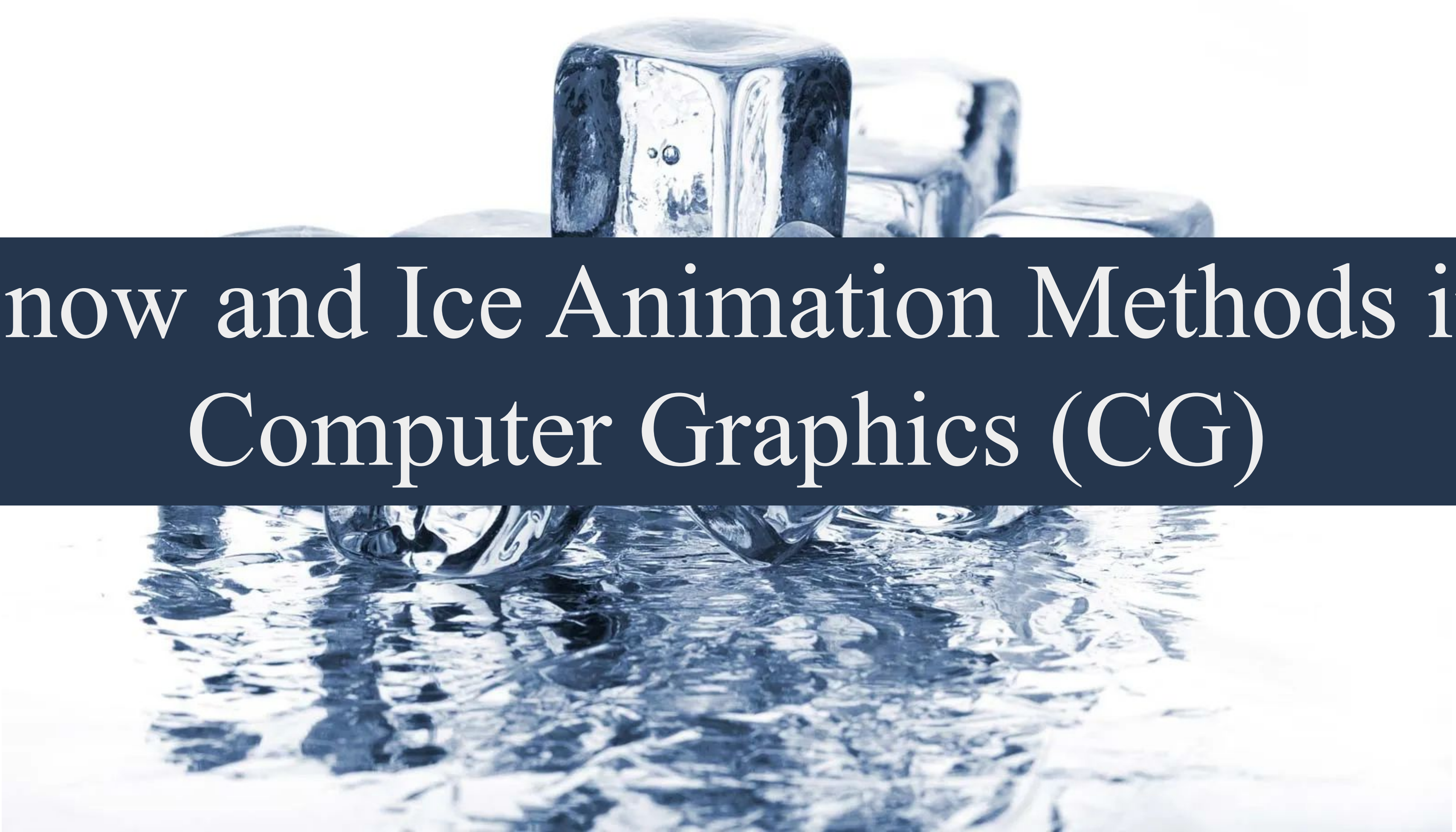
Snow and Ice Animation Methods in Computer Graphics (CG)



