

Chapter 27



Physical Simulation

Object Attributes



Set as rubber



Set as glass



Set as iron



Set as styrofoam



Set as paper



Set as wood



Set as rags



Erase physical attributes



Center of object's gravity



Object fixation point 1



Object fixation point 2

Vector Controls



Initial motion vector



Initial rotation vector



Acceleration motion vector



Acceleration rotation vector

Gravity and Atmosphere



Set grid as gravitational pad



Enable atmosphere

Wind Controls



Local physical wind



Global physical wind

Simulation Controls

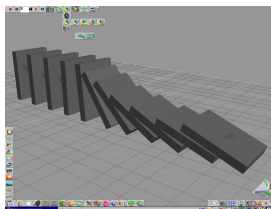


Start (or cont.) simulation



Rewind simulation

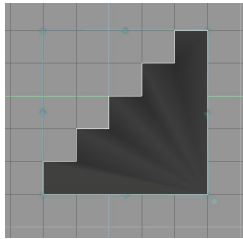
trueSpace fully implements integrated simulation of the physical behavior of real-world objects, including gravity, inter-object collisions, linear and rotational velocity and acceleration, wind, and even atmospheric density upon which an airplane or other flying object can glide. This feature lets you easily set up complex animations incorporating the accurate motion and physical interaction of dozens or even hundreds of objects. For instance, to create a flying airplane, just add an atmosphere, point the plane in the right direction, and let 'er fly! Or you can stack some bricks, and add wind to knock them all down. The bricks will bang into each other as they fall over, affecting their motion just as they would in real life.



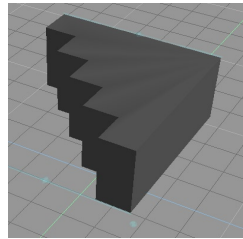
27.1 Physical Simulation Quick Start Tutorial

In this tutorial, you'll use trueSpace's physical simulation capabilities to bounce a rubber ball down a flight of stairs. You'll take advantage of the default gravity, and use the **Initial Rotation Vector** feature to give the ball a forward spin, so it doesn't just bounce on the top step.

1. Start trueSpace. Set the main window to **Top view**. 
2. Select the **Grid**  and **Polygon**  tools. Draw a profile view of a staircase with five steps.
3. Use the **Sweep** tool  on the profile. Sweep it to a height of about 8 units on the Z axis.

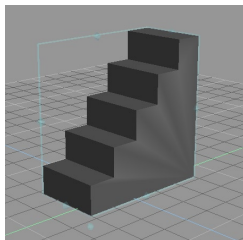


Step 2

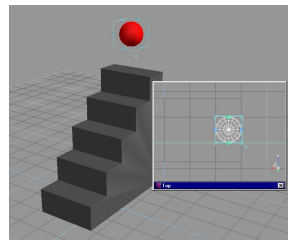


Step 3

4. Rotate the stairs object 90 degrees on the X axis, and raise it up so it's sitting on the ground. Use a **New Front View** window if it helps.
5. Add a primitive sphere. Use the **Object Move** tool to position it above the top step, and the **Object Scale** tool to make its diameter smaller than the step's depth. Switch the small window to **Top view** to assist in the positioning and scaling.



Step 4

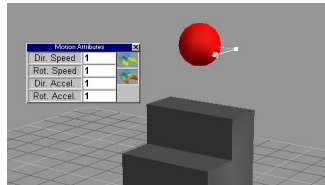


Step 5

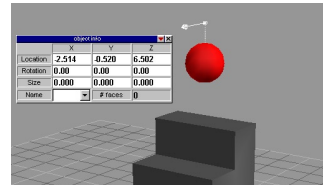
6. Make it a rubber ball by selecting the tire icon on the context toolbar to give the sphere **rubber attributes**. 
7. On the same toolbar, select the **Initial Rotation Vector**  icon, first with the left mouse button to impart the default initial rotation settings to the sphere, and secondly with the right

mouse button to open the **Motion Attributes** panel. In the panel, select the upper icon on the right side (**Initialization speeds rotate with object**) to make the rotation vector rotate with the sphere. This rotation occurs only during setup, and lets you change the initial rotation vector angle by rotating the sphere.

