PARTICLE STAINING: PHYSICALLY BASED TEXTURE GENERATION

A Thesis

by

JEAN MICHAEL MISTROT

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2003

Major Subject: Visualization Sciences

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Approved as to style and content by:

Donald House (Chair of Committee)	Richard Davison (Member)
John Keyser (Member)	Phillip J. Tabb (Head of Department)

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ABSTRACT

Particle Staining: Physically Based Texture Generation. (December 2003)

Jean Michael Mistrot, B.F.A., Pennsylvania Academy of the Fine Arts

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Computers are being employed in a variety of ways by a variety of individuals to create imagery. Much work has been done to accurately model natural phenomena in the context of computer graphics as well as model specific artists' tools and techniques.

Focusing on the dynamics of water flow across surfaces, it is the goal of this work to develop a physically inspired texturing tool that allows artists to create interesting staining and wearing effects on surfaces. Weathering or the wearing down of materials by natural forces can create complex and beautiful patterns on a variety of surfaces. In this process lies the very essence of the creative act.

To distill the essence of the elements of the water staining process, we employ a computer generated particle system in a phenomenological model. The motion of these particles is controlled by physically based constraints, such as wind, gravity, mass, etc. The way in which each particle interacts with or modifies the look of the surface is further controlled by parameters such as surface roughness, surface color and surface hardness. Each particle can remove or deposit material as it flows across the surface, creating complex patterns.

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CHAPTER I

INTRODUCTION

Fascination with pattern is a universal human trait. It is, in essence, the way by which we understand all things. From the moment we open the doors of perception we begin to compare, correlate and link patterns. The sound of a voice, the color of the sky, the warmth of breath, theses things form our universe layer upon layer as they flow through us. Figure 1 shows the familiar spiral growth pattern of a Coneflower [1]. While the Fibonacci sequence can describe this pattern mathematically, it is a product of our perception and not a structural element of the flower. It is this process of perception that has traditionally been the domain of the artist. Playing to and playing with our perceptions, artists attempt to widen the way in which we see not only the world around us, but also our position in and relation to that world. Humans strive for understanding.

This thesis follows the style and format of *Leonardo.*

Fig. 1. Pattern in nature.

The artist's hand holds a brush and paints upon canvas combining and recombining in an effort to form beauty. Not only observation but also the act of painting itself brings insight. Nature too is an artist. We are inspired by natural pattern and therefore natural process. Not only is mankind awestruck by the beauty of undulating clouds but also by the complex interaction of sun, water, earth and sky that causes this phenomenon. It is these things that nature holds in her hand as she paints upon our perceptions. Is it possible to weald such tools or some facsimile there of?

Visual perception is refracted into the visible spectrum of light, synthesized into paint and recombined using the tools of a painter. New forms arise and pass away as the artist combines and recombines the basic elements of various paradigms. Associations are formed as the mind attempts to incorporate what it currently perceives into its library of past experiences. This is the continuum of the creative process.

Just as visual perception is synthesized and recombined through the act of painting, the dynamics of a physical process can be, to some degree, broken down, distilled and reapplied. The understanding and abstraction of such a process suggests the creation of artist's tools that exhibit elements of the process. It is the goal of this thesis to create such a tool.

THE WATER STAINING PROCESS

Focusing on the dynamics of water flow across surfaces, it is the goal of this work to develop a physically inspired texturing tool that allows artists to create interesting staining and wearing effects on surfaces. Weathering or the wearing down of materials by natural forces can create complex and beautiful patterns on a variety of surfaces. The image below (Fig 2) is a beautiful example of a pattern generated by the weathering of metal and paint. In this process lies the very essence of the creative act.

Fig. 2. Rust stained paint.

To distill the essence of the elements of the water staining process, we employ a computer generated particle system in a phenomenological model. The motion of these particles is controlled by physically based constraints, such as wind, gravity, mass, etc. The way in which each particle interacts with or modifies the look of the surface is further controlled by parameters such as surface roughness, surface color and surface hardness. Each particle can remove or deposit material as it flows across the surface, creating complex patterns such as the one seen in Figure 3.

Fig. 3. Water-stained surface.

It is not the goal of this work to accurately recreate the characteristics of fluid flow or even the visual effects of such a flow on a surface. Rather the goal is to offer artists another avenue by which they can create work inspired by and directly drawn from, dynamic natural phenomena. By being able to manipulate the various parameters that control the model of the water staining process, artists are presented with a dynamic and interactive tool for creating complex, physically inspired patterns.

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While such an artistic tool employs physically based phenomena, it is not constricted by the demand for visual realism. Thus, the driving force behind this work is the final artifact of creation generated by the curious dabbling with dynamic forces propagated by the artist.

WHY COMPUTERS?

The computer's ability to encode and emulate any process together with its capacity for abstraction makes it the ideal artist's tool. Informed users have the ability to manipulate how and what the computer acts upon. The computer is a very simple machine. It is only able to work with two basic elements or states, one and zero or on and off. However by combining these basic elements in different ways users can create very complex structures. Figure 4 is a whimsical representation of this process. What gives the computer its usefulness is its ability to compare large numbers of these structures at great speeds channeling the results into secondary and tertiary subroutines.

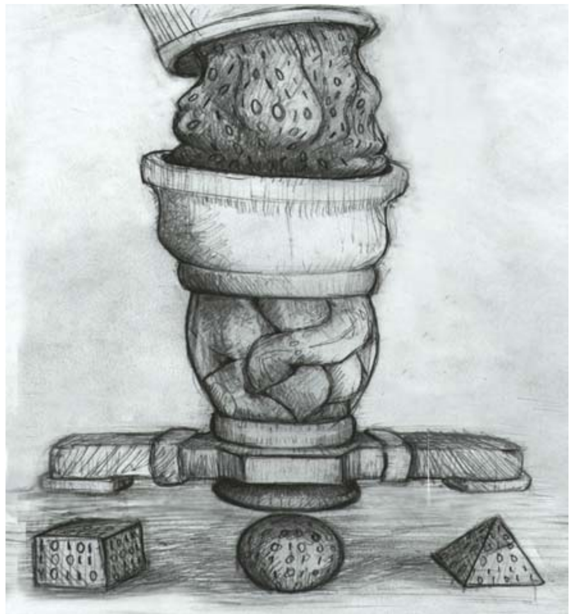


Fig. 4. “The Great Abstractor”.

Furthermore programmers are not only free to define structures in any way they see fit but are also able to define how and when the computer organizes and compares these structures. It is common practice to form structures within structures as well as methods for these abstractions to interact. One might envision these structures in a similar manner to that presented in the drawing below (Fig 5).

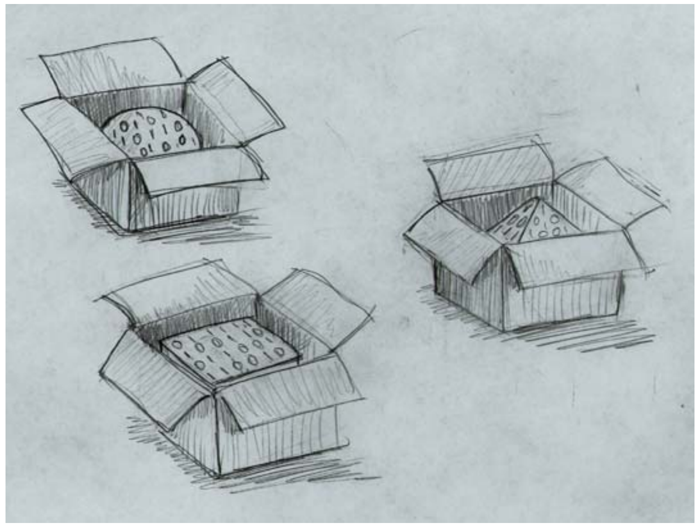


Fig. 5. A representation of abstracted structures.

The computer offers us the ability to compare many forms of input on many different levels, each comparison affords us the opportunity to craft intricate lattices of branching and looping data pathways creating layer upon layer of computational metaphor. Computer computation is a process that can be molded to imitate physical as well as a variety of other complex processes.

With this tool in hand, the artist is inspired to create new and interesting mappings across complex data sets. The artist might ask questions like: “What is the color of network traffic?” or “What does the velocity of a particle system sound like?” and “How might we visualize the rise and fall of world markets juxtaposed with the death rate in third world countries?” In this paradigm of ‘data-mapping’, information becomes the paint and palette and the computer the brush.

CHAPTER II

BACKGROUND

Computers are being employed in a variety of ways by a variety of individuals to create imagery. Much work has been done to accurately model natural phenomena in the context of computer graphics as well as model specific artists' tools and techniques. Even artists themselves have begun creating incarnations of computer tools for the creation of aesthetic work. I have divided the following examples into two basic categories: imitative and creative.

The imitative category denotes work whose primary aim is to reproduce as accurately as possible the look of a natural process. This work is relevant in that it analyzes a process and then develops tools to manipulate and model that process.

The creative category refers to work that uses a process to create new forms of visual expression by allowing the user to either interact with or directly manipulate those processes. This type of work is relevant in that it exploits the computer's inherent comparative abilities by allowing the user to set up or drive interesting data-mappings. A very simple example of the concept of data-mapping can be seen above (Fig.6). In this drawing numerical values are represented by shades of grey.

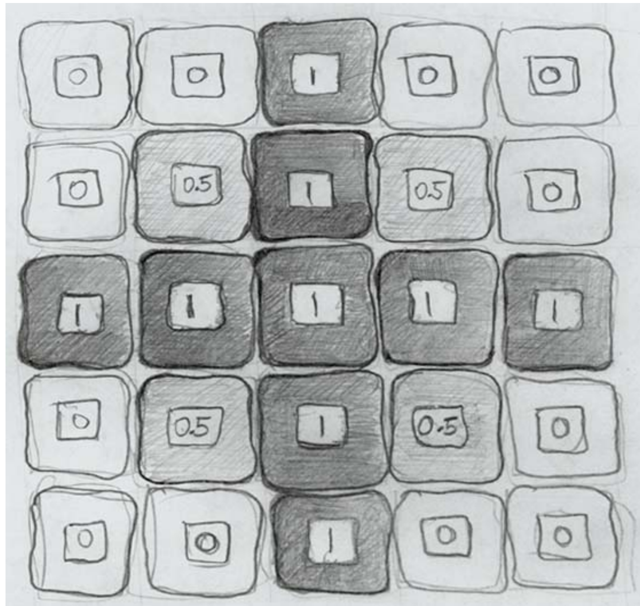


Fig. 6. Numerical values represented as shades of grey.

