Simulation in Computer Graphics
TamiFlu

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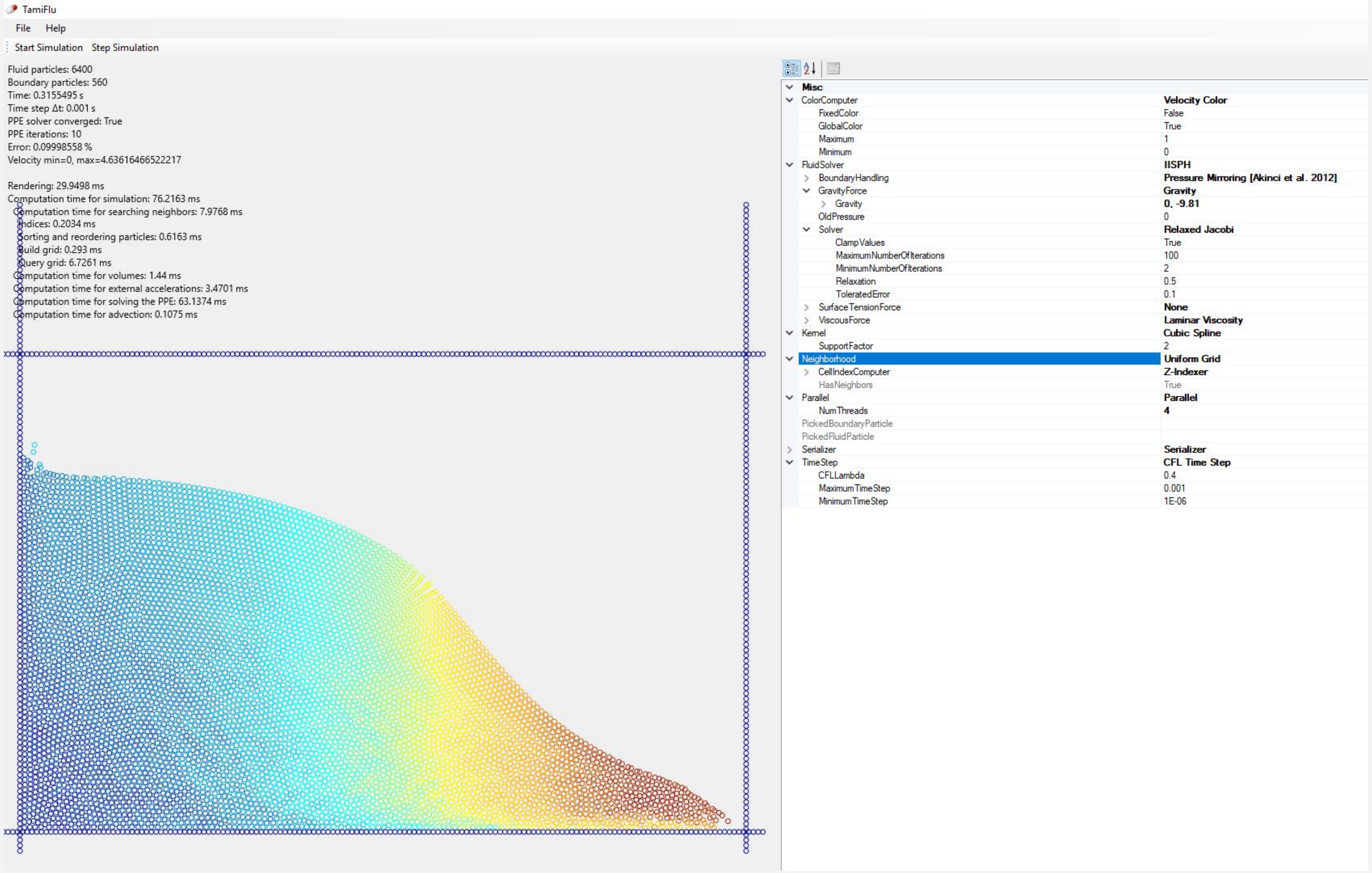
FREIBURG

Overview

- 2D fluid simulation framework
  - Written in C# / .NET 4.7.1
- Prerequisites
  - C# compiler, e.g. Microsoft Visual Studio 2017
- Author
  - Stefan Band