8. Click on the sphere to select it. Right click on the **Object** tool to open the **Object Info** panel, and set the **X Rotation** value to -90.00. This gives the sphere a forward rotation, instead of the default sideways rotation.

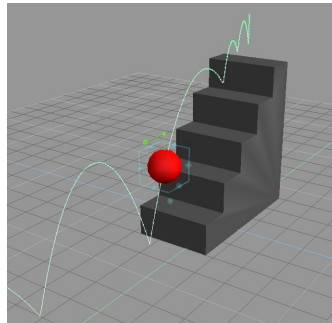


Step 7



Step 8

9. Click on the **Start Simulation** button on the toolbar in the bottom right corner of the screen. After a few bounces on the top step, the ball starts gaining forward momentum and bounces neatly down the steps.
10. Click the **Play** button in the **Animation Controls** group to play back the animation.



Bouncing ball demo with the Path tool selected to show the ball's bouncing path.

11. When it's done, rewind the animation by clicking on the **Return to Start** button, and experiment with the parameters. For example, see what happens if you change the rotational speed and/or direction by dragging on the arrow emanating from the sphere. (Select it first by clicking on it). Also try changing the ball's physical attributes, such as **Mass** and **Elasticity**. You can access these settings by right clicking on any of the icons in the Physical Attributes panel's two upper rows.

27.2 Simulation Control



Start (or Continue) Simulation

This control is similar to the Animation panel's **Play** button, except that it causes an animation to be generated, keyframe by keyframe, using the physical attributes of objects currently in the scene. Selecting it causes trueSpace to begin or continue the physical simulation at the current frame. While the simulation is in progress, the Help bar displays the current local frame, or simulation step, as well as approximate remaining duration of the resulting animation in seconds. The number of local frames required per animation frame depends on the complexity of the simulation or the Constant Time setting in the Physical Simulation Control Panel (described below).

Press the <ESC> key to halt the simulation. If Auto Rewind is enabled (this option is covered in the Physical Simulation Control Panel section, below), stopping the simulation rewinds the scene to the frame at which it was started.

After generating a simulation, use the Animation panel's **Play** button to play it back.

Right click on the **Start Simulation** tool to open the Physical Simulation Control Panel (described below).



Set Objects to Origin

This is a rewind function for the physical simulation. By default, when you halt a simulation by pressing the Esc key, the scene automatically resets itself to the starting conditions. However, you can use the Physical Simulation control panel's Auto Rewind switch to turn off this feature. If you have disabled Auto Rewind, use the Set Objects to Origin button (also found in the Animation Control panel) to return to the starting frame.

27.3 Object's Physical Attributes

In trueSpace's physical simulation, there are two types of objects: "dynamic" objects, which have physical attributes such as mass and elasticity and participate in the simulation; and "non-dynamic" objects which have no physical attributes, and are thus unaffected by the simulation.

Note: Although non-dynamic objects, to which physical attributes have not been assigned, do not move in physical simulations, they do act as obstacles to moving objects.

Note: IK objects and PlastiForm objects cannot be assigned physical attributes. If you attempt to assign physical attributes to a PlastiForm object, trueSpace asks if you want to delete the PlastiForm structure.

To define physical attributes for an object using default values, select the object, and then select the

Center of Object's Gravity tool. This causes two things to happen:

- The object becomes “dynamic,” and is assigned default physical attributes: a Weight of 10, Elasticity of 65, Resistance of 1, Friction of 50 and Buoyancy turned on.
- The object's center of gravity is placed at its axis' location, as indicated by the cross-hairs icon; by default, in its geometric center.

Preset Physical Attributes

Seven preset attribute sets are available:



Set Parameters of object as rubber



Set Parameters of object as glass



Set Parameters of object as iron



Set Parameters of object as styrofoam



Set Parameters of object as paper



Set Parameters of object as wood



Set Parameters of object as rags

If you select any of these with an object active, all previous physical attributes are erased, including any previous settings made with tools in this panel, such as Initial Motion Vector.

When applying preset attributes to an object, the assigned Mass value depends on the object's volume. For instance, a default cube primitive assigned the Styrofoam preset is given a mass of 203.199, while the default sphere primitive made of Styrofoam has a mass of 99.161.



