

Introduction to 2D and 3D Computer Graphics




Advanced Modeling

-- Fractals, Graftals, Partical Systems --


Advanced Modeling

Introduction

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- Many natural effects are not efficiently represented by geometric models discussed earlier in this course
 - For example, the tiny water drops in fog, trees in a forest , or leaves on a branch or twig can only be reasonably generated procedurally


Advanced Modeling

Introduction

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- Many natural effects may affect the environment in ways unlike those illumination models discusses earlier
 - For example, fog is seen as a blur in the air -- not as millions of drops of water; this means that fog alters the light reaching the viewpoint

Advanced Modeling

Introduction

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- Advanced Modeling...
 - ...goes beyond geometric models
 - ...allows simple modeling of complex phenomena
 - ...provides for *database amplification*
 - Advanced Modeling techniques include...
 - ...Grammar based models
 - ...Particle systems
 - ...Fractal systems

Advanced Modeling

Introduction

- Grammar based models...
 - ...provides methods for describing the structure of plants
 - ...use parallel graph grammar languages (*called graftals!*)
 - ...are languages described by a collection of productions which are all applied at once
 - ...for example, $A \rightarrow AA$ creates results of A , AA , $AAAA$, etc.
 - ...for example, $B \rightarrow A[B]$ creates results of B , $A[B]$, $AA[B]$, etc.

Advanced Modeling

Graftals

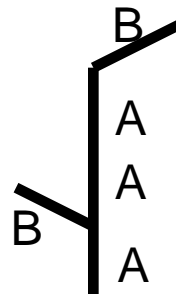
- Grammar based models...

- ...use [] for left branches and () for right branches

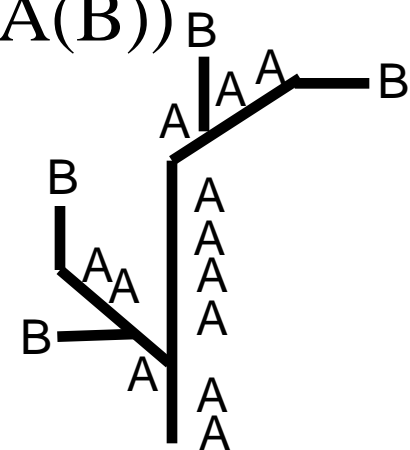
- $A \rightarrow AA$ and $B \rightarrow A[B]AA(B)$

- create a 2nd generation of:

$AA[A[B]AA(B)]AAAA(A[B]AA(B))$




First Generation



Second Generation


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Graftals

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- Grammar based models...
 - ...use biological productions to simulate plants in development
 - ...describe the topology of plants
 - ...also describe the shape including the directions of branches and the arrangement of leaves


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Graftals

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- To simulate the growth of plants using graftals, languages include information on...
 - ...the current age
 - ...the growth rate of each segment
 - ...the probabilities of death, dormancy, growth
 - ...the shape (depending on type and age)
 - ...the branch angles (depending on type and age)
 - ...the color and texture of each segment

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Graftals

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- Pseudo code simulates the growth of plants using graftals:
 - For (each moment in time)
 - » For (each bud that is still alive)
 - » Determine whether the bud dies, is dormant, or grow
 - » If (the bud does not die)
 - » If (the bud is not dormant)
 - » Create a portion of a stem, determining its direction, position, color, texture;
 - Create a new bud;

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Particle Systems

- Particle systems...

