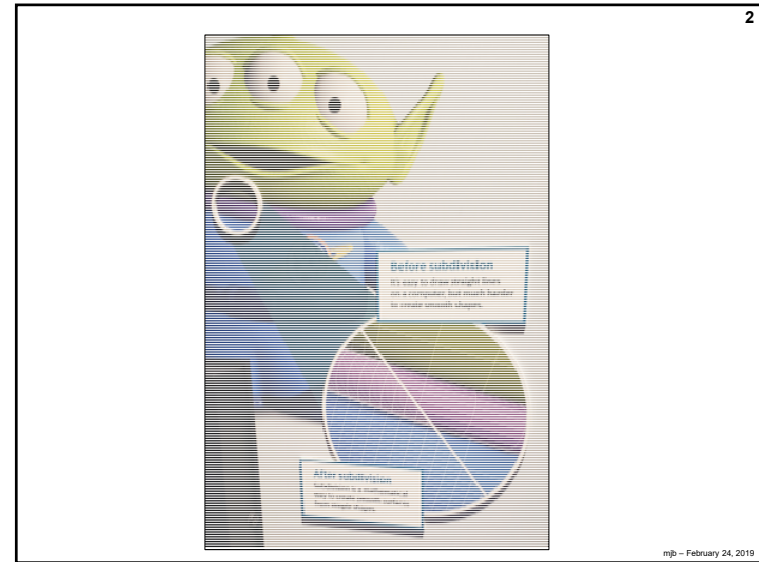
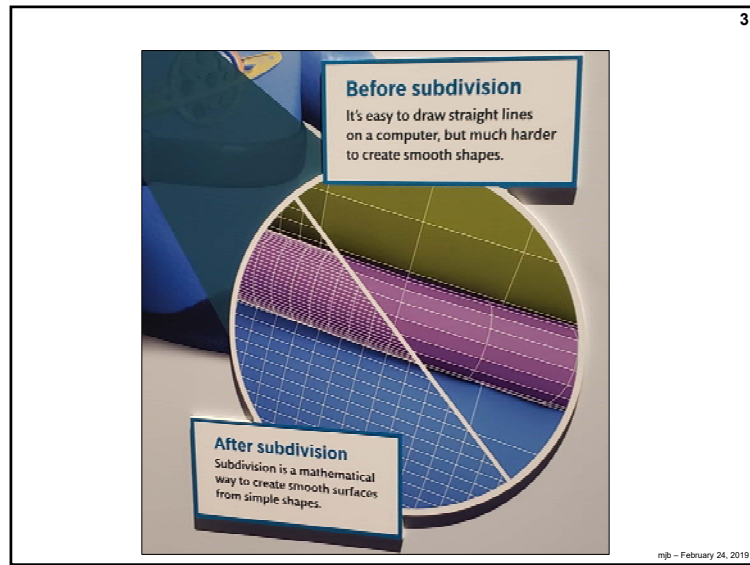




