

Neural Networks

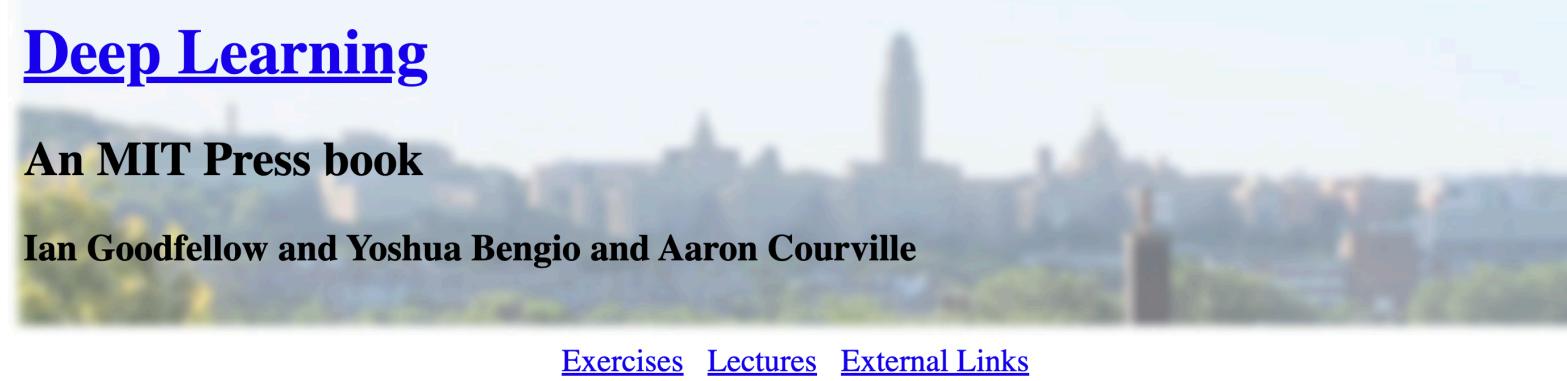
Theory and Practice

Rafał Nowak Mar 4, 2025

Practical information

- Course materials
 - SKOS (lecture notes) <https://skos.ii.uni.wroc.pl/course/view.php?id=738>
 - USOS: grades
- Additional on-line Resources:
 - <https://www.deeplearningbook.org/>
 - <https://d2l.ai/>

Online resources



The Deep Learning textbook is a resource intended to help students and practitioners enter the field of machine learning in general and deep learning in particular. The online version of the book is now complete and will remain available online for free.

The deep learning textbook can now be ordered on [Amazon](#).

For up to date announcements, join our [mailing list](#).

Citing the book

To cite this book, please use this bibtex entry:

```
@book{Goodfellow-et-al-2016,
  title={Deep Learning},
  author={Ian Goodfellow and Yoshua Bengio and Aaron Courville},
  publisher={MIT Press},
  note={\url{http://www.deeplearningbook.org}},
  year={2016}
}
```

To write your own document using our LaTeX style, math notation, or to copy our notation page, download our [template](#) files.

[Errata in published editions](#)

Deep Learning

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A screenshot of a web browser showing the homepage of "Neural Networks and Deep Learning". The title "Neural Networks and Deep Learning" is prominently displayed in a large white font against a dark blue header. The URL "neuralnetworksanddeeplearning.com" is visible in the address bar. The page content includes a brief introduction and a table of contents.

Neural Networks and Deep Learning is a free online book. The book will teach you about:

- Neural networks, a beautiful biologically-inspired programming paradigm which enables a computer to learn from observational data
- Deep learning, a powerful set of techniques for learning in neural networks

Neural networks and deep learning currently provide the best solutions to many problems in image recognition, speech recognition, and natural language processing. This book will teach you many of the core concepts behind neural networks and deep learning.

For more details about the approach taken in the book, [see here](#). Or you can jump directly to [Chapter 1](#) and get started.

A screenshot of a web browser showing the homepage of "Dive into Deep Learning". The title "Dive into Deep Learning" is in a large blue font. The page includes a sidebar with navigation links like "Preface", "Installation", "Notation", and chapters 1 through 11. A sidebar also lists "PyTorch", "MXNet", "Notebooks", and "Code". On the right, there's a thumbnail of the book cover and some statistics: "Interactive deep learning book with code, math, and discussions", "Implemented with PyTorch, NumPy/MXNet, JAX, and TensorFlow", and "Adopted at 400 universities from 60 countries". A star rating indicates 16,642 stars.

Goals for this course

- Understanding the math used in neural networks (NN)
- Teach **basics** of NN implementation
- Teach convolutional networks
- Design and train basic NN models for some various tasks
- Introduce to generative models (stable diffusion models)
- Introduce some good practices for MLOps
- Teach about NNs in NLP

Neural Networks

Artificial Intelligence

Machine
Learning

Neural
Networks

Deep
Learning

Kinds of ML problem

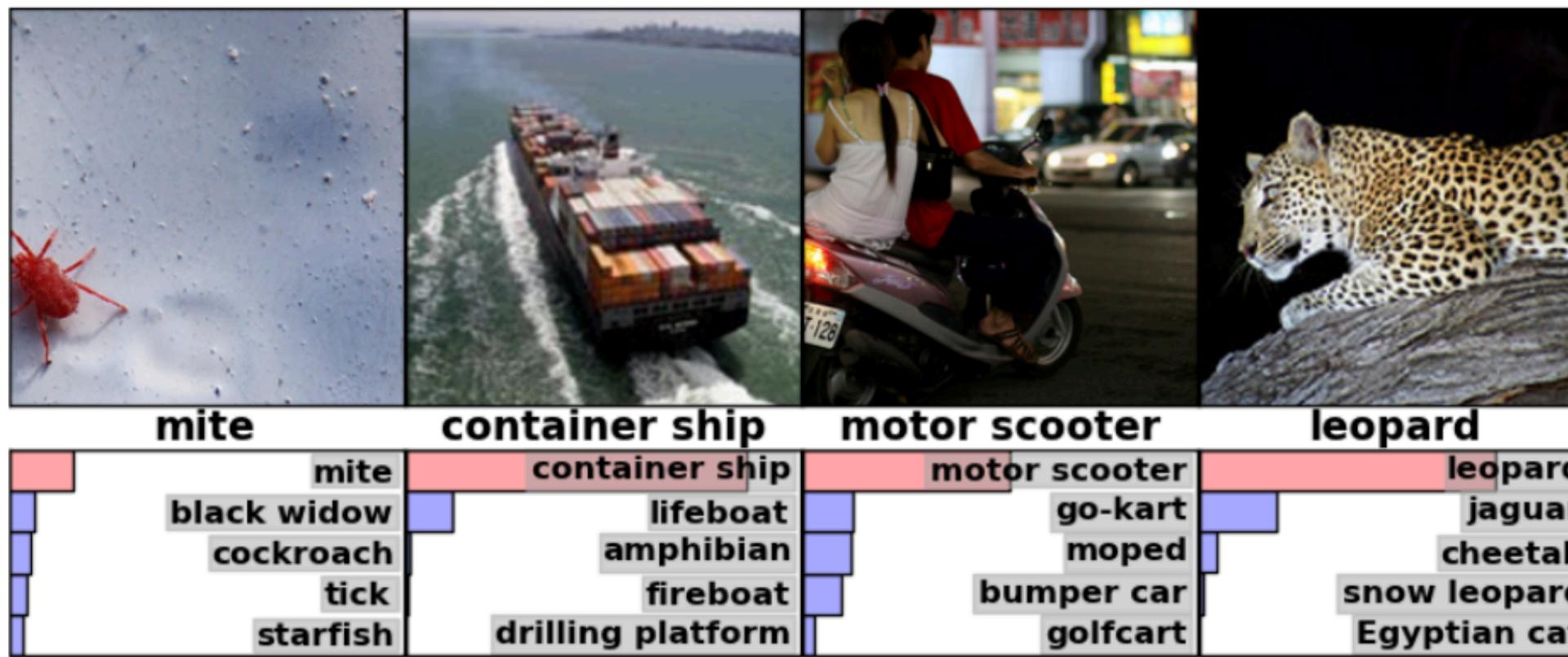
- Supervised learning
 - regression
 - classification
 - tagging
 - search
 - recommender systems
 - sequencer learning
- Unsupervised learning or self-supervised learning
- Reinforcement learning

Neural networks

Applications

- Automatic speech recognition
- Image recognition
- Visual art processing
- Natural language processing
- Drug discovery and toxicology
- Customer relationship management (deep RL)
- Recommendation systems
- Bioinformatics
- Medical image analysis
- Mobile advertising
- Image reconstruction, restoration (or super resolution)
- Financial fraud detection
- Partial differential equations
- ...

