Viewpoints Research Institute

Squeak Etoys, Children & Learning

Alan Kay

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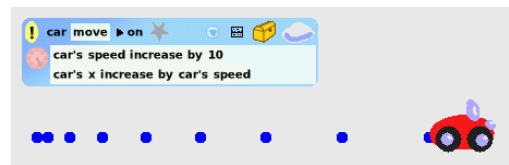by Alan Kay

Summary of Squeak Etoys

Squeak Etoys (www.squeakland.org) was inspired by LOGO, PARC-Smalltalk, Hypercard, and starLOGO. It is a media-rich authoring environment with a simple powerful scripted object model for many kinds of objects created by end-users that runs on many platform, and is free and open source. It includes 2D and 3D graphics, images, text, particles, presentations, web-pages, videos, sound and MIDI, etc. It includes the ability to share desktops with other Etoy users in real-time, so many forms of immersive mentoring and play can be done over the Internet. See companion note **Squeak Etoys Authoring & Media** for more information. It is multilingual, runs on more than 20 platforms bit-identically, and has been successfully used in USA, Europe, South America, Japan, Korea, India, Nepal, and elsewhere.

Squeak Etoys in Nepalese village

A typical 5th grade math-science project sequence: (given in more detail below in the examples)

Car leaving a trail showing acceleration

 - draw objects (such as cars)
 - write scripts to move them, have them follow edges, etc.
 - think about speed and acceleration by leaving trails
 - observe moving objects in the real-world: dropping weights, etc.
 - get detailed records of the drop using video cameras
 - look at every 5th frame and measure the speeds
 - compare the difference in speed between each frame
 - see that the differences (the acceleration) is constant
 - write a script to move a simulated ball with constant accelerated motion
 - find the constant that will match up the simulation with the real-world

This subject has been extensively studied with college students in US: 70% (including science majors) fail to understand this Galilean model of gravity near the surface of the Earth. The projects developed in Squeak use a different and simpler kind of incremental mathematics that allows very young children to understand some of the key ideas in calculus. We have found that more than 90% of 5th graders not only understand "Galilean gravity" but are able to derive the mathematical "formulas" (actually 2nd order differential equations) using this alternative mathematics, and author a simulation that matches up very well with the experimental data.


Dropping objects

Every fifth frame of video

Squeak Etoys also has a particle system that is scripted using the same conventions used for the larger media objects. This allows children to think through complex parts of a project – such as an ant or salmon following a scent gradient – in the large with a few large ants or fish, and then to use what has been discovered with a population of thousands of particle animals.

Finally, Squeak Etoys is a media system and web plugin which includes players and models of many kinds of media. These allow many kinds of presentations of the ideas to be made, from slides to "active essays" and immersive sessions that involve the "readers" as "cocreators".
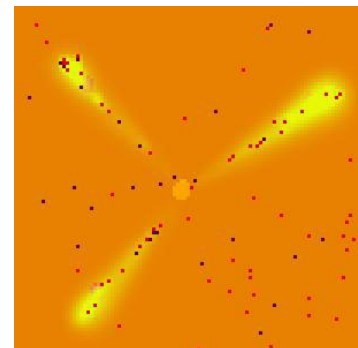
Simulation of ants, food and pheromones

Examples

A project that nine, ten and eleven year old children all over the world love is to design and make a car they would like to learn how to drive. They first draw their car (and often put big off-road tires on them like this).

So far this is just a picture. But then they can look "inside" their drawing to see its properties (for example where the car is located and heading) and behaviors (the ability to go forward in the direction it is heading, or change its heading by turning. These behaviors can be pulled out and dropped on the "world" to make a script which can be set "ticking" by clicking on the clock. The car starts moving in accordance with the script. If we drop the car's pen on the world, it will leave a track (in this case a circle), and we see that this is Papert's LOGO turtle in disguise – a turtle with a costume and easy ways to view and control it.

