext states: "for industry - deeplearning4j - nd4j".



# What is Deep Learning?

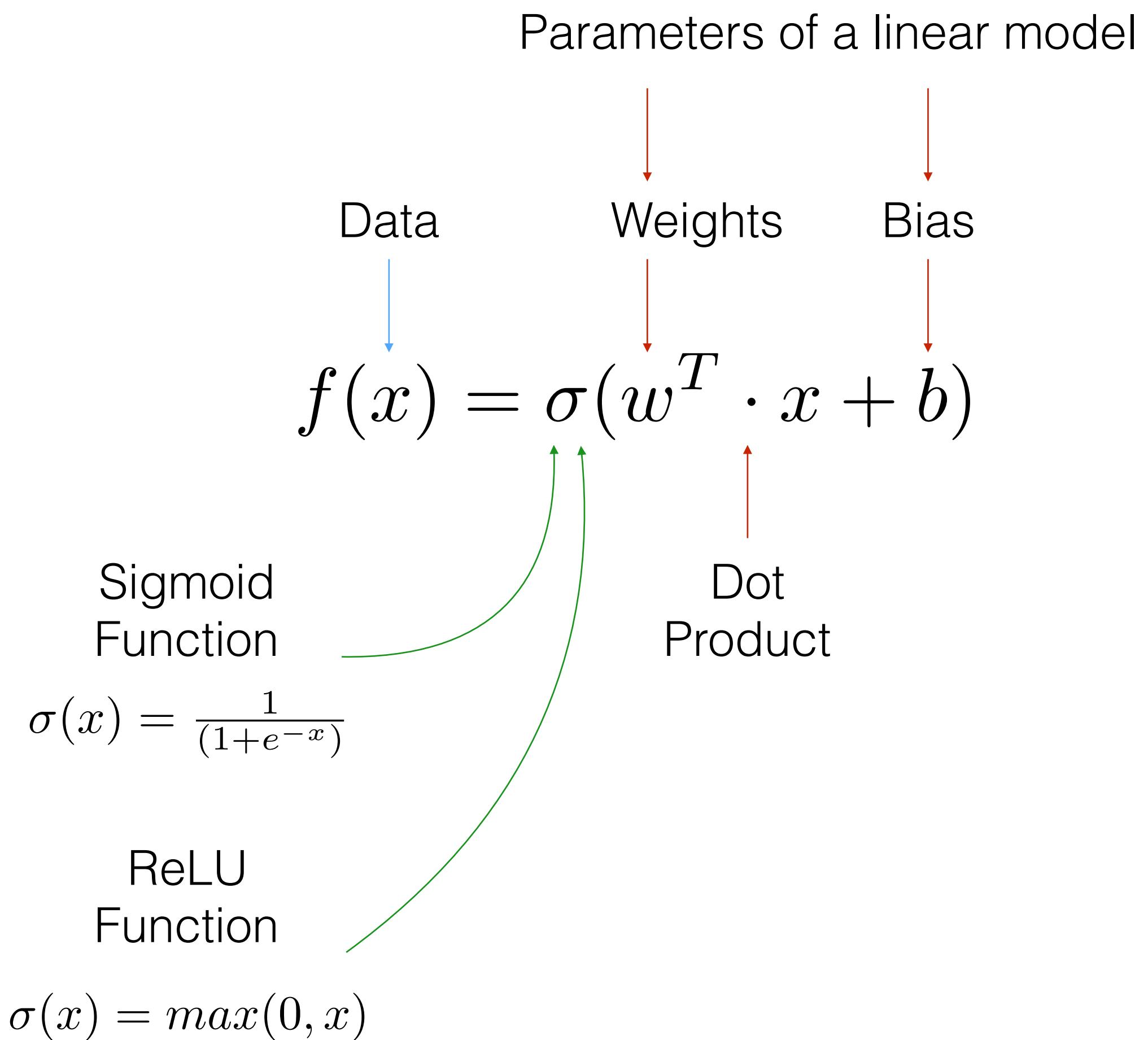
# Learning from Data

Training data: a set of  $(x^{(m)}, y^{(m)})$  pairs.

