The Science of Pixar
At the Oregon Museum of Science and Industry (OMSI)
Before subdivision
It's easy to draw straight lines on a computer, but much harder to create smooth shapes.

After subdivision
Subdivision is a mathematical way to create smooth surfaces from simple shapes.
Parabolas as grass

A blade of grass is a small thin curve that can be represented by a parabola.

Computer-generated variety

Real blades of grass don't all look alike. Pixar writes programs that vary the color, height, width, and curve of the virtual blades of grass.
Surfaces
Surface appearance is controlled separately from shape

The way something looks tells a story. What is it made of? Is it new or old? Well taken care of or neglected? After a virtual 3D model is created, a surfacing artist constructs its appearance with computer programs called shaders. Shaders determine the way light scatters off the surface so it looks shiny, transparent, and smooth (like glass) or dull and rough (like rust).

A virtual 3D model of Mater with no shaders. Mater after the shaders have been applied.
Shaders

Shaders are programs that tell a computer how to display all aspects of an object's surface appearance.
Pixar’s Surfaces Challenge

Math makes it look like metal
Lightning McQueen looks shiny because the light rays bouncing off his surface maintain their relative orientation.

Smooth surfaces reflect light like a mirror
Rough surfaces scatter light

BRDF
Bidirectional Reflectance Distribution Functions mathematically describe the way light scatters off of a surface.
The Rendering Equation

\[ L(x, \omega_o) = \int_{\Omega} f(x, \omega_i, \omega_o) L(x, \omega_i) \cos(\theta) \, d\omega \]

It's a mathematical description of how light bounces around in the environment.

\[ L(P, d_0, \lambda) = E(P, d_0, \lambda) + \int_{\Omega} L(P, d_i, \lambda) f(\lambda, d_i, d_0) |d_i \cdot \hat{n}| \, d\Omega \]
In plain language, this is a simultaneous-equation energy balance:

“The light shining from the point P is the reflection of the incoming light directed to the point P from all of the other points in the scene.”

\[ B(x, d_0, \lambda) = E(P, d_0, \lambda) + \int_{\Omega} B(x, d_i, \lambda) f(x, \lambda, d_i, d_0)(d_i \cdot \hat{n})d\Omega \]

\[ L(x, \omega_0) = \int_{\Omega} f(x, \omega_i, \omega_o)L(x, \omega_i)\cos(\theta)d\omega \]
Rendering

Rendering turns a virtual 3D scene into a 2D image

The virtual scene is set—the characters are shaded and posed, the lights and camera are in position, and the simulations are ready to run. But no one knows what it looks like until the rendering process turns all that data and programming into an image we can see. Pixar generates low-resolution renders for works in progress and high-resolution renders for the final film.

The virtual 3D scene
This wireframe is a visualization of the data that defines the scene.

The rendered 2D image
Rendering calculates the color of every pixel in an image.
Simplified images render quickly and show if a work in progress looks right.

Pixar’s Animation Challenge

Warning: Unauthorized access to computer systems is prohibited. Violators will be prosecuted.
Moving with math
Computer animators position digital models into key poses. Then the computer fills in the transitions based on mathematical functions called splines.

 Acting from pose to pose
Mr. Incredible is posed to run, but the transition to the next pose will tell if he is bounding along or tiring out.
Simulation

Computer programs create automated motion.

The movements of Merida's hair and dress are simulations.
While animators focus on acting, simulation programmers create motion that makes scenes feel alive and believable. Some simulations—hair, fur, and clothing—respond to the way a character moves. Other simulations recreate natural phenomena, such as fire or water. Programmers start with the underlying physics, but they balance believability with the artistic needs and the time it takes to run the simulation.
Automated oceans

All the water in Finding Nemo is simulated using computer programs, not animated by hand.
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