Building a simple system in Working Model

This tutorial will take you through the easy process of building a simple system, and simulating its behavior. The tutorial will also give you an overview of Working Model and its basic features.

What is Working Model?

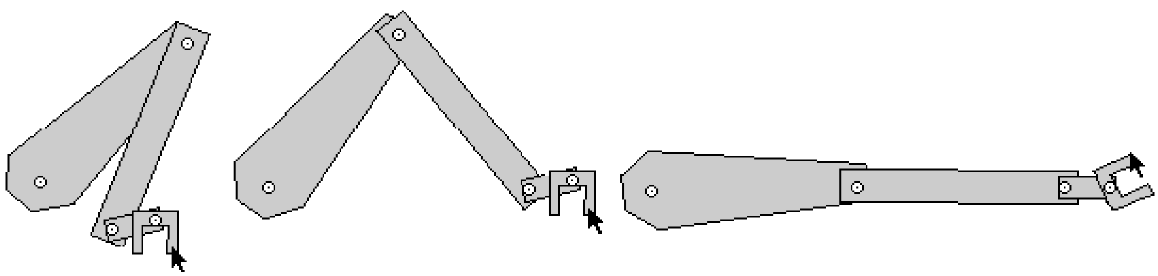
Knowledge Revolution Working Model™ combines advanced motion simulation technology with sophisticated editing capabilities to provide a complete, professional tool for engineering and animation simulation. The dynamic simulation engine provides a translation of real world Newtonian mechanics to the computer, while the simple but powerful graphical user interface makes it easy to experiment with different scenarios and situations.

Simulation Engine

The simulation engine of Working Model™ is designed for both speed and accuracy. It calculates the motion of interacting bodies using advanced numerical analysis techniques. The engine allows the construction of complex systems, and computes their motion under a variety of constraints and forces. In addition to user-imposed constraints such as springs, pulleys, or joints, the engine has the capability to deal with world-level interactions, such as collisions, gravity, wind-resistance, and electrostatics. The engine is fully configurable, and every aspect of a simulation from the time step (fixed or variable) to the integration technique can be specified by the user.

Smart Editor™

The Smart Editor™ is the core of the user interface, keeping track of connections and constraints among objects as they are constructed. To develop a mechanism, a user simply starts to draw the components on the screen and indicates where and how the pieces should be joined. The Smart Editor™ allows the mechanism to be rotated and dragged, while maintaining the fundamental integrity of the components and of the joints between them. Users can position objects by using the standard click-and-drag Macintosh paradigm, or by specifying their coordinates precisely in dialog boxes. In all cases, the Smart Editor™ makes sure that no link is broken and no mass is stretched. A robot arm, composed of many parts held together by pivot joints, can be positioned accurately using the Smart Editor™. By clicking and dragging the hand, the arm stretches out to the desired conformation.



FPU support

Working Model is designed to take full advantage of the Floating Point Unit (floating-point math coprocessor), if one is available. This speeds the computations enormously, allowing for faster, smoother animation.

If no such unit is available, Working Model™ defaults to standard Macintosh arithmetic.

Inter-Application Communication

Working Model uses Apple events to communicate with other applications during a simulation. Users can specify physical models of real-life mechanical designs and then control them externally through other programs. For instance, a Microsoft Excel™ worksheet can be used to model an external control system. Data can be passed to a spreadsheet, results can be calculated, and then the answer can be returned to Working Model, all while a simulation is in progress.

Complex functions, such as table lookup, can be implemented in a spreadsheet and then linked to a Working Model simulation.

Export of Static and Animated Data

Working Model imports and exports data to most popular CAD programs through the DXF file format. Also supported are the standard PICT, Meter Data, and QuickTime movie formats.

Animated data can be exported in a variety of formats. Because of the accuracy with which it models complex interactions of moving objects, Working Model is a natural tool for creating animated images of unprecedented realism. The frame sequences themselves can be exported in a variety of standard file formats, including MacroMind Three-D, Wavefront, and DXF animation, allowing a seamless integration of Working Model files with animation programs.

Input and Output Devices

Real-time input devices include sliders, buttons, and text fields.

Real-time output devices include graphs, digital displays, and bar displays.

Complete set of FastAction™ Buttons

You can create a button to execute Working Model menu commands, including Run, Reset, and Quit. Buttons can simplify pre-made simulations for the first-time user. With buttons, you can create Working Model documents that are similar to HyperCard stacks in that one document can lead to the next by the click of a button.