To drive the car, the children find that changing the number after **car turn by** will change its direction. Then they draw a steering wheel (the very same kind of object as the car, but with a different costume) and see that if they could put **steer's heading** right after **car turn by ...** this might allow the steering wheel to influence the car. They can pick up **steer's heading** (the name for the heading numbers that the steering wheel is putting out) and drop it into the script. Now they can steer the car with the wheel!

The children have just learned what a variable is and how it works. Our experience indicates that they learn it deeply from just this one example.

They quickly find that it is hard to control the car. They need to introduce a "gear" into the wheel's connection to the car. They can get the needed advice from a teacher, parent, friend, or from a child thousands of miles away via the mentoring interface over the Internet. They open the expression in the script, and divide the numbers coming out of the steering wheel by 3. This *scaling* makes turns of the steering wheel have less influence. They have just learned what divide (and multiply) are really good for.

Quite a bit of doing is "just doing", so it is a good idea to also reflect on what just happened. One way to do this is to have the objects leave trails that show what they were doing over time.

If the speed is constant then the trail of dots is evenly spaced, showing that the same distance was traveled in each little tick of time.
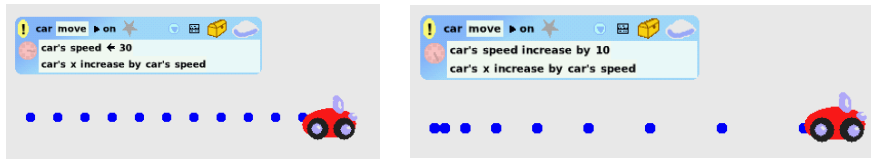
If we increase the speed each tick of the clock, we'll get a pattern that looks like the second picture. This is the visual pattern for uniform acceleration.
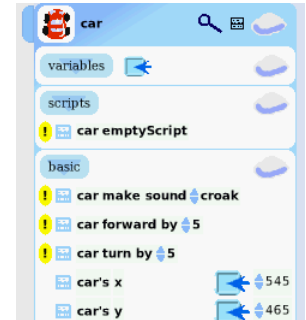
If we change to speed to be random each time, we will get an irregular pattern of distance traveled for each tick.
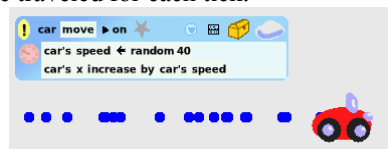
Random speeds are great for races!

Real Science With Children

So far we've been doing mathematics. To do science we have to look at the outside world. A nice example for 11 year olds is to investigate what happens when we drop objects of different weights.
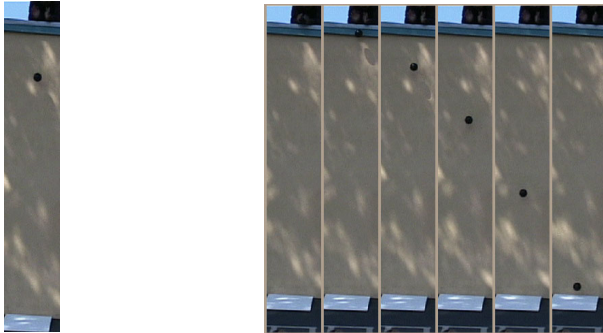
The children think that the heavier weight will fall faster. And they think that a stopwatch will tell them what is going on.

But it is hard to tell when the weight is released, and just when it hits.

In every class, you'll usually find one "Galileo child". In this class it was a little girl who realized: well, you don't really need the stop watches, just drop the heavy one and the light one and listen to see if they hit at the same time. This was the same insight that Galileo had 400 years ago, and apparently did not occur to any adult, (including the very smart Greeks) for our previous 80,000 years on this planet!

To really understand in more detail what is going on with gravity near the surface of the Earth, we can use a video camera to catch the dynamics of the dropping weight.

We can see the position of the ball frame by frame, $1/30^{th}$ of a second apart. To make this easier to see we can just pull out every fifth frame and put them side by side:

The "Galileo Girl" explains a simple way to see if different weights fall at the same or different speeds.