- ...can be used to simulate fire, clouds, water, fog, smoke, fireworks, trees, and grass
- ...are particularly useful for animating objects instead of just simulating static objects
- ...represent a collection of particles, evolve over time
- ...this means particle systems are best used to simulate objects whose behavior over time cannot be easily described using objects we have learned about so far


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Particle Systems

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- Objects are represented...
 - ...by a cloud of particles which are born, evolve in space, and die all at different times
 - ...using particles that move in 3D and change in color, transparency, and size as a function of time
 - Particle systems...
 - ...can simulate clouds by having each water droplet be a particle; each water droplet can be placed randomly inside the cloud according to some probability


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Particle Systems

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- Particle systems define the behavior of particles by a function that varies at each moment in time:
 - Property of particles =
 - » Number of particles in the population +
RandomVariable*Variance in population


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Particle Systems

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- Particles may be rendered by taking each particle as a point of light and computing the contribution of this light on the entire image
 - ...computed over the path of movement
 - ...where particles behind other particles still contribute to the image so hidden particle removal cannot be used easily

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Fractal Systems

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- Fractal systems...
 - ...originally developed in 1982 by Benoit Mandelbrot
 - ...are useful for describing natural attributes such as coastlines, terrain, etc.
 - ...provide descriptions for natural effects that tend to be self similar
 - ...for example, a coastline viewed at any level of detail tends to exhibit the same level of jaggedness (*self similarity*)

Advanced Modeling

Fractal Systems

- Fractal systems...

- ...this means that fractals are generated by infinitely recursive processes, similar to space filling curves



Fractals


Introduction



- So far...the objects we have created have been generally made up of planar polygons
- To describe a scene that looks natural (with mountains, trees, clouds, etc.)...
 - ...it would not be feasible to define all of the points that would be required to create a realistic looking picture ...
 - using all polygons would make the results look unnatural ...why? because it is too precise....to regular!

Fractals

Introduction

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- The solution for a natural looking environment...
 - ...is with fractals
 - ...which are sets of points with a "fractional dimension"
 - ...which can model irregular shapes
 - "Fractional Dimension" defines the origin of the term "fractals"

Fractals

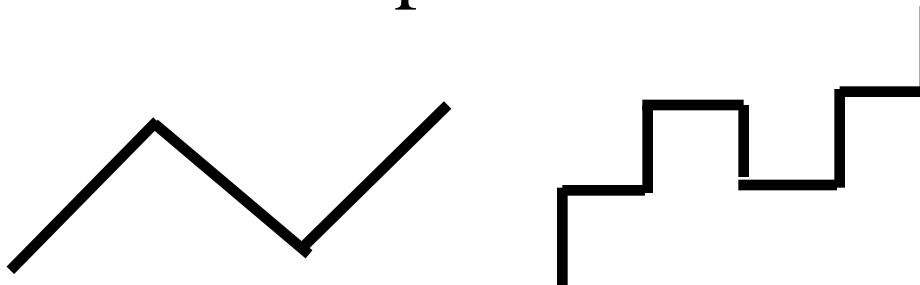
Generating Algorithms



- Fractals are generated by using production rules
- For example, with the Koch curve, a straight line is replaced by a shape



- Or, another example of a Koch curve

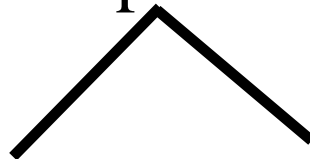


Fractals

Generating Algorithms



- Another example is the dragon curve...
 - ...which is eye-catching
 - ...starts with two sides a rectangular isosceles triangle
 - ...where each side is replaced by two sides of a rectangular isosceles triangle, where the replacement has to alternate between left and right
 - ...which also produces an area filling curve



Fractals

Random Fractal Surfaces



- In reality...objects rarely exhibit the self-similarity of the Koch curve, or Dragon curve
 - ...but nature is full of fractals that are self similar
 - ...where many times random numbers are included in the production rules...
 - ...creating different results every time to forge landscapes, mountains, surfaces, island clusters, waves, and clouds
 - ...which generally have dimensions higher than 2 (called fractal surfaces!)

