Paul Fearing - Computer modelling of fallen snow

Feldmann, O'Brien - Modelling the accumulation of wind-driven snow

Christopher Nenning

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Modeling of fallen snow

- Snow pack modeling
- Large scenes, limited resources
- Physical correctness less important
- Accumulation model
- Stability model
- Transformation into 3D mesh
- Implicit functions

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Accumulation model

- How much snow a surface receives
- Phenomena:
  - flake flutter
  - flake dusting
  - wind blown snow
- Technique: Shoot particles upwards
- Importance ordering
- Interruptible and still plausible
- Improving over time

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Stability model

- Move snow away from physically unstable areas
- Local stability test handles
  - Steep surfaces
  - Obstacles
  - Edges
  - Wind transit

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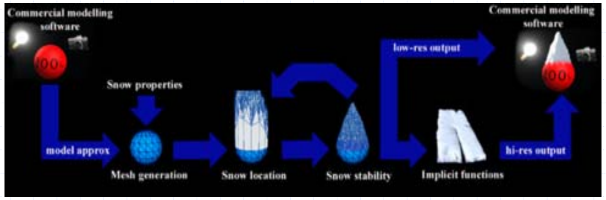
Snow pipeline

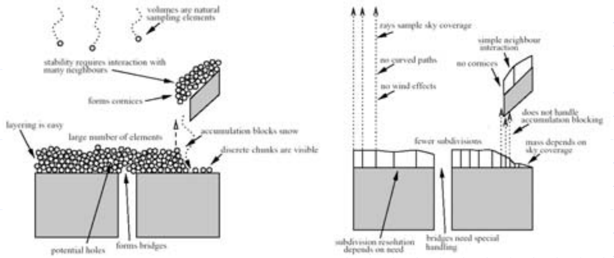


Previous work

- Mountainous terrains
  - DEM + Aerial photo
- Volume-based: Drop volume elements
  - Efficiency
  - Details lost
- Surface-based
  - No particles used to compute the exposure
- Hybrid based:
  - Combination. Described in this paper

Volume-based - Metaballs

Particle- vs. surface based



Particle based

Surface based

Accumulation model

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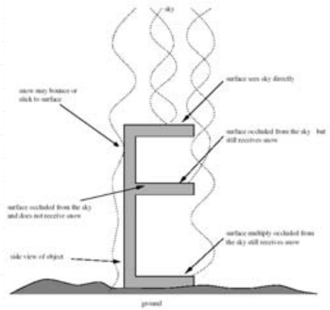
Flake flutter

- Cause
  - Crystal shape
  - Atmospheric micro-turbulence
- Effect
  - Flakes can avoid blocking surfaces



Accumulation model

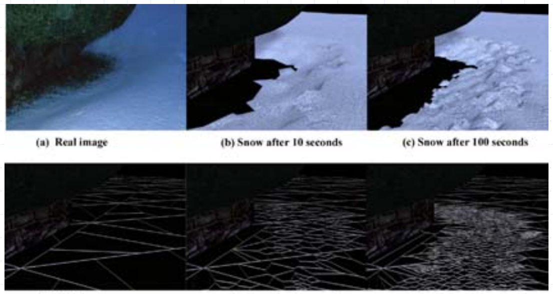
- Goal: Snowfall accumulation pattern for each surface
- Launch sites shoot particles upwards towards a sky bounding plane
  - Hit: surface receives snow
  - Miss: Blocked
- Difference in sky occlusions of adjacent sites
  - Join or merge sites

Accumulation model

Importance ordering

- Minimize sampling effort
- Maxmize visual information
- Prioritizing the samples
- Algorithm:
  - Most important launch site shoots a small batch of particles
  - Gets a new importance
- Heuristic weighting based on:
  - Completeness
  - Area
  - Neighbourhoods
  - Effort
  - Limits
  - Steepness
  - Camera
  - User

Accumulation model



(a) Real image (b) Snow after 10 seconds (c) Snow after 100 seconds

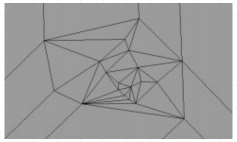
(d) Initial mesh (e) Mesh after 10 seconds (f) Mesh after 100 seconds

Accumulation model

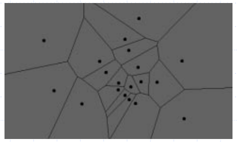
Launch site meshing

- Points
- Responsible for surrounding Voronoi area
- Connected in a constrained Delaunay triangulation (CDT)
- CDT: Preserve boundary edges, don't split into smaller edges