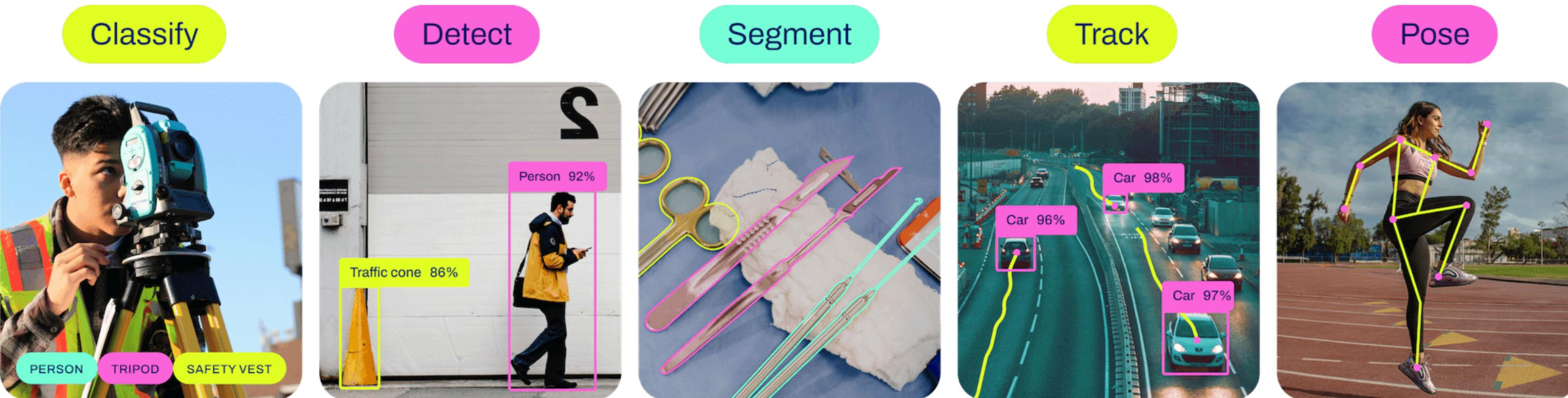
NN: Vision



[Krizhevsky 2012]



[Ciresan et al. 2013]



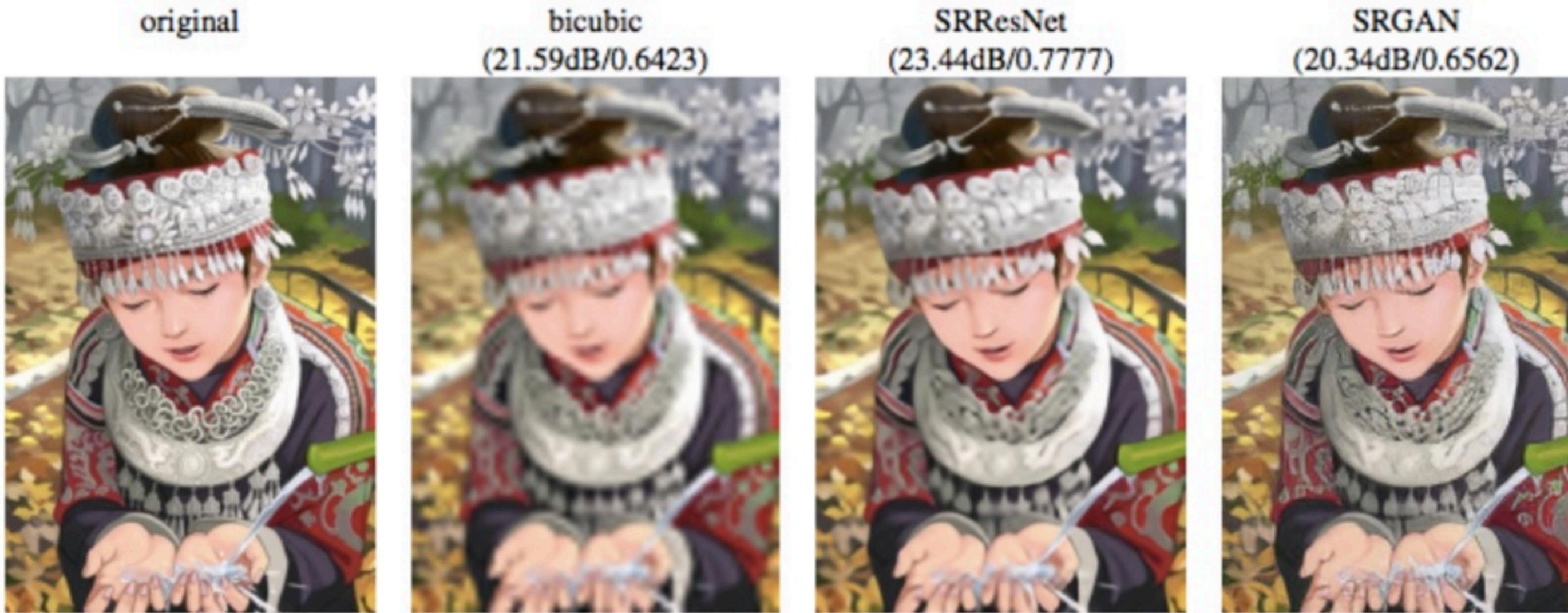
NN: Image translation



[DeepDream 2015]

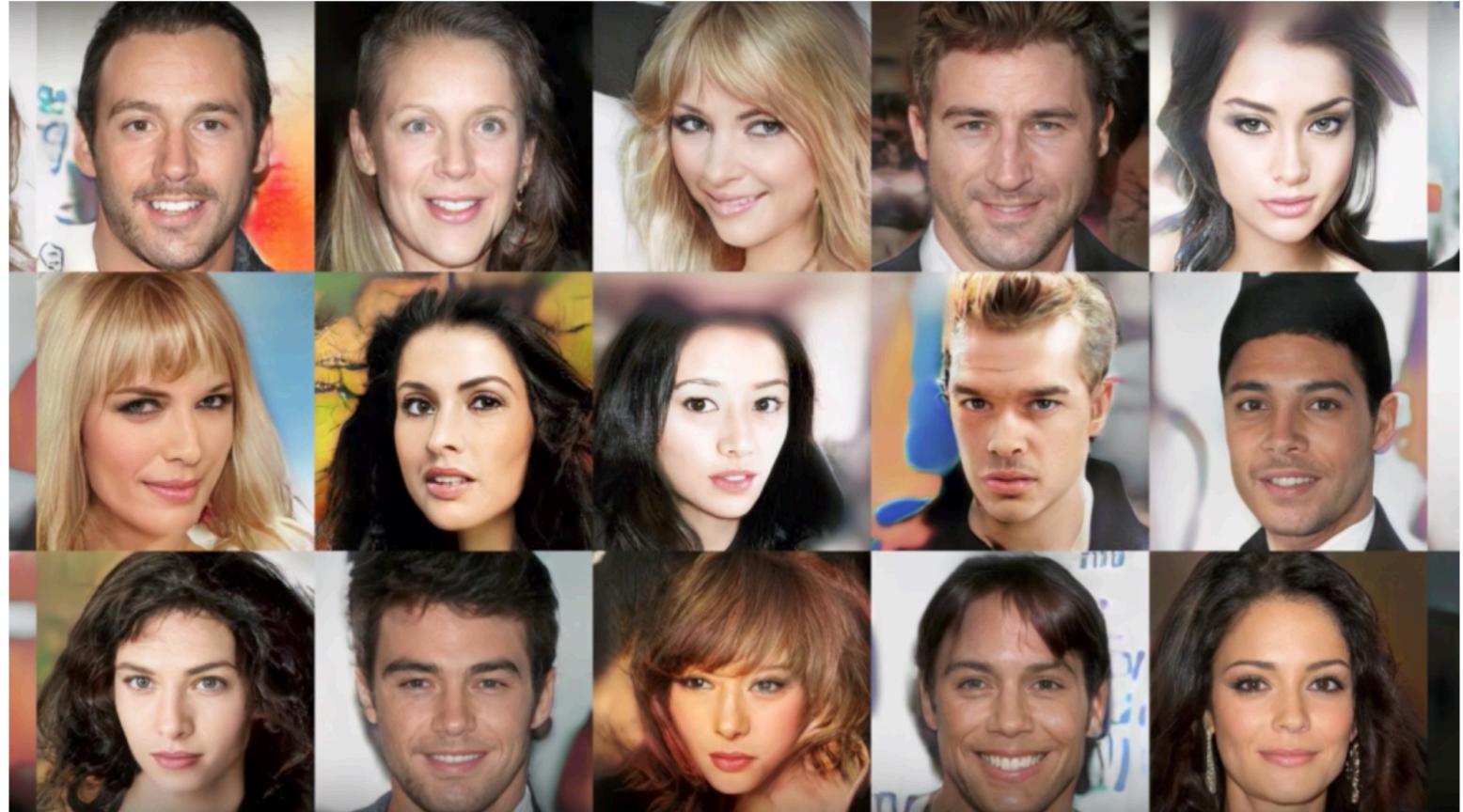


[Gatys 2015]



[Ledig 2016]

NN: Generative models, NLP + GenModels



Sampled celebrities [Nvidia 2017]

Text description	This bird is blue with white and has a very short beak	This bird has wings that are brown and has a yellow belly	A white bird with a black crown and yellow beak	This bird is white, black, and brown in color, with a brown beak	The bird has small beak, with reddish brown crown and white on the wingbars.	This is a small, black bird with a white breast and white on the wingbars.	This bird is white black and yellow in color, with a short black beak
Stage-I images							
Stage-II images							

