The Joe Monaghan Prize is awarded periodically to authors of a journal article which has made an outstanding advance on one or more of the SPHERIC Grand Challenges. For full details, please see the SPHERIC web page spheric-sph.org/joe-monaghan-prize. The prize is named in honour of the unique contributions made by Prof. Monaghan in the foundation of SPH, and in its continuous development since 1977, and was presented for the first time in 2015. Nominations were sought in 2017 for the second presentation of the prize. Articles published 2011-2015 addressing one or more of the SPHERIC Grand Challenges were eligible. This process resulted in a shortlist of the following 6 articles:


The award was decided by a vote of delegates at the 2018 Workshop. The Prize was presented by Prof. Monaghan to Salvatore Marrone, Matteo Antuono, Andrea Colagrossi, Giuseppina Colicchio, David Le Touzé, and Giorgio Graziani for their article on the delta-SPH model. Congratulations to all the authors on their major contribution to the development of SPH.
Since its foundation in 2005 in Paris, the SPHERIC organisation has flourished beyond our wildest expectations. Founded as a European special interest group of ERCOFTAC, SPHERIC now has over 75 institutions as members, the SPHERIC Workshops attract over 130 people from all over the world and we have successfully held our first Workshop outside of Europe in Beijing in 2017. With two workshops planned for 2020, in Harbin in China and New York in the US, the European part of the SPHERIC acronym no longer represents the truly international and diverse nature of our community and activities. It is unsurprising therefore that over the past few years, the SPHERIC Steering Committee has received numerous requests to change the meaning of the SPHERIC acronym. Being conscious of the internationally recognisable SPHERIC identity, the Steering Committee wished to retain the name SPHERIC. Even though the number of engineering applications of SPH is increasing all the time, with the origin of SPH in astrophysics research the SC wanted the meaning of our acronym to continue to communicate that research remains at the heart of SPHERIC’s activities. Hence, in November 2017 the Steering Committee voted to change the meaning of the acronym to the Smoothed Particle Hydrodynamics rEsearch and engineeRing International Community (SPHERIC). This change of acronym meaning was announced at the SPHERIC Galway workshop, June 2018.
The 13th SPHERIC International Workshop took place in National University of Ireland Galway from 26-28 June, 2018. 118 delegates gathered in the Alice Perry Engineering Building, named after the first woman in Europe to graduate with an engineering degree. Following tradition, the SPHERIC training day was held on the day before the workshop. Dr. Matteo Antuono of CNR-INSEAN opened the day with a lecture introducing SPH, ranging from the basic concepts to a deep analysis of the method. Dr. Salvatore Marrone, also of CNR-INSEAN, Italy, delivered a lecture on the recently developed delta-SPH method. Both lecturers have kindly shared video and downloadable slides on spheric2018.ie/training-day. In the afternoon, Drs. Ben Rogers (University of Manchester) Alex Crespo and José Dominguez (both of the University of Vigo) provided a hands-on training session with the DualSPHysics free open-source software.

In parallel, a team co-ordinated by Prof. Daniel Duque (Universidad Politécnica de Madrid) worked on the SPH Wikipedia page. The session resulted in a new structure for the page, which has been partly populated, but requires further work. Interested researchers are encouraged to contribute to the page at wikipedia.org/wiki/Smoothed-particle_hydrodynamics, and are welcome to contact Prof. Duque for guidance.

The Workshop itself included 58 research presentations, 3 keynote lectures and a discussion session. The opening keynote was given by Prof. David Le Touzé, presenting key lessons from his team’s progress at Ecole Centrale de Nantes on development and application of SPH for free-surface flows. Dr. Natasha Flyer of the US National Center for Atmospheric Research lectured on the Radial Basis Function Finite Difference method. Although this meshless approach was a new topic to the SPHERIC Workshop, there were clear parallels with recent progress on higher-order of accuracy in SPH. In the final keynote, Prof. Stefan Hickel (Technical University of Delft) spoke as chair of ERCOFTAC’s Scientific Programme Committee about the activities and organisation of ERCOFTAC. He also gave an overview of his work on Large Eddy Simulation.
58 papers were presented, including a number designated as industrial application topics in diverse fields. Most of these were organised into special sessions on Energy and Aerospace, Marine and Hydraulic, and Materials and Biotechnology. A panel on time-integration algorithms stimulated some lively discussion with strong views. Although we dedicate most of our discussion in SPH to the many aspects of the spatial discretisation, it’s clear that time-stepping is by no means a closed topic.

The Libersky Prize for the best student paper was presented to Thomas Fonty of EDF R&D and Saint-Venant Hydraulics Laboratory for the paper “An upwind scheme for conservative, realizable two-phase mixture SPH model with high density ratios,” co-authored by Agnès Leroy, Antoine Joly, Damien Violeau, and Martin Ferrand.