The stacked up frames that reveal the acceleration pattern

Another good thing to do is to take each frame and paint out the non-essential parts and then stack them. When the children do this, most of them will immediately say "Accelleration!" because they recognize that the vertical spacing pattern is the same as the horizontal one they played with using their cars several months before.

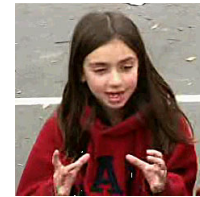But, what kind of acceleration? We need to measure.

Some children will measure directly on the spread frames, while others will prefer to measure the stacked frames.
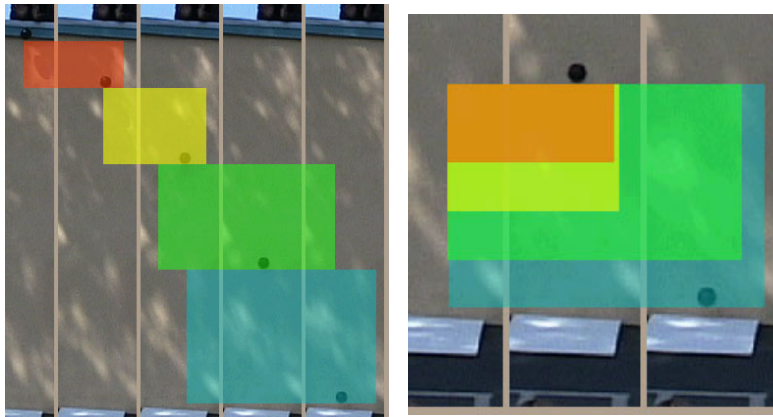
The translucent rectangles help because the bottom of the balls can be seen more accurately, The height of a rectangle measures the speed of the ball at that time (speed is the distance traveled in a unit of time, in this case about $1/5^{th}$ of a second).

When we stack up the rectangles we can see that the difference in speed is represented by the little strips that are exposed, and the height of each of these strips appears to be the same!

These measurements reveal that the acceleration appears pretty constant, and they made such scripts for their car months ago. Most quickly realize that since the ball is going vertically that they have to write the script so that it is the vertical speed that is

increased and the vertical position **y** that is changed. They paint a small round shape to be the simulated ball, and write the script:
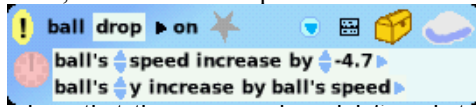
Now, how to show that this is a good model for what they have observed? 11 year old Tyrone decided to do as he did with his car months before: to leave a dot copy behind to show that the path of his simulated ball hit the very same positions as the real ball in the video.

Here is what he had to say when explaining what he did and how he did it for the Squeakers video:

> And to make sure that I was doing it <u>just right</u>, I got a magnifier which would help me figure out if I had it - if the size was just right.
>
> After I'd done that I would go and click on the little basic category button and then a little menu would pop up and one of the categories would be Geometry, so I clicked on that.
>
> And here it has many things that have to do with the size and shape of the rectangle. So I would see what the height is… I kept going along the process until I had them all lined up with their height.
>
> I subtracted the smaller one's height from the bigger one to see if there was a kind of pattern anywhere that could help me out. And my best guess worked: so in order to show that it was working, I decided to make – to leave – a dot copy (so that it would show that the ball was going at the exact right speed. And acceleration.)

An investigative work of beauty by an 11 year old!

By the way, in the United States about 70 percent of the college kids who are taught about gravity near the surface of the Earth fail to understand it. It's not because the college kids are somehow stupider than the fifth graders, it's because the context and the mathematical approach most college kids are given to learn these ideas are not well suited to the ways they can think.

Now that the kids have captured gravity, they can immediately make many games. In Lunar Lander, the gravity script that the children have just created will pull down the spaceship and crash it if it moves too fast. The rocket motor script can oppose gravity and a careful pilot can balance them to land the spaceship safely!

The Beauty and Importance of Complex Systems

We are all very aware now that one of the simple things that computers can do is to copy things quickly and cheaply.

