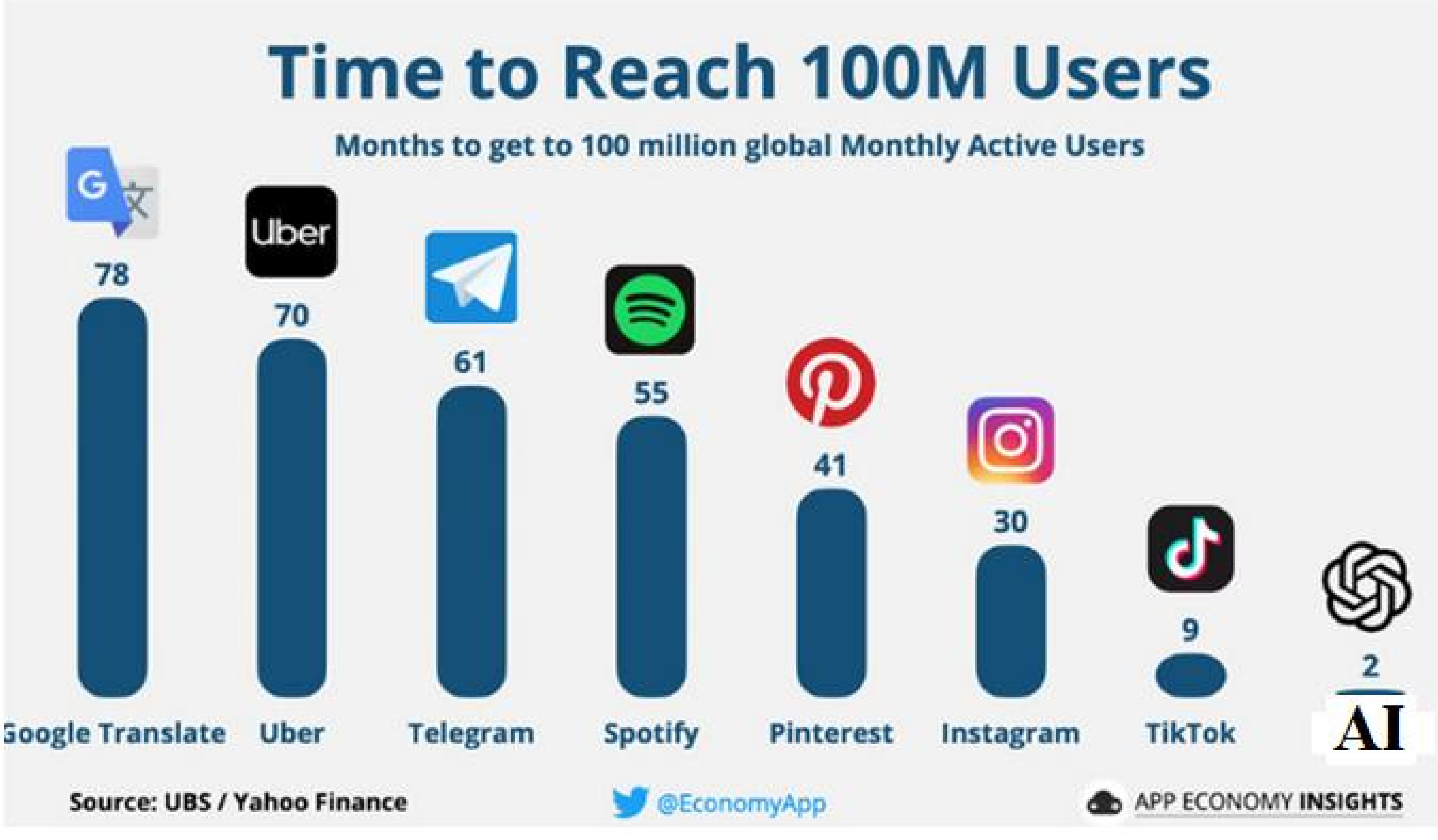
Recent progress of neural networks in nuclear structures

Amir Jalili

Outlines

- Nuclear structure: Properties of NN
- Statistics of AI
- First paper in AI (1980-1990)
- AI and Machine Learning (ML)
- How ML works
- How to apply in nuclear system
- Results

Statistics



Time to Reach 100M Users
Months to get to 100 million global Monthly Active Users
78
70
61
55
41
30
9
2
Google Translate
Uber
Telegram
Spotify
Pinterest
Instagram
TikTok
AI
Source: UBS / Yahoo Finance
@EconomyApp
APP ECONOMY INSIGHTS

- For Fifty years, we thought that our brain was a supercomputer or had microchips or super-processors. But we were wrong. These days, we believe that our brain, with those neurons and connections, is the simple artificial intelligence or (Machine learning). Neurons are like batteries. **Michio Kaku**