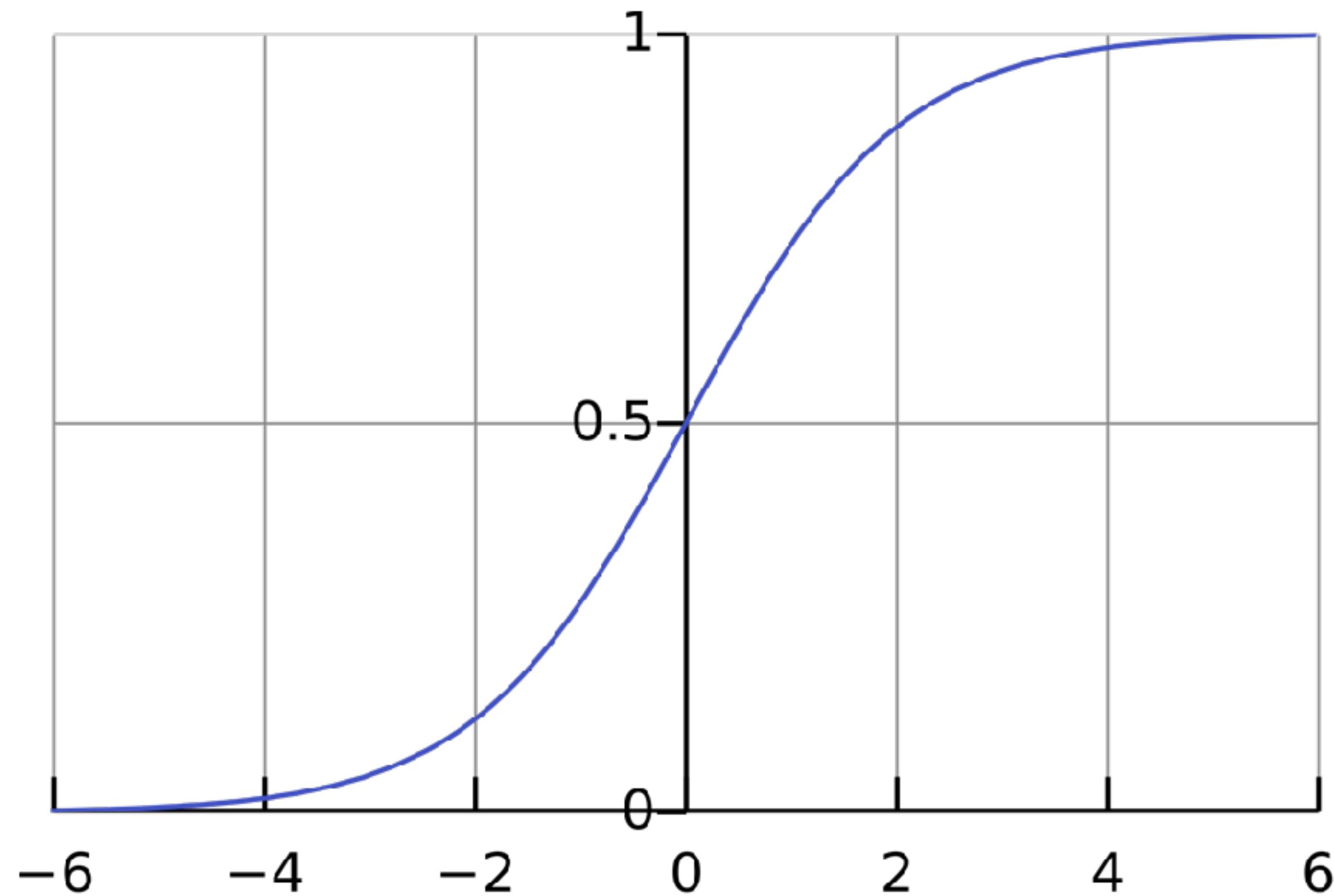
Learn a function  $f_w : x \rightarrow y$  to predict on new inputs  $x$ .