Because of this we can explore very complex systems by just scripting the behavior of one item and making many copies. For example, if we make lots of little dots, we can explore the behavior of contagious processes, such as rumors and disease. Here the scripts are very simple, and cause a dot to change color when it collides with an "infected" dot. The size of the arena for collisions determines the delays between collisions, and allows us to explore matters of life and death, such as really understanding the characteristics of epidemics: fast deadly ones like typhoid which are very noticeable, and slow deadly ones such as AIDS (which is deadly in part because the onset of an AIDS epidemic is not dramatic). A poor understanding of slow deadly epidemics in many parts of the world is one of the main causes of the AIDS disaster. People have to reach beyond their common sense into the "uncommon sense" of models for disasters in order to help their imagination spur them to early action. The computer will eventually create an even larger change in how humans think about ideas than the printing press.
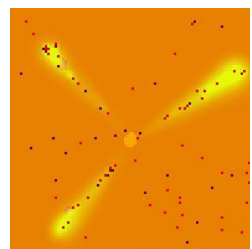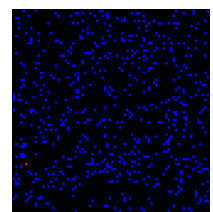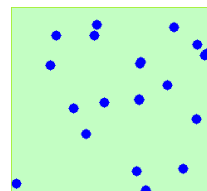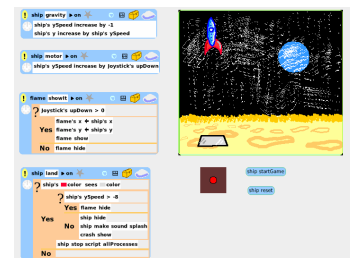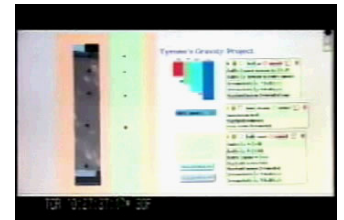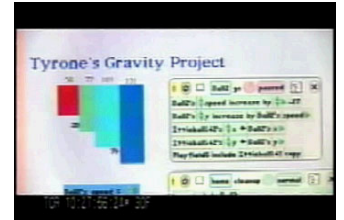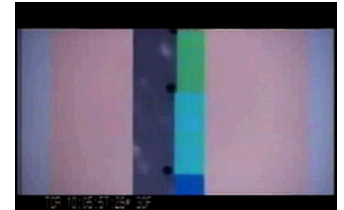
Lots of Things in the Universe are Springy!

Now, for the last set of ideas I'd like to show how easy observations of the real world plus very simple models plus the great power of the computer to do many simple things very quickly can reveal a whole new world of art and science.

One of the problems with classical science is that it reused common words – like know, theory, force, etc. – for very new ideas. New words should have been chosen.
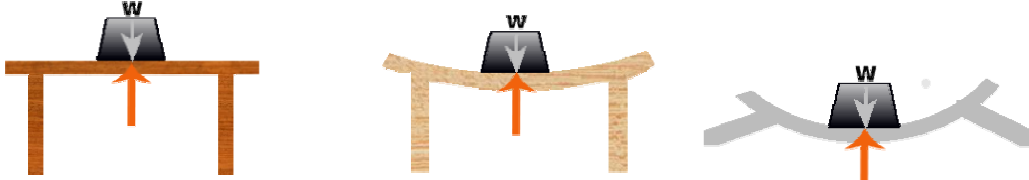

For example, the weight of an object is thought of in science as a force in the direction of the source of gravity. But if we place a weight on a sturdy table so that it moves no further, most people do not think of the table exerting an upwards force that balances the downward force of the weight.

If we try a table made from a flimsy wood, like balsa, we will see the table bend until it either breaks or is able to exert a balancing upwards force.

If we try this on a paper table, it will simply collapse down to the floor which exerts the upwards force.