Moving Graphics

You can paste pictures created with a paint or draw program directly on the workspace, as well as link them to objects. For example, you can create a circular mass object and attach a picture of a baseball to it.

Custom Global Forces

You can now simulate planetary gravity as well as earth gravity, electrostatic forces, and air resistance proportional to velocity or velocity squared, or create your own custom global forces by supplying an equation. For example, you can create magnetic fields, wind, and electron gun fields.

Text tool

You can annotate experiments directly on the workspace, using any font, size, or style of text.

Extensive Graphical Features

You can show and hide objects, fill objects with patterns and colors, display how objects are charged (+ or -), choose the thickness of an object's outline, show object names, display vectors in various ways and colors.

Multiple Reference Frames

You can now create different views using any mass or point as the frame of reference.

Complete Control of Units

Choose from standard metric units such as kilograms, meters, and radians; standard English units such as foot, inch, yard, second, degrees, pounds; or other kinds of units such as light-years for measuring distance.

Complete Scripting Language

Working Model has a scripting language for creating formulas that is very similar to the formula language used in Excel and Lotus 1-2-3.

Equations

Any value can be a formula rather than a number. For example, you can create a formula for a mass object that simulates a rocket, or create a formula for a force that simulates a sinusoidal driver.

No-Menu Player Documents

Player mode provides an experiment window with a limited menu bar and no palette, giving more room to display the experiment. Player mode documents can be used by people who are not familiar with Working Model.

Custom Tracking

You can track all objects or limit tracking to selected objects. Individual objects can leave tracks of their outline, center of mass, or vectors. You can also connect tracks with lines.

Object Layering

The experiment world consists of two layers: one for user objects such as meters, and one for physical objects such as masses and constraints. Full control of which objects collide is provided.

An Almost Infinite World

The experiment world can be as large as you like (up to ±1.0e4900 meters). Zoom is infinite within the bounds of the world.

Vector Displays

Working Model comes with a complete set of vector displays for showing velocity, acceleration, and force. Vectors can be displayed for electrostatic forces, for planetary forces, and at multiple contact points when two objects collide.

Save Time History

You can calculate and record complicated or time-consuming simulations overnight and play them back in real time. You can then save the entire experiment, to disk.

Group Center of Mass Object

You can show the center of mass of all objects. This feature is useful as a frame of reference for the center of mass in different views.

Pause Control

Stop or pause experiments automatically. For example, you can set the experiment to pause when two seconds have elapsed by entering the following formula: Pause when time > 0.2. You can also tell your experiments to loop and reset.

Apply Control

You can apply forces and constraints at different times. For example, you can apply a constant force on an object for one second, or you can apply a force when the object's velocity is greater than 10.

Unlimited Objects

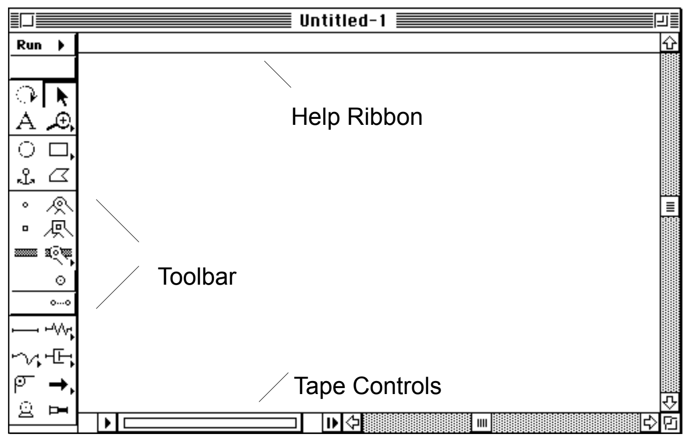
You can create as many objects and constraints as your computer's memory allows.

Starting Working Model

1. Double-click the Working Model Demo icon to start the program.

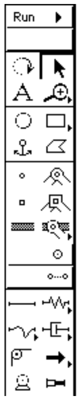
Working Model starts up and opens a new, untitled window. Your screen will look like Figure 1.

Figure 1
Untitled Working Model window



The new, untitled experiment document appears in its own window. You will see the toolbar on the left and the tape controls along the bottom of the window.

Figure 2
The toolbar



The toolbar contains tools you will use to create experiments. Tools are provided for creating masses, springs, ropes, forces, and many other objects. The toolbar also contains buttons for running and resetting experiments.

The tape controls give you more control for running and viewing experiments. You can use the tape controls to step through experiments, play experiments backwards, or move to a specific time in an experiment.

