New variable resolution in DualSPHysics

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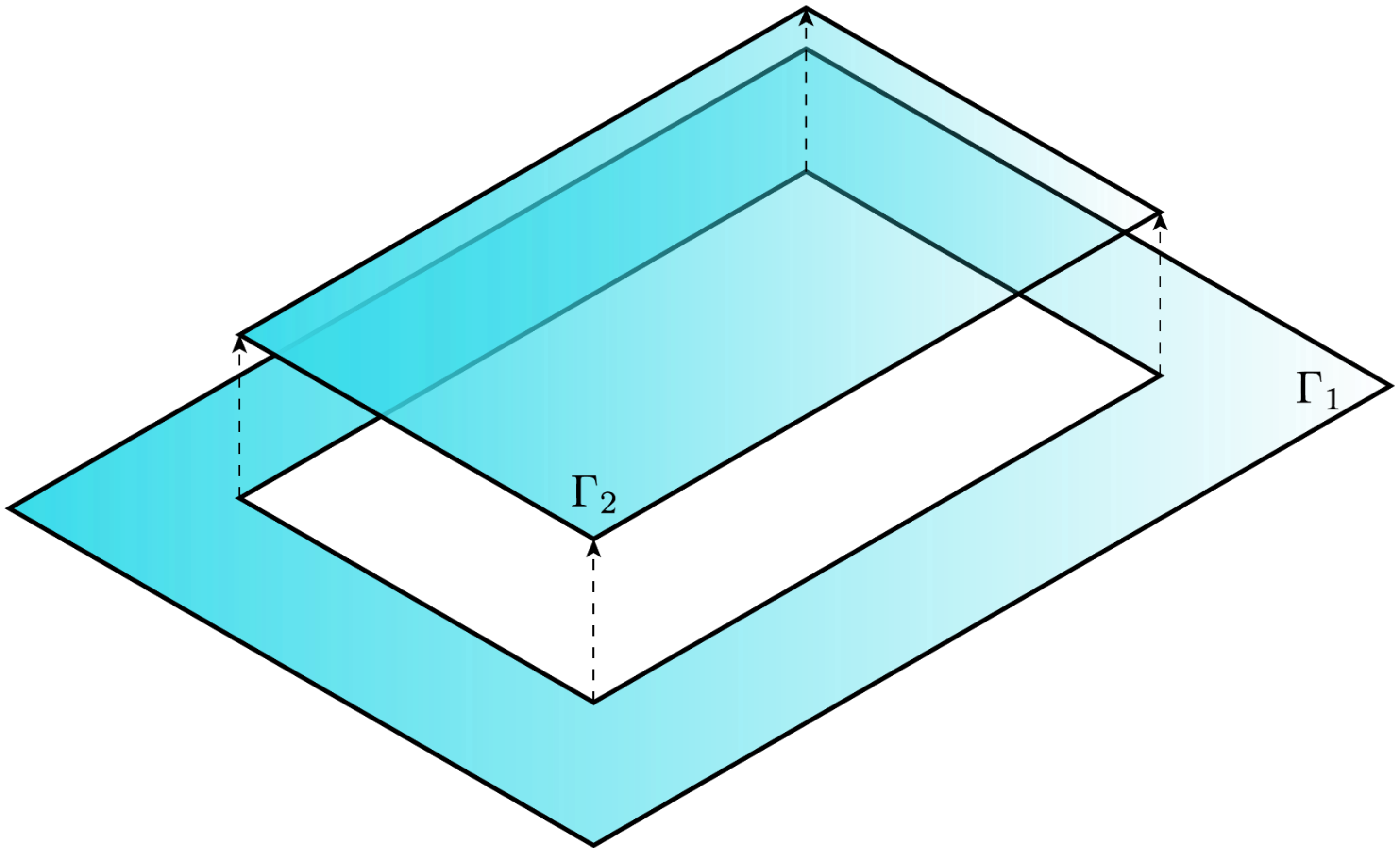
Outline

- Variable-Resolution formulation
- What it’s available in the beta and limitations
- Test Case examples
- Future Outlook

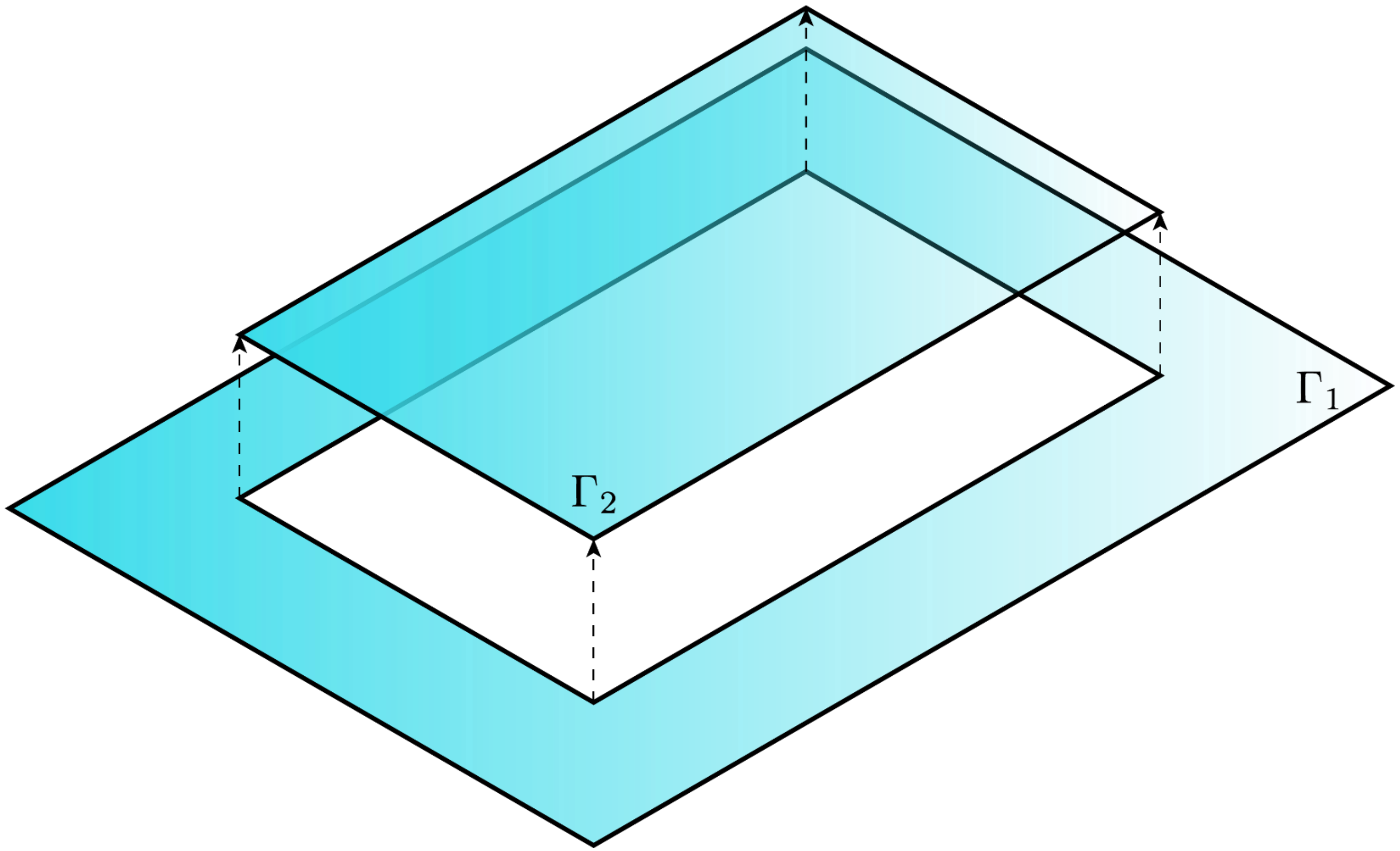
Numerical formulation

Domain coupling



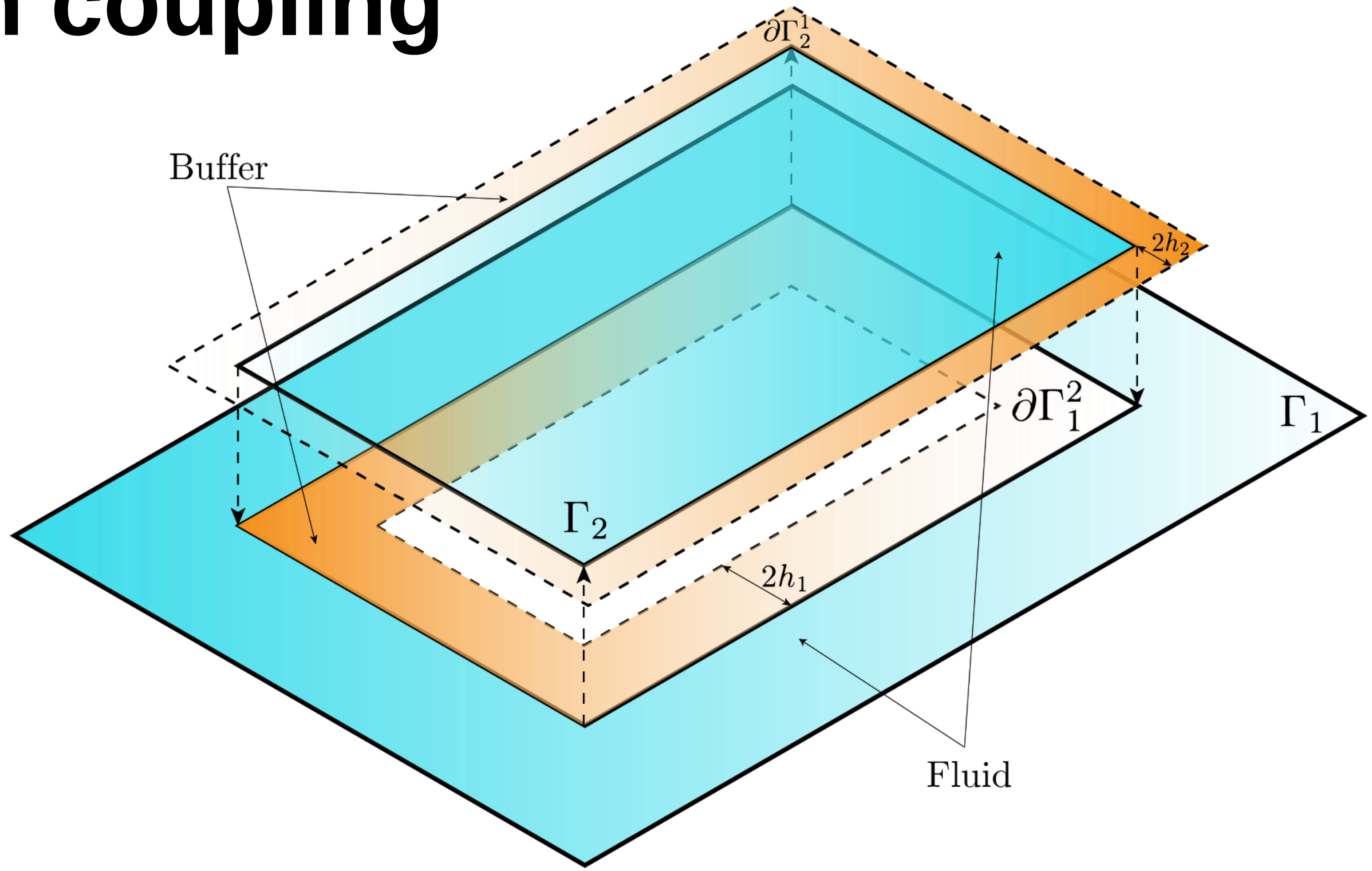
Computational domain is divided in sub-domains

