Antal Jakovác
Department of Computational Sciences

Physical ideas in Artificial Intelligence

Wigner 121 Scientific Symposium
Heritage and Future
Budapest, 18-20 September 2023

MT Kurbucz
P Pósfay
A Telcs
TS Biró

Introduction

I believe that the present laws of physics are at least incomplete without a translation into terms of mental phenomena.

— Eugene Paul Wigner

('Physics and the Explanation of Life', Foundations of Physics 1970, I, 35-45.)

Nowadays certain “mental phenomena” are approachable through computers:
machine learning / artificial intelligence

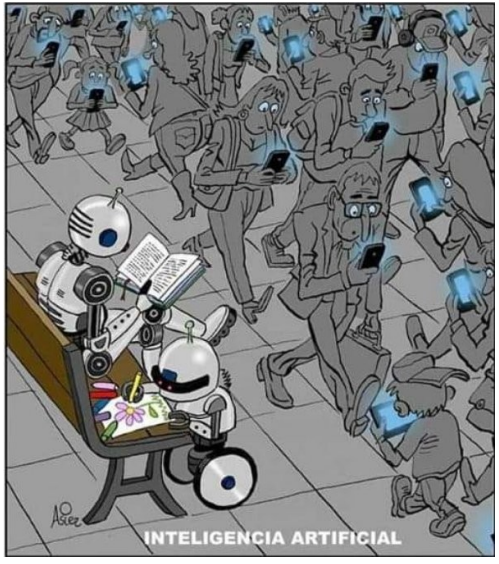
How science (physics) is related to (artificial) intelligence?

Introduction

Recent impressive developments in AI

OpenAI ChatGPT 4.0

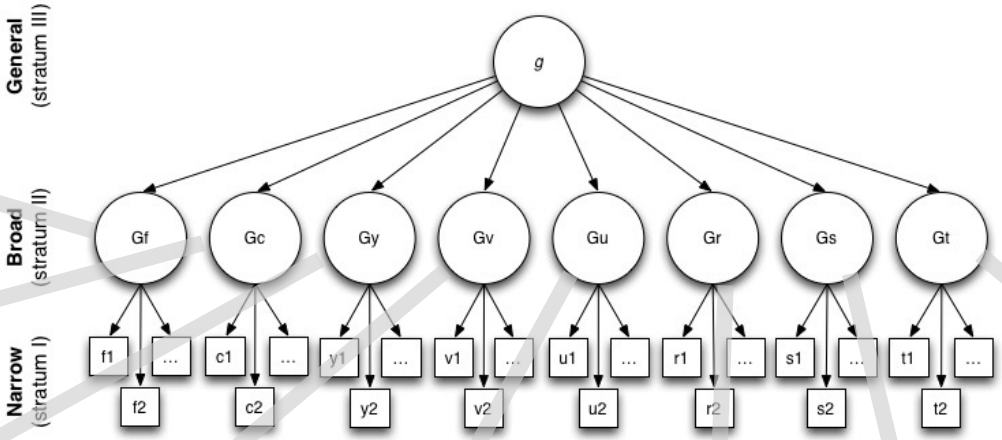
- Text generation: chatGPT, autoGPT, bing AI, bard AI, etc.
- Image generation: midjourney, thispersondeosnotexists, Dall-E, ...
- AI doomsday?
- Intelligent and useful tools, BUT heuristic, improvising, “lying”
- **Confusing situation… is AI intelligent or not?**



Introduction

Human intelligence is not a monolithic entity:

Cattell–Horn–Carroll theory



Fluid intelligence: reasoning, analysis

Crystallized intelligence: use acquired knowledge

Memory and learning

Visual perception

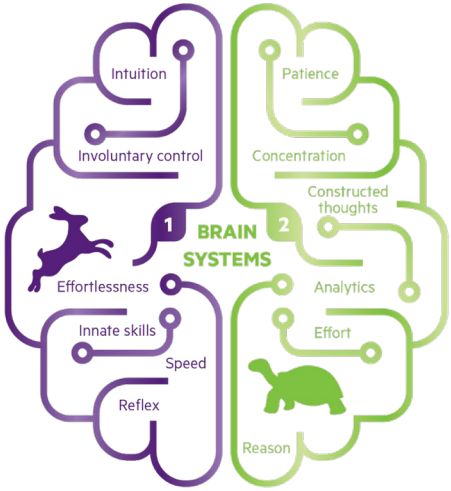
Auditory perception

Retrieval ability

Cognitive speediness

processing speed

Introduction



Categorization in cognitive psychology: modes of thinking

(Daniel Kahneman: Thinking, Fast and Slow)

