Fundaments of Machine learning for and with engineering applications

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1. Recursive Neural Network

2. Generative AI

Sequential Data

ORDER MATTERS

- Language Models
- Time series

Language model

- Prediction of the next word
- Prediction of next sentence

Time Series

- Weather data
- Stock market
- Monitoring
- Trajectories
- Etc

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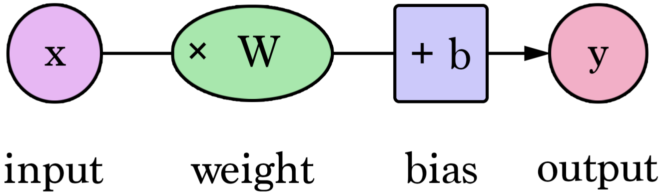
Feedforward (FF) vs Recurrent NN (RNN)

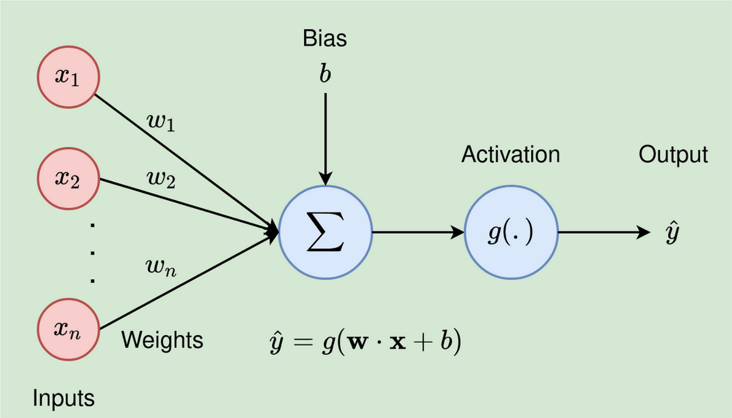
FF network

- One set of input
- One set of output
- Different parameters at each layer

- Multiple input set
- Multiple output
- Same parameter set

NN

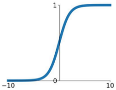



Bias
b
x_1
x_2
x_n
w_1
w_2
w_n
$\sum$
Activation
$g(.)$
Output
$\hat{y}$
Weights
$\hat{y} = g(\mathbf{w} \cdot \mathbf{x} + b)$
Inputs

Activation Functions

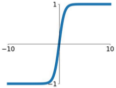
Sigmoid

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



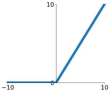
tanh

$\tanh(x)$



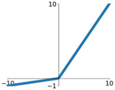
ReLU

$\max(0, x)$



Leaky ReLU

$\max(0.1x, x)$

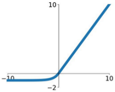


Maxout

$\max(w_1^T x + b_1, w_2^T x + b_2)$

ELU

$$\begin{cases} x & x \geq 0 \\ \alpha(e^x - 1) & x < 0 \end{cases}$$



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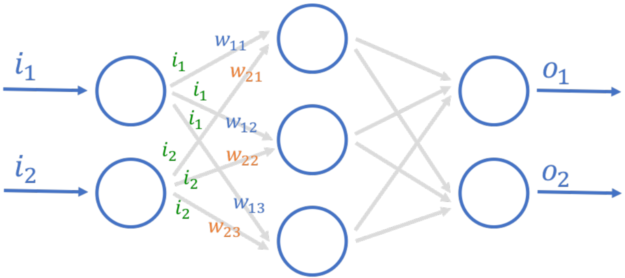
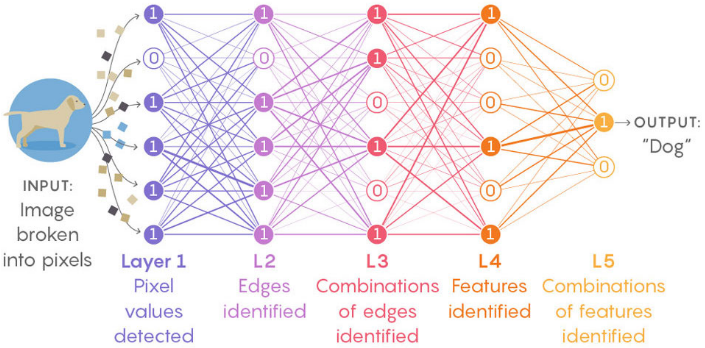