Domain coupling



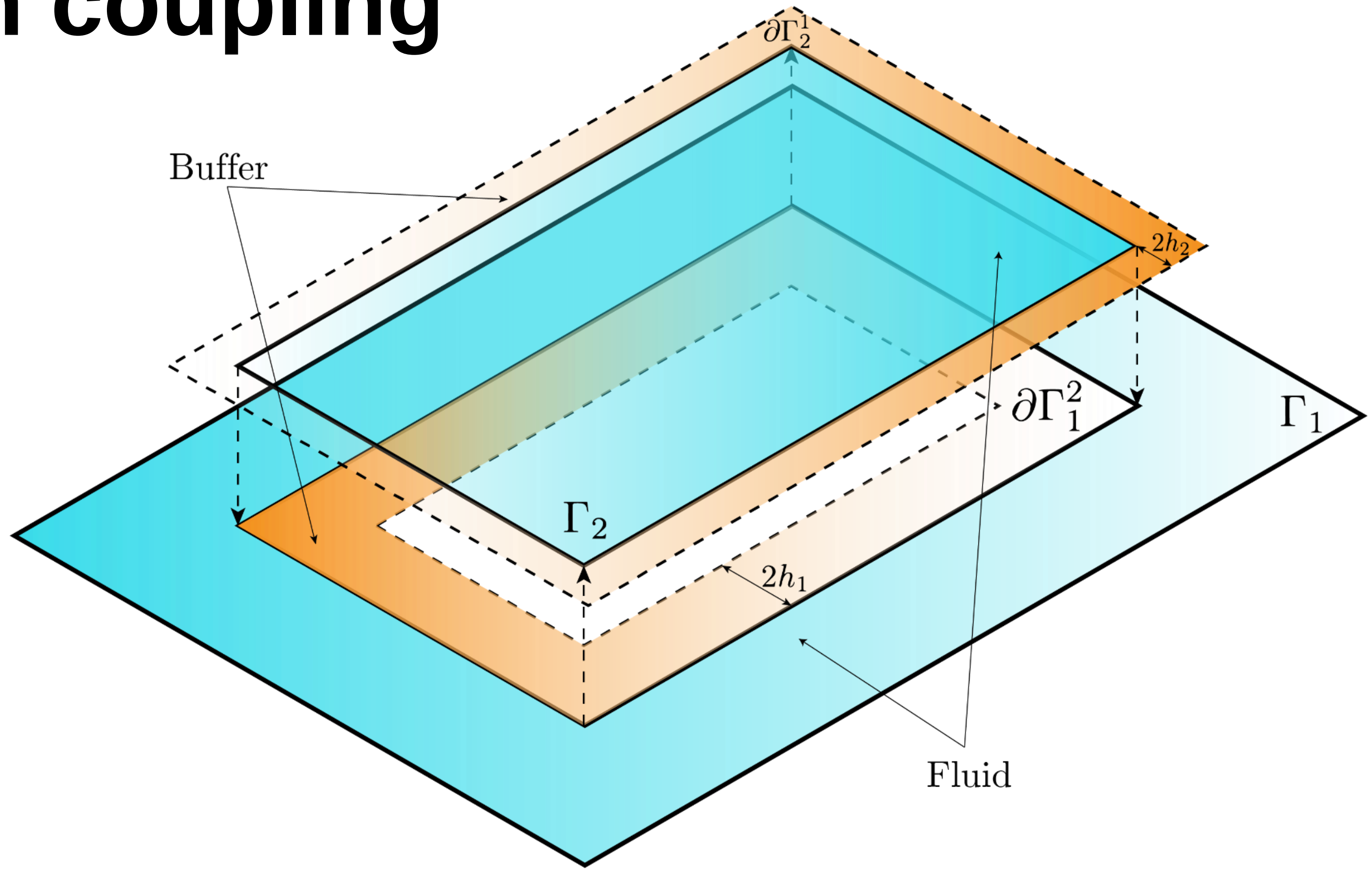
Each sub-domain has is own smoothing length hi and initial particle distance dpi

Domain coupling



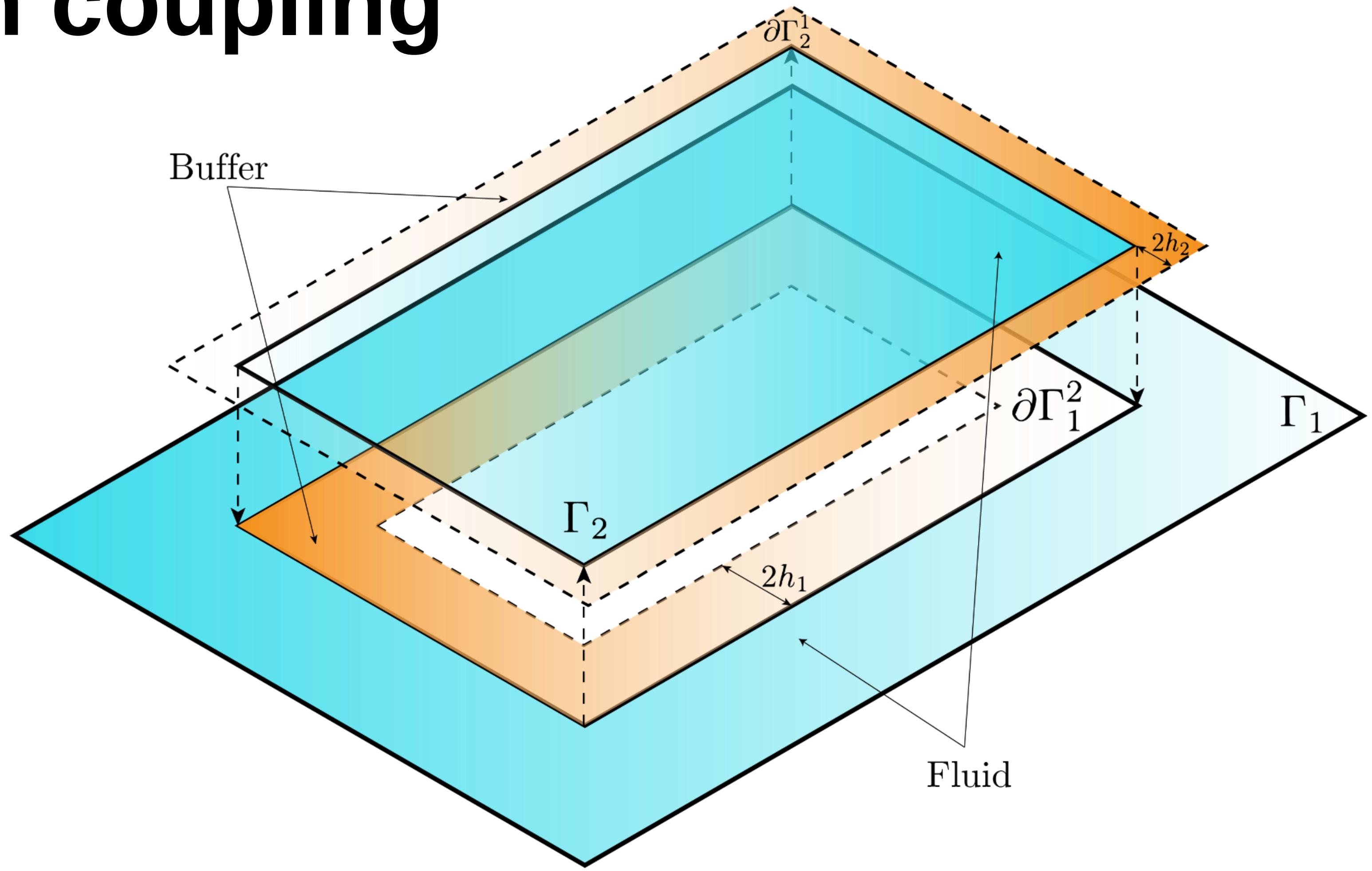
Each sub-domain is extended by a buffer region

Domain coupling



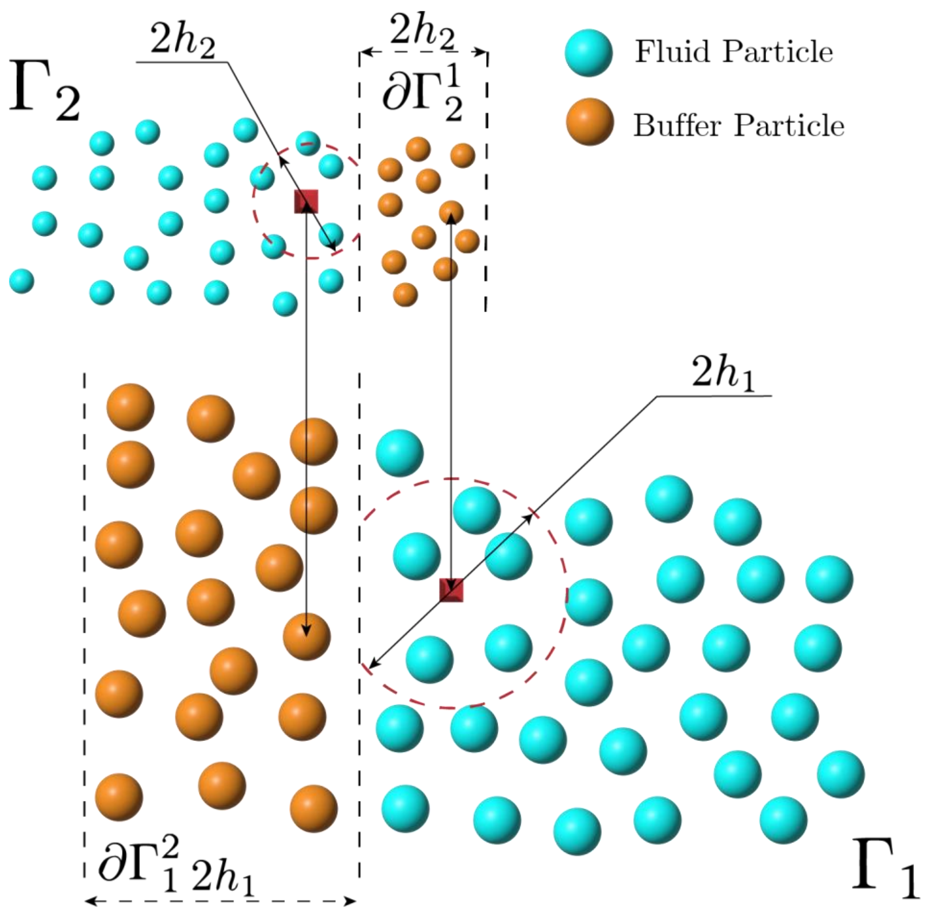
The buffer region act as Dirichlet boundary condition