Setting Up a Simple Experiment

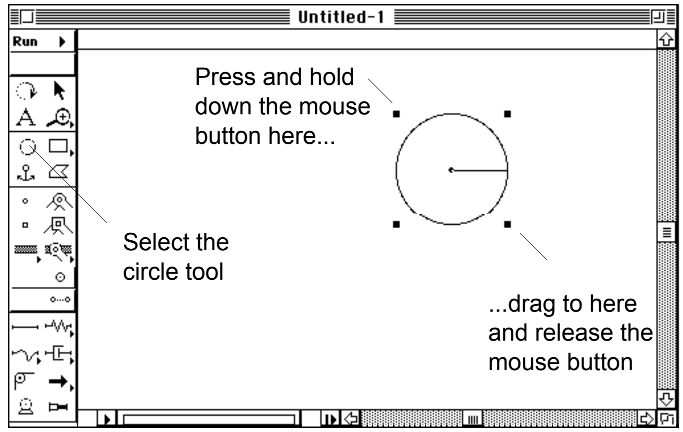
In this exercise, you will draw a circle to represent a projectile and specify its initial velocity. Then you will watch the projectile fly as you run the experiment

Drawing a circle

The toolbar provides a variety of tools for setting up experiments. To choose a tool, click on it.

To draw a circle (see Figure 3):

Figure 3
Drawing a circle



1. **Click the Circle tool.**

2. **Position the pointer at any starting point in the blank area of the screen.**

   The pointer changes from an arrow to a crosshair. This means you are ready to create an object.

3. **Drag the mouse until the circle is the size you want, then release the mouse button.**

   A line appears inside the circle. During an animated sequence, this line indicates the circle's rotation.

Moving the circle to its starting position

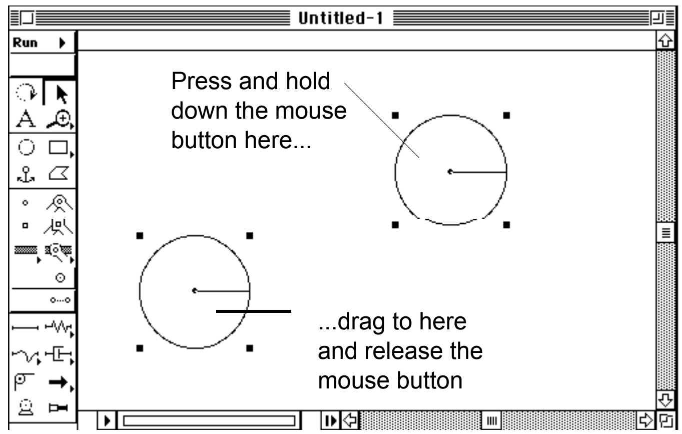
To position the circle for the start of the experiment:

1. **Select the Arrow tool if it isn't already selected.**

2. **Position the pointer anywhere inside the circle (except for the center of the circle, see next section).**

3. Drag the circle to the lower left corner of the screen, as shown in Figure 4.

Figure 4
Dragging the circle



Specifying an initial velocity

To specify the initial velocity of the projectile:

1. Click the circle to select it.

Four square dots appear around the circle and one round dot appears at its center.

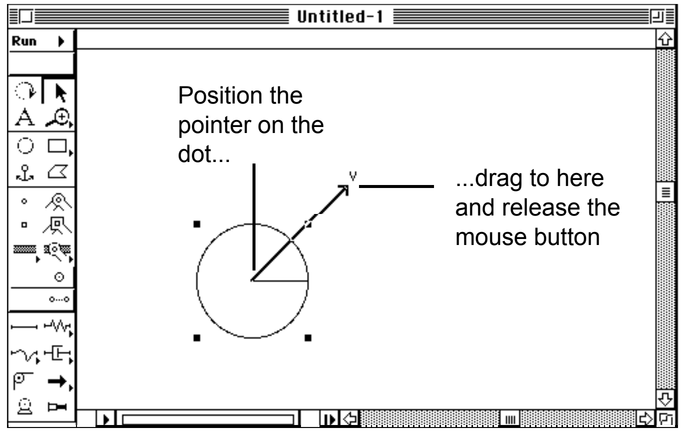
2. Position the pointer on the center dot in the circle and drag away from it to approximate the projectile's initial velocity (see Figure 5).

While dragging, try to match the arrow shown in Figure 5.

3. Release the mouse button at the desired initial velocity.

An arrow representing the projectile's initial velocity appears.