- 86 M neurons Human
- 175 M neurons Open AI-NN-2
- AI-NN-3 is 100 time AI-2
- NN-4 Will Have 100 Trillion Parameters
- 500x the Size of AI-3

Artificial intelligence

- **Artificial intelligence** (**AI**) is the intelligence of machines or software.
- You will try to create the machine then this machine will try to learn from you. Finally this machine solve your problems.
- Pros and cons: Speed

Artificial intelligence

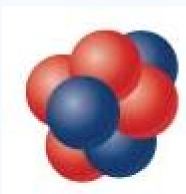
Why is artificial intelligence important?

- AI is important for its potential to change how we live, work and play. It has been effectively used in business to automate tasks done by humans, including customer service work, lead generation, fraud detection and quality control.
- In a number of areas, AI can perform tasks much better than humans.
- Particularly when it comes to repetitive, detail-oriented tasks, such as analyzing large numbers of legal documents to ensure relevant fields are filled in properly, AI tools often complete jobs quickly and with relatively few errors. Because of the massive data sets it can process, AI can also give enterprises insights into their operations they might not have been aware of. The rapidly expanding population of generative AI tools will be important in fields ranging from education and marketing to product design.

Neutron and Proton

- 1kg 1kg

Are they equal?

-
- 

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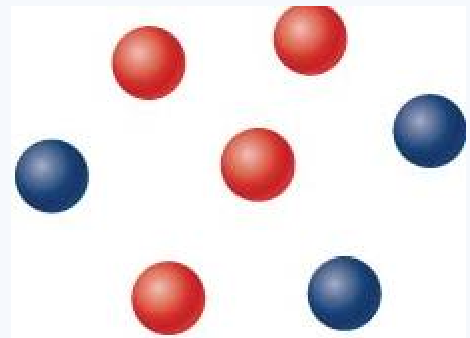
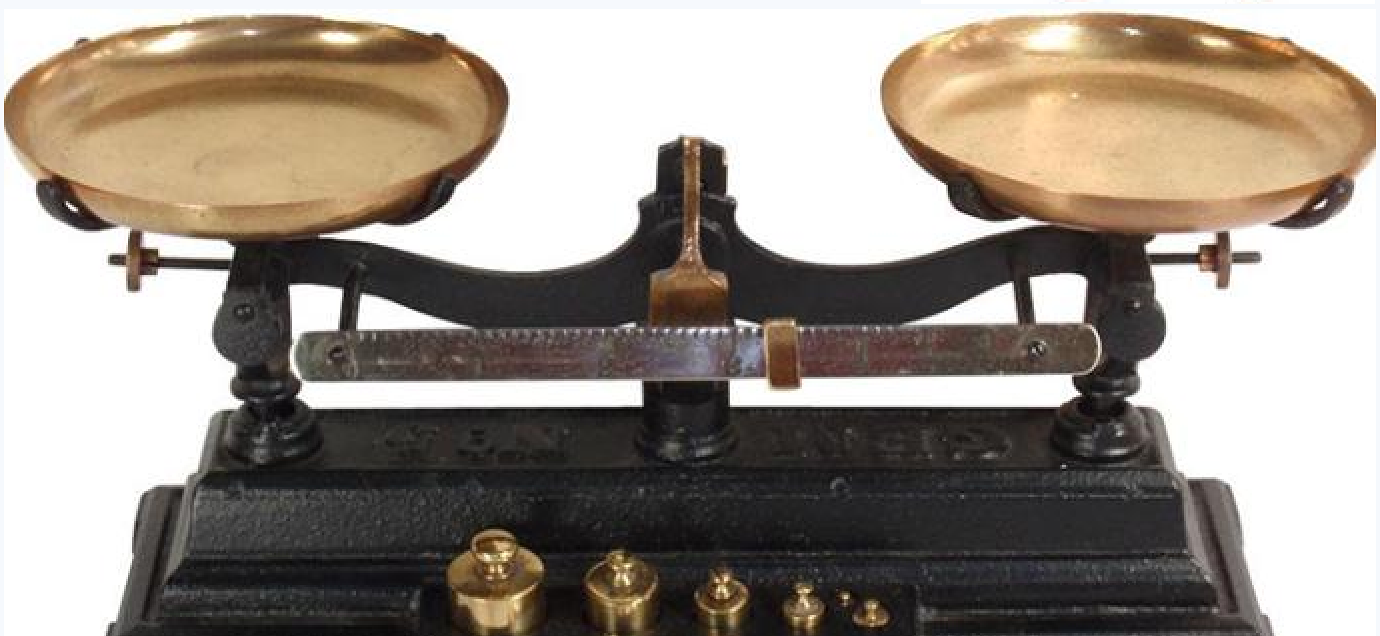
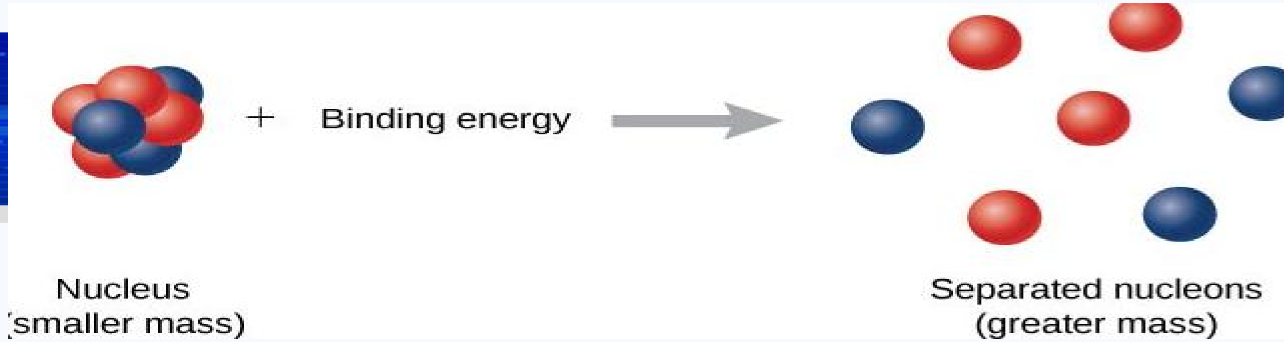
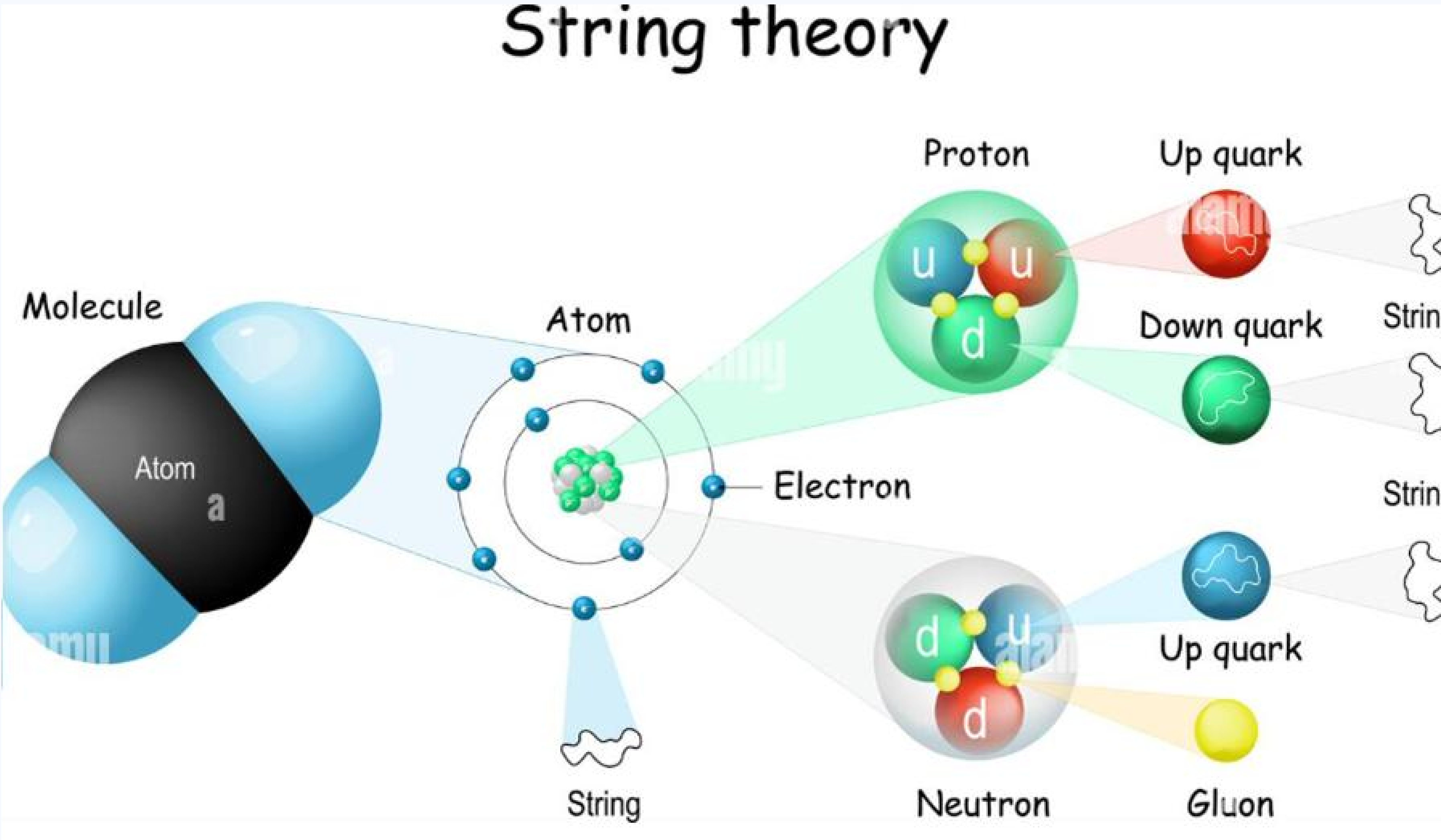





