Linkage 3.16

User's Guide

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Wednesday, August 03, 2022

Table of Contents

Quick-Start Guild

Here is a list of the next few sections and what you will discover if you read them. Skip past any information that doesn't seem useful:

- **Release Notes**
  Some notes about recent changes to the program, such as features that have moved from one menu or button to another.
- **Installation**
  How to install the software. Not useful stuff if you already installed it!

- **Running the Linkage Program**
  An image of the Linkage window, a short description of a few essential menu items, and a minimal description of a four-bar mechanism, almost the simplest mechanism you can design.
- **Simple Mechanism Tutorial**
  A tutorial that tells you how to design the four-bar mechanism using this software. **If you have not used the Linkage software, this is a good place to start after installation!**

Here is a simple glossary to help get you started:

Link: A link is like a physical piece of material in the real world that connects things together. For instance, your fingers probably have bones in them, and each bone is like a link that is connected to another bone on either end (except for the ends of your fingers, of course). The door on your car is also a link that is just connected to the car on one end and the other end swings in and out if the door is not latched closed. You can even think of an airplane propeller as a link that is connected to the engine in the middle and not connected to anything at the other end (just like the car door is only connected on one end).

Connector: A connector is the thing that connects one link to another. Your fingers have joints where the bones connect. The car door has a hinge. An airplane propeller has the shaft coming out of the engine. These are all connectors. The Linkage program will let you create a connector that is a motor just like an airplane propeller has an engine at the center.

Anchor: There is always one big link that is invisible in the Linkage program. That one big invisible link is the ground. Or perhaps it is the floor of a factory or the frame of a truck, depending on what you are designing and how you like to think of the one big hidden ground link. Whenever you design a mechanism, it is attached to the ground with an **anchor**. You can also think of the ground as the page that you are drawing on and all the parts that are attached to the page that cannot move are called **anchors**. New mechanism show up with an anchor to help get you started.

Mechanism: The thing you are drawing in the window is the mechanism. Sometimes only the part of the mechanism that can simulate mechanical movement is called the “mechanism” like when you select if you want to see or edit the mechanism elements versus the drawing elements. The drawing elements are still part of the overall “mechanism” but they are not mechanical parts – they just let you make shapes that can be fastened to the mechanical elements in order to see them move during the simulation.

There is a glossary at the end of this document just before the index.

Release Notes (Recently New and Changed Stuff)

- Splines have been added as drawing elements and as cams.
- Right-clicking on elements will show a context-specific menu. There are many options in the menu when editing spline nodes and spline segments.
- A new feature is available that lets you select two links that share a connector and then set their lengths to the same value at the same time. Select both links and use the “Length/Distance” option in the “Align” menu or just select both links and type the new length in the Dimension text box in the toolbar and hit the Enter key.
- There is a new feature for duplicating elements. It is only available using the Control+D key combination. If you move or rotate the duplicates immediately after making them, and then you do another duplication, the move or rotate is remembered and happens to the new duplicates. You can use the dimensions text box or the rotate option in the Align menu to make precise changes that can then be repeated multiple times.

- Clicking on the dimensions text box in the tool bar will select all of the text. This makes it easier to type in new and different values without having to delete the text that is there. A second click can be used to position the caret for editing the text instead of replacing it.
- If a sliding connector is moved by entering a distance from another connector, it is moved along it's path and not in a straight line away from the other connector. If the sliding connector would leave it's path due to the distance being too short or too long the new distance is ignore.
- Turning on Auto-Dimensions causes the speed of all connectors to be shown and the RPM of gears to be shown along with the dimensions. Speeds are in inches per second or millimeters per second. RPM is revolutions per minute (if you didn't already know that).
- Gears can be "unmeshed" using the Split button or T key.
- An adjustment was made to run the simulation a tiny bit faster to make to more accurate to real-world time.
- Negative RPM and CPM values are no longer needed. There are selections for "clockwise" and "counter-clockwise" for rotating inputs and selections for "push" and "pull" for actuators.
- Simulation errors are usually shown as a single error with other subsequent errors being hidden. This reduces clutter when a single error causes a lot of other elements to not be simulated.