1. Choose a model function family  $f_w$ .
2. Optimize parameters  $w$ .

# 1-layer neural net model



## Non-linearity



$$\sigma(x) = \frac{1}{(1+e^{-x})}$$

# Non-linearity



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

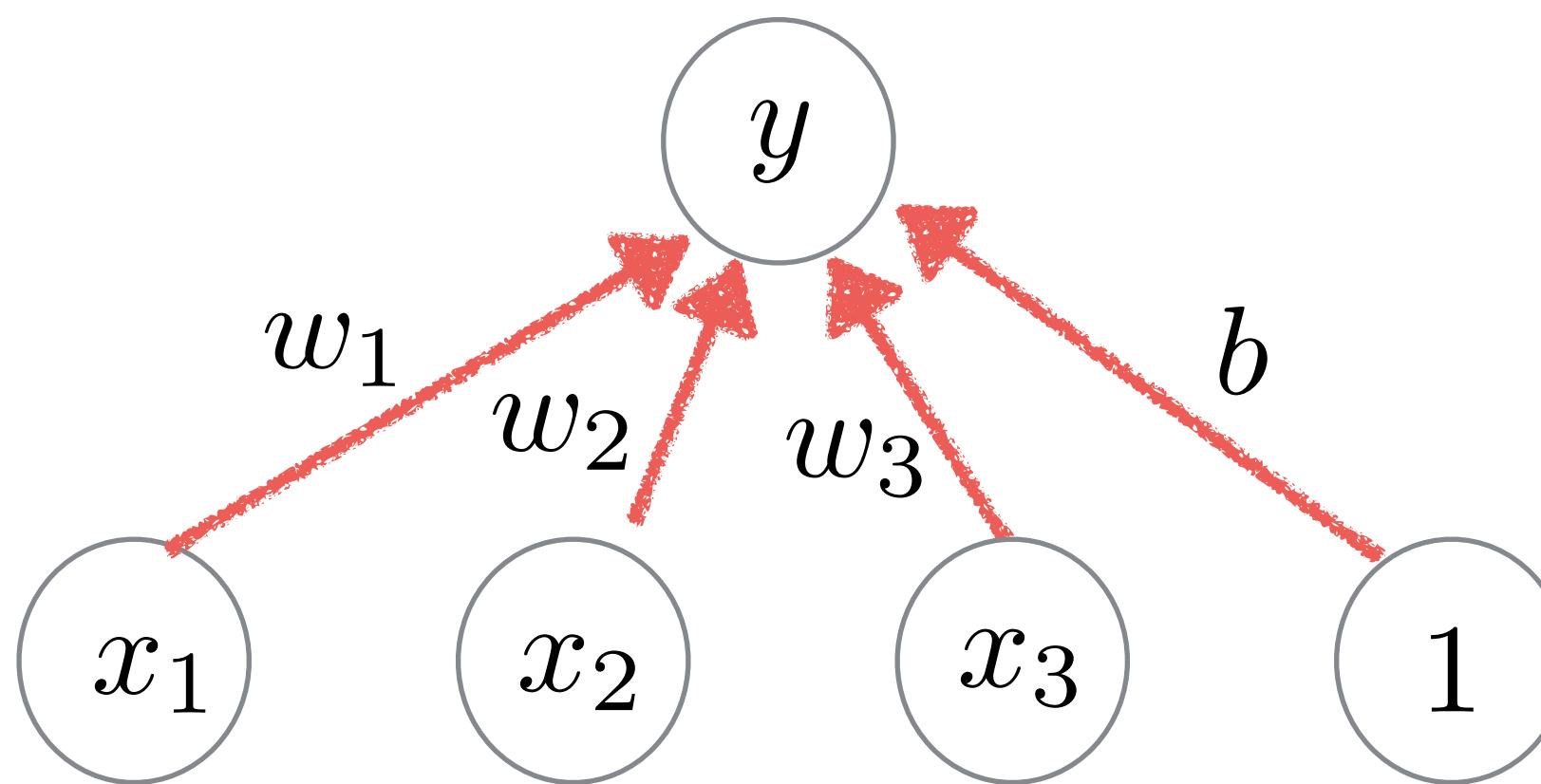
# Non-linearity

Table 3: Non-linearities tested.

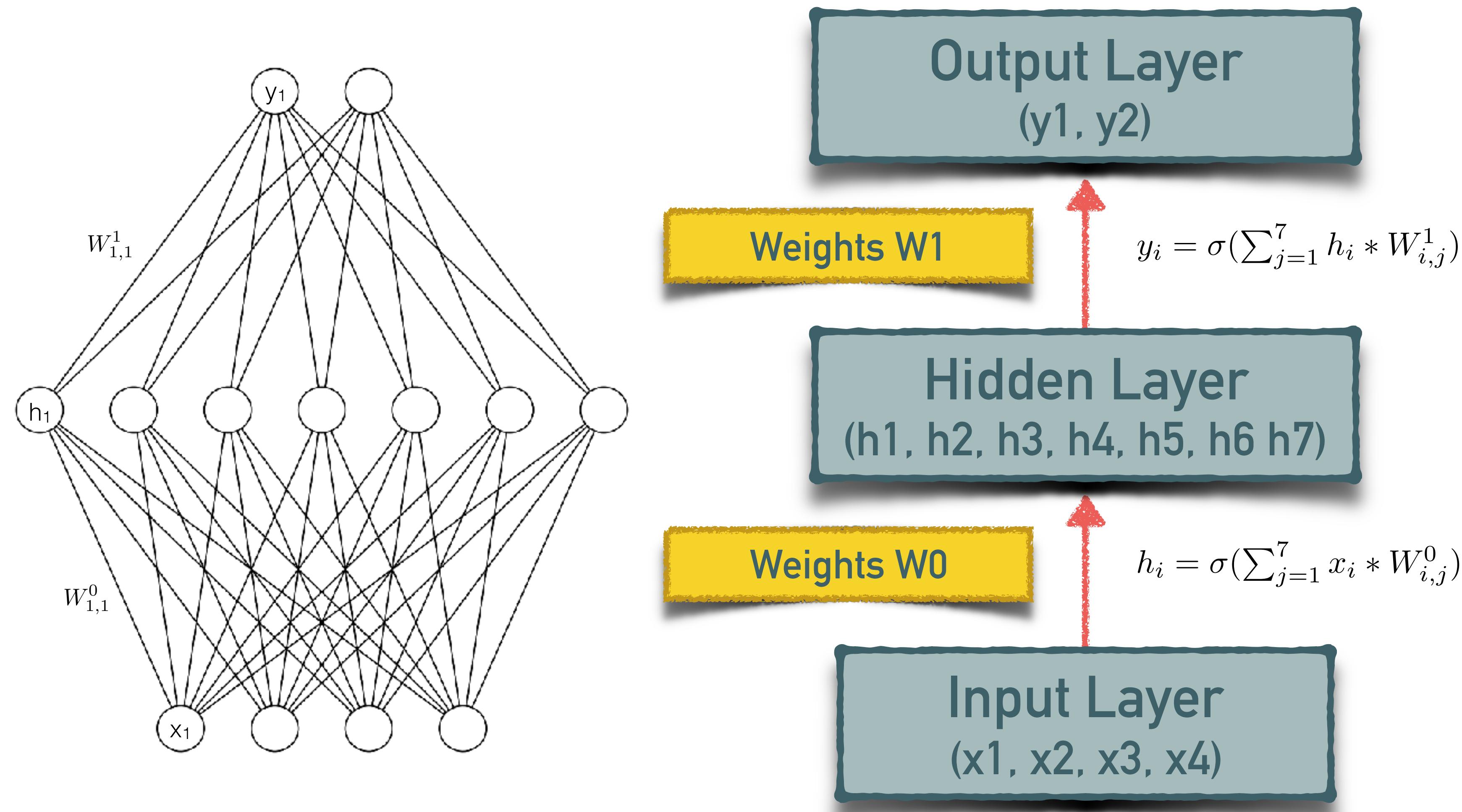
Name	Formula	Year
none	$y = x$	-
sigmoid	$y = \frac{1}{1+e^{-x}}$	1986
tanh	$y = \frac{e^{2x}-1}{e^{2x}+1}$	1986
ReLU	$y = \max(x, 0)$	2010
(centered) SoftPlus	$y = \ln(e^x + 1) - \ln 2$	2011
LReLU	$y = \max(x, \alpha x), \alpha \approx 0.01$	2011
maxout	$y = \max(W_1x + b_1, W_2x + b_2)$	2013
APL	$y = \max(x, 0) + \sum_{s=1}^S a_i^s \max(0, -x + b_i^s)$	2014
VLReLU	$y = \max(x, \alpha x), \alpha \in [0.1, 0.5]$	2014
RReLU	$y = \max(x, \alpha x), \alpha = \text{random}(0.1, 0.5)$	2015
PReLU	$y = \max(x, \alpha x), \alpha$ is learnable	2015
ELU	$y = x, \text{ if } x \geq 0, \text{ else } \alpha(e^x - 1)$	2015