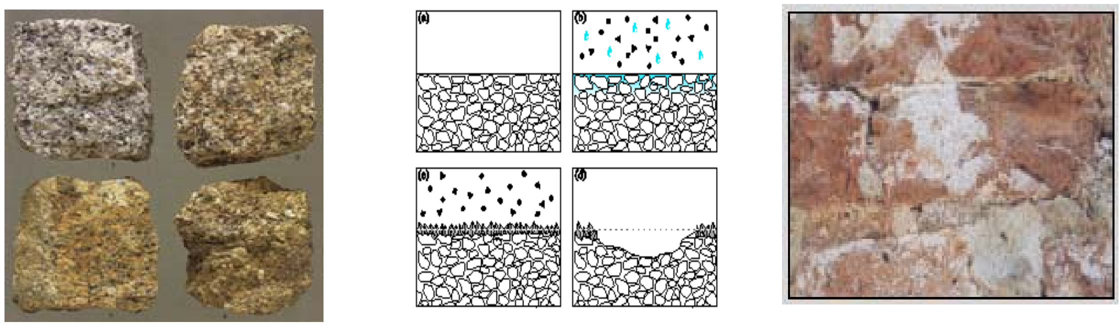
IMITATIVE WORK

Computer graphics researchers have used computer simulations extensively in their quest to achieve the look of realism with regard to natural processes. A phenomenon is observed and then an attempt is made to break down the process or processes that apparently cause it. This distillation of information is then fashioned into a model that a computer can employ to visually imitate the original phenomenon. The following work focuses on the artifact left behind by a natural process and for that reason is particularly relevant to this thesis. It is instructive to note that in each case the process of design can be broken down into four stages: concept, observation, distillation and modeling.

Modeling and Rendering Weathered Stone

Julie Dorsey et al. [2] developed a method to model and render the changes in shape and appearance of stone due to the weathering process. They break down the process into three major components: *rock and stone, stone weathering effects* and *stone wearing effects.*

1. *Rock and stone*, is classified into three major groups, igneous, sedimentary and metamorphic. (Fig. 7a)
2. *The stone weathering process*, is simplified and represented as the travel of moisture, the dissolution and re-crystallization of minerals, the chemical transformation of minerals and the deposition of atmospheric pollutants. (Fig. 7b)
3. *Stone weathering effects,* are derived from observations from nature and are divided into four categories; cornerstone weathering, yellowing, case hardening and efflorescence. (Fig. 7c)



a. b. c.

Fig. 7. Components of stone weathering. (a) Various rock types. (b) Travel of moisture. (c) Weathering

Dorsey et al. model this phenomenon by applying what they call a ‘slab’ structure to input geometry. Slabs are tri-linear volumetric entities aligned with surface boundaries. Each slab is voxelized creating a sampled density function. This volume is given procedurally generated material properties. A simulation is run modeling the effects of water and weather on this volume set. The value of the density function at each node is manipulated by the use of different erosion events representing the natural processes of moisture travel, clay formation and the dissolution and re-crystallization of minerals. The resultant data is then used to create images that exhibit the visual look of weathering effects on various types of stone. Figures 8a, 8b and 8c are examples of images created using Doresy’s model of weathered sandstone granite and marble respectively.

a.

b.

c.

Fig. 8. Computer generated weathering effects on various types of stone. (a) Eroded sandstone column. (b) Eroded Granite sphinx. (c) Stained and eroded marble statue of *Diana the Huntress.*

Modeling and Rendering of Metallic Patinas

Dorsey and Hanrahan [3] attempt to simplify and model the process of metallic patina formation due to exposure. As a result of the complex nature of the corrosion process, they chose to approach the problem in a phenomenological manner opting to merely reproduce the look of observed physical behavior.

Copper was used as the basis to observe the formation of patinas. Copper patinas are formed through the process of atmospheric corrosion. When exposed to the atmosphere copper develops a layer of tarnish that forms a base on which deposits of copper oxides, sulfides and inorganic and organic copper salts can grow. Figure 9 is a schematic diagram of the processes involved in the growth of copper patinas in different atmospheric environments.

The development of metallic patinas is modeled as a building up of a layered structure through the application of coating and eroding operators. These operators are regulated by a series of maps that specify coat material thickness, erode thickness, polish height and fill material height. A surface growth model seeded by particles is then used to simulate the variation of thickness over time.

Figure 10 is a diagram of randomly seeded particle placement and movement. Further care is taken when rendering the final images to model the reflection and transmission of light through the layered structure. Figure 11a depicts progressive stages of patina growth. Figure 11b is an example of a computer generated patina applied to a model.

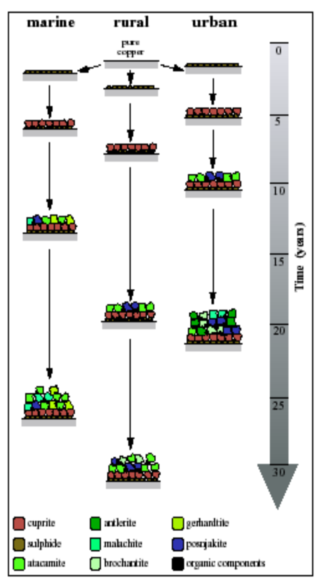


Fig. 9. Idealization of patina formation.

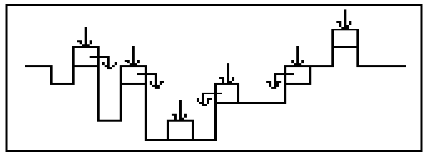
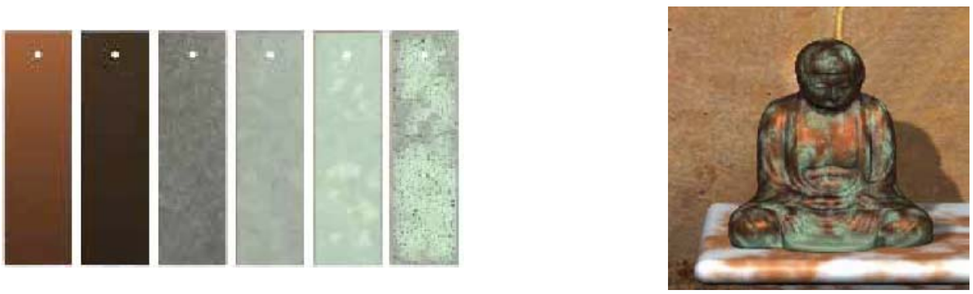


Fig. 10. Random particle deposition.



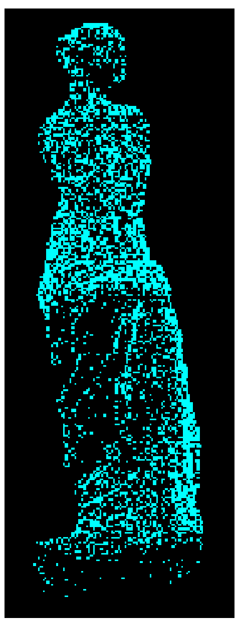
a.

b.

Fig. 11. Computer generated patinas. (a) Sample strips exhibiting different states of corrosion. (b) Patina applied to a bronze statue.

Flow and Change in Appearance

The final example in this category is one that is very closely related to this thesis. Dorsey et al. [4] are once again concerned with imitating the look of the artifact left behind by a natural process rather than accurately modeling the process. A phenomenological model is employed to simulate the washing and staining of a surface by water flow. A particle system is used to model this flow. Geometric surface descriptions are augmented by a set of texture maps that represent surface saturation, loose deposit concentration and color. The particles are placed on the surface based on a distribution function for incident rain and then allowed to flow across it depositing and removing sedimentation. Figure 12a is an example of the particle distribution applied to the surface of the *Venus de Milo*. The process of washing and staining is further regulated by a simple set of rate equations that defines the way in which the particles interact with the surface description. The final images are produced by rendering the base material and then compositing the textures generated by the simulation over them. Figure 12b shows the *Venus de Milo* after the simulation has been run on its surface.



a.

b.

Fig. 12. Computer generated Venus de Milo. (a) Particles placed according to distribution of incident rain. (b) Flow patterns applied to the *Venus de Milo*.

In all of these examples the computer is used to compare simplified abstractions of a natural process in an attempt to imitate the beautiful patterns that these processes create. It should be noted that in all of these cases even though a fairly thorough understanding of the science behind the natural process exists, it is the visual pattern that guides and ultimately justifies the implementation of the model.

CREATIVE WORK

The number of artists who use the computer in their work is on the rise. Their work is helping to move the computer out of the lab and into the studio. Of particular interest in this quickly growing genre is work that employs familiar processes to create new combinations or mappings of information. The examples below have particular relevance in that they are interactive, and thus promote collaborative creation.

Signwave Auto-Illustrator

Auto-Illustrator [5] (Fig. 13) is a vector graphics-authoring tool. The application presents the user with a familiar set of tools akin to those found in Adobe Photoshop or Adobe Illustrator. What separates this program from your average graphics application is the way in which it maps your intent. By using procedurally generative techniques Auto-Illustrator interprets the user's input, allowing for creation of interesting shapes and forms that the user may have otherwise never envisioned.

An example of this can be seen in the bug tool. The bug tool allows the user to place *bugs* anywhere in the composition. A small options panel (Fig. 14) allows the user to interact with the bugs by adjusting such parameters as nervousness, attention, maturity and distraction. The bugs then use whatever brush is currently active to create buggy patterns on the canvas. The random nature of this tool changes the way the user perceives the act of creation by adding a healthy dose of indeterminacy.