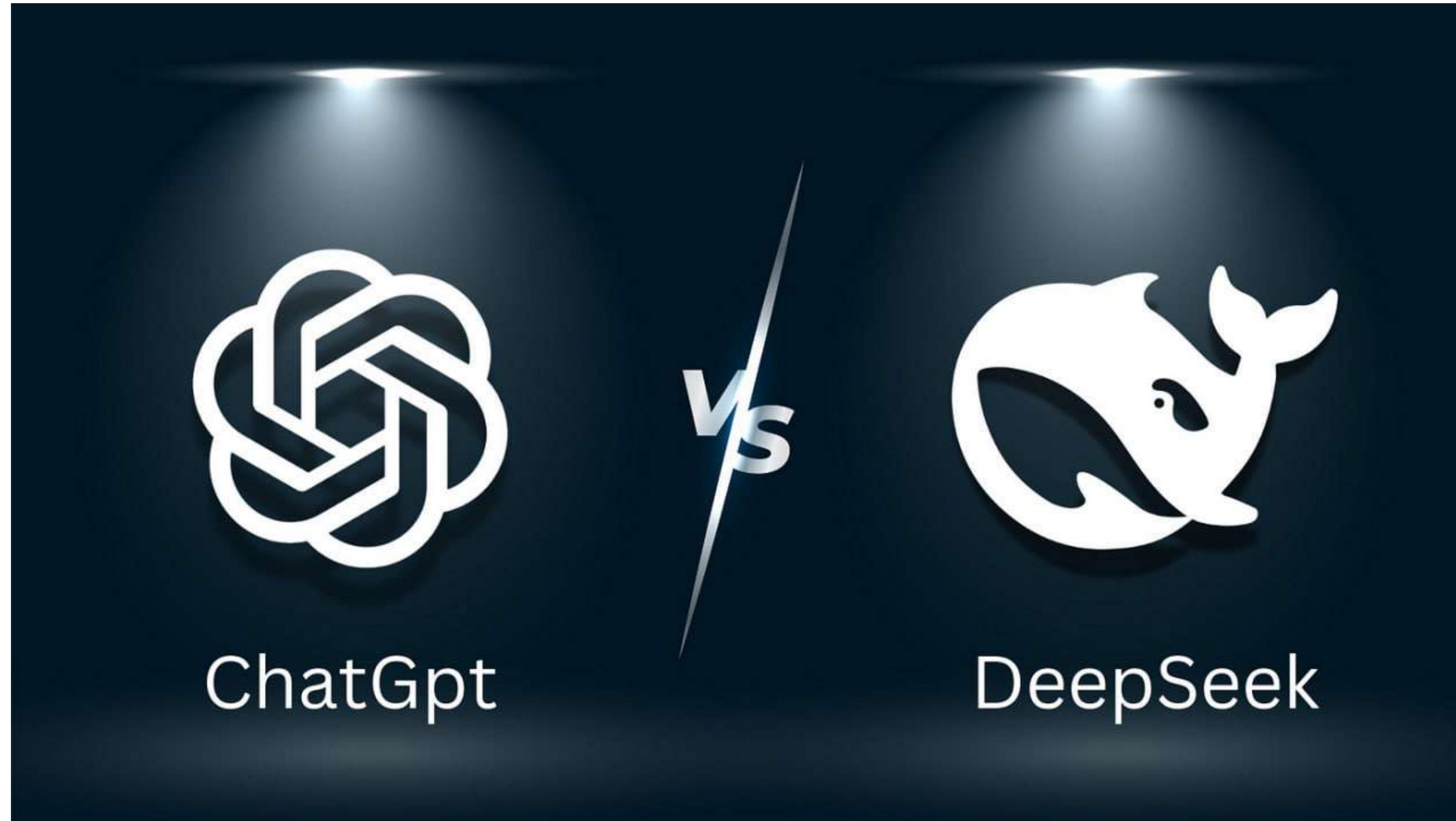
StackGAN v2 [Zhang 2017]

The screenshot shows the OpenAI DALL-E 2 interface. At the top, there's a navigation bar with links for API, RESEARCH, BLOG, and ABOUT, and buttons for LOG IN and SIGN UP. The main feature is a large, stylized text "DALL·E 2". Below it, there's a generated image of a person riding a motorcycle over a city skyline at night. To the right, there's a small image of Earth held in hands. On the left, there's a sidebar with links for SIGN UP, FOLLOW ON INSTAGRAM, VIEW API DOCS, VIEW RESEARCH, and EXPLORE. In the center, there's a generated image of a corgi sitting on a beach. At the bottom, there's a section for "TEXT PROMPT" with the prompt "an armchair in the shape of an avocado [...]" and a row of five generated images of green armchairs shaped like avocados.



View more or edit prompt ↴

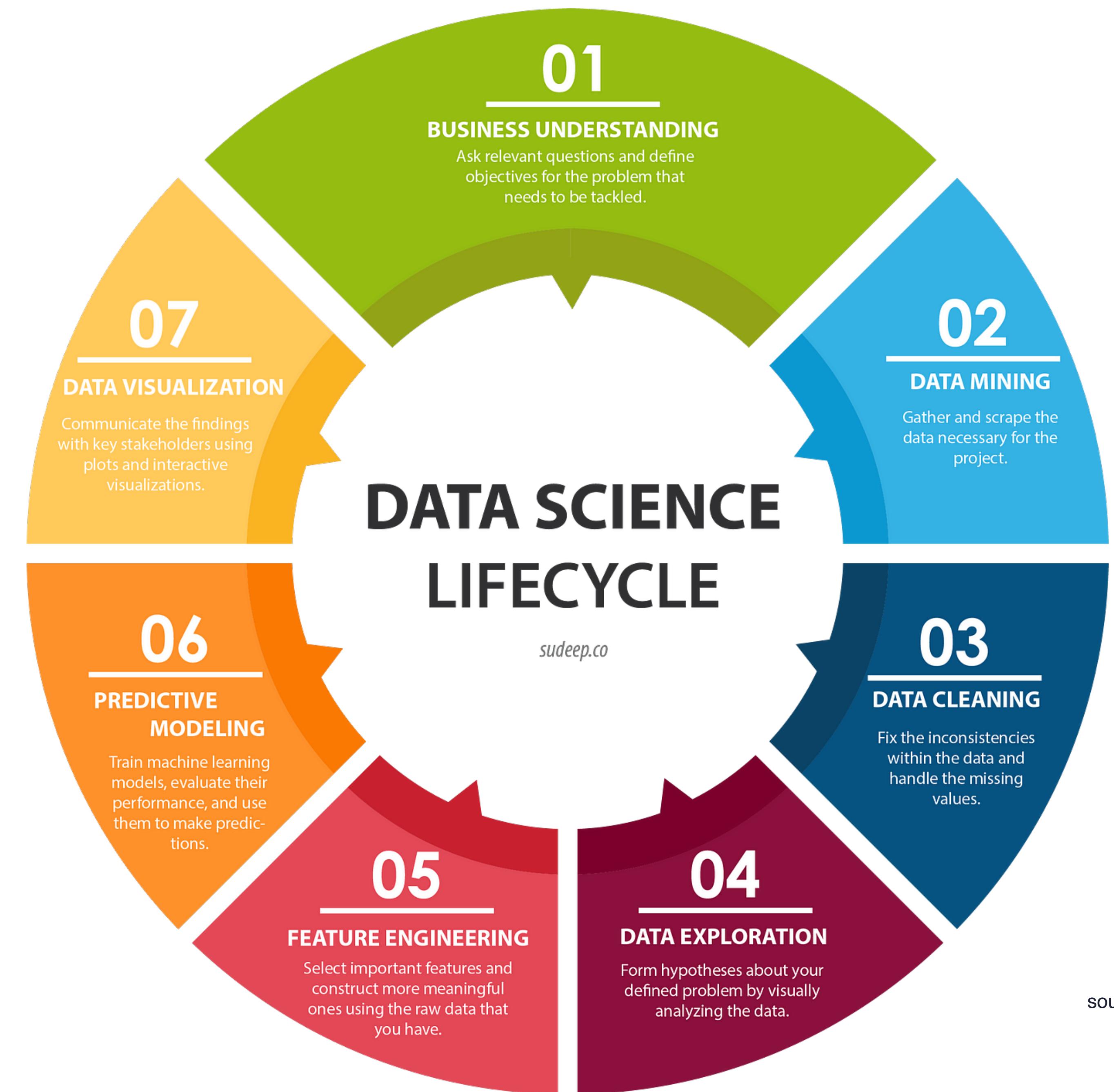
NN: Language models



Prompt Engineering + Generative models

Stable Diffusion models





source: Data Science - A Complete Introduction
<https://www.heavy.ai/learn/data-science>