Erase Physical Attributes

Deletes all of the object's physical attributes, returning it to its default status as a standard trueSpace object. Right click on this panel to open the Numerical Physical Attributes Panel, which lets you set the object's physical attributes directly (see the Numerical Physical Attributes Panel section below for details).

Important note: When manipulating any of the below entities, first select the object, then select the entity by clicking on it and then releasing the mouse button, and then click and drag again to move the entity. If, however, the Dynapick option is turned on (**Edit menu/Preferences**), you need simply click and drag on the appropriate entity. When you are finished manipulating the entity, re-select the object (or any other object) by clicking on it.



Center of Object's Gravity

Selecting this tool activates the center of gravity icon, which you can then move by dragging it with the mouse. An object's center of gravity is the same as center of object coordinate system. If you move an object's axes, the center of gravity moves as well.

You can manipulate the object's center of gravity without using this tool by clicking on it (the object need not be selected first). If Dynapick is not on, click and release to select it, and then click and drag to move it. If Dynapick is on, click and drag without selecting it first.

When manipulating the center of gravity, it remains selected until you select a different object, or the object whose center of gravity you are manipulating.

Note: If you use the **Axes tool** with a dynamic object to make its axes visible, the center of gravity icon is temporarily hidden. Select the **Axes tool** again to turn off display of the axes and re-enable display of the center of gravity icon.



Object Fixation Point 1



Object Fixation Point 2

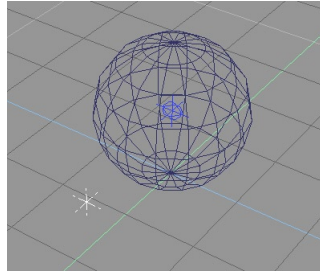
This two-part tool lets you add and remove one or two constraint points, which represent “nailing” an object to one or two points, respectively, in space. For example, in the above Quick Start, if you had given a fixation point and moved it to the sphere's side, instead of dropping, it would swing back and forth, using the fixation point as a fulcrum. With one fixation point, an object behaves as though it is connected to a hook, and with two points, it behaves as though connected to a wire (axis).

To enable the first fixation point, select the object to which it is to be attached, and then select either **Object Fixation Point** tool. This causes the **Object Fixation Point 1** tool to highlight, and the new, highlighted fixation point appears. It resembles a set of three crossed axes, and is superimposed over the object's center of gravity icon.

To move a fixation point, select the point, enable **Object Move** mode, position the mouse cursor anywhere in the workspace (it need not be on the icon), and then press and hold the left mouse button and drag the mouse in the desired direction, using the right mouse button to move the point vertically, as with moving any selected object.

When manipulating a fixation point, it remains selected until you select a different object, or the object whose fixation point(s) you are manipulating.

To add a second fixation point to an object, select the object, and then select the **Object Fixation Point 2** tool. One example of the practical application of two fixation points is a cogwheel. Such a wheel can impart rotational motion to an object it comes into contact with without moving away from the impact.



Object fixation points

To delete an object's fixation point(s), select the object, and then select the appropriate **Object Fixation Point** tool.



Initial Motion Vector

This control lets you interactively set an object's starting linear speed, or velocity, and direction in the simulation. Left click on the tool to set the default initial velocity of 1 along the X axis, in a positive direction, as depicted by a single-headed arrow. Drag the arrow to change the direction and speed; the length of the arrow indicates the speed. To accept the current settings, select the object you're manipulating, or any other object. To modify the setting, select the **Initial Motion Vector** tool again, or select the arrow icon directly.

Right click on the tool to open the Motion Attributes panel, which displays the speed numerically in units per second, and lets you set it with the mouse or keyboard.

During the simulation, if a moving object encounters another object, it will react according to real-world physics laws. For example, if you place a sphere on the ground and give it a horizontal initial motion, it will roll, rather than slide, if gravity is turned on (see Global Physical Properties, below).