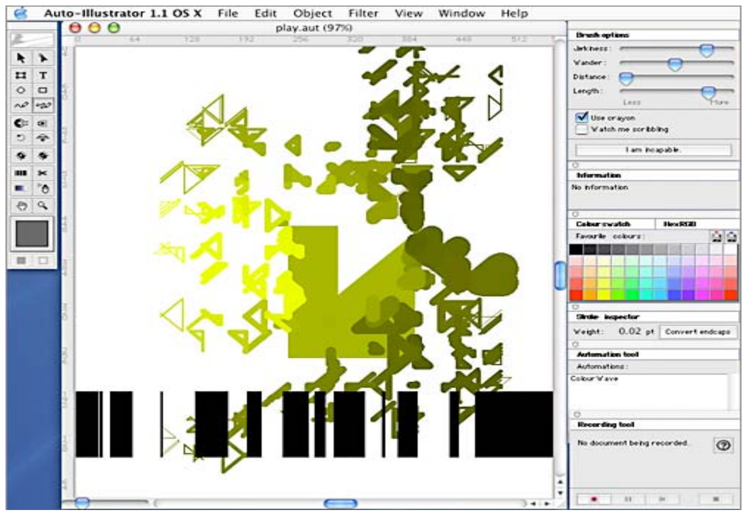


Fig. 13. The Auto-Illustrator application.

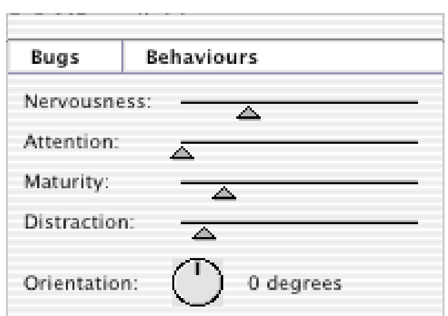


Fig. 14. Auto-Illustrator: Bug behaviors control panel.

CollageMachine

Kerne's [6] CollageMachine (Fig. 15) is another example of an application attempting to interpret the intent of the user to create interesting imagery. CollageMachine is an adaptive web browser. The application searches for and retrieves web content based on users' interaction with it. Each document retrieved by CollageMachine is contextually broken down into information elements. This content is then placed in the application window based on its relevance. All elements of the continually forming collage are processed to promote visual cohesion when viewed side by side. The users are free to arrange this content in any manner they choose.

Fig. 15. One state from a recombinant knowledge space session, featuring work in visualization and computer science at Texas A&M.

Using tools provided in the interface, a participant can delete, enlarge and associate positive or negative intent with each new element. CollageMachine tracks and interprets this interaction and responds accordingly by attempting to only collect things the user might want. CollageMachine slowly learns as interactions with the user increase and its experiences expand. By providing a recombinant space CollageMachine and the user work together to re-contextualize web content.

Yellowtail

Yellowtail [7] (Fig. 16) is a small interactive java application written in the scripting language called Processing being developed in the Aesthetics Computation Group at the MIT Media Lab. This simple little program allows the user to draw arabesques across the window. After the participant finishes a stroke Yellowtail begins to re-create the gesture used to pen the mark. An intricate pattern of form and motion emerges as the user adds more and more marks.

Yellowtail is just one of many programs at <www.proce55ing.net> that participants can playfully use to create a variety of imagery. Almost all of these small applications attempt to engage the user in the act of pattern recognition and creation. These art applications intuitively engage participants to explore and create new visual representations of familiar and unfamiliar input.

Fig. 16. A screen-shot of a Yellowtail composition.

CHAPTER III

METHODOLOGY

WATER STAINING: BREAKING DOWN A PROCESS

The project described in this thesis shares traits with work belonging to both the "imitative" and "creative" categories. Because this tool attempts to model a natural process it employs developmental methods similar to imitative work. These methods are the four stages of concept, observation, distillation and modeling. As Figure 17 suggests, the process of applying these methods is cyclically interconnected and iterative in nature. An idea for a tool is developed.

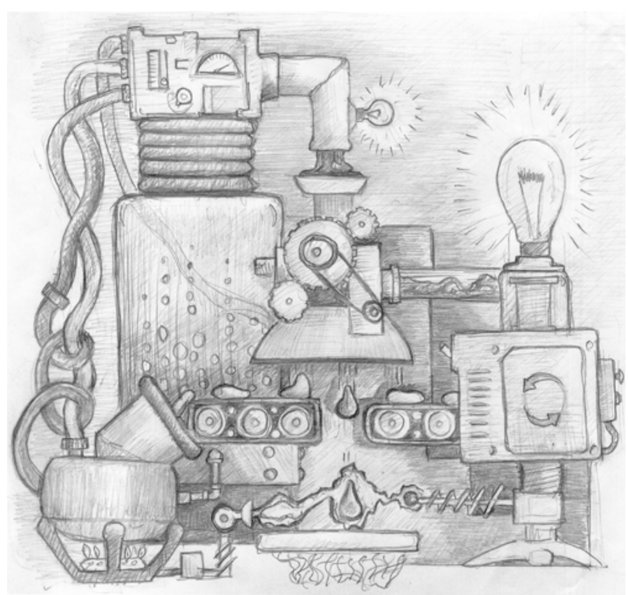


Fig. 17. "The Process of the Discovery Process"

The process that is to be modeled is observed and abstracted or simplified. Finally with this simplified or abstracted understanding of the process the construction of a model representing this process takes place. It should be noted that the end goal of this project is not to create an accurate simulation of a natural process but rather to create a tool that is able to re-contextualize that process.

The following sections describe the development process of this research. For convenience and brevity, observation and distillation have been lumped together as the latter springs forth naturally from the former.

CONCEPT

From its inception it was my goal to create an interactive tool that not only described a natural process but also offered its user a very high level of artistic control over that process. A tool was envisioned that would allow the user to employ the dynamics of a natural process to compare, recombine and manipulate potentially divergent forms of data.

Patterns

The intricate patterns created by water such as those below (Fig 18), are fascinating. Water and its motion hold deep symbolism in many cultures and cosmologies. Continually breaking down and building up, water shapes the world around us. It is perhaps the most destructive and yet creative force on our planet. The flow of water across a surface and the marks that it leaves there are symbolic of the creative act. It is for these reasons that this process was chosen as the inspirational guide for the development of this tool.

Fig. 18. A sedimentation pattern created by water flow.

OBSERVATION & DISTILLATION

The analysis presented below is an idealization of the water staining process broken into three very general areas: Dynamic Attributes, Surface Attributes and Fluid Attributes. While this description may seem very coarse, the focus is not on accurately modeling fluid flow across surfaces but rather on reproducing the general look and feel of the process.

DYNAMIC ATTRIBUTES

Natural Forces

Gravity and wind are the first and most obvious forces acting on the system. Gravity is a constant acceleration drawing fluid downward to the lowest point on a surface. Wind acts as an intermittent shaping force sculpting the nature and direction of fluid flow through space.

Wearing, Staining and Sedimentation

The staining of surfaces can generally been seen as the result of water picking up or dissolving small bits of material (wearing) and re-depositing them elsewhere (sedimentation). Different materials have different responses to this process. Figure 19 is an example of a staining and erosion pattern left on cement by water runoff.

Fig. 19. A staining pattern on concrete caused by water flow.

Fluid itself can contribute to the pattern generation process by adding its own color contribution in the form of chemical reaction. Material properties that affect the way in which surfaces are stained include, among others, topography, hardness and roughness.

Roughness and Dispersion

Moving objects will tend to follow the path of least resistance, and this insight holds true for fluid flows. By examining the way in which fluid is diverted as it flows across surfaces, a correlation can be drawn between the amount of dispersion experienced by the flow and the degree of roughness possessed by the surface. In other words, the smoother a surface is, the less the fluid will be diverted from its original course. In the image below (Fig. 20) fluid disperses quickly as it flows across a rough concrete surface.

Fig. 20. Water dispersing across a rough surface.

Erosion and Channeling

As fluid acts upon a surface over time, areas of wear and sedimentation begin to develop into small peaks and valleys. These microscopic features promote the formation of channels or flow lines as fluid is guided along them into lower lying regions. This phenomenon can be observed quite easily in this satellite photo of the Mississippi Delta (Fig. 21).

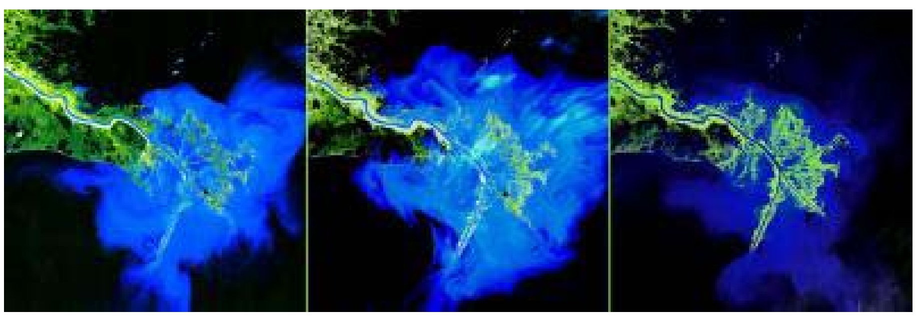


Fig. 21. LandSat images of the Mississippi Delta.

Adhesion

Fluid flowing along the underside of a surface tends to want to adhere to the object it is flowing across. A drop of dew clinging to a blade of grass demonstrates this dynamic quite effectively (Fig 22). While the process that causes this phenomenon is very complex the general dynamic can be easily modeled. Simply, if the velocity of a flow is great the fluid will be less likely to adhere to the surface.

Fig. 22. A drop of dew clinging to a blade of grass.

SURFACE ATTRIBUTES

Color

Every surface exhibits some form of coloration. It is the combination recombination and modification of these colors through the wearing staining and sedimentation process that creates intricately beautiful patterns across surfaces.

Hardness

Surface hardness varies from material to material playing an important role in the process of sedimentation. The hardness of a surface, such as those depicted in Figure 23, dictates the probability that a piece of material will be removed by passing fluid. If a material is soft it will easily crumble and wash away. Conversely very hard surfaces such as granite may take years to lose material to the process of erosion.

Fig. 23. Material of varying degrees of hardness.

Roughness

Surface roughness is similar to hardness in that it too plays a significant role in the way sedimentation occurs on surfaces. This attribute also guides the dynamic of fluid dispersion. Figure 24 shows a close-up of a piece of brick in profile. Note the small undulations across its surface. The peaks and valleys of rougher surfaces tend not only to attract but also to disperse sediment. It can be observed that the rougher the surface, the more likely the tooth of that surface is to catch passing sediment as well degrade fluid cohesion.

