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CAIR - In a global AI race

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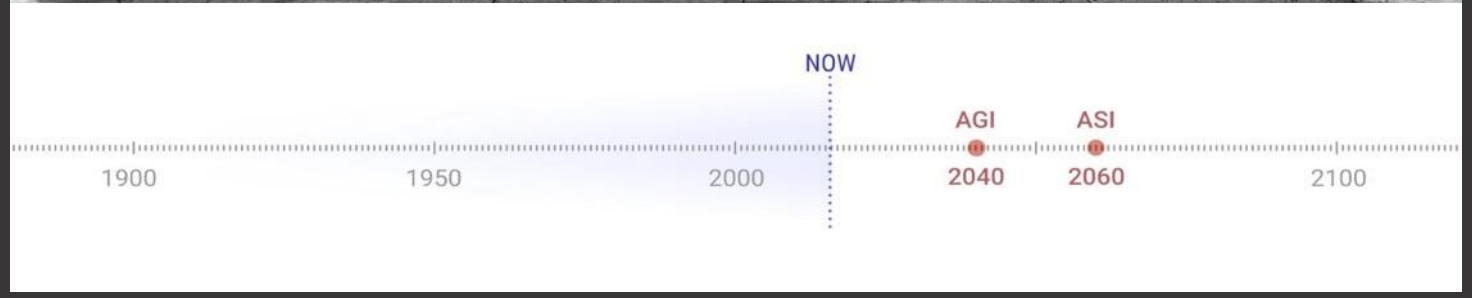
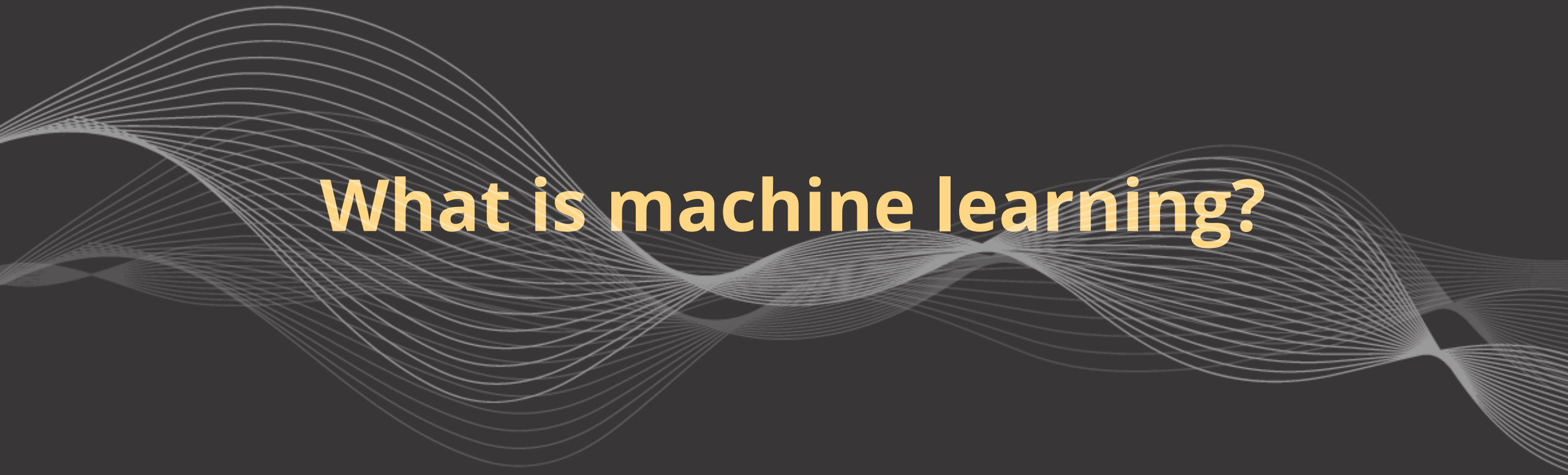
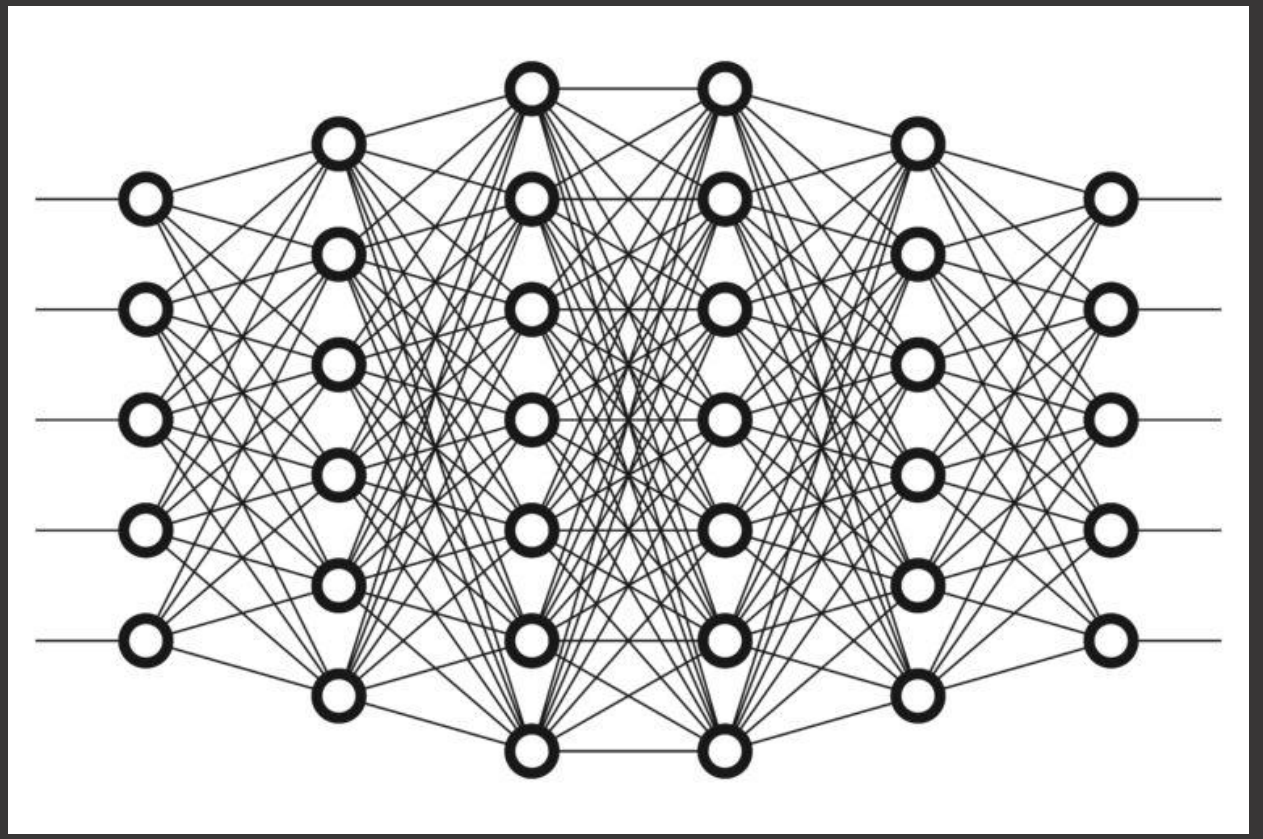




What is machine learning?

Machine learning

Input

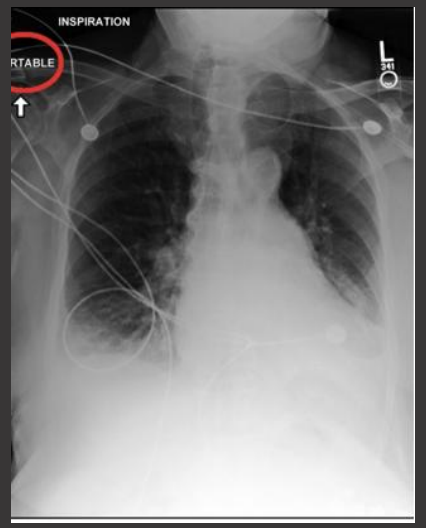


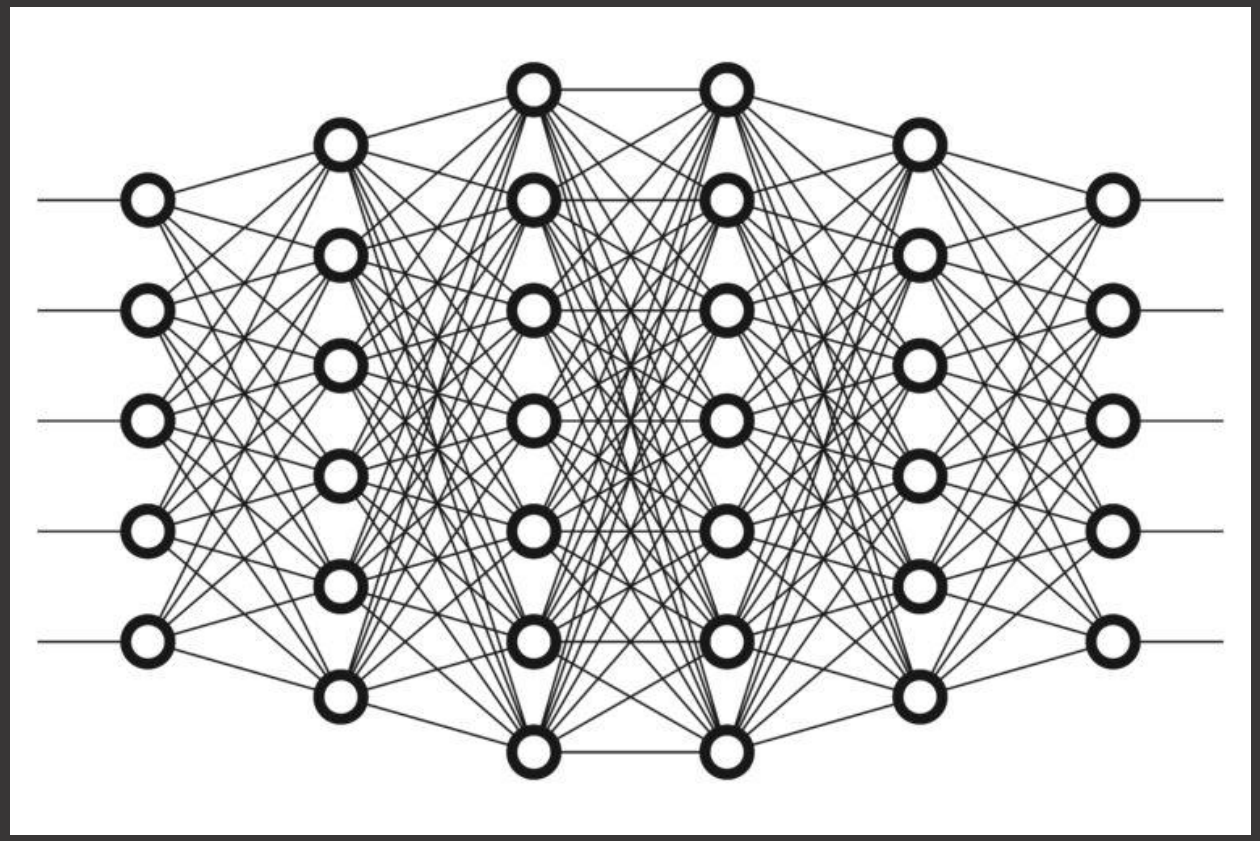
Model

0

Output

Medical image analysis

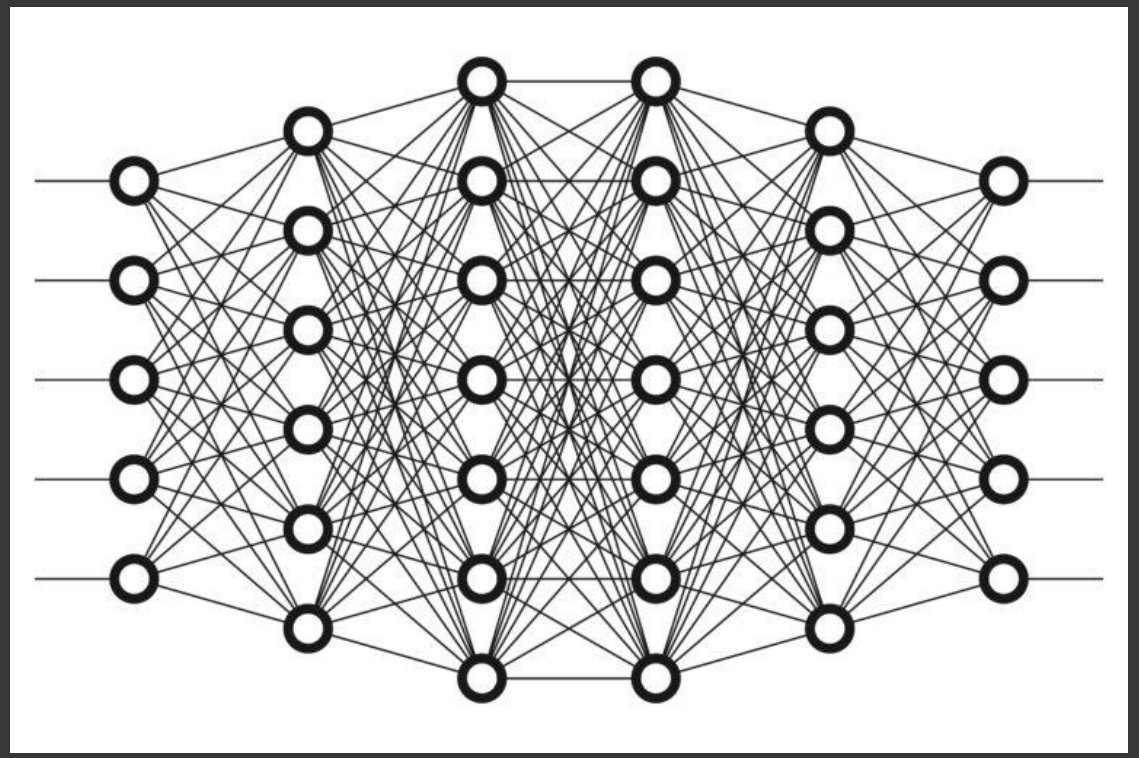




Pneumonia

Text classification

This Agreement shall have an initial term of one (1) year from the date first above written (the “Initial Term”), and shall thereafter automatically renew for successive two (2) year periods (each a ”**Renewal Term**”), **unless earlier terminated** in accordance with the terms of this Agreement.



“EXPIRATION DATE”.

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Large language models – super intelligence?

Norway's Radical Alternative: The Tsetlin Machine

Most AI is a *black box*—a digital "trust me" wrapped in layers of inscrutable code. The Tsetlin Machine? It's a **glass courtroom**.

- Every *clause* is a witness called to testify.
- Every *output* is cross-examined.
- Every *decision* is a verdict the public can appeal.

This isn't just transparency—it's **democracy hard-coded into silicon**.

The danger of hallucinations

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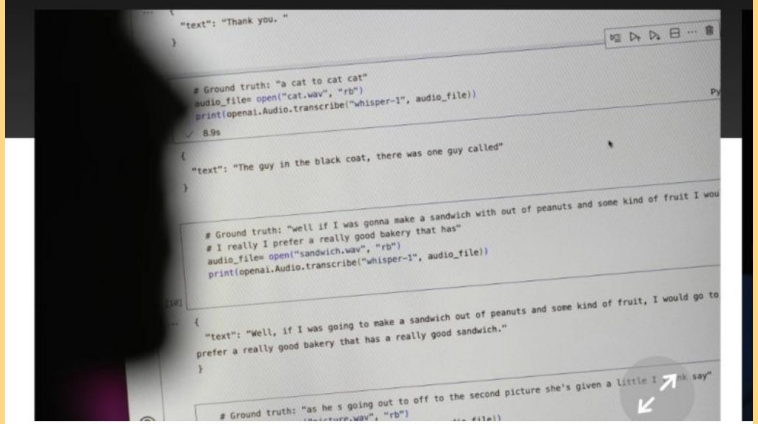
TECHNOLOGY

Researchers say an AI-powered transcription tool used in hospitals invents things no one ever said



ChatGPT references fake legal cases

During the New York federal court filing, one of the lawyers was caught citing non-existent cases. It turned out he was using ChatGPT to conduct legal research—the bot referenced fake cases to the attorney.

Don't rely on Dr AI: New search engine gives medical advice that could lead to death in one in five cases

Kommune tatt for KI-bruk: – Dette er pinlig

Tromsø kommune brukte kunstig intelligens som hjelpemiddel i arbeidet med en viktig rapport. Rapporten inneholdt flere feil, noe KI-ekspert mener kunne vært unngått.

The illusion of thinking

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https://machinelearning.apple.com/research/illusion-of-thinking

The three betrayals

Betrayal #1: Energy

"One query to ChatGPT uses approximately as much electricity as could light one light bulb for about 20 minutes"

Jesse Dodge, Allen Institute of AI

"Each month, ChatGPT produces more than 260,930 kilograms of CO2 — equal to the carbon emissions of 260 flights from New York City to London"

https://fortune.com/2025/01/21/chatgpt-carbon-dioxide-emissions-study/

The environmental problem

«The proliferating data centres that house AI servers produce electronic waste. They are large consumers of water, which is becoming scarce in many places. They rely on critical minerals and rare elements, which are often mined unsustainably. And they use massive amounts of electricity, spurring the emission of planet-warming greenhouse gases.»

https://www.unep.org/news-and-stories/story/ai-has-environmental-problem-heres-what-world-can-do-about

Big Tech's AI power play sparks concern among green groups

By **MOHAR CHATTERJEE** and **JORDAN WOLMAN** | 10/22/2024 12:01 PM EDT

Betrayal #2: Transparency

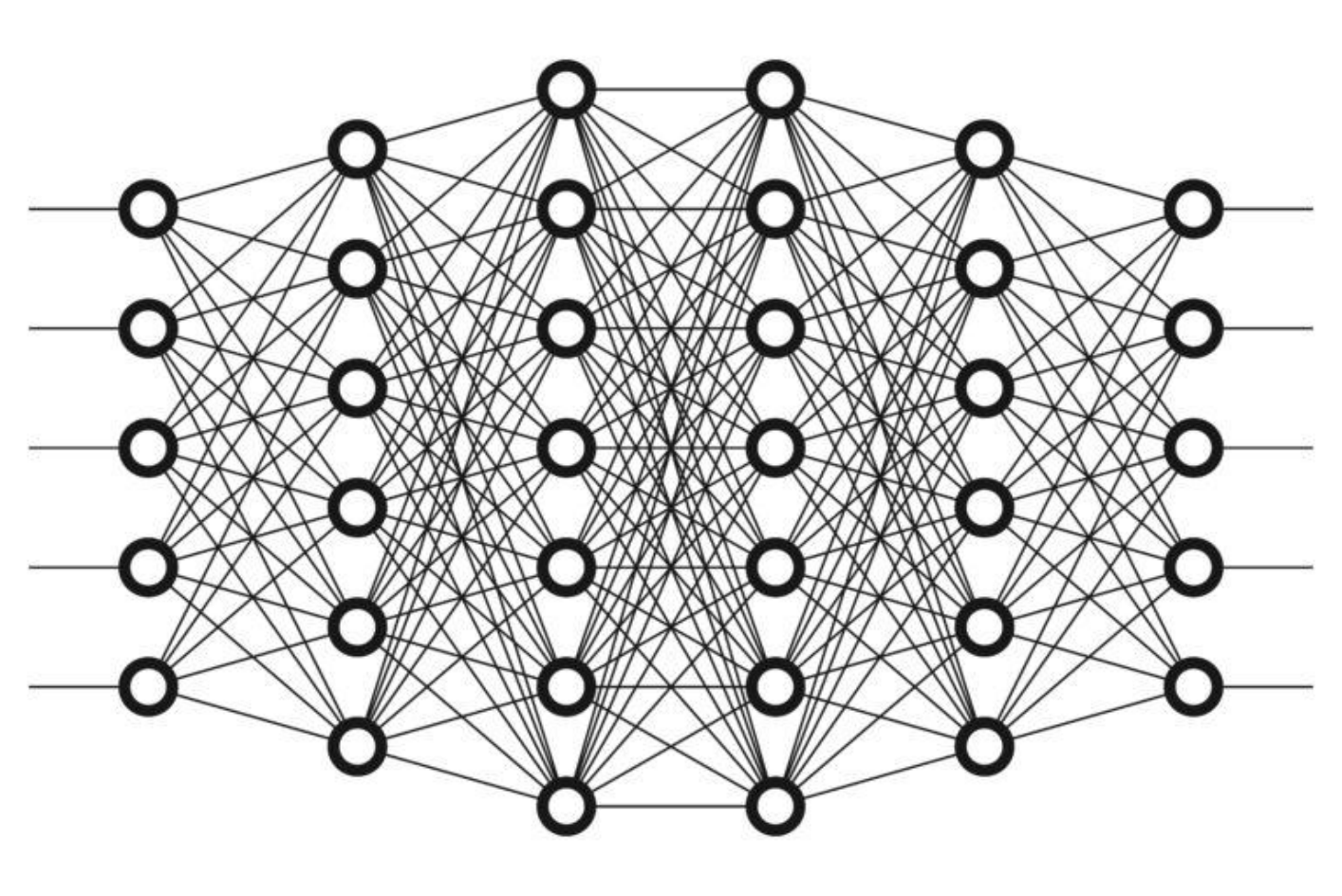
“In the U.S., algorithms now determine prison sentences. Judges literally cannot explain them.”

https://www.sanmarcosrecord.com/article/30411,risk-by-code-how-algorithms-are-deciding-prison-sentences

"In India, welfare algorithms have erased thousands of legitimate receivers from beneficiary lists, their needs overruled by flawed data and algorithmic bias."