+ Binding energy
Nucleus
(smaller mass)
Separated nucleons
(greater mass)


String theory
Molecule
Atom
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Up quark
Down quark
String
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Electron
Neutron
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Up quark
Gluon
String

PHYSICS REPORTS (Review Section of Physics Letters) 158, No. 2 (1988) 91–157. North-Holland, Amsterdam

STATISTICAL MECHANICS OF NEURAL NETWORKS

John W. CLARK

Theoretical Division (T-11) and The Center for Nonlinear Studies, Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA

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*Department of Physics and McDonnell Center for the Space Sciences, Washington University, St. Louis, Missouri 63130, USA**

Received June 1987

Physics Letters B 300 (1993) 1–7
North-Holland

PHYSICS LETTERS B

Neural network models of nuclear systematics

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McDonnell Center for the Space Sciences and Department of Physics, Washington University, St. Louis, MO 63130, USA

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Received 13 November 1992

We describe a novel phenomenological approach to many-body systems based on multilayer feedforward neural networks. When subjected to appropriate training schemes, such networks are capable of learning the systematics of atomic masses and nuclear spins and parities with high accuracy while forming an efficient internal representation of the training data. When tested on nuclei outside the training set, these neural-network models demonstrate a predictive power competitive with that of traditional theoretical approaches, provided the test nuclei are not too different from those of the training set. The relative performance on training and test sets may be used as a measure of the homology of nuclei with respect to given observables.

ELSEVIER

Neural Networks
Volume 8, Issue 2, 1995, Pages 291-311

Contributed article

Neural networks that learn to predict probabilities: Global models of nuclear stability and decay

Klaus A. Gernoth, John W. Clark

Show more

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https://doi.org/10.1016/0893-6080(94)00071-S

John W Clark
Re: Your recent progress in nuclear...
Dear Prof. Clark, Sorry to reply la... 11:10

NSP2025
Re: Ynt: NSP-2025
Hi Dear Peof. Serkan, Thanks a mil... 昨天

schmitt
Values of Fission yields product
Hi Dear Prof. Schmitt, Hope you ar... 昨天

schmidt-erzhausen
Values of Fission yields product
Hi Dear Prof. Schmidt, Hope you a... 昨天

NSP2025
Re: NSP-2025
Dear Prof. Serkan, Many thanks fo... 周三

stephane.goriely
Re: Joint Project between China and Be...
Dear Stephane, Thank you for you... 周三

nsp2025
Abstract-NSP2025-SİVAS CUMHURİ...
Hi, I have submitted my abstract, b...周三

stephane.goriely
Re: Joint Project between China and Be...
Dear Prof. Stéphane Goriely, Have ...周一

Thomas Elias Cocolios
Re: Joint project between China and B...
Dear Thomas, Many thanks for yo... 5/15

julien.colaux
Joint project China and Belgium
Dear Prof. julien, Hope you are do... 5/15

Stijn.Buitink
Joint Project between China and Belgium
Dear Prof. Stijin, Hope you are doi... 5/15

New chat

---- Replied Message ----

From	John W Clark<jwc@physics.wustl.edu>
Date	4/28/2025 22:53
To	<draayer@lsu.edu>, <jalili@zstu.edu.cn>
Cc	Babette Dellen<dellen@hs-Koblenz.de>, Paulo Sérgio Abreu Freitas<paulo.freitas@staff.uma.pt>
Subject	Your recent progress in nuclear machine learning

Dear Jerry and Amir,

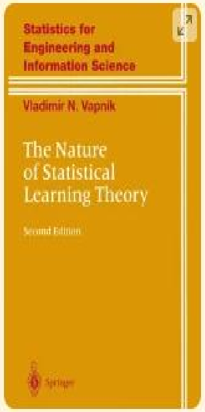
I have been greatly impressed by your recent publications in *Nature* and *Phys Rev C* on learning and prediction of alpha and beta decay processes. As you may well expect, I am also gratified. At this point, you have established a "state of the art" in this domain.