Input data

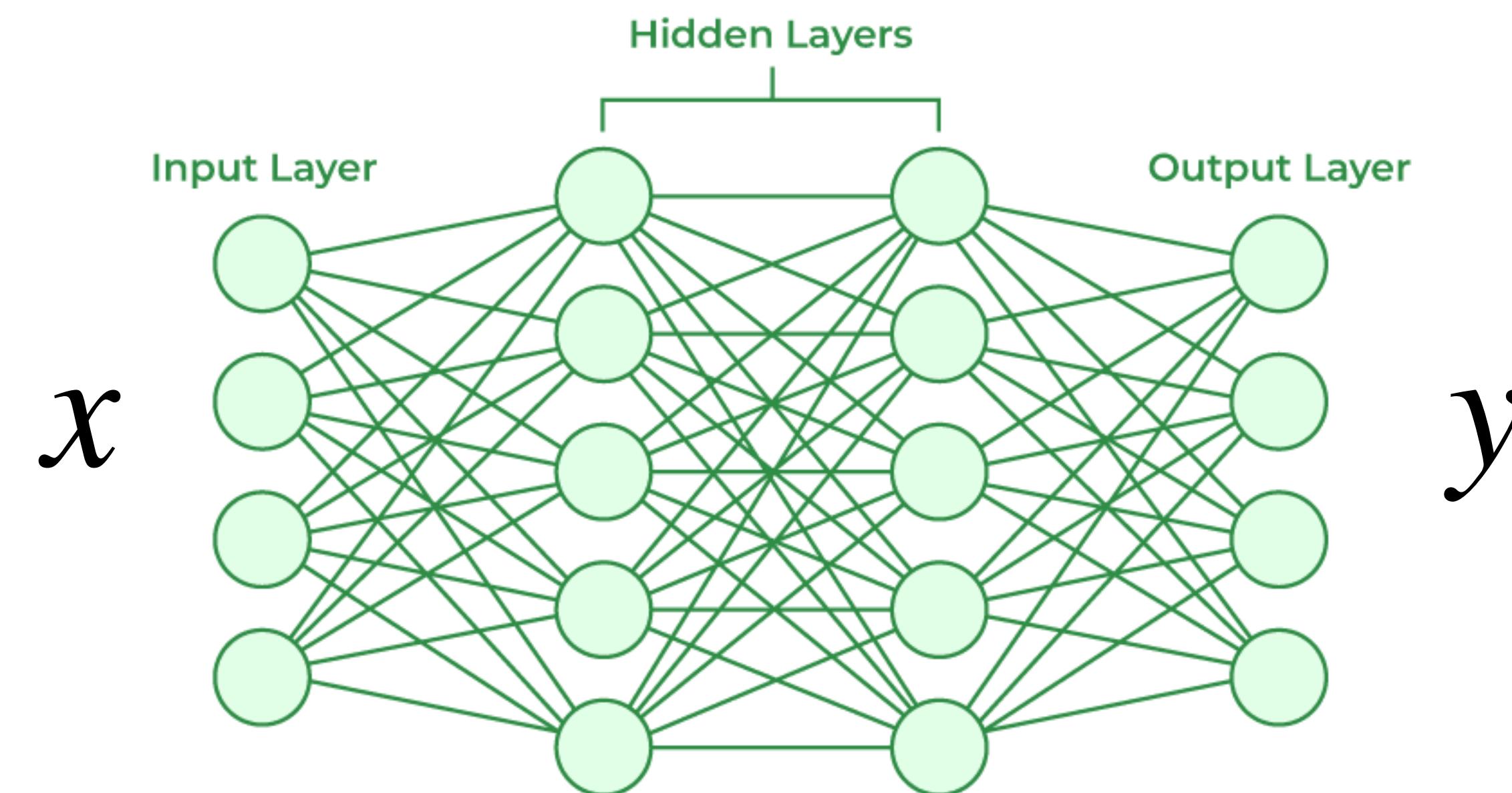
- structured
 - tabular (json, csv, ...)
- unstructured
 - images, video, text (natural language)

Neural Network

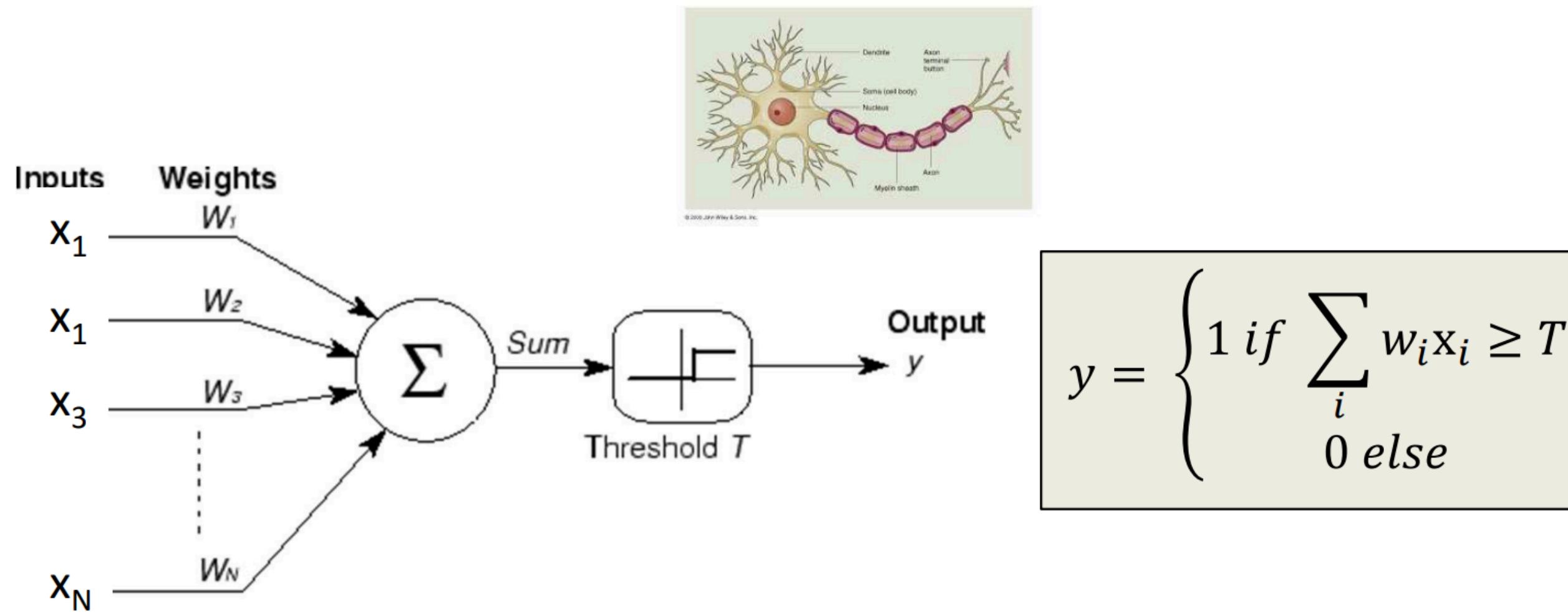
Intro (basics)

- neural network = parametrized, non-linear function

$$y = f(x; \theta)$$

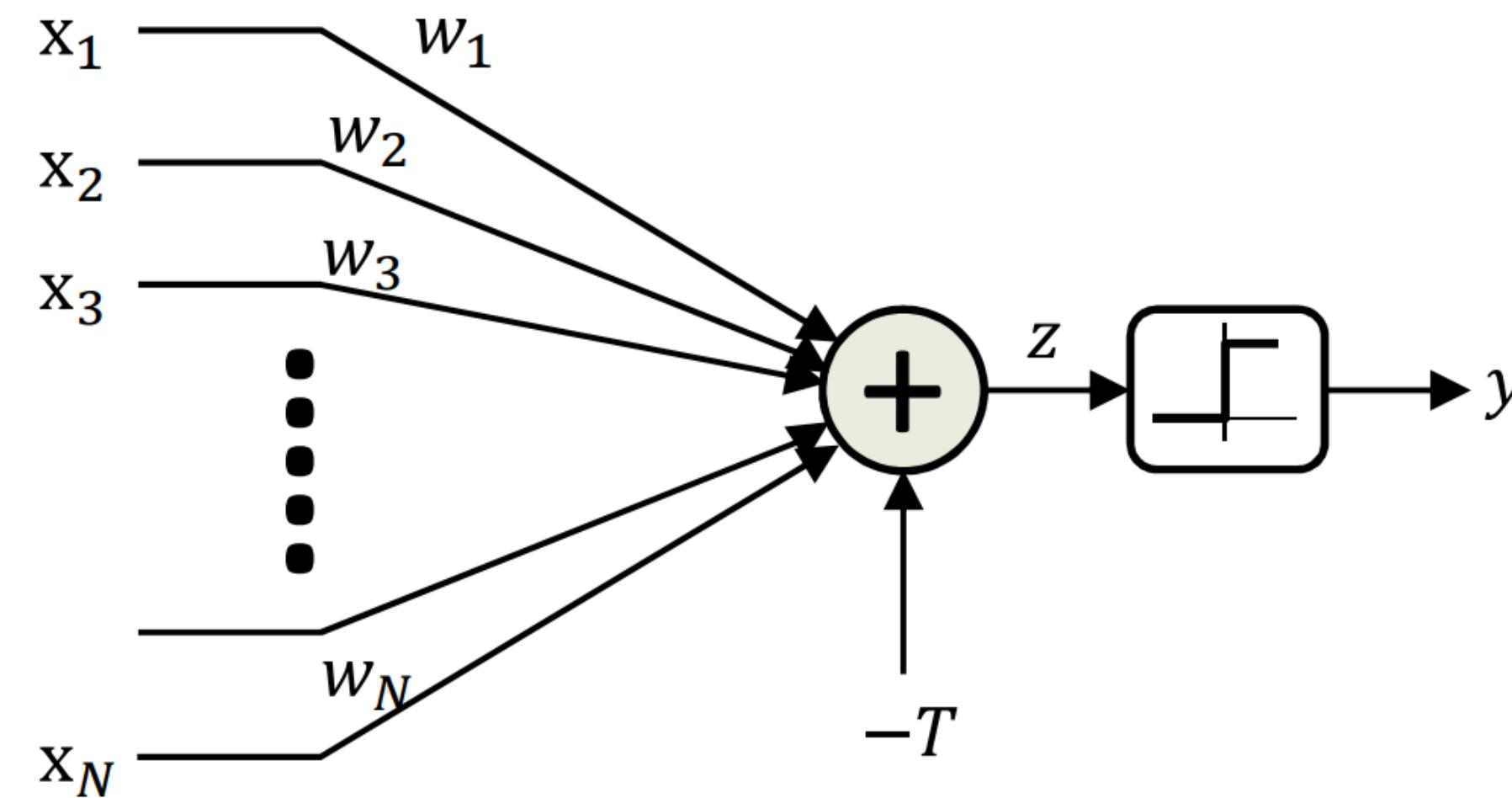


Recap: the perceptron



- A threshold unit
 - “Fires” if the weighted sum of inputs exceeds a threshold
 - Electrical engineers will call this a *threshold gate*
 - A basic unit of Boolean circuits