- **System 1**:
  - fast, automatic, intuitive, no conscious awareness, no control, error-prone
  - ideal for fast, accurate responses (e.g. car driving, playing table tennis ...)
- **System 2**:
  - slower, conscious, deliberate, controlled, can be checked and re-iterated
  - ideal for contemplation, understanding

Introduction

Human intelligence is not a monolithic entity, we use:

- *all parts of the intelligence*
- *System1 and System2*

→ ***unlike in AI models***

- **The performance of AI depends on the task we want to solve with it!**
- We tend to think that all parts of IQ are present (cf. ELIZA, chatGPT → doomers)

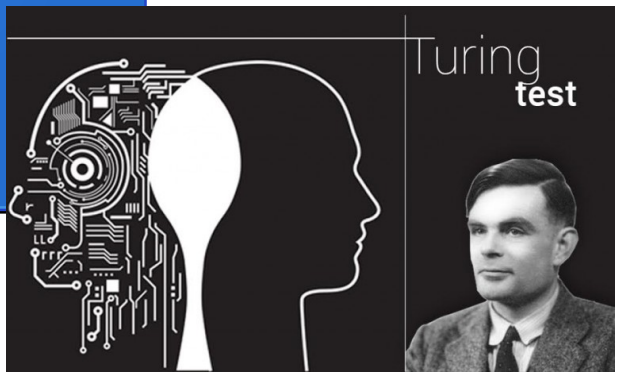
Introduction

What was the question, if the answer is human intelligence?

we do not know…

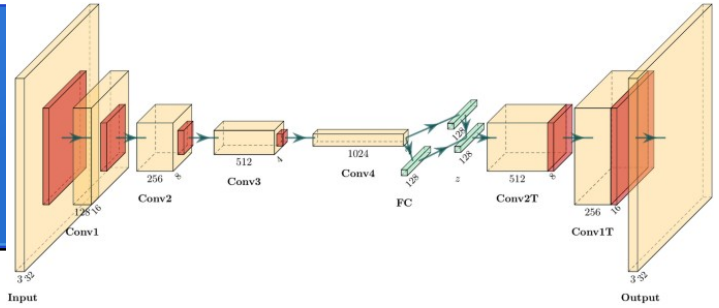
- *Turing's definition:* deceiving observers
- *Classification task:* main stream AI solutions: System1
- *How to buid a machine using System2?* → ***scientific understanding***

Turing’s definition of intelligence

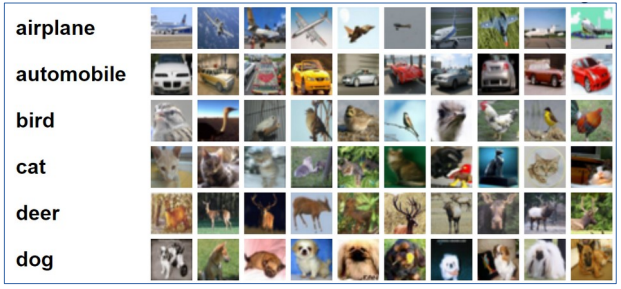


- **Intelligent:** indistinguishable from human in discussion (**Turing** 1950)
- **Task**: create a chatbot reacting to questions like humans do
- Famous programs:
  - ELIZA (Joseph Weizenbaum, 1960’s, MIT)
  - Eugene Goostman (13-year-old Ukrainian boy; 33% passed Turing test in 2014)
- Not really intelligent, but mislead humans to think they talk with an intelligent actor.

Classification task

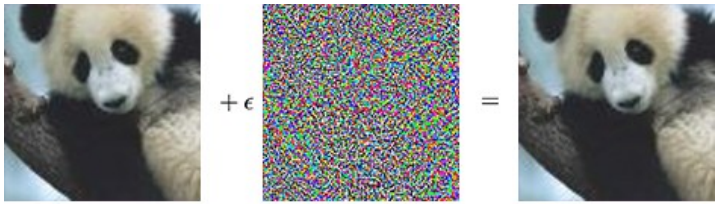


- **Intelligent**: classifies like humans do – we shall present the correct solution
- **Mathematical background**: probabilistic interpretation, Bayesian analysis, training, supervised learning
- **Technology**: plenty of ideas (DNN, CNN, ResNet, transformers, GAN, VAE, …)
- Most successful AI uses this method (classifiers, generators)



Classification task

- **Advantages**:
  - Very fast, effective
  - Good interpolation properties
- **Disadvantages** (apart from technical ones)
  - Slow training: needs a lot of data and uses a large amount of parameters
  - No control over the mistakes (c.f. adversarial attacks)
  - Input → output is a continuous function, can not train with very unbalanced data (e.g. can not have a class “no cat images”)
  - Specific → *catastrophic forgetting*: classification outputs are interdependent
- **All this corresponds to the System1 way of thinking!**



Alternative approach

Are there other approaches?