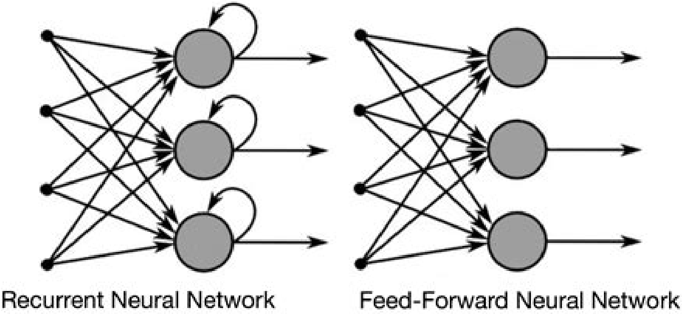
$$\begin{bmatrix} w_{11} & w_{21} \\ w_{12} & w_{22} \\ w_{13} & w_{23} \end{bmatrix} \cdot \begin{bmatrix} i_1 \\ i_2 \end{bmatrix} = \begin{bmatrix} (w_{11} \times i_1) + (w_{21} \times i_2) \\ (w_{12} \times i_1) + (w_{22} \times i_2) \\ (w_{13} \times i_1) + (w_{23} \times i_2) \end{bmatrix}$$

NN



INPUT:
Image broken into pixels
Layer 1
Pixel values detected
L2
Edges identified
L3
Combinations of edges identified
L4
Features identified
L5
Combinations of features identified
OUTPUT:
"Dog"

RNN



RNN

Advantages

- Model size is fixed
- Each info is stored/learned
- The weights can be forwarded

Problems

- Computationally demanding: long training times
- Problematic with Long series
- It can diverge (explode) or gradient vanish
- It cannot be very deep
- Unable to handle long time dependencies

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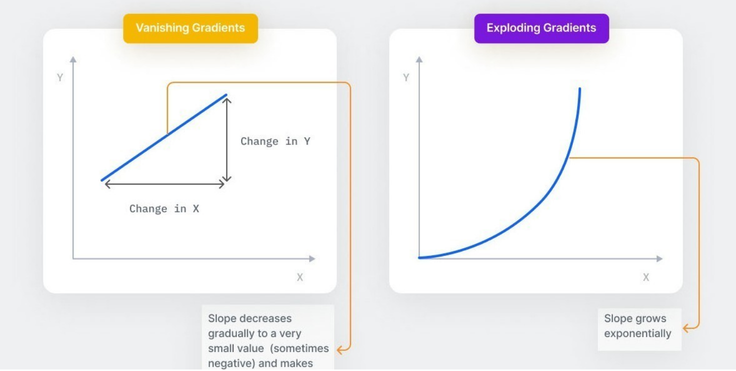
RNN problems



RNN problems

Exploding gradients

- Large weights update
- Gradient descent diverge (solution method)

Vanishing gradients

- Weights get marginally upgraded
- Very slow convergence speed

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LSTM: Long Short Term Memory

NB...

Filters forget data...

What about if we purposely forget data?

LSTM includes Forget Gates

Automatic filter!

The forget gates learn to forget what is not interesting

This is extremely useful but also rather worrisome: you have no control!

LSTM is an advanced version of GRU (Gated Recurrent Units)...
What is GRU?

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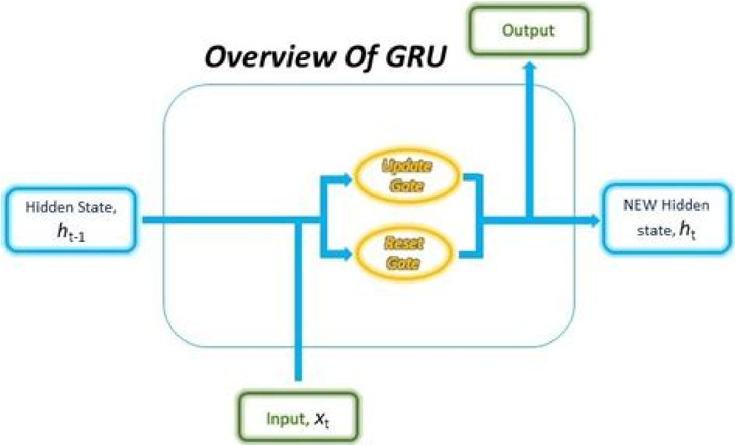

Overview Of GRU
Output
Hidden State, h_{t-1}
Update Gate
Reset Gate
NEW Hidden state, h_t
Input, x_t