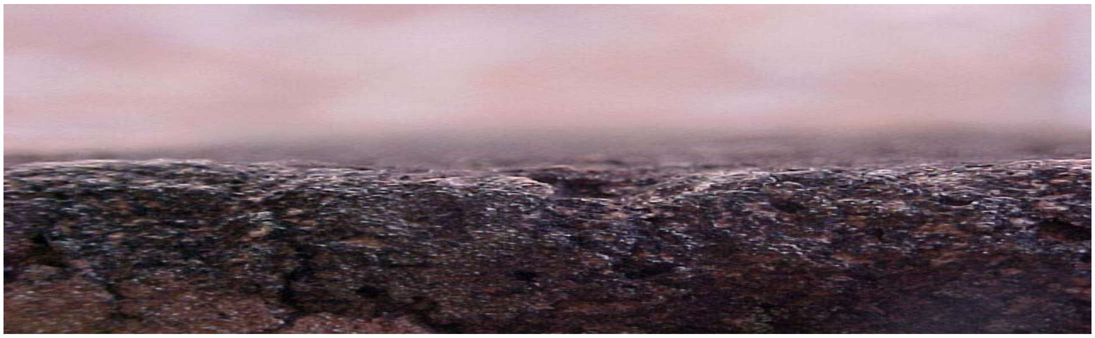


Fig. 24. The profile of a rough surface.

Fluid Attributes

In the staining process fluid can be thought of as discrete units or droplets. These droplets travel across the surface picking up and transporting deposits of material from one place to another. Droplets not only have the ability to transport material but can also stain that material and thereby contribute their own color into the overall palette of colors.

MODELING

Conforming to the initial goals of this project, where appropriate, design decisions were guided by the need to maintain inter-activity and real-time display. The following sections are organized in such a way that they follow the life cycle of a droplet through the various stages of the overall process.

Particle Systems and Falling Bodies

Particle systems have been used extensively in computer graphics to model everything from trees and grass to water and fire [10, 11]. For example figure 25 shows a firework explosion modeled with a particle system. Very often particle systems are the vehicle of choice to model such phenomena due to their ability to represent complex behavior using a simple system of rules. A good description of the techniques used to model the motion of particles can be found in Barraff and Witkin's "Physically Based Modeling Course Notes" [12].

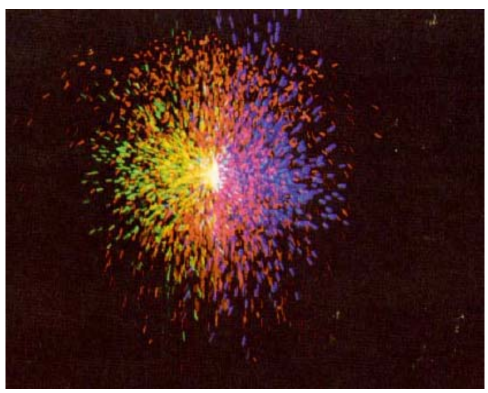


Fig. 25. A fireworks display created with a particle system.

Due to the complex and computationally expensive nature of accurately modeling fluid flow with particles, for our system a very simple set of rules was chosen to achieve an approximation of this process. This simplification allows maintenance of real-time interactivity. Employing a fourth-order Runge-Kutta integration scheme, particles are modeled as falling bodies acted upon by the forces of gravity and wind. The use of particle emitters under user control allows a high level of user guided control over the flow of droplets.

Objects and Collision

Surfaces are generally described in computer graphics as either being parametric or polygonal. In both cases points in three-dimensional space describe the geometry of a given surface. Polygonal surface descriptions are used throughout this work. Polygonal surfaces are typically broken up into two basic elements, triangles or quadrilaterals. Many algorithms exist to determine whether or not a particle has collided with a surface. A very useful collection of a few of these can be found in Akenine-Moller and Haines book *Real-Time Rendering* [14]. The use of triangles has the advantage of ensuring that all surface fragments are planer. This is very useful in terms of collision detection as it is very difficult to determine if a particle has hit a facet of a polygonal surface if it is not planar.

To maintain speed and interactivity during collision detection, the triangles that describe the surface are organized into a hierarchical binary tree structure sometimes referred to as an AABB tree [15]. Figure 26 is a visual representation of such a structure constructed around a simple polygonal mesh. The AABB structure is built by recursively creating axis aligned bounding boxes of successively smaller size. In this way it can quickly and easily be determined whether a particle is near a given triangle or group of triangles by comparing its position to the maximum and minimum values of the bounding volume. If it is determined that the particle is near a triangle then the more computationally expensive collision check is performed so that the particle can respond by either reflecting its velocity or continuing on its present course.

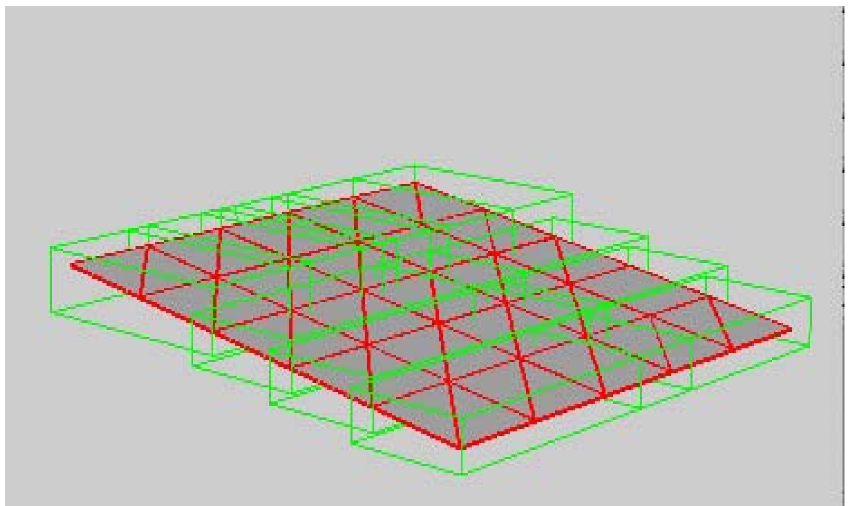


Fig. 26. An AABB tree constructed around a polygonal mesh.

Surface Collision and Adhesion

Once it has been determined that a particle has collided with a surface, the following questions need to be addressed:

1) Where on the surface has the particle collided? (i.e. which triangle and where on the triangle?)
2) Is the velocity of the particle such that it should adhere to the surface?
3) If the particle is already on the surface and adhering should it continue to do so?

To answer the first question it is necessary to accurately locate the point of collision in space so that the velocity and direction of the particle can be modified appropriately. This is achieved by employing a bounds checking algorithm in the baricentric co-ordinate system of the relevant triangle. The algorithm used can be found on pg. 581 in [14]. This algorithm returns three values usually denoted as *u*, *v*, *w*, that allow the system to know exactly where the particle is in terms of the three sides of the triangle. The drawing above (Fig 27) represents a particle as it relates to the baricentric coordinate system of a triangle face.

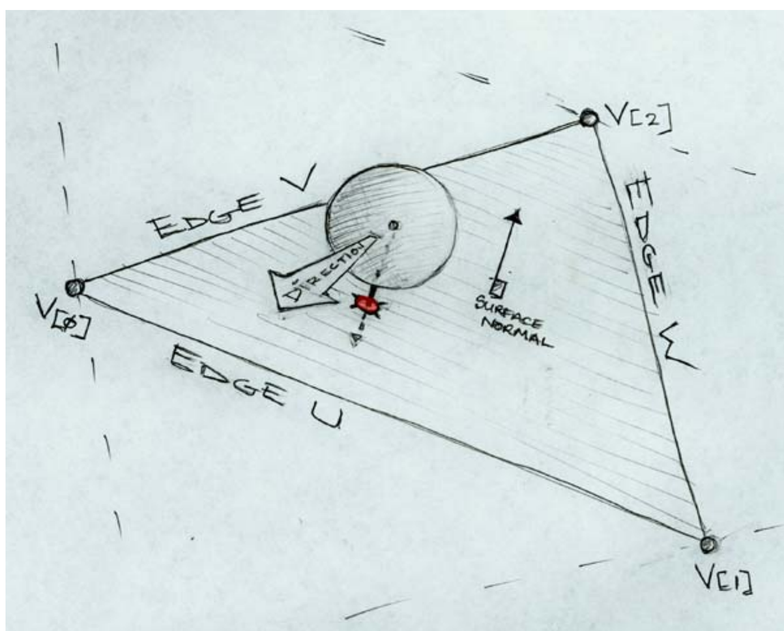


Fig. 27. A particle's location in the *u*, *v*, *w*, coordinate space.

Once the particle is known to be on the surface a decision is made as to whether or not adhesion will occur. To model adhesion, two factors are considered. First, is the particle traveling along the under side of the surface and second if so, is its velocity such that it should adhere to the surface as depicted in Figure 28.

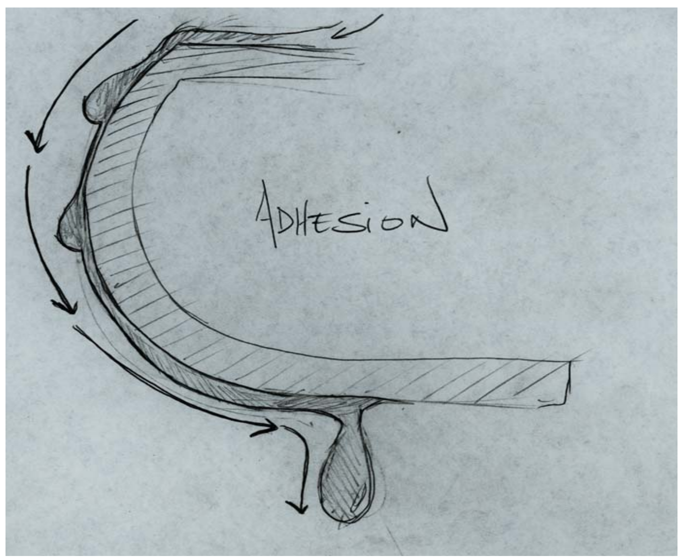


Fig. 28. Adhesion simplification.

By comparing the magnitude of the component of the velocity of the particle normal to the triangle's surface with a predetermined scalar value representing adhesion, a determination is made whether or not the particle should adhere. If this magnitude is less than the adhesion term then the component of the velocity normal to the surface of the triangle is subtracted from the system. This causes the particle to stick to the surface. The constituent parts of this algorithm are presented in Figure 29.