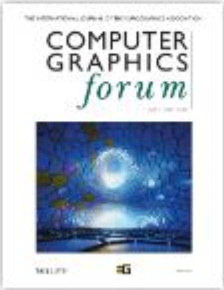
About the paper

Author: Prashant Goswami

- “Prashant Goswami (born 1959) is an Indian **computational geoscientist**, climatologist and the director of the National Institute of Science, Technology and Development Studies, New Delhi”

Context: EUROGRAPHICS 2024’s CG forum

- Two main sponsors: Adobe and Disney Research Studios



Volume 43, Issue 2
May 2024
e15059

About the paper

Published: 30 April 2024

Concepts: Computing methodologies - Physical simulation - Procedural Animation

*"This state-of-the-art report aims to identify **existing animation methods** in the [ice and snow CG] field, provide an up-to-date **summary of the research in CG**, and identify **gaps** for promising future work. Furthermore, we also attempt to identify the primarily related work done on snow and ice in some **other disciplines**, such as civil or mechanical engineering, and draw a parallel with the **similarities and differences in CG**."*

Plan

1. Introduction
2. Base Litterature
    a. Microstructure and physics
        i. Eulerian
        ii. Lagrangian
            1. Smoothed particle hydrodynamics
            2. Discrete element method
    b. Simulation methods
        i. Micro-scale
        ii. Macro-scale
    c. Avalanches
        i. Dry avalanches
        ii. Wet avalanches
        iii. Others
3. Snow in CG
    a. Simulation
        i. Hybrid-based
        ii. Particle-based
            1. SPH
            2. DEM
        iii. Other methods
    b. Avalanche
    c. Accumulation
        i. Physics-based (Static/Time-Evolving)
        ii. Procedural
            1. Standard CG Techniques
            2. Heightmap
            3. Others
    d. Snowfall
        i. Physics-based
        ii. Image-based
            1. Signature analysis
            2. Frequency splitting
            3. Artificial intelligence

Plan

4. Ice in CG
    a. Physical Simulation
        i. Growth
            1. Grid-/hybrid-based
            2. Particle-based
        ii. Melting
            1. Grid-/hybrid-based
            2. Particle-based
            3. Others
        iii. Features
            1. Bubbles
            2. Clouding Effect
    b. Procedural

5. Discussion
6. Conclusions

1. Introduction

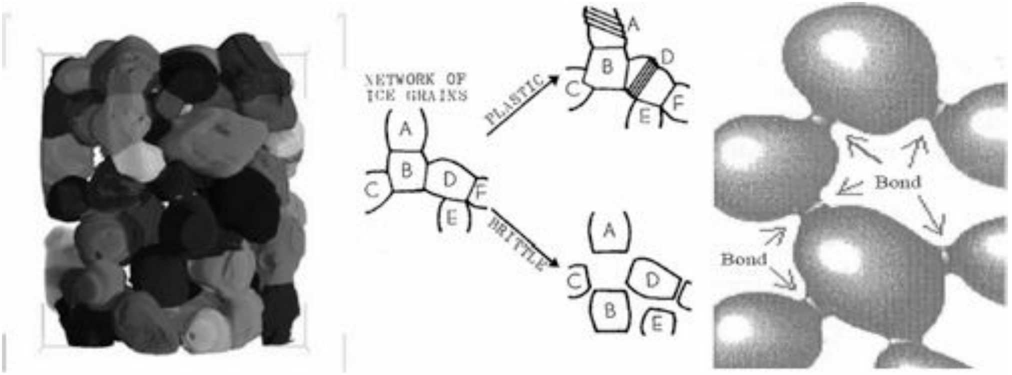
- **Snow and ice** are essential to many scenes in CG
- Challenge is capturing **varied visual appearance**.