Screenshot



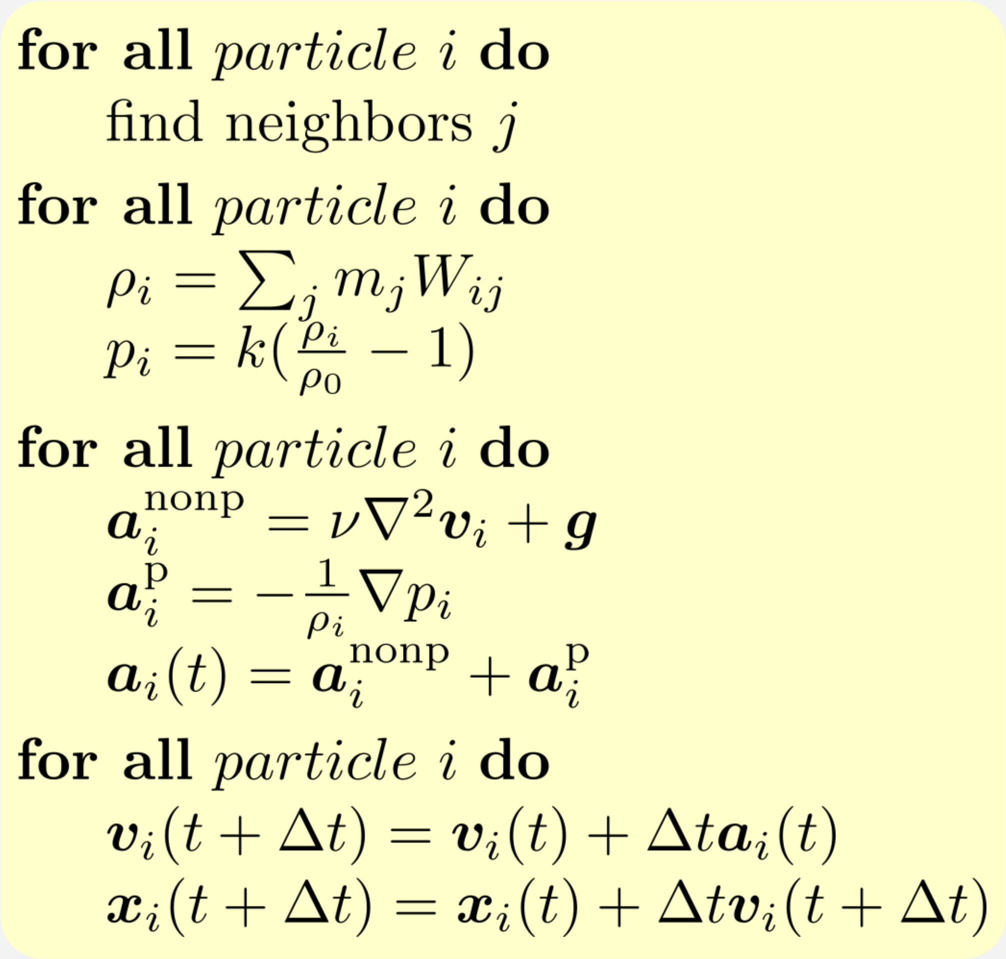
```
Fluid particles: 6400
Boundary particles: 560
Time: 0.3155495 s
Time step Δt: 0.001 s
PPE solver converged: True
PPE iterations: 10
Error: 0.09998558 %
Velocity min=0, max=4.63616466522217

Rendering: 29.9498 ms
Computation time for simulation: 76.2163 ms
  Computation time for searching neighbors: 7.9768 ms
    Indices: 0.2034 ms
    Sorting and reordering particles: 0.6163 ms
    Build grid: 0.293 ms
    Query grid: 6.7261 ms
  Computation time for volumes: 1.44 ms
  Computation time for external accelerations: 3.4701 ms
  Computation time for solving the PPE: 63.1374 ms
  Computation time for advection: 0.1075 ms
```

Misc	
ColorComputer	**Velocity Color**
FixedColor	False
GlobalColor	True
Maximum	1
Minimum	0
FluidSolver	**IISPH**
BoundaryHandling	**Pressure Mirroring [Akinci et al. 2012]**
GravityForce	**Gravity**
Gravity	**0, -9.81**
OldPressure	0
Solver	**Relaxed Jacobi**
ClampValues	True
MaximumNumberOfIterations	100
MinimumNumberOfIterations	2
Relaxation	0.5
ToleratedError	0.1
SurfaceTensionForce	**None**
ViscousForce	**Laminar Viscosity**
Kernel	**Cubic Spline**
SupportFactor	2
Neighborhood	**Uniform Grid**
CellIndexComputer	**Z-Indexer**
HasNeighbors	True
Parallel	**Parallel**
NumThreads	**4**
PickedBoundaryParticle	
PickedFluidParticle	
Serializer	**Serializer**
TimeStep	**CFL Time Step**
CFLLambda	0.4
MaximumTimeStep	0.001
MinimumTimeStep	1E-06

