Directional Surface Wear via Tangent Flow Fields
A Small Geometry-Driven Experiment in Houdini

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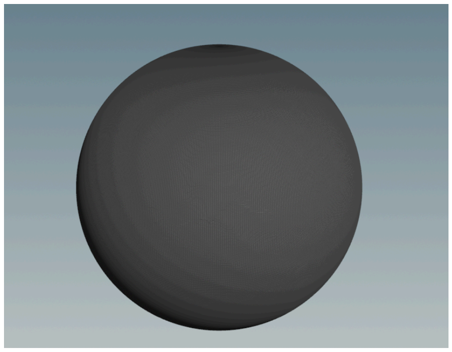
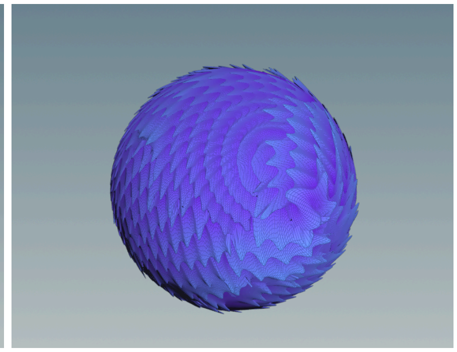

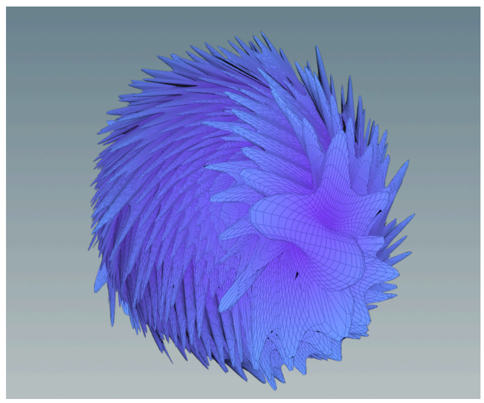

Abstract:

Most procedural wear techniques in visual effects are based on hand-painted textures, curvature masks, or isotropic noise. While these approaches can be effective in production, they often overlook a key aspect of real-world wear: direction. Erosion, abrasion, and polishing are processes that nearly always indicate some kind of flow, whether it is caused by motion, wind, gravity, or frequent contact.

In this technical article, we present a method for generating directional surface wear using only geometry-derived data and simple surface advection. By analysing surface curvature and normal-map details, we generate a flow field that follows the natural shape of the object. This flow field is then stabilised to prevent numerical artefacts in advection and used to alter the surface geometry, guided by an artist-created wear map.

The primary goal of the system is to be simple and transparent, serving as a clear methodological foundation for subsequent research, refinement, and comparative evaluation.

1. Introduction:

In production, wear is usually introduced later in the asset pipeline through manual texture painting, curvature-based masks, or layered noise setups. Although this approach often yields satisfactory results, the wear usually feels aesthetically flat and disconnected from the underlying form. Directional patterns, such as streaking, banding, or aligned breakup, are typically approximated through texture manipulations rather than being derived directly from the surface itself.

From a geometry-processing standpoint, this is notable because surfaces inherently encode rich directional information in their curvature and normal variations. Vector fields defined on surfaces are an effective tool for creating visual structure, as demonstrated by earlier computer graphics research (Hertzmann and Zorin, 2001).

Rather than implementing a full erosion simulation, which would introduce substantial complexity, this work focuses on a simpler, more focused question: can the surface geometry by itself provide a meaningful flow for directional wear?

Contributions:
This paper presents (1) a geometry-driven method for constructing tangent surface flow fields from curvature and normal information, (2) a stable surface advection scheme for generating directional wear patterns, and (3) a compact procedural implementation suitable for interactive graphics workflows.

2. Overview of the approach

Two observations serve as the foundation for the approach examined here. First, surface normals reveal fine details of the surface, while curvature describes its larger, overall shapes. Second, transporting material along a vector field that follows the surface enables the creation of directional wear patterns, transforming geometric cues into visually cohesive surface effects.

3. Constructing a surface flow field

Surface curvature provides a robust signal for identifying ridges, folds, and other large-scale geometric features. Per-point curvature values are computed using Houdini's *Measure SOP*, which implements standard discrete differential geometry operators on triangulated surfaces (Meyer et al., 2003). From these values, a curvature gradient is estimated using neighbouring surface samples to capture the dominant direction of curvature change.

To ensure that the resulting vectors remain aligned with the surface, we project the curvature gradient onto the local tangent plane induced by the surface normal. This projection removes the normal component, yielding a vector field that fully aligns with the surface and is suitable for driving directional wear.

To capture high-frequency directional variation beyond that provided by curvature alone, a tangent-space normal map is incorporated from the original geometry. The curvature-derived field is blended with the normal-map signal using a single scalar parameter, allowing continuous control over their relative contributions and producing a direction field with enhanced local variation.

$$\mathbf{g}_i = \sum_{j \in \mathcal{N}(i)} (k_j - k_i) \frac{\mathbf{P}_j - \mathbf{P}_i}{\|\mathbf{P}_j - \mathbf{P}_i\|}$$

Figure 1: Discrete curvature gradient estimated over a point neighbourhood

Early testing revealed that direct advection along the curvature gradient can introduce sinks in the vector field, leading to surface collapse. This behaviour is expected, as gradients of scalar fields are inherently curl-free and therefore induce convergent flow, which manifests as sinks when used directly for advection. This issue is mitigated by rotating the blended flow by 90 degrees within the local tangent plane, producing a divergence-free field.

$$\mathbf{g}_i \leftarrow \mathbf{g}_i - (\mathbf{g}_i \cdot \mathbf{n})\mathbf{n}$$

Figure 2: Projection of the curvature gradient into the surface tangent plane.

