Freedom of Will, Physics, and Human Intelligence: An Idea

Miroslav Svítek[1], Vladik Kreinovich[2], and Nguyen Hoang Phuong[3]

[1]Faculty of Transportation Sciences, Czech Technical University in Prague
Prague, Czech Republic, svitek@fd.cvut.cz
[2]University of Texas at El Paso, El Paso, Texas 79968, USA
olgak@utep.edu, vladik@utep.edu
[3]Division Informatics, Math-Informatics Faculty
Thang Long University, Nghiem Xuan Yem Road, Hoang Mai District
Hanoi, Vietnam, nhphuong2008@gmail.com

1. What is science about?

- Science studies the world.
- Most of the studies cover different objects.
- Generally speaking, this is what physics is about – be it:
  - physics proper,
  - chemistry (and chemical physics),
  - biology (and biophysics),
  - geosciences (and geophysics),
  - astronomy (and astrophysics), etc.
- We humans also study ourselves, not just our own biology, but also the way we think and reason.

2. Fundamental challenges

- Science is an evolving body, it has many open problems, many challenges.
- Every year, new discoveries are made, new challenges appear:
  - how to describe a new phenomenon?
  - how exactly will different observed phenomena evolve?
- These are all serious challenges, and Nobel prizes are awarded to those who solve them.
- In addition to such "usual" scientific challenges, there are also fundamental challenges; these challenges deal:
  - not with our ability or inability to predict new phenomena,
  - but rather with some perceived fundamental flaws of the current theories.

3. Fundamental challenges (cont-d)

- Let us describe the main such challenges:
  - challenges of physics,
  - challenges arising from the relation between physics and study of human reasoning, and
  - challenges related to the study of human reasoning itself.

4. Fundamental challenges in physics

- To describe these challenges, let us start with physics proper; let us recall why:
  - many physicists are not always completely happy with their theories,
  - even when their theories provide a perfect prediction of the corresponding phenomena.
- To a naive mathematician, a physical theory may be nothing else but the corresponding set of equations.
- However, physicists understand that physics is much more than the set of equation.
- Physics also involved deep understanding of the related phenomena, an understanding that helps physicists make predictions.
- A classical example of the need to have something beyond equation is the history of General Relativity.

5. Fundamental challenges in physics (cont-d)

- It is known that the great mathematician David Hilbert came up with the same equations as Einstein.
- Hilbert submitted his paper two weeks later than Einstein, so Einstein was first.
- This is a known historical fact.
- What may be less known is that even if Hilbert was first, Einstein would still deserve his fame.
- Indeed, all Hilbert did was derive the equations – the system of complex non-linear partial differential equations.
- Hilbert did not provide any solutions to these equations – they were too complex to solve by known mathematical methods.
- In contrast, Einstein not only proposed the equations.
- He also provided some approximate solutions, solutions that were experimentally tested in a few years.

6. Fundamental challenges in physics (cont-d)

- Einstein came up with these solutions not because he was a better mathematician.
- He came up with these solutions because he had a good physical intuition.
- This intuition enabled him to understand which terms in the original nonlinear system could be safely ignored.
- This led to a solvable approximation.
- Another Einstein-related example: a guide who showed, to Einstein's wife, a state-of-the-art computer.
- He explained that this computer was busy finding the structure of the Universe as a whole.
- She replied that her husband did the related calculations on the back of an envelope.

7. Fundamental challenges in physics (cont-d)

- From this viewpoint, it is not enough to come up with mathematical formulas for prediction.
- We also need to gain a good intuitive understanding of the corresponding phenomena.
- This intuition would enable us to provide experimental confirmations of the resulting theory.
- Whenever such an understanding is missing, we have a fundamental challenge.
- And in theoretical physics, there is indeed such a challenge.

8. Specific challenge

- Current equations of quantum field theory predict many future events with very high accuracy; however:
  - if we write down seemingly natural equations of quantum field theory in our usual 4-dimensional space-time,
  - then, for some quantities, we get meaningless infinite values.
- In many cases, physicists came up with several tricks to avoid such infinities.
- A fundamental solution to this problem was found by string theory.
- Namely, a consistent quantum theory is only possible in space-times of dimension 11 and higher.
- This is an exciting and useful mathematical result.

