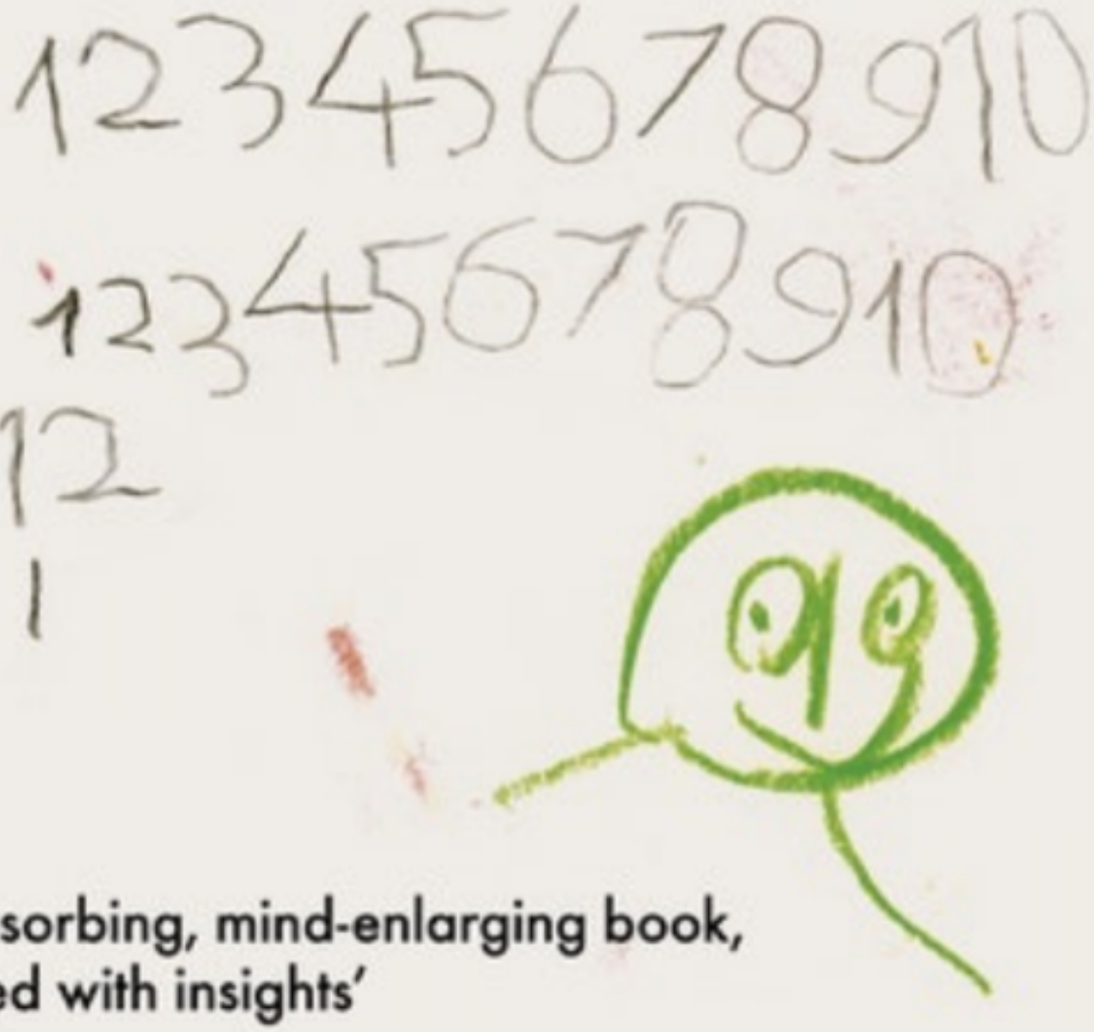
STANISLAS DEHAENE

How We Learn

The New Science of Education and the Brain



'An absorbing, mind-enlarging book, studded with insights'