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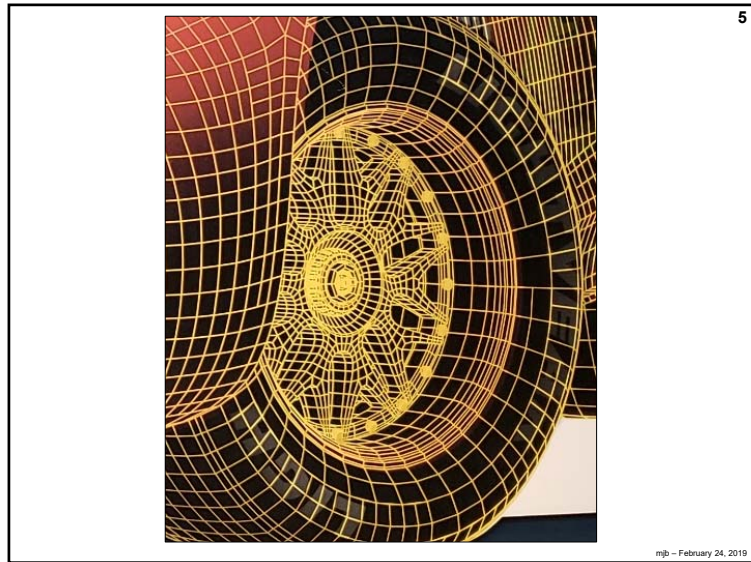
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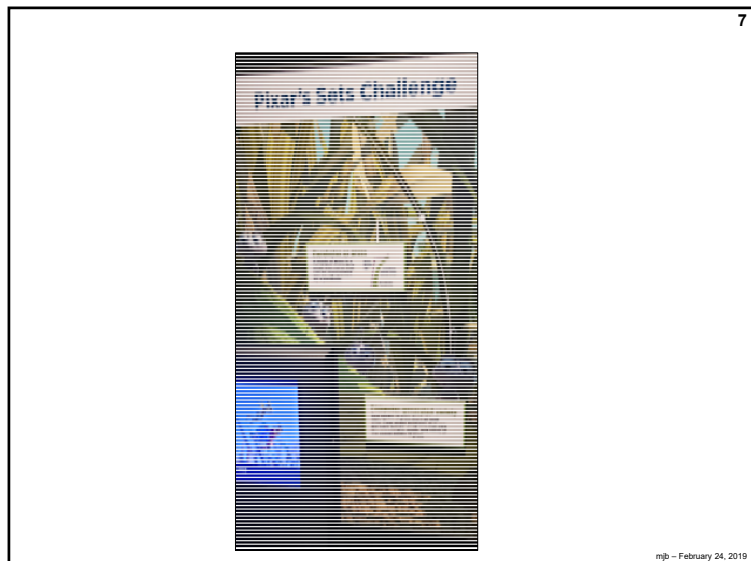
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Parabolas as grass

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

grass grows up...
...and then bends over

Parabola

Computer-generated variety

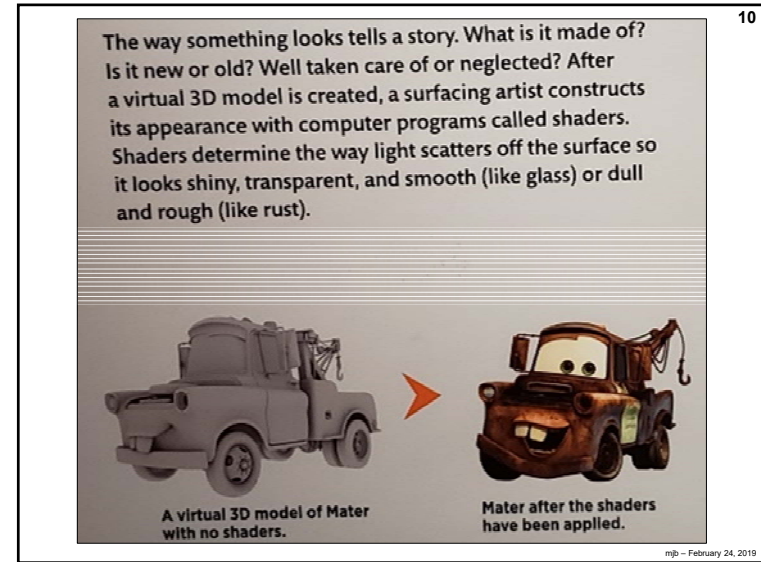
Real blades of grass don't all look alike. Pixar writes programs that vary the color, height, width, and curve of the virtual blades of grass.