I am currently spending much of my time since formal retirement on the island of Madeira, where I have a condo located on a cliff above the university, which provides me with an office with a great view. UMa has some strength in physics-related stochastic processes due to the presence of Ludwig Streit (Bielefeld) over an extended period. He married a Portuguese woman, who was one of his students. UMa has, for multiple decades, sponsored Madeira Math Encounters, a kind of mini-Aspen, generally lasting two weeks. That's how I first got hooked. Here, it's literally like living in 2 1/2 dimensions, a vertical fractal.

Until recently, my research activity post "retirement" has been concentrated on developments in strongly correlated electron systems and their treatment by generalizations of Landau quasiparticle. "When you hear hoofbeats, think horses, not zebras or unicorns."

However, due to interaction with a young mathematician here in Madeira, I have been revisiting ML applications to nuclear physics as it has grown into a major industry.

In 2019 I presented a set of lectures on machine learning in nuclear physics at the Asia Pacific Center for Theoretical Physics in Pohang, Korea, during a program in recent developments in nuclear theory. There I introduced the SVM procedure along with the more traditional multilayer perceptrons (MLP). That was followed by a similar program at the Institute for Basic Sciences in Daejeon, where there were closer interactions with students. In preparation for these programs/schools, I enlisted a young faculty colleague in the math department here, Paulo Freitas, in a straightforward application of state-of-the art MLPs to alpha decay. The resulting paper was published in the APCTP newsletter/journal. I'll ask Paulo to send both of you a copy.



The Nature of Statistical Learning Theory

Book | © 2000

Latest edition

Overview

Authors: Vladimir N. Vapnik

- The aim of this book is to discuss the fundamental ideas which lie behind the statistical theory of learning and generalization.
- It considers learning as a general problem of function estimation based on empirical data.
- Omitting proofs and technical details, the author concentrates on discussing the main results of learning theory and their connections to fundamental problems in statistics.

Part of the book series: Information Science and Statistics (ISS)

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PHYSICAL REVIEW C **106**, L021301 (2022)

Letter

Physically interpretable machine learning for nuclear masses

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(Received 4 March 2022; revised 10 May 2022; accepted 21 July 2022; published 1 August 2022)

We present an approach to modeling the ground-state mass of atomic nuclei based directly on a probabilistic neural network constrained by relevant physics. Our physically interpretable machine learning (PIML) approach incorporates knowledge of physics by using a physically motivated feature space in addition to a soft physics constraint that is implemented as a penalty to the loss function. We train our PIML model on a random set of approximately 20% of the atomic mass evaluation (AME) and predict the remaining 80%. The success of our methodology is exhibited by a $\sigma_{\rm rms} \approx 186$ keV match to data for the training set and $\sigma_{\rm rms} \approx 316$ keV for the entire AME with $Z \geqslant 20$. We show that our general methodology can be interpreted using feature importance.

DOI: 10.1103/PhysRevC.106.L021301

PHYSICAL REVIEW C **99**, 064307 (2019)

Predictions of nuclear β-decay half-lives with machine learning and their impact on *r*-process nucleosynthesis

Z. M. Niu (牛中明),[1,2] H. Z. Liang (梁豪兆),[3,4,*] B. H. Sun (孙保华),[5] W. H. Long (龙文辉),[6] and Y. F. Niu (牛一斐)[6,7]

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[3]*RIKEN Nishina Center, Wako 351-0198, Japan*
[4]*Department of Physics, Graduate School of Science, The University of Tokyo, Tokyo 113-0033, Japan*
[5]*School of Physics and Nuclear Energy Engineering, Beihang University, Beijing 100191, China*
[6]*School of Nuclear Science and Technology, Lanzhou University, Lanzhou 730000, China*
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(Received 2 October 2018; revised manuscript received 7 April 2019; published 5 June 2019)

Nuclear β decay is a key process to understand the origin of heavy elements in the universe, while the accuracy is far from satisfactory for the predictions of β-decay half-lives by nuclear models to date. In this work, we pave a novel way to accurately predict β-decay half-lives with the machine learning based on the Bayesian neural network, in which the known physics has been explicitly embedded, including the ones described by the Fermi theory of β decay, and the dependence of half-lives on pairing correlations and decay energies. The other potential physics, which is not clear or even missing in nuclear models nowadays, will be learned by the Bayesian neural network. The results well reproduce the experimental data with a very high accuracy and further provide reasonable uncertainty evaluations in half-life predictions. These accurate predictions for half-lives with uncertainties are essential for the *r*-process simulations.

