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For my summer internship at the Centre for Theoretical Cosmology, DAMTP, I worked on adaptive mesh code for the simulation of scalar field bubble collisions. Since the simulations are calculation-intensive they were run on the COSMOS supercomputer. Ultimately, these simulations will enable us to investigate the conditions under which black holes are formed in collisions.

Adaptive mesh refinement

Continuous real world phenomena must be discretised before being modelled by a computer: continuous space for example is replaced by a discrete mesh. This leads to a discretisation error which can be controlled by choosing a smaller mesh spacing. The resulting higher computational cost, however, often makes it impossible to use a smaller mesh spacing for the entire domain. Hence, we want our code to choose finer spacings only where it is needed (see video 1 below). This is called *Adaptive Mesh Refinement* and is rather challenging to implement. Fortunately, there are several sets of libraries to ease the task. We have used the Chombo framework for all of our simulations.

Scalar field bubble collisions

In models of eternal inflation our universe is just one of many bubbles in a rapidly expanding parent universe. The formation and expansion of these bubbles is governed by a *scalar field* filling the entire space. Scalar fields, and the associated scalar particles, have the characteristic that they look the same in all inertial frames. The value of the field at a given point is associated with a potential energy through a function whose shape is not determined a priori but heavily influences the resulting physics: the local minima of the potential energy function, for example, correspond to classically stable states.

Consider now a parent universe filled with a scalar field trapped in the highest minimum of the potential energy function shown in the figure below. Through quantum tunneling some regions will fall into the intermediate vacuum state and, if large enough, will expand and might collide with other bubbles that formed in the parent universe. Under the right circumstances the energy released in such collisions is enough to lift a small region over the potential barrier to the lowest minimum creating a new bubble (video 1 & 2). This shows that bubble universes can be created not only through quantum tunnelling but also through classical collision processes. (Easther, Giblin, Hui and Lim arxiv 0907.3234)

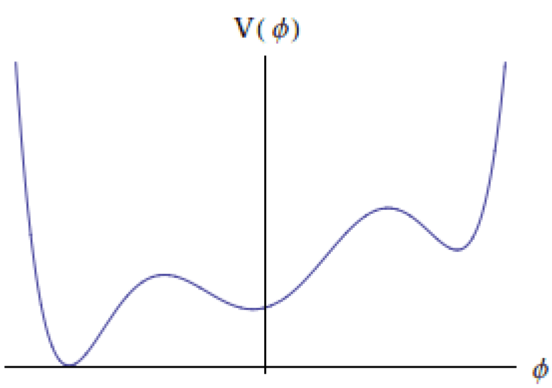

Figure: Scalar field potential with three vacuum states.

General relativistic collisions

In general relativity space is not flat but is curved by energy and momentum. For our bubble simulations this means that we have to evolve both the field and the curvature of space with time. Computationally, this is very tricky as Einstein's equations, which govern the curvature of space, are strongly non-linear. It was only about fifteen years ago that the first stable algorithm was proposed. If enough energy is concentrated in a small region of space, for example through an energetic collision, a black hole is formed. By making the scalar field bubble collisions general relativistic we expect to be able to investigate the details of this process. This work is ongoing.

Videos:

Video1.mpeg: Two colliding scalar field bubbles with the adaptive nature of the mesh clearly visible. The value of the scalar field is given by the colour. New (blue) bubble universes are created by the collisions. Collisions also take place at the upper and lower edge of the computational domain since we have used periodic boundary conditions.

Video2.mpeg: Two colliding scalar field bubbles. The value of the scalar field is given on the z-axis.