A better figure

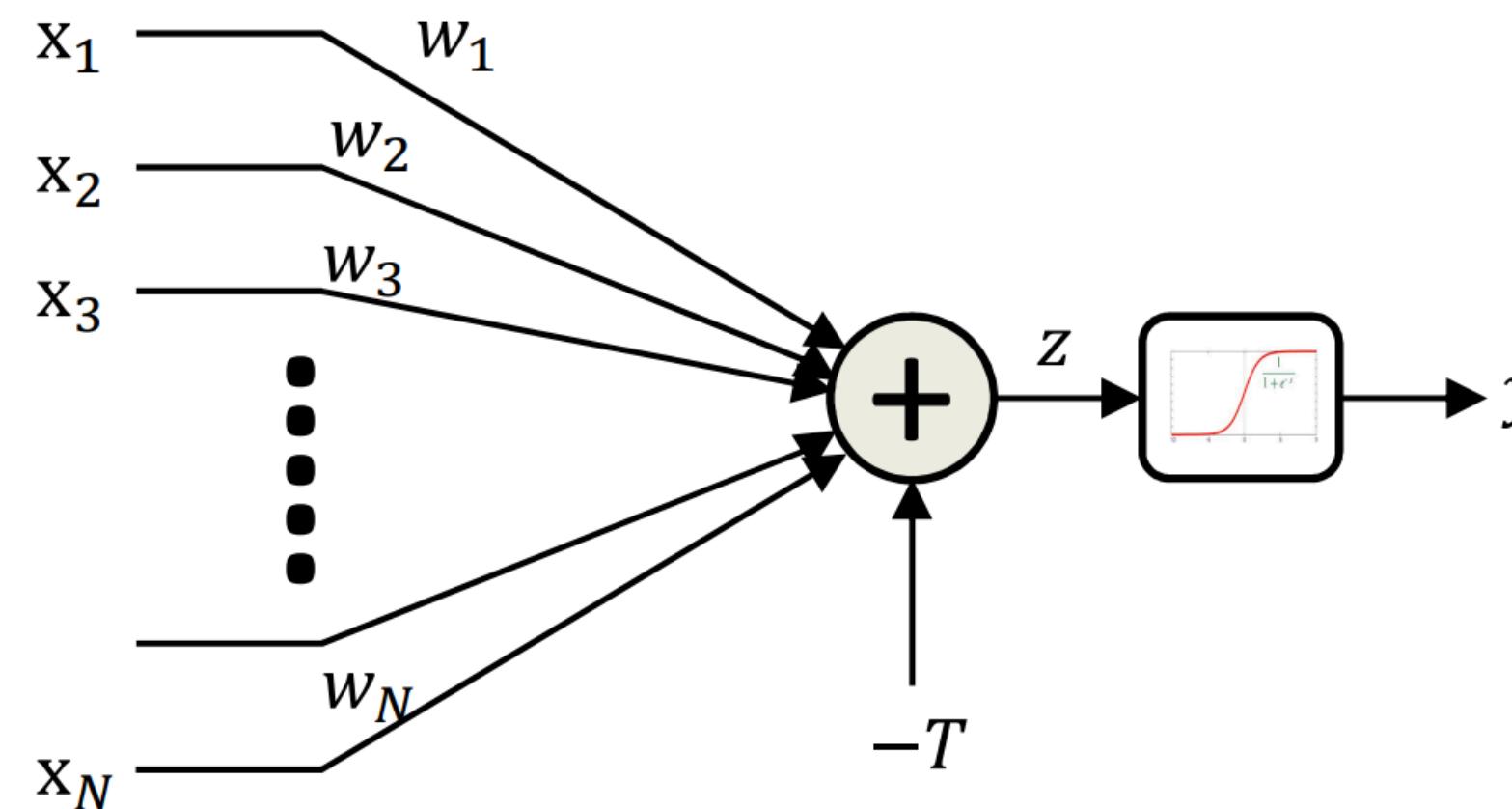


$$z = \sum_i w_i x_i - T$$

$$y = \begin{cases} 1 & \text{if } z \geq 0 \\ 0 & \text{else} \end{cases}$$

- A threshold unit
 - “Fires” if the weighted sum of inputs and the “bias” T is positive

The “soft” perceptron (logistic)