Domain coupling



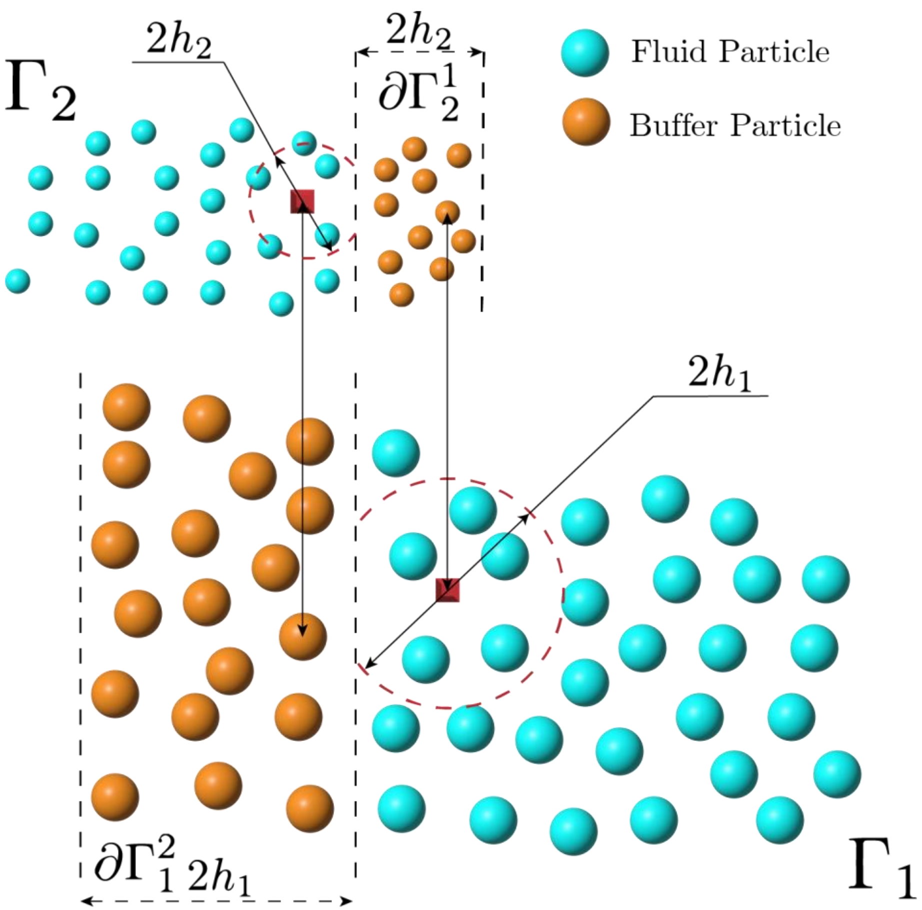
The buffer region is populated by buffer particles

Buffer interpolation



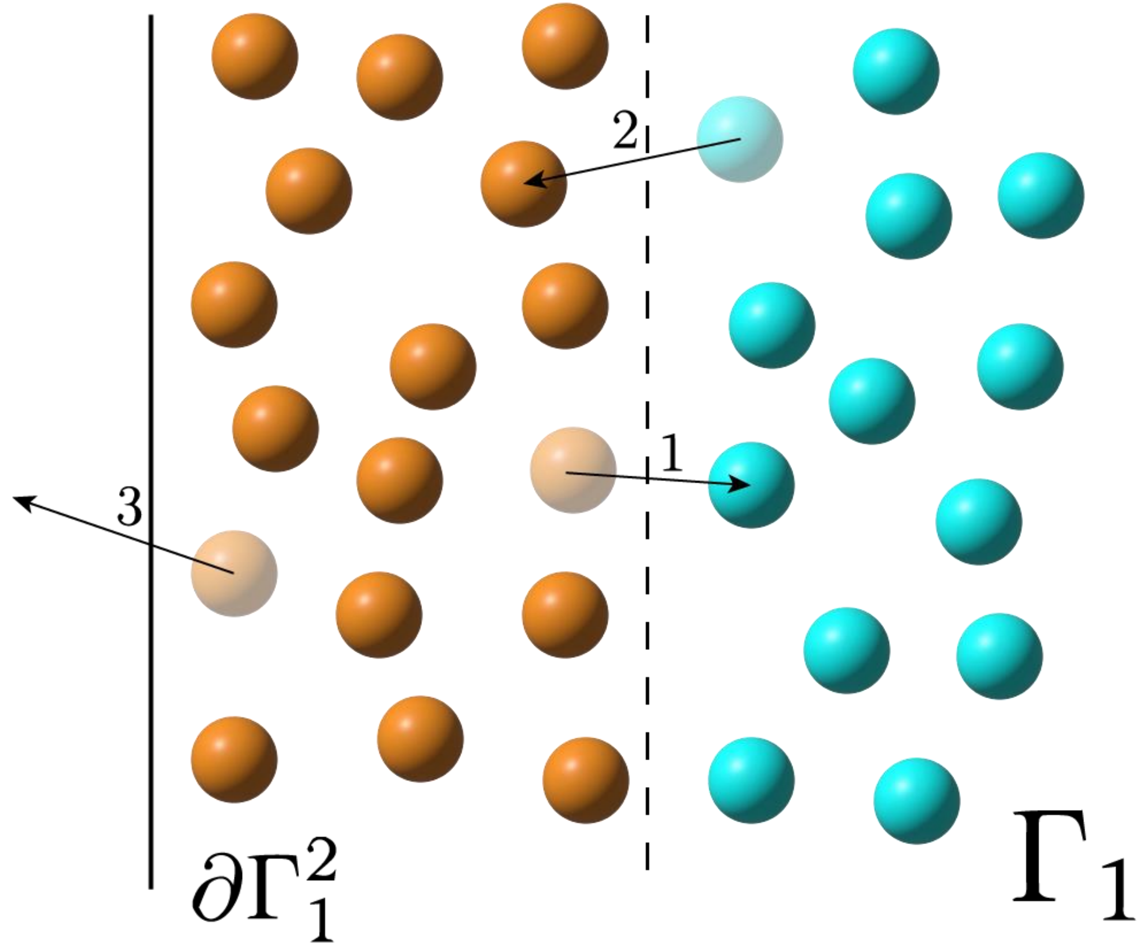
The buffer particles obtain their physical properties interpolating over the coupled sub-domain

Buffer interpolation

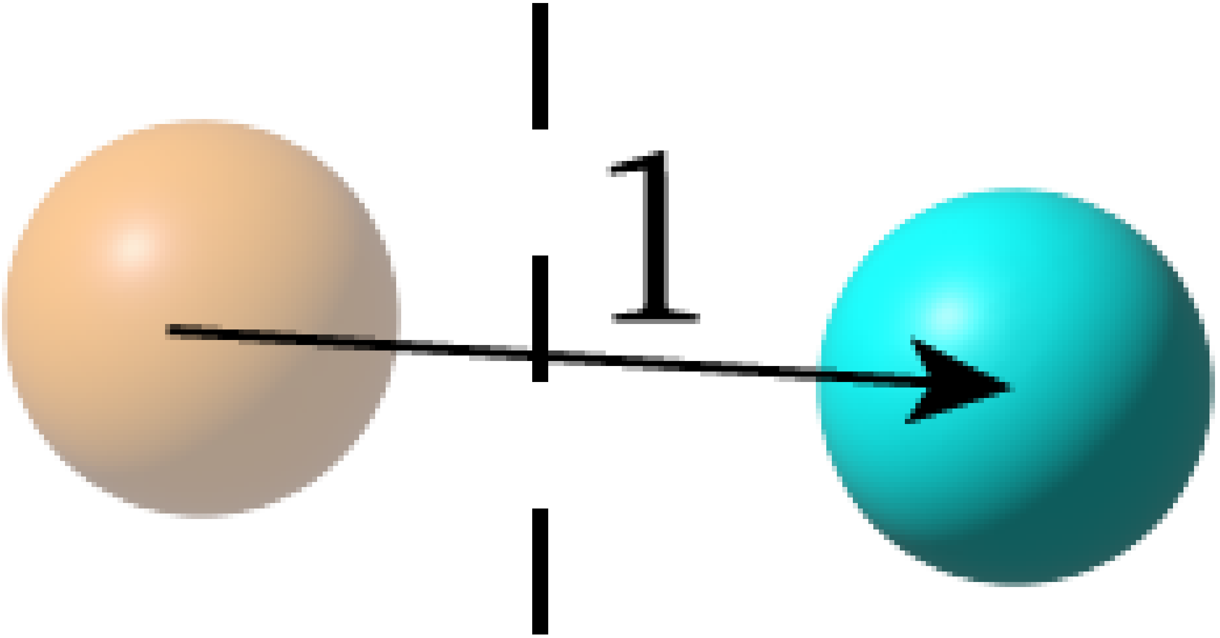


The buffer particles obtain their physical properties interpolating over the coupled sub-domain