8

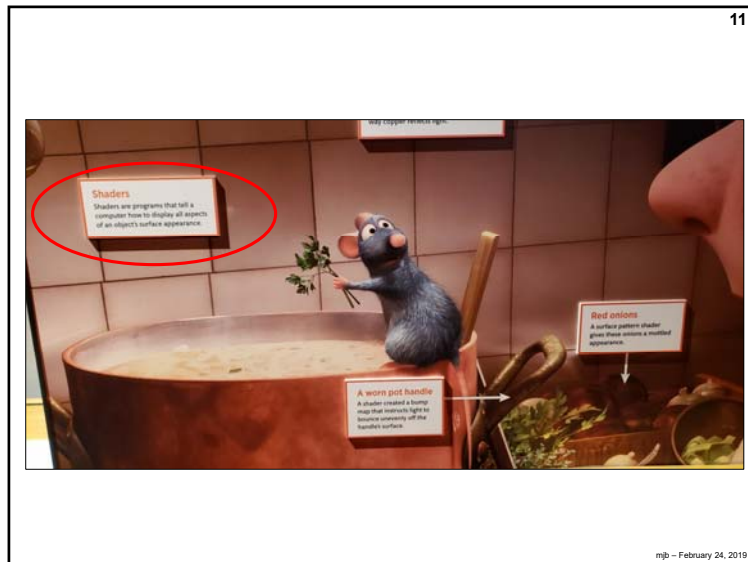
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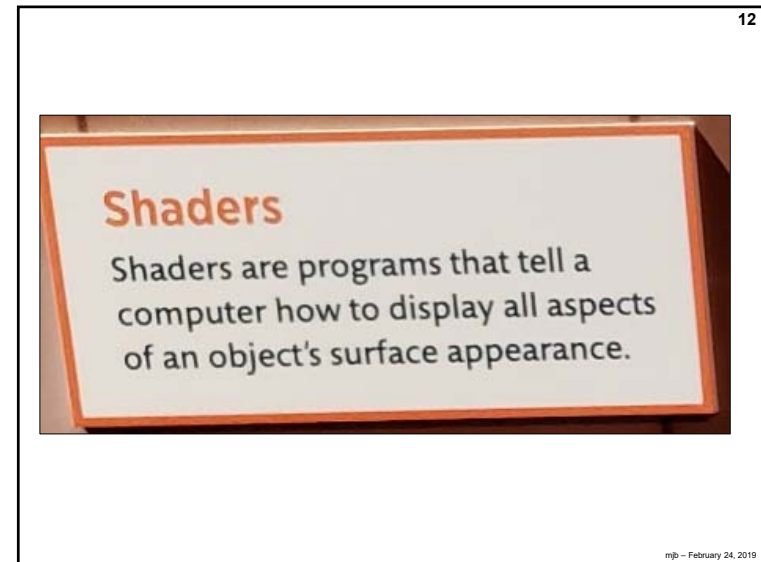
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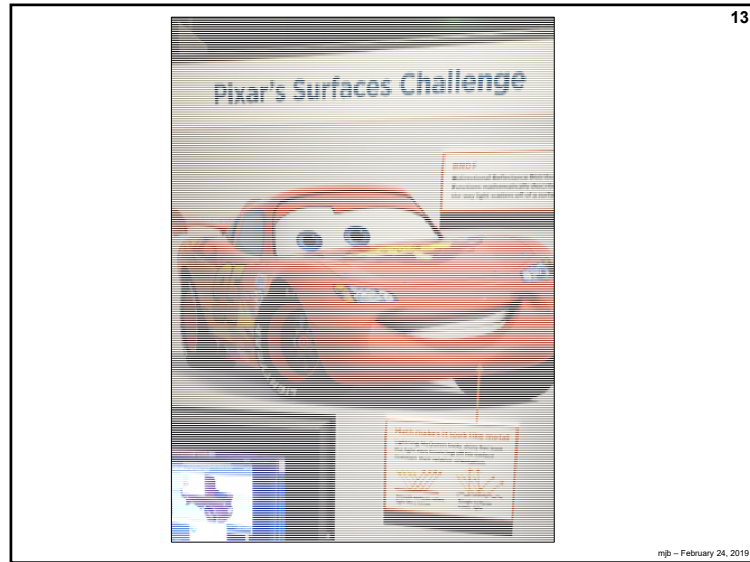