Beams have the same characteristics. And all these are examples of "springy things".
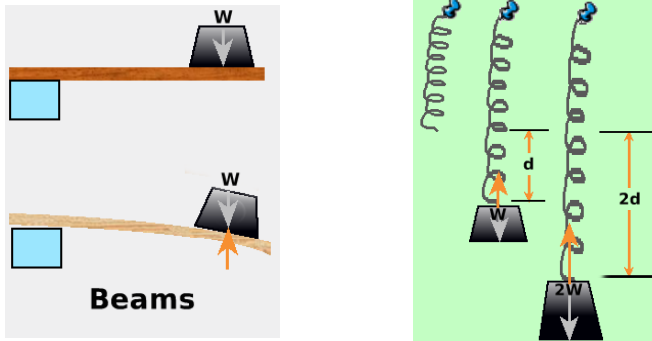

If we look at a spring with a weight hung on it we can measure how much it stretches until it is able to balance the force.

If we put on twice the weight most springs will stretch very close to twice as much. This gives us a way to simply describe the force of the spring: it is proportional to the length it is stretched.

Now we can use the ideas about acceleration and speed we learned from the falling weight. But the acceleration is not constant now because it is proportional to the stretch of the spring. What can we do?

What is really nice here is that we can get the computer to compute very small little movements in which we can pretend the acceleration is constant. Then we can measure the stretch of the spring and do this again. This gives us a very simple but good model of the spring, and is a great example of how easy it is for young children to learn the ideas of calculus with the environment of a computer.
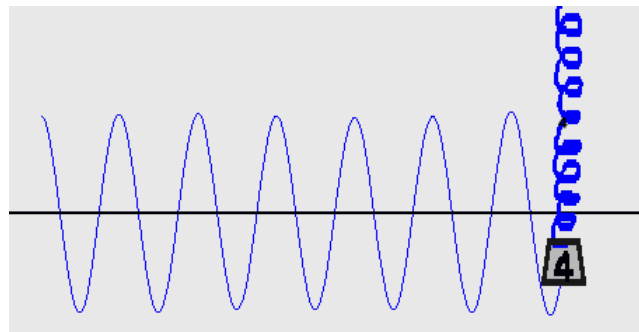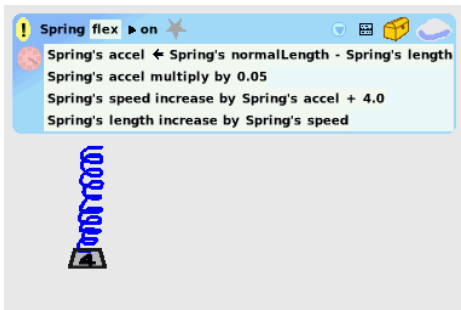

To plot what the spring does, we turn on its pen and move it sideways

Even better, once we've made one spring, we can get the computer to copy it over and over to get more springs.

Here is a movie all engineers see in college of a bridge with a 100 mile an hour wind blowing across it. It is quite startling to see how elastic the steel bridge is!

Let's make a simple bridge from two springs and a weight. If we turn on gravity and the spring models we see this: If we turn on the wind, we see that it will find a balance. But if we gust the wind but turning it on and off, we start to see behavior like the bridge.
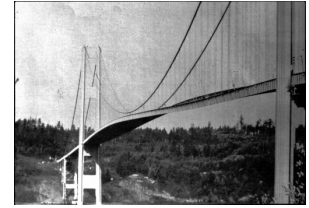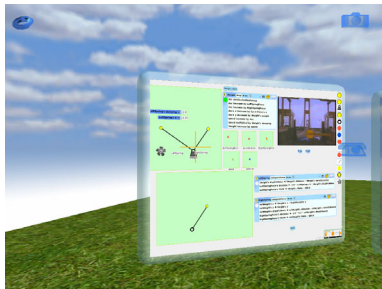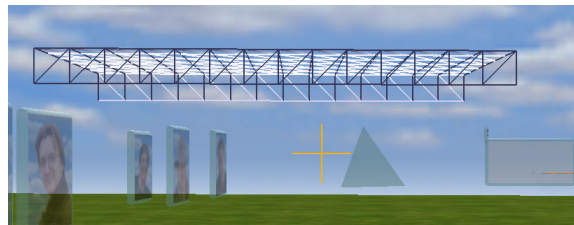