SPH Fluid Solver

IFluidSolver

- void Simulate(IParticleContext)



```
for all particle $i$ do
    find neighbors $j$
for all particle $i$ do
    $\rho_i = \sum_j m_j W_{ij}$
    $p_i = k(\frac{\rho_i}{\rho_0} - 1)$
for all particle $i$ do
    $\boldsymbol{a}_i^{\text{nonp}} = \nu \nabla^2 \boldsymbol{v}_i + \boldsymbol{g}$
    $\boldsymbol{a}_i^{\text{p}} = -\frac{1}{\rho_i} \nabla p_i$
    $\boldsymbol{a}_i(t) = \boldsymbol{a}_i^{\text{nonp}} + \boldsymbol{a}_i^{\text{p}}$
for all particle $i$ do
    $\boldsymbol{v}_i(t + \Delta t) = \boldsymbol{v}_i(t) + \Delta t \boldsymbol{a}_i(t)$
    $\boldsymbol{x}_i(t + \Delta t) = \boldsymbol{x}_i(t) + \Delta t \boldsymbol{v}_i(t + \Delta t)$
```

Neighbor Search

IParticleNeighborhood

  void SearchNeighbors()

```
for all particle i do
    find neighbors j
for all particle i do
    $\rho_i = \sum_j m_j W_{ij}$
    $p_i = k(\frac{\rho_i}{\rho_0} - 1)$
for all particle i do
    $\boldsymbol{a}_i^{\mathrm{nonp}} = \nu \nabla^2 \boldsymbol{v}_i + \boldsymbol{g}$
    $\boldsymbol{a}_i^{\mathrm{p}} = -\frac{1}{\rho_i} \nabla p_i$
    $\boldsymbol{a}_i(t) = \boldsymbol{a}_i^{\mathrm{nonp}} + \boldsymbol{a}_i^{\mathrm{p}}$
for all particle i do
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```
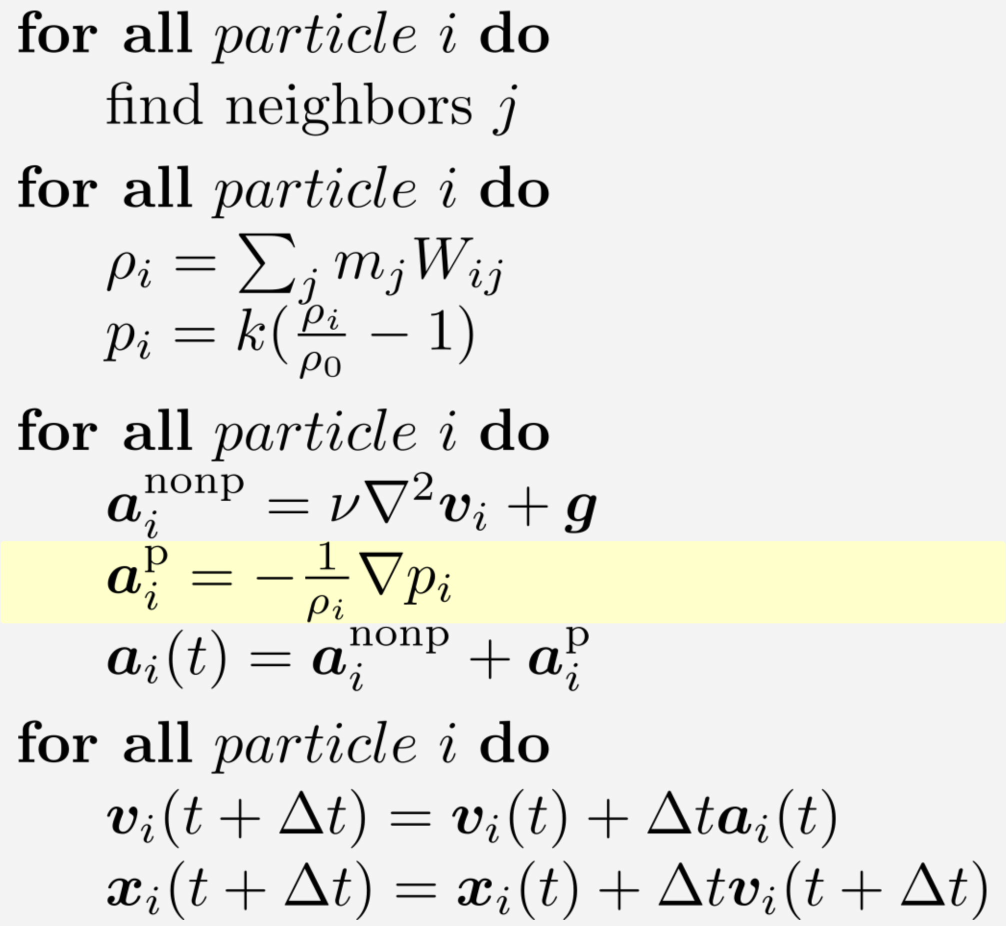

Pressure Force

IPressureForce

- void ApplyToFluidParticles()