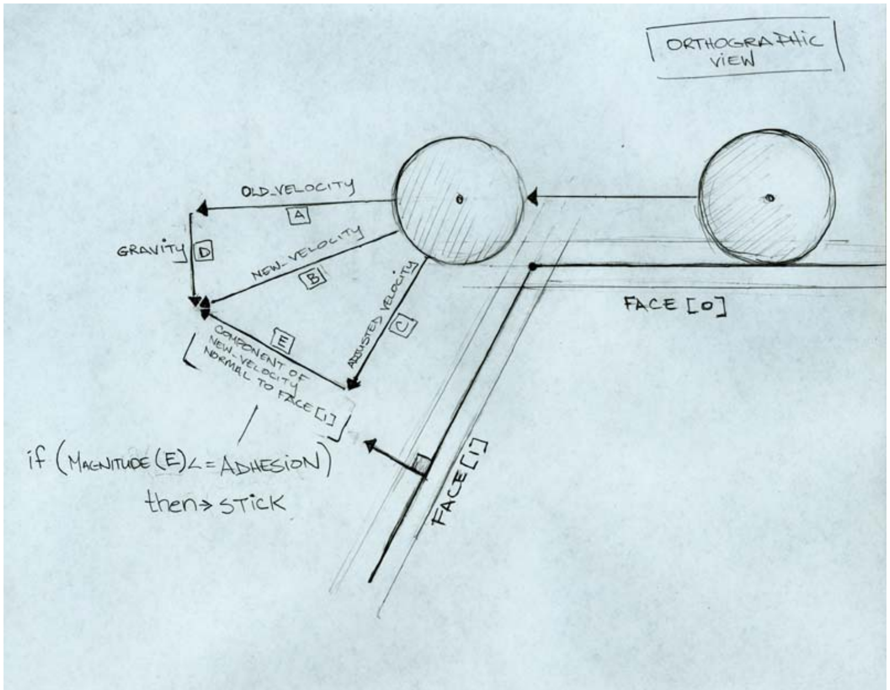


Fig. 29. Face crossing and the adhesion calculation.

As the particle moves along the surface it is necessary to keep checking its position in order to correctly adjust its direction and velocity. This is accomplished by keeping track of the baricentric coordinates of the particle. If at any time these values fall below zero the particle has crossed a triangle boundary and its position must be reevaluated. If it has crossed on to the surface of another triangle face, as the particle shown in Figure 29 has, question two needs to be reapplied adjusting the particle's velocity appropriately. If the particle has crossed the triangle boundary and there are no more triangle faces in its immediate vicinity it will continue falling and be passed back to the general collision routine.

DEPOSIT MAPS

Surface Topography

Mention was made above of the role that a material's roughness plays in not only dispersing fluid flow across a surface but also in promoting sedimentation. To achieve a reasonable amount of surface roughness using a polygonal model, it would be necessary to use a large number of triangles. This would in turn require an exorbitant amount of memory and be computationally prohibitive. For this reason, texture maps are employed to represent the microscopic local geometry created by inherent material properties and the process of wearing and sedimentation. The map that represents inherent material roughness is considered to be constant, while the map or combination of maps that represents wearing and sedimentation is dynamically updated as the system runs. As the particle travels across the surface, roughness data from the texture at the particle's current location is used to calculate a local roughness value. This value scaled by a user manipulated roughness term is used to modify the particle's trajectory when appropriate. The data that these maps hold is accessed in the standard parametric way. Color information is obtained by employing a zero to one coordinate axis as seen in Figure 30.

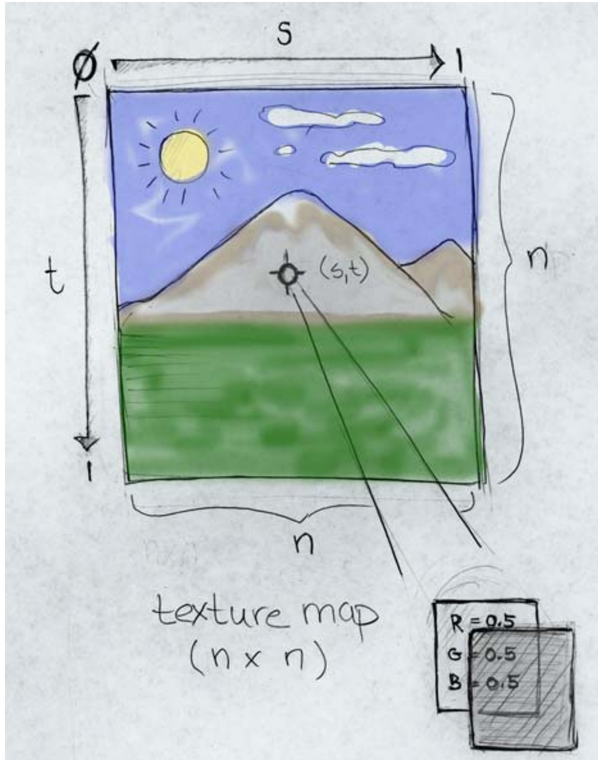


Fig. 30. Parametric texture data access.

Deposits Stacks

To approach the topic of Flow Dynamics it is necessary to understand how deposits that are removed and replaced by the wearing and sedimentation process are represented in the system.

The image below (Fig 31) is a visual conceptualization of the deposit structure. Each surface can be seen as being made up of a finite number of discrete deposits. Depending on an initial thickness value entered into the system by the user, a number of deposits are stacked on each other as represented below (Fig. 32).

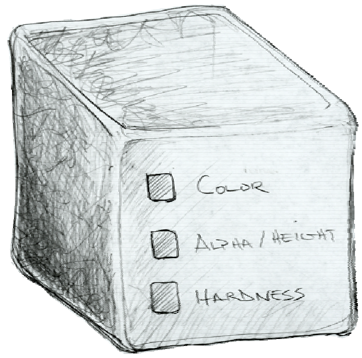


Fig. 31. The Deposit structure.

Each deposit has three basic attributes: color, height and hardness. These values are all derived from texture maps input by the user. Deposits are mobile and can be arranged and rearranged creating different stack combinations. This shuffling process dynamically changes the color and topography of the surface. The varying stack heights across the surface are used in the calculations that model flow dynamics and channeling.

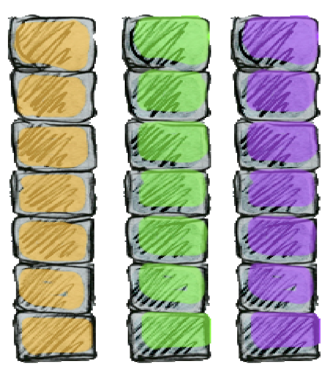


Fig. 32. Deposit stacks.

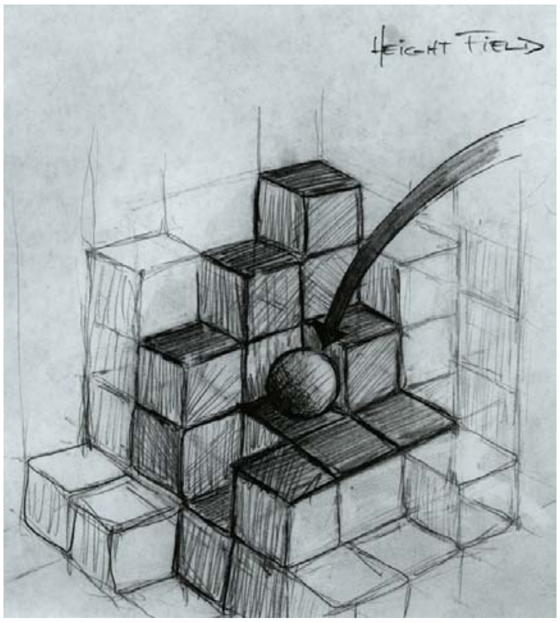
FLOW DYNAMICS

As a droplet flows across a surface its motion should be appropriate to the topology of that surface. As mentioned in the *Observation and Distillation* section above, fluid tends to want to seek out the lowest ground. Visually this is seen as dispersion and channeling

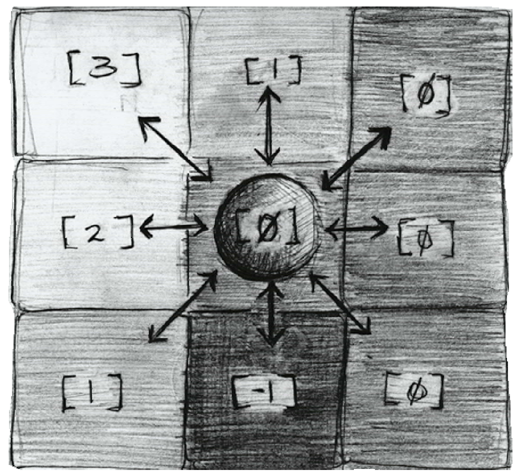
Dispersion

Dispersion is directly linked to surface roughness and the deposit stack structure mentioned above. Figure 33a is an example of how the relationship between a droplet and the position it occupies in the deposit stack height-field might be visualized. Summing the height value of all the deposits in a given stack and comparing them to the summed value of neighboring stacks produces a number that is used to represent the local degree of roughness due to the current state of wear and sedimentation. The numbers in Figure 33b represent the height stack value at each pixel used to make this calculation.

This local roughness term is used in conjunction with the inherent roughness value and the global roughness value mentioned above, to perturb the direction of the particle as it passes over the region. As seen in Figure 34, the dynamic of dispersion is achieved by rotating the direction of the droplet around the axis normal to the triangle the droplet currently inhabits. The amount of rotation applied is calculated in a probabilistic manner using a Gaussian distribution whose standard deviation is scaled by the combined roughness term. The resulting range of rotation values falls between +90 and –90 degrees with the majority of values being distributed around the mean.



a) A 3D visualization of a particle and the local height-field surrounding it.



b) A particle and its local height-field used to calculate the flow-vector and local roughness term.

Fig. 33. Stack height-field visualizations.

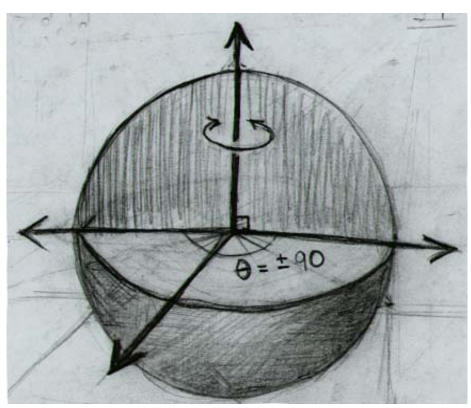


Fig. 34. Axis of rotation due to dispersion.