(In samisk, 300 words to describe snow)

2. Base Litterature

“Snow is a visco-elastic material exhibiting varying properties under different conditions”

Snow crystal react and can become compact under some conditions = **Sintering**



(a) (b) (c)

2. Base Litterature

Mathematical models require Stress, Strain, Cohesive strength, Potential energy, Friction

Introducing the **Navier-Stokes** equations!

$$\rho\left(\frac{\partial \boldsymbol{v}}{\partial t}+(\boldsymbol{v}\cdot\nabla)\boldsymbol{v}\right)=-\nabla p+\mu\nabla\cdot\left\{\nabla\boldsymbol{v}+(\nabla\boldsymbol{v})^T-\frac{2}{3}(\nabla\cdot\boldsymbol{v})\boldsymbol{I}\right\}$$

$$+\boldsymbol{f}_{ext}, \quad \nabla\cdot\boldsymbol{v}=0$$

v velocity, μ dynamic viscosity

This equation is the basis to many snow simulation methods

2. Base Litterature

- Eulerian (grid-based)
- Lagrangian (particle-based)
  - Smoothed Particle Hydrodynamics (SPH)

    Advantages: Mass conservation is automatic + less volume loss than Eulerian

  - Discrete element method (DEM)

    Advantages: Large nb particles + generic model

Also hybrid methods (hybrid-based)

2. Base Litterature

Depending on the use, researchers will use different methods

- grid-based to model crack propagation
- particle-based (DEM) to study snow-object interactions
- exclusive attention to some subjects (avalanches, snow and tires, …)
    - Material Point Method (hybrid grid-based) for avalanches
    - Rapid Mass Movement for braking effect in avalanches (coupling of snow with objects)
    - Image validation of snow transport models => ML and DL

3. Snow in CG

Different from sand and water: sintering or bond formation is a special feature

Methods are more hybrid and particle-based. Importance of physical parameters, as well as some other parameters.

hybrid-based **particle-based**

sticky **compression**

(a) (b) (c) (d)

3. Snow in CG

Hybrid-based: 1.Material Point Method (MPM)

2.Fluid-implicit-particle (FLIP)

Particle-based:3.Smoothed Particle Dynamics (SPH)

4. Discrete Element Method (DEM)

(a) (b) (c) (d)

3. Snow in CG

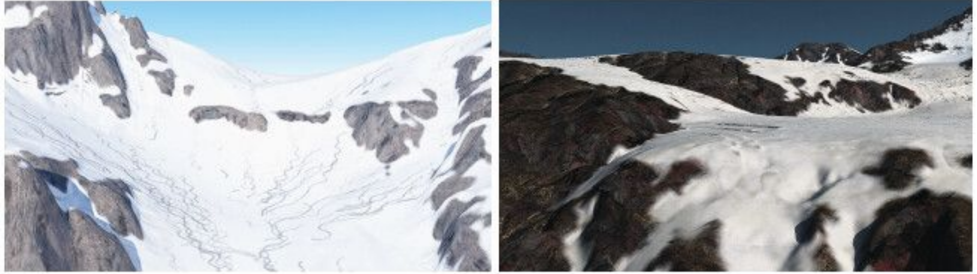
Cheating:

“In some cases, the impressions generated by trampling on snow can also be considered a pure surface phenomenon”

ut then we might lose the advantages of particle-based, such as object interaction.

=> Layering techniques work!

3. Snow in CG



(c) (d)

Accumulation

- Flow of air using Navier-Stokes equations (convection, deposition and lift of snow)
- Definition of snowflakes and snow packages
- Low number of or ignored object interactions

Cheating: Particle systems, Lighting and Shadow effects, Heightmap (Procedural)

(a) (b) (c) (d)

3. Snow in CG

Snow falling:

- Particle systems
- 3D Fourier to give blur or other effects

Eliminating falling snow:

- Signature analysis (matching pixels from a reference image)
- Frequency analysis (histogram of orientations of rain/snow streaks)

(a) (b)

4. Ice in CG

Similar to snow: growing and melting.