Figure 5
Specifying an initial velocity for the projectile



4. Drag the tip of the arrow to adjust the velocity.

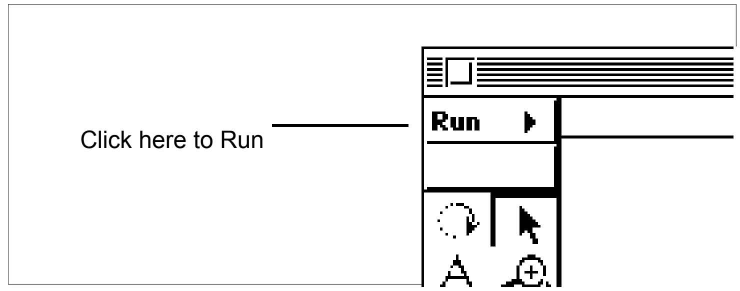
Running the experiment

You are now ready to run your experiment. To run the experiment:

1. Click Run in the toolbar.

Watch your first experiment run. Because normal earth gravity is on by default in a new document, the circle flies with the motion of a typical projectile.

Figure 6
Run and Reset buttons



2. **Click once to stop the experiment.**

3. **Click Reset in the toolbar to rewind the experiment.**

4. **Go back to step 3 under "Specifying an initial velocity" and try running this experiment with different velocities.**

Measuring Properties from an Experiment

Working Model allows you to measure many physical properties such as velocity, acceleration, and energy by using meters and vectors.

Meters and vectors provide visual representations of quantities you want to measure. Meters can display information as:

- numbers (digits)
- graphs
- level indicator (bars)

Vectors represent the properties of velocity, acceleration, and force as visual arrows. The direction of the arrow shows the direction of the velocity, acceleration, or force. The length of the arrow corresponds to the magnitude of the velocity, acceleration, or force.

In the following exercises, you will measure a projectile's velocity and display it in various ways. First, you will display it as a digital meter. Then you will change that meter to a graph. Finally, you will display the velocity of the projectile as an animated vector.

Displaying a velocity meter

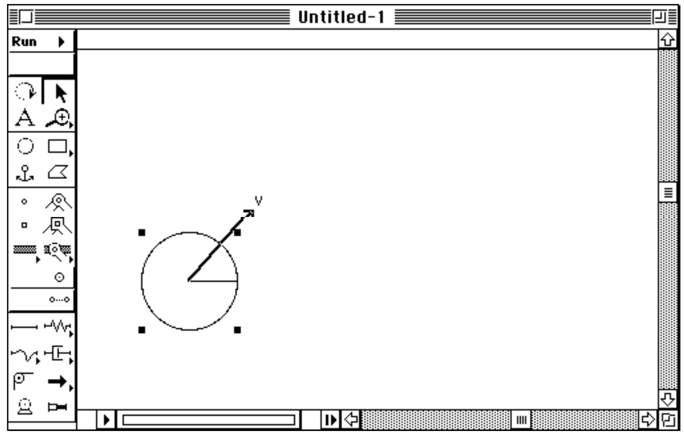
To display a digital meter that measures the velocity of the projectile, follow these steps:

1. **Click Reset in the toolbar.**

2. **Draw a circle in the lower left-hand corner of the workspace if you don't already have one. Select the circle.**

   Your screen should resemble Figure 7. The circle becomes selected: four small dots and the velocity arrow appear. If your screen does not resemble Figure 7 you can repeat the steps of the previous section. If you already know how to create objects and give them initial velocities, create a single circular mass, and give it an initial velocity similar to that shown in Figure 7.

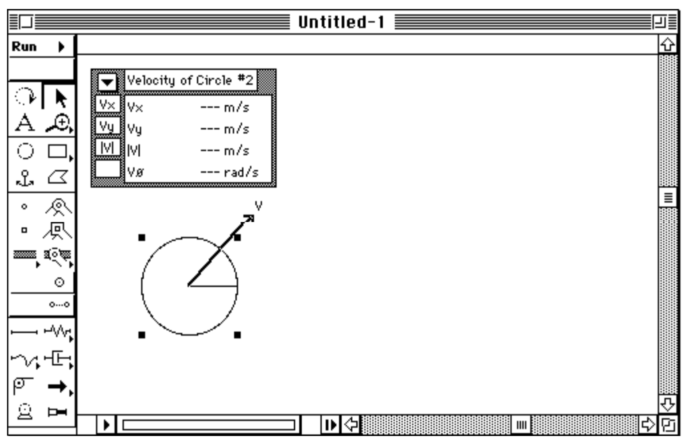
Figure 7
A circular projectile with an initial velocity



3. **Choose Velocity from the Measure menu, and All from the Velocity sub menu.**

   A digital velocity meter appears (Figure 8).

