It's all downhill: ignoring the bumps in the road using gradient-only optimisation

by Janine Smit

An associate professor and a PhD student from the Department of Mechanical and Aeronautical Engineering at the University of Pretoria believe they have developed a solution to the centuries-old problem of optimisation simulations.

"Optimisation is where you are not just trying to design or analyse something. You are trying to do it in an optimal way," says associate professor Schalk Kok who, along with PhD student Nico Wilke, has developed a new optimisation algorithm. Optimisation is a means to an end. It is a tool used by engineers, scientists and economists to obtain more than just an answer or solution for their needs. For example, when one is asked to design a chair (something a human being can sit on), most things around one would suffice as a solution to one's design problem, but why do we not see people buying flower pots or concrete blocks to sit on?

Even when considering 'proper' chairs, why are there so many different designs, even after hundreds of years of designing chairs? The answer is obvious. The first suggestion of flower pots is ridiculous, while concrete blocks are impractical. As for 'proper' chairs, people have different needs. This seems to render optimisation as useless as it is obvious, but what happens when the answer is not obvious?

This is exactly what happens when engineers run simulations of systems such as cars crashing into walls, aircraft taking off, space shuttles being launched or nuclear plants generating power. To do these simulations, engineers model the physical reality as accurately as possible, or at least they attempt to do so.

To optimise these systems, engineers need to run many simulations of a system to construct an objective function. An objective function basically tells an engineer how good one system configuration is with respect to another configuration of the same system. What happens in some cases is that snags – scientifically known as step discontinuities – occur when engineers start constructing these objective functions. These snags are artificial. They have nothing to do with the physics of the system, but are errors made when modelling a system. Therefore, snags mislead 'classical' optimisation tools when trying to figure out the best (optimal) solution to a problem.

Traditionally, engineers work very hard to avoid these snags from occurring, which makes the modelling of systems in an optimisation context much harder and more complicated than when modelling a system as a stand alone simulation.

The spanner

Prof Kok and Mr Wilke tried to find a shape that would assist in solving the problem of optimisation algorithms. "What we've done is to design the stiffest possible spanner subject to constraints on the amount of material we can use by asking what the stiffest spanner is we can make with one kilogram of metal. The freedom we're allowed in the design process is the coordinates of a lot of points and we say you can move this up and down as you wish – we let an algorithm choose how to move these points up and down," explains Prof Kok.

A formal mathematical analysis was applied onto a fault plane, force was put on the load and the deflection was computed: the less deflection, the stiffer the spanner. According to Prof Kok, this method of solving an optimisation problem has been standard practice the past 200 to 300 years. "The problem is that you expect the displacement to come down as the thickness increases, but this leads to discontinuities – you get snags or traps – that are purely due to the numerical technique... which is unwanted because you want to minimise the displacement."

He explains that this then leads to the mistaken identification of the snags as the optimal point, which is not a desirable outcome. He says the solution lies in the algorithm used. While all algorithms look at the slope created in the equation (does it increase or decrease in value) and at function value, Mr Wilke only considered the slope of the algorithm in solving the problem. "The slope will tell you in which direction to go – the function value will tell you how far you must go in that direction. So what happens now is that we are no longer looking for an increase in function value, but a change in slope from negative to positive," says Prof Kok. Using this method, it is possible to eliminate the step discretisations and therefore make a more accurate calculation.

Prof Kok says this new method of viewing optimisation algorithms will find a significant application in all fields of engineering optimisation. The two have compiled a lengthy draft paper of their findings and conclusions and submitted it to the international Society for Industrial and Applied Mathematics (SIAM). They are eagerly awaiting feedback on this. "We believe this is a big deal and what we'll have to do now is actually tackle and solve optimisation problems for others to take notice but, essentially, we know it has a significant area of application," concludes Prof Kok.

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