Older notes:

- The ALT key can be used with a mouse left button click to select all connectors at the mouse pointer location. There is the typical active selection area around the mouse pointer, so the connectors do not need to be at the exact same location, just very close.
- Planetary gears will now be simulated. Situations like having a planet gear that is meshed with another planet to form a chain of gears from the sun gear to the ring gear, will not work.
- Gears now act more like regular links and can have connectors other than the center of the gear.
- Select a connector and a link with only two connectors and the Slide feature is enabled.
- There is no separate Stop button. The Run button changes to be the Stop button.
- There are guidelines (not rules, lines that get snapped to).
- There is now a Run-Fast button.
- Gears were not working right. They are now fixed.
- The "R" key now runs the simulation and stops a running simulation. The "S" key is now used to create sliding connections!
- New mechanisms always start with a single anchor since all mechanisms must have at least one anchor.
- Changed the shape and contents of the popup element gallery for selecting elements to drop into the mechanism.
- Fixed a bunch of gear rotation bugs as well as slider bugs caused by some other recent changes (such as changing angle calculations and display information).
- I changed the "Connect" button to be a "Link" button. The keyboard "L" key now creates a link between two selected connectors.

Installation

Skip this if you already installed the software or already know how to install software.

The installation file, called "linkage.msi", can be run by double clicking on the file name. It can also be run from a browser at the time it is downloaded. The installation program will show a few dialog boxes and will ask for a location to install the program. Once the installation is done, there should be a Linkage entry in the Start Menu program list or on the Start Screen, as well as an icon on the desktop.

Windows XP users may need to install Windows XP Service Pack 3. Linkage was developed and tested on Windows 7 through Windows 10 but has worked on Windows XP with the most recent service pack installed. **But only if you download and install the special XP version of the Linkage program!**

If you are an experienced Windows user and want to get started with creating a mechanism, skip to the tutorial on page 7.

Running the Linkage Program

Linkage, for lack of a better name, is a computer program that lets you design and edit a two-dimensional planar mechanism and then simulate the movement of that mechanism. The editing and simulation are both done in the same window and are part of the same user interface.

Run the Linkage program using the desktop icon, the start menu Linkage entry, or however programs are usually run on the computer. The window in Figure 1 will appear, or something very close to this (the toolbars might shrink to ensure all tools are visible in the window).