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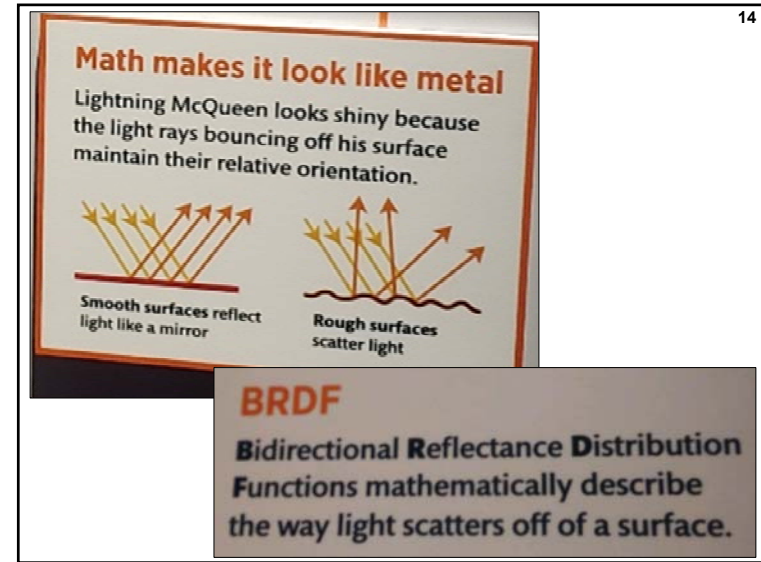
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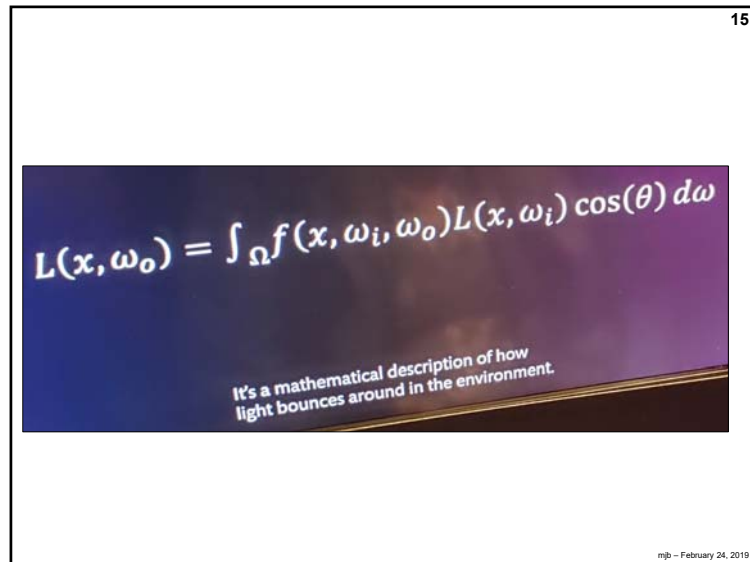
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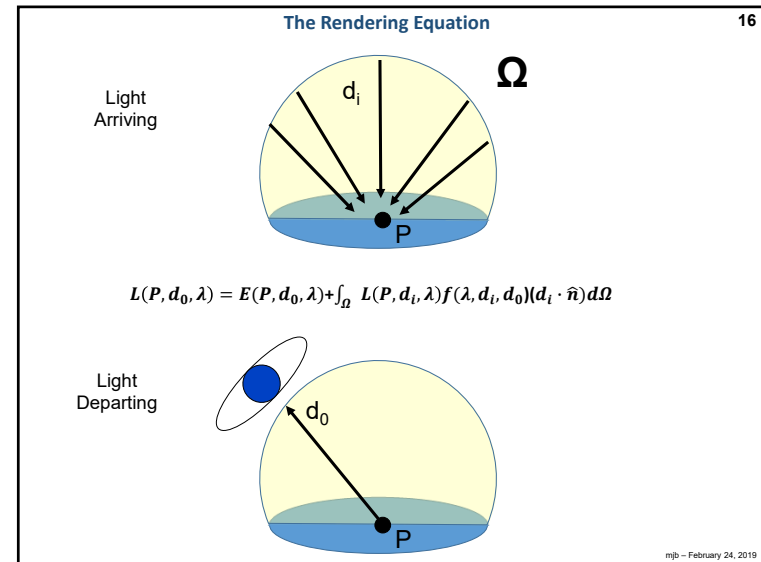
13