Channeling

The values used to model the channeling dynamic are attained in similar fashion to those used for the dispersion calculation. By comparing the height of the surrounding deposit stacks to the height of the stack on which the particle sits, a group of eight vectors is derived. The arrows in Figure 33b represent the direction of these initial vectors. The average of these vectors is then transposed into 3D space creating a "flow-vector" which is then added to the current velocity vector of the particle. This encourages the particle to flow toward stacks that are lower and away from stacks that are higher than the present position of the particle, producing the channeling dynamic.

SURFACES, DROPLETS AND DEPOSITS

Surface and Deposits

Deposits initially derive all their attributes from texture maps. The user can attach multiple texture maps to a surface in a variety of ways. Depending upon the user input, these maps describe all aspects of the surface excluding polygonal geometry. When users specify a map to represent a layer of color they are also asked to specify the thickness of that layer. This integer thickness term in conjunction with the texture map's alpha value and color value is used to generate deposits. One stack of deposits is created per image pixel. The number of deposits in each stack is equal to the value specified by the thickness term. The drawing below (Fig 35) represents three different texture maps subdivided into their constituent deposits.

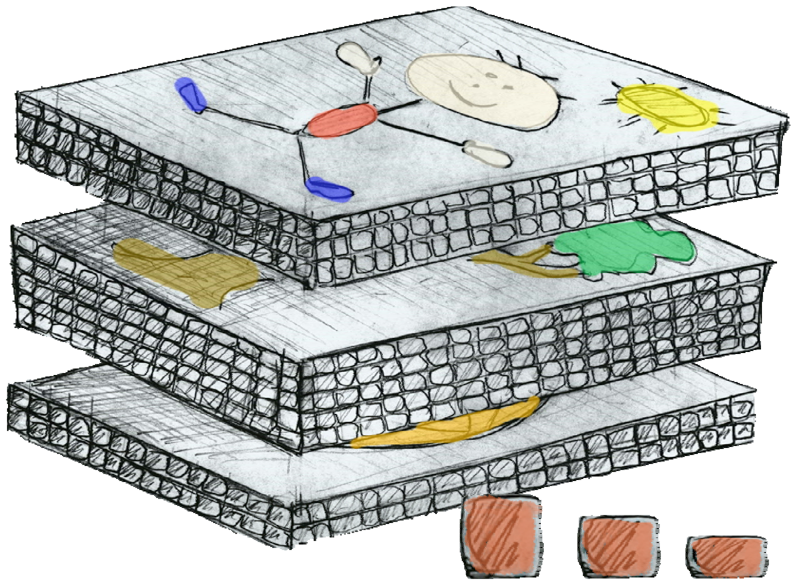


Fig. 35. Maps subdivided into Deposit layers.

From top to bottom the maps have thicknesses of 3, 5 and 2 respectively. The height of each deposit is calculated by dividing the resident alpha value stored in the map by the thickness term. The color of each deposit is calculated by multiplying the resident color by the deposit's height. This is done to better facilitate color blending when deposits are combined for final output and display. That last attribute to be set by users is the hardness attribute. This value can be input directly as a uniform value or it can be read from yet another map that users can associate with each individual layer. Figure 36 is a drawing of a sample hardness map. Darker regions on the map are considered harder while lighter regions are considered softer. The harder a deposit is the less likely it is to be transported. The values taken from the hardness map are used in a probabilistic manner to determine the likelihood of a deposits removal from the surface.

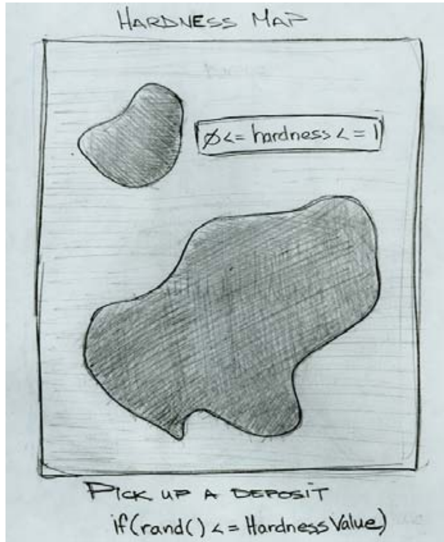


Fig. 36. The Hardness Map.

Droplets and Deposits

Droplets are modeled in this system in a very simple fashion. A drawing of the droplet structure and its components is presented below (Fig 37). A droplet's primary function is to act as a medium by which deposits are transported from one location on the surface to another. A droplet's capacity to hold and carry deposits is related to its size. Each integer increase in a droplet's size corresponds to its ability to carry a single additional deposit. As a droplet moves through space it ages. If a droplet surpasses its designated lifespan it will be recycled; similarly if a droplet's size causes its capacity to fall to zero it will be recycled. A droplet's size reduces only when it is in contact with a surface. The speed of size-reduction is related to the roughness of the surface a droplet is traveling across. If a droplet encounters a deposit and is capable, based on its capacity, of acquiring that deposit it will pick it up and modify or stain the deposit's color by mixing it with its own.

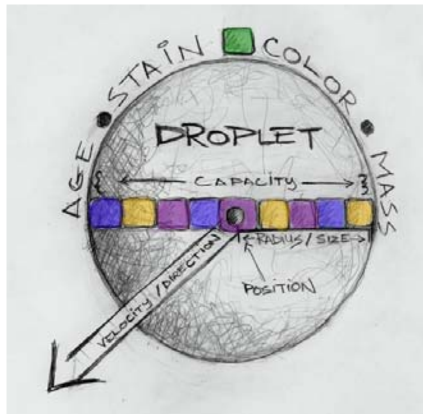


Fig. 37. The Droplet structure.

WASHING, STAINING AND SEDIMENTATION

The patterns that are created by our model of the washing staining and sedimentation process are a culmination of all of the structures and dynamics described up to this point. As droplets wander across the surface they pick up and drop deposits. This dynamic is controlled by two factors. Droplets are described such that they wish to pick up as many deposits as they can at any one time. Droplets will only attempt to pick up a deposit if their size and capacity attributes will allow it. Similarly, if for any reason a droplet's capacity should fall below the current number of deposits held; the droplet will be forced to release deposits until this imbalance is reconciled. Figure 38 depicts this transport and sedimentation of deposits.

Imitating the dispersion process, a droplet's size is constantly being reduced by the surface. The rate of size reduction is dictated by surface roughness. If a surface is very rough the droplet will die rather quickly as it moves, transporting material a short distance. Furthermore, the probability that any given deposit will be transported is controlled by its hardness value. The harder the material is the smaller the probability that it will be picked up by a passing droplet.

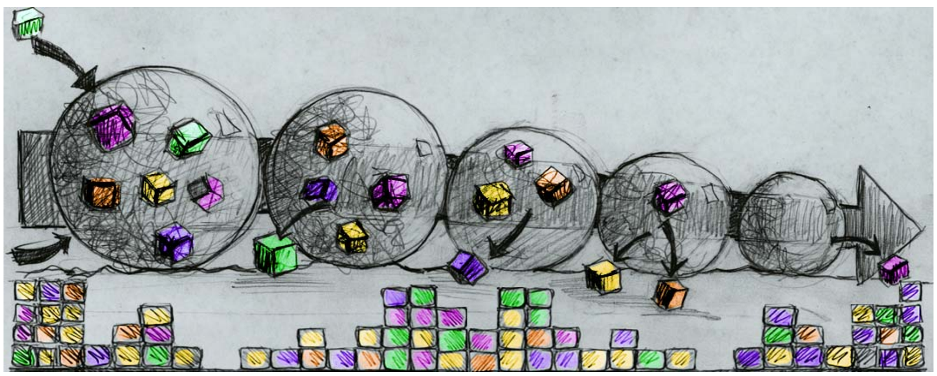


Fig. 38. Deposit transport

CHAPTER IV

IMPLEMENTATION

DESIGN

Two principals guided the design phase of this project. A conscious decision was made to make every effort to ensure real-time interaction as well as provide a high degree of control over system variables (Fig. 37). While the task of learning an interface with many controls may seem confusing to the first-time user it promotes exploration and experimentation. This type of curious dabbling leads to creative discovery and a deeper understanding of the tool and the processes it controls.

The program written to test the ideas of this thesis was written in C++ and OpenGL [16]. Its interface was built using GLUT [17] and GLUI [18] libraries. Rendering capabilities were implemented through the use of the C binding for Pixar's Photo-Realistic RenderMan [19].

INTERFACE

Data Input

When the application is initialized, models are loaded and maps are associated with the different surface attributes of each model as discussed in previous sections. Users are able to create and place as many particle emitters as they desire.

As users run the simulation, they can dynamically change the way in which patterns are formed on the surface of models by manipulating system variables. The program's display is constantly being updated in real-time so that users can see the progress of their creation (Fig 39).

A render button allows a render preview to be obtained while the program is running. This action signals a subroutine that passes data to RenderMan, which in turn produces a high quality image displayed in a preview window.