On Wednesday evening, the delegates travelled up the River Corrib by boat for the banquet at Glenlo Abbey, featuring the presentation of the second Joe Monaghan Prize. After the close of the workshop, some delegates took the opportunity for a tour of some city restaurants, kayaking on Galway Bay, or a visit to Birr Castle.

The Workshop was generously supported by Science Foundation Ireland, ERCOFTAC, Fáilte Ireland / Meet in Ireland, and NUI Galway. More pictures can be viewed at spheric2018.ie/gallery.
An upwind scheme for conservative, realizable two-phase mixture SPH model with high density ratios

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Multi-fluid flows with high density ratio and complex strong dynamics are pivotal for many engineering applications. SPH is well-suited for such cases. However, using a particle discretisation of less than the size of an air bubble or water drop prevents the modeling of scale domains. The prohibitive cost of local instantaneous formulation drove the development of multi-phase averaged models. The interface between phases is no longer explicitly tracked and phases are followed through a volume fraction representation. Mixture models are of particular interest: the flow is seen as a single-fluid with one continuity and one momentum equation that rule the evolution of mixture quantities, complemented by a mass conservation equation of one phase. Additional terms linked to the relative velocity between phases, closed by a case-dependent expression, appear. Instead of having different sets of SPH particles for each phase, each individual particle carries the different phases with their respective volume fractions \( \alpha \) and \( \beta \) using a unique mixture velocity field as shown in Figure 1. Such models have already been tested in SPH: in the astrophysical framework, gas/dust mixtures were studied in [7]; in the graphics community, Ren et al. [8] captured multiphase phenomena but without quantitative validation; Cueille [2], followed by Grenier [4], detailed a mixture model including diffusion of phases between particles.

In this work, we detail the physical and SPH numerical formulations chosen for a new two-phase mixture model. In view of high density ratio flows, a volume formulation of phase fractions and mixture velocities is chosen. A relative velocity term \( \mathbf{v} \) accounts for the motion of the light phase w.r.t. the heavy phase. In addition to the averaged mixture continuity and momentum equations, as described in [6], an equation on \( \alpha \) is introduced under the assumption of constant phase densities \( \rho^\alpha \) and \( \rho^\beta \):

\[
\frac{\partial \alpha}{\partial t} + \mathbf{j} \cdot \nabla \alpha = -\mathbf{v} \cdot (\alpha \beta \mathbf{v}^r)
\]

The usual SPH discretisation of this equation leads to non-conservative and non-realizable resolution. Through a finite-volume-like approach and guided by the principles of conservativity, realizability (positive phase volumes), degeneration towards single phase model and symmetry w.r.t. phases, we derived the following \( \alpha \) phase volume equation:

\[
\frac{dV^\alpha_a}{dt} = \alpha_a \frac{dV_a}{dt} - 2 \frac{V_a}{\gamma_a} \sum_b V_b \left( \alpha_a \beta_b (\mathbf{v}^r_{ab} \cdot \mathbf{v}_{wb})^+ \right) + \alpha_b \beta_a (\mathbf{v}^r_{ab} \cdot \mathbf{v}_{wb})^-
\]

where the “plus” and “minus” signs stand for the positive and negative parts, respectively. Following [3] the mixture volume derivative in the right hand side is integrated exactly temporally to avoid error accumulation. Volume diffusion is introduced to prevent checkerboard effects. An adapted state equation is used within the Weakly Compressible SPH framework. Semi-analytical SPH wall boundary conditions of [3] are used.

Figure 1 - Control volume (green area) in two-phase flow and the corresponding velocity fields

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Figure 2 - Separation of an oil-water dispersion: evolution of the upper and lower interface positions. Comparison of experimental and numerical results reported in [1]
This approach was successfully applied to the separation of phases in a settling tank with low to high density ratios. A good agreement is obtained with numerical and experimental results for the separation of an oil-water dispersion (Figure 2). The final interface position at 30% of the height agrees with the initial volume fraction of oil. An analytical solution on a two-phase mixture plane Poiseuille flow is used to check the accuracy of the model. A longitudinal force generates a flow in a periodic channel bounded by walls. Starting from a homogeneous mixture at rest, an analytical solution is derived at steady state. Starting with a uniform volume fraction, one gets at steady state the volume fraction profile displayed in the Figure 3 that agrees well with the analytical solution.

Finally, a Rayleigh-Taylor instability test case is performed to compare with multi-fluid SPH and shows an overall good agreement with other numerical results (Figure 4).

Figure 3 - Two-phase mixture Poiseuille flow: volume fraction profile at steady state

Figure 4 - Rayleigh-Taylor instability case: comparison between Level-Set (red line) and SPH (blue line) results of Grenier et al. (2009) and the present SPH model (black line) for the same resolution.