Tacoma Narrows Bridge in the wind
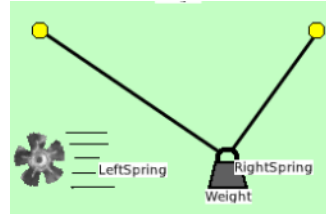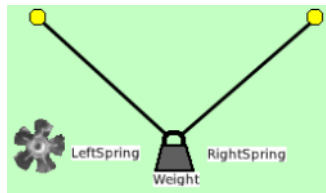
Tacoma Narrows Bridge shaking itself apart because it was too springy and started to resonate in the wind

But now let's make a real bridge! Since real bridges are in our 3D world, we need a 3D world to make our model – and we see that we've been in a 3D world the whole time!
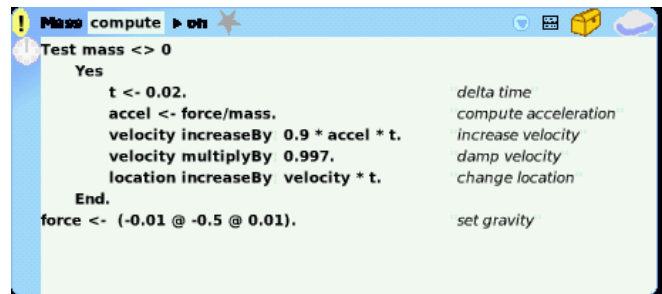

We are really in a 3D Computer World

Manifest a 3D bridge

But now let's make our bridge work. This structure is the same as the simple one we built with two springs and a mass, but now we are using the power of the computer to make many copies of the springs and the weights to make a bridge structure.

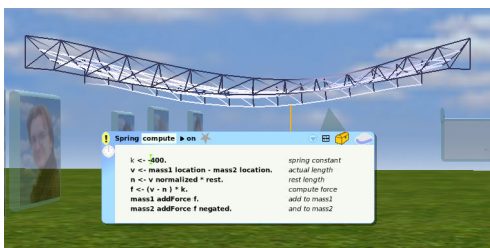Let's first turn on gravity. This will make the bridge sag a bit – notice that it is a bit springy.
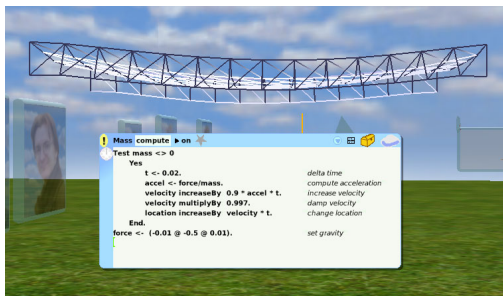
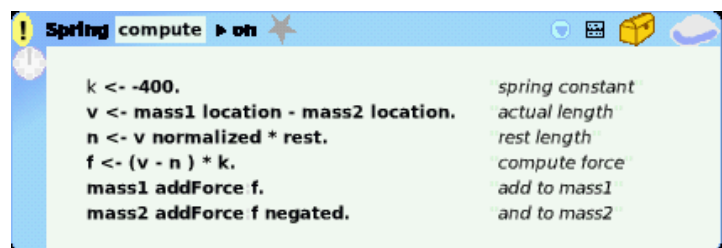Turning on gravity to affect the masses in the bridge

The gravity script (same as the one the children derived!)

```
! Mass compute  ▶ on  ✦
Test mass <> 0
    Yes
        t <- 0.02.                          delta time
        accel <- force/mass.                compute acceleration
        velocity increaseBy  0.9 * accel * t.   increase velocity
        velocity multiplyBy  0.997.         damp velocity
        location increaseBy  velocity * t.  change location
    End.
force <-  (-0.01 @ -0.5 @ 0.01).            set gravity
```

Now let's look at the script for the springs. Let's make them more springy by changing the stiffness number to -400.