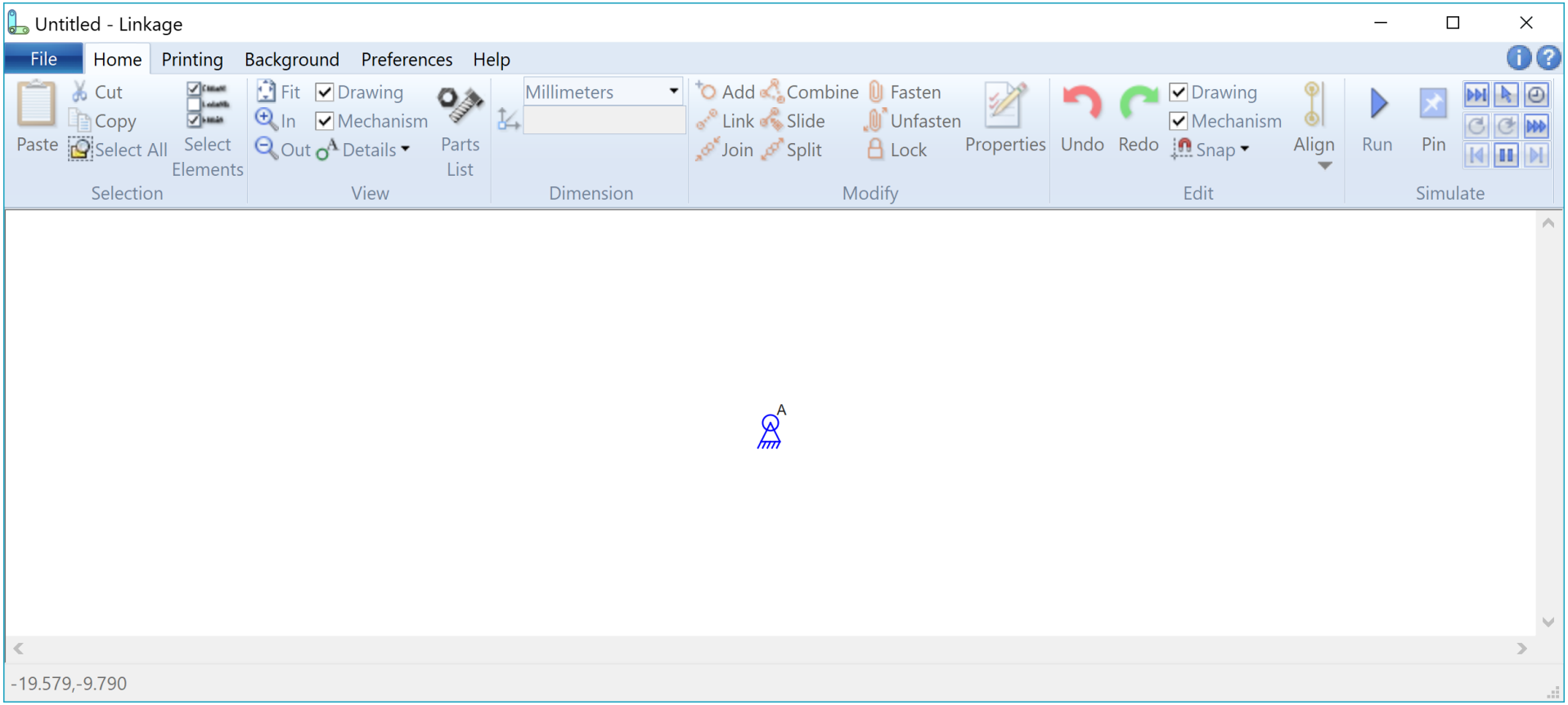


Figure 1. Linkage Window

This is the Linkage window above. The Linkage program can be used to edit a single mechanism at a time. To edit more than one mechanism at a time, run multiple copies of the Linkage program.

Almost all functions of the Linkage program are accessible in the tool bar at the top of the window. A few features are only available using the keyboard. Editing is done using the mouse and keyboard within the edit area of the window. The keyboard can be used to access common menu and tool bar features as well as modify the way a mouse action works. The keyboard cannot be used to move, rotate, etc., elements of the mechanism. This is a mouse-driven editor, not an editor where you select things and enter a lot of numbers to move them into position and connect them to other elements.

The **File** menu for opening files, and other file related tasks, is in the upper left of the window. There is a **Samples** menu item that provides access to a variety of sample mechanisms. Select the top-left sample mechanism in the samples set and the mechanism shown in Figure 2 will open in the Linkage window.

Figure 2. Simple Example Mechanism

This is a four bar linkage. Click on the **Run** button in the tool bar or press the **R** key. The mechanism movement will be animated in the window. Press the **Stop** button or press the **S** key to stop the mechanism. The display is reset back to the original position when the simulation is stopped.

- The mechanism cannot be modified while a simulation is running. A few things like the zoom and pan features will still work.
- The simulation can be paused or moved one step at a time. This is described later.

Simple Mechanism Tutorial

This is a short tutorial for creating a simple mechanism like the one described in the previous section.

1. Run the Linkage program.

2. Click on the anchor in the middle of the window and tap the Delete key to delete it. We will start from scratch for this tutorial. If there was no starting anchor because you are using an older version of the Linkage program, then the connector labels will all be different in your mechanism and you will need to interpret the tutorial with that in mind.
3. Move the mouse pointer to the center of the window and right-click at that location. A visual list of elements will show up.

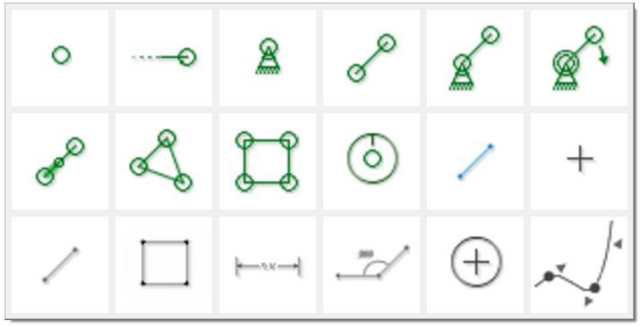


Figure 3. Popup Element Gallery

4. Move the mouse pointer over the sixth element on the top row  and click on it. This is an anchor that is also a rotating input (like a motor), along with a link sticking out from it. When the simulation runs, the link will rotate.
5. Move the mouse pointer down and to the right and repeat the previous operation but insert the fifth element in the top row. This is an anchor that is not an input. An anchor is just a connector that is connected to the "ground". The ground is the one link in the mechanism that is not displayed. It is like the ground that your house sits on or like the frame of a truck.

   If any of the symbols are not clear, jump to the section called **Things That You See in a Mechanism** and familiarize yourself with links, anchors, connectors, and what the various labels mean. Then come back here and finish the tutorial.

   The mechanism should look like what is shown below with two links that both have anchors.