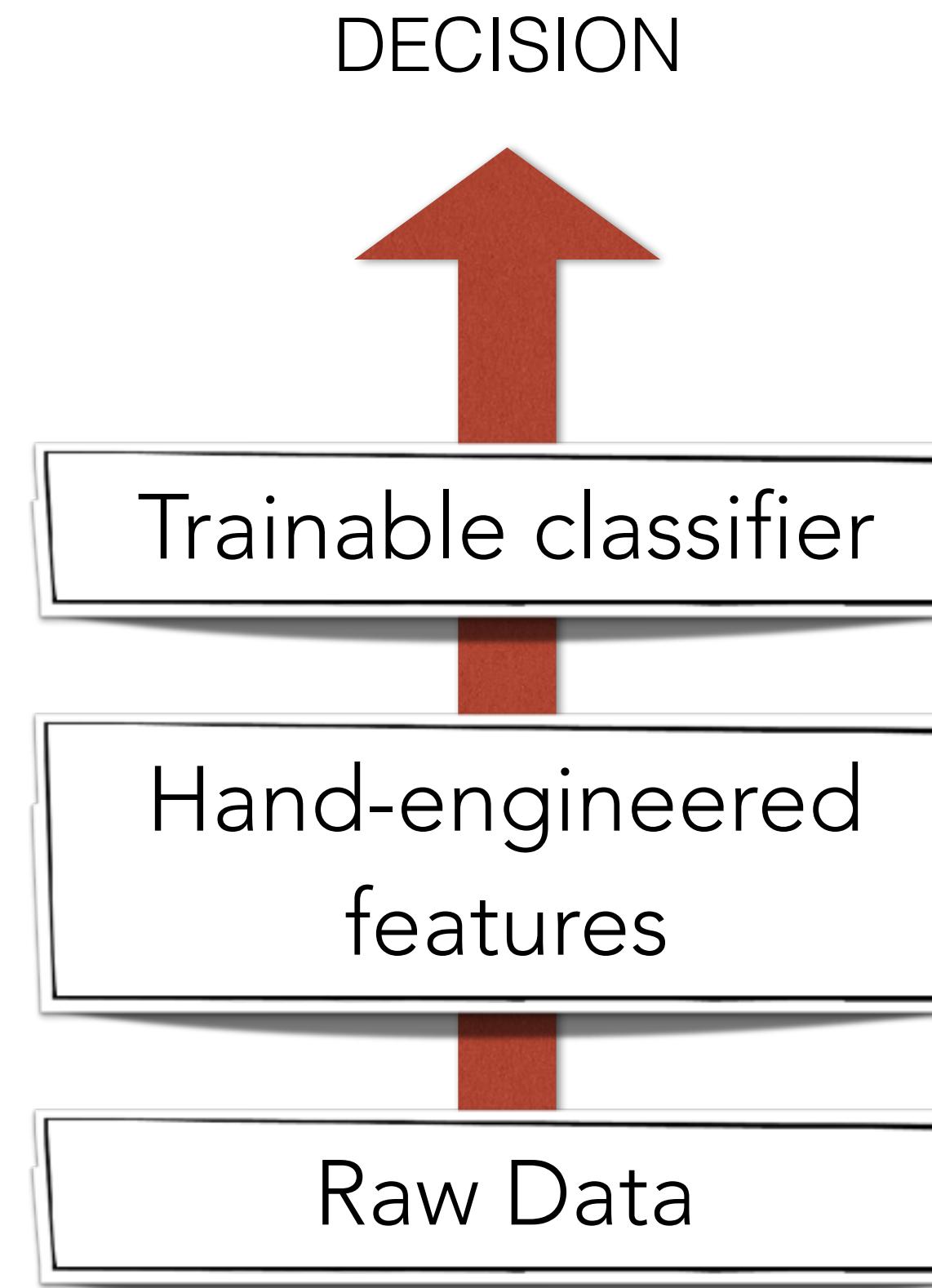
# Graphical representation of 1-layer neural net model