Fractals


Random Fractal Surfaces



- The greater the dimension...
 - ...the more rugged the landscape
 - ...for example, natural scenes usually have a dimension of 2.15
 - ...the French Alps have been reproduced with a dimension of 2.5

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Fractal Systems

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- The two most famous types of fractals are...
 - ...the Julia Fatou set ...the Mandelbrot set
 - Gaston Julia (1893-1978) was a French mathematician who together with Pierre Fatou (1878-1929) created the basis for the theory for iterations of rational mappings in a complex plane

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Fractal Systems

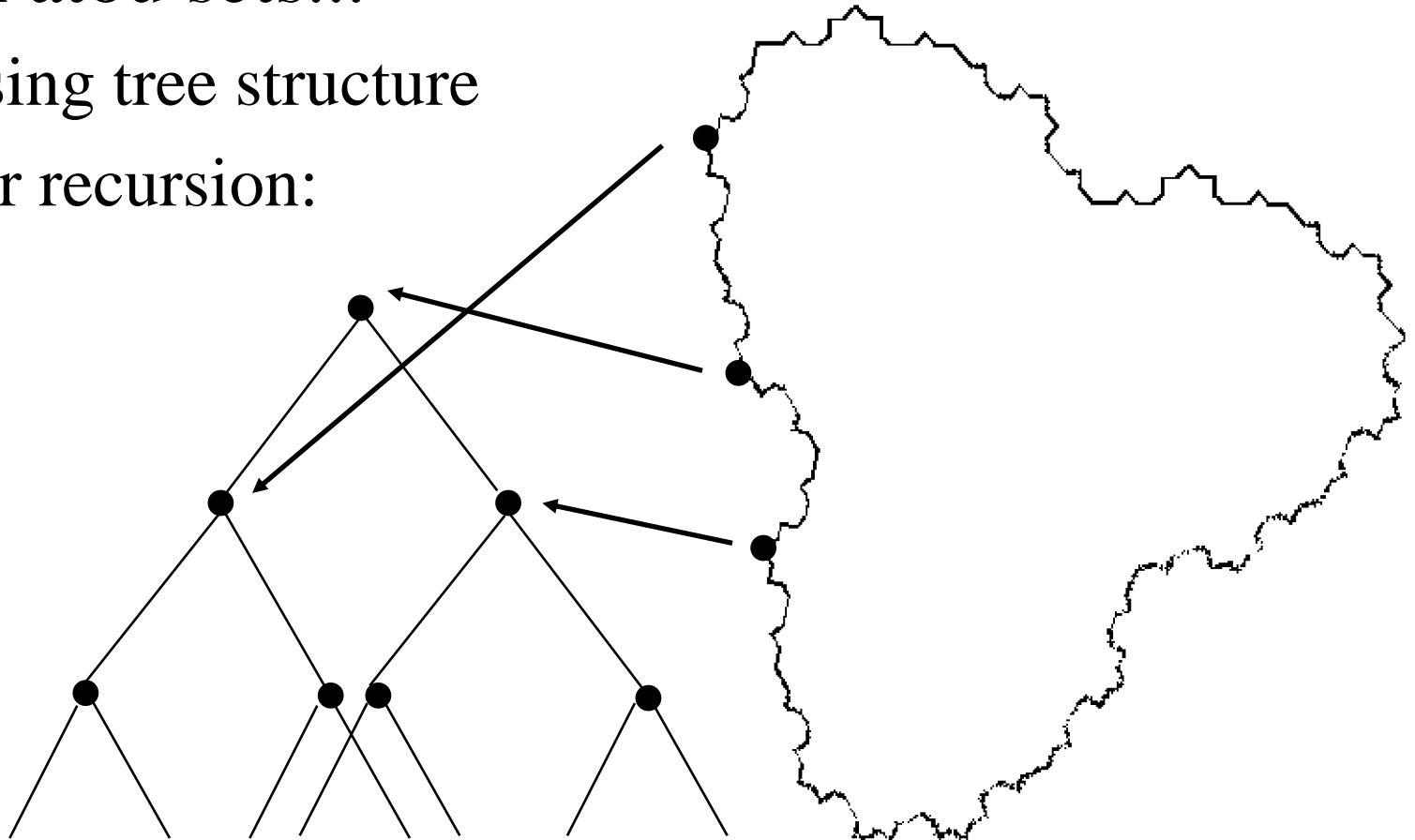
- Julia Fatou sets...

