Paul Fearing - Computer modelling of fallen snow
Feldmann, O'Brien - Modelling the accumulation of wind-driven snow

Christopher Nenning

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

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

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

Particle- vs. surface based

Accumulation model
- 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

Hit: surface receives snow
Miss: Blocked

Importance ordering
- Minimize sampling effort
- Maximize 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

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

Constrained Delaunay triangulation

Corresponding Voronoi diagram

Obstacle causes mesh improvement in transition zone

Initial mesh started with 8 launch 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

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

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

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.

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.

Stability model

Snow stability

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

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

Placement of affected sites in u2

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 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

- Alg 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

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

Bridge creation parameters

Before and after bridging

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)

Validation

- Experiments (difficult)
- Observations in nature

Real (left) and computer generated model (right)
Future work

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

Modelling the accumulation of wind-driven snow

- 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

Wind-driven snow

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

Wind-driven snow

- 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
Examples

Examples

References