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The development of a numerical wave basin has been long-sought-after for use as an engineering tool to design structures and vessels deployed in aggressive offshore environments. Several codes exist which attempt to reproduce the non-linear effects of steep waves interacting with fixed or dynamically responding bodies. However, those of a mesh-based approach suffer from mass dissipation at the free-surface, and to avoid expensive remeshing procedures, an ALE-type formulation is commonly used. Even then, flows of a fragmented nature such as breaking-waves, cannot be dealt with effectively. Chow et al. (2018) recently presented a validated GPU-based ISPH model implemented in the highly optimised DualSPHysics code, allowing for the computation of such flows with the millions of particles required for engineering applications in reasonable time. The advantage here over well-established GPU implemented weakly-compressible SPH models are the highly accurate noise-free pressure fields produced. This work presents the extension, and first application, of ISPH on the GPU in DualSPHysics (Incompressible-DualSPHysics) to breaking-wave-structure interaction.

For wave propagation and impact, the numerical methodology of Chow et al. (2018) requires extensions: extra Laplacian terms to implement the Schweiger operator, applying a kernel-weighted normal in particle shifting, a variable timestep size, excluding boundary particles above the free surface, and using a radial particle configuration to model a cylinder. The wave generation model demonstrates an order of 1.78 for $L_2$ error norm convergence rate of the peak free-surface elevation at a focal point, compared to linear theory, for a low amplitude focused wave group. The improved 3-D Incompressible-DualSPHysics model is tested by comparison to the experiments of Zang et al. (2010), who recorded the forcing on a vertical cylinder due to focused wave groups of non-breaking and breaking nature, and the 2-D ISPH results of Lind et al. (2016), which utilised a Froude-Krylov approximation for prediction of the 3-D cylinder loads. Figure 1 shows the free-surface particles of an ISPH-GPU simulation snapshot showing a breaking wave impacting on a vertical cylinder. The simulation uses 5 million fluid particles and computes 20 seconds of physical time in 15 hours.

Additionally, the work presents unique post-processing analysis of the fluid-structure interaction enabled by the new model. The differences in free-surface behaviour between non-breaking (NBW) and breaking (BW) waves are explored for the first time by showing that for comparable wave heights, although the global cylinder loads are similar, local peak pressure forces due to a BW are significantly higher. Such free-surface effects are shown in Figure 2 with the instantaneous non-zero non-dimensionalised local pressures around the cylinder (rolled out in 2D) relative to the hydrostatic pressure of the mean still water level for a NBW and BW case.
General relativistic Smoothed Particle Hydrodynamics

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In regions of strong field gravity, such as close to a black hole, the motion of matter can be significantly different than in Newtonian gravity. For example, Einstein’s theory of general relativity predicts the precession of elliptic orbits that would otherwise close in Newton’s theory. One must therefore take care to account for such effects when performing numerical simulations of astrophysical phenomena in the vicinity of black holes.

In this work, we have developed a method for smoothed particle hydrodynamics (SPH) in general relativity, based on an entropy-conservative form of the general relativistic hydrodynamic equations for a perfect fluid. We aim to replace previous SPH simulations where general relativity is given only an approximate treatment [1,2].

We benchmark our scheme in 1D and 3D against a range of simple tests. In particular we simulate mildly and ultra-relativistic shock tubes, and reproduce exactly the (epicyclic and vertical-oscillation) frequencies associated with nearly circular orbits around both rotating and non-rotating black holes [3].

Figure 1 shows our results of an ultra-relativistic shock tube. According to [4] this problem ‘is still a challenge for state-of-the-art codes today’, since it produces a very narrow shell of material with velocity 98.6% the speed of light. By evolving an entropy variable instead of the thermal energy, we are able to simulate ultra-relativistic shocks with no smoothing of the initial conditions, and without the code failing due to negative pressures.

Importantly, we also split the viscous and thermal conduction components of the shock dissipation terms. This allows us to accurately treat contact discontinuities [5] unlike in previous works [6,7]. The shock dissipation terms are also formulated such that the contribution to the total entropy of the system is positive definite.

Furthermore, we have designed a modified Leapfrog time integration scheme that is efficient for relativistic SPH and conserves angular momentum for relativistic orbital dynamics.

An immediate application for general relativistic SPH is the tidal disruption of stars from close encounters with supermassive black holes. Figure 2 shows the preliminary results for a simulation of a star being shredded by a supermassive black hole, using general relativistic SPH.