Mass exchange

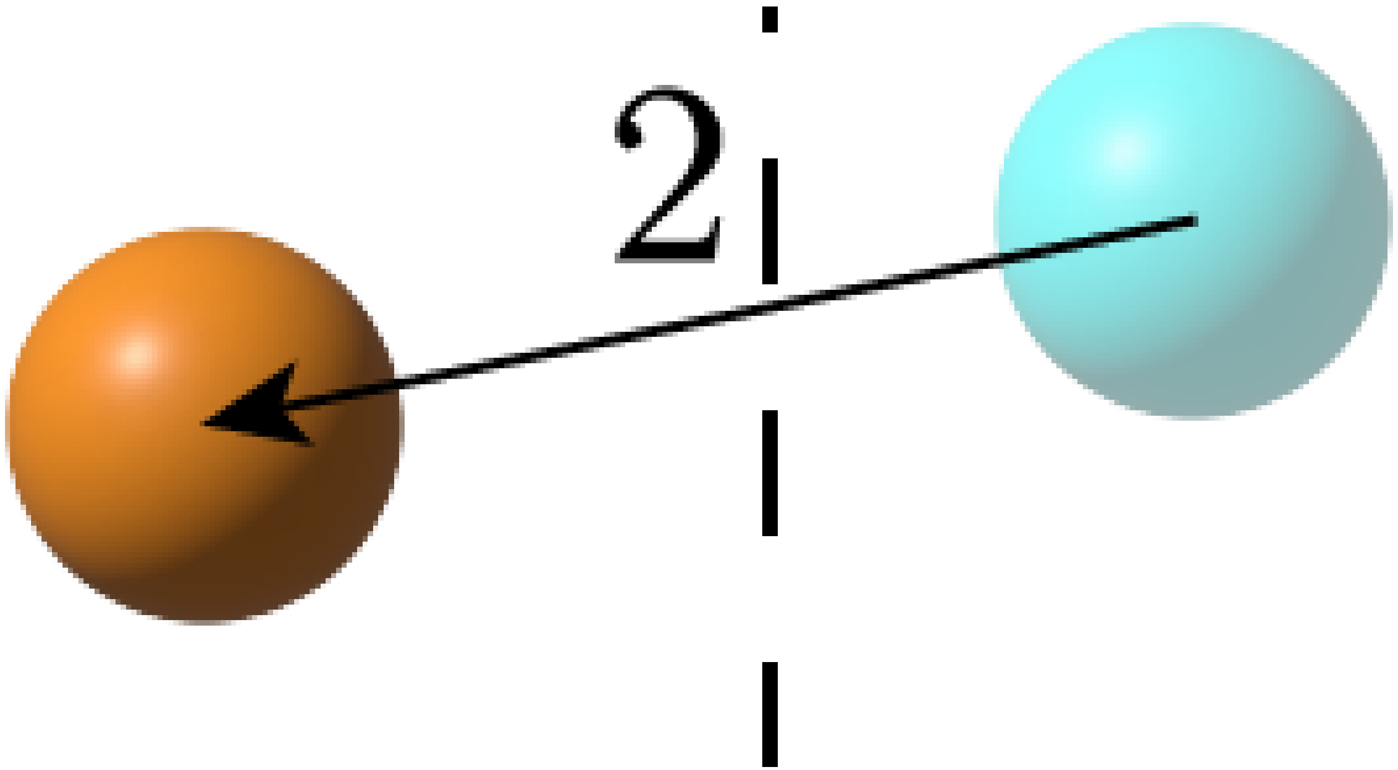


Mass exchange



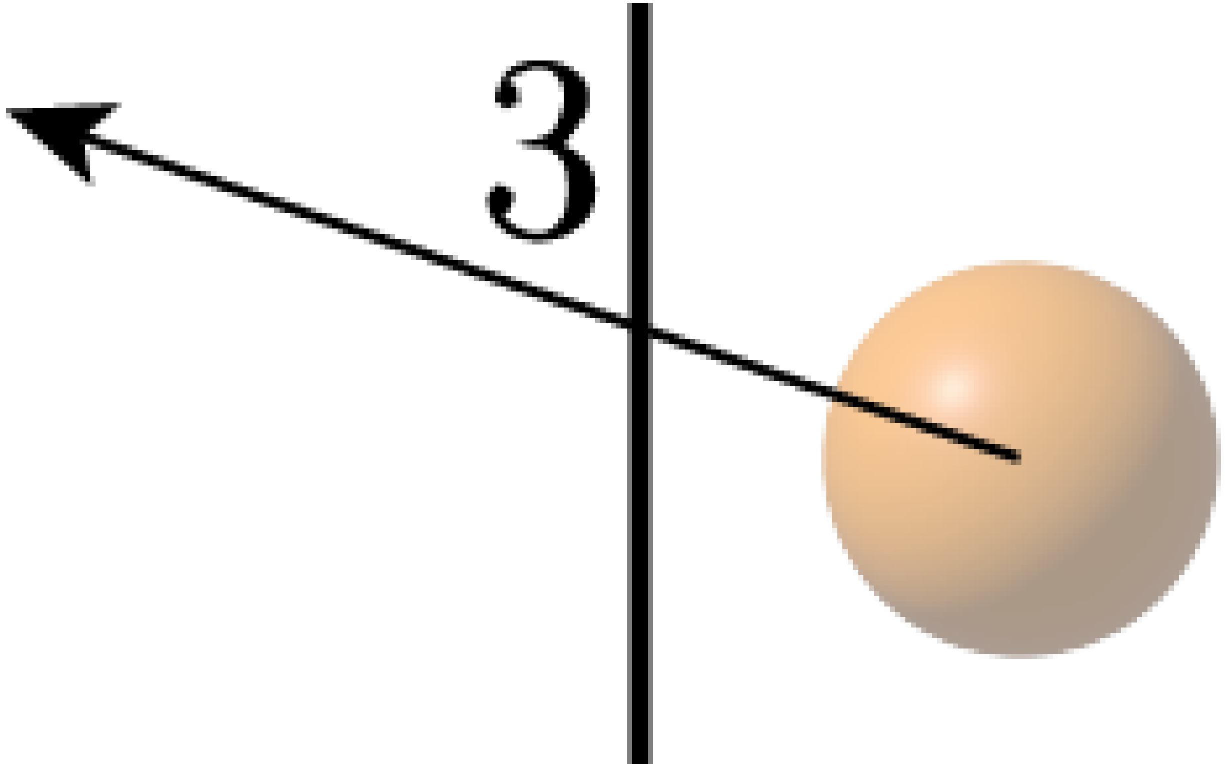
1. Buffer particle to fluid region become fluid particle

Mass exchange



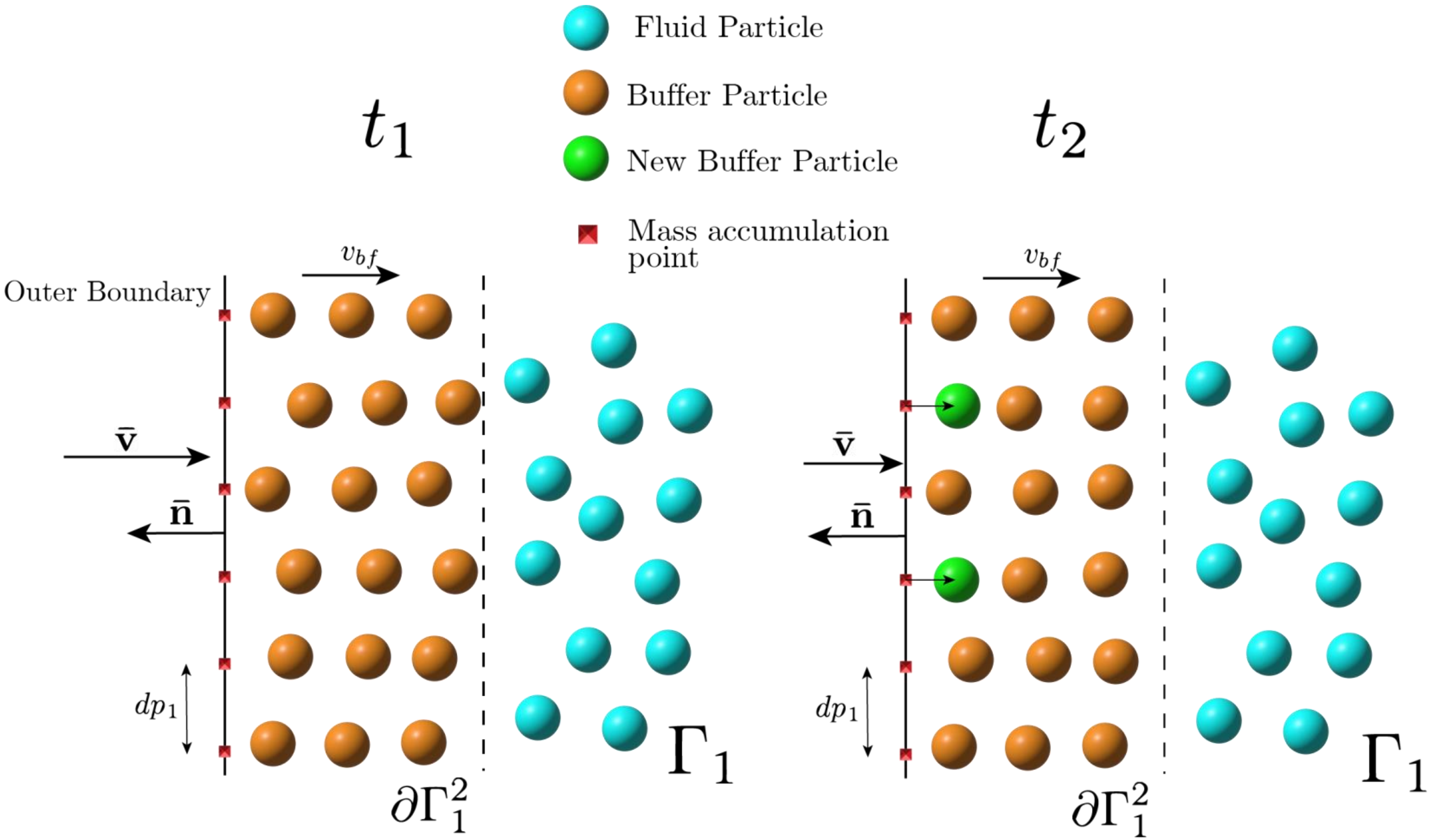
2. Fluid particle to buffer become fluid particle

Mass exchange



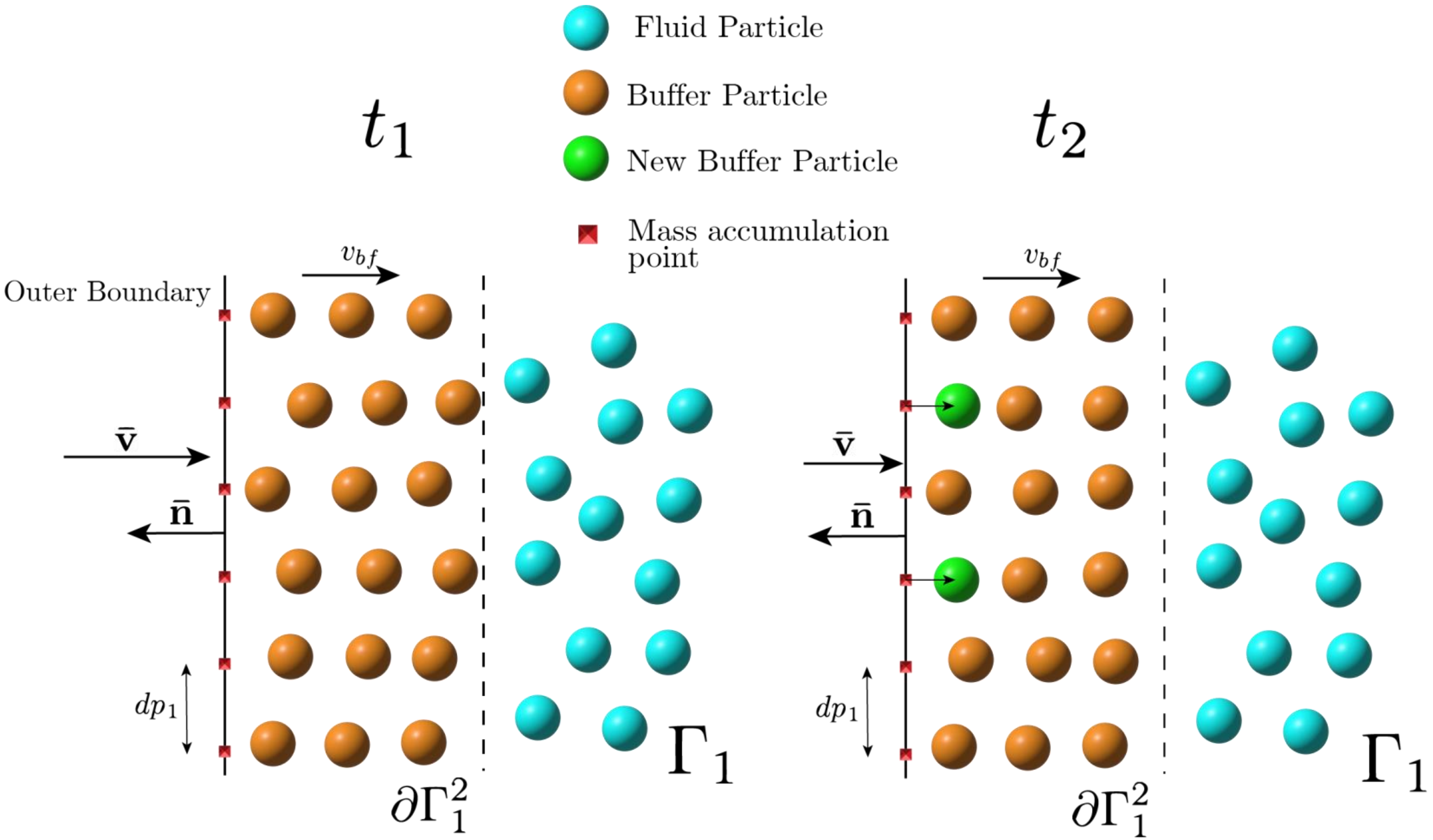
3. Buffer particles out of the domain domain is deleted