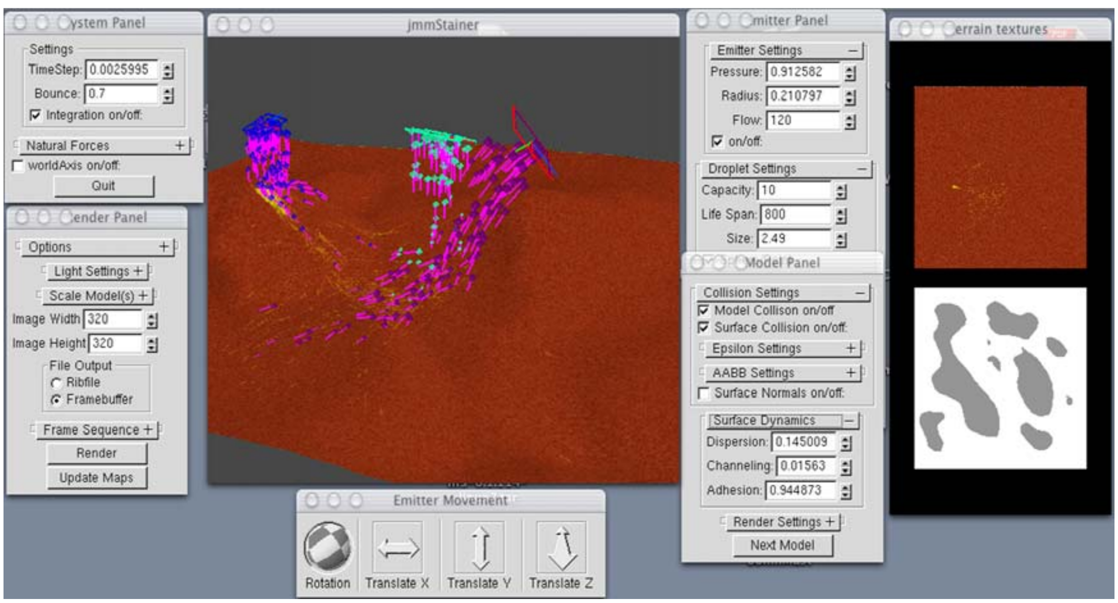
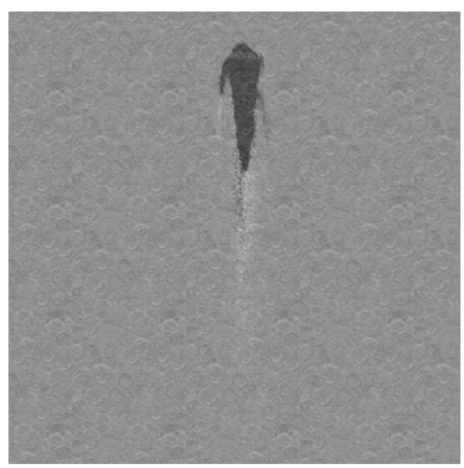


Fig. 39. Application interface.

Data Output

The final output of this program is two texture maps (Fig 40). The first of these (Fig. 40a) represents the mixing of the various colors caused by the process of wearing, staining and sedimentation. This map is generated by blending the colors of the deposits contained in each stack of the Deposit Map structure into one final value that is then written to an output image. The second map (Fig 40b) is a normalized representation of the height field generated by the deposit stacks. All deposits contained in each stack are summed into a final stack height. These stack height values are compared one to another and then normalized between the values of one and zero. These final values are then written to a grayscale image to be used by a rendering algorithm as bump or displacement information.

a.) Color output map.



b.) Normalized grayscale output map.

Fig. 40. Output maps produced by running the simulation on a spherical model.

CHAPTER V

RESULTS AND DISCUSSION

The end goal of this work was to create an artist's tool. Many hours of playful experimentation as an artist were spent developing ways of working with the tool that produced interesting and beautiful imagery. The images created during these sessions as well as the processes used to create them are presented in the following pages. Groupings have been formed according to the visual characteristics of each session. The examples below generally share the following procedure:

1.) A model is loaded.
2.) Texture maps are attached to the model, applied to the surface layer by layer.
3.) Each layer is assigned attributes according to user input
4.) Droplet emitters are placed in the scene.
5.) The simulation is run.
6.) Images are rendered

Each of these steps allow for a large amount of user input and manipulation; which in turn can create a large variety of combinations.

CORROSIVE

The images in Figure 41 were all created during one session. Three simple textures colored blue, red and yellow and were attached to the surface in that order. Each layer was given equal thickness and was given a very low hardness value. The yellow layer was demarked as the base texture thus prohibiting any deposits being removed from their corresponding stack once all but the last in that stack had been transported. A fourth slightly undulating grey-scale texture map was attached to the surface to act as the local roughness layer. A few droplet emitters were then arranged over the surface and let run for varying lengths of time. Height field information taken from the state of the Deposit Map was used to displace, to varying degrees, the surface of the model in the final renders.

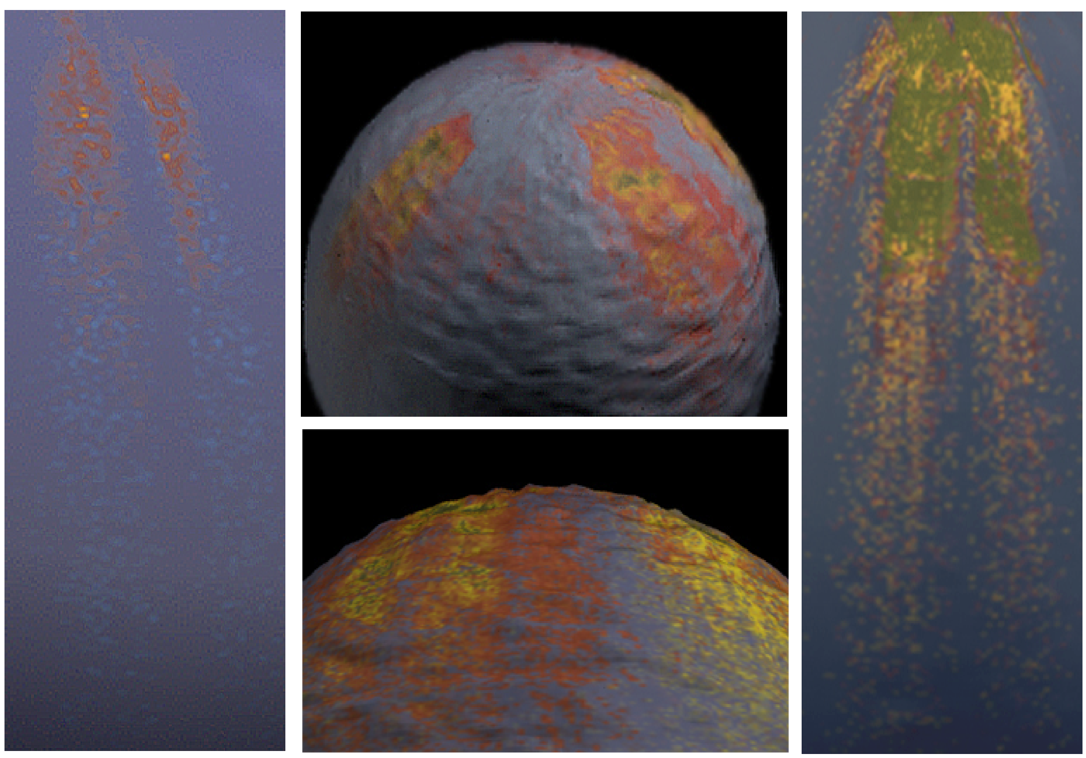


Fig. 41. Corrosive looking images.

ERODED

One droplet emitter running for extended periods of time over three different smooth surfaces created the images in Figure 42. Three simple texture maps were once again employed to seed the Deposit Map structure. A uniform grey texture map described the initial local roughness of the surface. After running the application the resultant height field was used to create the grooves and depressions seen in the final renders.

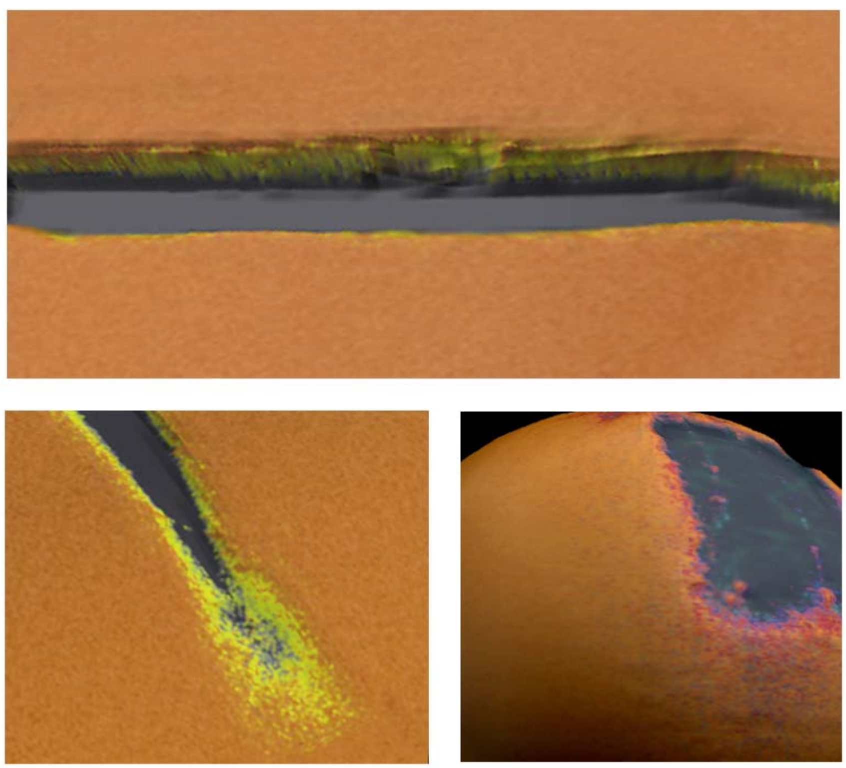


Fig. 42. Grooves and gullies.

SEDIMENTATION

While creating the images above it became apparent to me that it would be advantageous to allow the base material of an object to be considered infinitely thick. This would allow for effects akin to the sedimentation created by volcanic eruptions or meteor impacts. Placing a droplet emitter over the model and allowing it to run for an extended period of time created the images in Figure 43. The base in these examples is infinite, continuously allowing passing droplets to pick up deposits for transport. The result is a build up of base material around the initial droplet impact zone.