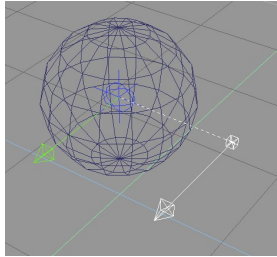
Initial Rotation Vector

This control lets you interactively set an object's starting rotational speed and direction in the simulation. Left click on the tool to set the default initial rotational velocity of 1 around the Z axis, as depicted by a single headed arrow on the object's side, connected to the object's center with a dotted line. Drag the arrow's head to change the speed by changing the arrow's length, and the direction in which the arrow points. If you drag the arrow base (a small cube), you can change the direction of rotation by altering its position.

For example, at the default setting, the object rotates around its vertical axis. However, if you position the arrow at the top center of the object, the object will rotate around a horizontal axis in the direction of the arrow. If you position the arrow at the bottom center of the object, the object will rotate around a horizontal axis opposite the direction of the arrow.

To accept the current settings, select the object you're manipulating or any other object. To modify the setting, select the **Initial Rotation Vector** tool again, or select the arrow icon directly.

Right click on the tool to open the Motion Attributes panel, which displays the speed numerically in units per second, and lets you set it with the mouse or keyboard.



Initial Motion and Rotation vectors



Acceleration Motion Vector

The **Acceleration Motion Vector** lets you create linear motion that increases in speed throughout the simulation (assuming no friction). Its usage is similar to that of the **Initial Motion Vector**, except that it is displayed as double arrow, and during the simulation it rotates (unlike velocity) with the object. You would generally use this in place of the **Initial Motion Vector** to simulate a motorized vehicle, such as a car or airplane.

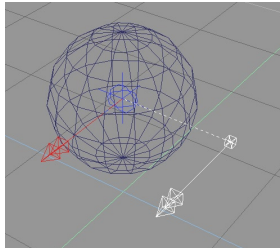
Right click on the tool to open the Motion Attributes panel, which displays the acceleration numerically in units per second, and lets you set it with the mouse or keyboard.



Acceleration Rotation Vector

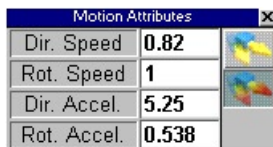
The **Acceleration Rotation Vector** lets you create rotational motion that increases in speed throughout the simulation (assuming no friction). Its usage is similar to that of the **Initial Rotation Vector**, except that it is displayed as double arrow, and during the simulation it rotates with the object.

Right click on the tool to open the Motion Attributes panel, which displays the acceleration numerically in units per second, and lets you set it with the mouse or keyboard.



Acceleration Motion and Rotation vectors

Motion Attributes Panel



If you right click on any of the **Motion** or **Rotation Vector** icons, the Motion Attributes panel will open. This panel allows you to set values for speed and rotation numerically with the keyboard. These numbers will also update as you modify vectors with the mouse.

Note: The values shown in this panel indicate units per second.

The icon in the upper-right corner is the **Relative Initialization Speed** toggle. This affects the initial rotation vectors during editing. When enabled, if you rotate the object, the initial vectors rotate with the object. When disabled, if you rotate the object, the initial vectors remain in their original orientation(s).

The lower icon on the right side of the panel is the **Relative Acceleration Speed** toggle. This affects the acceleration motion and acceleration rotation vectors during editing, and also during simulations. When enabled, if you rotate the object, the acceleration vectors rotate with the object. This can be useful, for instance, with an airplane that should rotate as it turns. When disabled, if you rotate the object, the acceleration vectors remain in their original orientation(s).

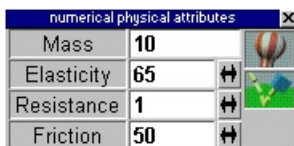
Object Collision

Collision between objects in a trueSpace physical simulation is automatic, and follows the same real-world physics as other aspects of the simulation. Even non-dynamic objects (i.e., those to which physical attributes are not assigned) participate in collisions, although they do not move as a result. No special preparation is required. In fact, even invisible objects (see Object Info panel) follow these rules.

Note: trueSpace cannot detect a collision with a primitive plane or an un-swept polygon, because these objects have no height, and thus no volume.

It is possible to turn off collisions on a per object basis through a switch in the Numerical Physical Attributes panel.