- ...are known for $x \rightarrow x^2 + c$, where x is a complex number making numbers fall toward zero or fall toward infinity when they are squared
- ...by repeating this formula, complex numbers are attracted to infinity, others to finite numbers, and others form the boundary between zero and infinity

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Fractal Systems

- Julia Fatou sets...
 - ...using tree structure for recursion:




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Fractal Systems

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- The Mandelbrot set...
 - ...discovered by B. B. Mandelbrot in 1980
 - ...is "the most complex object mathematics has ever seen!"
 - ...combines self similarity with properties of infinite change
 - ...can be considered as the pictorial manifestation in the infinite variety of Julia sets

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Fractal Systems

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- Such fractals are good for modeling...
 - ...natural forms such as mountain peaks (which have smaller peaks, etc.)
 - ...trees with limbs, branches, and twigs that all look similar
 - ...coastlines with bays, inlets, estuaries, rivulets, and drainage ditches that all look similar

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Fractal Systems

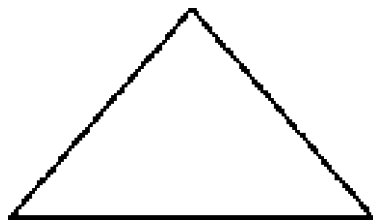


- A practical way to handle fractals is by subdivision...
 - ...for example, take a 2D shape (like a triangle)
 - ...mark the midpoint of each edge
 - ...connect the three midpoints
 - ...iterate this process, creating realistic looking mountains!

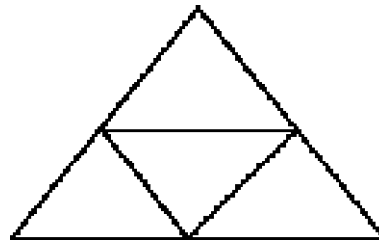
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Fractal Systems

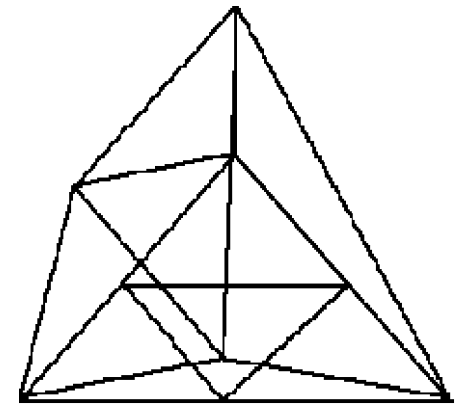
- This process can be expanded to quadrilaterals in three-dimensional space where each edge generates a displacement along a midpoint vector that is normal to the plane of the original facet



Start with a triangle




Begin subdividing...



...extend in the y direction

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Fractal Systems

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- Another approach was developed by Mandelbrot...
 - ...who realized that midpoint-displacement produces symmetrical surfaces making mountains look the same inverted
 - ...but in reality, real mountains look very different than valleys
 - ...supports asymmetrical displacements by using a different method of subdivision