DOI: 10.1103/PhysRevC.99.064307

[HTML] Nuclear energy system's behavior and decision making using machine learning
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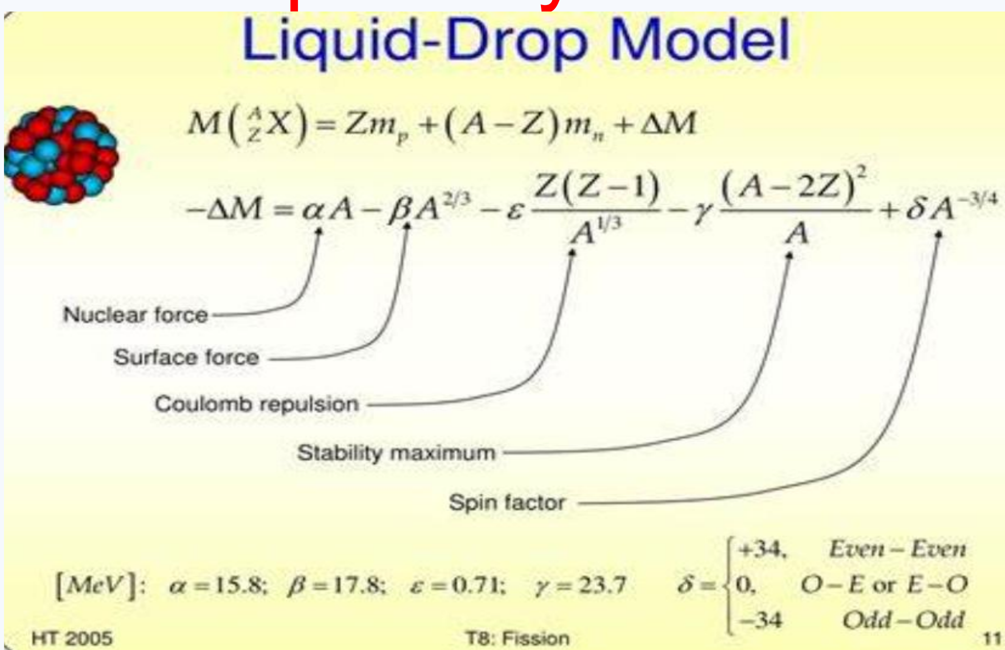
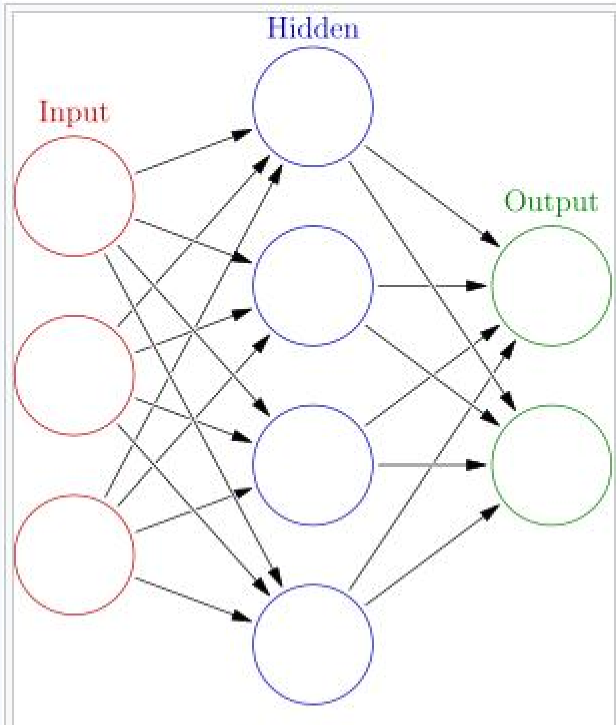
Model-repair capabilities of tree-based machine-learning algorithms applied to theoretical nuclear mass models
GP Liu, HL Wang, ZZ Zhang, ML Liu - Physical Review C, 2025 - APS

Neural Networks

- Input layer:Data
- Hidden layer: Objective or activation functions
- Outputs layer: Results



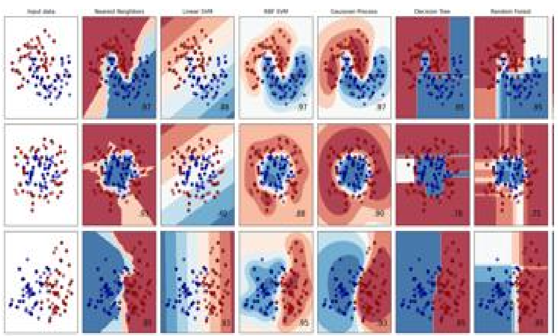


An artificial neural network is an interconnected group of nodes, akin to the vast network of neurons in a brain. Here, each circular node represents an artificial neuron and an arrow represents a connection from the output of one artificial neuron to the input of another.

