The Level Set Interface-Tracking Model Coupled to SPH Method

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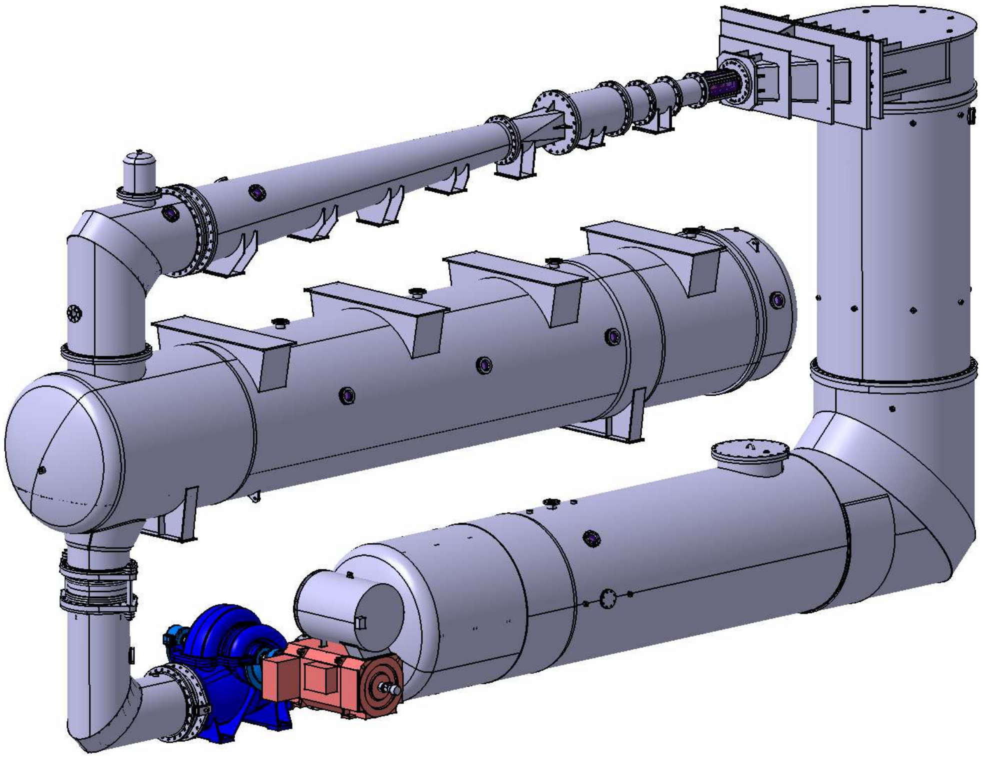
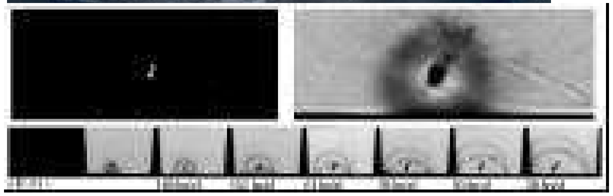
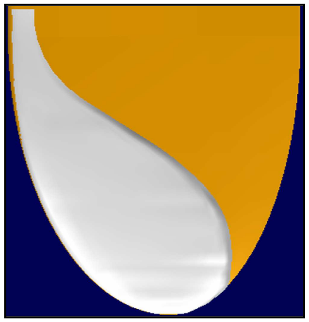
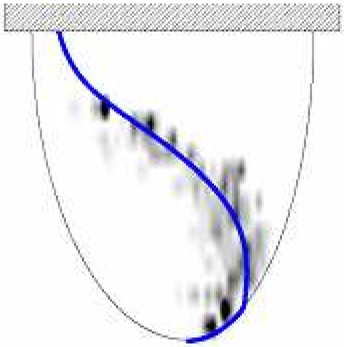
Cavitation Physics

- **Onset, Development & Collapse**
- **Modeling & Control**
- **Materials Erosion, Bio Effects**









Max Flow Velocity : 50 m/s
Max Pressure : 20 bar
Optical Instrumentation
p-transducers