Figure 8
A velocity meter



4. **Click Run in the toolbar.**

   As the projectile flies, you can monitor its velocity by watching the velocity meter.

5. **Click on the Stop button to stop the experiment.**

Displaying vectors

To display the velocity of the projectile as an animated vector:

1. **Select the circle.**

2. **Choose Vectors from the Define menu.**

   The Vectors sub menu appears.

3. **Choose Velocity from the Vectors menu.**

   In the future, a check mark will appear next to Velocity in the Vectors menu, indicating that velocity vectors are being displayed.

4. **Click Run in the toolbar.**

   When you run the experiment, a vector appears on the circle, showing its velocity.

5. **Click the Stop button to stop the experiment.**

For more information about vectors, see “Tracking” in chapter 8, “Running Experiment”.

Tracking

Tracking shows the path of an object by recording its location at specific intervals.

1. **Click Reset in the toolbar if you have run and not yet reset the experiment.**

2. **Choose Tracking from the World menu, and then choose Every 8 frames from the sub menu.**

When you run the experiment, Working Model will display the position of the circle at eight frame intervals.

3. Click Run in the toolbar.

The projectile's path will be traced as it flies .

4. Click Stop to stop the experiment.

Creating or editing objects erases the track.

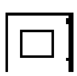
The Smart Editor™

You will now use the Working Model Smart Editor to create and edit a mechanism. When you drag the mechanism with the mouse, it will move like a real mechanism. The Smart Editor will enforce constraints while you edit.

To construct a four-bar linkage:

1. Create a new Working Model document by selecting New from the File menu.

Close all open documents prior to starting this exercise.

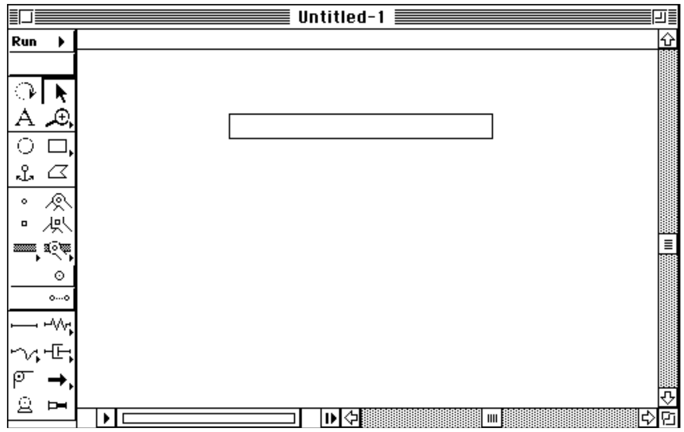


2. Double click the rectangle tool on the toolbar.

The tool will turn black, indicating that it can be used multiple times.

3. Sketch a rectangle similar to the one in Figure 9.

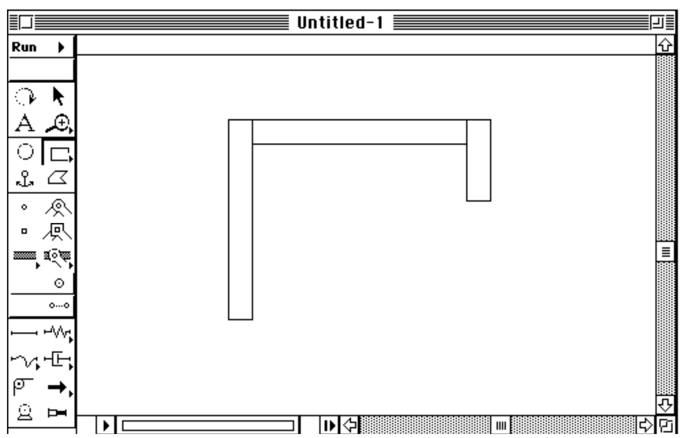
Figure 9
A single rectangle



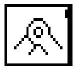
4. **Sketch two rectangles projecting below the horizontal rectangle.**

   Make sure the rectangles overlap since you will need to join them together. Your screen should resemble Figure 10.

Figure 10
The beginnings of a four-bar linkage



You will now create pin joints. A pin joint acts as a hinge between two mass objects. The Smart Editor will prevent joints from breaking during a drag operation.