Classification

Identifying which category an object belongs to.

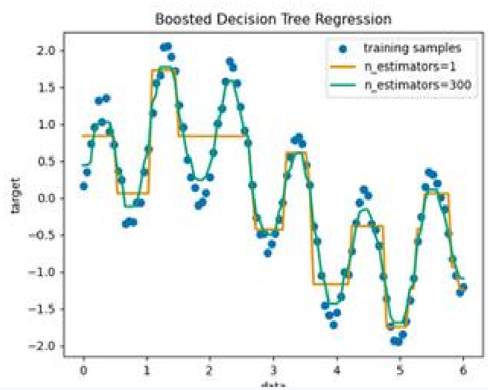
Applications: Spam detection, image recognition.
Algorithms: Gradient boosting, nearest neighbors, random forest, logistic regression, and more...



Regression

Predicting a continuous-valued attribute associated with an object.

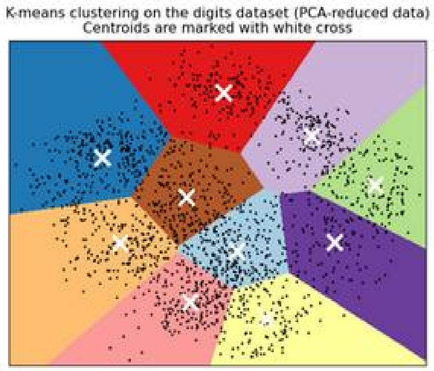
Applications: Drug response, Stock prices.
Algorithms: Gradient boosting, nearest neighbors, random forest, ridge, and more...



Clustering

Automatic grouping of similar objects into sets.

Applications: Customer segmentation, Grouping experiment outcomes
Algorithms: k-Means, HDBSCAN, hierarchical clustering, and more...



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of Physics

PAPER

Prediction of ground state charge radius using support vector regression

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2 School of Physics, Nankai University, Tianjin 300071, People's Republic of China

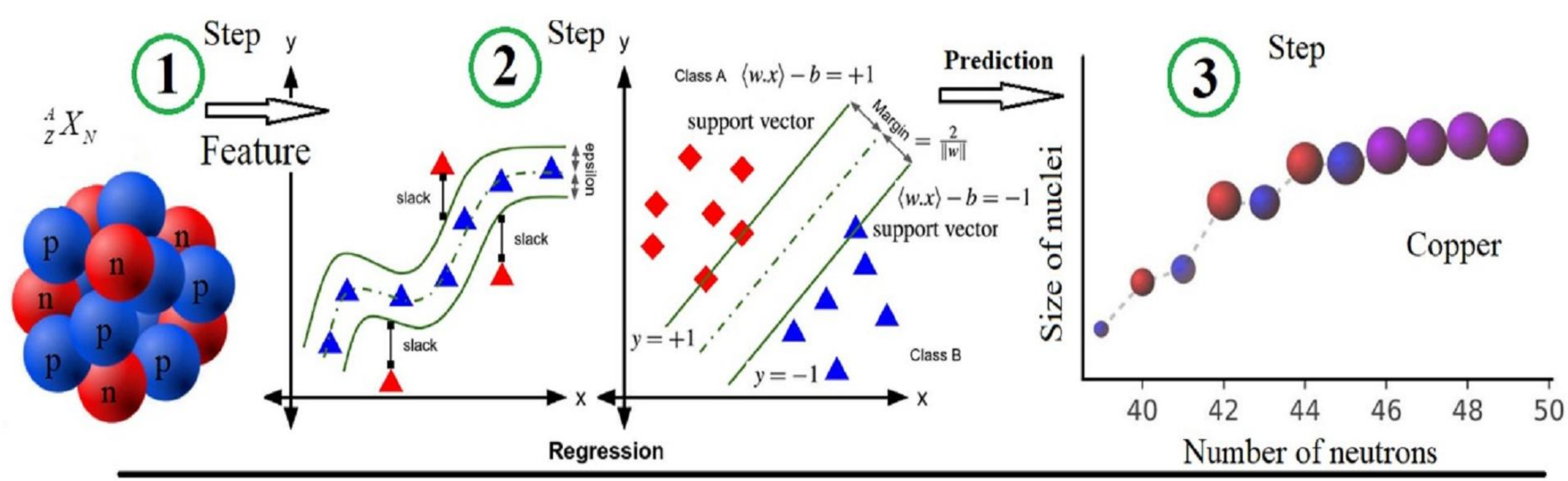

Figure 1. Schematic representation of the adjustable SVR structure utilized in this study.