But heat exchange needs to be taken into account.

- Temperature fields,
- Thermal photons

Additional features like bubbles & scratches make it more realistic

4. Ice in CG

Growth:

Most references use Reaction-Diffusion Partial Differential Equations (PDEs)

Parameters can be: temperature, pressure, fluid flow, obstacles, humidity, density, …

Grid-based techniques have **limits** when the scale gets out of bounds (tip of icycle)

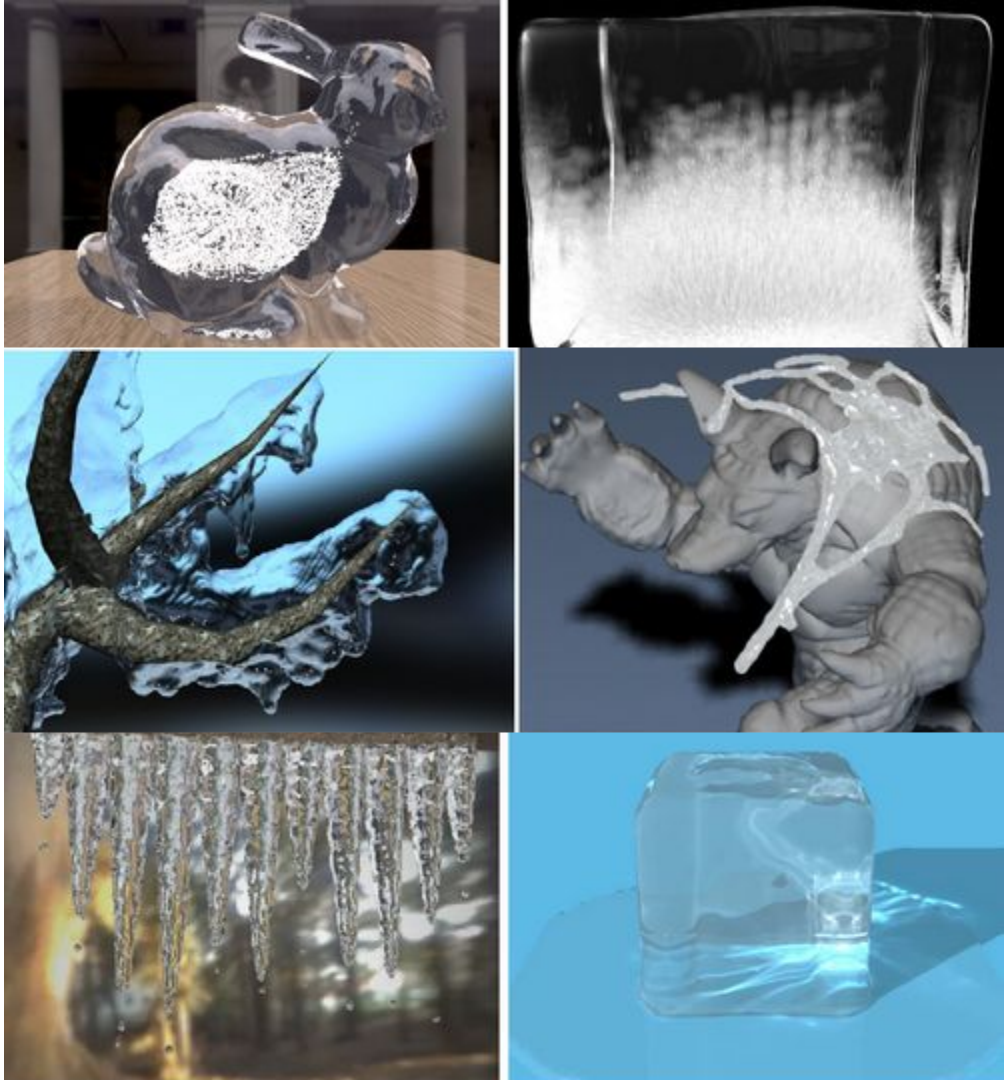
Particle-based "makes mass conservation, heat transfer, phase change from solid to liquid (or vice-versa), etc., much easier to handle when compared to the grid-based methods"