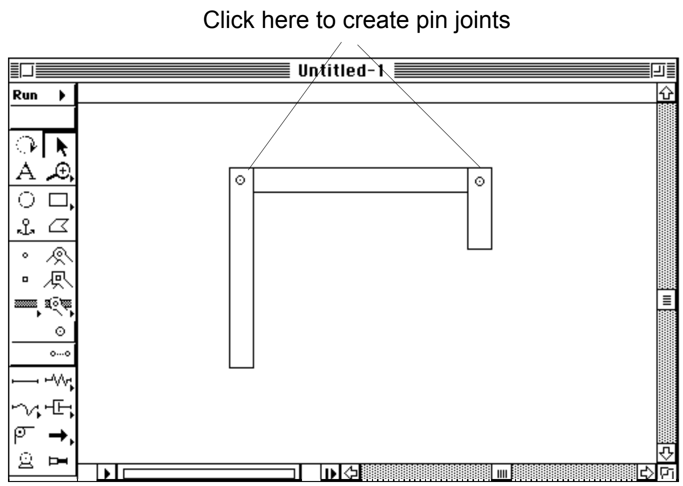
5. Double click on the Pin Joint tool.

The tool will turn black, indicating that it can be used multiple times.

6. Sketch two pin joints by clicking once with the mouse for each joint.

Your screen should resemble Figure 11.

Figure 11
Pinning the mechanism together



Pin joints automatically connect to the top two mass objects that lie beneath them. If only one mass object lies beneath a pin joint, the pin joins the mass to the background.

7. Select the arrow tool by clicking on the toolbar.

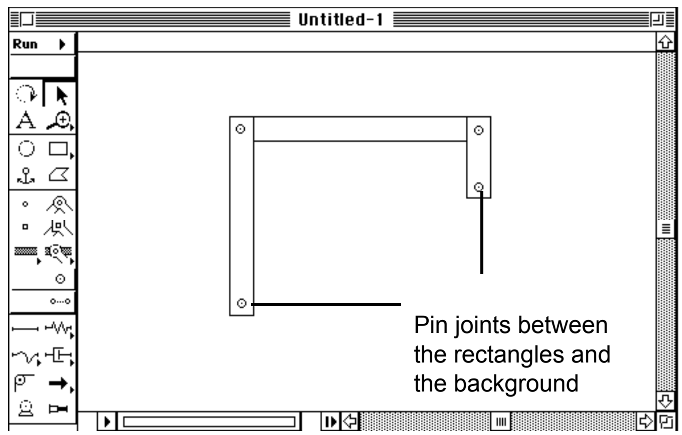
8. Try dragging the top rectangle.

All three rectangles should follow the motion of the mouse, because the pin joints connect them. If the rectangles break apart, one of the pins did not join two rectangles together, but instead one rectangle to the background. Delete the pin, make sure the two rectangles overlap, and re-join them.

9. Add two new pin joints at the bottom of the two vertical rectangles.

Your screen should resemble Figure 12 These pins will join the rectangles to the background.

Figure 12
Pinning the mechanism to the background



10. Click the arrow tool and then drag the top bar.

The joints pivot and the bars now move relative to one another. The Smart Editor moves the mechanism while making sure that pin joints do not separate.

Figure 13
Dragging the mechanism

Click here and drag the mechanism

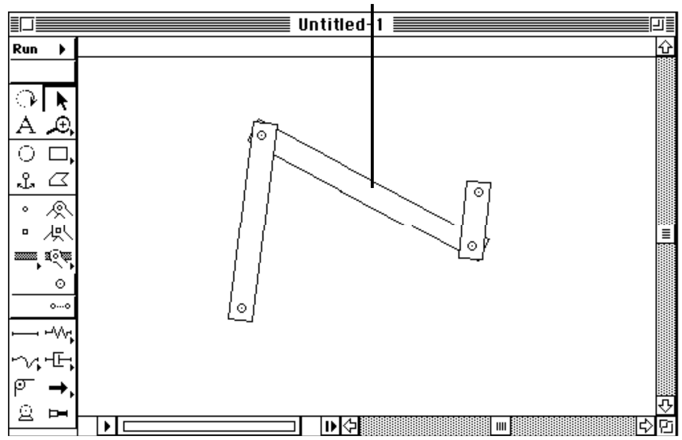


Figure 14
Selecting a pin joint

Joining and Splitting

The smart editor can automatically assemble a mechanism. The Split tool "splits" pin joints, leaving a separate point on each mass object. These points can be edited individually, and then the pin joint can be re-assembled with the Join command.