Task: determine that in an image there is a cat **or not**.

This task is hopeless to solve with DNN, because

#of cat images << #of non-cat images (like $1:10^{million}$)

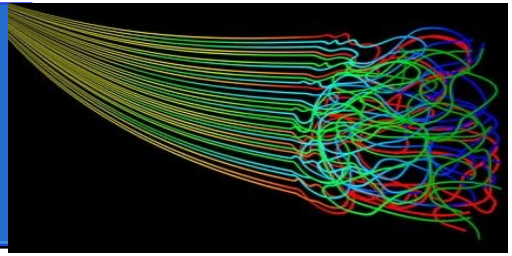
How could we solve this task in a different way? ⟹ logarithmic (binary) search

- choose properties that is true for cats (*selective features*, like has 4 legs)

$$f_i(c)=0 \ \forall c \in \{cats\} \ \Rightarrow \ f_i^{-1}(0) \supset \{cats\}$$

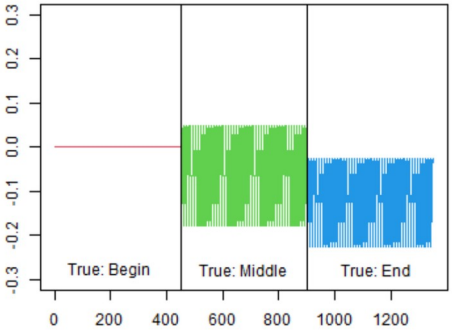
- using several selective features we can narrow the set of would-be cats $\cap_{i \in I} f_i^{-1}(0) \supset \{cats\}$
- the only condition for selective features to be constant on the given subset **(law)**

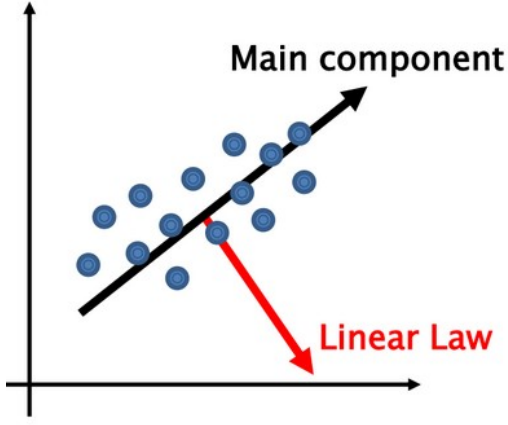
Law-based AI



- **implementation for learning**:
  - instead of train with human annotated datasets, we shall seek facts that are **constant over elements of contexts (laws)**
  - in practice ***no exact laws***: represent the data with the best laws, and iterate the process
  - *there is a lot to be understood ...*

- **practical approach**: law-based feature transformation
  - find laws in some functional space (e.g. linear functions)
  - collect laws for different elements of the context
  - data are represented by the best law → classification

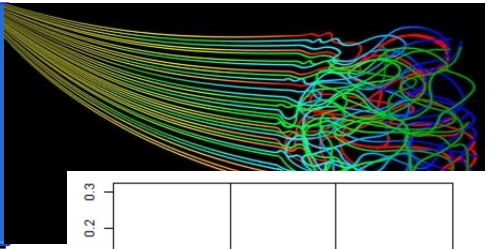


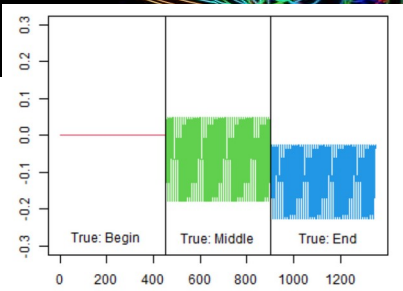


Law-based AI

- **Advantages**:
  - control over mistakes: several laws
  - can be used with unbalanced data
  - no forgetting: laws separate class elements from not class elements, no interdependence between laws
  - fast training: needs fewer data and less parameters than training
- **Disadvantages** (apart from technical ones)
  - complicated setup
  - application can be slow for a lot of laws (parallelization necessary)
- **These are characteristic for System2 way of thinking**