$$f(x) = \sigma(w^T \cdot x + b)$$

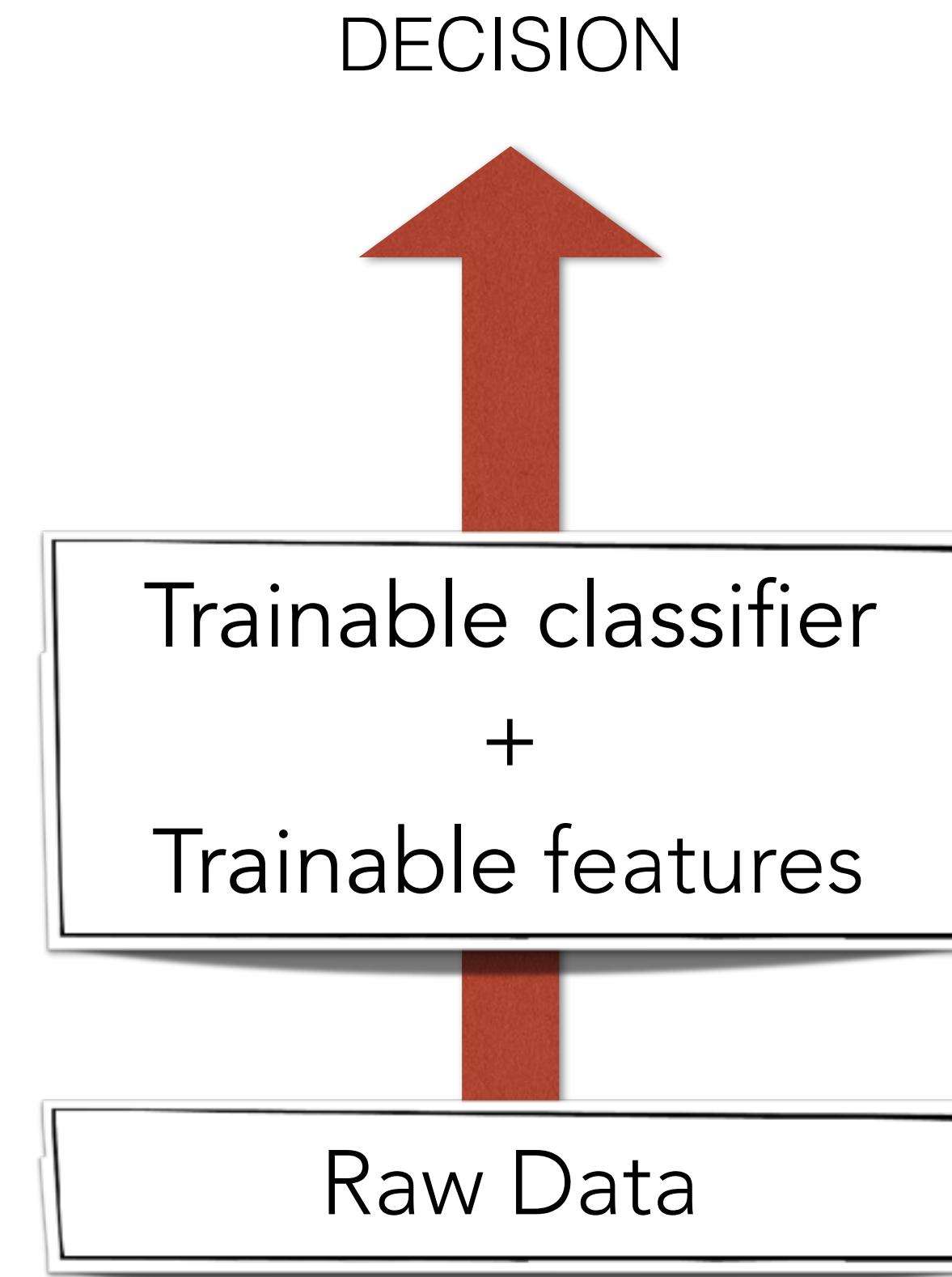


## 2-layer neural net model



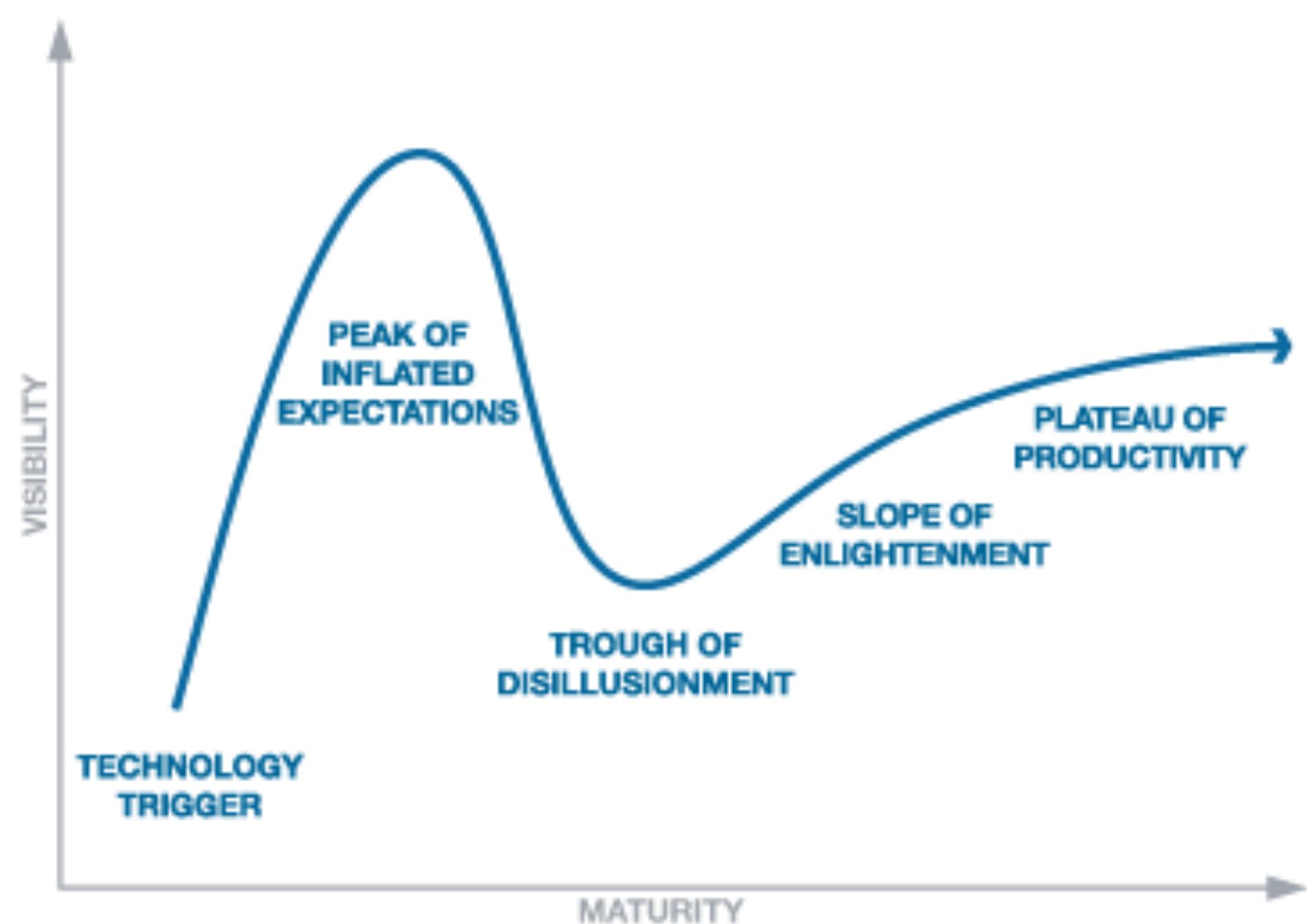


STANDARD MACHINE  
LEARNING



DEEP LEARNING

# Is Deep Learning Overhyped?



# Hype is not new

## NEW NAVY DEVICE LEARNS BY DOING

Psychologist Shows Embryo of Computer Designed to Read and Grow Wiser

WASHINGTON, July 7 (UPI) —The Navy revealed the embryo of an electronic computer today that it expects will be able to walk, talk, see, write, reproduce itself and be conscious of its existence.

The embryo—the Weather Bureau's \$2,000,000 "704" computer—learned to differentiate between right and left after fifty attempts in the Navy's demonstration for newsmen.

The service said it would use this principle to build the first of its Perceptron thinking machines that will be able to read and write. It is expected to be finished in about a year at a cost of \$100,000.

Dr. Frank Rosenblatt, designer of the Perceptron, conducted the demonstration. He said the machine would be the first device to think as the human brain. As do human be-

ings, Perceptron will make mistakes at first, but will grow wiser as it gains experience, he said.

Dr. Rosenblatt, a research psychologist at the Cornell Aeronautical Laboratory, Buffalo, said Perceptrons might be fired to the planets as mechanical space explorers.

### Without Human Controls

The Navy said the perceptron would be the first non-living mechanism "capable of receiving, recognizing and identifying its surroundings without any human training or control."

The "brain" is designed to remember images and information it has perceived itself. Ordinary computers remember only what is fed into them on punch cards or magnetic tape.

Later Perceptrons will be able to recognize people and call out their names and instantly translate speech in one language to speech or writing in another language, it was predicted.

Mr. Rosenblatt said in principle it would be possible to build brains that could reproduce themselves on an assembly line and which would be conscious of their existence.

1958 New York Times...

In today's demonstration, the "704" was fed two cards, one with squares marked on the left side and the other with squares on the right side.

