Intelligent Computing: Time to Gather Stones (a brief preview of the Fall class CS4365/CS5354)

Vladik Kreinovich

Department of Computer Science
University of Texas at El Paso
El Paso, Texas 79968, USA,
vladik@utep.edu

1. Main Objective

- The main objective is to learn theoretical foundations for modern intelligent techniques.
- The emphasis will be on:
  - foundations of fuzzy techniques,
  - foundations of neural networks (in particular, deep neural networks), and
  - foundations of quantum computing.

2. Time to Gather Stones

- Many heuristic methods have been developed in intelligent computing.
- Some of them work well, some don't work so well.
- And promising techniques – that work well – often benefit from trial-and-error tuning.
- It is great to know and use all these techniques.
- It is also time to analyze why some technique work well and some don't.
- Following the Biblical analogy, we have gone through the time when we cast away stones in all directions.
- It is now time to gather stones, time to try to find the common patterns behind the successful ideas.
- Hopefully, in the future, this analysis will help.

3. Case Studies

- In this class, we will mainly concentrate on three classes of empirically successful semi-heuristic methods.
- Fuzzy techniques, techniques for translating:
  - expert knowledge described in terms of imprecise ("fuzzy") natural-language words like "small"
  - into precise numerical strategies.
- Neural networks (in particular, deep neural networks), techniques for learning a dependence from examples.
- Quantum computing, techniques that use quantum effects to make computations faster and more reliable.

4. Fuzzy Case

- In fuzzy case, we start with explaining, in detail, the main stages of processing fuzzy data:
  - we associate, with each imprecise word, a function describing the corr. degrees of uncertainty;
  - then, we select "and"- and "or"-operation that best reflect the reasoning of specific experts;
  - these operations transform expert's rules into a degree to which each action is reasonable;
  - if needed, finally, we transform these degrees into a single recommendation;
  - this selection of a single recommendation is known as *defuzzification*.
- We show how to select the optimal "and"- and "or"-operations and the optimal defuzzification.

5. Neural Network Case

- We will briefly overview the main ideas behind neural networks.
- We will then explain:
  - why deep networks are efficient,
  - what is the best selection of an activation function,
  - what optimality criterion should we use – and why KL is better than least squares,
  - what is the best combination rule for combining intermediate results.
- Specifically, we explain:
  - the use of softmax in neural processing itself and
  - the use of geometric mean in dropout training.
- If time allows, we will also discuss how to avoid mistaken recognitions.

6. Quantum Computing

- We will learn the basic ideas behind quantum computing.
- Then, we will study the main quantum algorithms:
  - Deutch-Josza's algorithm for checking which inputs are relevant (1-bit case in detail),
  - Grover's algorithm for fast search in an unsorted array (briefly),
  - Shor's algorithm for factoring large integers (briefly),
  - algorithms for quantum teleportation (in detail), and
  - algorithms of quantum cryptography (in detail).

7. Quantum Computing (cont-d)

- We will show:
  - that the current teleportation algorithm is, in some reasonable sense, optimal, and
  - that the current quantum cryptography algorithm is, in some reasonable sense, optimal.
- We will also discuss:
  - how best to represent functions in quantum computing, and
  - how best to represent input's uncertainty in quantum computing.

8. General Techniques

- The main idea behind the theoretical results in all three application areas is the idea of symmetry.
- Why symmetry? And what is symmetry?
- Everyone is familiar with symmetry in geometry:
  - if you rotate a ball around its center,
  - the shape of the ball remains the same.
- Symmetries in physics are similar.
- Indeed, how do we gain knowledge?
- How do we know, for example, that a pen left in the air will fall down with the acceleration of $9.81\ \text{m}/\text{sec}^2$?
- We try it once, we try it again, it always falls down.

9. General Techniques (cont-d)

- You can shift or rotate, it continues to fall down the same way; so:
  - if we have a new situation and it is similar to the ones in which we observed the pen falling,
  - we predict that the pen will fall in a new situation as well.
- At the basis of each prediction is this idea:
  - that we can perform some symmetry transformations like shift or rotation, and
  - the results will not change.
- Sometimes the situation is more complex.
- For example, we observe Ohm's law in one lab, in another lab, etc.
- Then, we conclude that it is universally true.

10. General Techniques (cont-d)

- Symmetries have been very successful in physics.
- We will show that they are very helpful in analyzing intelligent computing as well.