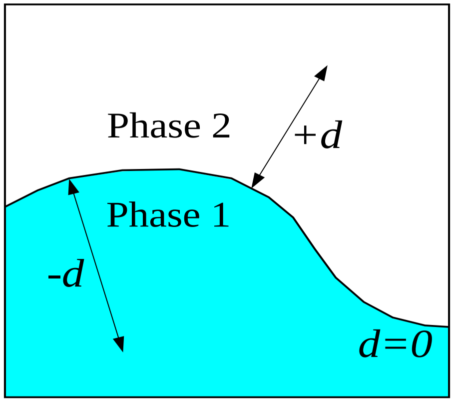
Unique Research Facility: **High Speed Cavitation Tunnel**

Cavitation Modeling by SPH

- Methodology:
  - ✓ Rayleigh-Plesset equation
  - ✓ Level Set equations for multiphase flows
    - Collaboration with Prof. Koumoutsakos, ETH Zürich
  - ✓ Adaptation of sph2000
    - Collaboration with University of Tübingen, Germany
- Test cases using High Performance Computing:
  - ✓ Bubble implosion
  - ✓ Oscillating drop
  - ✓ Bubble collapse
  - ✓ Instability of a liquid jet
- Post-processing: thanks to Paraview

The Level Set Method

- The two-phase mixture is as a single fluid
- Density, viscosity are smoothed across the interface
- The LS marker function is continuous and it is set to the signed minimum distance to the interface



- Reasons for using the LS function:
  - ✓ Minimal numerical diffusion since the function is continuous across the interface, with $|\nabla \phi| = 1$
  - ✓ Easy to interpolate phase properties across the interface in the two-fluids formulation

The Level Set Method

Non-conservative form of Level Set equations:

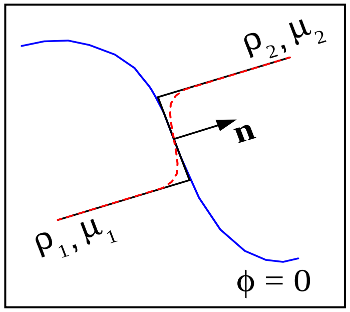
$$\frac{\partial \phi}{\partial t} + \mathbf{u} \cdot \nabla \phi = 0,$$

$$\frac{\partial \phi}{\partial \tau} + \mathrm{sign}(\phi_0)\left(\left|\nabla \phi\right| - 1\right) = \lambda \left|\nabla \phi\right| \delta_\varepsilon(\phi)$$

Interpolation of phase properties across the numerical interface:

$$\rho(\mathbf{x},t) = \rho_1 + (\rho_1 - \rho_2) H_\varepsilon\left(\phi(\mathbf{x},t)\right)$$

$$\mu(\mathbf{x},t) = \mu_1 + (\mu_1 - \mu_2) H_\varepsilon\left(\phi(\mathbf{x},t)\right)$$



- Straightforward to couple Level Set and SPH
- LLSM = best mass conservation of the existing LS

SPH2000

- A parallel object-oriented SPH-framework
- Dr. Roland Speith’s PhD. Work, University of Tübingen, 1998
- C++ code by Sven Ganzenmüller, University of Tübingen, 2000-2006,..

Classic SPH modeling method

- Summation density or continuity equation
- Artificial viscosity ($\alpha=1$, $\beta=2$, $\varepsilon=0.01$)
- Viscous stress tensor (Flebbe et al, 1994)
- Total Energy balance
- Surface tension (end of 2006)