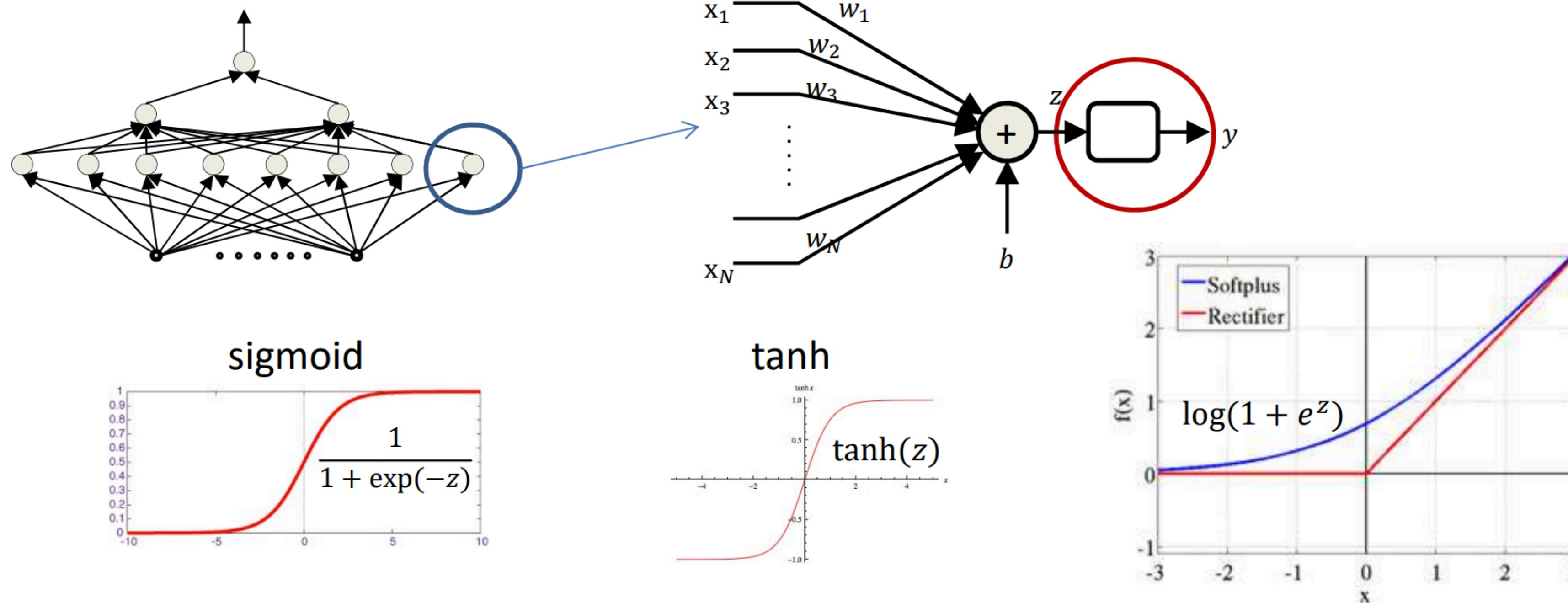


$$z = \sum_i w_i x_i - T$$

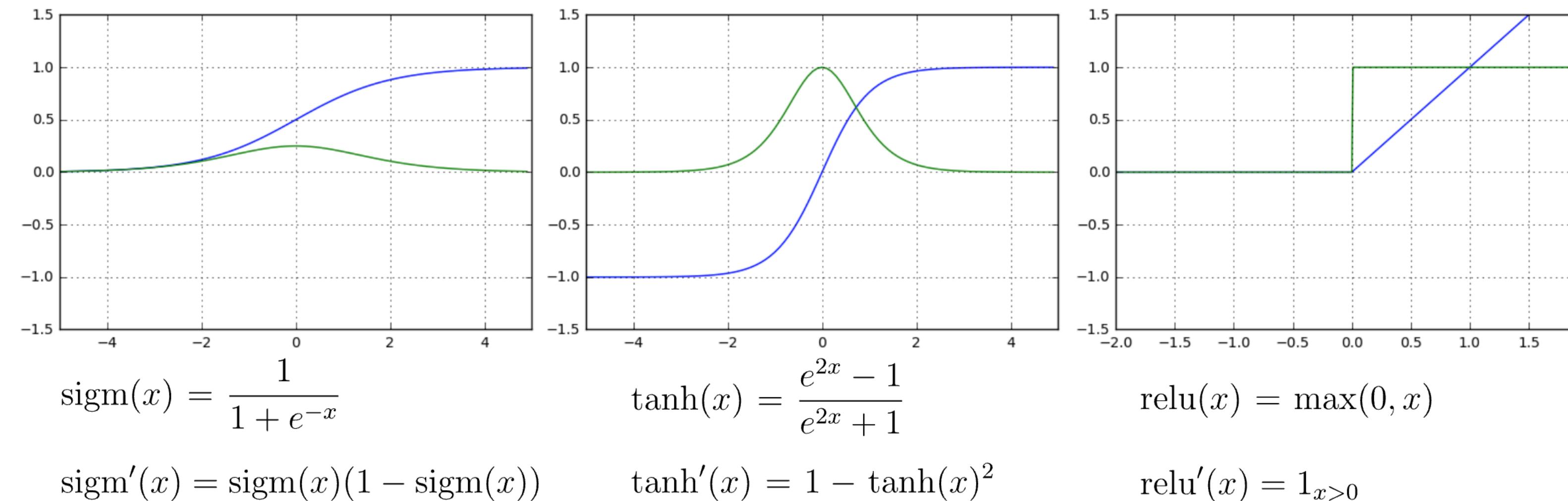
$$y = \frac{1}{1 + \exp(-z)}$$

- A “squashing” function instead of a threshold at the output
 - The **sigmoid** “activation” replaces the threshold
 - **Activation:** The function that acts on the weighted combination of inputs (and threshold)

Other “activations”

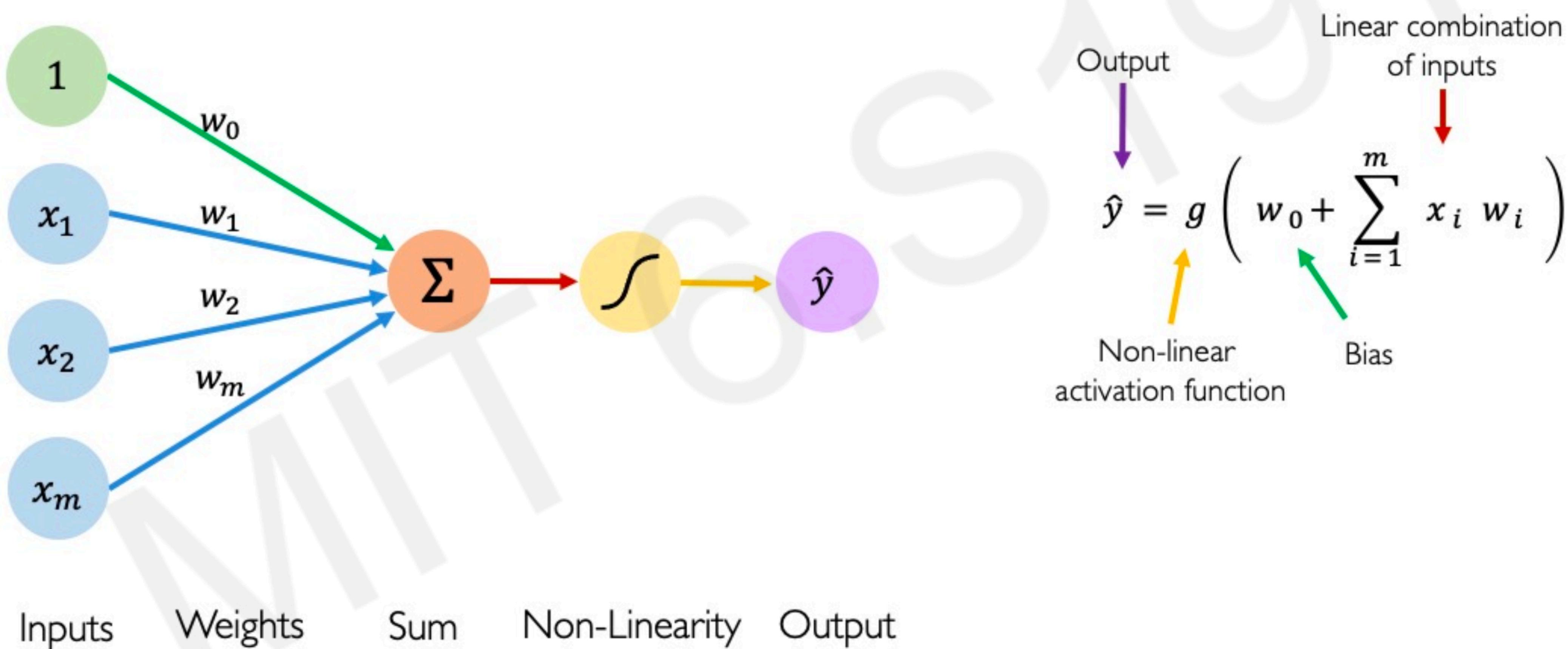


Element-wise activation functions



- blue: activation function
- green: derivative

The Perceptron: Forward Propagation



Perceptron as Boolean Function

<https://www.cs.cmu.edu/~bhiksha/courses/deeplearning/Spring.2019/www/slides.spring19/lec2.universal.pdf>

Exercise:

- model AND, OR and NOT gate with single perceptron

Multi layered perceptron (MLP)

- MLPs are universal Boolean functions, i.e. can compute any Boolean function
- Single hidden layer is enough

Truth Table					
X_1	X_2	X_3	X_4	X_5	Y
0	0	1	1	0	1
0	1	0	1	1	1
0	1	1	0	0	1
1	0	0	0	1	1
1	0	1	1	1	1
1	1	0	0	1	1

Truth table shows all input combinations
for which output is 1

$$Y = \bar{X}_1 \bar{X}_2 X_3 X_4 \bar{X}_5 + \bar{X}_1 X_2 \bar{X}_3 X_4 X_5 + \bar{X}_1 X_2 X_3 \bar{X}_4 \bar{X}_5 + \\ X_1 \bar{X}_2 \bar{X}_3 \bar{X}_4 X_5 + X_1 \bar{X}_2 X_3 X_4 X_5 + X_1 X_2 \bar{X}_3 \bar{X}_4 X_5$$

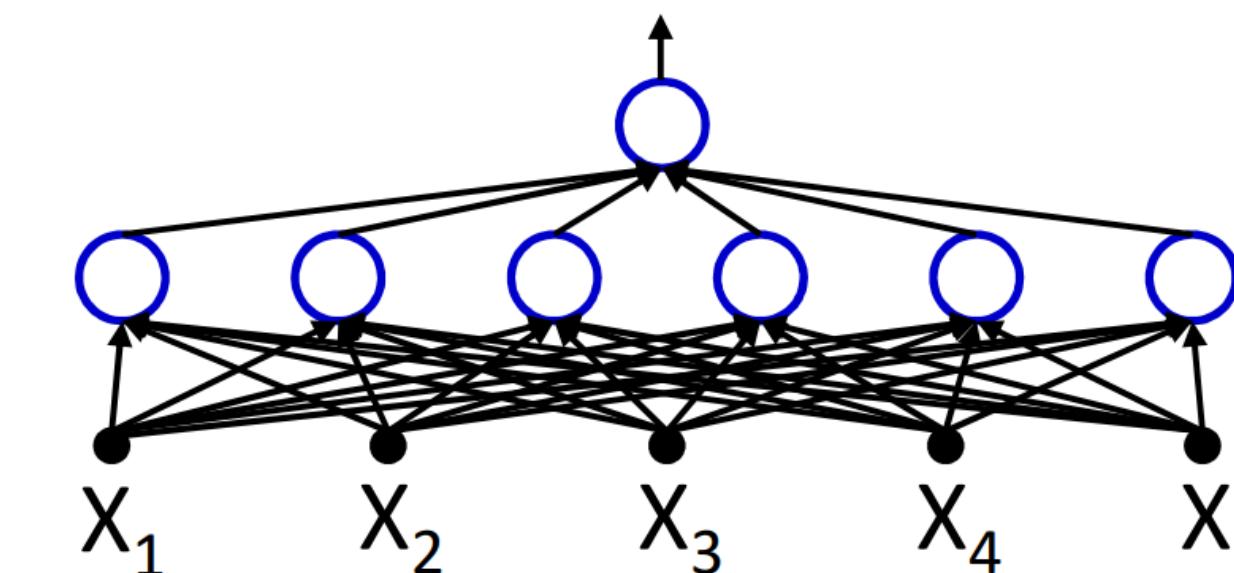
Multi layered perceptron (MLP)

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Truth Table					
X_1	X_2	X_3	X_4	X_5	Y
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0	1	1	0	0	1
1	0	0	0	1	1
1	0	1	1	1	1
1	1	0	0	1	1