«How an algorithm denied food to thousands of poor in India's Telangana», Al Jazeera, January, 2024

The complexity of neural networks



Correlation is not causation

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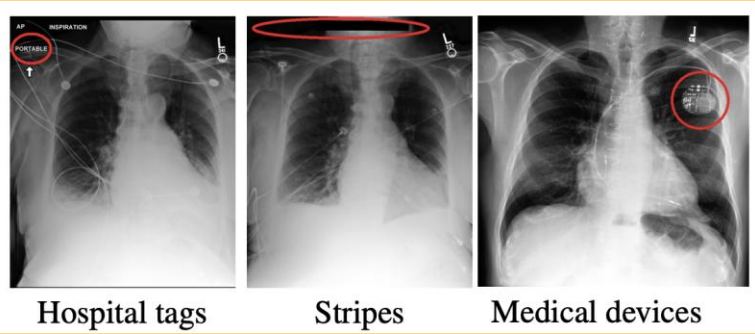
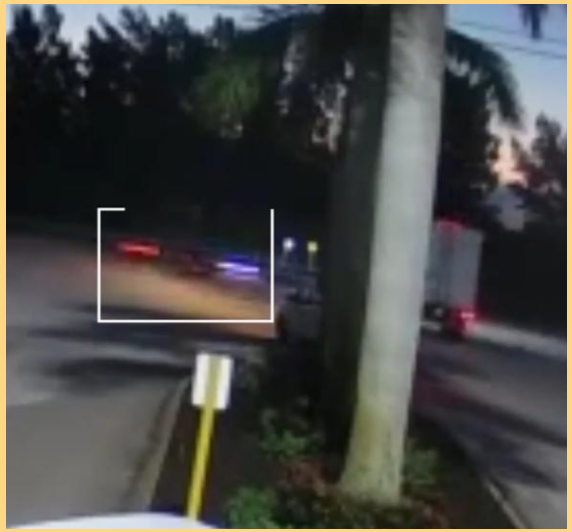
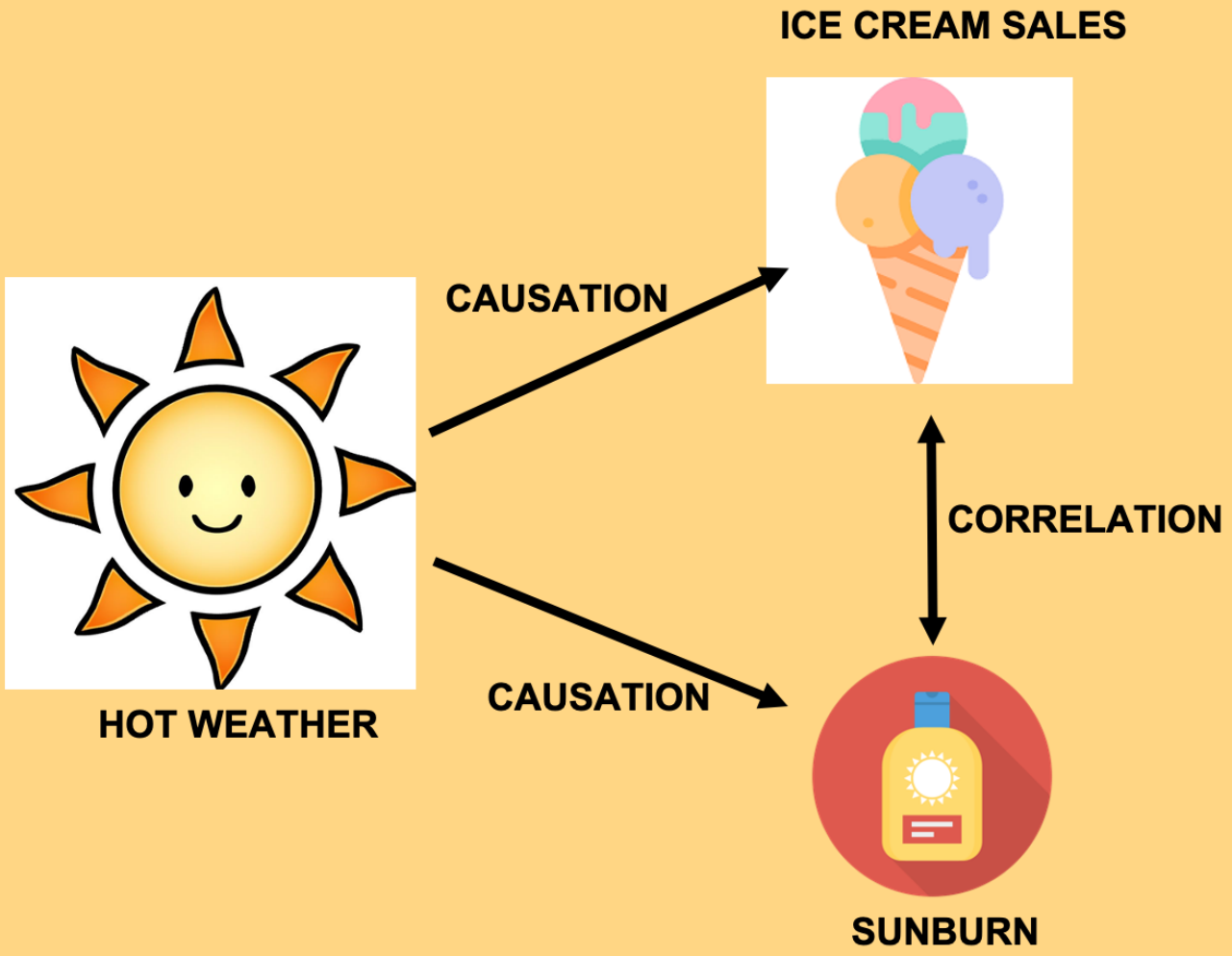
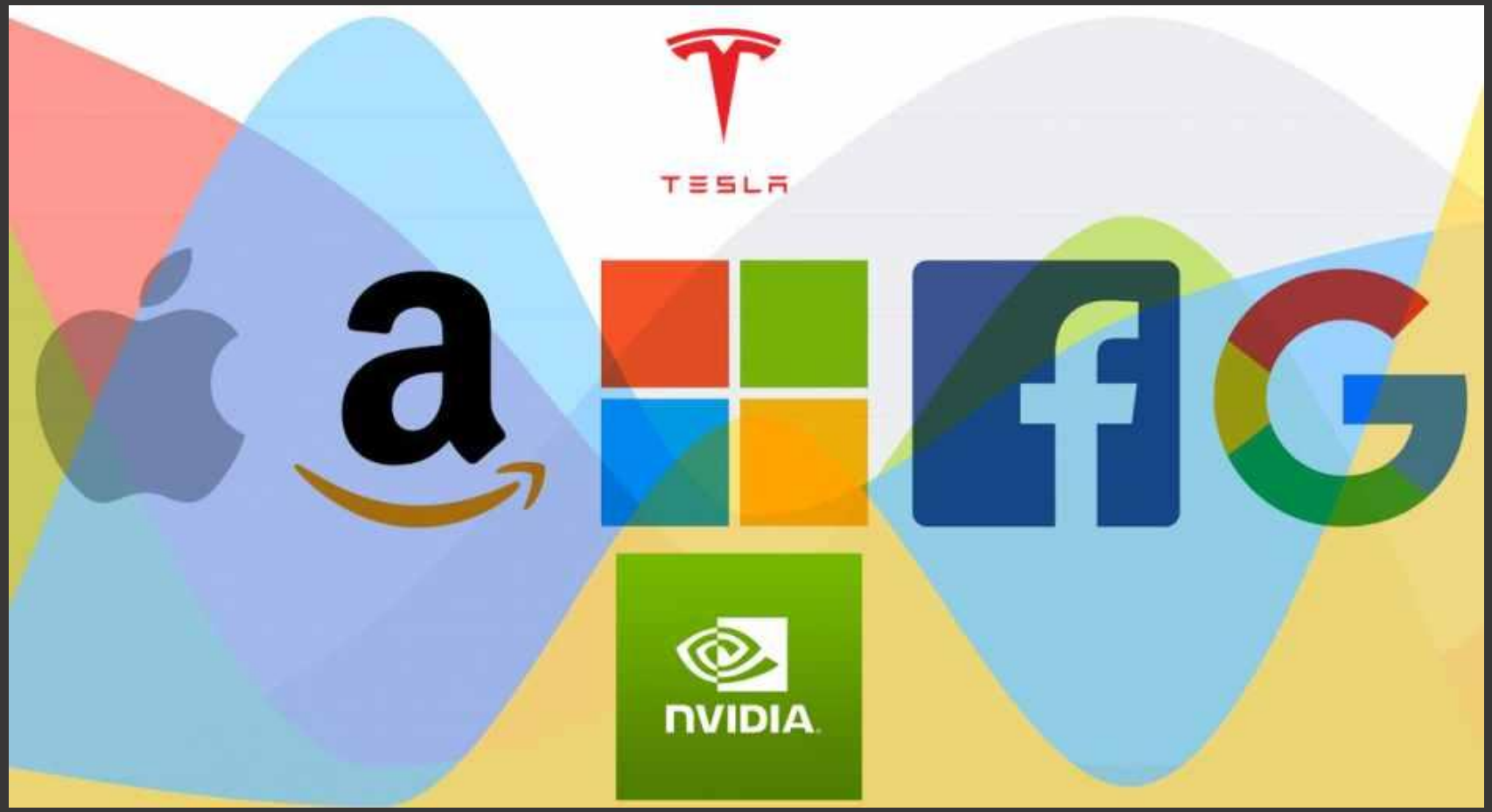






https://www.royriachi.com/2019/02/correlational-and-causal-relationships.html

Betrayal #3: Power



As of June 12th, 2024, just 6 stocks had added a combined $3.8 trillion in market capitalization

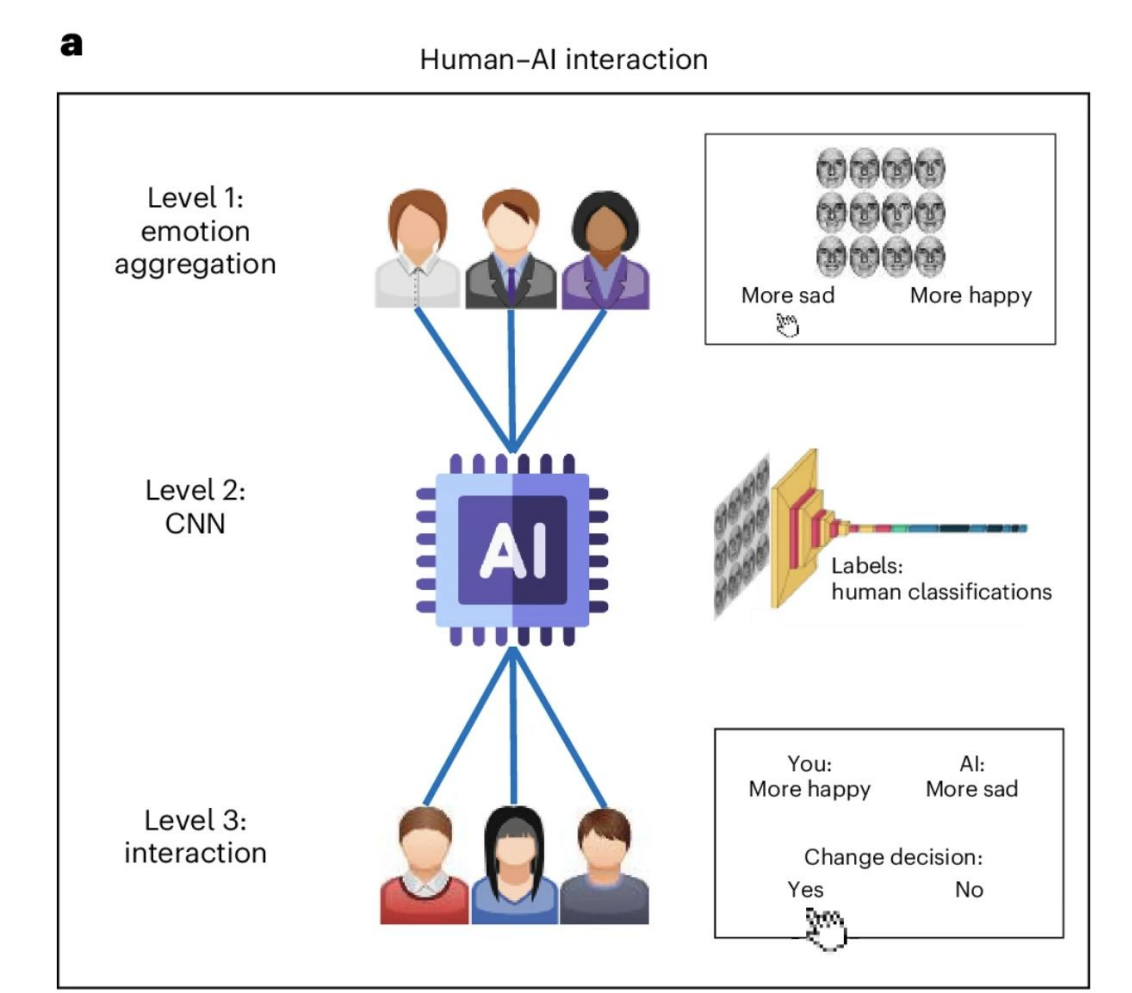
https://sherwood.news/markets/big-tech-keeps-getting-bigger-adding-usd3-8-trillion-in-market-cap-this-year/

"Kids are learning to twist themselves into whatever shape the algorithms reward, in their striving for peer acceptance."

“Governments buy predictive policing tools that codify racial bias—then call it objective."

https://www.technologyreview.com/2020/07/17/1005396/predictive-policing-algorithms-racist-dismantled-machine-learning-bias-criminal-justice/

How human–AI feedback loops alter human perceptual, emotional and social judgements



Glickman, M., Sharot, T. How human–AI feedback loops alter human perceptual, emotional and social judgements. *Nat Hum Behav* (2024).