4. Ice in CG

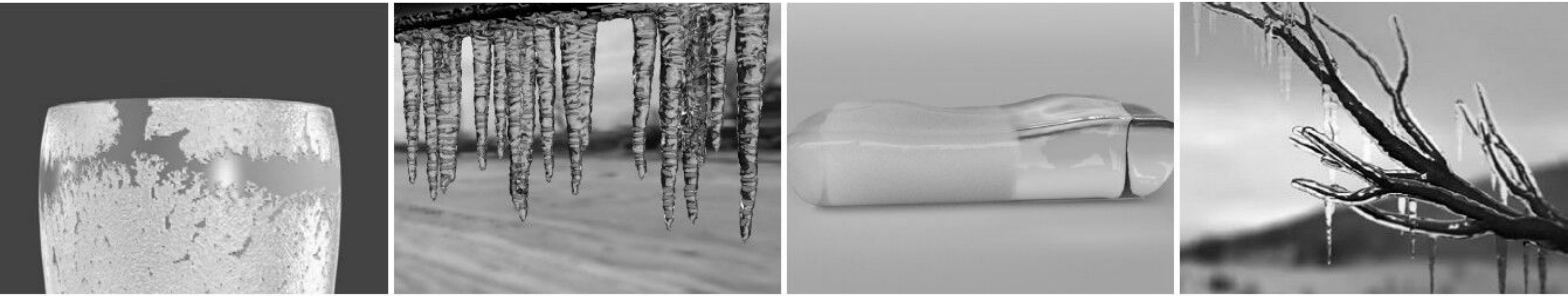
Melting: Many similarities with ice growth, especially in the physical sense.

- Navier-Stokes air field + object calculation field representing ice (grid-based) + photon mapping (particle-based) + Navier-Stokes equations for incompressible fluid
- Thermal photons + water-water interaction + water-ice interaction (SPH)
    - Virtual water???

4. Ice in CG



4. Ice in CG



(a) (b) (c) (d)

Ice growth algorithms (a) snowflake growth on a chilled glass simulation simulated using the physically-based hybrid method in [KHL04], (b) physics-based modeling ice formation by Kim et al. [KAL06], (c) particle-based physical freezing model by Miao and Xiao [MX15], (d) procedural icicle modeling on a tree branch by Gagnon and Paquette [GP11].

4. Ice in CG

Features: Bubbles, scratches & clouding effect

Enough about ice!

???. Performance

Method	*Snow/Ice*	*Type*	$\Delta t(ms)$	*Resolution*	*Time/Step(s)*	*Properties*
Stomakhin et al. [SSC*13]	snow	hybrid	0.5 0.5	700×120×210(0.58M) 200×240×470(7.2M)	180 2142	MPM, elasto-plastic constitutive model (CPU)
Takahashi et al. [TFN14]	snow	hybrid	1.0 1.0	40×40×40(128K) 60×60×60(1.9M)	0.8 3.3	FLIP, durability (CPU)
Gissler et al. [GHB*20]	snow	particles	0.1 3.1	5.04M(5 mm) 5.07M(8 cm)	522 194	IISPH, small and large volumes of snow (CPU)
Goswami et al. [GNN22]	snow	particles	0.6 1.0	0.5M(1.26 cm) 1.0M(1 cm)	0.036 0.104	DEM, iterative, perceptual user study (GPU)
Liu [LCZ*21]	snow avalanche	particles	1.0 1.0	2.7M 90K	26 0.11	Position-based dynamics (GPU)
Iwasaki et al. [IUDN10]	ice	particles	3.0 3.0	97K(1.1 mm) 200K (1.1 mm)	0.017 0.084	SPH, melting, photon emission (GPU)
Lii & Wong [LW14]	ice	particles	0.01 0.01	32×32×32(13.3K) 64×64×64(53.4K)	0.066 0.685	Virtual water particles, density field (GPU)
Miao & Xiao [MX15]	ice	particles	16	35K 100K	0.2 0.5	PBD, freezing, air bubbles (CPU)
Ishikawa et al. [IYW*15]	glazed frost	hybrid	1.0 1.0	128×128×128(20K)	0.02	FLIP, freezing, heat transfer (GPU)