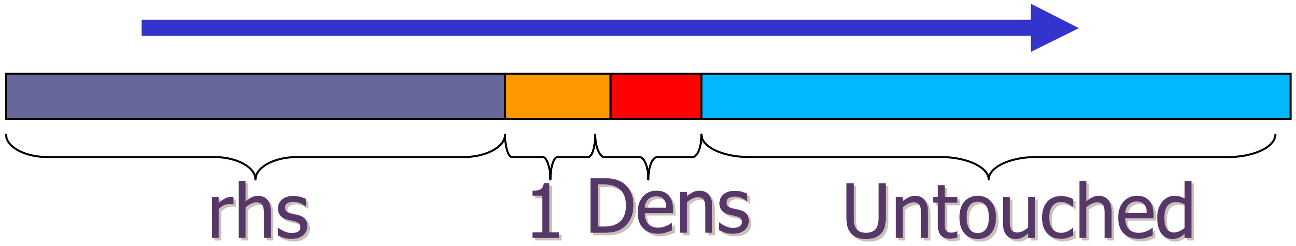
- Kernel functions: a cubic spline (Monaghan, 1992)

- Boundary: Reflecting
- Ghost particles

- Integrator: RK1 (Euler) to RK5CashKarp (RK5 + error detection + step adjustment)

Finding interactions

- Uniform spatial grid with a cell size = *h* cst
- To calculate rhs of SPH equations = 3 sums (one for the density, 2 for first and second order derivatives) → Interaction list



- This algorithm reduces the total memory requirement to about one tenth without increasing the overall computing time

SPH2000: Parallelization

- A cuboids region of the simulation domain to every processor
- Cuboids with different sizes which vary in time

- The interface to the other regions = real, physical boundary (like periodic boundary with communication to neighbour processors)

- The size of interaction list = a tuning parameter for a size versus speed tradeoff

- Communication between processors thanks to the Tübingen Parallel Objects (TPO++), an object-oriented message passing library for C++ with a load balancing function

IBM Blue Gene/L

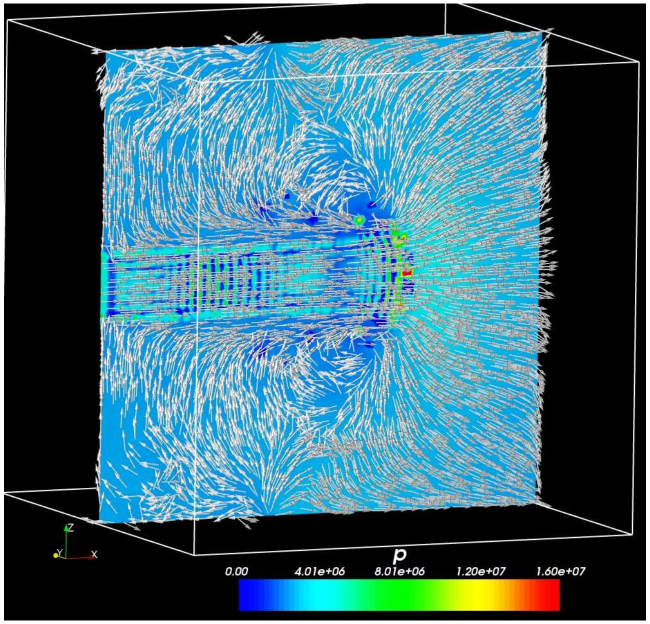
- Processors: 8192 IBM 440, 700 MHz, 512 MB
- Memory: 2 TB
- LINUX (Suse Linux Enterprise Server 9)
  - ✓ frontend nodes for compilation job submission and debugging
- Space sharing:
  - ✓ one parallel job per partition
  - ✓ one process per processor
- SPMD model
- XL Fortran90, XL C/C++
- IBM MPI library