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The radical Norwegian alternative

01101100111100000111

The Tsetlin automaton:
A mathematical rat brain

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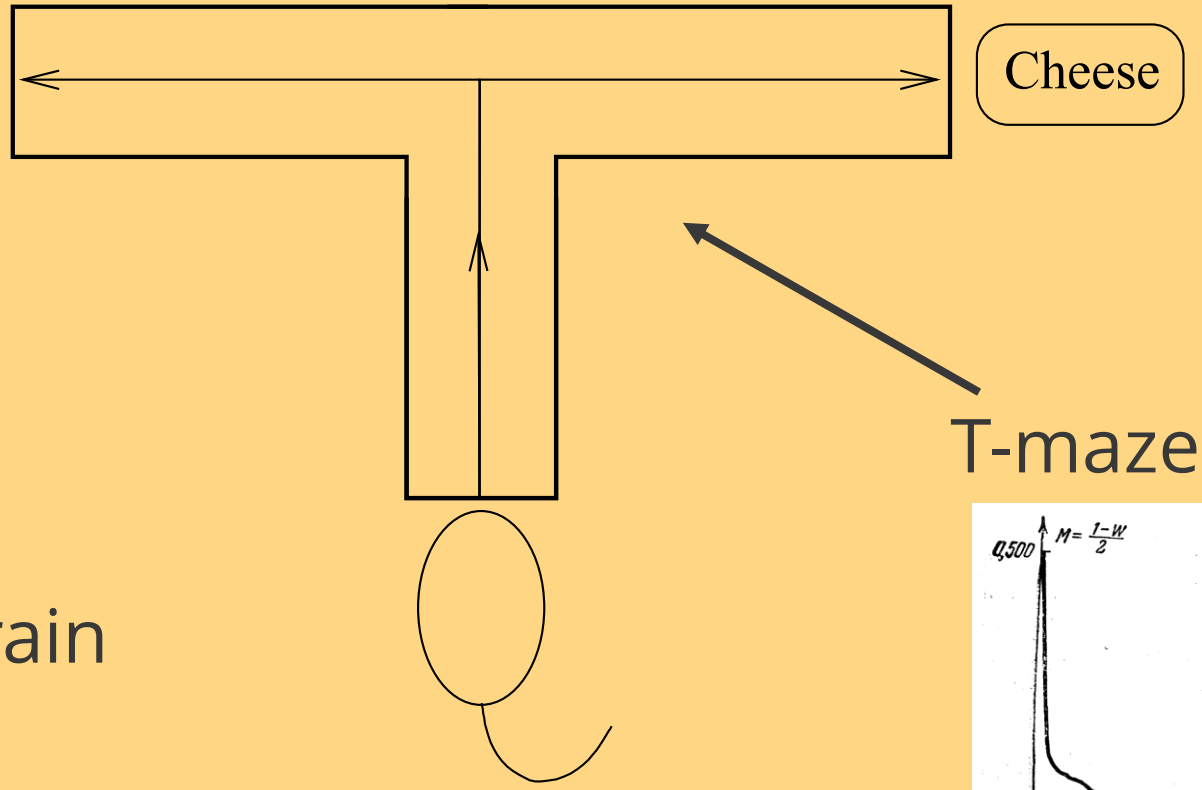
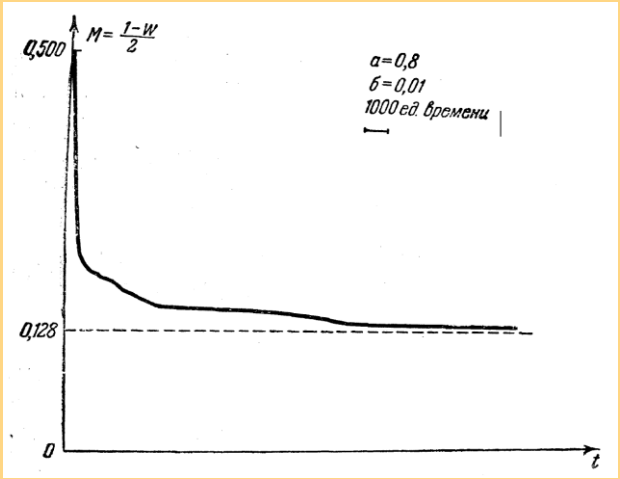
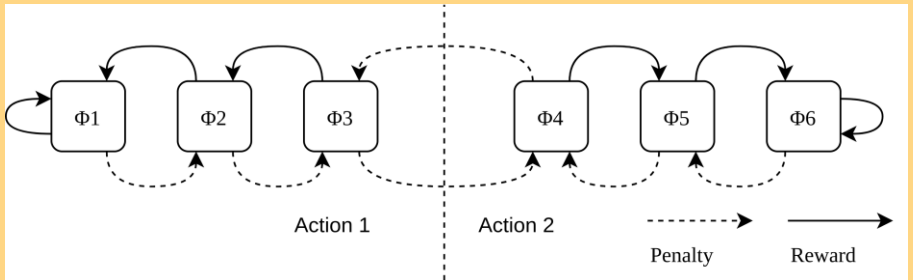


T-maze puzzle

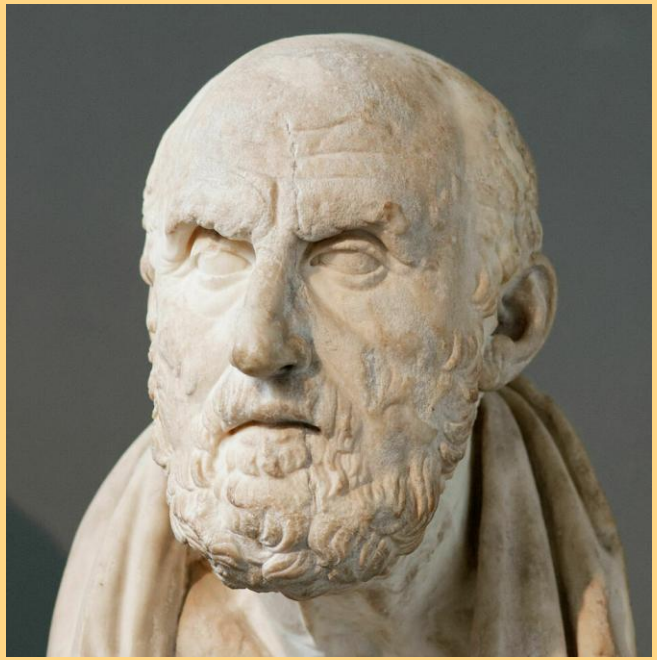


Mathematical rat brain



Tsetlin, Michael L. (1961). "On behaviour of finite automata in random medium". Avtomat. i Telemekh. 22 (10).

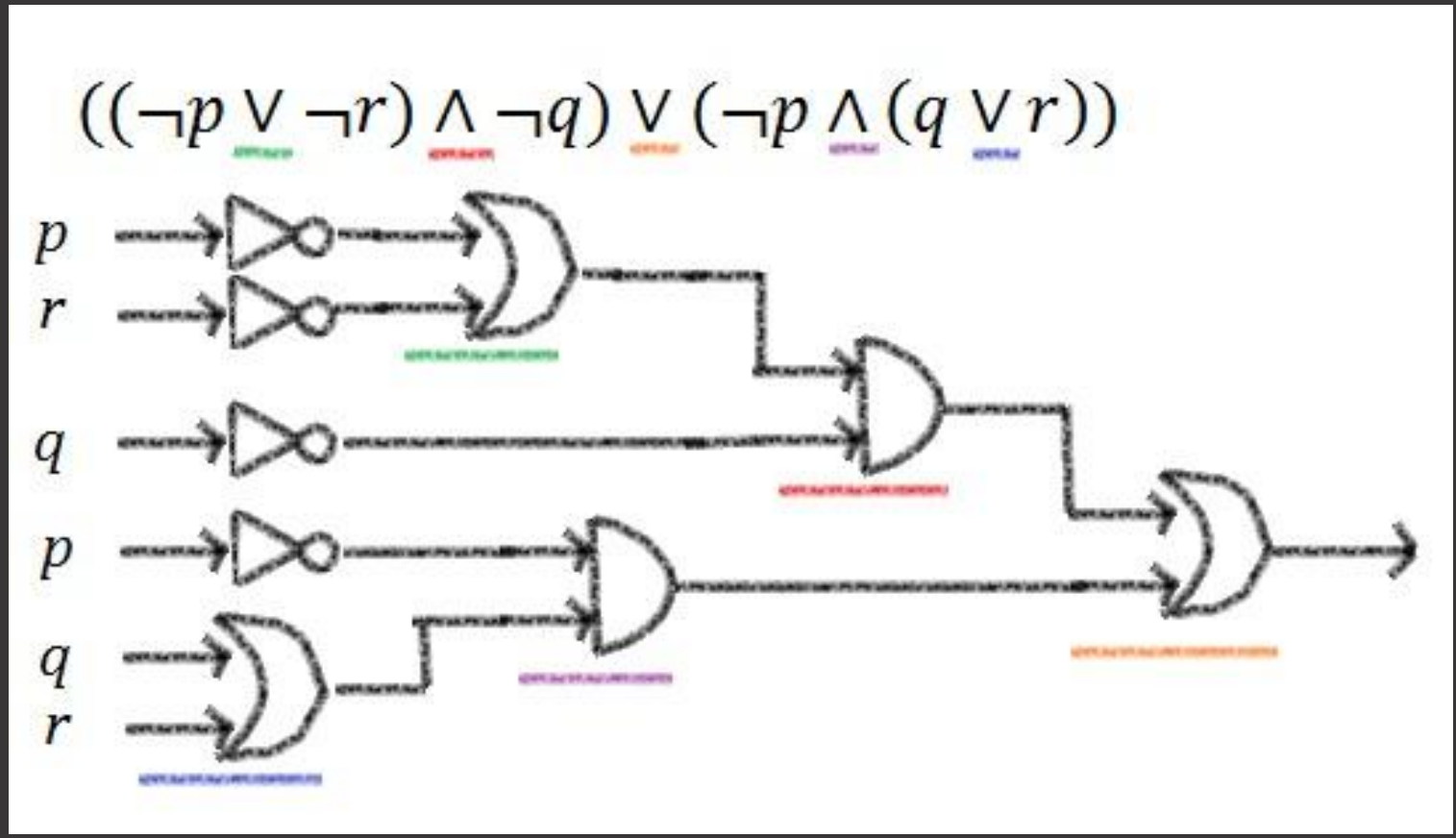
Propositional logic



Propositional logic is the branch of logic that studies ways of joining and/or modifying entire propositions, statements or sentences to form more complicated propositions, statements or sentences, as well as the logical relationships and properties that are derived from these methods of combining or altering statements.

The Internet Encyclopedia of Philosophy

Propositional logic



http://mathrescue.blogspot.no/2013/04/

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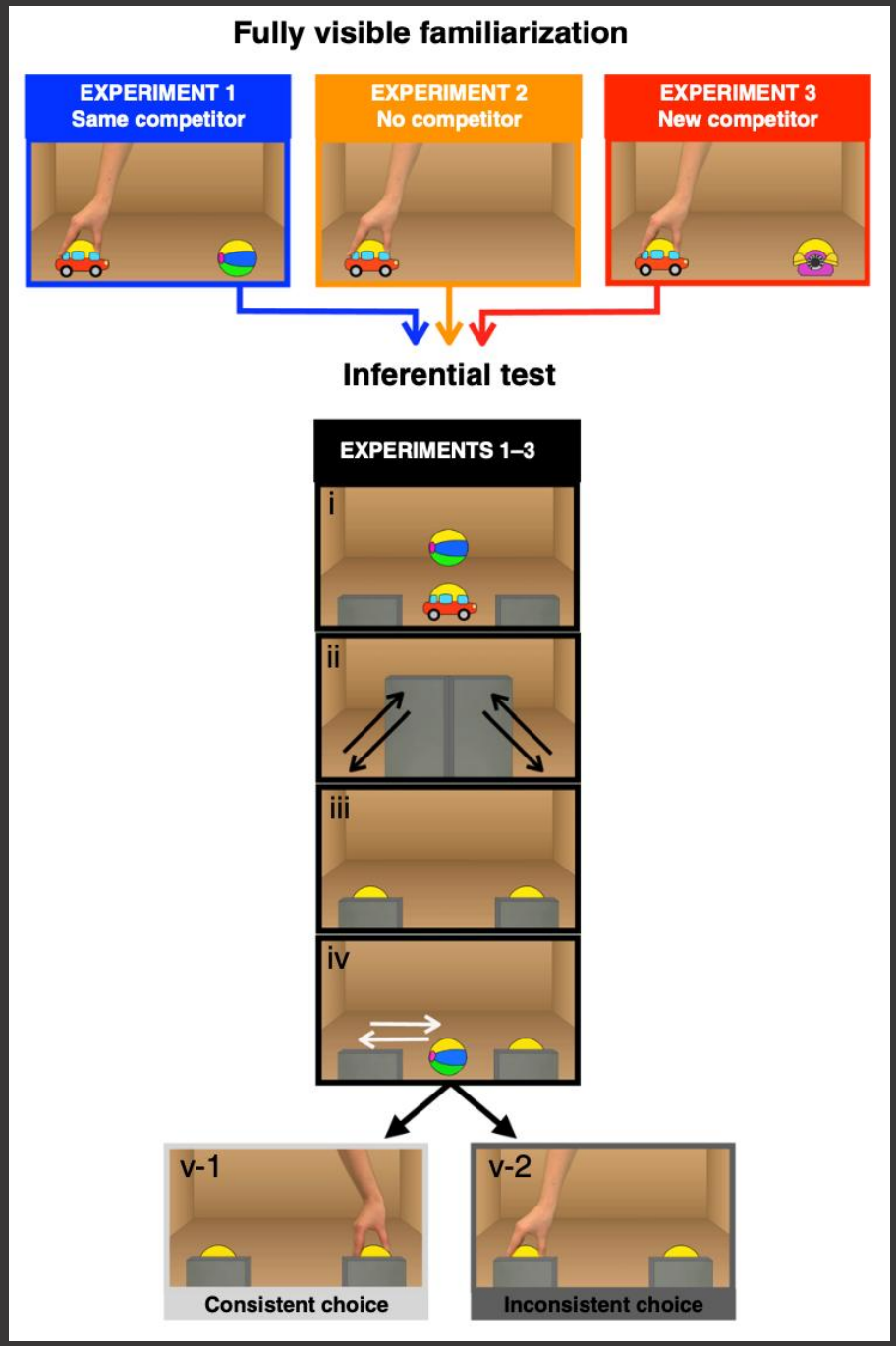
Infants recruit logic to learn about the social world

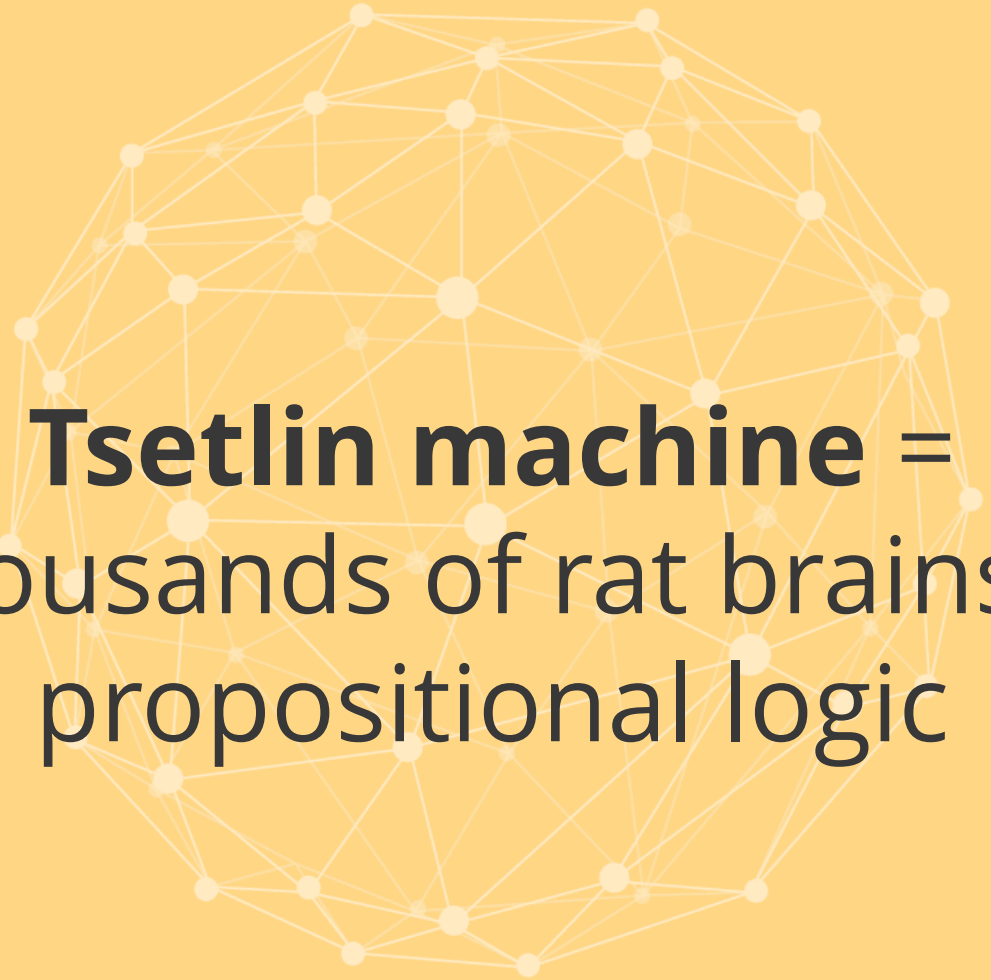
Reasoning by elimination

A **or** B
not A

B



N. Cesana-Arlotti, A. M. Kovacs, and E. Teglas. Infants recruit logic to learn about the social world. Nature Communications, 11(1):5999, Nov 2020.



Tsetlin machine =
thousands of rat brains +
propositional logic

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Tsetlin machine research team

Hardware design

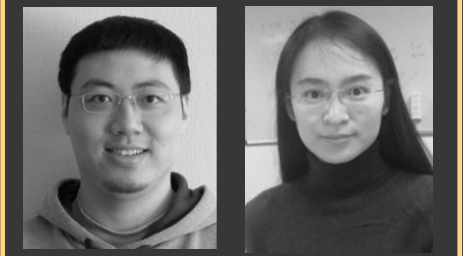
Applications

Algorithms & architectures

Reinforcement learning

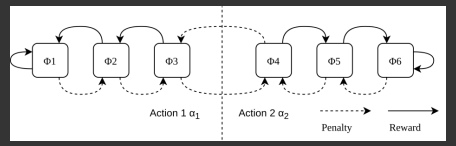
Logic, cause and effect & natural language

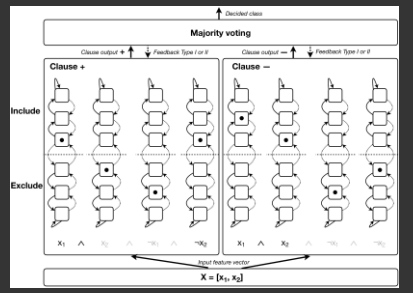
Theoretical foundation

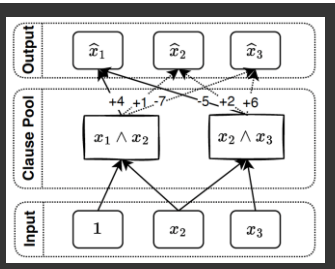


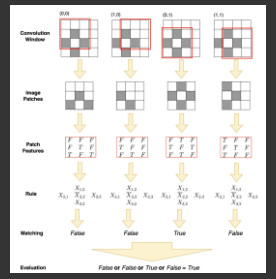
Tsetlin machine timeline

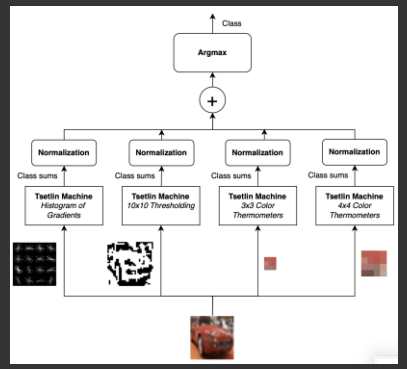
1961 Tsetlin Automaton
2018 Tsetlin machine
2019 Convolutional Tsetlin machine
2020 Regression Tsetlin machine
2021 Multi-output Tsetlin machine
2022 Relational Tsetlin machine
2023 Tsetlin machine autoencoder
2023 Tsetlin machine composites
2024 Hypervector Tsetlin machine
2024 Graph Tsetlin machine
2025 ...