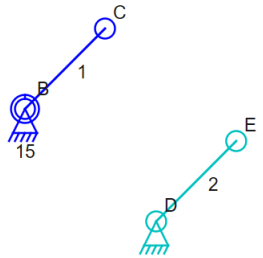


Figure 4. Tutorial Mechanism after Step Five

6. Click on the connector labeled **C** by clicking near the center of the circle. If the label is not visible and you need to see it then click on the **Details** button in the tool bar, then click on the **Labels** button to show labels.

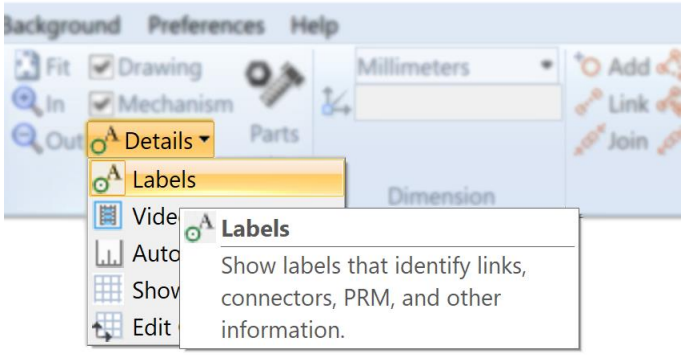


Figure 5. Labels Option in Tool Bar

7. Hold down the **Shift** key while clicking on the connector labeled **E**. This should leave connector **C** selected because you held down the **Shift** key. You should see both connectors selected with a dotted line between them and some black squares around the entire selected area. The black squares are the adjustment handles or knobs and can be used to stretch or scale the selected elements. Ignore the black squares. The line between them is a hint that you can create a link between them.

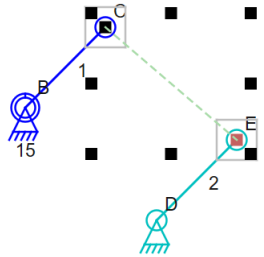


Figure 6. Tutorial with Two Connectors Selected

8. Click on the **Link** button in the tool bar.

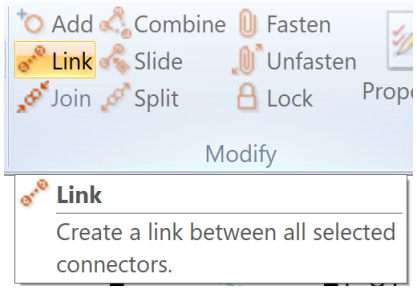


Figure 7. "Link" Button in Tool Bar

The mechanism should look like the one in Figure 8. This is a fully functional mechanism because all connectors and links can be simulated.

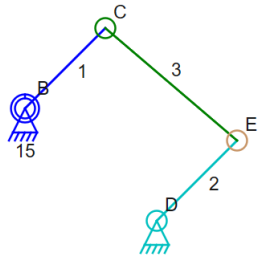


Figure 8. Tutorial Mechanism Almost Done

9. To remove the selection of the two connectors, click with the mouse pointer pointing to some blank area in the window. Continue once nothing in the mechanism is selected. The Escape key (ESC on the keyboard) will also deselect all elements in the mechanism.
10. Click on connector **E** and hold down the mouse button. Move the mouse pointer up and to the right to drag the connector to a new position. Release the mouse button when the connector is in the new position. **It is important that link 2 is more than twice as long as link 1**. If it is not long enough, the mechanism might bind. Binding is when the parts don't fit together in a way that lets the mechanism run continuously. If another adjustment is needed, drag connector **D** downward.

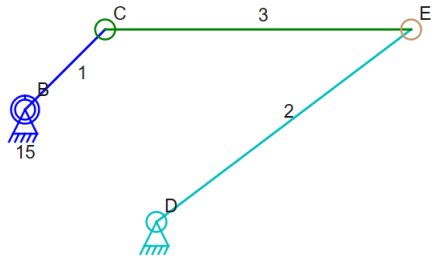
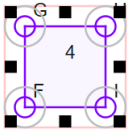
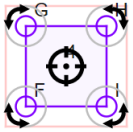
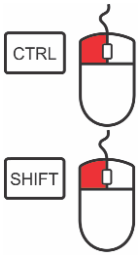
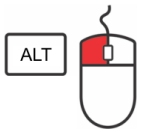
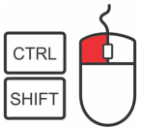
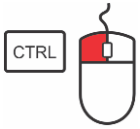


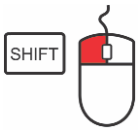
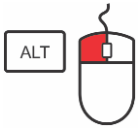
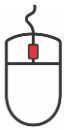
Figure 9. Finished Tutorial Mechanism

11. Figure 9 shows the finished mechanism. Click on the **Run** button in the tool bar and the mechanism will be animated in the window. Link 1 will rotate clockwise around anchor A and link 2 will move back and forth. Make adjustments to see what happens when the links are too long or too short for the mechanism to work correctly.