Making the bridge structure springy

The spring script

```
! Spring compute  ▶ on  ✦
    k <- -400.                              spring constant
    v <- mass1 location - mass2 location.   actual length
    n <- v normalized * rest.               rest length
    f <- (v - n ) * k.                      compute force
    mass1 addForce f.                       add to mass1
    mass2 addForce f negated.               and to mass2
```

We can see the bridge sag and bounce a little more.

Now we'll turn on a gusting wind that is like the one that started the suspension bridge in the movie oscillating. This has a few more details, but is still easy and small.


The wind starts the bridge oscillating
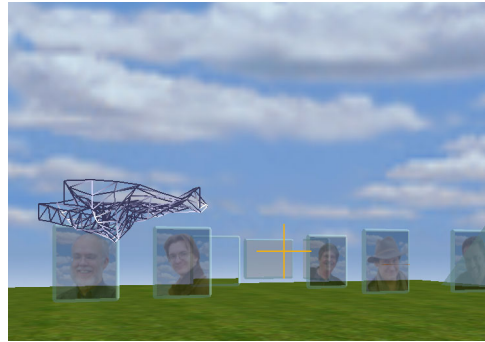

From the side with strong wind

The simulated bridge really starts oscillating violently, very similar to the movie of the real bridge! Let's move around to the side so we can look down it. It is so flexible and elastic that it looks kind of like a cloth fabric to me. And that pops up an idea. Let's detach one end of the bridge, gradually put a texture on it, and see what happens in the wind and gravity. We get a nice surprise! It's a flag!
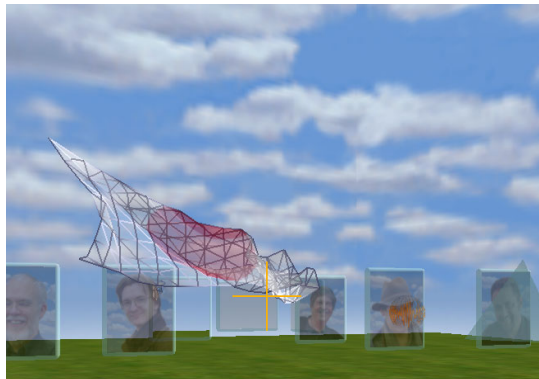
The bridge unfolding and starting to show a texture
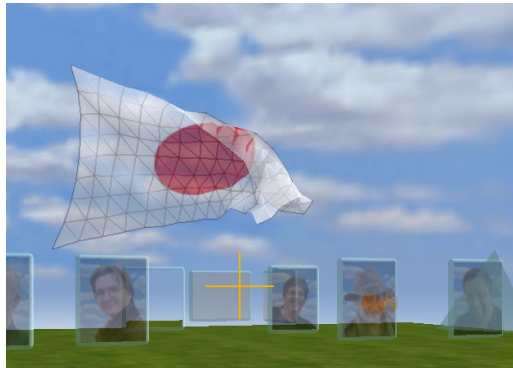
The texture becomes more intense and the structures fade
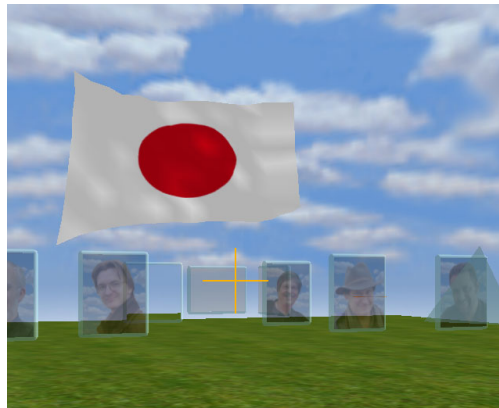
It is quite startling that bridges and flags are abstractly similar! Most of the startling "reality" in the universe was not even suspected until a few hundred years ago. "Making the invisible a little more visible" via helping children learn powerful ideas by building them is the goal of the Squeak Etoys project.