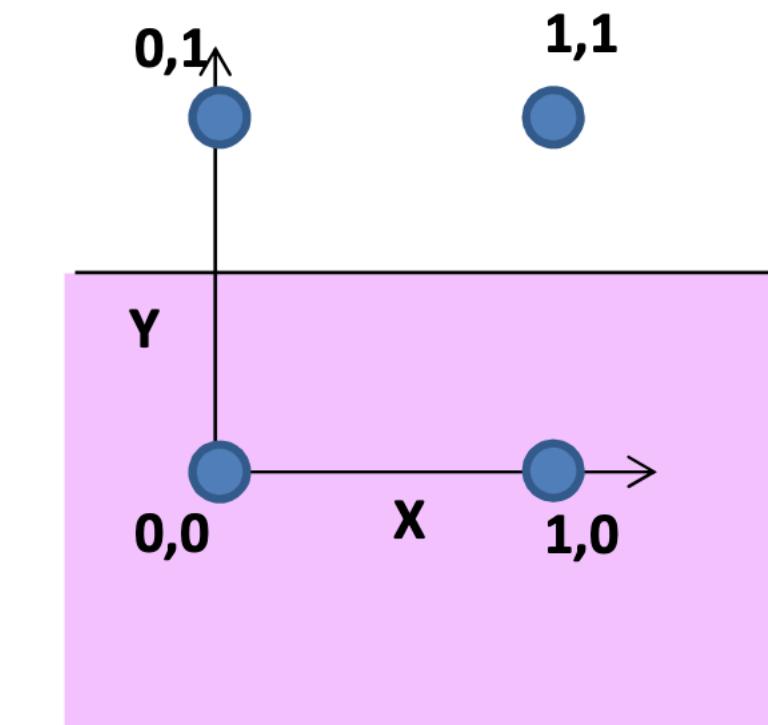
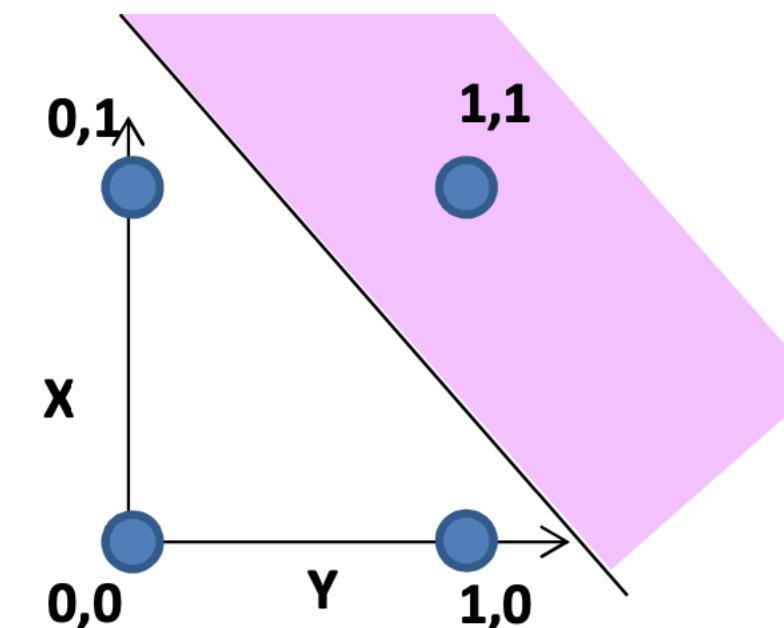
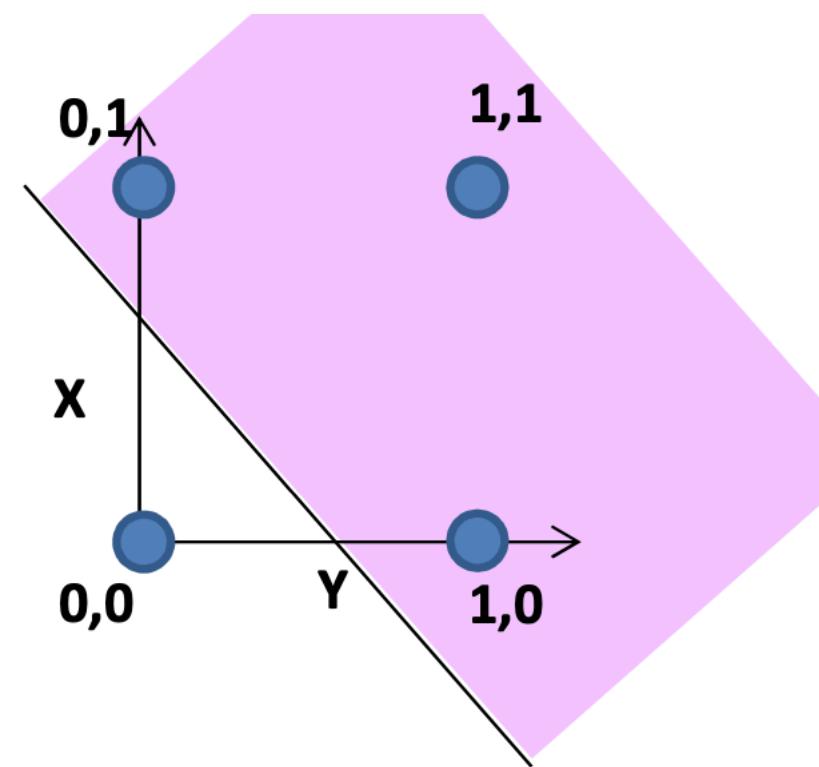
Truth table shows all input combinations for which output is 1

$$Y = \bar{X}_1 \bar{X}_2 X_3 X_4 \bar{X}_5 + \bar{X}_1 X_2 \bar{X}_3 X_4 X_5 + \bar{X}_1 X_2 X_3 \bar{X}_4 \bar{X}_5 + X_1 \bar{X}_2 \bar{X}_3 \bar{X}_4 X_5 + X_1 \bar{X}_2 X_3 X_4 X_5 + X_1 X_2 \bar{X}_3 \bar{X}_4 X_5$$