Numerical Physical Attributes Panel



You can set values for a specific object's physical attributes by right clicking on one of the following buttons:

- Preset Physical Attributes (any)
- Erase Physical Attributes
- Center of Object's Gravity
- Object Fixation Point

The attributes are:

- **Mass:** This is the object's physical mass in kilograms. If you give an object a mass of 100,000,000 or greater (do not type the commas), the value is displayed in the panel in scientific notation. This method of displaying large numbers consists of a decimal number between 1 and 10, then the letter "e," and then a positive or negative integer giving the power of 10 by which the decimal number is multiplied. For example, the number 150,643,000 is displayed in scientific notation as 1.50643e+006. With very long strings of numbers, trueSpace may truncate some of the rightmost digits, and/or you may need to click in the value field and press the right arrow key several times to see the rightmost part of number (i.e., the exponent). In some cases, a very small number (e.g., 0.0001) may be displayed as 0. In such a case, the weight is still stored in memory as the entered value.
- **Elasticity:** This setting defines the percentage of energy retained after a collision with another object. The possible range of values is 0 to 200. If you specify an amount greater than 100, the object's energy will actually increase after each bounce (ever heard of flubber?).
- **Resistance:** The Resistance setting determines an object's air resistance. The possible range of values is 0 to 100. If you set an object's Resistance to 0, it has no resistance and the simulation does not calculate air resistance, making the simulation run faster.

When a real-world object moves through Earth's atmosphere, its progress is affected by a number of factors, not the least of which is the size of its leading edge. Typically, all other factors being equal, an object with a large leading edge encounters greater air resistance (e.g., a flat sheet of paper) than does one with a small leading edge (e.g., the same sheet of paper crumpled into a ball), and thus (for example) falls less rapidly. In addition, an object with a larger leading edge tends to be more greatly affected by moving air, such as the wind.

This principle is followed in trueSpace's physical simulation. You can prove this by adding a sphere and a plane primitive, raising both to the same level, setting a high atmospheric density (e.g., 1,000), and starting the simulation. The sphere will drop more quickly than the plane, even though both have the same Resistance setting.

Particularly with complex objects, trueSpace's physical simulation may need a bit of help determining an object's air resistance, which you can provide via the Resistance setting.

You can observe the effect by adding two identical objects, raising both above the ground, setting a high atmospheric density (e.g., 1,000) and then giving the two objects markedly different Resistance settings (e.g., 1 and 1,000). When you start the simulation, the object with the higher Resistance setting will fall more slowly.

- **Friction:** This setting determines the amount of friction between an object and other surfaces it encounters. A Friction setting of 0 results in a very polished object that slides smoothly. And a setting of 100, the highest possible value, indicates an object with a very rough surface.



Buoyancy

This switch lets you set whether the atmospheric force can lift the object. As you may know, objects that are less dense than the medium in which they're contained rise. For example, a ping pong ball released at the bottom of a swimming pool immediately shoots up to the top of the pool. Similarly, a balloon filled with helium, which is less dense than air, rises. Setting high values trueSpace's atmospheric Density and Thinning parameters lets you simulate a body of water.

Objects will be "buoyed" with the calculated force:

$$F = \text{Volume} * \text{AtmosDensity}$$

Calculation of the volume of complicated objects may take some time.

Note: Gravity must be enabled (i.e., the Set **trueSpace Grid as Gravitation Pad** switch) for buoyancy to take effect.



Allow/Disable Collision with Objects

This switch is enabled by default. If collision is disabled, the object will not collide with other objects during the simulation.

For example, if a ball is rolling towards a wall, turning collision off for the ball, wall, or both will result in the ball passing through the wall. If collision is enabled for both objects, the ball will bounce off the wall, or at least be stopped by it.

27.4 Gravity and Atmosphere



Set trueSpace Grid as Gravitation Pad

By default, gravity is turned on in trueSpace's physical simulation world. Use this tool to toggle the trueSpace grid as a source of gravity. Right click on the tool to open a panel that displays and lets you change the gravitational force.

In trueSpace, gravity affects only objects completely above the grid. Also, gravity must be on for buoyancy to take effect. Thus, objects that intersect with the grid or are below it cannot be buoyant. Actually, such objects are not detected as physical entities.