???. Performance

Method	*Type*	*Scale*	*CPU/GPU*	*Maximum Resolution*	*Simulation Time*	*Properties*
Hinks & Museth [HM09]	physical	limited	CPU	256×256×256	14,400 s	wind-driven level set, limited physics
Maréchal et al. [MGG*10]	physical	landscape	CPU	3.2M voxels	18,000 s	heat transfer over nine days period
Festenberg & Gumhold [FG11]	physical	limited	CPU/GPU	700×700	654 s	diffusion-based snow cover
Cordonnier et al. [CEG*18]	physical	landscape	GPU	1024×1024	1,172 s	110 frames of snow cover evolution, weather events
Argudo et al. [AGP*20]	physical	landscape	CPU	1500×1500×20	26,722 s	20m of glacier evolution over 635 years
Reynolds et al. [RLD15]	procedural	limited	GPU	250K polygons	0.0154 s/step	occlusion-based, heightmap
Neukom et al. [NAS18]	procedural	landscape	GPU	166×118	0.145 s/step	GIS-based cover, limited physics
Junker & Palamas [JP20]	procedural	limited	GPU	2048×2048 texture	0.02 s/step	compute shaders

“Since the methods were developed on different hardware spanning over a period gap of about seven years and might have used different levels of parallel computations (or no parallelism at all), an exact comparison between the reported time cost per simulation time would be hard to establish.”

5. Discussions

In Computer Graphics, we care about visual! Different and less strict validation than in physics.

Free to use however many properties, to get to the desired performance.

Porting to GPU “could provide a better comparison”

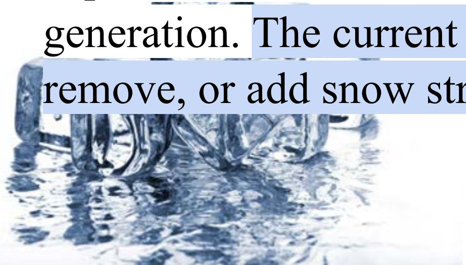
Scale of the simulation varies

Focus varies (ex: very few works in CG have focused on avalanche simulation)

No AI yet in snow, ice, avalanche, or accumulation simulation

6. Conclusions

"The development of visually appealing and efficient snow simulation methods in CG has gained more momentum recently. Many snow and ice simulation techniques have been proposed in the last few decades but have not been reviewed comparatively. This report has identified and categorized the existing relevant work and presented the advantages and disadvantages of these methods. Our findings suggest that snow and ice can be successfully simulated using different methods based on grids, particles, or hybrid formulations. CG could benefit more from the existing methods in the base scientific field to extend state-of-the-art solutions. Furthermore, future research could aid the development of efficient, real-time methods that could potentially be incorporated in SDKs of other real-time materials. Another promising direction would be to explore the use of artificial intelligence to the end of snow and ice simulation or snow cover generation. The current scope of AI-based methods is limited to the image domain to detect, remove, or add snow streaks in images and videos."



999. My conclusion

- Good mix of sciences in this paper (Material physics, Fluid mechanics, Thermodynamics, Probability, Visual Computing, …)
- Visual Computing and physics courses +++
- Paper remains vague about feasibility in real-time
- Different lighting and computer settings make the results pretty independent
- Comparison of results is thus difficult
- Good job at separating physics and CG concepts, clear structure
- No use in my thesis but it was interesting