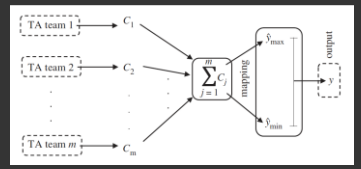


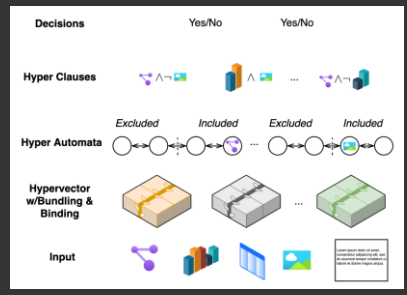


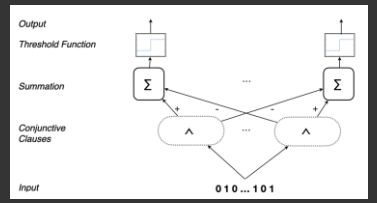


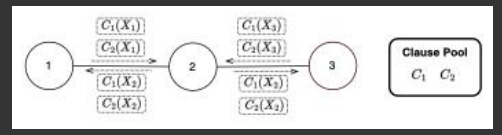












Tsetlin machine research horizon

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Pittsburg Uni. – NLP, Health

NMBU – Analysis of Healthcare Data

Uni. of Groningen – Interpretable Reinforcement Learning

PwC Switzerland – Interpretable Machine Learning

Newcastle university – Hardware Implementation

Beijing Uni. of Posts and Telecom. – NLP

Uni. of Goettingen – Auto-encoding

Uni. of Bergen – Formal Verification

Uni. of Amsterdam – Reinforcement Learning

Sichuan Uni. – Medical Image Analysis

Indian Inst. of Tech. Bhubaneswar – UAVs

Research Inst. for AI, Bucharest – NLP

Peter the Great St. Petersburg Polytechnic Uni. – Intrusion Detection

MILA/McGill University – Reinforcement Learning

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Top-tier publications

- S. Maheshwari et al., "REDRESS: Generating Compressed Models for Edge Inference Using Tsetlin Machines," in IEEE Transactions on Pattern Analysis and Machine Intelligence, vol. 45, no. 9, pp. 11152-11168, 1 Sept. 2023
- Jivitesh Sharma, Rohan Yadav, Ole-Christoffer Granmo, and Lei Jiao. Drop Clause: Enhancing Performance, Robustness and Pattern Recognition Capabilities of the Tsetlin Machine. AAAI 2023.
- Raihan Seraj, Jivitesh Sharma and Ole-Christoffer Granmo: Tsetlin Machine for Solving Contextual Bandit Problems. NeurIPS 2022.
- Lei Jiao, Xuan Zhang, Ole-Christoffer Granmo and K. Darshana Abeyrathna, "On the Convergence of Tsetlin Machines for the XOR Operator. IEEE Transactions on Pattern Analysis and Machine Intelligence. 2022.
- Rohan Kumar Yadav, Lei Jiao, Ole-Christoffer Granmo, Morten Goodwin: Robust Interpretable Text Classification against Spurious Correlations Using AND-rules with Negation. IJCAI 2022.
- Ahmed Abouzeid, Ole-Christoffer Granmo, Christian Webersik, Morten Goodwin: Socially Fair Mitigation of Misinformation on Social Networks via Constraint Stochastic Optimization. AAAI 2022.
- Rohan Kumar Yadav, Lei Jiao, Ole-Christoffer Granmo, Morten Goodwin: Human-Level Interpretable Learning for Aspect-Based Sentiment Analysis. AAAI 2021.
- Kuruge Darshana Abeyrathna, Bimal Bhattarai, Morten Goodwin, Saeed Rahimi Gorji, Ole-Christoffer Granmo, Lei Jiao, Rupsa Saha, Rohan Kumar Yadav: Massively Parallel and Asynchronous Tsetlin Machine Architecture Supporting Almost Constant-Time Scaling. ICML 2021.
- Xuan Zhang, Lei Jiao, Ole-Christoffer Granmo, Morten Goodwin: On the Convergence of Tsetlin Machines for the IDENTITY- and NOT Operators. IEEE Transactions on Pattern Analysis and Machine Intelligence. 2021.
- Sondre Glimsdal, Ole-Christoffer Granmo: Thompson Sampling Guided Stochastic Searching on the Line for Deceptive Environments with Applications to Root-Finding Problems. JMLR 2019.

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FEBRUARY 7-14, 2023 · WASHINGTON, DC, USA
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NeurIPS | 2022

IJCAI ECAI VIENNA 22

ICML | 2021
Thirty-eighth International Conference on Machine Learning

35th AAAI Conference on Artificial Intelligence
A Virtual Conference
February 2–9, 2021

IEEE TRANSACTIONS ON
PATTERN ANALYSIS AND MACHINE INTELLIGENCE

JMLR

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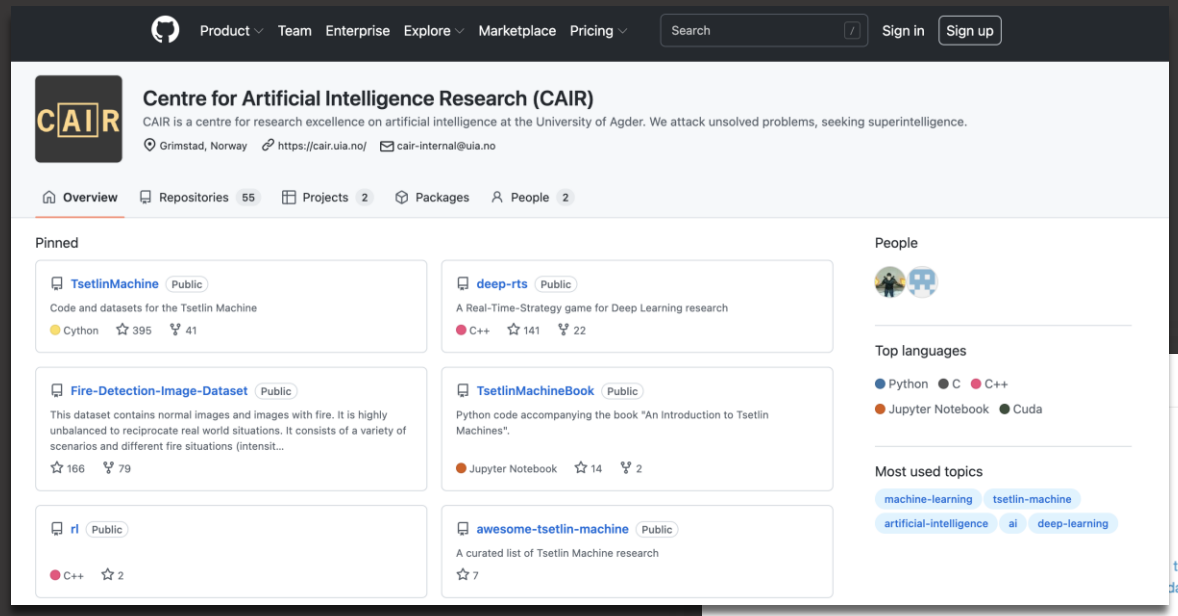
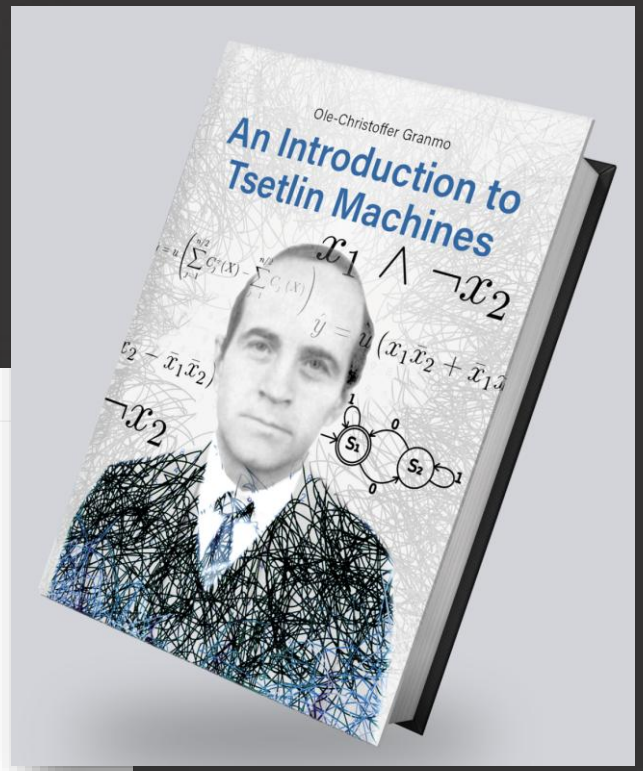
Open and live research – accessible and free AI for all



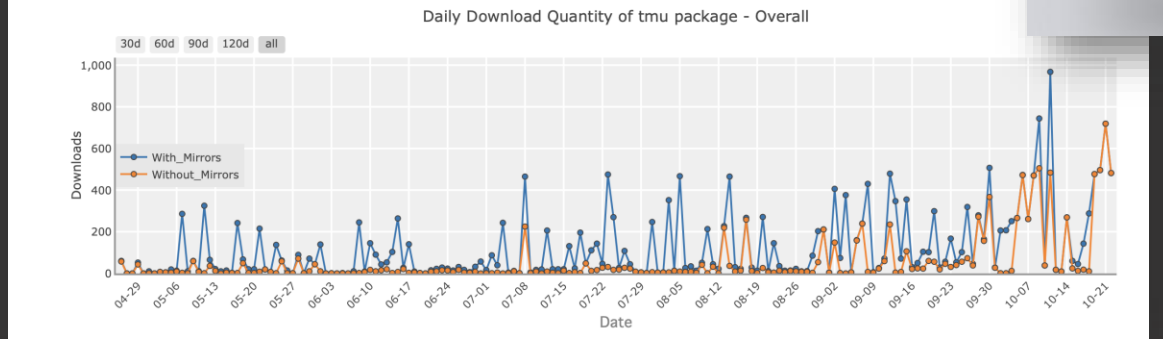
https://github.com/cair/TsetlinMachine



https://tsetlinmachine.org

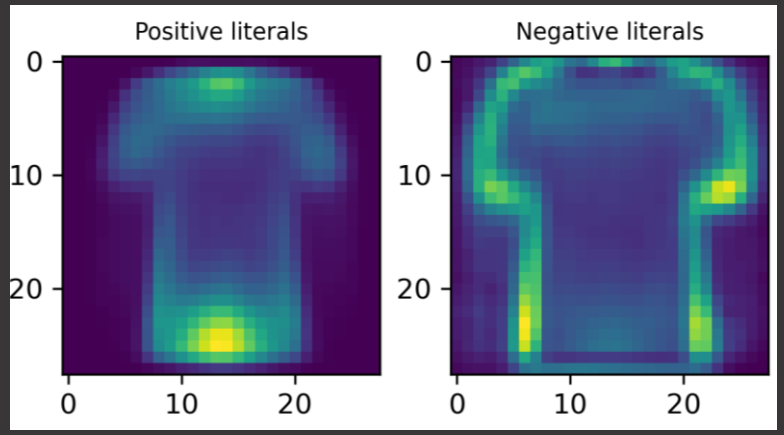
tqdm | xxhash
dantic | pytest | scikit-learn | tensorflow

Downloads last day: 482
Downloads last week: 2,214
Downloads last month: 6,103

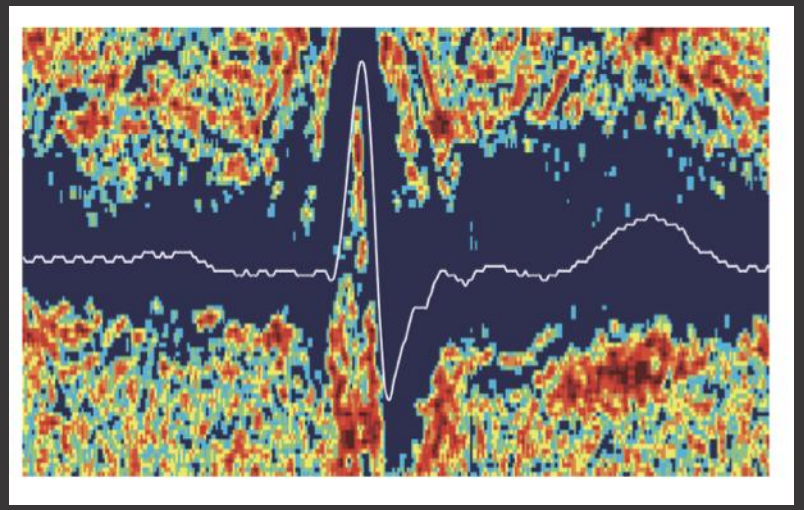


Self-explanatory logical models

Tsetlin machine model of T-shirt

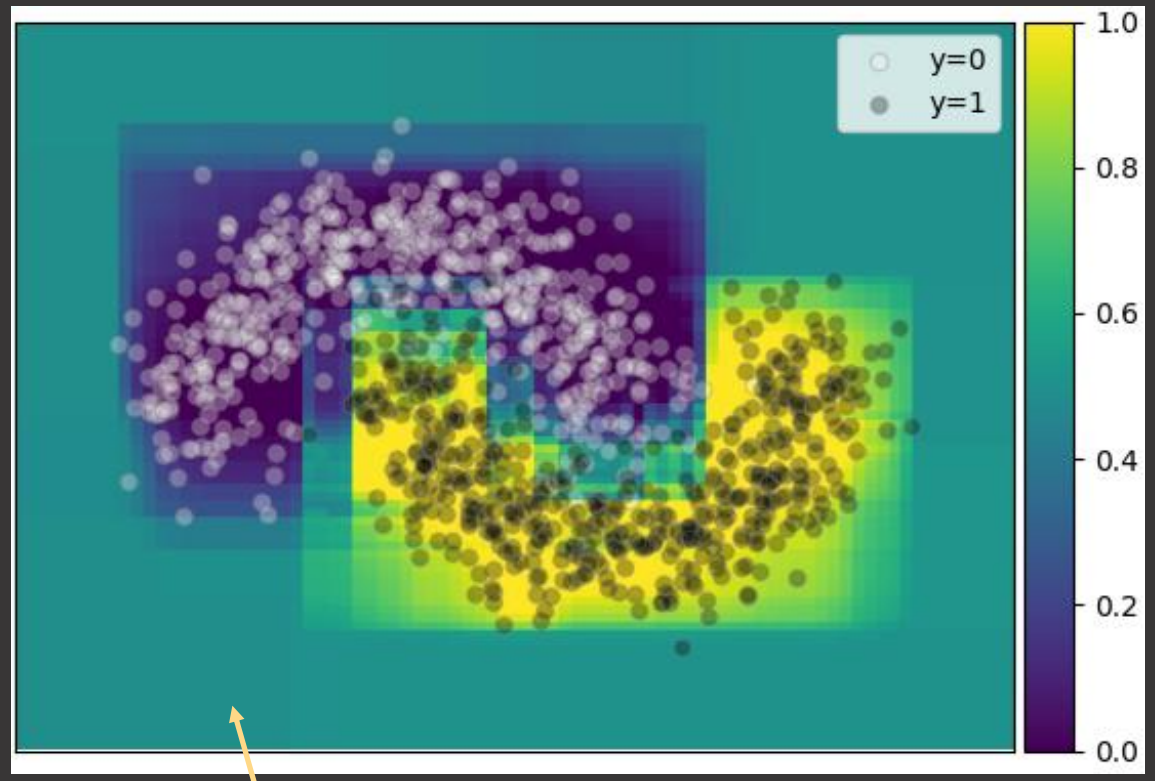


Tsetlin machine model of premature ventricular contraction



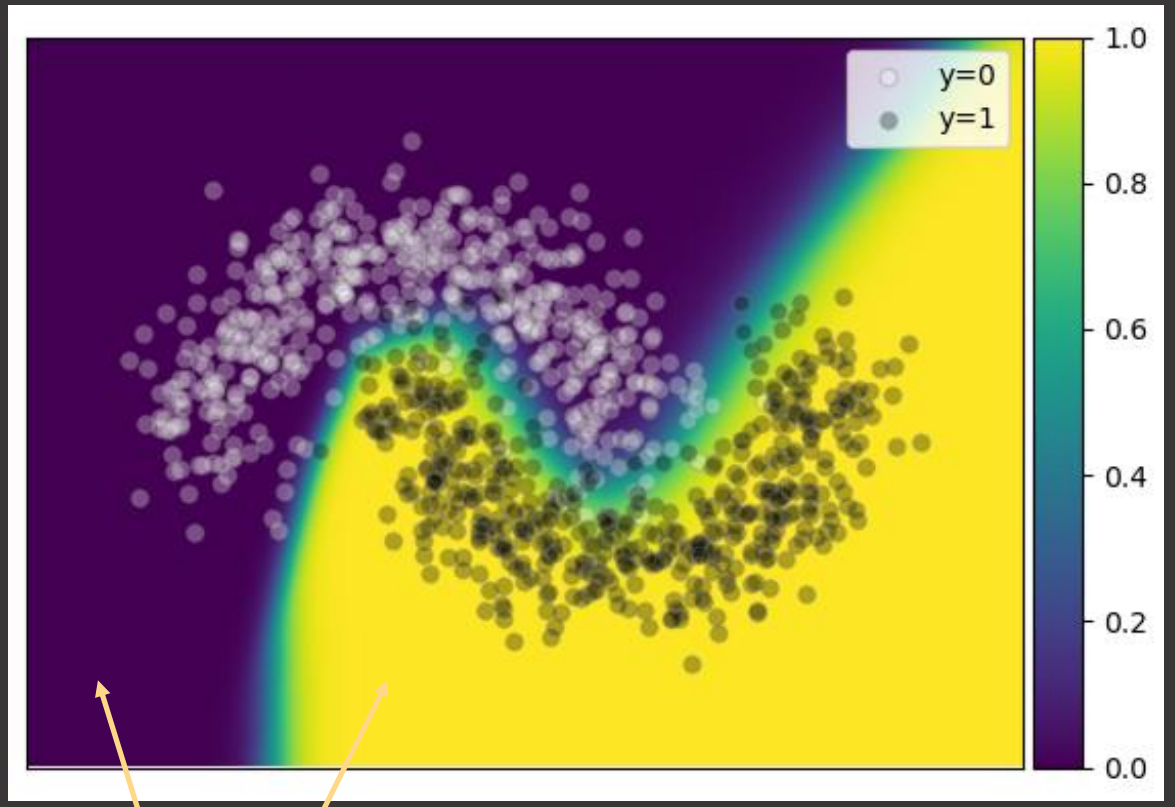
«The model is the explanation. The explanation is the model.»

A Tsetlin machine knows when it does not know



I do not know

Tsetlin machine



I know

Neural network

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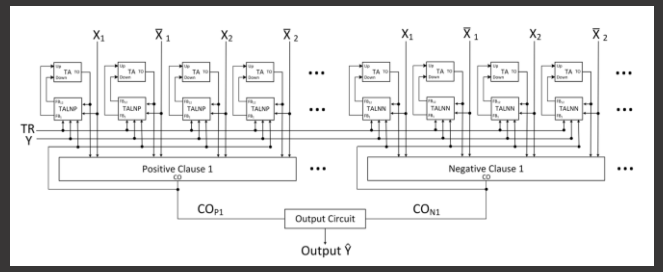
Green AI – 10 000x lower energy

Svein Anders Tunheim, Lei Jiao, Rishad Shafik, Alex Yakovlev, Ole-Christoffer Granmo, Convolutional Tsetlin Machine-based Training and Inference Accelerator for 2-D Pattern Classification, Microprocessors and Microsystems, Volume 103, 2023, https://doi.org/10.1016/j.micpro.2023.104949.

Superconducting rapid single-flux quantum (RSFQ) Tsetlin machine architecture



R. Cheng, D. Vasudevan and C. Kirst, "Super-Tsetlin: Superconducting Tsetlin Machines," in IEEE Transactions on Applied Superconductivity, doi: 10.1109/TASC.2024.3375275

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NOKIA Bell Labs

Newcastle University

CAMBRIDGE FUTURE·TECH

Abu Bakar, Tousif Rahman, Rishad Shafik, Fahim Kawsar, and Alessandro Montanari. Adaptive Intelligence for Batteryless Sensors Using Software-Accelerated Tsetlin Machines. In Proceedings of SenSys 2022. ACM, 2022.