14

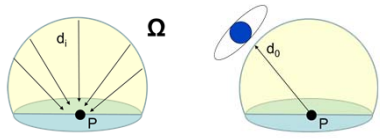


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The Rendering Equation 17



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

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.”

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

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

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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.



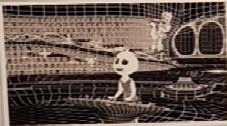
Rendered images render quickly and show if a work is progress looks right.
Get higher quality, an average image took about 70 hours to create at that resolution.

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The virtual 3D scene
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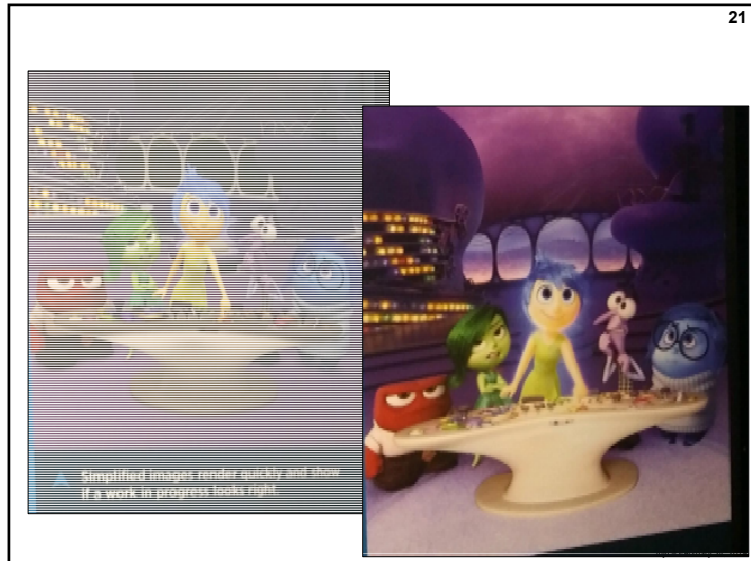
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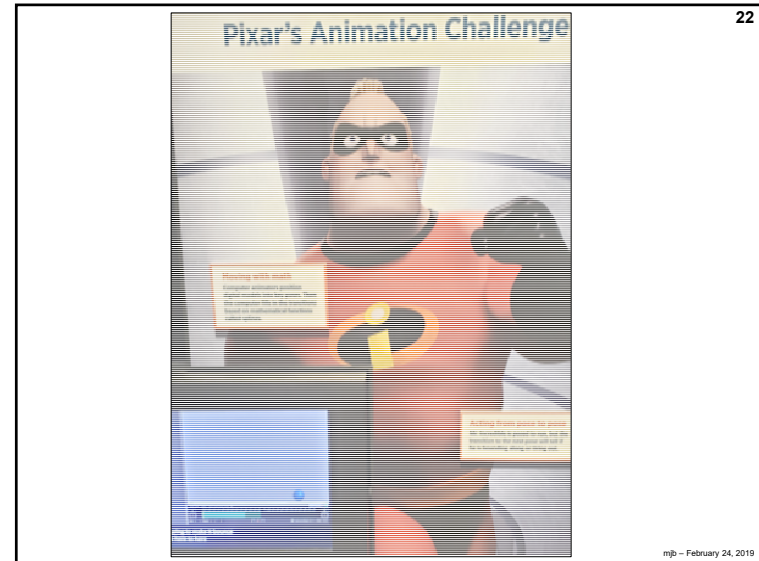
The rendered 2D image
Rendering calculates the color of every pixel in an image.