On 10-11th April, the University of Manchester hosted 25 people for a 2-day continual professional development (CPD) course for engineers from industry and researchers on the simulation technique smoothed particle hydrodynamics (SPH). Delegates came from Australia, Saudi Arabia and all across Europe. The course covered fundamentals of the method including a hands-on practical session with the open-source code DualSPHysics. Lead by Dr Ben Rogers, Dr Steven Lind and Prof. Peter Stansby, the course also had talks from international keynote speakers Dr Ricardo Canelas (University of Lisbon), Dr José Dominguez (Universidade de Vigo) and Dr Renato Vacondio (University of Parma) on the state-of-the-art SPH for fluids, structures, hardware acceleration and future directions. On the following day, 12th April, the University of Manchester hosted the 2nd SPH Special Interest Group (SIG) Meeting as part of the UK Fluids Network of academic and industrial researchers. This event was research focused with experts from around the UK showcasing their use of SPH in diverse applications, including sampling and computer graphics, plant root tissue modelling, and laser welding, amongst several others. The day provided a clear reminder of the versatility and promise of SPH for solving new and varied problems. And of course, no visit of SPH researchers to Manchester would be complete without a quick look at the Osborne Reynolds Experiment (see picture below). A full list of speakers with abstracts is available on the UK Fluids Network SPH SIG website: https://fluids.ac.uk/sig/SPH

SPH SIG members in front of the original Reynolds Experiment, University of Manchester, 12th April 2018
The first-ever SPH Wikipedia edit-a-thon was held the day before the 13th SPHeric workshop, on 25 June 2018 in Galway, Ireland. An edit-a-thon (a portmanteau of “edit” and “marathon”) is “an organized event where editors of online communities such as Wikipedia ... edit and improve a specific topic or type of content, typically including basic editing training for new editors.” [1]

Recent studies [2] show a growing influence of wikipedia in scientific research. It therefore makes sense to take advantage of scientific conferences in order to advance relevant wikipedia articles. The session begun with a brief introduction to wikipedia editing, focusing on topics most important for the SPH community:
- Basic formatting, sectioning, and linking
- Mathematics (fortunately, this is mostly LaTeX)
- Citations and references

The slides used may be found in [3]. In most circumstances, editing is surprisingly easy, specially for scientist that have to deal on a daily basis with LaTeX, bibliography management, etc. New contributors may test these features in their own wikipedia user space (see mine as an example [4]). The target was then to provide a framework for the “perfect” SPH article, by focusing on sections. The session ended with a writing effort: whereas some of the available content could be recycled, most of the new content must be written from scratch. Many sections were provided with content that day. Nevertheless, and despite the impression that may be given by the sectioning structure in the picture, the article is far from completion. We would therefore like to invite all SPH researchers to improve the article, providing relevant information at the sections which need more help. Additional expansion and polishing of existing material is of course appreciated.

Programming on the GPU with CUDA:
a course for researchers and students

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The first application of Graphics Processing Units to SPH dates back to Harada et al, 2007. Since then, popular SPH solvers, such as DualSPHysics and GPUSPH, have been using CUDA extensions and libraries to perform simulations on single- and multi-GPU systems (Crespo et al, 2011; Hérault et al, 2010). The knowledge on scientific programming on GPUs with CUDA is relevant for SPH scholars who are interested in developing new features or just reviewing existing implementations.

General-purpose GPUs have grown from devices for video rendering to processing units carrying out double-precision arithmetic. A single GPU device can contain upwards of thousands of number-crunching processors that provide supercomputer-like speed-ups at affordable costs. CUDA (Compute Unified Device Architecture) is a software development tool kit for programming on the graphics cards produced by the mainstream manufacturer NVIDIA. CUDA provides language extensions for C, C++, FORTRAN, and Python as well as knowledge-specific libraries; these enable working with a single source code that instructs CPU and GPU alike. CUDA codes also keep pace with the rapid development of the underlying technology.

Implementing efficient parallelism with GPUs, however, requires the understanding of promises and constraints from three knowledge areas. Firstly, the architecture and compute capabilities of the hardware. Secondly, the special programming syntax for instructing a GPU-equipped computer. Thirdly, tailored algorithms for executing algebraic operations in parallel. With these challenges in mind, the Delft Institute for Computer Science and Engineering (DCSE) holds a 2-day course on scientific programming on GPUs with CUDA roughly every quarter.

DCSE is a cross-faculty organization of Delft University of Technology. The course is offered by the staff of the Institute of Applied Mathematics. It covers introductory matters on day 1 and advanced topics on day 2, both with hands-on sessions. Participants (up to 20) can attend one (€200) or both days (€350). The fee includes registration, lunch, refreshments, and the course materials. Also, SPHERIC members receive a 20% discount. The next session is planned for 26-27 September 2018. For more information and registration see https://www.tudelft.nl/en/tu-delft-institute-for-computational-science-and-engineering/education/courses/cuda-course/
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