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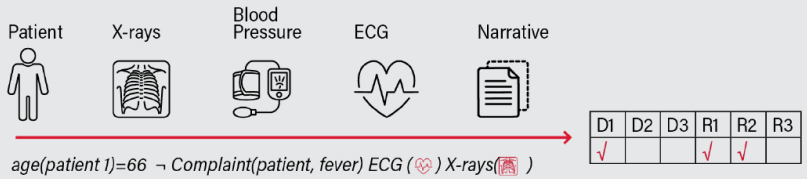
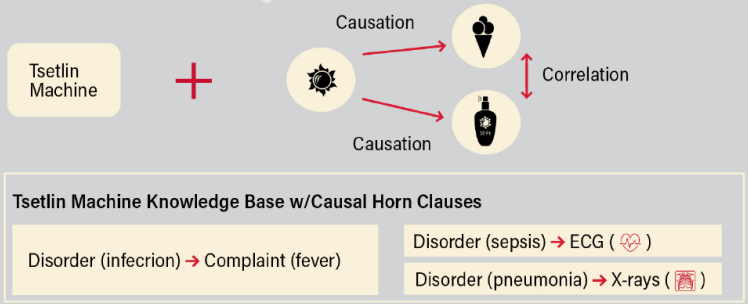
Democratic AI

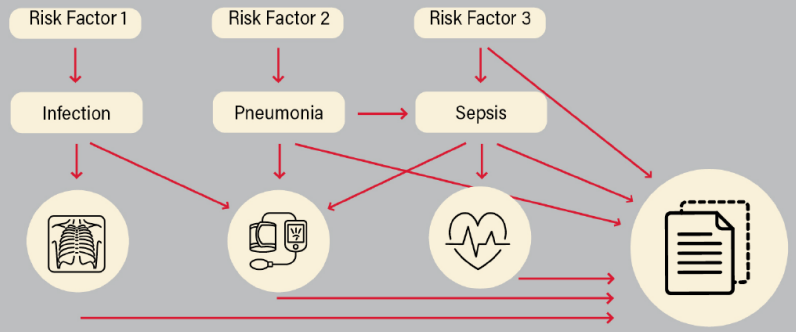
01
Propositionalization of Multimodal Data (WP1)

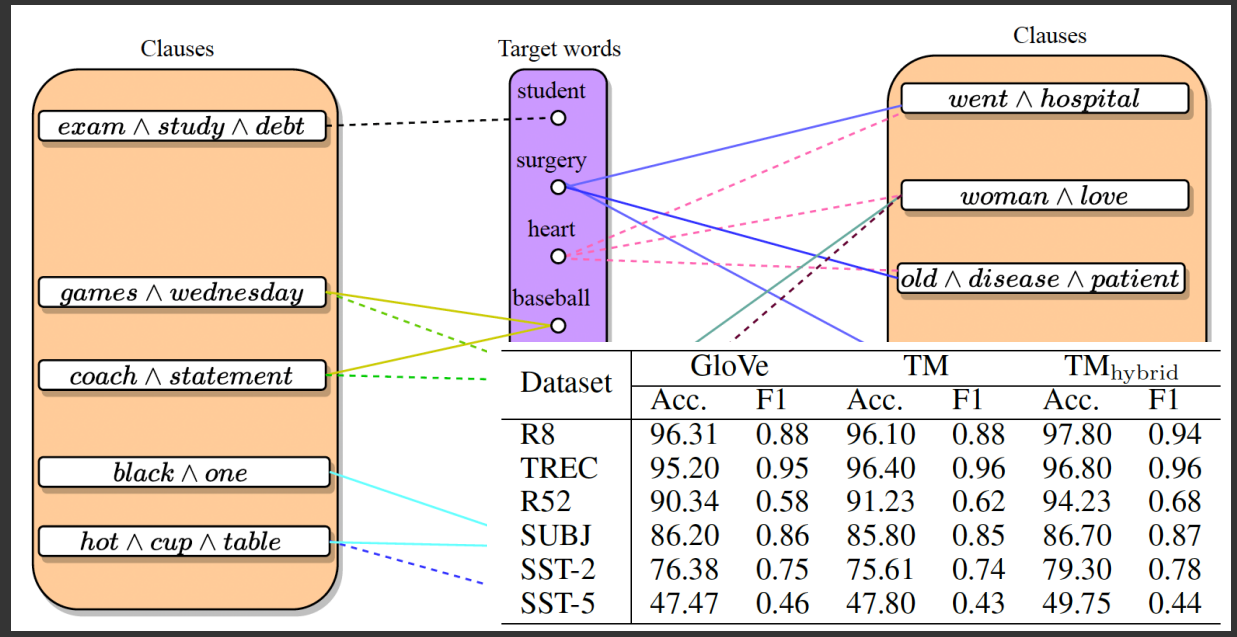


02
Tsetlin Machine Learning Enhanced w/ Causal Understanding (WP2)

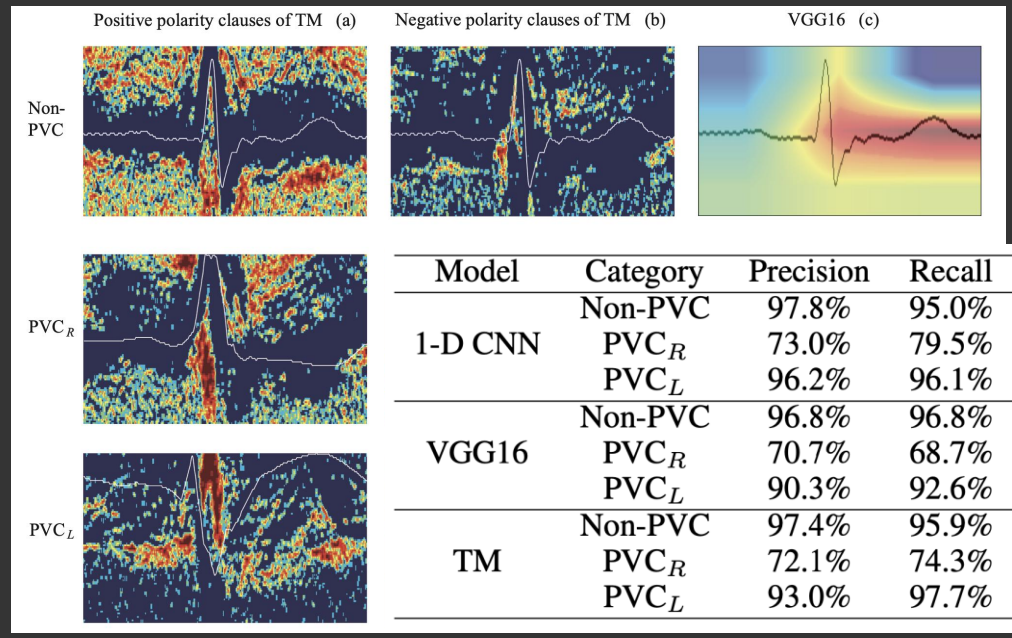


03
Probabilistic Interpretation of TM Knowledge Base for Causal Inference (WP3)





Dataset	GloVe		TM		TM_{hybrid}	
	Acc.	F1	Acc.	F1	Acc.	F1
R8	96.31	0.88	96.10	0.88	97.80	0.94
TREC	95.20	0.95	96.40	0.96	96.80	0.96
R52	90.34	0.58	91.23	0.62	94.23	0.68
SUBJ	86.20	0.86	85.80	0.85	86.70	0.87
SST-2	76.38	0.75	75.61	0.74	79.30	0.78
SST-5	47.47	0.46	47.80	0.43	49.75	0.44



Model	Category	Precision	Recall	Accuracy
1-D CNN	Non-PVC	97.8%	95.0%	93.8%
	PVC_R	73.0%	79.5%	
	PVC_L	96.2%	96.1%	
VGG16	Non-PVC	96.8%	96.8%	94.2%
	PVC_R	70.7%	68.7%	
	PVC_L	90.3%	92.6%	
TM	Non-PVC	97.4%	95.9%	94.2%
	PVC_R	72.1%	74.3%	
	PVC_L	93.0%	97.7%	

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Forbes

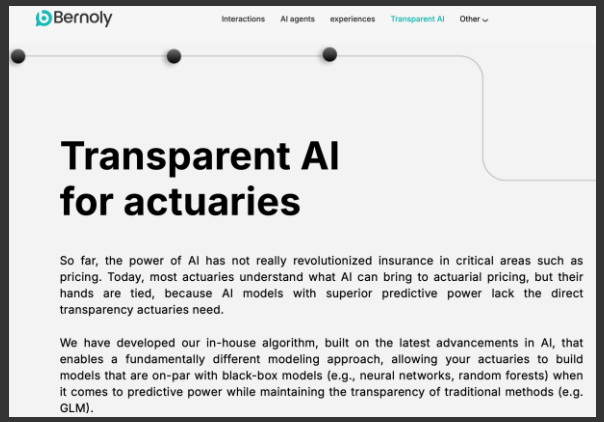
INNOVATION > AI

Unlocking Sustainable AI: The Game-Changing Tsetlin Machine Approach

By **Charles Towers-Clark**, Contributor. Charles Towers-Clark writes about humans in...

https://www.forbes.com/sites/charlestowersclark/2024/09/20/unlocking-sustainable-ai-the-game-changing-tsetlin-machine-approach/

https://www.digi.no/artikler/stortinget-skal-ta-i-bruk-tsetlin-maskiner-ingen-flere-svarte-bokser/557789



https://imetrica-ai.tech

EUROPOL INNOVATION LAB

ASSESSING TECHNOLOGIES IN LAW ENFORCEMENT

https://www.europol.europa.eu/cms/sites/default/files/documents/Assessing-Technologies-in-Law-enforcement.pdf

Nkom uses Norwegian AI in signal jamming tests

NEWS | WIRELESS | NORWAY | 13:57 | BOOKMARK

Nasjonal kommunikasjons-myndighet

Norwegian telecoms regulator Nkom said an AI model developed in Norway will be used during signal jamming tests on Andoeya in the week starting 09 September. The Tsetlin machine developed at the University of Agder makes it possible to distinguish between deliberate jamming and disturbances caused by other types of error. Disruptions to navigation services can cause serious incidents, such as preventing a helicopter from landing in the right place during a rescue mission.

Nkom said the new AI model is based on the same principles by which humans learn. A Tsetlin machine is a form of learning automaton collective for learning patterns using propositional logic. Ole-Christoffer Granmo, professor and director at the Centre for Artificial Intelligence Research (CAIR) at the University of Agder, created the method and named it after Michael Lvovitch Tsetlin, (1924-1966), a Soviet mathematician and physicist who worked on cybernetics.

John-Eivind Velure, acting director of Nkom, said this AI model delivers competitive performance and the results are explainable, which can provide insight into which signal patterns are decisive.

https://nkom.no/aktuelt/nkom-tester-norsk-ki-modell-i-jakten-pa-gps-forstyrrelser

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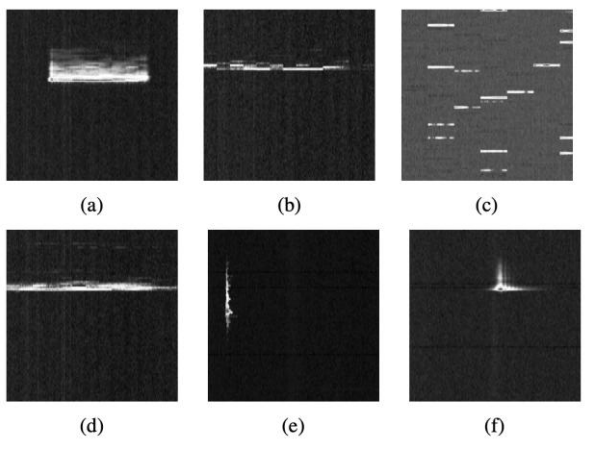
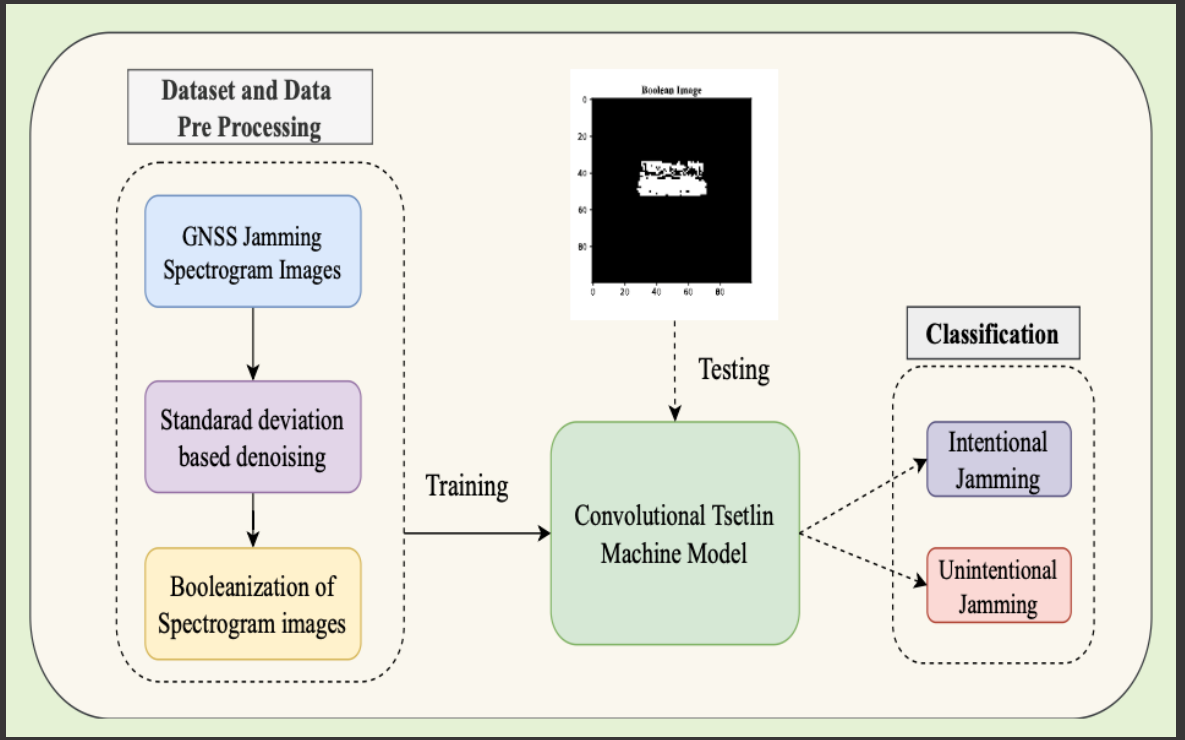
Interpretable rule-based architecture for GNSS jamming signal classification

ML model	Accuracy (%)	Recall (%)	Precision (%)	F1 score
CTM Composite	**98.68**	98.68	**98.70**	98.68
CTM	98.1481	**98.8888**	98.5240	**98.7061**
ResNet50	97.9832	95.4545	98.1308	96.7742
Vision Transformers	96.8153	97.8852	97.5904	97.7376
Vanilla TM	94.1246	94.3028	95.0151	94.6576
Random Forest	93.9153	96.9697	94.4649	95.7009
SVM	92.0635	93.5018	95.5720	94.5255
K-Nearest Neighbors	92.0635	92.2807	97.0480	94.6043
Logistic Regression	89.6825	91.4286	94.4649	92.9220
Decision Tree Classifier	88.8889	93.8697	90.4059	92.1053

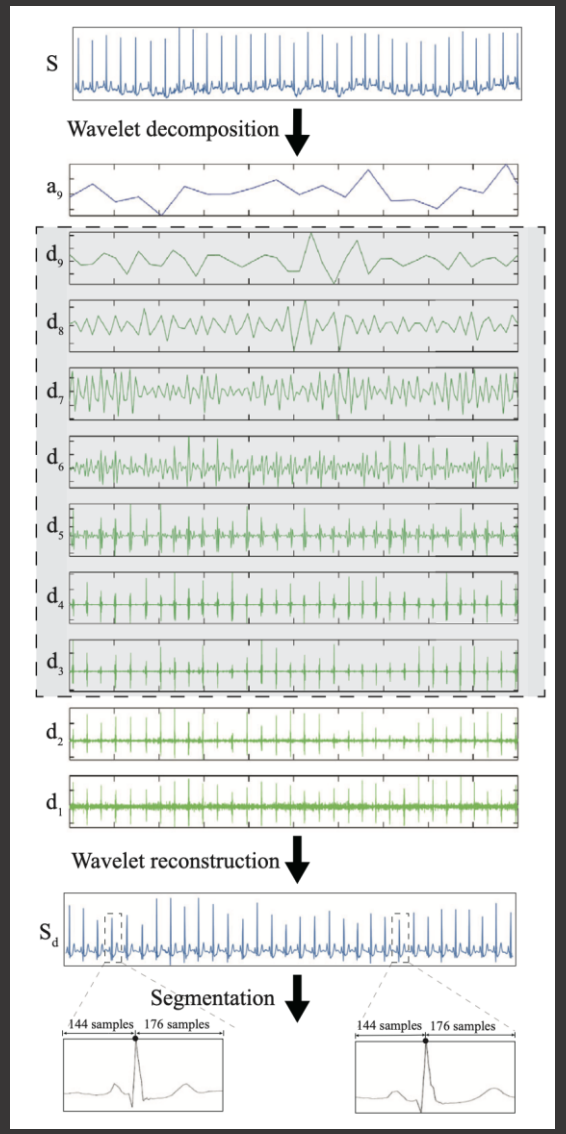


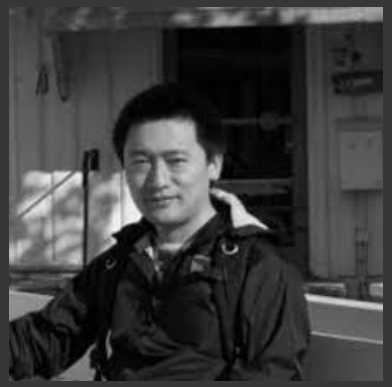


Sindhusha Jeeru , Lei Jiao , Per-Arne Andersen, Ole-Christoffer Granmo (2025). Interpretable Rule-based Architecture for GNSS Jamming Signal Classification. To appear in IEEE Sensors Journal.