GRU

Reset gates

To capture short-term dependencies

Update gates

To capture Long-term dependencies

pause Each gate has its own weight

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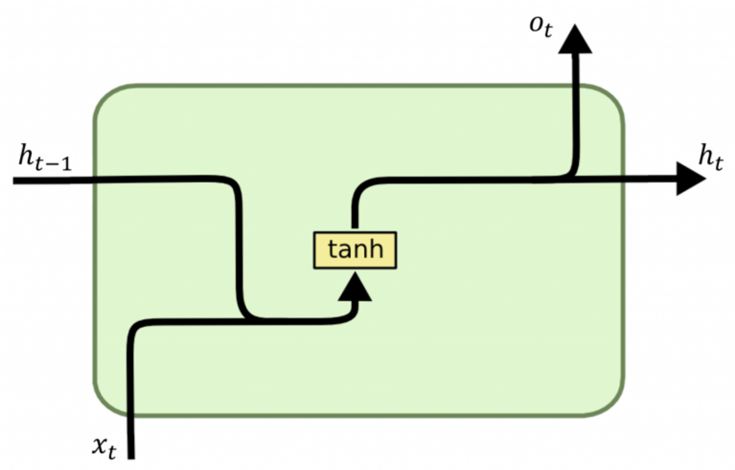
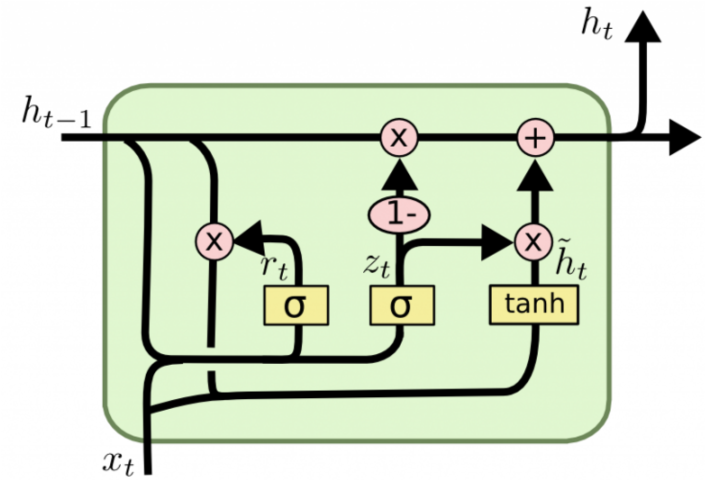


x_t: input vector, h_t: hidden layer vector o_t: output vector

GRU



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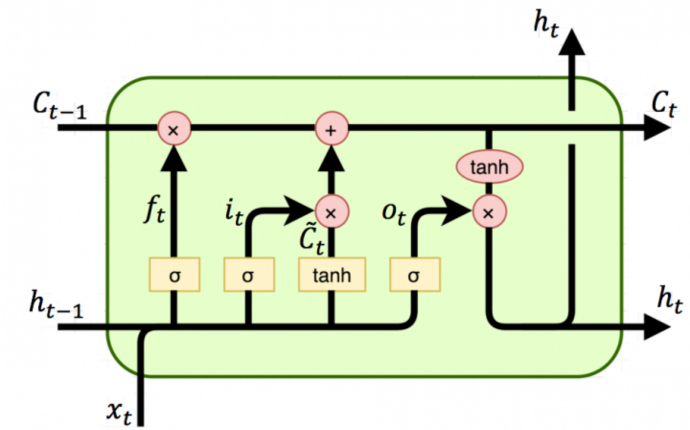
LSTM



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Generative AI

A generative AI model is a type of artificial intelligence that is designed to generate new content, based on the data it has been trained on.

It started in 1932, with the **mechanical brain** by Georges Artsrouni that was suppoused to translate automatically between languages,

Here a nice recaps of Generative AI and its storyline

Current status

A valuable report

A foundation model, also known as large X model (LxM), is a machine learning or deep learning model that is trained on vast datasets so it can be applied across a wide range of use cases.

Key characteristics of generative AI models include:

1. Learning from Data: They are trained on large datasets, enabling them to learn patterns, styles, or features inherent in the data.
2. Generating New Content: Generative models can create new data instances. For example, a model trained on a dataset of paintings can generate new images in the style of those paintings.

Trained generative models are thus able to input information at a low resolution/dimension and give output with a much greater dimensionality.