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Fractal Systems

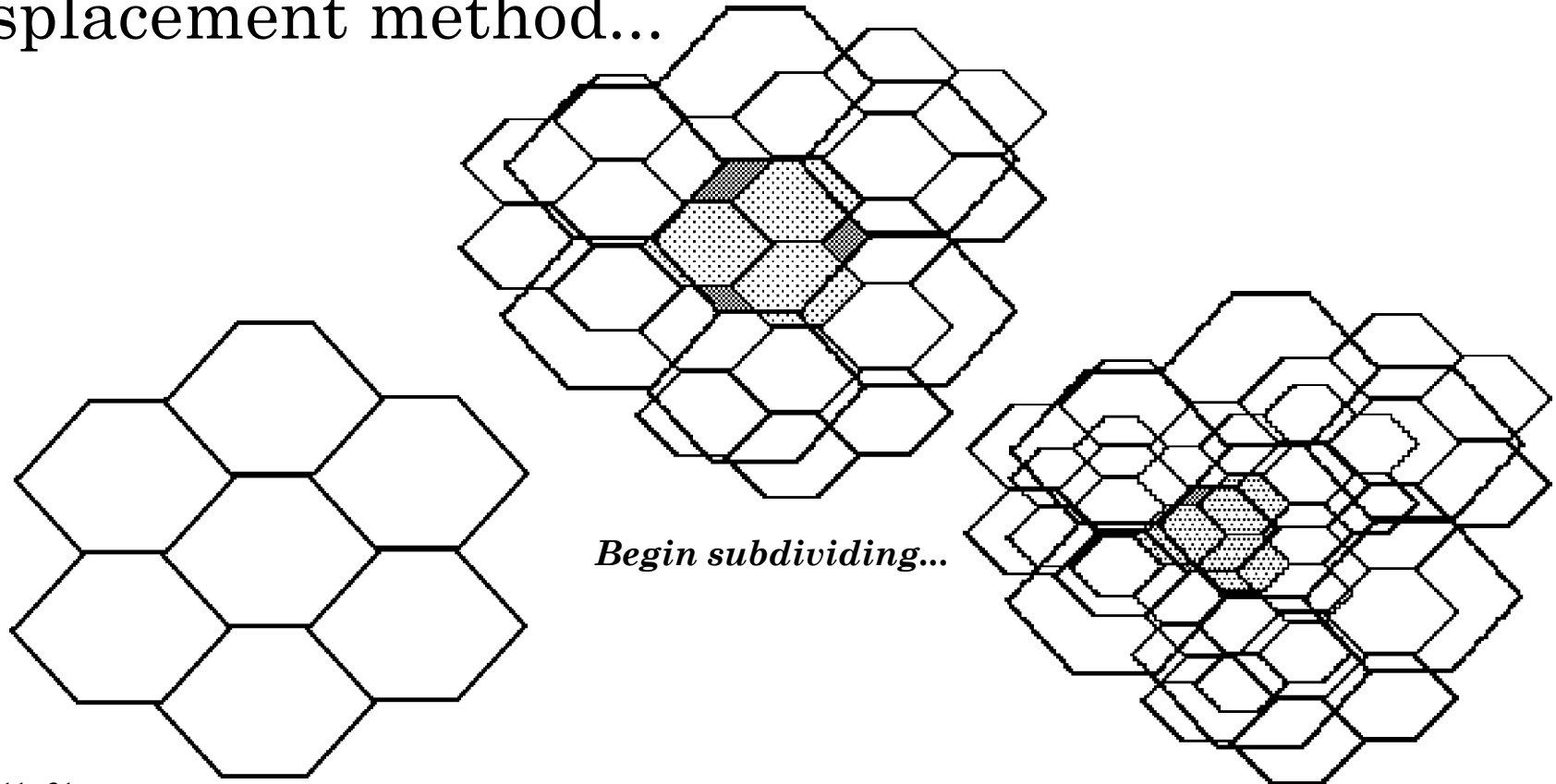


- Instead of using a mesh of triangles, he starts from a mesh of hexagons, where high values are only associated with vertices in a mesh
 - ...each hexagon is subdivided with a smaller set of three hexagons
 - ...this means that at the edges of the original hexagons, where creases might have formed, are now distorted into multiple edges making creases far less apparent

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Fractal Systems

- Using the Mandelbrot hexagonal displacement method...



Advanced Modeling

Texture Mapping

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- Textures can be expanded using solid textures...
 - ...remember with bump mapping, textures were extracted from a 2D image that was mapped onto the surface being rendered
 - ...this means that for every point on the surface, a 2D texture is computed

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Texture Mapping

- Solid textures...