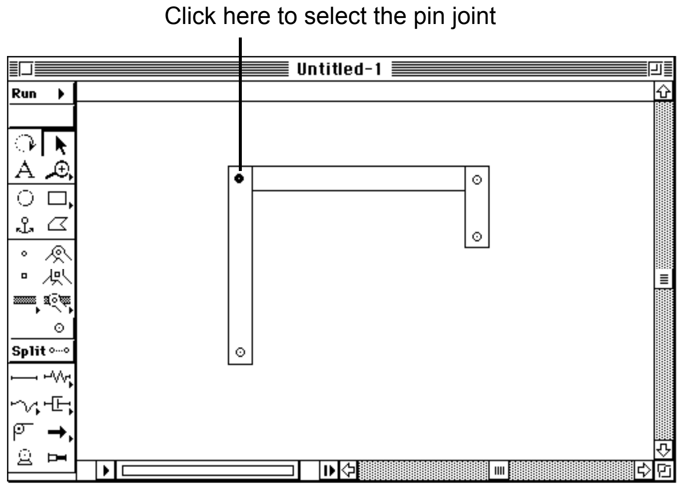
1. Restore the mechanism to its original form.

Your screen should resemble Figure 14. If you have only dragged the mechanism one time, you can select Undo from the Edit menu. Otherwise, drag the mechanism until it is resembles its original form.

2. Select the arrow tool.

3. Click on the top left pin joint to select it.

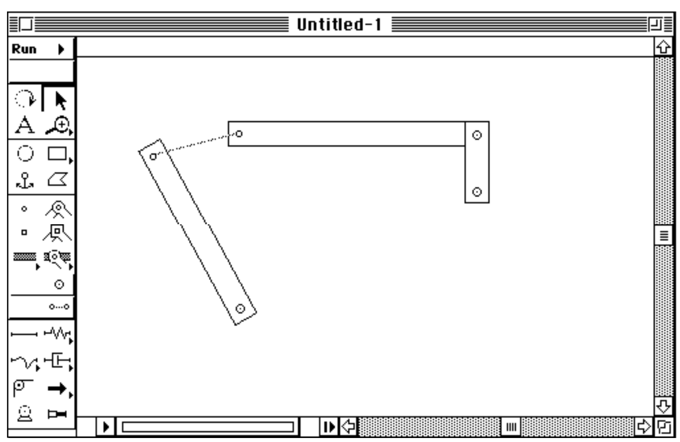
The pin joint turns black when selected.



4. Click the Split button in the toolbar.

The pin joint is split, or temporarily broken. You can move the left vertical rectangle independently. The vertical rectangle is still attached to the background. The other two rectangles are free to move as a unit. While you move the rectangles around, the split pin joint is connected by a dotted line.

Figure 15
A split pin joint



5. **Try dragging the different mass objects.**

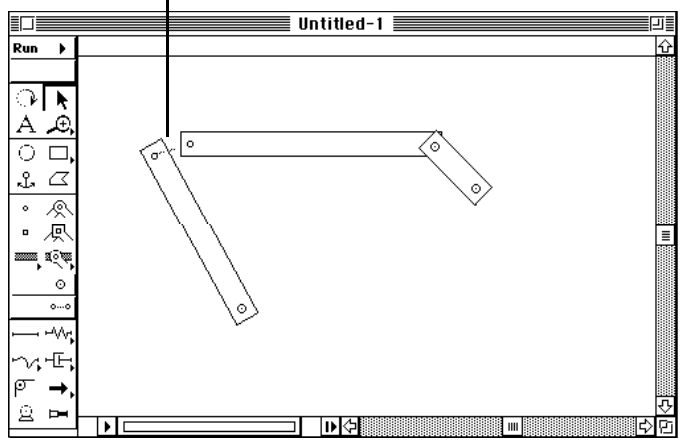
   Do not drag the pin joints.

6. **Move the mass objects to a position where the pin joint is almost connected.**

   Try dragging each of the different mass objects. Your screen should resemble Figure 16.

Figure 16
Preparing to join

Move until the points are almost overlapping



7. **Click on the left mass object.**

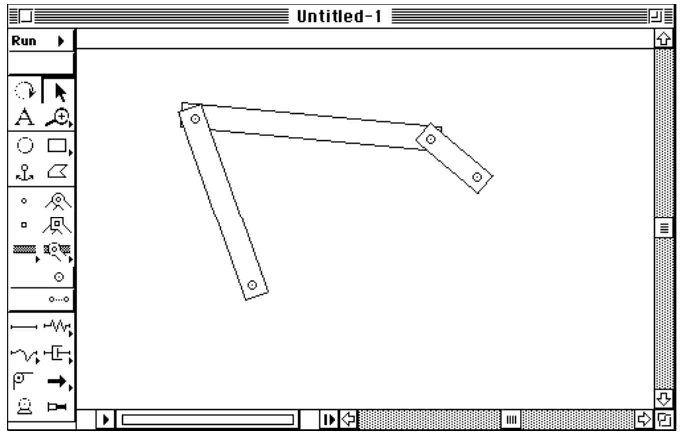
   The Join button becomes active. The tool is active because there is a point attached to the mass object, and the point can be joined to another point.