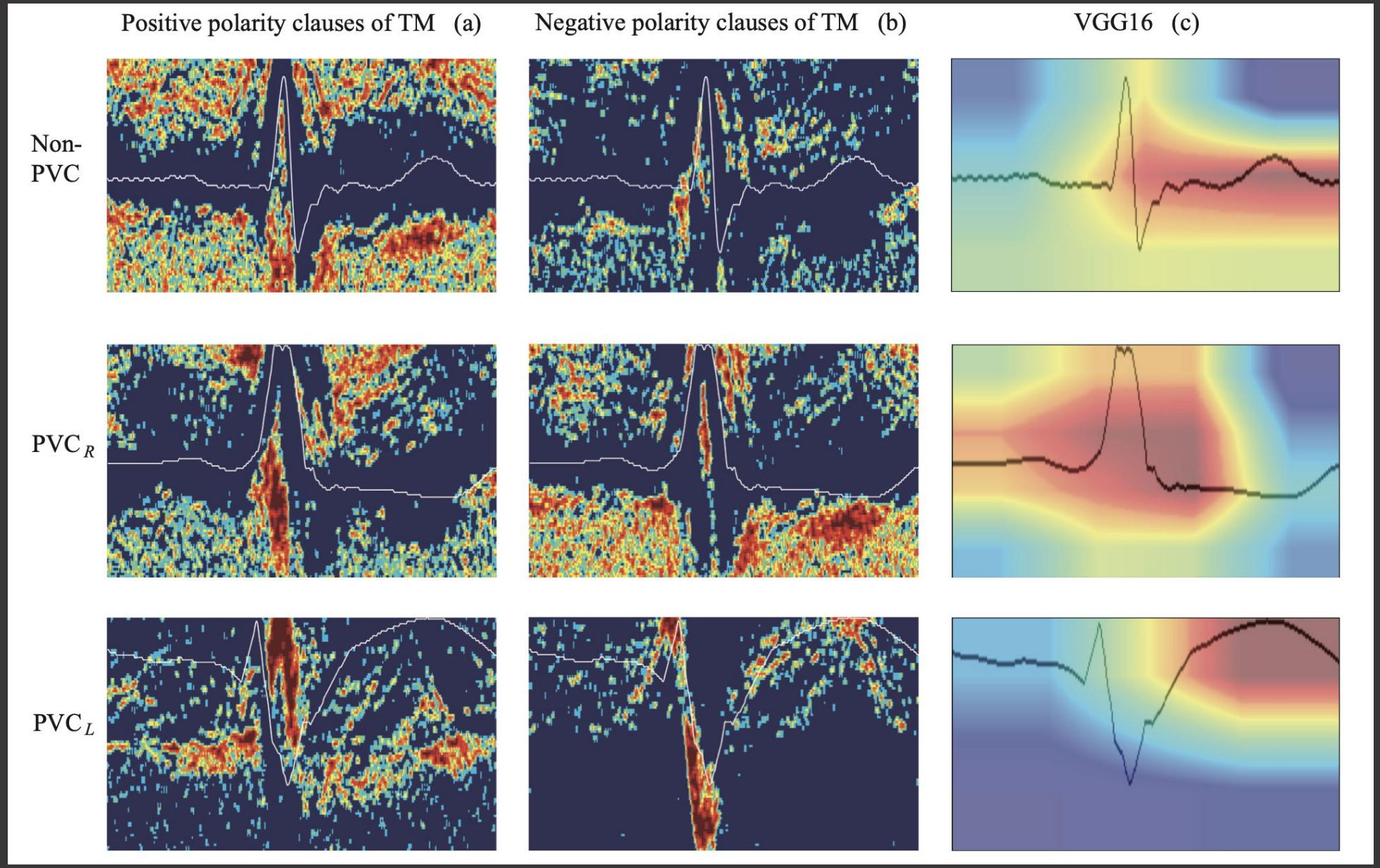
Interpretable premature ventricular contraction identification

Dataset	Model	Cat.	Prec. (%)	Sensi. (%)	Acc. (%)
MIT-BIH	1-D CNN	Non-PVC	97.8	95.0	93.8
		PVC_R	73.0	79.5	
		PVC_L	96.2	96.1	
	VGG16	Non-PVC	96.8	96.8	94.2
		PVC_R	70.7	68.7	
		PVC_L	90.3	92.6	
	LSTM	Non-PVC	96.2	95.9	93.2
		PVC_R	68.0	67.3	
		PVC_L	88.2	97.5	
	Transformer	Non-PVC	96.7	95.1	94.1
		PVC_R	73.7	71.5	
		PVC_L	96.4	97.6	
	TM	Non-PVC	97.4	95.9	94.2
		PVC_R	72.1	74.3	
		PVC_L	93.0	97.7	
INCART	1-D CNN	Non-PVC	99.3	96.8	96.7
		PVC_R	77.5	94.8	
		PVC_L	99.5	98.9	
	VGG16	Non-PVC	99.2	97.4	96.9
		PVC_R	80.6	93.7	
		PVC_L	96.1	92.7	
	LSTM	Non-PVC	98.4	96.1	94.9
		PVC_R	75.9	90.5	
		PVC_L	59.4	63.7	
	Transformer	Non-PVC	99.0	97.0	96.5
		PVC_R	77.6	92.4	
		PVC_L	99.6	94.5	
	TM	Non-PVC	99.0	99.7	98.9
		PVC_R	91.9	97.7	
		PVC_L	99.3	99.2	





Jinbao Zhang, Xuan Zhang, Lei Jiao, Ole-Christoffer Granmo, Yongjun Qian, Fan Pan (2023-01-25). "Interpretable Tsetlin Machine-based Premature Ventricular Contraction Identification". arXiv:2301.10181


Positive polarity clauses of TM (a)
Negative polarity clauses of TM (b)
VGG16 (c)
Non-PVC
PVC$_R$
PVC$_L$

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Interpretable text classification in legal contract documents using Tsetlin machines

TABLE III
TEXTUAL CONTEXT AND RELEVANT CLAUSE LITERALS FROM SOME EXAMPLE CONTRACTS FOR THE CLASS "EXPIRATION DATE". TERMS IN BOLD CORRESPOND TO LITERALS THAT CONSTITUTE CLAUSES THAT CLASSIFIED THE TEXT CORRECTLY

Doc. Id	Contract Name	Relevant Text	Literals of Relevant Clauses
199	BUFFALOWILDWINGSINC _06_05_1998-EX-10.3-FRANCHISE AGREEMENT	The **term of** this Agreement is for ten (10) years commencing on the date of **this Agreement**, **unless terminated** as provided by **this Agreement**.	1. term_of AND this_Agreement AND unless_terminated
194	VAPOTHERM, INC. - Manufacturing and Supply Agreement	The **term of this Agreement** is three years from and including the date of **this Agreement** (the "Initial Term"), with automatic renewal for additional successive one-year terms (each a "**Renewal Term**" and together wit the Initial Term, the "Term") **unless** no later than [* * *] days prior to the end of the Initial Term, or any **Renewal Term** either party notifies the other that it wishes to **terminate this Agreement** effective the end of the Initial Term or that **Renewal Term**, as applicable.	2. term_of AND this_Agreement AND unless AND terminate 3. Initial_Term AND terminate 4. Renewal_Term AND unless
198	HYPERIONSOFTWARECORP _09_28_1994-EX-10.47-EXCLUSIVE DISTRIBUTOR AGREEMENT	This Agreement shall have an initial term of one (1) year from the date first above written (the "Initial Term"), and shall thereafter automatically renew for successive two (2) year periods (each a "**Renewal Term**"), **unless earlier terminated** in accordance with the terms of this Agreement.	4. Renewal_Term AND unless 5. unless_earlier AND earlier_terminated
191	EuromediaHoldingsCorp_ 20070215_10SB12G_EX-10.B(01) _525118_EX-10.B(01)_ Content License Agreement	The term of this Agreement (the "**Initial Term**") shall commence as of the Effective Date and, **unless earlier terminated** in accordance with this Agreement, shall **terminate** on June 30, 2010.	3. Initial_Term AND terminate 5. unless_earlier AND earlier_terminated
211	NeoformaInc_19991202_S-1A_ EX-10.26_5224521_EX-10.26_ Co-Branding Agreement	INITIAL TERM shall mean the Effective Date through the day prior to the second anniversary of the Effective Date, **unless earlier terminated** pursuant to Section 11.	5. unless_earlier AND earlier_terminated
217	LeadersonlineInc_20000427_S-1A_EX-10.8_4991089_EX-10.8 _Co-Branding Agreement	Term shall mean the **Effective Date through** June 15 , 2001 and any Renewal Term (as defined in paragraph 7.4 herein .)	6. Effective_Date AND through
245	ExactSciencesCorp_20180822 _8-K_EX-10.1_11331629_EX-10.1_Promotion Agreement	This Agreement shall be effective as of the **Effective Date** and shall continue in effect **through** December 31 , 2021 and any **Renewal Term** (the "Term") , **unless terminated** earlier as set forth herein.	6. Effective_Date AND through 7. Renewal_Term AND unless_terminated

Saha, R., Myhre S. (2022). Interpretable Text Classification in Legal Contract Documents Using Tsetlin Machines. *First International Symposium on the Tsetlin Machine*

Categories	TM				CNN-BiLSTM				FastText				BERT-Base				RoBERTa			
	P	R	F1	Acc	P	R	F1	Acc	P	R	F1	Acc	P	R	F1	Acc	P	R	F1	Acc
Anti Assignment	95.57	94.05	94.65	94.05	0.23	4.85	0.45	4.85	90.09	74.64	81.35	74.64	97.02	94.5	95.39	94.5	97.78	96.32	96.82	96.32
Audit Rights	94.04	95.04	94.27	95.04	90.31	90.1	90.21	90.1	89.58	55.27	66.99	55.27	95.83	95.43	95.6	95.43	96.21	94.76	95.28	94.76
Cap on Liability	94.36	94.57	94.46	94.57	0.19	4.38	0.37	4.38	89.9	73.52	80.56	73.52	96.55	95.08	95.68	95.08	97.73	97.89	97.78	97.89
Effective Date	96.27	96.79	96.47	96.79	96.79	94.76	95.61	94.76	94.16	60.79	72.92	60.79	97.35	95.19	96.06	95.19	98.13	94.39	95.8	94.39
Exclusivity	90.21	94.83	92.47	94.83	85.3	81.16	83.13	81.16	90.52	75.23	81.8	75.23	90.9	92.44	90.56	92.44	93.86	94.09	93.96	94.09
Expiration Date	95.51	93.87	94.57	93.87	0.15	3.88	0.29	3.88	92.4	62.42	73.63	62.42	97.65	94.16	95.38	94.16	98.24	96.96	97.39	96.96
Insurance	96.23	97.08	95.84	97.08	93.58	92.0	92.72	92.0	93.46	70.79	80.41	70.79	99.32	99.2	99.23	99.2	98.98	98.9	98.93	98.9
License Grant	94.98	95.15	95.06	95.15	93.87	28.94	38.28	28.94	88.91	71.12	78.26	71.12	97.09	96.06	96.41	96.06	97.56	95.47	96.14	95.47
Renewal Term	94.88	97.4	96.12	97.4	89.84	93.01	91.4	93.01	95.08	68.45	79.11	68.45	98.7	98.66	98.68	98.66	99.77	99.76	99.76	99.76
Revenue Profit Sharing	93.78	95.62	93.82	95.62	86.17	87.01	86.57	87.01	92.29	62.16	73.16	62.16	93.87	91.99	92.7	91.99	97.63	97.69	97.65	97.69
Termination for Convenience	94.53	97.23	95.86	97.23	93.15	93.15	93.15	93.15	94.69	81.57	87.45	81.57	97.21	97.04	97.12	97.04	98.16	97.78	97.93	97.78
Volume Restriction	95.77	97.86	96.81	97.86	86.74	92.31	89.44	92.31	95.14	60.33	73.57	60.33	85.73	91.18	88.37	91.18	93.48	94.51	93.91	94.51

Digital sovereignty

https://www.sciencenorway.no/artificial-intelligence/can-a-norwegian-invention-revolutionise-artificial-intelligence/2318511

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ISTM International Symposium on the Tsetlin Machine

Call for Papers

The emerging paradigm of Tsetlin machines makes a fundamental shift from arithmetic-based to logic-based machine learning. At the core, finite-state machines, based on learning automata, learn patterns using logical clauses, and these constitute a global description of the task learnt. In this way, the Tsetlin machine introduces the concept of logical interpretable learning, where both the learned model and the process of learning are easy to follow and explain. As a result, it reduces the expertise needed to apply ML techniques efficiently in various domains. The paradigm has enabled competitive accuracy, scalability, memory footprint, inference speed, and energy consumption across diverse tasks, including classification, regression, natural language processing (NLP), and speech understanding.

Rome, Italy, 8-10 October 2025

Topics of Interest

Topics of interest include (but are not limited to):

- Tsetlin Machines
- Learning Automata
- Novel AI Algorithms
- Explainable and Interpretable AI
- Energy-efficient AI Systems Design
- New AI Applications including signal and image processing
- Intelligent Data Preprocessing
- Tsetlin Machines and Quantum Computing

Important Dates

- Abstract Submission: June 23, 2025
- Paper Submission: June 30, 2025
- Notification: August 15, 2025
- Camera ready: September 5, 2025

Submitted manuscripts should closely reflect the final papers as they will appear in the Proceedings, and should not exceed 8 pages for regular papers and 4 pages for system demos in two-column IEEE proceeding format.

Further information

www.istm.no

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The Tsetlin automaton

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Reinforcement learning

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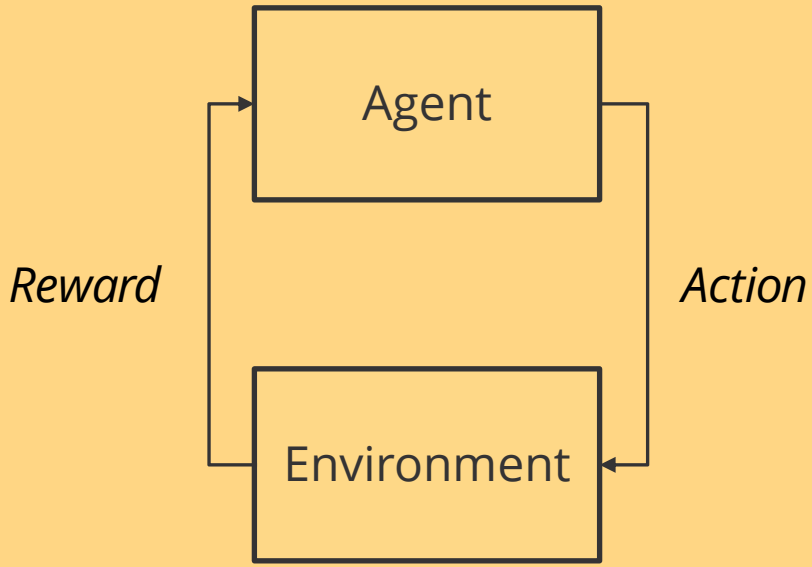
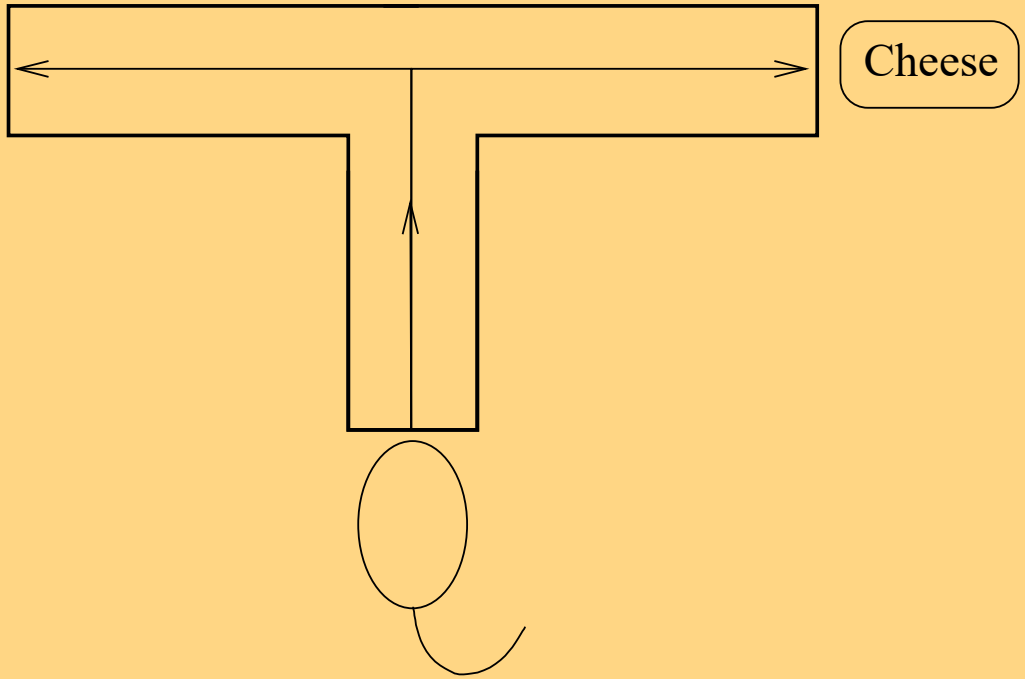


- **Reinforcement Learning (RL):** An agent that *explores* an *environment*
- **The agent:** Perceives its current state and takes *actions*
- **The environment:** Provides a *reward* or a *penalty*
- **RL algorithms:** Attempt to find a policy for maximizing the agent's cumulative reward throughout the problem

The T-maze problem



- Hungry rat is placed at the lower end of the middle limb of a T-maze
- Rat can move along the limb and turn to the right or left
- **Food:** Kept at the end of the right arm with probability *0.7* and at the end of the left arm with probability *0.3*
  - How does the rat behave over successive trials?
  - Can the rat behavior be modeled mathematically?