Mouse Actions

Key, Button, and Movement		Action
	Left Button Click	*Selects things…* Clicking at the center of a connector will select it. Selected connectors have squares or dots inside of them. The last selected connector will have a red square or dot instead of a black square or dot. Some operations act on the most recently selected connector or connectors.  Clicking on any line of a link will select it as will clicking inside of the area of the link. Selected elements other than a single selected connector will be surrounded by a set of black “handles” around it. The handles can be used to stretch the selected elements in various directions. Each selected link is also surrounded by a gray rectangle.  Clicking on an unselected element will remove the selection from any other elements. Clicking on already selected elements will change the mode of the selection from stretch mode to rotate mode or vice-versa. Selected elements in rotate mode are surrounded by a set of black curved arrows. The arrows can be used to rotate the selected elements around the center point. The center point is a circle with crosshairs in it and it can be moved if needed. 
	Control Key and Left Button Click ***or*** Shift Key and Left Button Click	*Selects multiple things…* Clicking on an unselected element will select it without removing the selection on any other elements. Clicking on a selected element will remove the selection without removing the selection on any other elements.

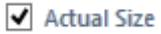
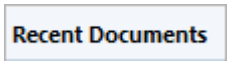
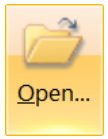
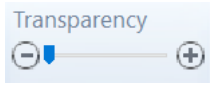
Key, Button, and Movement		Action
	Alt Key and Left Button Click	*Selects multiple connectors…* Clicking on one or more connectors in the same location will select all of them. They do not need to be at the exact same location; They only need to be all within the area near the mouse pointer where selection occurs. This will also select drawing points if they are at the selected location.
	**Both** Control Key and Shift Key, and Left Button Click	*Selects things that are hard to select…* Clicking on one element or multiple overlapping elements will select one of them. If there are overlapping elements and the control-shift-click selection is done after one of the elements is already selected this, a different element will be selected. This feature lets you select "buried" elements at different "depths". Note that if an element is selected with a left mouse click or box drag (no keys pressed), using this feature might select the same element again and the selection will not appear to change. Just control-shift-click again to select a different element.
	Left Button Drag	*Drags selected things…* Dragging selected elements moves them. Dragging the small circular control knob on a linear actuator changes the throw distance of the linear actuator. Dragging the small circular control knob on a circle changes the radius of the circle. Dragging the stretch handles stretches the selected elements. Dragging the rotate handles rotates the selected elements. Dragging the rotate center mark changes the center point used for rotation. Once elements are selected or deselected, the center mark will revert to the center of the selected elements. Dragging outside of any selected elements will drag a selection box for selecting multiple elements within the box when the mouse button is released.
	Control Key Left Button Drag	*More dragging things…* This is identical to a left button drag but snapping is toggled when the control key is held during the drag operation. If all snapping is turned off, the Control Key will enable snapping to elements. Otherwise, if any snapping is turned on, the Control key turns off all snapping.

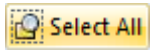
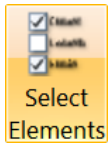
Key, Button, and Movement		Action
	Shift Key and Left Button Drag	*More dragging things…* This is identical to a left button drag but snapping is toggled when the control key is held during the drag operation. If all snapping is turned off, the Shift Key will enable snapping to the grid. Otherwise, if any snapping is turned on, the Shift key turns off all snapping.
	Alt Key and Left Button Drag	*Selects with a box anywhere…* Clicking and dragging with the Alt key pressed and the left mouse button pressed will drag a selection box for selecting all element within the box when the mouse button is released. The Alt key does not need to remain pressed after the mouse button is held down. This is useful for selecting connectors or other small elements that are in front of larger links or other large elements.
	Right Button Click	*Inserts things, moves the mechanism in the window, or shows a context menu…* Clicking and releasing the right button without moving the mouse will show the popup element gallery window if the mouse cursor is over an empty location in the document. An element selected from this window will be inserted into the mechanism at the location of the click. Clicking and releasing the right button without moving the mouse will show a context-specific menu for the element under the mouse pointer if the mouse cursor is over an element. Clicking and dragging with the right button will pan the view of the mechanism. This essentially moves the entire mechanism within the window.
	Scroll Wheel	Moving the mouse scroll wheel towards the top of the mouse (away from your body) will zoom in on the mechanism. This makes the mechanism appear larger. Moving the mouse scroll when away from the top of the mouse (towards your body) will zoom out from the mechanism. This makes the mechanism appear smaller.
	Middle Button Drag	Some mice have middle buttons like my mouse. Clicking and dragging with the middle button will pan the view of the mechanism. This essentially moves the entire mechanism within the window.