Boolean functions with a “real” perceptron

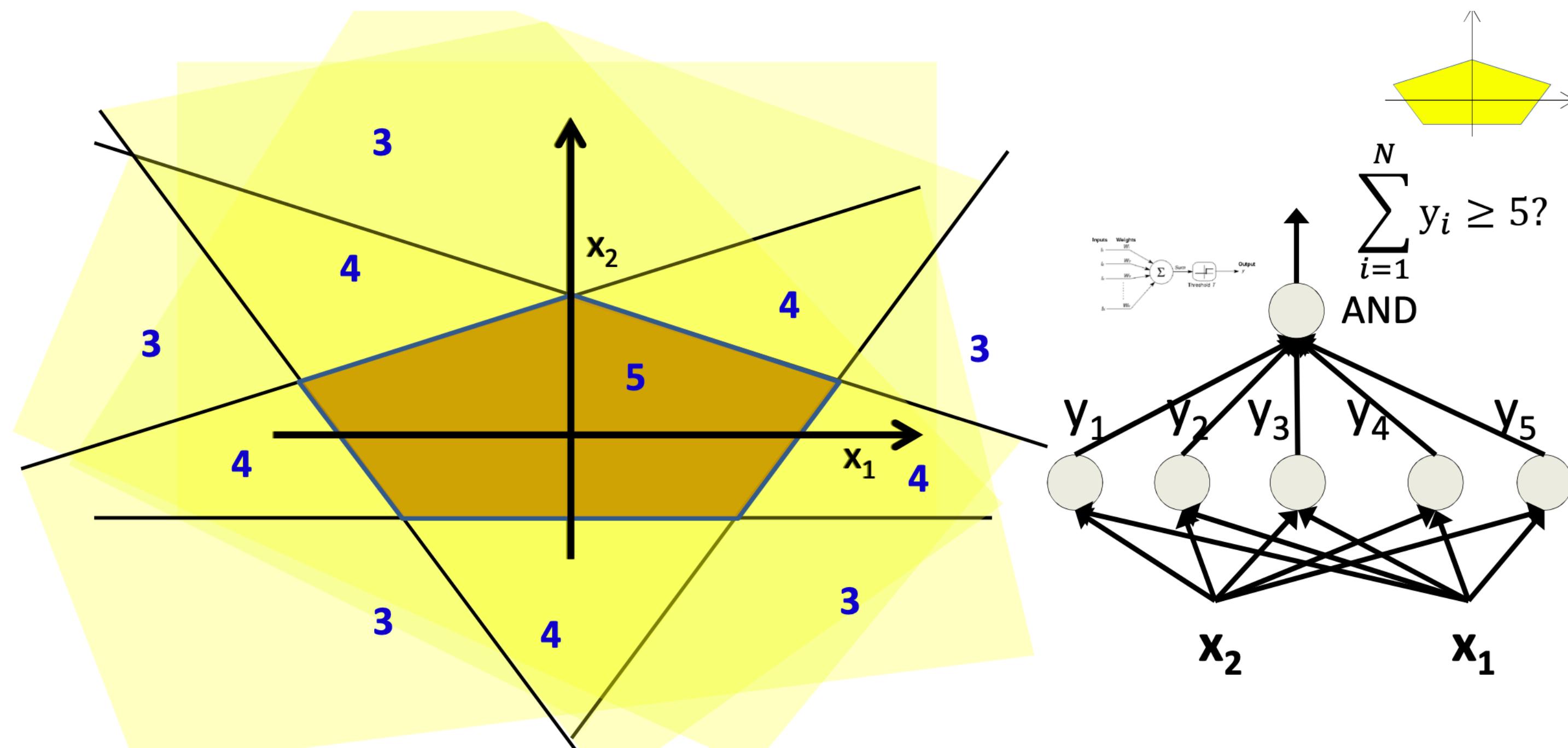
- OR, AND



- We cannot model XOR

More complex shape

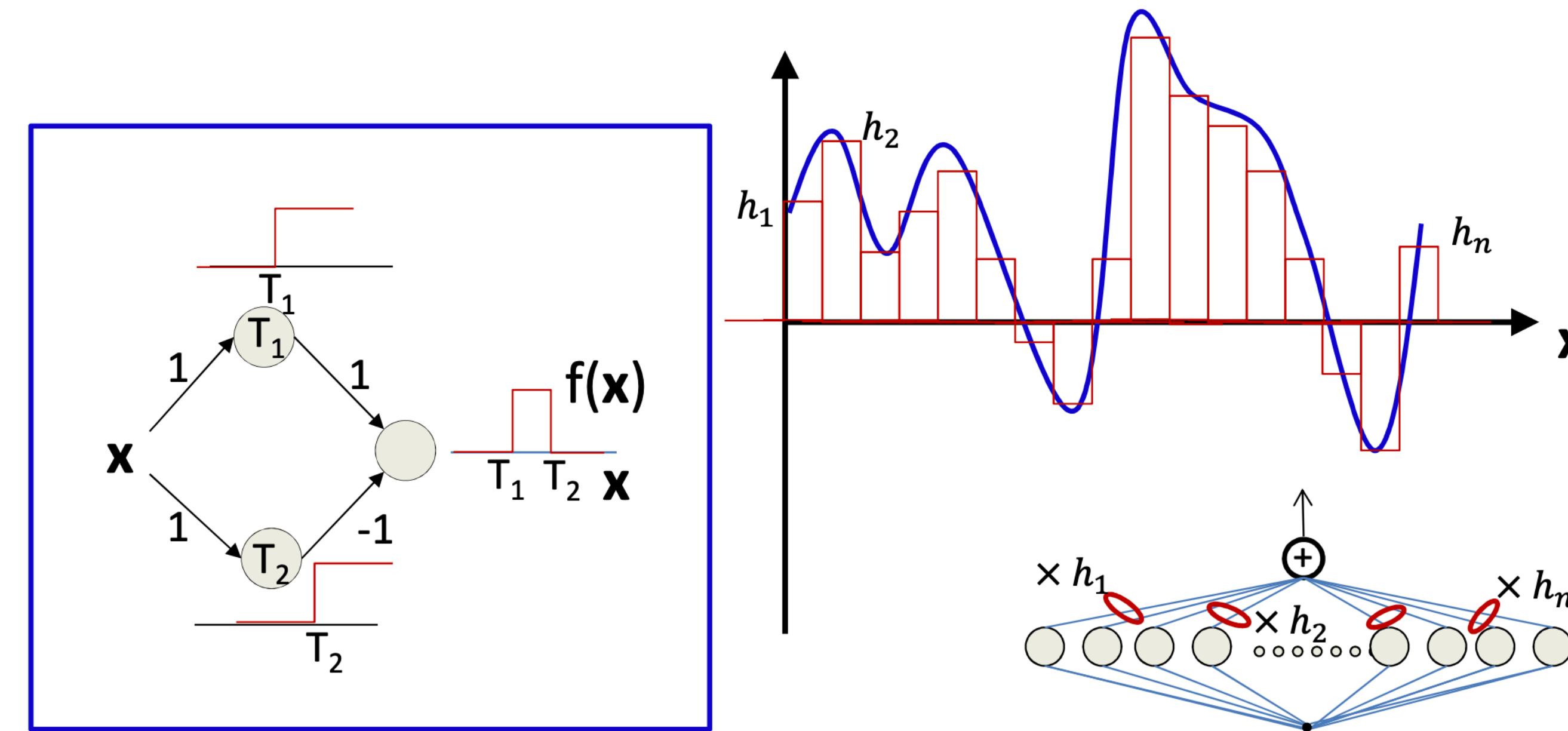
- One hidden layer is enough



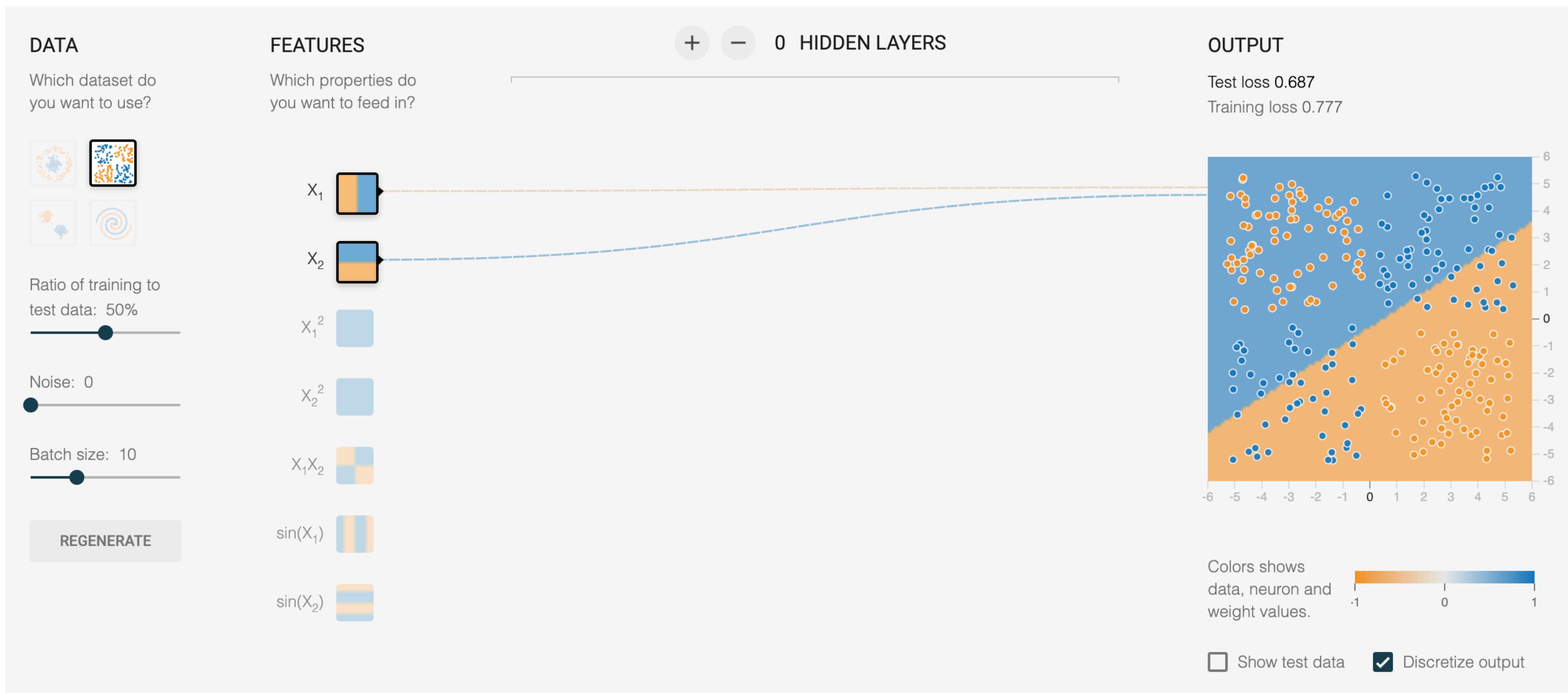
Universal Approximation Theorem

see demo

<http://neuralnetworksanddeeplearning.com/chap4.html>



Linear model



source: [Playground Tensorflow](#)

Multilayer Perceptron (MLP)

Notation

Linear models

- see slides “1 - Linear models.pdf”

Neural network $f: \mathbb{R}^{m \times n} \rightarrow \mathbb{R}^m$

m - batch size

n - # features

Linear model (single neural unit) ^{perceptron}

$$\vec{y} = f(X) = X\vec{w} + b \quad w \in \mathbb{R}^n \quad b \in \mathbb{R}$$

$$y_i = \sum_{j=1}^n w_j x_{ij} + b \quad (i=1, 2, \dots, m)$$

Logistic regression

$$\vec{y} = f(X) = \sigma(Xw + b)$$

$$y_i = \sigma\left(\sum_{j=1}^n w_j x_{ij} + b\right)$$

$$\sigma: \mathbb{R}^m \rightarrow \mathbb{R}^m$$

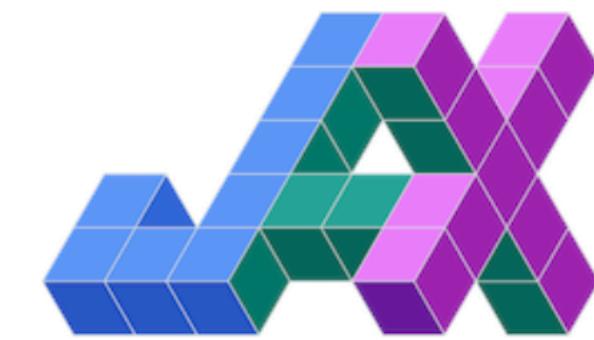
$$\sigma(z) = \frac{1}{1+e^{-z}}$$

elementwise

Libraries and Frameworks



PYTORCH



Microsoft
CNTK



dmlc
mxnet

gensim **spaCy**

theano