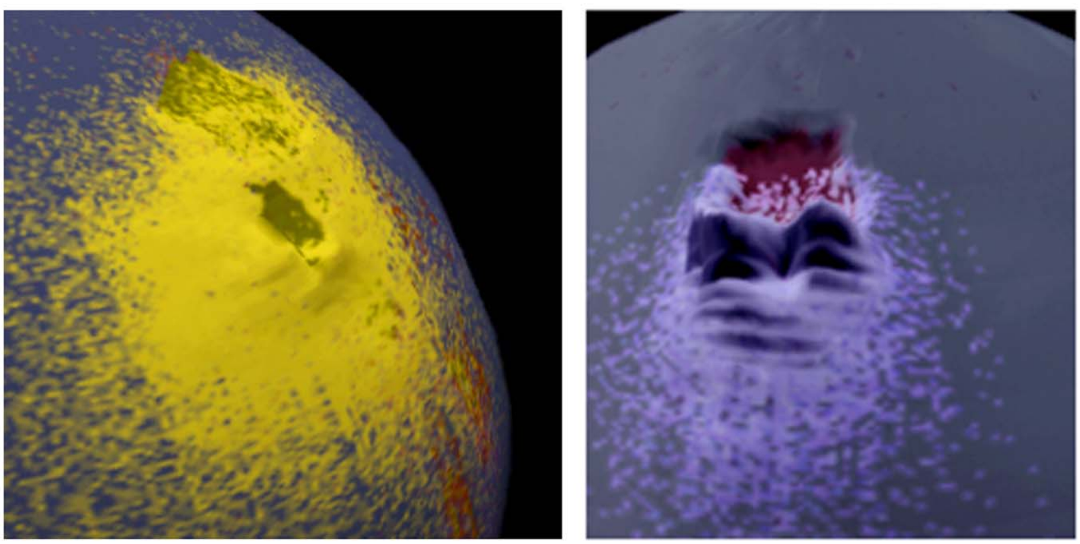


Fig. 43. Images created using an infinite base layer.

Figure 44 exhibits sedimentation on a terrain-like polygonal model. This was a very simple setup employing only three deposit layers and a modulated grayscale image as the roughness layer. Six emitters were placed in the scene and let run for an extended period of time. Deposits were slowly transported into small gullies in the landscape. By manipulating render settings color combinations were enhanced and accentuated.

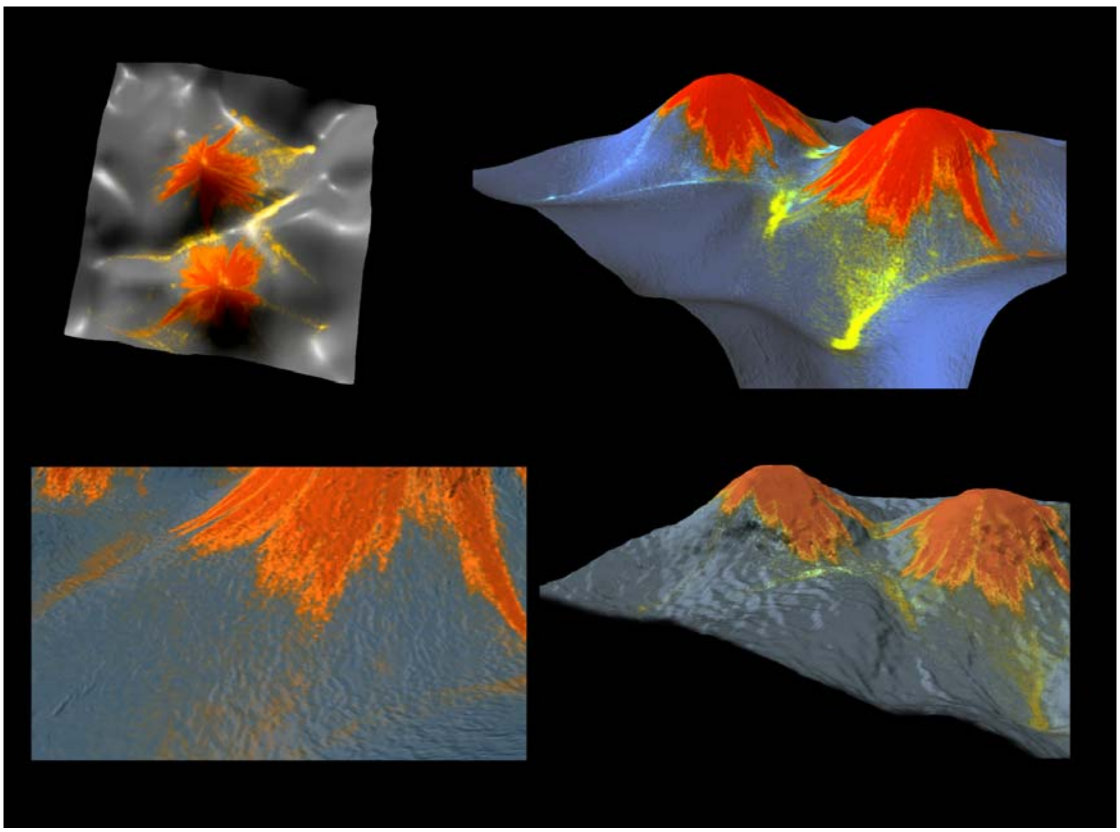


Fig. 44. Sedimentation on a terrain.

MISCELLANEOUS

This category represents various exploratory sessions using the application on fairly simple geometry. Curious play with the variables of the simulation produces a wide variety of effects.

Peachy

The peach image (Fig 45) was created with three layers and a slight amount of droplet color contribution. Each layer was relatively thin and the base was finite. A uniform grey texture map was attached as the initial local roughness value. The image was created in an interactive fashion starting and stopping the simulation frequently to render previews and reposition the emitter. No displacement was applied in the final render.

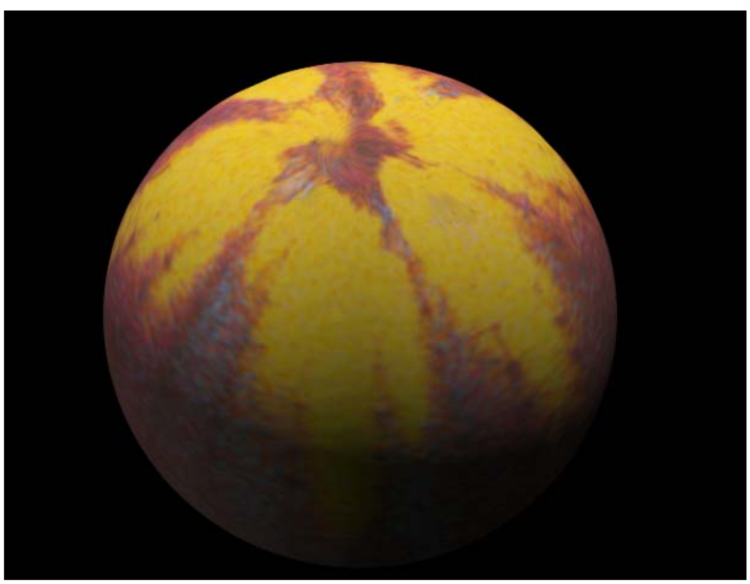


Fig. 45. A pattern reminiscent of a peach.

Droplet Splatting

By attaching two layers of similar color to the surface of a model and increasing the stain strength of each droplet, the effect of droplet color contribution can be highlighted. Figure 46 displays a dark brown layer atop a light brown base map whose combined color has been assaulted by a rain of droplets. A slightly more perturbed roughness layer than the peach was used to help facilitate deposit sedimentation. The visual effect created by this technique is very similar in nature to a potter's glaze.

Fig. 46. Droplet color contribution used to create a potter's glaze.

Fantasy Landscape

The landscape in Figure 47 was created by simultaneously running four droplet emitters over the surface of a valley like shape. The resultant height field created by the sedimentation of deposits was then used to displace the surface. Droplet stain strength was set to a very high level for rendering. The variation between images was achieved by experimenting with different parameters passed to the rendering subroutine.

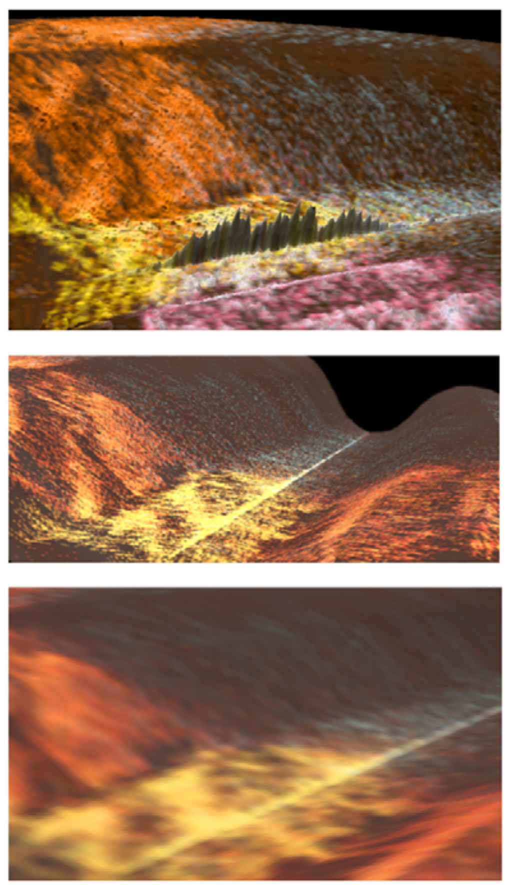


Fig. 47. A fantastical landscape.

Theses are but a few of the variations that can be created with this application. Through experimentation with initial input values and system variables a wide range of effects can be produced.

CHAPTER VI

CONCLUSIONS

Focusing on the dynamics of water flow across surfaces, it was the goal of this work to develop a physically inspired texturing tool that allows artists to create interesting staining and wearing effects on surfaces.

To distill the essence of the elements of the water staining process, we employed a computer generated particle system in a phenomenological model. The motion of these particles is controlled by physically based constraints. The way in which each particle interacts with or modifies the look of the surface is further controlled by user manipulated parameters such as surface roughness, surface color and surface hardness.

It was not the goal of this work to accurately recreate the characteristics of fluid flow or even the visual effects of such a flow on a surface. Rather we offer artists another avenue by which they can create work inspired by and directly drawn from, dynamic natural phenomena. By being able to manipulate the various parameters that control the model of the water staining process, artists are presented with a dynamic and interactive tool for creating complex, physically inspired patterns.

Having a high degree of control over the physically based system described above, users are able to create interesting artistic artifacts reminiscent of patterns created by natural processes. Gaining facility with the various aspects of the simulation takes quite a bit of experimentation, but it is this experimentation and discovery process, that draws the user into the application. As users' understanding of the effect that each control has on the larger simulation increases they become better equipped to express their intent, opening new vistas of creative control and imagery.

Future work along these lines might include the ability to link different aspects of the system to a variety of data inputs. For example one could imagine linking particle velocity or the rate of particle creation to data representing some ongoing social phenomena. What might the staining artifact derived from the transit of individuals across international borders look like? How might we map the characteristics of an individual to material properties? The creative combinations are seemingly limitless. Through the process of creation we discover subtle connections that broaden our vision and stimulate our senses.

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