9. Specific challenge (cont-d)

- However, from the physical viewpoint, this solution is not fully satisfactory, since:
  - in contract to the usual 4 dimensions that have precise physical meaning,
  - the additional 7 or more dimensions largely remain purely mathematical constructions.
- What is the physical meaning of these extra dimensions is not clear.
- Another path to extra dimensions comes from foundations of quantum physics.
- One of the main interpretations of the stochastic character of quantum predictions is that:
  - there are actually many possible worlds, and
  - when we perform an experiment, we branch – with appropriate probabilities – into one of these possible worlds.

10. Specific challenge (cont-d)

- From the fundamental viewpoint, it is the same idea as extra dimensions – namely, the world we observe is a tiny part of the larger world.
- In this case, additional dimensions make some physical sense – they correspond to possible worlds.
- However, in this case too, all we observe is *one* possible world, a tiny portion of the whole multi-world universe.
- And physicists understandably do not like theories that heavily rely on unobservable quantities.
- This sounds too much like speculations rather than physics.
- Researchers have been trying to find some physical meaning of the extra dimensions.

11. Specific challenge (cont-d)

- For example, the Nobelist Andrei Sakharov – best known for his human rights activities – conjectured that:
  - in contrast to usual understanding,
  - there is actual interaction between possible worlds.
- He concluded that strong interaction between protons and neutrons can be explained in this way.
- This idea sounded – and still sounds – promising, it was even cited in a textbook on gravitation.
- However, no experimental confirmation of such interaction was found.

12. Fundamental challenges about the relation between physics and study of human reasoning

- Modern physics is largely deterministic.
- According to physics' equations:
  - once we know the initial state of the Universe – or of any closed system,
  - this initial state uniquely determines the future state at all future moments of time.
- To be more precise, before quantum physics, the world's description was fully deterministic in this sense.
- Quantum physics added an additional level of uncertainty; according to quantum physics:
  - the state does not uniquely predict results of future measurements,
  - but it does uniquely predict the probabilities of different future measurement results.

13. Fundamental challenges about the relation between physics and study of human reasoning (cont-d)

- Many equations of physics have been confirmed on multiple examples with high accuracy.
- However, their deterministic nature contradicts our intuitive understanding that we have freedom of will.
- We can make decisions and select different alternatives – thus changing the future state of our environment – and therefore the state of the Universe.
- Some people are so much convinced by physics that they start really believing that freedom of will is an illusion.
- For example, Einstein, who could not swim, nevertheless liked to go yachting on his own.
- He argued that whether he drowns or not is pre-determined by the initial state of the Universe and does not depend on his decisions.

14. Fundamental challenges about the relation between physics and study of human reasoning (cont-d)

- To most people, however, this sounds weird, they believe that we can change the state of the universe.
- But how can we reconcile this belief with physics?
- The world consists of elementary particles.
- So, the fact that we change the state of the Universe means that we can, by our sheer will, change the state of these particles.
- Many experiments tried to see if such "telekinesis" – using willpower to change the state of the material objects – is indeed possible.
- No such ability was found.
- No matter how much people tried, they were never able to affect the results of physical experiments.

15. Challenges related to the study of human reasoning

- We have come a long way towards understanding how we reason and how we think.
- We know, in many detail, how signals are processes in our brains:
  - the signals go from a neuron to a neuron, and
  - these signals are processed by these neurons in a (largely) known way.
- This knowledge has led to development of artificial devices that simulate this activity – artificial neural networks.
- Current deep neural networks indeed have spectacular successes.

16. Challenges related to human reasoning (cont-d)

- However, in many aspects, these networks are still not as smart as we are – and not as smart as we have hoped them to be.
- Deep networks perform well on tasks with which previous computer programs had trouble, such as distinguishing cats from dogs.
- However:
  - a small change in the input – a change that would not affect human decisions
  - can lead a neural network to a completely erroneous classification.
- A drastic increase in the number of neurons does not make the artificial neural networks as close to our intelligence as we hoped.
- So, many researchers speculated that the human brain uses physical phenomena beyond the usual processing of electric signals.

17. Challenges related to human reasoning (cont-d)

- For example, Roger Penrose famously conjectured that the human brain is actually involved in quantum computing.
- And it is known that quantum computing can indeed drastically increase the system's computational abilities.
- This was a very interesting and very promising hypothesis.
- However, no evidence of such quantum activity was found, so this hypothesis was abandoned.
- As a result, the challenge remains: why are we so smart?
- To be more precise, why are our brains much smarter than similar-size artificial neural networks that emulate them?

18. Let us summarize

- In modern science:
  - in addition to the "usual" challenges – how to predict future phenomena, how to explain the observed phenomena,
  - there are several fundamental challenges.
- We have mentioned three such challenges:
- What is the physical meaning of extra spatial dimensions?
- How to reconcile freedom of will and physics?
- How to explain that we are often much smarter than computer models that seem to adequate simulate our brains?
- In this talk, we show that all these three challenges can be resolved if we view them together.