```
for all particle i do
    find neighbors $j$
for all particle i do
    $\rho_i = \sum_j m_j W_{ij}$
    $p_i = k(\frac{\rho_i}{\rho_0} - 1)$
for all particle i do
    $\boldsymbol{a}_i^{\mathrm{nonp}} = \nu \nabla^2 \boldsymbol{v}_i + \boldsymbol{g}$
    $\boldsymbol{a}_i^{\mathrm{p}} = -\frac{1}{\rho_i} \nabla p_i$
    $\boldsymbol{a}_i(t) = \boldsymbol{a}_i^{\mathrm{nonp}} + \boldsymbol{a}_i^{\mathrm{p}}$
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```

External Forces

IExternalForce

- void ApplyToFluidParticles()

```
for all particle i do
    find neighbors $j$
for all particle i do
    $\rho_i = \sum_j m_j W_{ij}$
    $p_i = k(\frac{\rho_i}{\rho_0} - 1)$
for all particle i do
    $\boldsymbol{a}_i^{\mathrm{nonp}} = \nu \nabla^2 \boldsymbol{v}_i + \boldsymbol{g}$
    $\boldsymbol{a}_i^{\mathrm{p}} = -\frac{1}{\rho_i} \nabla p_i$
    $\boldsymbol{a}_i(t) = \boldsymbol{a}_i^{\mathrm{nonp}} + \boldsymbol{a}_i^{\mathrm{p}}$
for all particle i do
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```

TamiFlu – Fluid Solver Step

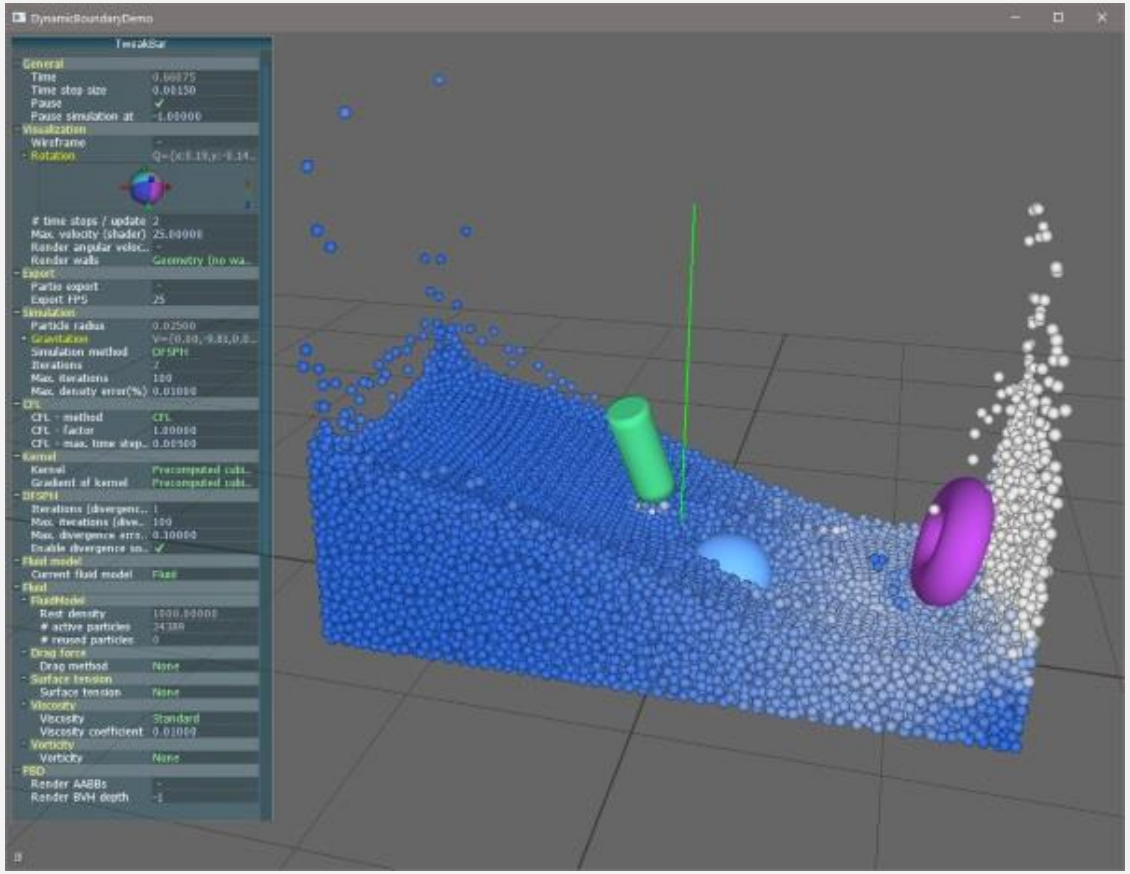
```
particleContext.Neighborhood.SearchNeighbors(particleContext);