PHYSICAL REVIEW C **111**, 034321 (2025)

Nuclear β-decay half-life predictions and r-process nucleosynthesis using machine learning models

Amir Jalili,[1,2,*] Feng Pan,[3,4] Y. A. Luo,[2] and Jerry P. Draayer[4]

[1]*Zhejiang Key Laboratory of Quantum State Control and Optical Field Manipulation, Department of Physics, Zhejiang Sci-Tech University, Hangzhou 310018, China*

[2]*School of Physics, Nankai University, Tianjin 300071, People's Republic of China*

[3]*Department of Physics, Liaoning Normal University, Dalian 116029, People's Republic of China*

[4]*Department of Physics and Astronomy, Louisiana State University, Baton Rouge, Louisiana 70803-4001, USA*

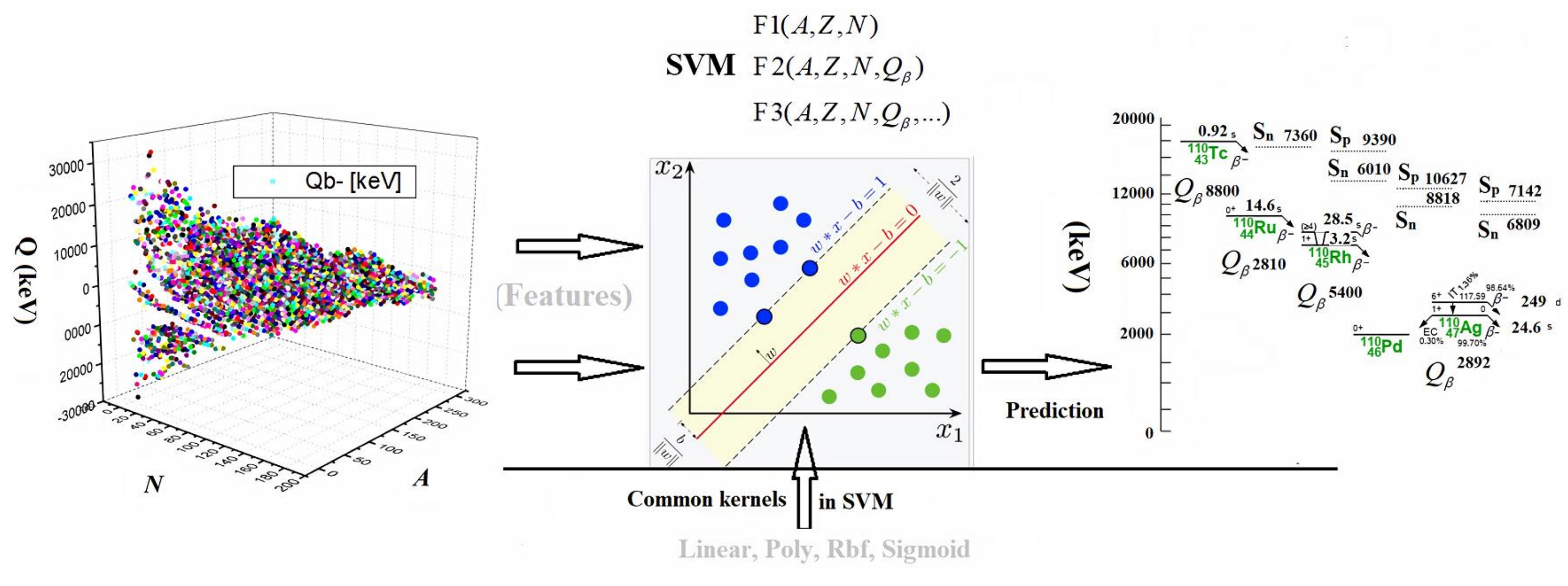

FIG. 1. Schematic of the adjustable SVM structure for β-decay half-lives and r-process abundance.

Optimization algorithm

- GA: Genetic Algorithm
- PSO: Particle Swarm *optimization*
- Common ML algorithms:
- *Neural networks*
- Support Vector Machines
- Random Forests
- eXtreme Gradient Boosting
- Cluster and regression
- Hybrid model

Suggestion for prospective works

- **Nonlinear dynamic pattern**
- **New neural networks**
- **Earthquake prediction by ML+hybrid**
- **RMT in cosmology (Astro)**
- **New network in stock market**
- **New network in high energy physics**
- **Spectral statistics**

我欠中国人民一份情。

THE END

Thanks for your attention