19. Let us start with the first challenge

- How to explain the physical meaning of additional spatial dimensions?
- What are the physical (= observable) consequences of the existence of possible worlds – worlds that exist in parallel to our world?
- To answer this physical challenge, let us take the second challenge into account – the existence of free will.
- Intuitively, free will means that which possible world we get into is not just randomly determined.
- *We* can select to which of the possible worlds we move.
- In other words, free will means that we can move in the space of possible worlds.
- In other words, we can move in the extra spatial dimensions corresponding to these possible worlds.

20. Let us start with the first challenge (cont-d)

- If we assume that we humans can indeed move in these extra dimensions, this provides the desired physical meaning to these dimensions.
- Namely, there are objects that function and move in these extra dimensions – and we ourselves are these objects.

21. This also helps with the second challenge

- This idea also explain why:
  - in spite of the fact that our will cannot change anything in the 3-D world,
  - we can (and do) make changes by our choices.
- We *cannot* change anything in the usual 3-D world.
- However, when we *can* do is move between possible worlds.
- In other words, our free will can select in which of the possible worlds we will be in the future.

22. This also helps with the third challenge

- Let us show that the possibility to move in extra dimensions increases our computational abilities.
- How is the complexity of an algorithm usually measured in computer science?
- By the time T_{seq} needed to perform this algorithm step-by-step on a sequential computer.
- For many problems, this is too long.
- For example, if it takes a week to predict tomorrow's weather, then this prediction algorithm is useless.
- We will observe tomorrow's weather way before the algorithm finishes its computations.
- In such situations, it is desirable to speed up computations.
- How can we speed up computations?

23. This also helps with the third challenge (cont-d)

- If a human being has a time-consuming task – e.g., cleaning all the offices in a building before an inspection, and:
  - it would take too long for one person to clean all the rooms,
  - a natural idea is to have several people cleaning rooms at the same time.
- Similarly, if a task takes too long a time for a single processor, a reasonable idea is to have several processors working in parallel.
- At first glance, it may seem that the more processors we add, the faster the computation can be.
- However, in reality, there is a limit to the possible speedup.
- This limit is caused by the fact that, according to modern physics, all the speeds are limited by the speed of light c.
- Suppose that we have a computational device in which several processes work in parallel.

24. This also helps with the third challenge (cont-d)

- Suppose that this device finishes its computations in time T_{par}.
- In other words, T_{par} is the time between:
  - the moment when we present the task to this device and
  - the moment when the device presents us the result.
- During this time, if any processor is involved in this computation:
  - some signal must reach this processor, and
  - some results from this processor must eventually find their way back to us.
- So, if this processor is located at some distance r from us, the signal must travel at least a distance $2r$.
- During the time T_{par}, the largest distance that can be covered is the distance $c \cdot T_{\text{par}}$.
- Thus, we must have $2r \leq c \cdot T_{\text{par}}$ and hence, $r \leq (c/2) \cdot T_{\text{par}}$.

25. This also helps with the third challenge (cont-d)

- So, all processors that affect the computation result must be located within the sphere of radius $R \stackrel{\text{def}}{=} (c/2) \cdot T_{\text{par}}$.
- In the usual 3-D space, the volume V of this inside-sphere region is equal to
$$V = \frac{4}{3} \cdot \pi \cdot R^3 = \frac{4}{3} \cdot \pi \cdot \left(\frac{c}{2}\right)^3 \cdot T_{\text{par}}^3.$$
- Let us denote by ΔV the size of the smallest possible processor, and by N_{proc} the number of processors involved in the computation.
- Overall, these processors occupy at least the volume $N_{\text{proc}} \cdot \Delta V$.
- This volume cannot exceed the overall volume V: $N_{\text{proc}} \cdot \Delta \le V$, so we get an upper bound on the possible number of processors:
$$N_{\text{proc}} \le \frac{V}{\Delta V} = C \cdot T_{\text{seq}}^3, \text{ where } C \stackrel{\text{def}}{=} \frac{1}{\Delta V} \cdot \frac{4}{3} \cdot \pi \cdot \left(\frac{c}{2}\right)^3.$$
- Computations on a parallel computer can be simulated on a sequential computer.