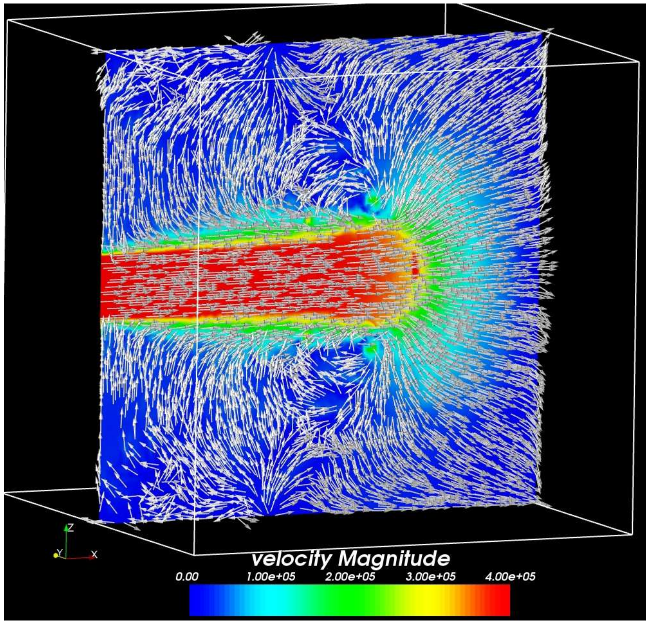
Our experiences with sph2000

- Successful compilation:
  - ✓ release 5
    - on bipro dual core PC under Linux Suse10
    - On High Performance Machine : IBM Blue Gene/L under Linux Suse Pro

- Benchmark case on BG/L: 3D-simulation, 2 fluids:
  - ✓ 1 million air particles,
  - ✓ 18,876 diesel particles on BG/L
  - ✓ Smoothing length: 1.2 E-5 m
  - ✓ Neighbor / particle: 30
  - ✓ 774 time steps, V_{diesel}=20 m/s
  - ✓ Iteration/sec/processor: 0.6 s

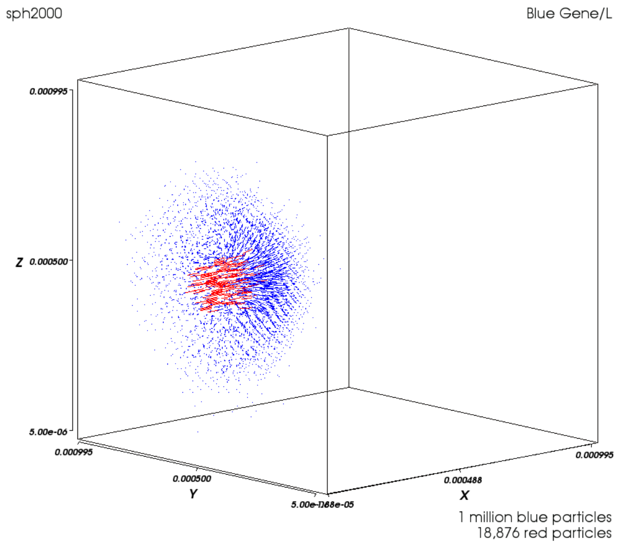
3D simulations on Blue Gene/L





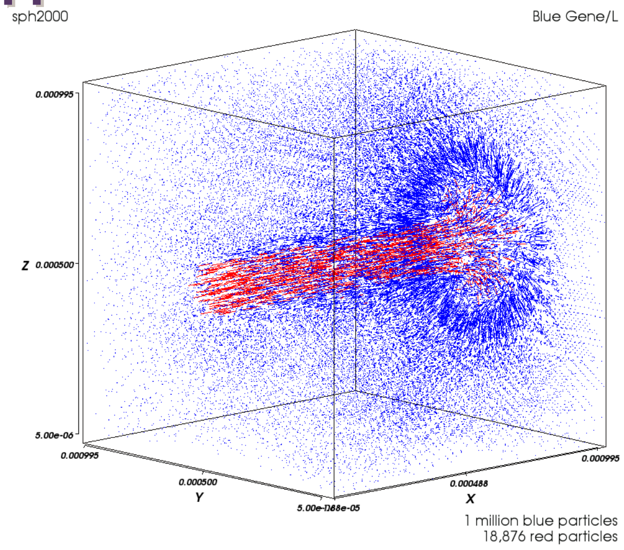
- Post-processing with PARAVIEW
- P and V frames thanks to a Delaunay triangulation realized by Dr. Jean Favre from CSCS (Manno, Switzerland)

A glyph animation



🟥 Diesel particles

🟦 Air particles



Speed-up:
1 million particles, 10 time steps