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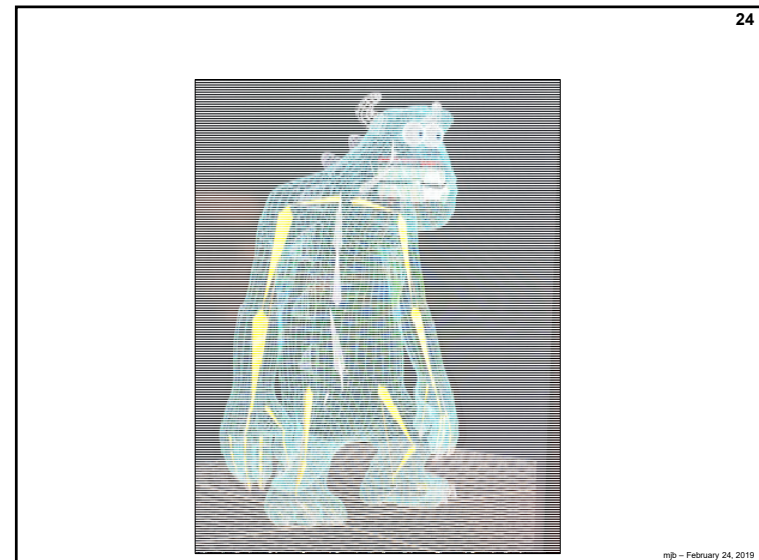
Moving with math

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.

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Simulation

Computer programs create automated motion

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.

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▲ The movements of Merida's hair and dress are simulations.

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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.

A frame from *Brave* before the simulated elements were included.

The same frame with the simulations added.

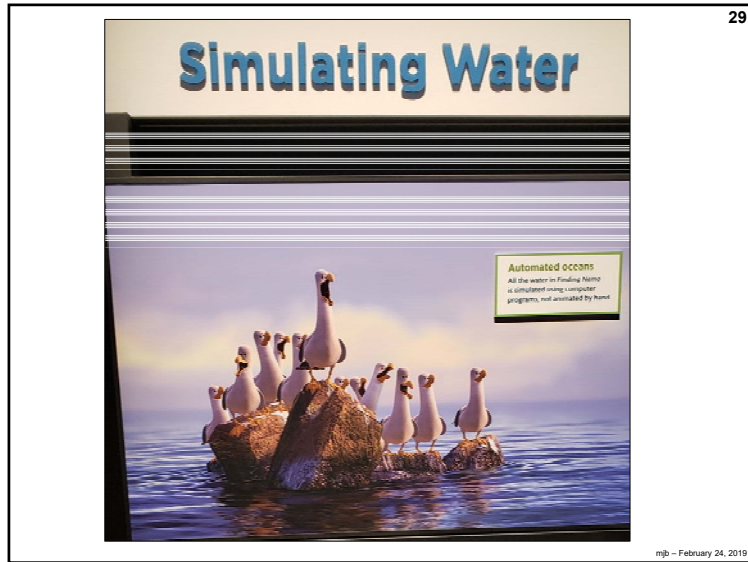
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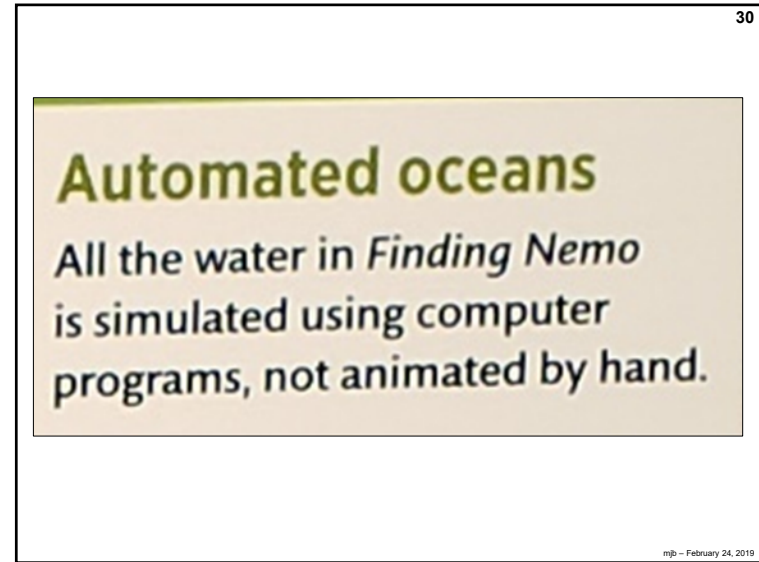
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