Mass exchange



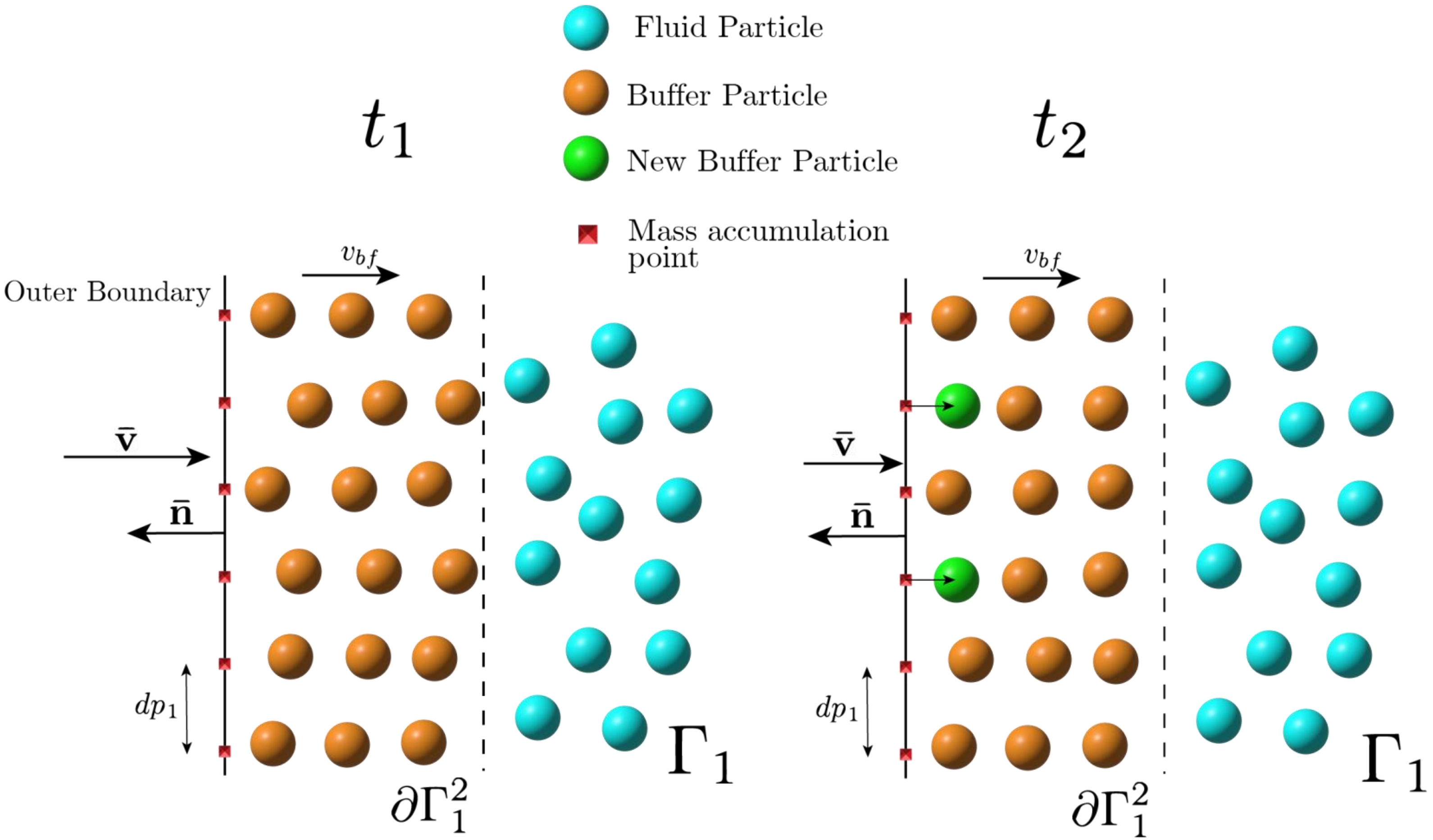
The outer boundary is divided in mass segments with dp.

Mass exchange



$$\dot{m}_a = \max(0, -\rho_{m_a}(v_{m_a} - v_{b_f}) \cdot \mathbf{n}\, dp_i\, dt)$$

Mass exchange



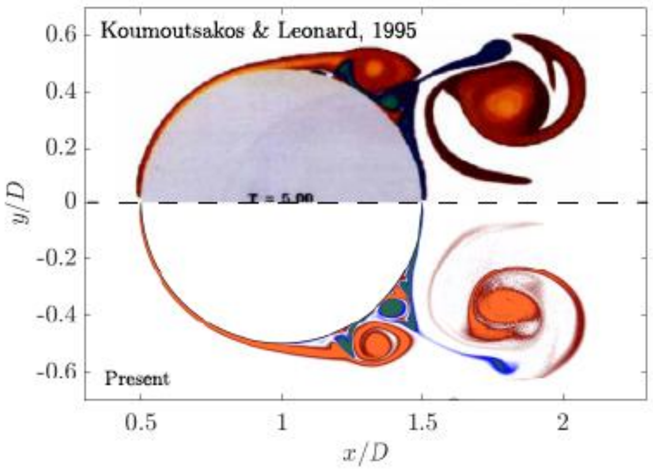
If $m_a \geq (dp)^D/\rho_0$ a new particle is created at dp/2

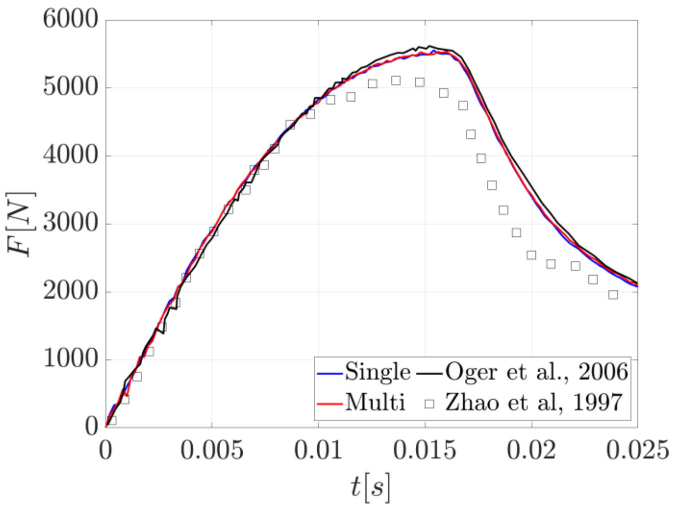
References

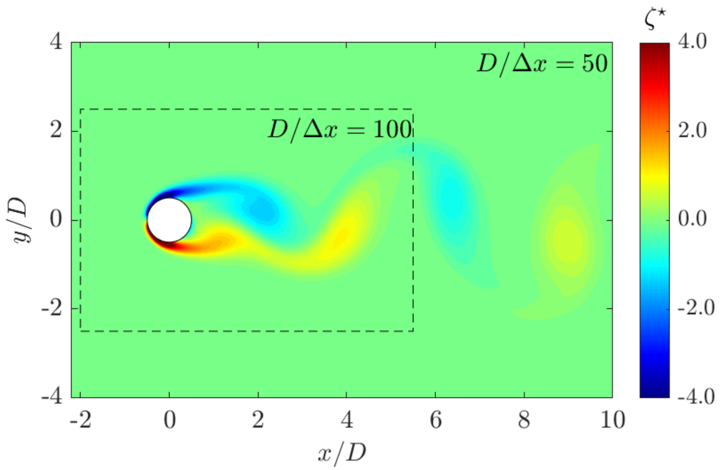
Main reference:

F. Ricci, R. Vacondio, and A. Tafuni. Multiscale smoothed particle hydrodynamics based on a domain-decomposition strategy. Computer Methods in Applied Mechanics and Engineering, 418:116500, 2024.

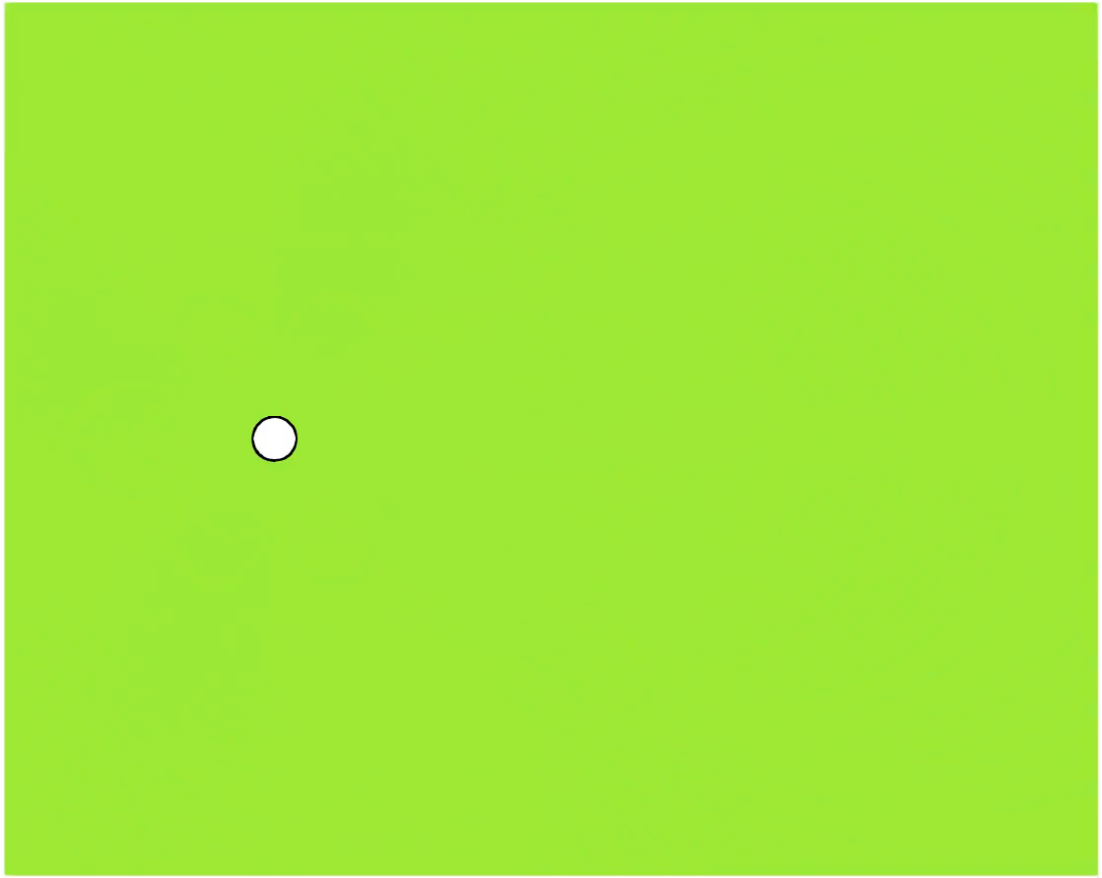
Validation results on different two dimensional test cases:







References



What it's available in the beta and limitations

DualSPHysics_v5.4_BETA

Current limitations:

- 2D only
- GPU only
- Works only with mDBC solid boundary
- The Vres executable is not able to run single resolution simulation
- Executable only (no source code available)

DualSPHysics_v5.4_BETA Tools available

Pre- and Post-Processing tools have been updated for the Vres code

- GenCase

- PartVtk

PartVtk is able to visualize all the different sub-domains in the same vtk file (see the examples)

DualSPHysics_v5.4_BETA

The Vres code is updated with the DualSPHysics_V5.4

The only difference is the Particle Shifting Technique (Lind et al., 2012) instead of (Skillen et al., 2013):

$$\delta \mathbf{x} = -D\nabla C \qquad D = Ah^2 \qquad \nabla C = \sum_b \frac{m_b}{\rho_b} \nabla_a W_{ab}.$$

See the example for the reference values of the A coefficient (usually 1/50 respect to the Skillen formulation)

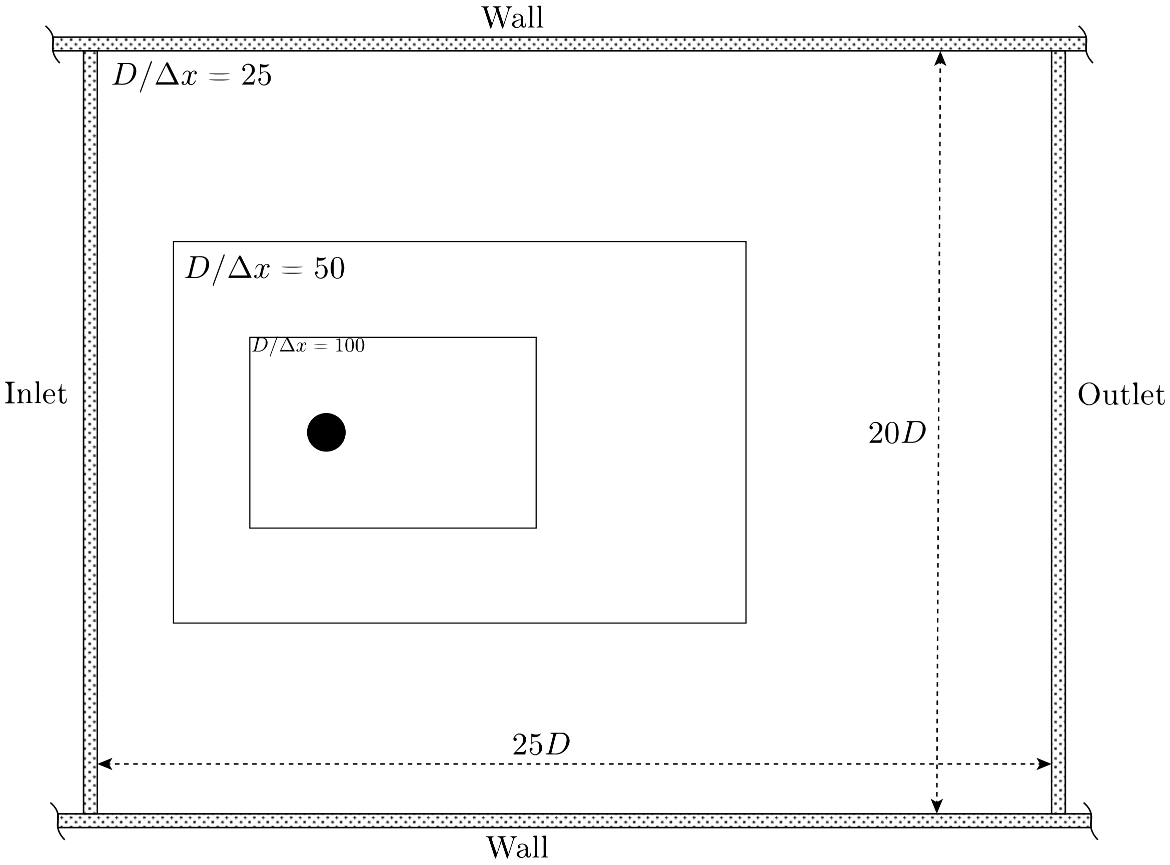
Test Case examples

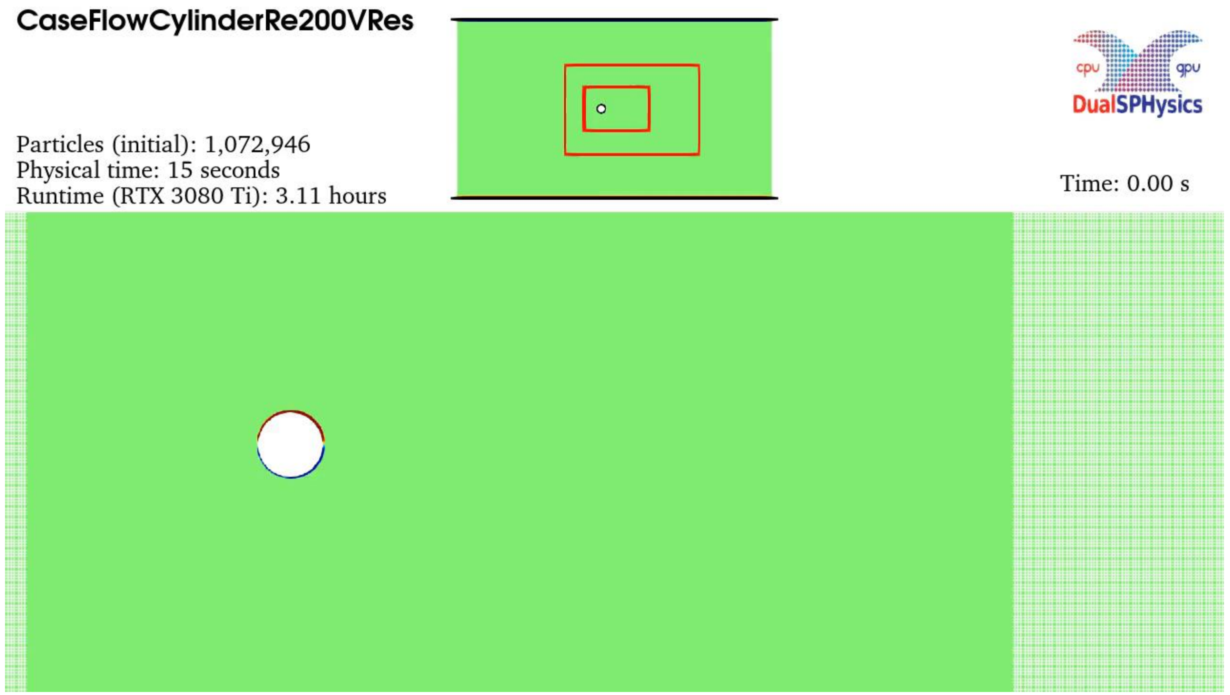
DualSPHysics_v5.4_BETA

Examples available in the package:

- 01_DamBreak2D
- 02_CaseFlowCylinder
- 03_CaseFlowCylinderTandem
- 04_FallingWedge2D

Example: CaseFlowCylinder_Re200





Example: CaseFlowCylinder_Re200

```xml
<mainlist>
    <!-- SIMULATION DIMENSIONS AND OTHER CONFIGURATIONS -->
    <newvarcte xini="-1.510" xsize="3.520" zsize="2.000" zini="-zsize/2" _rem="Fluid domain" />
    <newvarcte xoversize="0.090" zoversize="Dp*6" _rem="Extra size for boundary domain" />
    <newvarcte cylx="0.1" cylz="0.0" cylradius="0.05" _rem="Cylinder values" />
    <newvarcte fluidvel="1.0" _rem="Fluid velocity" />
    <!-- BASIC CONFIGURATION -->
    <setshapemode>actual | bound</setshapemode>
    <setdrawmode mode="full" />
    <!-- FLUID DOMAIN -->
    <setmkfluid mk="1" />
    <drawbox>
        <boxfill>solid</boxfill>
        <point x="#xini" y="-0.1" z="#zini" />
        <size x="#xsize" y="0.2" z="#zsize" />
    </drawbox>
    <!-- OPEN BOUNDARIES -->
    <setmkfluid mk="2" />
    <drawbox>
        <boxfill>left</boxfill>
        <point x="#xini" y="-0.1" z="#zini" />
        <size x="#xsize" y="0.2" z="#zsize" />
    </drawbox>
    <setmkfluid mk="3" />
    <drawbox>
        <boxfill>right</boxfill>
        <point x="#xini" y="-0.1" z="#zini" />
        <size x="#xsize" y="0.2" z="#zsize" />
    </drawbox>
    <setmkbound mk="1" />
    <drawbox>
        <boxfill>solid</boxfill>
        <point x="#xini-xoversize" y="-0.1" z="#zini-zoversize" />
        <size x="#xsize+xoversize*2" y="0.2" z="#zoversize" />
    </drawbox>
    <setmkbound mk="2" />
    <drawbox>
        <boxfill>solid</boxfill>
        <point x="#xini-xoversize" y="-0.1" z="#-zini" />
        <size x="#xsize+xoversize*2" y="0.2" z="#zoversize" />
    </drawbox>
    <!-- CYLINDER -->
    <setmkbound mk="0" />
    <setfrdrawmode auto="true" />
    <drawcylinder radius="#cylradius-Dp/2">
        <point x="#cylx" y="0" z="#cylz" />
        <point x="#cylx" y="0.1" z="#cylz" />
    </drawcylinder>
    <setmkvoid mk="0" />
    <setfrdrawmode auto="true" />
    <drawcylinder radius="#cylradius-Dp*5">
        <point x="#cylx" y="0" z="#cylz" />
        <point x="#cylx" y="0.1" z="#cylz" />
    </drawcylinder>
    <setfrdrawmode auto="false" />
    <!-- END -->
    <shapeout file="" />
</mainlist>
</commands>
</geometry>
<vres active="true">
    <buffsizeh v="2" comment="Buffer size according to H (H*v) (default v=2)" />
    <bufferbox>
        <!-- Refinement level 1 -->
        <point x="-0.30" y="0" z="-0.51" />
        <size x="1.5" y="0.0" z="1" />
        <dpratio v="2" comment="Refinement ratio." />
        <buffsizeh v="2" comment="Buffer size according to H (H*v) (default v=2)" />
        <bufferbox active="true">
            <!-- Refinement level 2 -->
            <point x="-0.10" y="0" z="-0.250" />
            <size x="0.75" y="0.0" z="0.5" />
            <dpratio v="2.0" comment="Refinement ratio." />
        </bufferbox>
    </bufferbox>
</vres>
</casedef>
```

```xml
<vres>
    <buffsizeh v="2" comment="Buffer size according to H (H*v) (default v=2)" />
    <bufferbox>
        <!-- Refinement level 1 -->
        <point x="-0.30" y="0" z="-0.51" />
        <size x="1.5" y="0.0" z="1" />
        <dpratio v="2" comment="Refinement ratio." />
        <buffsizeh v="2" comment="Buffer size according to H (H*v) (default v=2)" />
        <bufferbox active="true">
            <!-- Refinement level 2 -->
            <point x="-0.10" y="0" z="-0.250" />
            <size x="0.75" y="0.0" z="0.5" />
            <dpratio v="2.0" comment="Refinement ratio." />
        </bufferbox>
    </bufferbox>
</vres>
```