Enable Atmosphere for World

This switch lets you toggle the impact of the atmosphere on all objects. Right click on the tool to open a panel that lets you define the atmospheric density and rate at which the atmosphere thins with height. The atmosphere thins exponentially, so you can simulate a water surface with high Density and Thinning values.



Atmosphere Control Panel

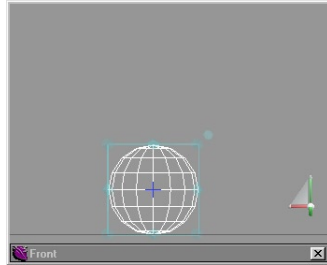
- **Density:** This value determines the atmospheric density. The lowest possible value is 0, and beyond the upper limit, the density is considered to be infinite. Settings of 1,000,000 and greater are displayed in scientific notation (see explanation under Mass, above).
- **Thinning:** This value determines the rate at which the atmosphere density decreases with height, and its reciprocal value directly expresses the height (or length) at which the atmospheric density decreases by half. For example, if you set Thinning to 0.5, then for every 2 units of height, the density would decrease to about half of its value. (If at 0, atmospheric density were 1000, at 2 units it would be 500, at 4 units it would be 250, and so on.) Possible values range between 0 and 3,000, with 0 representing a slow falloff and 3,000 representing a rapid falloff.

27.5 Buoyancy Tutorial

1. Add a sphere.
2. Set the sphere's attributes as **styrofoam**.  Next, right click the **Styrofoam** icon to open the Numerical Physical Attributes panel, and change Resistance to 1.
3. Right click on the **sky/clouds**  icon. This opens the Atmosphere control panel.
4. Use the keyboard to set Density to 20,000 (do not type the comma) and Thinning to 1. Be sure to press <ENTER> for both settings.
5. Open a new **Front View** window, and use the **Eye Move** and **Zoom** controls so the sphere is at the bottom of the window, and about one-fifth its height.
6. Start the simulation, and let it run for a few minutes. As the sphere rises, it starts to decelerate,

indicating that the atmosphere is thinner. When it gets to about three-fourths the height of the **Front View** window, it starts to bounce, as though on the surface of a body of water.

7. Change the Density setting to 5,000 and run the simulation again. This time, because there's less of a differential between the densities of the sphere and atmosphere, it doesn't rise as high.



Step 7

8. Experiment with various combinations of settings of the sphere's mass, the atmospheric density, and thinning.

27.6 Wind



Set Global Physical Wind

This sets a global wind for the whole scene. Selecting this tool places in the workspace a non-rendering 3D object that indicates the strength and direction of the wind. The following controls are available for the **global wind**:

- Change the global wind's direction by rotating the object.
- Change the global wind's strength by scaling the object, or by right clicking on the **Global Wind** icon and setting it in the numeric field labeled Power.
- Because the global wind permeates the scene, moving the object has no effect.
- Selecting the icon again will turn off the wind, but any changes will be remembered (and saved with the scene), and restored if you turn the wind back on.
- To restore the global wind to its default settings, delete the object and add a new one.

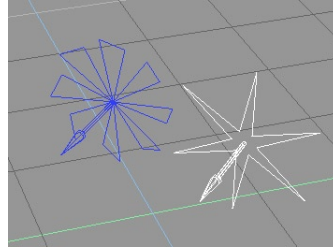


Add Local Physical Wind

You can add as many local wind objects to your scene as you like. The local wind is similar to the global wind, but its effects depend on the position of the object, and its intensity decreases with distance. Properties are:

- Change the local wind's direction by rotating the object

- Change the local wind's strength by scaling the object, or by right clicking on the **Local Wind** icon and setting it in the numeric field labeled Power.
- The object's position indicates the center of the local wind's volume of influence. The local wind's force actually occupies a spherical volume around the object, so even objects "behind" a local wind object can be affected by it.
- To add more local wind sources, select the **Add Local Physical Wind** icon.

