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50 years of high-performance computing for numerical simulation

Since its inception, the CEA/DAM has successfully utilized numerical simulation to perform scientific and technological studies leading to nuclear weapons design. Indeed, it has been essential for the preparation and then interpretation of the relatively few, costly, nuclear experiments performed.
Numerical simulation of nuclear weapons is a formidable challenge. Such a calculation must take account of complex systems which involve a very large number of rapidly changing, strongly interacting, physical phenomena. In particular, the interaction of matter that is in motion with radiation of different types needs to be described. The many relevant physical models lead to strongly non-linear mathematical equations for which numerical solution, using special approximation methods, has proved to be very costly.
Moreover, the systems simulated exhibit a wide range of geometric and physical parameters. The optimum choice of these parameters, which is the responsibility of the weapons designers, requires a very large number of numerical simulations to be performed, resulting in turn in an unusually large volume of data. The same is true for the step which validates these calculations by comparison with experiment.
This is why numerical simulation of nuclear weapons requires very large computational resources including use of the most powerful computers available at the time and devices for storage, archiving and examination of the data. These resources will be used by the numerical simulation software: the computer codes themselves as well as application software and interfaces for CAD, meshing, data management, visualisation, etc…
The exceptional character of the resources required is characteristic of the intensive computing, researched since the inception of the CEA/DAM.

With 50 years of history, a look back is essential on the extraordinary development of numerical simulation at the DAM. This development has resulted from progress in three areas: computers, physical models and mathematical methods, the codes and the software. Computing power has advanced from several thousand floating point operations per second (Kflop/s) to tens or hundreds of Teraflops (a thousand billion operations per second). Petaflops, another factor of 1000, are now within reach. Computer memory capacity, the capacity to store the results, has increased in comparable proportions. Sequential, then vector and now parallel programming models have also brought significant gains.

This progress in hardware has yield huge improvements in the associated physical models and data, as well as in the coupling between the physical models.
Simultaneously, great progress has been achieved in the mathematical and numerical methods used to solve the equations of the physical models. As an example these new methods are used for solving the equations of gas dynamics, diffusion, transport and associated coupling. Finally, scientific data processing methods and software engineering, together with the progress of computing languages, have led to great improvements in the development of codes and software. It has moved from the "skilled craftsman" scale to large-scale organised industrial projects, with development platforms that include all the aspects of the life cycle. It thus results in "computer systems" associated with the software applications (CAD, meshing, visualisation…) used in the "office" of the scientist-engineer. Hence we can speak of the "weapons simulator".

In the last 50 years, numerical simulation has progressed in all areas and formerly heroic computations have become common place. Today, the software codes of the CEA/DAM can guarantee the performance of nuclear weapons without nuclear testing.
Progress has occurred equally in equipment, technologies and methods. This would not have been possible without the teams of engineers and scientists who have pooled their skills and experience in the fields of physics, mathematics and computer science.