Example: CaseFlowCylinder_Re200

- A new section in added in the **<casedef></casedef>** section of the xml file
- The **<vres></vres>** section is structured to reflect the hierarchical structures of nested region.
- The definition of a variable resolution zone is done in **<bufferbox></bufferbox>** section.
- In order to define a refinement region nested inside another region, a **<bufferbox></bufferbox>** section must be inserted inside the previously defined **<bufferbox></bufferbox>** section.

```xml
<vres>
    <buffsizeh v="2" comment="Buffer size according to H (H*v) (default v=2)" />
    <bufferbox>
        <!-- Refinement level 1 -->
        <point x="-0.30" y="0" z="-0.51" />
        <size x="1.5" y="0.0" z="1" />
        <dpratio v="2" comment="Refinement ratio." />
        <buffsizeh v="2" comment="Buffer size according to H (H*v) (default v=2)" />
        <bufferbox active="true">
            <!-- Refinement level 2 -->
            <point x="-0.10" y="0" z="-0.250" />
            <size x="0.75" y="0.0" z="0.5" />
            <dpratio v="2.0" comment="Refinement ratio." />
        </bufferbox>
    </bufferbox>
</vres>
```

Definition zone 3
D/dx=100

Definition zone 2
D/dx=50

Example: Vres parameters

point starting point of a variable resolution zone.

size define the extension of the variable resolution zone. It also possible to use **endpoint** to define the ending point of the Vres domain.

dpratio refinement ratio between parent and child domain. A value 0.5<**v**<2.0 is recommended

buffsizeh Buffer size according to smoothing length h. The default value is **v**=2

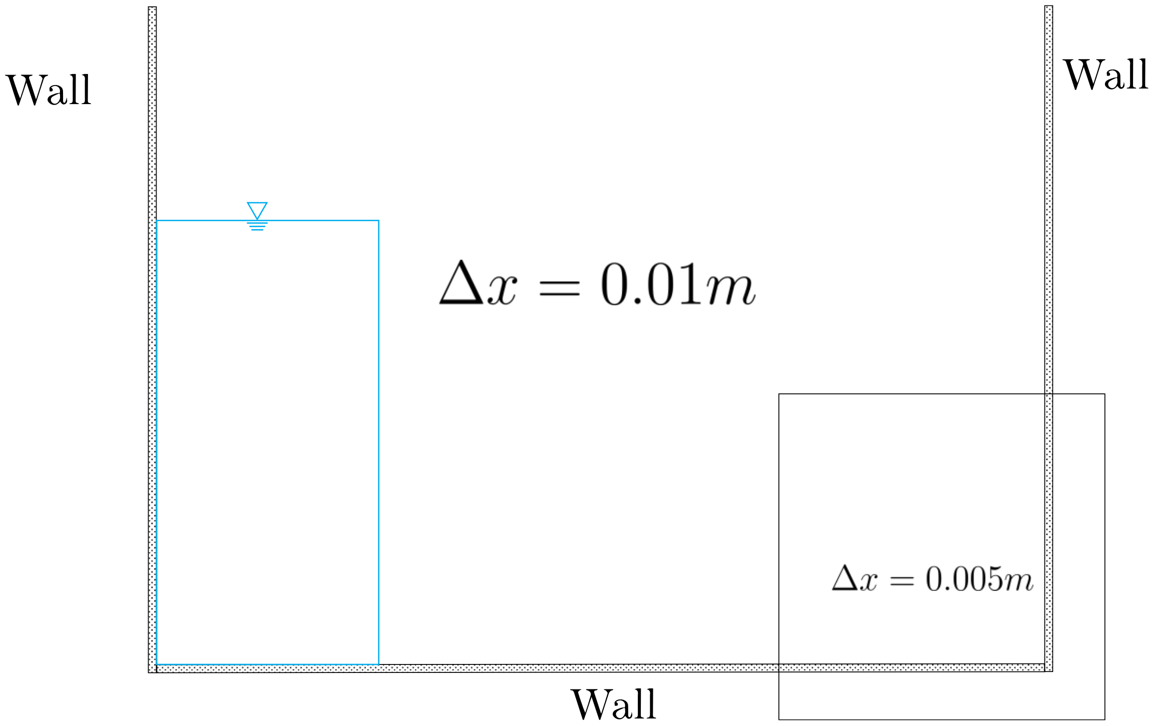
overlappingh Extension of the overlapping region according to length h. Only applied when **overlappingh** is explicitly declared in the Vres domain definition. Recommended when interface between Vres regions crosses solid boundaries and/or in presence of free-surface flows.

tracking If enabled, the Vres domain moves according the translational motion of the moving or floating body specified by the **mkbound** value.

Example: DamBreak2D

Geometry definition

```xml
<definition dp="0.01" units_comment="metres (m)">
    <pointref x="#Dp/2" y="0" z="#Dp/2" />
    <pointmin x="-0.1" y="0" z="-0.4" />
    <pointmax x="4.2" y="0" z="3.5" />
</definition>
<commands>
    <list name="GeometryForNormals">
        <setactive drawpoints="0" drawshapes="1" />
        <setshapemode>actual | bound</setshapemode>
        <setnormalinvert invert="true" />
        <!-- Tank -->
        <setmkbound mk="0" />
        <drawbox>
            <boxfill>bottom | left | right</boxfill>
            <point x="0" y="-1" z="0" />
            <size x="#sizex" y="2" z="#sizez" />
        </drawbox>
        <shapeout file="hdp" />
        <resetdraw />
    </list>
    <mainlist>
        <!-- Actual geometry at dp/2 -->
        <runlist name="GeometryForNormals" />
        <!-- Particles -->
        <setdrawmode mode="full" />
        <!-- Fluid -->
        <setmkfluid mk="1" />
        <drawbox>
            <boxfill>solid</boxfill>
            <point x="0" y="-1" z="0" />
            <size x="1" y="2" z="2" />
        </drawbox>
        <!-- Tank -->
        <setmkbound mk="0" />
        <drawbox>
            <boxfill>bottom | left | right</boxfill>
            <point x="0" y="-1" z="0" />
            <size x="#sizex" y="2" z="#sizez" />
            <layers vdp="0.5,1.5,2.5,3.5" />
        </drawbox>
    </mainlist>
</commands>
```



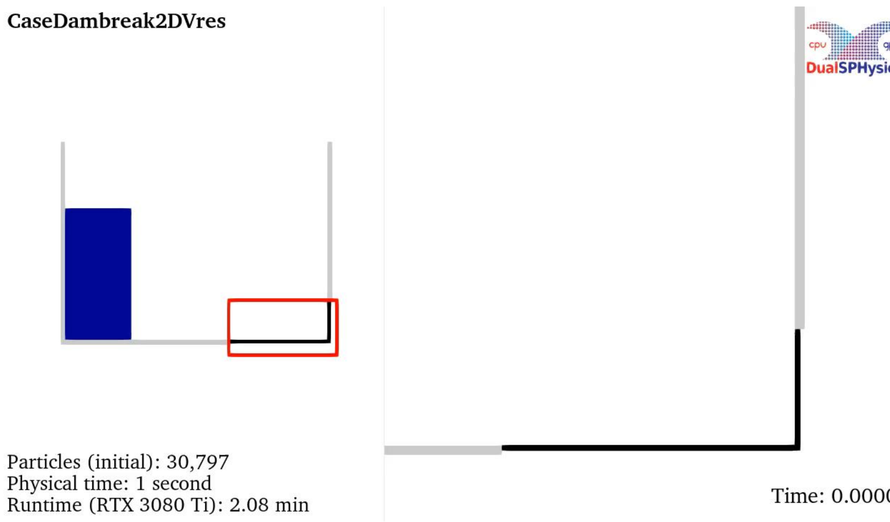
When is present a solid boundary that is crossed by an variable-resolution interface, is suggested to set:

<pointref x="#Dp/2" y="0" z="#Dp/2" />

This allow the correct definition of solid boundaries with different resolutions.

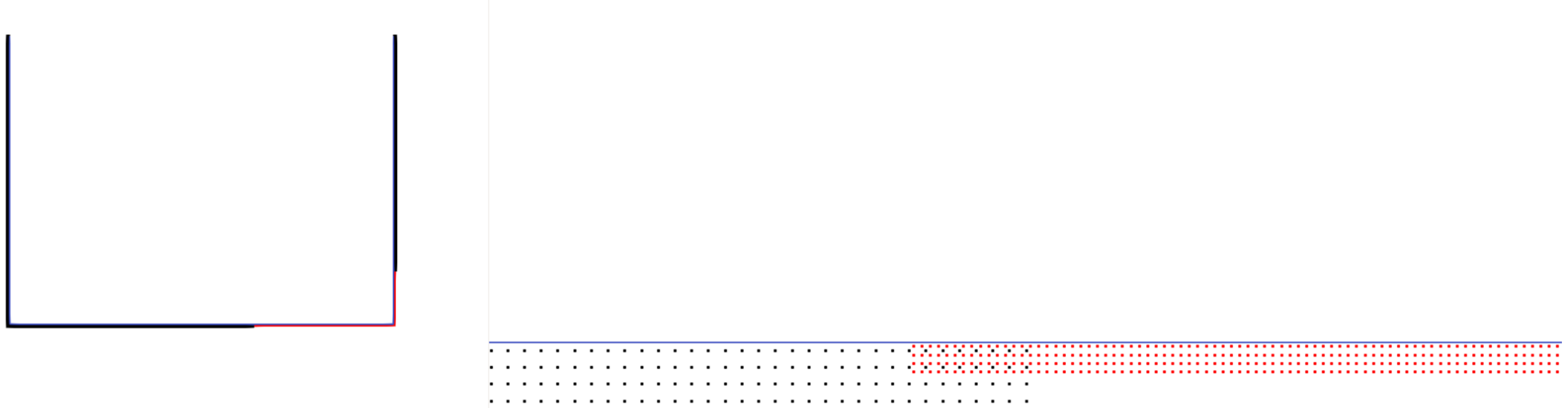
Example: DamBreak2D

```
<vres active="true">
    <buffsizeh v="2" comment="Buffer size according to H (H*v) (default v=2)" />
    <bufferbox>
        <point x="2.5" y="0" z="-0.20" />
        <endpoint x="4.1" y="0" z="0.60" />
        <dpratio v="2" comment="Refinement ratio." />
        <buffsizeh v="2" comment="Buffer size according to H (H*v) (default v=2)" />
        <overlappingh v="2" comment="Overlapping size according to H (H*v) (default v=0)" />
    </bufferbox>
</vres>
```