- ...computes for each point on the surface a 3D texture
- ...for example, a block of marble (3D) can have both its surface and the inside of the marble block mapped to a 3D surface; if that surface were a sphere, then the sphere would appear as if it had been carved out of a block of marble


Advanced Modeling

Texture Mapping

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- Solid textures...
 - ...should be applied in Modeling Coordinates, since changing the position and orientation of the surface should not affect its texture (i.e., the 3D texture should be part of the object's definition space)
 - ...can be a 3D image...can be created from a noise function that can modulate the color and perturb the normal of three-dimensional objects
 - ...can also be represented as *projection textures*


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Texture Mapping

- 
- Projection textures...
 - ...can create effects like that of a slide projector: when someone walks in front of a screen, the image is mapped onto the person instead of the screen
 - ...are most interesting when several of these types of textures are combined
 - ...have a constant along certain parallel lines in a volume (i.e. it might be constant along the z axis, but on any xy plane it might look like a regular texture)


Advanced Modeling

Physical Models

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- Physically-based modeling...
 - ...uses the behavior of an object's gross physical properties to determine its shape or motion
 - ...include how a cloth drapes over objects as a function of surface friction, the weave, and the internal stresses and strains generated by forces from the objects
 - ...include how a chain suspended between two poles hangs in an arc, as a function of gravity and the forces between the links in the chain


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Physical Models

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- Examples of physical models include...
 - ...cloth
 - ...flexible surfaces
 - ...solids
 - ...clouds
 - ...atmosphere

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Physical Models

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- Cloth...
 - ...as modeled by Weil in 1986/1987
 - ...is simulated as a rectangular weave of inelastic threads
 - ...is suspended by holding certain points on the cloth at positions in three-dimensions
 - ...has direction vectors between each point to provide for tension in the threads...simulating elasticity

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Physical Models

- Flexible surfaces...

- ...as modeled by Terzopoulos and Fleischer in 1988 simulate a more general media than just cloth, but all flexible surfaces
- ...are grids (which are 2D for cloth)
- ...where adjacent points in a grid are connected by springs, shock absorbers (called dashpots), and plastic slips

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Physical Models

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- Flexible surfaces are controlled by...
 - ...springs that respond to forces by deforming elastically in an amount proportional to the force (when the force goes away, so does the deformation)
 - ...dashpots that respond to forces by deforming at a rate proportional to the force (when the force is constant, stretches caused by dashpots are removed, causing the deformation to go away)
 - ...plastic slips that respond to forces by doing nothing until the force reaches a certain level and slips freely

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Physical Models



- Grids made up of these three types of units...
 - ...deforms and stretches
 - ...can model cloth using plastic slips; when the tension gets too great, the units will slip and the thread will break; a tear will result!


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Physical Models

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- Flexible solids...
 - ...have been modeled by Platt and Barr in 1988
 - ...can simulate deformable solids like putty or gelatin
 - ...use a combination of solid mechanics for the underlying structures with dynamic constraints
 - ...are simulated using a large collection of differential equations that determine a finite-element mesh at each moment in time


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Physical Models

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- Clouds...
 - ...can be simulated using fractals
 - ...or, can be simulated using textured ellipsoid
 - ...where clouds are modeled by their observed shape (what they look like)
 - ...include a sky plane, where the clouds reside, ellipsoids used to model thick clouds, and texturing functions to vary shading and translucency

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Physical Models

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- Atmospheric effects...
 - ...allow for simulating objects of less substance than clouds, such as haze, dust, and fog
 - ...have four aspects: phase, low albedo, shadowing, and transparency
 - Phase:
 - means that a tiny spherical particle reflects incident light to the viewer in the same way as the moon reflects the sun's light; it depends on relative positions of the light source, the particle, and the viewer

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Physical Models



- Low albedo: means that if the reflectivity of each particle is low, then the light from reflections bouncing off two or more particles is insignificant
- Shadowing: means that particles more distant from the light source are shadowed by particles in front on them
- Transparency: means that a cloud layer can be described as a probability that a ray passing through it hits no particles