Accumulation model



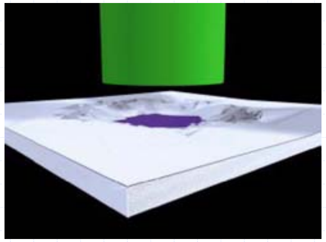
Triangle mesh

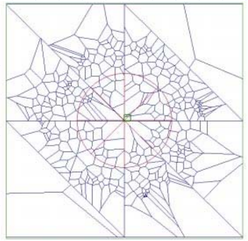


Corresponding Voronoi diagram

Constrained Delaunay triangulation

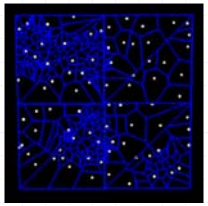
Accumulation model

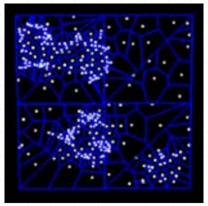


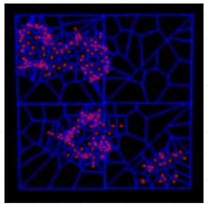


Obstacle causes mesh improvement in transition zone
Initial mesh started with 8 launch sites

Accumulation model







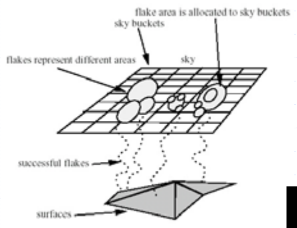
Initial sites on final mesh — Final sites — Added sites

Accumulation model

Locating particles in the sky

- Ensure that a large concentration of flakes (for example above a tree) draws the same total snow as would the sky above a sparse flat surface
- Bucketing and filtering scheme
  - Sky: Grid of constant size buckets
  - For successful flakes: Spread representative area across buckets
- Representative area
  - Launch site's projected area divided by the number of flakes in the current batch

Accumulation model



- At the end of the accumulation phase
  - Allocate mass to sky buckets
  - usually constant mass

Non-constant allocation of snow-mass

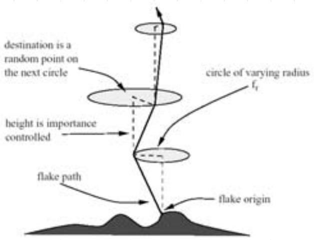
Accumulation model

- Bucket b computes a **mass per area value,** based on available mass of b and the summation of all representative flake areas extending into b
- Launch site l receives new mass proportional to the summation of the representative areas of all its flakes that hit b
- Variation
  - Since accumulation pattern may change
  - Split snow depth
  - Run accumulation phase more than once

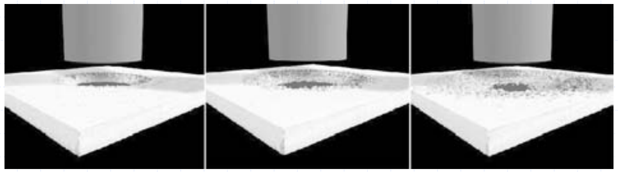
Accumulation model

Snowflake Motion

- Approximation:
  - Random walk on circle with random radius f_r and Z step resolution h
  - f_r: at each step randomly chosen
  - h: influenced by importance ordering



Accumulation model



Increased flake variability leads to more snow under an obstacle.

f_r increases from 1 to 4 to 7 cm from left to right.

Accumulation model

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Surface construction

- Elevate each launch site by the accumulated snow mass divided by the site area
- The snow surface is then the constrained Delaunay triangulation of the elevated launch sites

Accumulation model

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Flake dusting

- If the snow is not thick enough to completely obscure the underlying surface
- Generate semi-transparent dusting textures
- Possibility for view-dependent scenes:
  - Replace sufficiently thin and distant snow layers with a white texture
  - Reduces polygon count

Accumulation model

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(a) Real sign
(b) Computer generated sign and snow
Dusting density increases near the top and edges in both models

Stability model

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Snow stability

- Redistribution of snow mass
- Generate stable configuration based on simple surface and snow properties
- After accumulation phase

Stability model

Algorithm

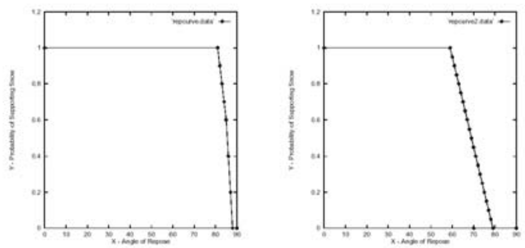
- List u1: unresolved sites
  - contains sites sorted by absolute Z height plus accumulation
- Traverse u1, resolve unstable sites
  - Lower sites may receive snow
  - Loss of snow can create unstable higher (previously stable) neighbours
- Place affected sites in u2
- After entire pass through u1:
  - Replace u1 by u2
  - Repeat
- Length of u1 is not guaranteed to decrease on each pass
  - For example: Very unstable snow on a wide flat surface

Stability model

Angle of repose (AOR)

- Main parameter for algo
- Fixed for particular snow type
  - Almost 90° for fresh snow
  - 15° for extreme slush conditions
  - Water: AOR = 0°
- Transition curve for probability of stability
- Based on relative heights of accumulated snow
  - Not on angle of the surface
- Changes during snow movement

Stability model



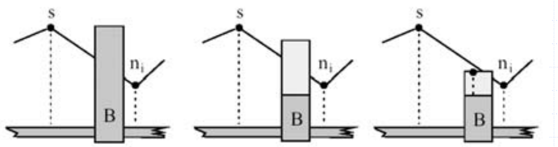
Transition curve simulating fairly fresh (left) and older snow (right)