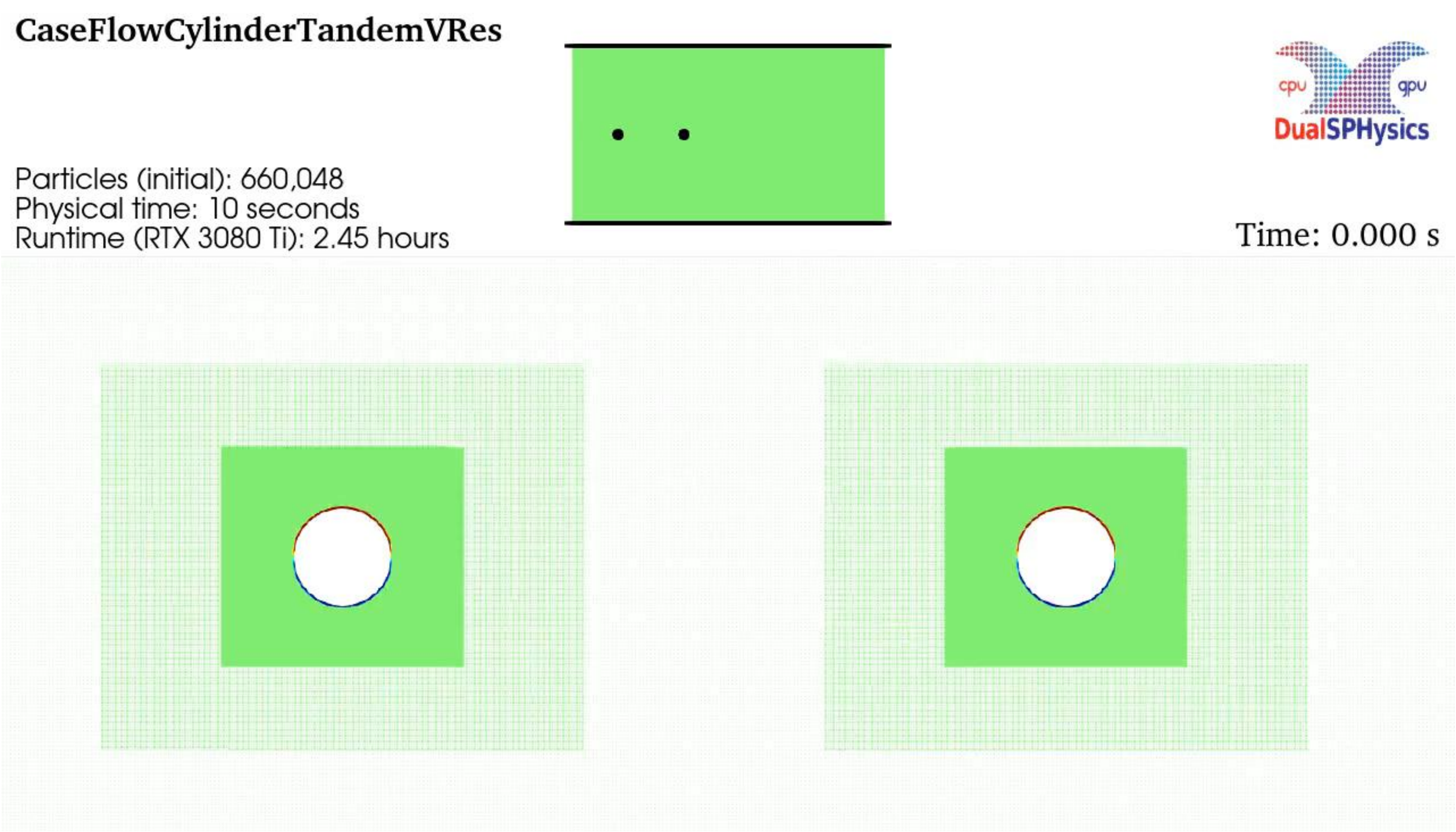


overlappingh Extension of the overlapping region according to length h.

Example:



Example: CaseFlowCylinderTandem



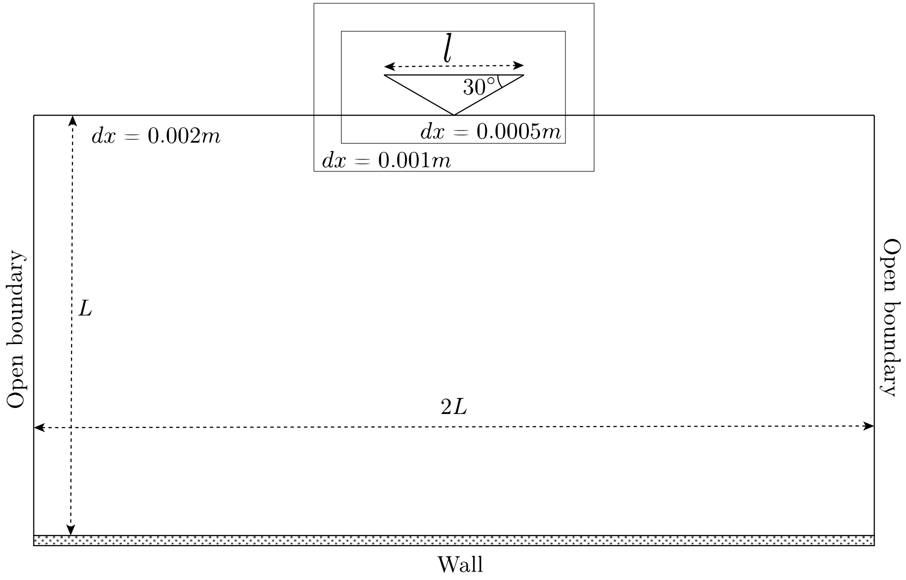
Example: CaseFlowCylinderTandem

```
<vres active="true">
    <buffsizeh v="2" comment="Buffer size according to H (H*v) (default v=2)" />
    <!-- Refinement for cylinder 1 -->
    <bufferbox>
        <point x="#cylx-5*cylradius" y="0" z="#cylz-4*cylradius" />
        <size x="#cylradius*10" y="0.0" z="#cylradius*8" />
        <dpratio v="2" comment="Refinement ratio." />
        <buffsizeh v="2" comment="Buffer size according to H (H*v) (default v=2)" />
        <tracking mkbound="1" comment="Reference to moving or floating object inside refinement region." />
        <bufferbox>
            <point x="#cylx-2.5*cylradius" y="0" z="#cylz-2.25*cylradius" />
            <size x="#5*cylradius" y="0.0" z="#4.5*cylradius" />
            <dpratio v="2.0" comment="Refinement ratio." />
            <tracking mkbound="1" comment="Reference to moving or floating object inside refinement region." />
        </bufferbox>
    </bufferbox>
    <!-- Refinement for cylinder 2 -->
    <bufferbox>
        <point x="#cylx2-5*cylradius" y="0" z="#cylz-4*cylradius" />
        <size x="#10*cylradius" y="0.0" z="#8*cylradius" />
        <dpratio v="2" comment="Refinement ratio." />
        <buffsizeh v="2" comment="Buffer size according to H (H*v) (default v=2)" />
        <tracking mkbound="2" comment="Reference to moving or floating object inside refinement region." />
        <bufferbox>
            <point x="#cylx2-2.5*cylradius" y="0" z="#cylz-2.25*cylradius" />
            <size x="#5*cylradius" y="0.0" z="#4.5*cylradius" />
            <dpratio v="2.0" comment="Refinement ratio." />
            <tracking mkbound="2" comment="Reference to moving or floating object inside refinement region." />
        </bufferbox>
    </bufferbox>
</vres>
```

Example: CaseFlowCylinderTandem

Wedge Geometry definition

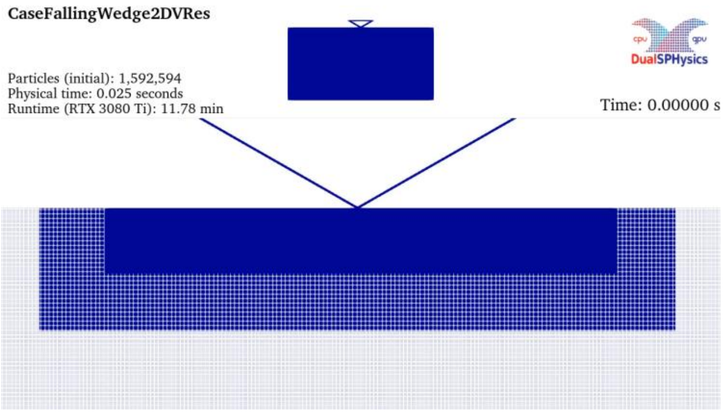
```
<setfrdrawmode auto="true" />
<setmkbound mk="51" />
<drawextrude closed="true">
    <extrude x="0" y="1" z="0" />
    <point x="0" y="-0.5" z="1.5" />
    <point x="0.25" y="-0.5" z="1.64433" />
    <point x="-0.25" y="-0.5" z="1.64433" />
    <layers vdp="0,1,2,3" />
</drawextrude>
<setfrdrawmode auto="false" />
```



Floating object definition

```
<floatings>
    <floating mkbound="51">
        <massbody value="241" />
        <linearvelini x="0" y="0" z="-6.15" />
    </floating>
</floatings>
```

```
<vres >
    <bufferbox>
        <point x="-0.49" y="0" z="1.31" />
        <size x="0.98" y="0" z="0.59" />
        <dpratio v="2.0" comment="Refinement ratio" />
                <overlappingh v="2" comment="Overlapping size according to H (H*v) (default v=0)" />
        <tracking mkbound="51" comment="Reference to moving or floating object inside refinement region." />
        <bufferbox>
            <point x="-0.39" y="0" z="1.40" />
            <size x="0.79" y="0" z="0.398" />
            <dpratio v="2.0" comment="Refinement ratio" />
                <overlappingh v="2" comment="Overlapping size according to H (H*v) (default v=0)" />
                <tracking mkbound="51" comment="Reference to moving or floating object inside refinement region." />
        </bufferbox>
    </bufferbox>
</vres>
```



The two refinement regions defined are tracking the solid object with **<mkbound="51">**

Future outlook

Future Outlook

- Validation of the present formulation for 3D application and release of the source code.
- Update of the post-processing tools (Compute_forces, MeasureTool) for Variable-resolution simulations.
- Integration of the multi-resolution model with other features available in DualSPHysics.