

ALMA MATER STUDIORUM Università di Bologna



Al: historical overview and state of the art

Daniel Remondini

DIFA UNIBO & INFN Group V INFN "next_AIM" initiative

Al: my personal history

UNIVERSITÀ DEGLI STUDI DI BOLOGNA

FACOLTÀ DI SCIENZE MATEMATICHE FISICHE NATURALI

Corso di laurea in Fisic

STUDIO DELL'EFFETTO DI CONNESSIONI INIBITORIE SU NEURONI BCM PER LA SIMULAZIONE DI UN MODULO DELLA CORTECCIA VISIVA



The Effect of Noise on a Class of Energy-Based Learning Rules

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Neural Computation 15, 1621-1640 (2003) © 2003 Massachusetts Institute of Technology



Neurocomputing 44-46 (2002) 591-595

www.elsevier.com/locate/neucom

NEUROCOMPUTING

Optimal spontaneous activity in neural network modeling

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...long-lasting love!

Al foundations: nervous system

Staining of neuronal cells: Camillo Golgi, Ramon Cajal (Nobel prizes)



NEURON: fundamental brain unit(10¹⁰-10¹¹ neurons) BRAIN STRUCTURE: CONNECTIVITY (10¹³-10¹⁵ synapses)

Nervous cell functionality

Electrophysiology (60's & 70's, Neher & Sackman, Nobel Prizes)



Signalling: "binary" code (action potential) frequency-modulated Cell response varies as a function of previous stimulation **LEARNING & MEMORY**



Artifical neuron



ML & AI : backpropagation algorithm



D.E. Rumelhart, G.E. Hinton, R.J. Williams Learning representation by back-propagating errors. *Nature*, 323 (1986), pp. 533–536



Learning: adapt WEIGHTS to minimize a cost/error/energy function (supervised learning)

$$E = \sum_{esempi} (OUT_{EX} - OUT_{NET})^2$$



Natural neural network structure: visual cortex

Layered structure: increasing processing levels of visual stimuli (60's , Hubel & Wiesel, Nobel prizes)









Retina "raw" image > contours > shapes > complex objects

бо µл

Somatotopic organization

Receptive field



Artificial cortex: Convolutional Neural Networks

Hyerarchical elaboration – increasing abstraction levels







Deep learning sharpens views of cells and genes Convolution & pooling = processing & scaling of receptive field

Object recognition Image processing



Artificial Intelligence in Medicine





with colleagues working in Clinical context

INFN - CSN5 2022-2024

BA, BO, CA, CT, FE, FI, GE, LNS, MI, NA, PI, PV



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CNN Deep Learning: super-resolution

Improve image quality (pixel resolution) INPUT: low resolution (natural) image OUTPUT: 2x 4x higher resolution image





Original image 0887 from DIV2K



HR (PSNR/SSIM)



Bicubic

(23.93 dB/0.729)

(25.31 dB/0.788)(25.37 dB/0.791)





SC / 25.58 dB

SRCNN / 27.95 dB

Dong et al., arXiv:1501.00092v3



Super-resolution on NMR brain images





C. Fiscone, N. Curti , C. Testa, et al. (DIFA & IRCCS Bellaria)

RMSE – root mean square error pSNR – peak signal-to-noise ratio SSIM – structural similarity index HFEN – high-frequency error norm



Super-res: application to breast mCT

Image enhancement: improvement for clinical diagnosis? Feedback from radiologists (in progress) - explaination (Dott. N Curti DIMES & INFN BO, Prof. G Mettivier Team INFN NA)





Nervous cells: short- and long-term memory

Real neurons have different levels of learning & memory Short-term memory can be converted into long-term memory

Concurring mechanisms: Electrochemical processes Change in conductance Protein phosphorylation





Artificial long-short-term memory neuron LSTM

LSTM



LONG SHORT-TERM MEMORY

NEURAL COMPUTATION 9(8):1735–1780, 1997

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Recurrent networks that can keep/forget signals over time (also very far in time – learn from **context**)

Application: analysis of time series (also symbolic)



Viral protein variant analysis





Figure. 2: Overview of the envisaged VEO system, enabling handling, integration and analysis of currently used biodata data (light grey box)) and various novel 'non-traditional' contextual data sets (dark blue box, top left) for forecasting, nowcasting and tracking of changes in key global drivers of EID emergence and generating actionable information for early warning, risk assessment and monitoring of EID threats. Numbers 1-7 refer to the VEO project objectives.

OBJECTIVE 1 – TO DEVELOP AND OPERATE THE VEO DATA PLATFORM

The VEO data platform will support rapid mining sharing integration presentation and analysis of traditional

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LSTM & NLP



Input = symbolic strings Protein = "sentence" Aminoacid = "word"

Similar sentences = functional proteins Different sentences = immune escape [Hie et al. Science 2021]

NOTE: self-supervised learning

The learning task is to reconstruct the sentence itself (one word at a time)





SARS-CoV-2 Spike protein





UMAP1

Host similarity

- bat
- human
- other
- pangolin



Antigenic map reconstruction from protein sequence alone

Antigenic map: [Smith et al. Science 2004]

Experiments on animal sera: antigenic response to virus



In silico "gain of function"



Try single-aminoacid mutations and test immune escape



Mutations in same positions

Hotspot regions



Challenges and future directions

Istituto Nazionale di Fisica Nucleare

Explaination: why it works

Semi & self supervised learning

Manifold learning

Synthetic data generation

Physics (& physiology)-informed models