THE TIMES

Human Brain

and

Neural Networks

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Content

Foundation for learning

- Architecture
- Sensing / Encoding

Process of learning

- Stages
- Bayesian reasoning
- Learning is elimination

Pillars of learning

- Attention
- Active engagement
- Error feedback
- Consolidation

Progress since 2020 incl. LlaMa4

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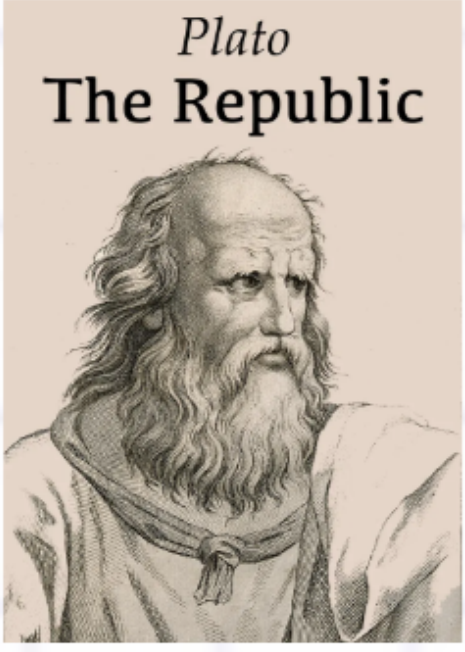
Every soul possesses two mechanisms:

the power of knowledge

and

the organ by which we acquire instructions



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Built-In from the beginning

The Power of Knowledge = Architecture

The Organ = Sensory system (Human)

The Organ = Encoders (Neural Network)

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Architecture: foundation for learning

Brain	Neural Network
The structure	
Regions or circuits	Layers
Information is processed in...	
Neurons	Nodes
Information is transferred via...	
Synapses between neurons	Weights between nodes
Information is transfered as...	
Electromechanical spikes	Weighted input aggregation

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Senses and Encoders: obtaining information

Brain	Neural Network
Abstract perception	Tabular data, structured arrays
Vision	
Eyes	Pixel arrays, spatial encodings
Language: speech and writing	
Eyes and ears	Tokenized text, embeddings
Hearing	
Ears	Waveforms, spectrograms
Touch	
Skin	Pressure/force sensors, tactile grids
Smell and Taste	
Nose and tounge	Chemical sensors, molecular inputs

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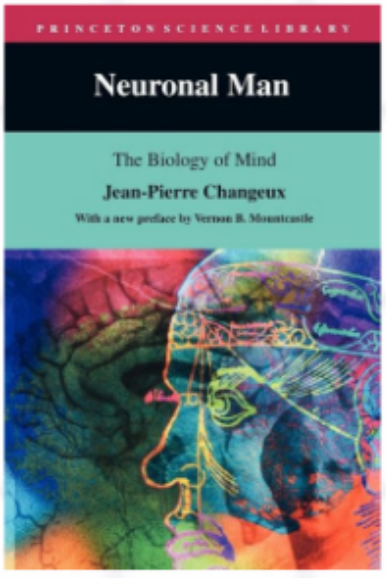
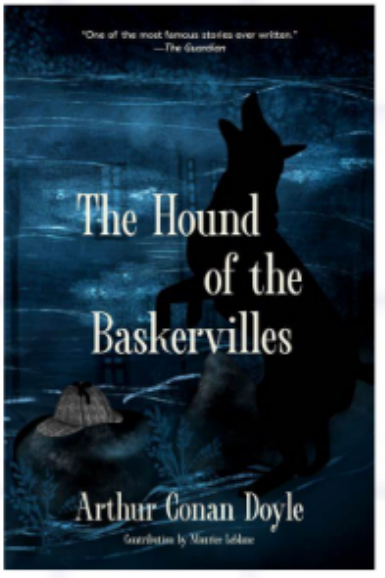
"To learn is to eliminate"

"When you have eliminated the impossible, whatever remains, however improbable, must be truth"





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Stages of learning

Receiving input (perception)

↓

Reconciling vs internal model (memory, beliefs)

↓

Generating output. Expecting result

↓

Updating internal model (memory, beliefs)
if the result is different from expected

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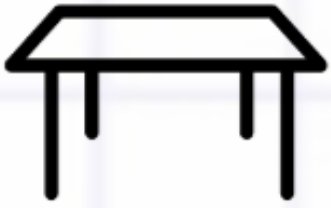
Example: foreign language

Input 

Internal model   

Result "This is a table"

Correction "Das ist ein Tisch"

Memory  = Tisch (masc.)