26. This also helps with the third challenge (cont-d)

- For each moment of time, we simulate what the first processor does, then what the second processor does, etc.
- In this simulation, one time period of the parallel computer is simulated in N_{proc} time periods.
- Thus, the overall computation time increases by a factor of N_{proc}.
- As a result, we perform the same computations on a sequential computer in time $N_{\text{proc}} \cdot T_{\text{par}} \le C \cdot T_{\text{par}}^3 \cdot T_{\text{par}} = C \cdot T_{\text{par}}^4$.
- So, if we denote by T_{seq}, the smallest possible time needed to solve the corresponding problem on a sequential computer, then we get

$$T_{\text{seq}} \le C \cdot T_{\text{par}}^4.$$

- From this inequality, we can conclude that $T_{\text{par}} \ge C^{-1/4} \cdot T_{\text{seq}}^{1/4}$.
- In other words, we can speed up computations, but there is a limit to this speedup.

27. This also helps with the third challenge (cont-d)

- The main reason why we need speedup is that many problems are NP-hard.
- Unless it turned out that P = NP, solving such problems requires, in the worst case, exponential time $\approx 2^n$, where n is input size.
- For reasonable-size inputs $n = 300$ and $n = 600$, we will need, correspondingly, $2^{300} \approx 10^{100}$ and $2^{600} \approx 10^{200}$ steps.
- This would take much larger time than the lifetime of the Universe.
- Let us see what happens if we parallelize these problems.
- Suppose that the lower bound for sequential computer is $2^{300} \approx 10^{100}$, which is much larger than the lifetime of the Universe.
- Then the parallel computations can be, potentially, performed in the time of $(2^{300})^{1/4} = 2^{75} \approx 10^{25}$ steps.
- At the usual Gigabyte speed of 10^9 computational steps per second, this means $10^{25}/10^9 \approx 10^{16}$ seconds.

28. This also helps with the third challenge (cont-d)

- Taking into account that there are approximately $3 \cdot 10^7$ seconds in a year, this means that the parallel computations would require

$$10^{16}/(3 \cdot 10^7) \approx 3 \cdot 10^8 = 300 \text{ million years.}$$

- It is still not very practical, but at least theoretically feasible.
- On the other hand, suppose that computations on a sequential computer require $2^{600} \approx 10^{200}$ computational steps.
- Then the parallel computations would require

$$10^{50}/(10^9 \cdot 3 \cdot 10^7) \approx 3 \cdot 10^{33} \text{ years.}$$

- This is still much larger than the lifetime of the Universe.
- But what if we take into account that the space is actually multi-dimensional, of dimension $d > 3$?
- In this case, similar arguments lead to a better bound on T_{par}:

$$T_{\text{par}} \geq C \cdot T_{\text{par}}^{1/(d+1)}, \text{ for some constant } C.$$

29. This also helps with the third challenge (cont-d)

- In particular, for $d = 10$, the sequential time of $2^{600} \approx 10^{200}$ seconds leads $(10^{200})^{1/11} = 10^{22}$ parallel steps, i.e., to

$$10^{22}/(10^9 \cdot 3 \cdot 10^7) \approx 3 \cdot 10^5 = 300\,000 \text{ years.}$$

- This is a more feasible time.
- So, additional dimensions do help to speed up computations.

30. Let us summarize

- Extra dimensions – in line with the many-world interpretation of quantum physics – represent possible worlds.
- The main difference between this interpretation and the proposed idea is that in the proposed interpretation, we can use our free will:
  - we can use our free will to select one of the possible worlds,
  - i.e., to move in these additional dimensions.
- How can we resolve the second challenge, that:
  - we can affect the state of the universe, but
  - no one's will was able to move any material object.
- Our explanation of this challenge is straightforward.
- Yes, according to all the experiments so far, our will cannot change anything in the 3-D world.

31. Let us summarize (cont-d)

- However, probably what we can do is move between possible worlds.
- In other words, our free will can select in which of the possible worlds we will be in the future.
- How we can resolve the third challenge: why are we smart.
- Why are we smarter than similar-size artificial networks? Maybe because:
  - the artificial neural networks live in the 3-dimensional space, while
  - our brain can operate in the higher-dimensional space – and this increases our computational abilities.

32. Acknowledgments

- This work was supported in part by the National Science Foundation grants:
  - 1623190 (A Model of Change for Preparing a New Generation for Professional Practice in Computer Science), and
  - HRD-1834620 and HRD-2034030 (CAHSI Includes).
- It was also supported by the AT&T Fellowship in Information Technology.
- It was also supported by the program of the development of the Scientific-Educational Mathematical Center of Volga Federal District No. 075-02-2020-1478.