particleContext.ForEachFluidParticleInParallel((ref FluidParticle f) => f.Pressure
= stateEquation.ComputePressure(f.Density,f.Properties.RestDensity));

particleContext.ForEachFluidParticleInParallel((ref FluidParticle f) =>
f.Acceleration = Vector.Zero);
GravityForce.ApplyToFluidParticles(particleContext);
ViscousForce.ApplyToFluidParticles(particleContext);
SurfaceTensionForce.ApplyToFluidParticles(particleContext);
PressureForce.ApplyToFluidParticles(particleContext);

particleContext.ForEachFluidParticleInParallel((ref FluidParticle f) =>
{ f.Velocity += timeStepValue * f.Acceleration;
  f.Position += timeStepValue * f.Velocity;});
```

TamiFlu – Boundary Handling

```
particleContext.ForEachFluidParticleInParallel((ref FluidParticle f) => {

   var numberDensity = selfKernelValue;

   foreach (var ffIndex in f.FluidNeighbors) {
      ref readonly var ff = ref fluidParticles[ffIndex];
      numberDensity += kernel.ComputeValue(f.Position, ff.Position); }

   foreach (var fbIndex in f.BoundaryNeighbors) {
      ref readonly var fb = ref boundaryParticles[fbIndex];
      numberDensity+=(fb.Volume/restVolume)*kernel.ComputeValue(f.Position,fb.Position); }

   f.Volume = 1f / numberDensity; });
```

SPlisHSPlasH

- – SPH Framework
- – Author: Jan Bender, RWTH Aachen
- – https://github.com/InteractiveComputerGraphics/SPlisHSPlasH



```
- General
   Time                      0.00075
   Time step size            0.00150
   Pause                     ✓
   Pause simulation at       -1.00000
- Visualization
   Wireframe                 -
 - Rotation                  Q=(x:0.19,y:-0.14...
   # time steps / update     2
   Max. velocity (shader)    25.00000
   Render angular veloc...   -
   Render walls              Geometry (no wa...
- Export
   Partio export             -
   Export FPS                25
- Simulation
   Particle radius           0.02500
 - Gravitation               V=(0.00,-9.81,0.0...
   Simulation method         DFSPH
   Iterations                2
   Max. iterations           100
   Max. density error(%)     0.01000
- CFL
   CFL - method              CFL
   CFL - factor              1.00000
   CFL - max. time step...   0.00500
- Kernel
   Kernel                    Precomputed cubi...
   Gradient of kernel        Precomputed cubi...
- DFSPH
   Iterations (divergenc...  1
   Max. iterations (dive...  100
   Max. divergence erro...   0.10000
   Enable divergence so...   ✓
- Fluid model
   Current fluid model       Fluid
- Fluid
 - FluidModel
    Rest density             1000.00000
    # active particles       24389
    # reused particles       0
 - Drag force
    Drag method              None
 - Surface tension
    Surface tension          None
 - Viscosity
    Viscosity                Standard
    Viscosity coefficient    0.01000
 - Vorticity
    Vorticity                None
- RBD
   Render AABBs              -
   Render BVH depth          -1
```