   The Join button will also become active if you select either of the split points.

8. **Click the Join tool.**

   The linkage will reassemble itself, moving its component pieces around to *make them overlap where necessary.*

Figure 17
The re-joined mechanism



If the points that make up the pin joint are a long distance apart, the Smart Editor will ask you to move the points closer together before making the join.

Precision numerical assembly

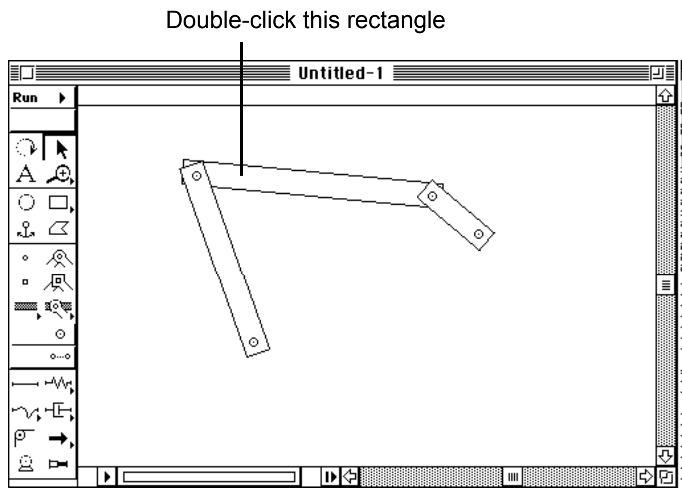
The Smart Editor assembles mechanisms based on numerical values. Whenever you enter the position of a mass object, point, or joint, the Smart Editor makes sure that joints are not broken. If necessary, the smart editor will move other mass objects to keep the integrity of all joints in a mechanism.

You can use the Smart Editor to set the initial conditions of an experiment. In this example, you will use the Smart Editor to return the mechanism to its exact initial position.

1. Double-click on the rectangle that is pinned between two other rectangles.

This is the rectangle that was originally horizontal.

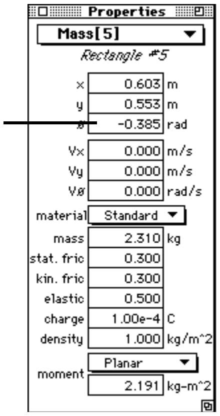
Figure 18
Double-clicking a rectangle



The Properties utility window will appear. You can also select the mass object and choose Properties from the Window menu to show this window.

Figure 19
Properties utility window for a mass

Edit this field



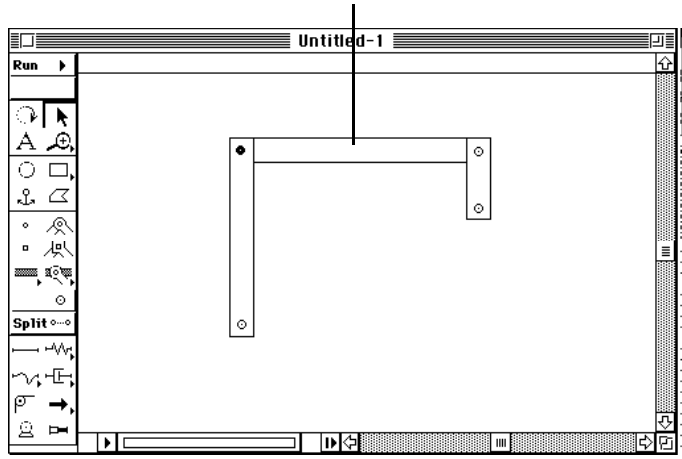
2. **Enter the value 0 in the rotation (ø) field of the Properties utility window.**

3. **Enter a Tab or Return.**

   The mass will be moved to a position where its rotation is 0.00. The other masses in the mechanism will move to satisfy this condition.

Figure 20
Using numerical editing for precision alignment

This mass now has a rotation of 0.00



The Next Step

To learn more about Working Model you can open the file Complex Tutorial, which will take you through building a more complex model. Alternatively you can look at some of the pre-built demonstration models available in the Tutorials, Engineering and Animation folders.