The multi-armed bandit problem

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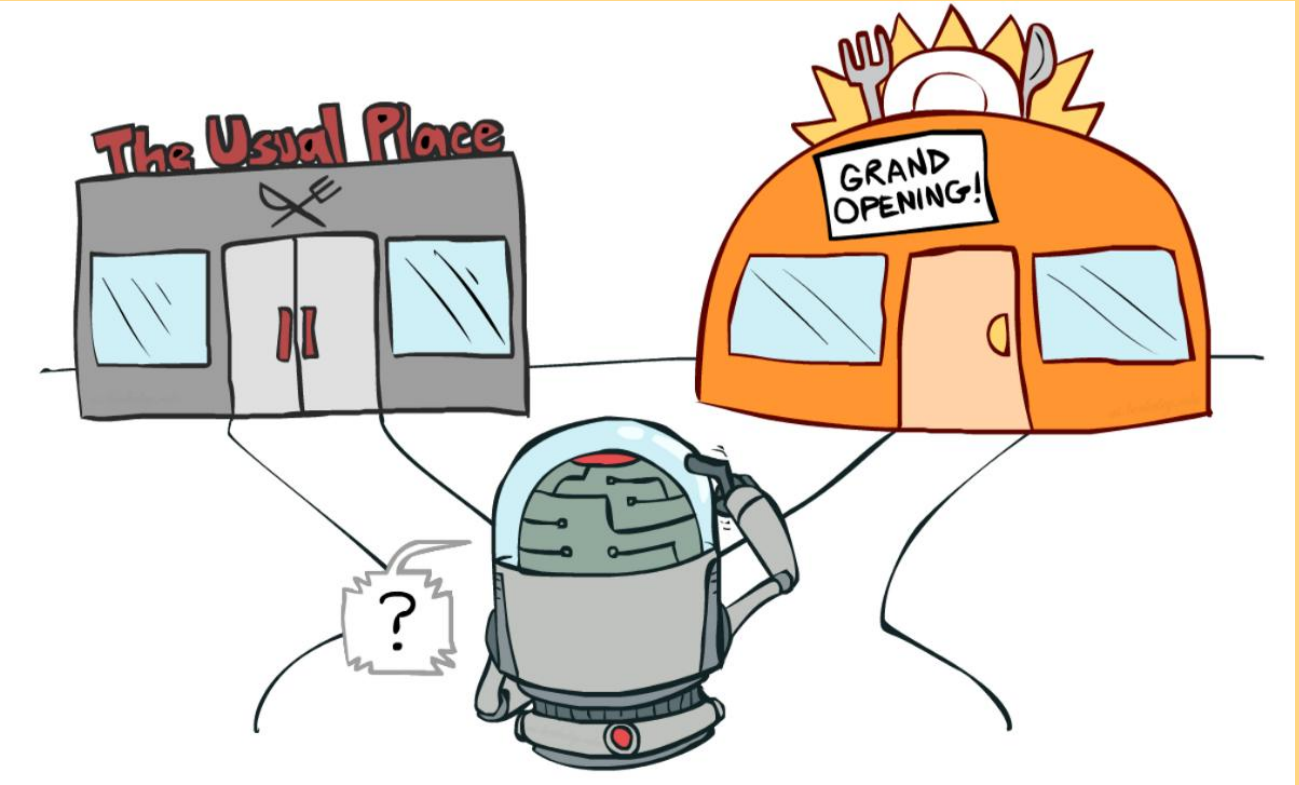

Source: Berkley AI Course

- **Exploration vs. Exploitation:** The conflict between Exploration vs. Exploitation is well-known in RL and other areas of AI
- **The Multi-Armed Bandit Problem:** Captures the essence of this conflict
- Has thus occupied researchers for over fifty years

The multi-armed bandit problem

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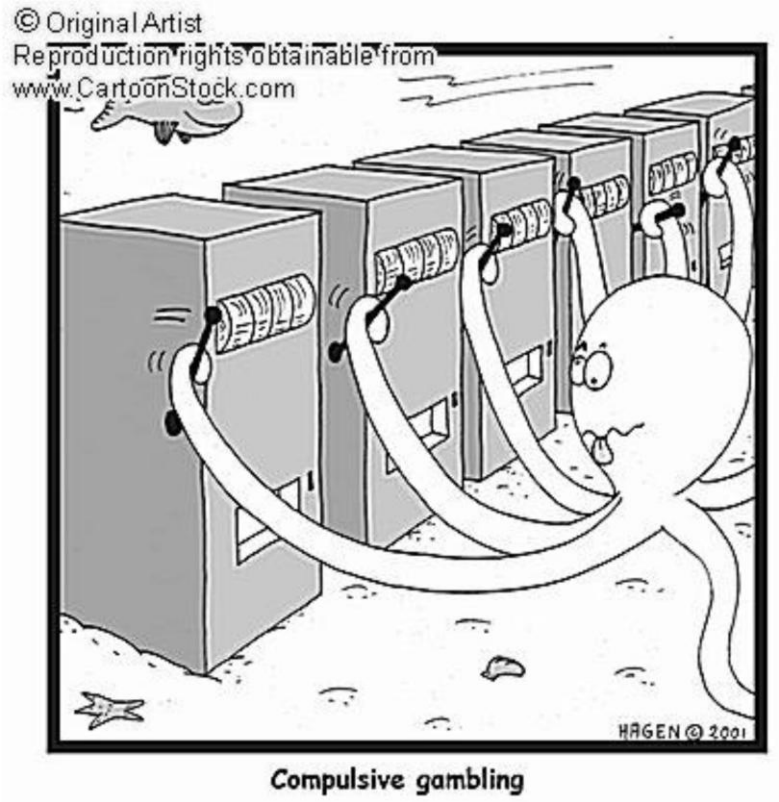

- **The Multi-Armed Bandit Problem** is a classical optimization problem where an agent sequentially pulls one of *n* arms attached to a gambling machine
  a) Each pull results either in a *reward* or a *penalty*
  b) The reward probabilities, $(r_1, \ldots, r_n)$, of arms are unknown
- **Challenge:** One must balance between exploiting existing knowledge and obtaining new information in order to maximize the amount of rewards received

Learning automata

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The concept of learning automaton grew out of the work of:

- Psychologists in *modeling observed behavior*
- Statisticians to model the *choice of experiment*s based on past observations
- Operation researchers to implement *optimal strategies* in the context of the two-armed bandit problem
- System theorists to make *rational decisions* in random environments.

Learning automata characteristics

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- Learning Automata (LA) are adaptive decision-making devices that can operate in:
  - **Unknown Environments:** They do not need information about the effect of their actions at the start of the operation
  - **Random Environments:** An action does not necessarily produce the same response each time it is performed
- A powerful property of LA is that they progressively improve their performance by the means of a “learning” process
  - Combine rapid and accurate convergence
  - Low computational complexity

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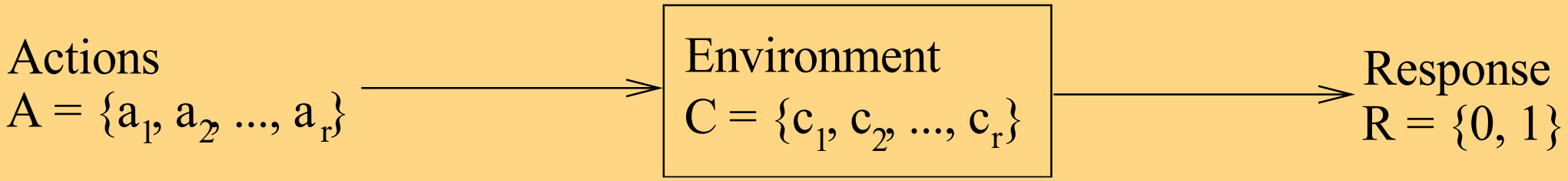
The environment

The environment



Environment → Large class of general unknown media in which an LA or a group of LA can operate

- **Input:** Action from action set $A = \{a_1, a_2, ..., a_r\}$
  Output: *Reward* ('0') or *Penalty* ('1')
  Penalty probabilities: For each action *i*, there is a certain probability that the *Environment* responds with a *Penalty:*
  $$P(\text{Penalty} \mid \text{Action} = a_i) = c_i, 1 \leq i \leq r$$
- If the Environment does not respond with a *Penalty*, it responds with a *Reward* instead

Static and dynamic environments

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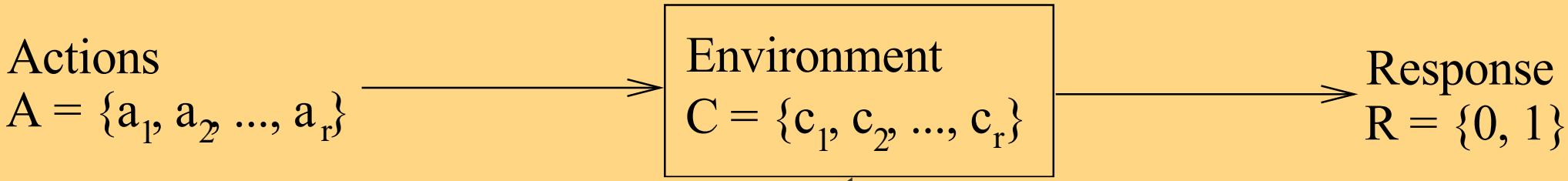

An environment can be:

- **Static:** Penalty probabilities do not change
- **Dynamic:** Penalty probabilities change

Simulation of two-action environment

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Penalty probabilities

Stochastic output

```
class Environment:
  def __init__(self, c_1, c_2):
      self.c_1 = c_1
      self.c_2 = c_2

  def penalty(self, action):
     if action == 1:
         if random.random() <= self.c_1:
             return True
         else:
             return False
     elif action == 2:
         if random.random() <= self.c_2:
             return True
         else:
             return False
```

The Tsetlin automaton

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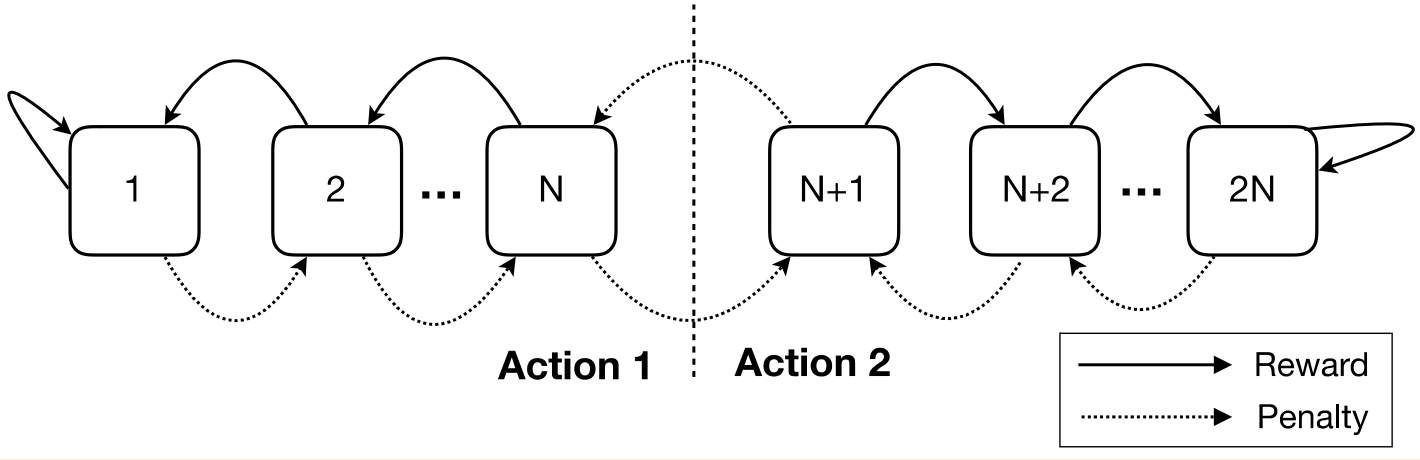

- An automaton remembers which action is “best” by maintaining a state $s_t \in \{s_1,\ldots,s_n\}$
- **Operation** – an automaton:
  1. Selects and *outputs* an action based on its present state
  2. Takes a response from the environment as *input*
  3. Changes its *state* based on (a) the *response* and (b) the *action* performed
- An automaton can be said to *learn* if it reduces the number of penalties received as a result of interacting with the environment

The Tsetlin automaton

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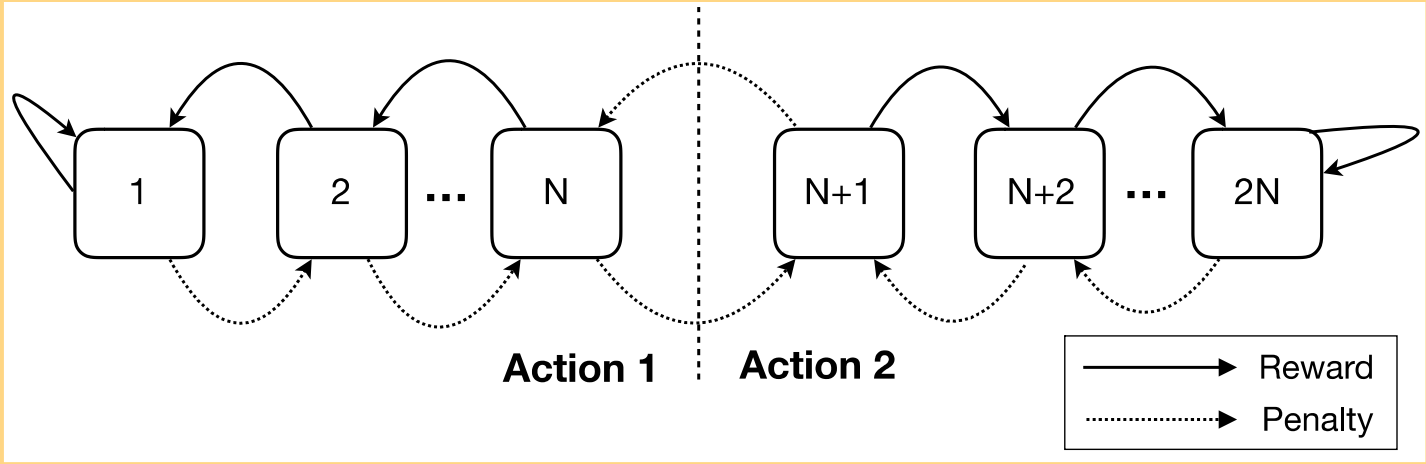
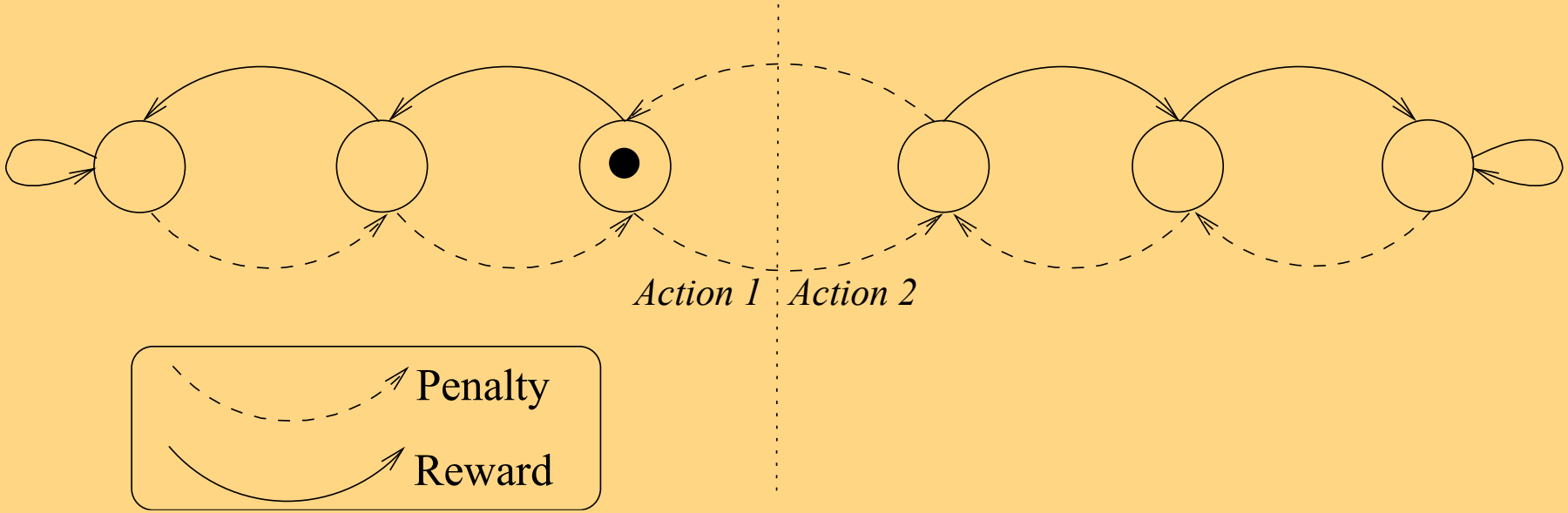


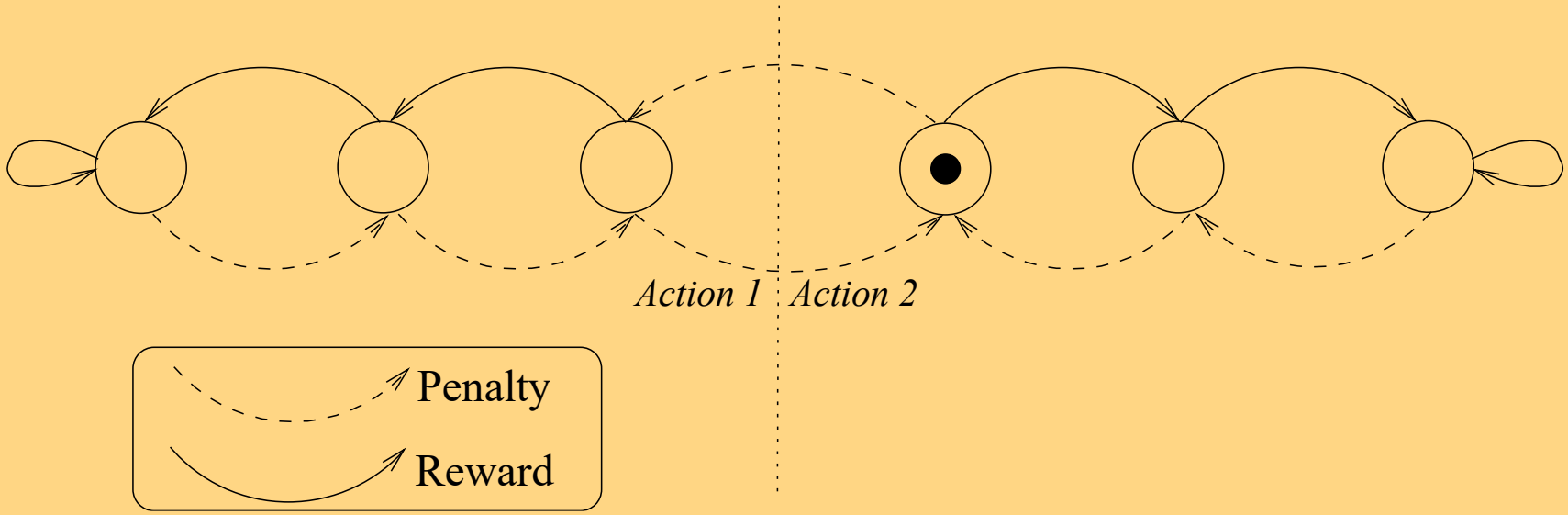
- A Tsetlin automaton can learn the optimal action if the lowest penalty probability is below *0.5*
- The number of automaton states determines learning *accuracy* and *speed*

The Tsetlin automaton



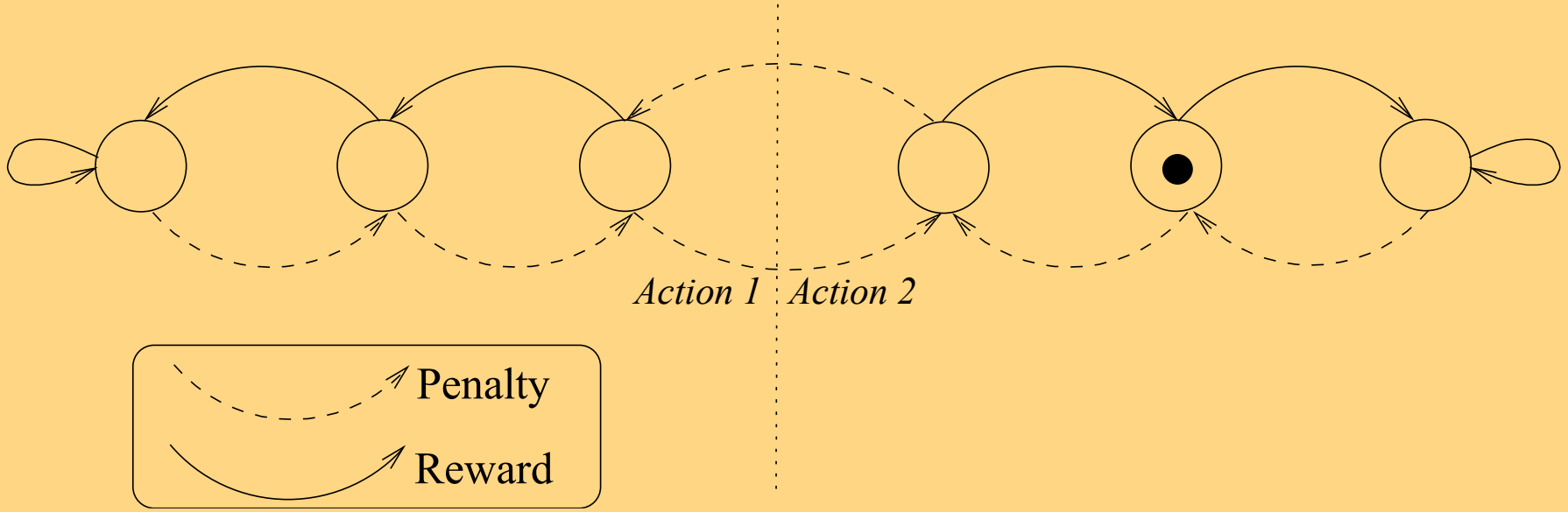
Selected Action: Action 1
Response from Environment: Penalty