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Learning = Bayesian process

Priors (current internal model = memory, beliefs = expected probability)

↓

Receiving input (perception)

↓

Reconciling vs priors (Bayesian reasoning)

↓

Generating output. Expecting result, basing on probabilities

↓

Updating priors (memory, beliefs) if the result is different from expected

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Learning = eliminating

Is it a mammal? Yes -> not bird, reptile...

↓

Is it domesticated? No -> not dog, cat, cow...

↓

Larger than humans? Yes → not fox, monkey...

↓

Lives in water? No→ not whale, seal...

↓

Does it have a trunk? Yes → elephant

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All together: full process of learning

Brain	Neural Network
Signal received	
Senses capture stimulus	Encoder processes raw data
Input	
Sensory neuron fires	Input layer activated
Early processing	
Signal passes through thalamus / primary cortex	Data flows through early layers
Pattern recognition	
Stored representations activate (memory)	Learnt weights activate
Memory retrieval	
Comparison to known experiences and beliefs	Using weights and embeddings shaped by training data
Interpretation and Response	
Brain reacts (decision, motor response)	NN updates output and loss function (decoding at the end of the process)
Learning and Updating	
Beliefs are challenged → Beliefs update (Bayesian adjustment)	Bad evaluation → Weights update (Backpropagation)
Result	
Adjusted worldview	Corrected output, better performance

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4 pillars of learning

Attention

Active engagement

Error feedback

Consolidation

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Attention

Mechanisms by which a brain selects information, amplifies, channels and deepens its processing

Attention Systems

Alerting = when to attend (vigilance)

Orienting = what to attend for (object of interest)

Executive attention = how to attend (importance of different inputs). Not ingrown but learnt.

In Neural Networks

Mechanism to integrate attention was discovered in 2014 by Y.Bengio and K.Cho

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Active Engagement

Active attention, formulating hypotheses, testing predictions, correcting errors and updating beliefs.

Curiosity = the source of motivation

Occurs when a brain identifies a gap between what we know and what we would like to know

Curiosity has a bell curve shape

Too simple = boring. Too unusual = repulsion

In Neural Networks

Curious robot (F. Kaplan, P.-Y. Oudeyer)
3 module system: prediction, self-evaluation for speed of learning, self-reward for choosing the path of highest learning

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Error correction

Comparing expectations vs actual outcomes. Discrepancies trigger internal signal to revise future behaviors to improve the outcome.

Feedback is critical for learning

Without realizing the the output is wrong, no correction, adjustment and learning happens.

Best feedback = what and how to improve

In Neural Networks

Backpropagation (neural network is given explicit feedback about the response it should produce)

Reinforcement learning

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Consolidation

Strengthening relevant traces, pruning irrelevant ones and intergrating learnings

In humans consolidation happens in sleep

A brain replays the day's experiences, reinforces key information and reorganizes it into existing knowledge structures

In Neural Networks

Model checkpointing
Retraining over compressed, curated data
Pruning low-weight connections
Transferring knowledge across tasks or layers

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Brain vs Machine: the gap

The book was published in 2020. What changed?

Processing efficiency

2020: Slowness is the biggest challenge (huge datasets)
2025: High compute cost is the biggest challenge
LlaMA 4: becoming leaner and faster (MoE, FP8, MetaP)

Memory (context length)

2020: Only short-term
2025: ~256K tokens
LlaMA 4: 10M tokens but still no persistent memory

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Brain vs Machine: the gap

Multimodal reasoning

2020: weak

2025: image + text

LlaMA 4: joint training on text, image, video

Abstract reasoning

2020: none / very limited

2025: improved with prompting

LlaMA 4: fine-tuned for multilingual, image and logical reasoning, but remains mimicking and not mastering

Compositionality

2020: very weak

2025: some symbolic capabilities

LlaMA 4: still limited, no innate structure

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Brain vs Machine: as in 2020

Social learning

— Systematic generalization

One-shot learning

Self-awareness

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