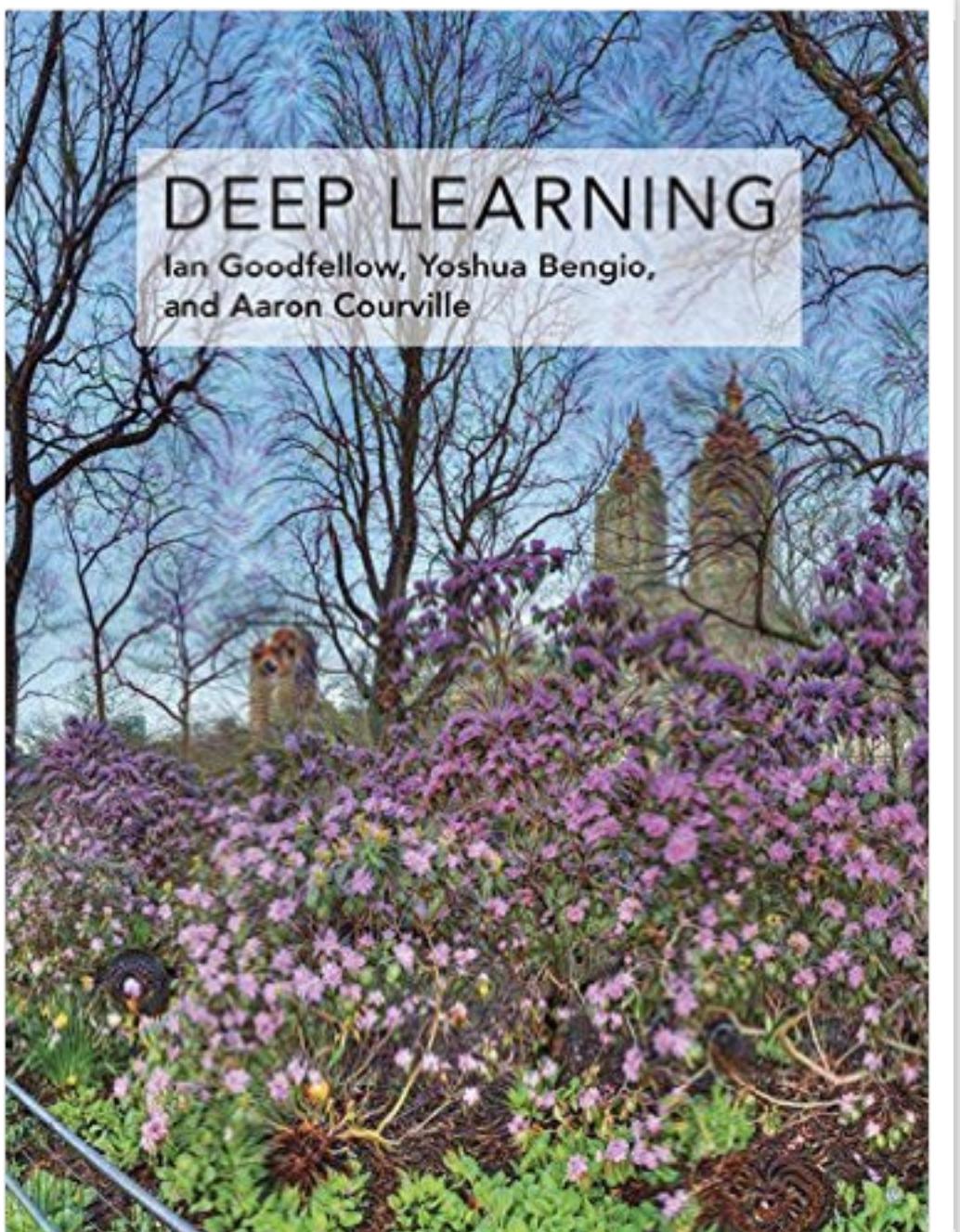
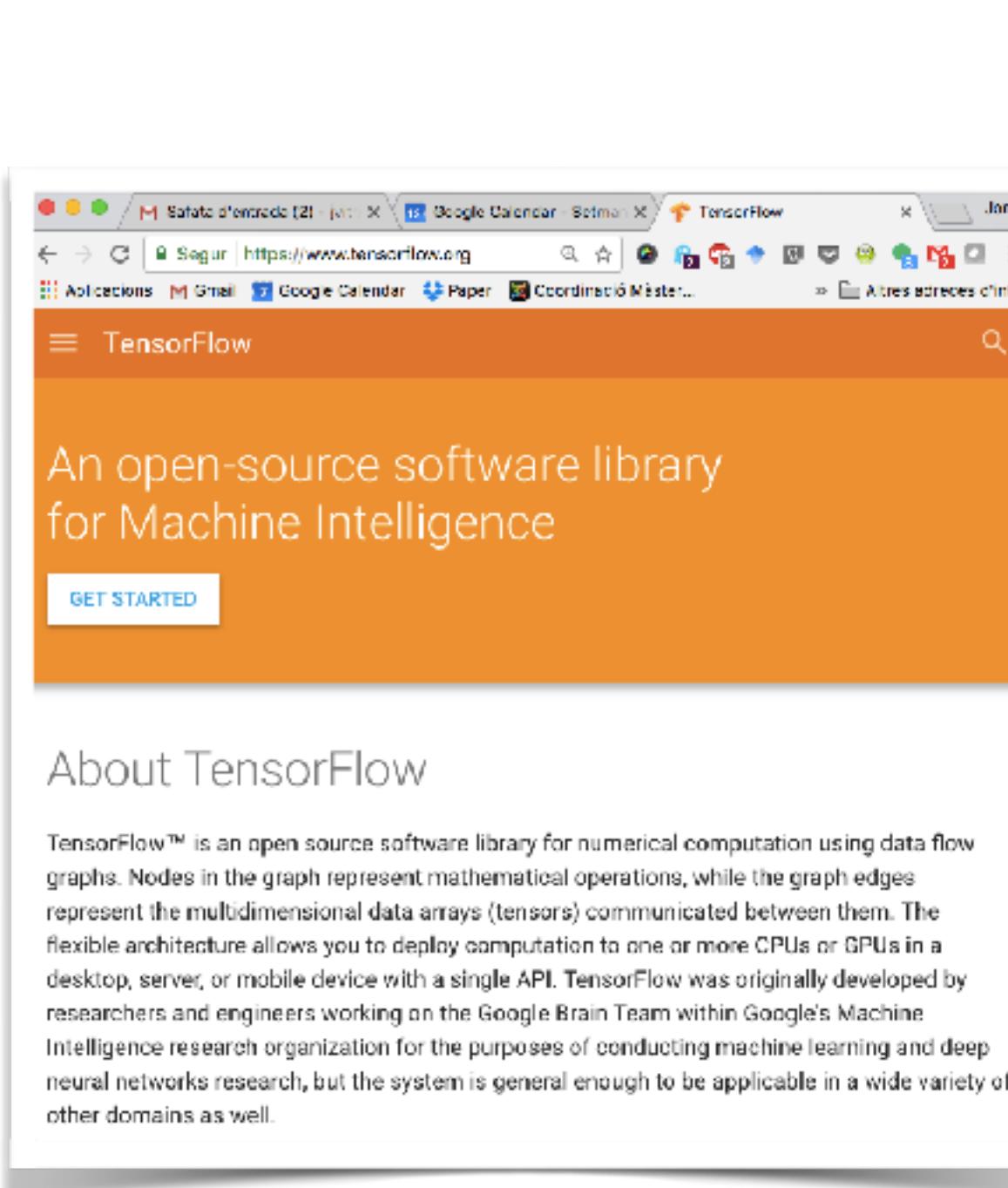
### Learns by Doing

In the first fifty trials, the machine made no distinction between them. It then started registering a "Q" for the left squares and "O" for the right squares.