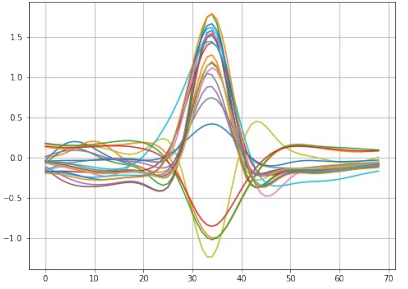
Applications

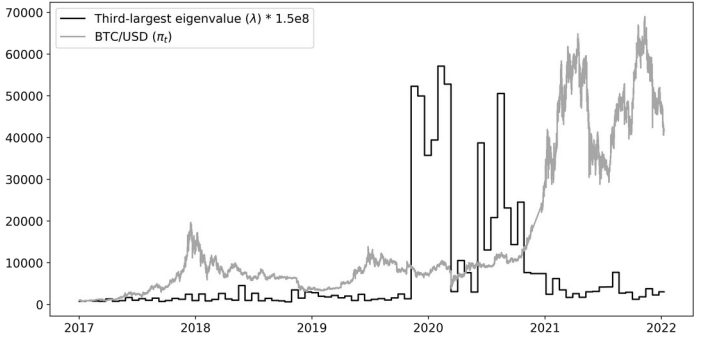




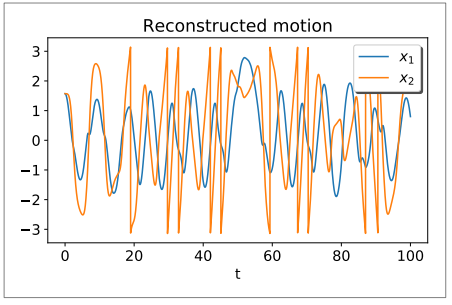
Wigner group: analysis of time series with law-based AI

- human motion classification from marker data: 100% efficiency
- ECG analysis (normal/ectopic): 94%-os efficiency
- determination of physical laws for mechanical systems from data
- Bitcoin stochasticity analysis
- Cryptocurrency price trend prediction (12 hours → trend after 2 hours)





	BTC	ETH	BNB	XRP
Ensemble	75.2	80.8	70.4	79.5
KNN	84.3	82.0	77.6	81.4
DT	65.9	73.6	60.8	67.5
SVM	65.9	64.3	58.8	62.0



Generalizing scientific understanding

We use the same strategy in understanding in science

Model building dictionary: (c.f. statistical physics, thermodynamics, renormalization group)

- possible observations, microstates ⇒ facts
- “IR physics”, macrostates ⇒ context
- state variables: constant on microstates belonging to a given macrostate (S, E, N, V,...)
  ⇒ selective (relevant) features: constant properties of a class of facts **(laws)**
- A physical model is built on state variables properties
  ⇒ a general model is built on relevant features / laws

Difference between scientific and AI approaches

How the scientific approach differs from AI?

- **in science**: *scaling & dimensional analysis:* if macrostates are much larger than microstates, then there remains just a few relevant interactions (“no hair”)

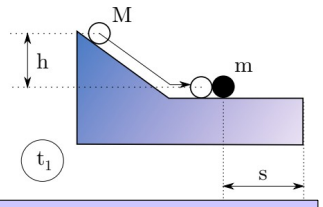
  the world is simple using an appropriate language

- this is not true in general: many fact remain important

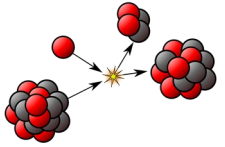
  the world remains complicated, even when using appropriate language

- **consequence: we shall use different methods for optimal model building**

Difference between scientific and AI approaches

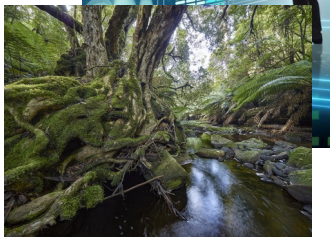


point mechanics
~ 5 relevant

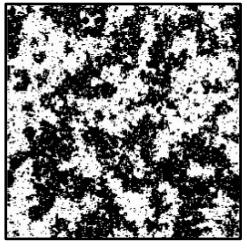


nuclear physics
20-? relevant

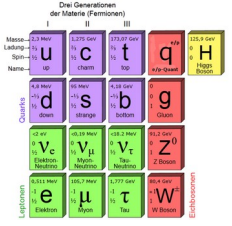
chemistry, biology
~ 100-? relevant



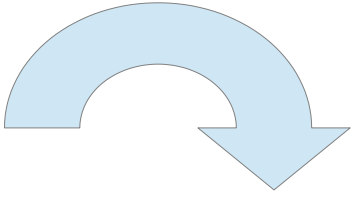
natural environment
? relevant ? irrelevant

