Hypothetic Paraparticles and How They Can Potentially Speed Up Computations

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1. Hypothetic paraparticles and their possible use in computing

- Usually, elementary particles have a single stable state, i.e., the state with the smallest possible energy.
- However, recently, researchers raised the possibility of having particle that have two different minimum-energy states.
- These particles are called *paraparticles*.
- This feature makes paraparticles a perfect tools for storing one bit of information.
- If we use only one elementary particle to store a bit (instead of several molecules), that will make computers:
  - drastically smaller and
  - thus, faster.

2. Can we speed up computations even further?

- We do not know the exact equations describing the paraparticle's energy, it can be any analytical function.
- In such situations:
  - to get a first approximation to the particle's description,
  - it is reasonable to restrict the general Taylor expansion of the energy function to the first few terms
  - as long as that allow to explain the basic behavior of the particle.
- For many physical systems – such a pendulum – such a first approximation comes from consider quadratic terms.
- To find the minimum-energy state, we can:
  - differentiate the energy function with respect to all unknowns, and
  - equate all the resulting derivatives to 0.

3. Can we speed up computations even further (cont-d)

- Differentiating a quadratic function leads to a linear expression, so we get a system of linear equations.
- Such systems either have a unique solution, or the whole linear space of solutions – but they cannot have just two solutions.
- So, to describe paraparticles, we need to go beyond quadratic terms.
- The next after quadratic are cubic terms. However, a cubic polynomial cannot have a global minimum:
  - in some directions, it reaches infinity and thus,
  - in opposite directions, it tends to $-\infty$.
- Thus, to describe paraparticles, we need to also take into account the next order terms – i.e., consider 4th order polynomials.
- An interesting feature of 4th order polynomials is that for then, finding a global minimum is NP-hard.

4. Can we speed up computations even further (cont-d)

- So, in general, finding the minimum-energy state of a paraparticle is probably an NP-hard problem.
- A particle, left to itself, reaches its minimum-energy state – and usually does it fast.
- So by observing hypothetic paraparticles, we may be able to find, in short time, solutions to an NP-hard problem.
- By definition, NP-hardness means that we can reduce any problem from the class NP to this problem in feasible time.
- Thus, paraparticles may lead to feasible algorithms may lead:
  - to a feasible way of solving all the problems from the class NP,
  - i.e., in effect, to solution of all the problems in mathematics, physics, and engineering!

5. How to prove that minimizing 4th order polynomials is NP-hard

- We can prove this by reducing, to this problem, the known NP-hard subset sum problem:
  - we have a list of natural numbers $s_1, \ldots, s_n$ and a natural number s, and
  - we need to find a subset $S \subseteq \{1, \ldots, n\}$ over which the sum of s_i's is equal to s.
- This is equivalent to finding $x_i \in \{0, 1\}$ for which $\sum_i x_i \cdot s_i = s$.
- For each instance of this problem, let us form the following 4th order polynomial:

$$\sum_i (x_i \cdot (1 - x_i))^2 + \left(\sum_i x_i \cdot s_i - s \right)^2 .$$

- This polynomial is always non-negative.

6. How to prove that minimizing 4th order polynomials is NP-hard (cont-d)

- Its minimum is equal to 0 if and only if all the terms in the sum are 0s.
- In particular, this means:
  - that $x_i \cdot (1 - x_i) = 0$ (so either $x_i = 0$ or $1 - x_i = 0$, i.e., $x_i = 1$), and
  - that $\sum_i x_i \cdot s_i = s$.
- So, if we could minimize this polynomial, we would be able to solve the subset sum problem.
- This reduction proves that the above minimization problem is also NP-hard.

7. Bibliography

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