4. Applying directional wear

After establishing a stable tangent flow field, surface wear is applied by advecting points along the flow. This approach guarantees that material is removed consistently in the direction defined by the vector field, resulting in anisotropic wear patterns that closely align with the surface's geometry.

$$\mathbf{P}_{t+1} = \mathbf{P}_t + \mathbf{f} w(\mathbf{P}) s$$

Figure 3: Surface advection equation used to apply directional wear.

5. Implementation notes

The framework is fully implemented at the SOP level, combining procedural nodes with concise VEX to maintain transparency, control, and ease of adjustment. Geometric Gaussian curvature is computed with a Measure SOP, and curvature and normal maps are baked via Maps Baker SOPs, providing readily accessible surface attributes for downstream processing. Surface wear is synthesised through a Copernicus-based workflow, enabling fine-grained, texture-driven detail for realistic surfaces. Temporal dynamics are handled within a SOP Solver using two Attribute Wrangles: one for advecting surface properties and one for constructing the flow field.

The entire system requires fewer than fifty lines of VEX, yielding a compact, fully procedural pipeline that supports qualitative inspection, quantitative analysis, and iterative exploration of curvature-driven surface effects with minimal implementation overhead.

6. Results and observation

The technique produces consistent, visually coherent directional wear patterns on simple geometries such as spheres, with deformations aligned to the tangent flow field and exhibiting curvature-driven streaking and banding. The system is simple to control as patterns respond predictably to modifications in both geometry-derived curvature and artist-authored wear maps. By separating direction (from geometry) and magnitude (from texture), the approach provides an interpretable control model in which low-wear regions remain largely unaffected. At the same time, high-wear areas amplify directional distortion, enabling predictable and artistically guided surface modification.

While the method performs reliably on simple shapes, more complex surfaces expose certain limitations where stretching and distortion are most pronounced in regions of high curvature, thin features, or uneven topology. These artefacts arise because all deformations are performed directly in object space, without parameter-space transport or remeshing to help distribute errors. Quantitative analysis and visual inspection show that vertex displacement alone may fail to accurately track surface flow, particularly as feature size approaches the mesh spacing, suggesting that adaptive remeshing or hybrid strategies can help preserve surface accuracy.

Within these constraints, the method is most effective when applied as a visual overlay with moderate deformation strength or as a directional wear mechanism on relatively clean topology. Maintaining stability under stronger or prolonged transport requires additional infrastructure, such as adaptive remeshing, intrinsic surface parameterisations, or UV-space advection.

7. Related Work

Early investigations into physically inspired terrain and surface formation, such as Musgrave et al. (1989), demonstrated how procedural erosion models can generate realistic structures. In subsequent years, advances in geometry processing have demonstrated that surface-based vector fields serve as an effective tool for directing transport phenomena and sculpting fine geometric detail (Crane et al., 2013). In visual computing, carefully designing direction fields has been shown to enhance perceptual coherence, a principle widely used in illustrative rendering and stylisation techniques (Hertzmann and Zorin, 2001).

While these approaches provide realism or perceptual clarity, they often lack intuitive user control, require complex simulations, or are limited in interactive applications. In contrast, our approach unifies these insights into a straightforward, controllable framework that lets users interactively shape coherent surface features, providing an interactive, controllable, and visually plausible framework without the overhead of full physical simulation.

8. Limitations and scope

The scope of this work is to keep the method simple, transparent, and easy to interpret. We do not incorporate remeshing, UV-space transport, or fully physically based erosion models. Surface deformation is applied via point advection directly in object space. This can produce stretching or distortion in regions with complex geometry, including areas of high curvature, concavities, or uneven topology. These artefacts are a known limitation of surface transport techniques that operate in a parameterised domain or do not modify mesh connectivity. More advanced techniques, such as intrinsic surface parameters, dynamic remeshing, or PDE-based solvers defined on intrinsic or UV coordinates, can reduce distortion and improve accuracy; they also increase computational complexity and reduce interpretability.

Our approach does not model erosion as a physically driven process, nor does it enforce conservation of volume, mass, or material thickness. Surface deformation is guided solely by an artist-specified wear mask and a geometry-derived direction field, prioritising controllability and visual clarity over physical realism. Despite these limitations, this work demonstrates that even a simple, geometry-driven flow can generate coherent and visually meaningful wear patterns. Future extensions such as UV-space advection, remeshing, or physically inspired erosion could improve accuracy while maintaining interactive control.

9. Conclusion

This work demonstrates that simple surface advection, guided by a geometry-driven tangent flow field, can produce directed and visually coherent surface wear. While it does not physically simulate erosion, the method effectively captures directional patterns that would otherwise require extensive manual effort or complex texture workflows. The wear patterns it produces are directly linked to the surface geometry, making them predictable, controllable, and easy to understand. This framework shows how straightforward, geometry-driven methods can create detailed surface effects, offering a solid base for interactive, artist-driven modelling and opening the door to future enhancements with greater realism or physically based techniques.

By deliberately excluding remeshing, UV-space transport, and physical simulation, the approach isolates directional surface transport as a stand-alone mechanism and highlights the utility of geometry-derived vector fields for procedural modelling. Rather than a full erosion system, it functions as a controllable wear layer.

The method supports extensions such as parameter-space advection, erosion accumulation, GPU-accelerated implementations, or physically based techniques. This demonstrates that simple, geometry-driven mechanisms can generate rich, controllable surface detail, providing a practical and interactive tool for artist-guided surface modelling.

References

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