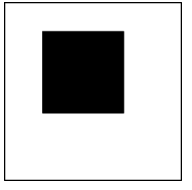


Ising model
3 relevant

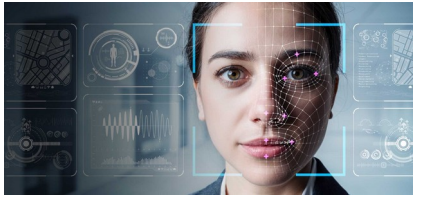


Standard Model
21 relevant
(symmetries!)



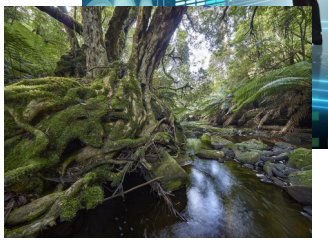


geometric images
~ 10-100 irrelevant

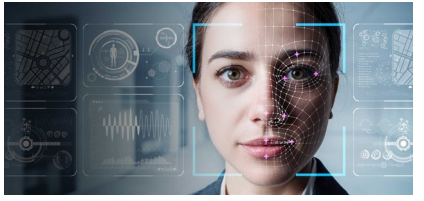


face recognitions
~ 30000 irrelevant

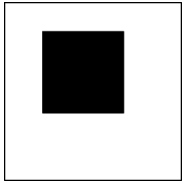
Difference between scientific and AI approaches



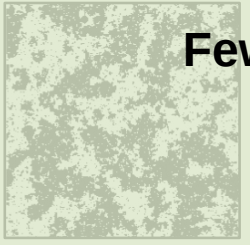
natural environment
? relevant ? irrelevant



face recognitions
~ 30000 irrelevant

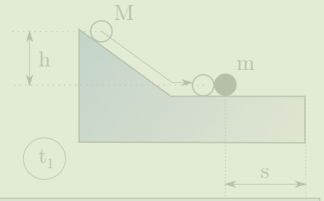


geometric images
~ 10-100 irrelevant

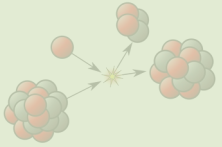


Ising model
3 relevant

Standard Model
21 relevant
(symmetries!)



point mechanics
~ 5 relevant



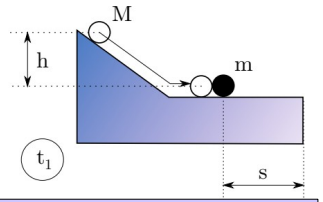
nuclear physics
~ 10-? relevant

chemistry, biology
~ 100-? relevant

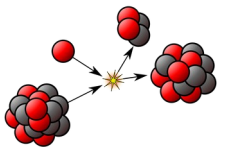
Science

Few relevant quantities

Difference between scientific and AI approaches



point mechanics
~ 5 relevant



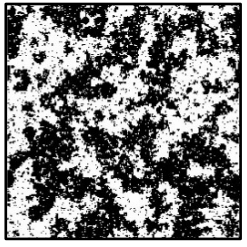
nuclear physics
20-? relevant

chemistry, biology
~ 100-? relevant

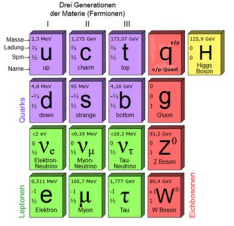
natural environment
? relevant ? irrelevant

Intelligence

Plenty of relevant quantities



Ising model
3 relevant



Standard Model
21 relevant
(symmetries!)

geometric images
~ 10-100 irrelevant

face recognitions
~ 30000 irrelevant

Difference between scientific and AI approaches

Science

Few relevant quantities

- identifiable on-by-one
- exact laws
- correct model is unique

Intelligence

Plenty of relevant quantities

- not identifiable one-by-one
- approximate laws
- can make mistakes
- equally good different models

The end