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Applications

Here a list of possible applications:

- Images/video: Image generation, Super-resolution, Deep fakes.
- Music: noise filter, voice and music generation, voice deep fake.
- Text(LLM): chatGPT, bard, Gemini, etc.
- Chemistry: DeepMind (Alphafold).
- Coding (co-pilot)
- Speech
- Attacks and Hacking (Security testing)
- Generating training sets
- And many more

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Science fiction?

This is scary:

1. Virtual best friends
2. Medical images to show diseases consequences
3. Synthetic data for digital twins
4. Preemptive suggestions (e.g. driving)
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Problems (currently)

New possibilities do not come with side effects.

1. Lack of transparency: how the output is generated, and why?
2. Accuracy: a lot of hallucinations
3. Bias: human biases are kept, supported and eventually increased
4. Intellectual properties (IP): who owns what is produced?
5. Cybersecutiry and frauds: mass cyber attacks can be created
6. Sustainability: massive quantity of electricity is used
7. Responsibility (who to blame?): Will AI get citizenship everywhere?

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Where generative AI is ?

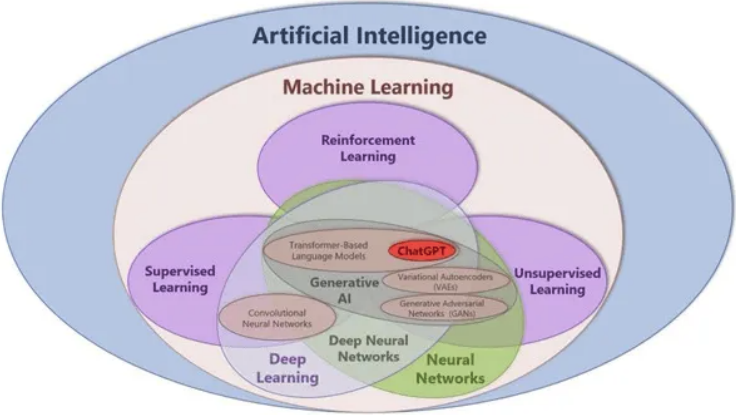

Image: https://iot-analytics.com

Structure of generative AI

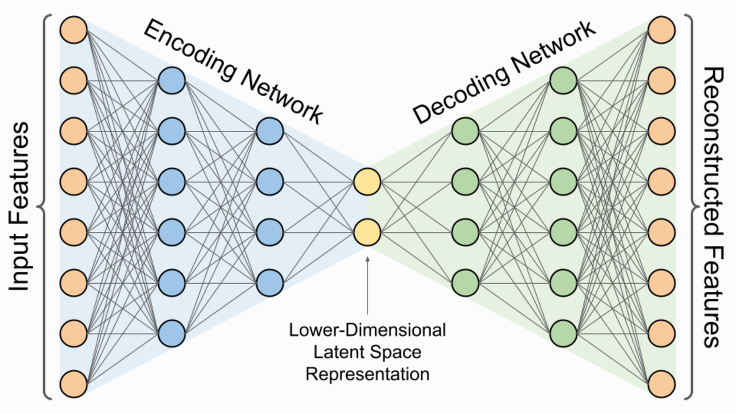

Image: https://www.rapidops.com

A new field?

Generative AI is actually a new evolution.

It is based on Neural Network, and in comprises a set of advanced tools (numerical recepites):

1. Generative Adversarial Networks
2. Generative Pre-trained Transformers
3. Variational Autoencoders
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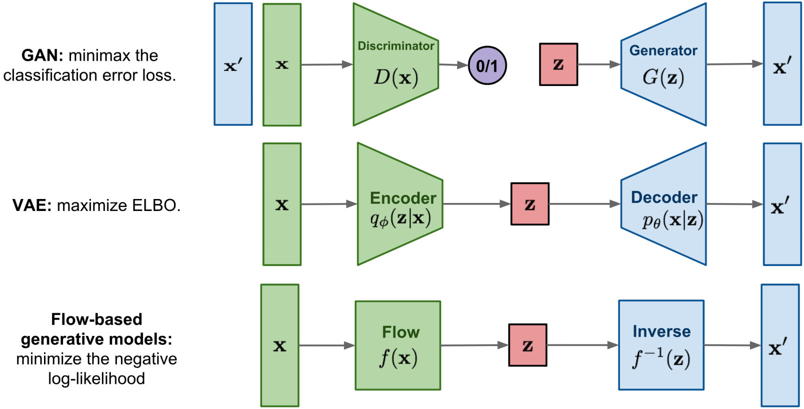
Types of generative AI

It is quite an advanced technique



Source: Lilian Weng