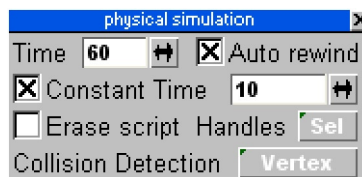


Global (left) and local (right) wind

Note: In order for the wind to affect an object, it is necessary to set up a proper combination of the mass of the object, the strength of the wind, the density of atmosphere and the profile of the object. For example, it is not possible for the wind to blow away a heavy cube with a small active profile if the wind is not strong enough. Also, it is necessary to take into account the subdivision of the object. If an object's surface against which the wind is blowing consists of nine faces (instead of just one), its air resistance is evaluated nine times instead of once, and the whole computation is much more precise.

27.7 Physical Simulation Control Panel

In the **Local Physical Attributes** panel, right clicking on the Start Simulation or the **Set Objects to Origin** tool lets you set these global values for the simulation:



- **Time:** This setting defines the simulation's duration, in seconds. The default value is 60.
- **Auto Rewind:** If checked, objects will automatically return to their original positions when you stop the simulation. If not checked, objects remain in their final positions. Then, if you click Start Simulation, the simulation will continue from that point. This way, you can change values during the simulation. If you want to restart the simulation from the beginning press **Set Objects to Origin** before restarting the simulation to return objects to initial

positions and velocities.

- **Constant Time:** The **Constant Time** checkbox and numeric field let you set the number of simulation steps calculated per generated animation frame; alternatively, it lets you tell trueSpace to make its best guess about the number of steps required.

By default, **Constant Time** is enabled, and set to 10 simulation steps per animation frame. You can change this setting by entering a new value, either from the keyboard or by clicking and dragging on the double-headed arrow to the right of the field. Use low values (5 or less) for faster simulation speed, and higher values (30 or more) for greater accuracy (e.g., with collisions).

When **Constant Time** is disabled (called “auto-step”), trueSpace determines the appropriate number of simulation steps per animation frame on the fly. This may work best in complex simulations, where the need for speed versus accuracy can change from moment to moment.

This setting does not affect how fast trueSpace calculates or plays back a simulation. The speed at which a simulation runs can vary, and is dependant on the complexity of the simulation at any given moment.

- **Erase Script:** For every simulation start (not for continuing an existing simulation), any existing keyframes are erased. If you want to extend an existing simulation, the check box should not be checked.
- **Draw Handles:** This combo box lets you indicate how the handles (arrows) for initial velocities and accelerations are to be drawn.
 - **None** - No handles are drawn
 - **Sel (default)** - Handles are drawn for the selected object only
 - **All** - All handles are drawn
- **Collision Detection:** Allows you to specify the precision level of collision detection. If Vertex is selected, only vertex collision between objects is considered. For the Vertex-Face option, both vertex and face collision between objects is considered for computation of physical response. This option is more precise, but computation time is longer in comparison with the Vertex option.

27.8 Tips for Improving Performance

You may find that you get slightly different results upon running a simulation twice with the same settings, typically manifested as colliding objects bouncing in different directions. This is caused by coinciding edges, and is typically remedied by moving one of the objects.

Speed

For most scenes, the optimum settings are the defaults. If, however, you find you are getting unsatisfactory performance while running a simulation (i.e., it's running too slowly), here are some suggestions for speeding up the simulation:

- Use Wireframe Display mode.
- Set the simulation to draw only the selected object, rather than the entire scene (works only in Wireframe Display mode).
- Turn on Constant Time, and set the number of steps to 1.
- Turn off Atmosphere.
- Turn off Buoyancy, and/or disable the atmosphere or set Atmosphere Density to 0.
- Using objects with concave surfaces can slow down simulation. If possible, create a concave object by gluing together several convex objects.

Accuracy

If you find, on the other hand, that the accuracy of the simulation needs to be improved (e.g., velocities vary when they should not), here are some things to try:

- Turn on Constant Time and set the number of steps to a high number (30 or above).
- Turn on Atmosphere.
- Turn on Buoyancy.

If objects behave strangely during collisions (e.g., a light object does not fall over when hit by a heavy one, or objects stick to each other), give these a try:

- Turn on Constant Time with appropriate settings (on the high side).
- Change the ratio of object's weights.
- Quad Divide objects. (The more faces and vertices, the more accurate the collision.)