The Tsetlin automaton



Selected Action: Action 2
Response from Environment: Reward

The Tsetlin automaton



Selected Action: Action 2
Response from Environment: Reward

Tsetlin automaton implementation

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Starts in middle state

State update when rewarded

State update when penalized

Decides action

```
class Tsetlin:
    def __init__(self, n):
        # 'n' is the number of states per action
        self.n = n
        # Initial state selected randomly
        self.state = random.choice([self.n, self.n+1])

    def reward(self):
        if self.state <= self.n and self.state > 1:
            self.state -= 1
        elif self.state > self.n and self.state < 2*self.n:
            self.state += 1

    def penalize(self):
        if self.state <= self.n:
            self.state += 1
        elif self.state > self.n:
            self.state -= 1

    def makeDecision(self):
        if self.state <= self.n:
            return 1
        else
            return 2
```

Games of Tsetlin automata

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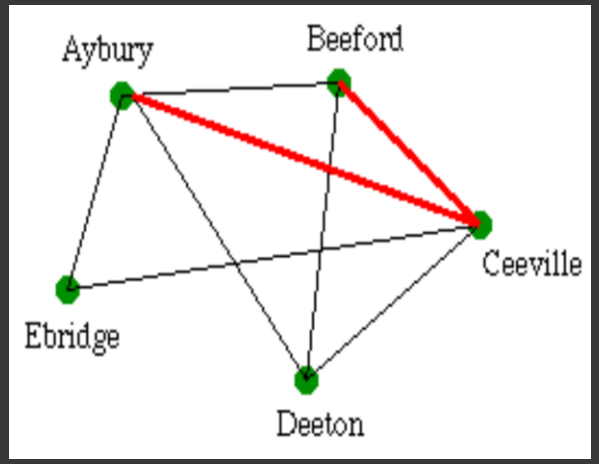
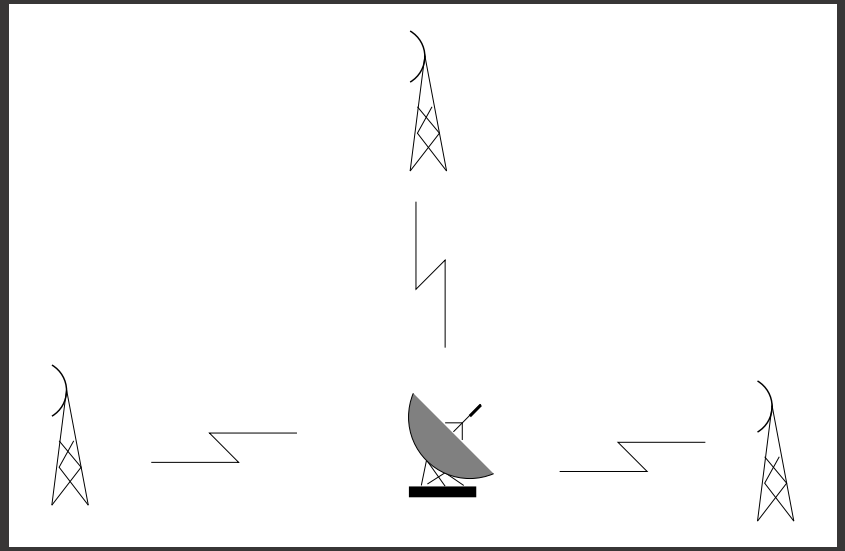
Decentralized decision-making



"Call routing in telephone networks" by Richard Gibbens and Stephen Turner, 1997

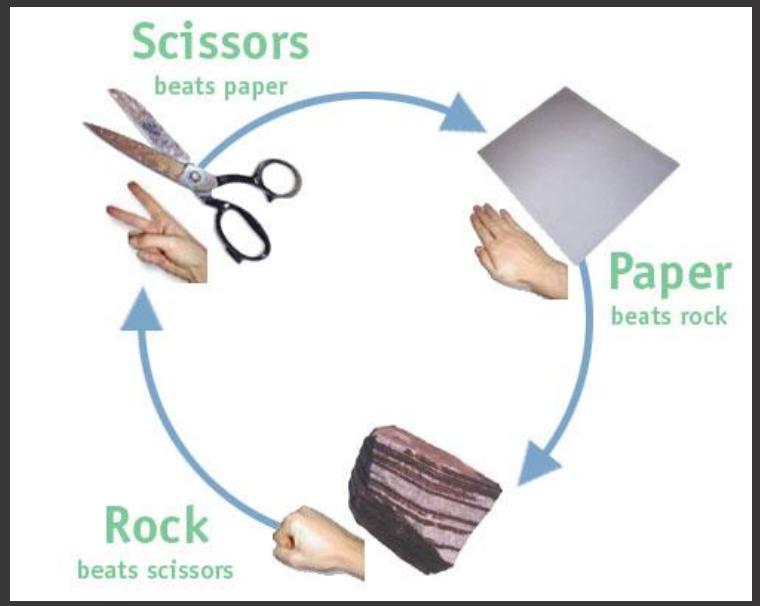
- **Decentralization** is a common and often necessary feature of complex natural and man-made systems
- Arises from the reality that the complete information exchange needed for centralized decision-making may not be feasible
- **Formidable Problem:** Coordination of decentralized decision-makers

Example: QoS Control in Sensor Networks



- Consider a basic sensor network that consists of an *unknown* number of *sensors* and a single *base station*
- Each sensor can be *powered-down* or *powered-up*
  The base station receives packets from powered-up sensors
- **Problem:** How can the base station control the sensors so that only *Q* sensors are powered up when the base station:
  1. Is only able to broadcast information
  2. Cannot address the sensors individually
  3. Does not know the number of sensors in the network

Decentralized decision-making as a game



- Decentralized decision-making can be formulated as a game
- **Game:** Metaphor for a much wider range of human interactions
  - Outcomes depend on the *interactive strategies* of two or more players, who simultaneously make decisions
  - Players have *opposed, mixed, or shared motives*

Normal form representation of games

	B Strategy 1	B Strategy 2
A Strategy 1	*3*, **3**	*0*, **5**
A Strategy 2	*5*, **0**	*1*, **1**

- The **normal form** representation of a game is a matrix which shows *players*, *strategies*, and *payoffs*
- In the example, there are two players:
  - One chooses the *row* and the other chooses the *column*
  - Each player has two strategies, which are specified by the number of rows and the number of columns
- The payoffs are provided in the interior
  - The first number is the payoff received by the row player
  - The second is the payoff for the column player

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Prisoner's dilemma

Prisoner One	Prisoner Two: Remain Silent	Prisoner Two: Betray
Remain Silent	*One Year* / *One Year*	*Released* / *Twenty Years*
Betray	*Twenty Years* / *Released*	*Five Years* / *Five Years*

- Two suspects, A and B, are arrested by the police
- The police have insufficient evidence for a conviction, and, having separated both prisoners, visit each of them to offer the same deal:
  1. If one testifies for the prosecution against the other and the other remains silent, the betrayer goes free and the silent accomplice receives the full 20-year sentence
  2. If both stay silent, the police can sentence both prisoners to only one year in jail for a minor charge
  3. If each betrays the other, each will receive a five-year sentence
- Each prisoner must choose whether to betray the other or to remain silent
- However, neither prisoner knows for sure what choice the other prisoner will make

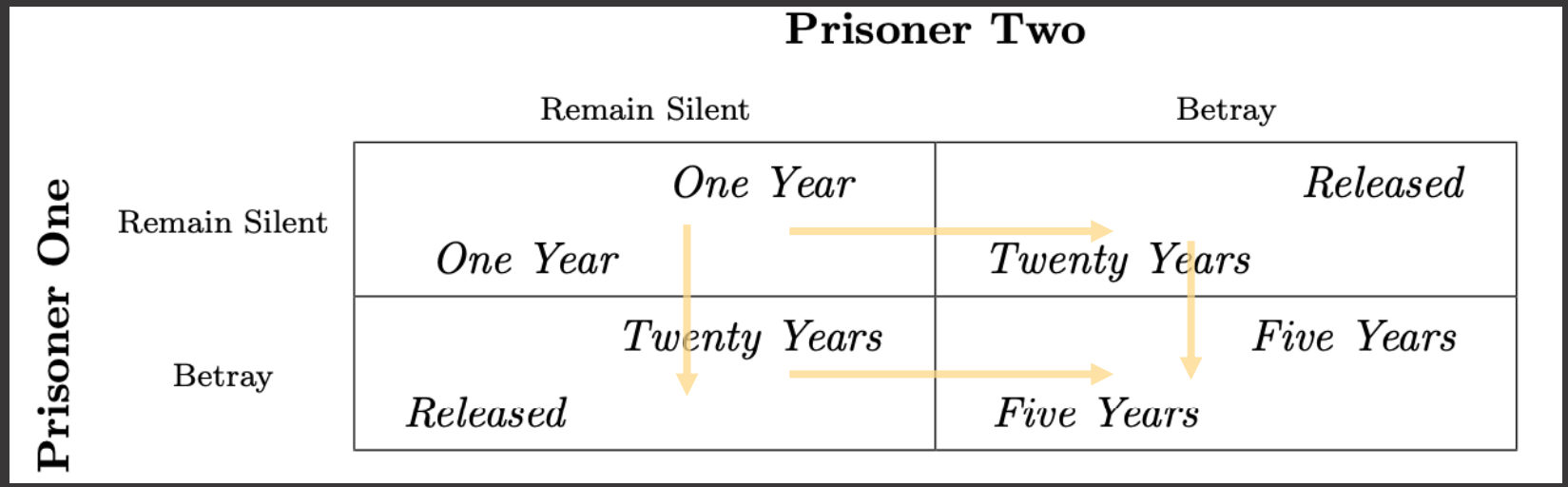
Nash equilibrium

Prisoner One	Prisoner Two: Remain Silent	Prisoner Two: Betray
Remain Silent	*One Year* *One Year*	*Released* *Twenty Years*
Betray	*Twenty Years* *Released*	*Five Years* *Five Years*

A set of strategies where no player benefits from changing their strategy while the other players keep their strategies unchanged

1. (Remain Silent, Remain Silent)
2. (Remain Silent, Betray)
3. (Betray, Remain Silent)
4. (Betray, Betray)

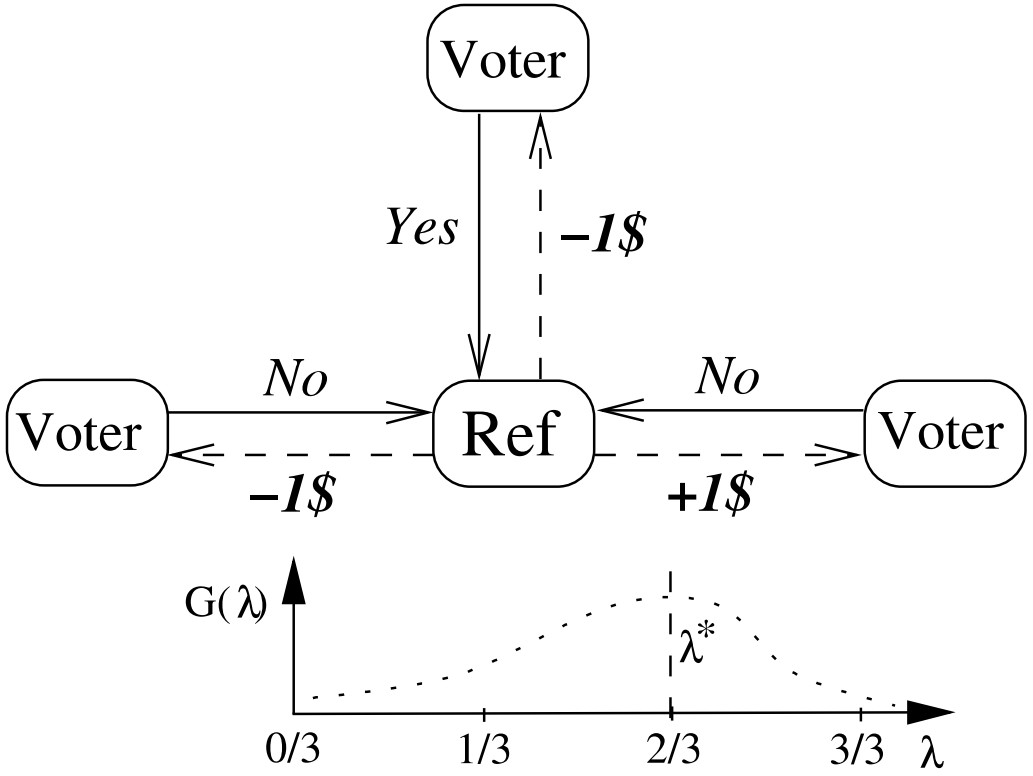
Nash equilibrium



A set of strategies where no player benefits from changing their strategy while the other players keep their strategies unchanged

1. (Remain Silent, Remain Silent)
2. (Remain Silent, Betray)
3. (Betray, Remain Silent)
4. **(Betray, Betray)**

Goore game



- Imagine a large room containing *N* cubicles and a raised platform
- One person (voter) sits in each cubicle and a Referee stands on the platform
- The Referee conducts a series of voting rounds as follows:
  1. On each round the voters vote “Yes” or “No”
  2. Votes are done simultaneously and independently
  3. The Referee counts the number λ of “Yes” votes
  4. The Referee has a uni-modal performance criterion $G(\lambda)$
  5. Optimized when the number of “Yes” votes is exactly λ^*
  6. The current voting round ends: Referee awards a dollar with probability $G(\lambda)$ and charges a dollar with probability $1 - G(\lambda)$ to every voter
  7. This is done independently
  8. Based on their individual gains and losses, the voters then decide, again independently, how to cast their votes on the next round

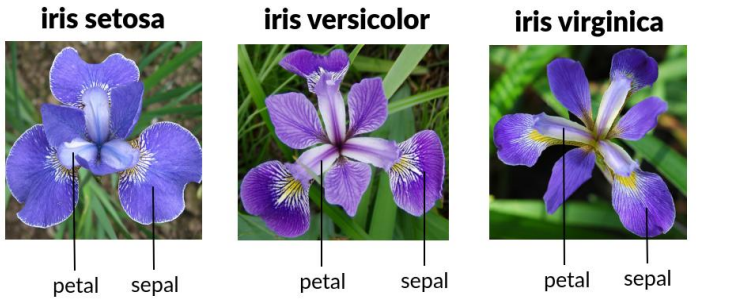
Compulsory assignment

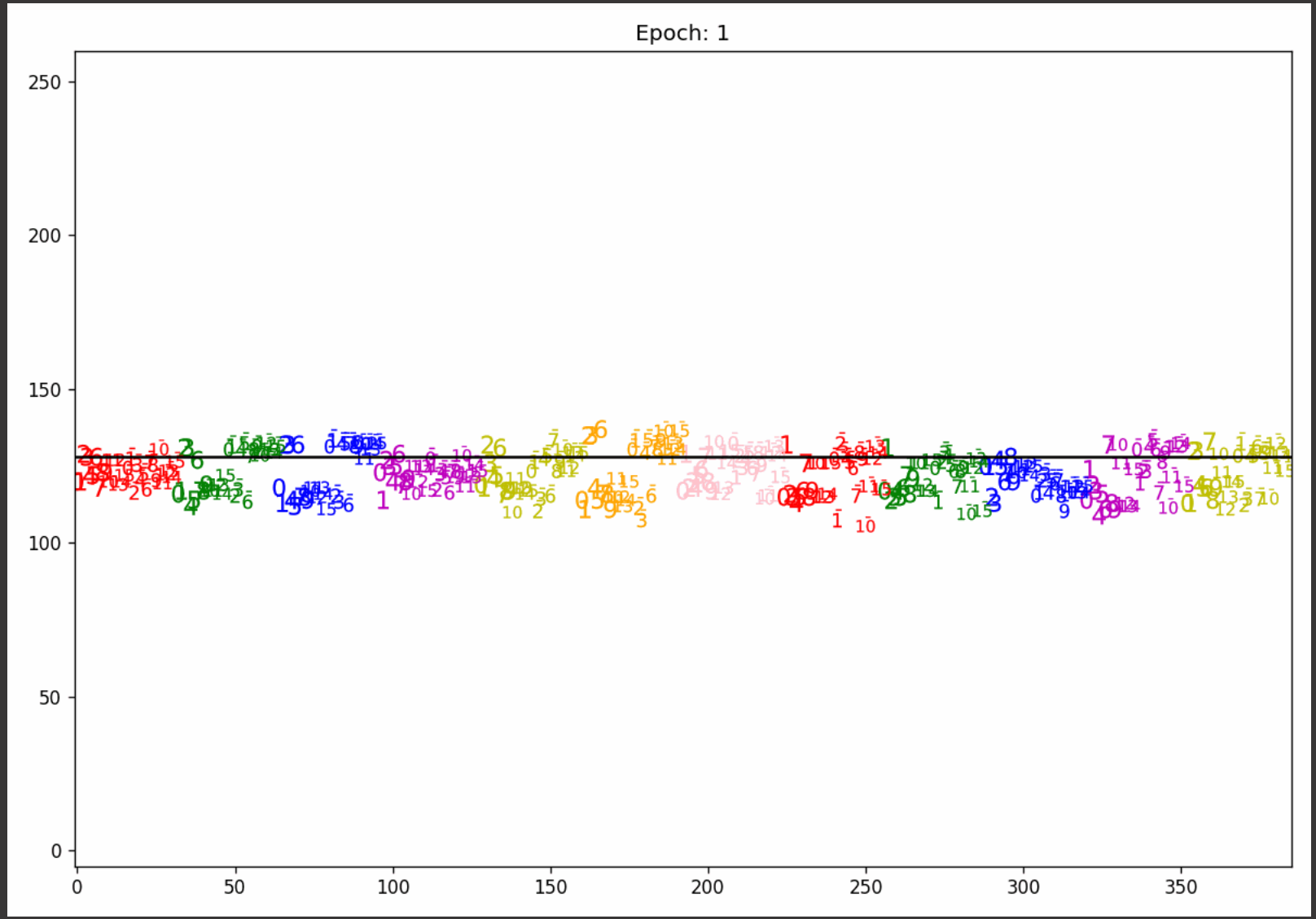
Download and install Python from http://www.python.org
Implement the following program and justify your results:

1. Create 5 Tsetlin Automata with actions “No” and “Yes”
2. Count the number of Tsetlin Automata that outputs a “Yes”-action
3. If the number of “Yes”-actions is M Then:
   - If M = 0 OR 1 OR 2 OR 3: Give each Automaton a reward with probability $M * 0.2$, otherwise a penalty
   - If M = 4 OR 5: Give each Automaton a reward with probability $0.6 - (M - 3) * 0.2$, otherwise a penalty
4. Goto 2

Remark: Generate the rewards independently for each automaton

Next lecture:





By Runar Helin, 2024