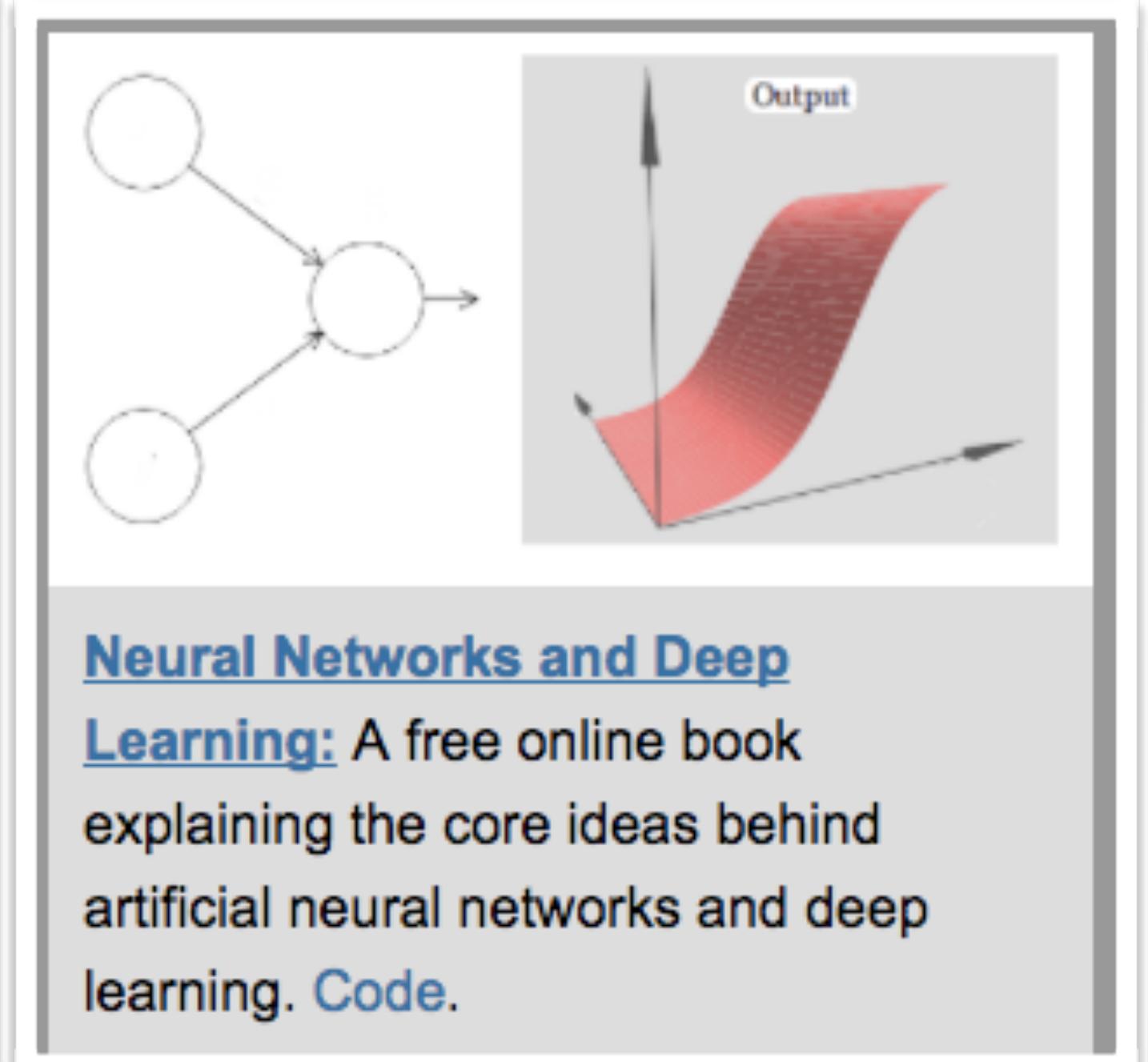
Dr. Rosenblatt said he could explain why the machine learned only in highly technical terms. But he said the computer had undergone a "self-induced change in the wiring diagram."

The first Perceptron will have about 1,000 electronic "association cells" receiving electrical impulses from an eye-like scanning device with 400 photo-cells. The human brain has 10,000,000,000 responsive cells, including 100,000,000 connections with the eyes.

# Bibliography



**Deep Learning**, Yoshua Bengio, Ian Goodfellow, Aaron Courville, MIT Press, 2017  
<http://www.deeplearningbook.org/>



[Neural Networks and Deep Learning](#): A free online book explaining the core ideas behind artificial neural networks and deep learning. [Code](#).

A screenshot of the Keras Documentation website. The header reads "Keras Documentation". The main content area is titled "Keras: Deep Learning library for Theano and TensorFlow". It includes sections like "Getting started", "FAQ", "Models", and "Layers". The footer notes that Keras is compatible with Python 2.7-3.5.

By Michael Nielsen / Jan 2017  
<http://neuralnetworksanddeeplearning.com/>