Stability model

Stability test

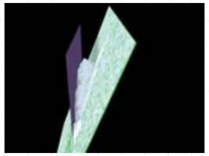
- Algo (for each launch site s)
  - Compute AOR between s and all neighbours n(i) lower than s
  - For each n(i) with AOR too steep to support snow do obstacle test
  - Evenly shift snow from s to all n(i) until at least one n(i) becomes stable
  - Repeat until no more unstable n(i), or s bare of snow
- Obstacle test:
  - If non-snow obstacle in the way - avalanche blocked, ignore n(i)
  - If vertical snow surface – blocked, ignore n(i)
  - If non-vertical snow surface, there is an interpenetrating surface B which could receive snow – replace n(i) with the closest launch site on B

Stability model



Stability test obstacle cases

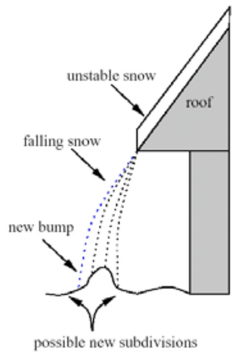
Snow on very steep surface



Stability model

Moving snow over edges

- Simulate avalanche by shooting a few (<5) particles over the edge



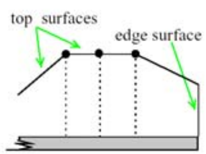
Stability model

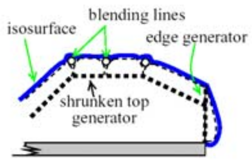
Stability termination criteria

- Algo completes if …
  - u1 becomes empty
  - it runs out of time
  - small moved amount of snow in last pass

Implicit functions

- Optional step
- Surface-based
  - Snow can only accumulate on supporting objects
- Unsupported snow:
  - Gap bridging
  - Edge bulges
  - Wind cornices
- Use implicit functions





Implicit functions

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- Implicit functions generate ISO-surfaces
- Marching cubes
- Mesh reduction

Bridging and clumping

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Implicit functions

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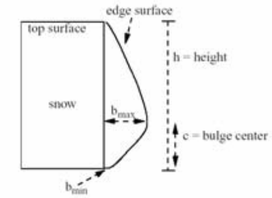
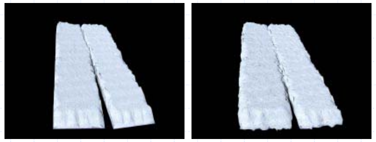
Bridge creation parameters





Before and after bridging

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Wind

- During accumulation
  - Flakes influenced by velocity vector (constant or precomputed field)
- During stability
  - Modified stability test
  - Transport dependent on wind

Scene without (left) and with wind (right)

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Validation

- Experiments (difficult)
- Observations in nature

Real (left) and computer generated model (right)

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Future work

- Add more physical properties
  - Snow compression and packing
  - Layers
  - Melting
  - ...
- Improve smoothness
  - Sampling method is noisy
- Real avalanches are more complex

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Modelling the accumulation of wind-driven snow

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- Snow accumulation combined with incompressible fluid flow techniques
- Compute flow field for wind around obstacles
- 3d grid
  - Cells inside obstacles marked as impermeable
  - Cells directly above upward facing horizontal surfaces: landing sites
- Flow field computation
  - Navier-Stokes equations
  - Boundary cells are initialized with the desired average wind velocity
  - Sequence of alternating mass- and momentum-conserving steps
  - Terminate when flow field has converged

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Wind-driven snow

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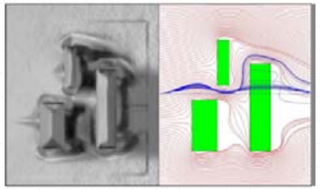
- Top view of the model and the flow field with highlighted streamlines
- Large amount of snow around 3 m tall obstacles



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Wind-driven snow

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- Direction of snow: Sum of field value and gravitation
- Landing cell
  - removes a portion of snow
  - stores it as resting on the corresponding surface
  - If large wind velocity, remove some snow from surface, return it to flow field
- Run stability procedure
  - Return unstable snow to flow field,
  - or pass it on to neighbours
- If necessary recompute flow field
- Generate height field
- Rendered as Catmull-Clark subdivision surface

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Examples

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Examples

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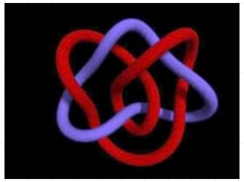
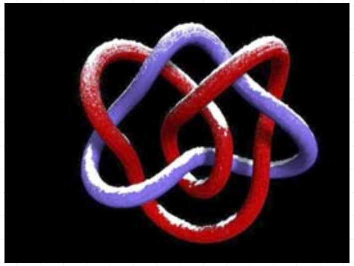
Examples





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References

- Fearing, Paul. Computer modelling of fallen snow. In Proceedings of ACM SIGGRAPH 2000, 37–46
  - Homepage: http://www.cs.ubc.ca/nest/imager/contributions/fearing/snow/snow.html
- Bryan E. Feldman, James F. O'Brien. Modeling the Accumulation of Wind-Driven Snow. In Proceedings of ACM SIGGRAPH 2002

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