Menus and Tool Bars

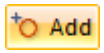
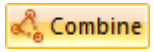
The tool bar, the **File** menu, the popup element gallery, and the context-specific popup menu, can all be used to modify a mechanism or the mechanism file in the following ways:

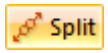
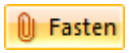
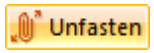
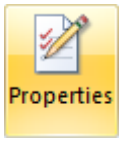
What You See	Keyboard	Action
	Ctrl+N	Create a new empty mechanism.
	Ctrl+O	Open a mechanism stored on disk or elsewhere.
		Open one of the sample mechanisms. A set of small pictures are shown, and a sample can be picked from them. Tool tips show a short description of the sample mechanisms.
	Ctrl+S	Save the current mechanism to disk or elsewhere using the existing file name. You will be prompted for a name and location to store the file if this is a new mechanism not opened from a file (a new mechanism or a sample).
		Save the current mechanism to disk or elsewhere.
		Show export choices in a sub menu. Exporting creates files that are used by other programs but can never be read back into the linkage program. See the Image, Animation, DXF, and Motion Path export actions below.
		Create a PNG or JPEG file showing the mechanism in its starting state. The image can also be copied to the clipboard using this feature.
		Create an AVI video file with an animation of the running mechanism. You must have a video codec installed that is capable of generating video data, such as the x264 MPEG codec.
		Create a DXF file with the mechanism in its starting state. ***This feature is only partially working and created DXF files that may not have the entire mechanism. Some features like polygons/poly-lines or groups lines are not working quite right. Also, links with more than two connectors are not treated as a single entity in the DXF file. Use this data with caution.***
		Create a text file with coordinate information for the motion path draw by drawing connectors. This is a CSV file with information for every step of the simulation including the starting positions of all of the appropriate elements.
	Ctrl+P	Print the current mechanism.

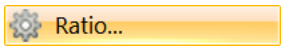
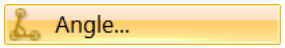
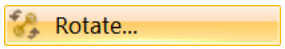
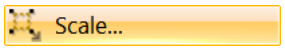
What You See	Keyboard	Action
		Print immediately without showing any print options.
		Show a preview of how the mechanism will print.
		Configure printers.
		Print the mechanism actual size on multiple sheets of paper. This option might cause some blank sheets to print if the mechanism doesn't cover the entire printing area. The printed pages should, when combined together, be an almost exact full size drawing of the mechanism. The accuracy of the drawing is only limited by the printer, print driver, and other things outside of the control of the Linkage program. ***There is no test for giant mechanisms, so the program could print large numbers of pages if care is not taken when using this feature***.
		Close the Linkage program.
		Open a previously saved mechanism.
		On the Background tab, this Open button lets you open a background image file. The image is shown as the background of the mechanism and is always centered on the 0,0 coordinates of the mechanism.
		On the Background tab, this transparency slider lets you select the transparency of the background image. Since the image is drawn under any grid and on a white background, this essentially fades the image to white when there is more transparency.
	Ctrl+V	Insert the Clipboard contents into the mechanism. The Linkage data is textual data and can be pasted into a text editor, modified, then copied and pasted into the Linkage program.
	Ctrl+X	Cut the selection and put it on the Clipboard. The Linkage data is textual data and can be pasted into a text editor, modified, then copied and pasted into the Linkage program.

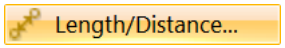
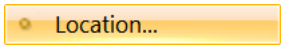
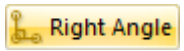
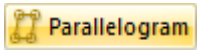
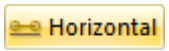
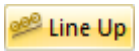
What You See	Keyboard	Action
	Ctrl+C	Copy the selection and put it on the Clipboard. The Linkage data is textual data and can be pasted into a text editor, modified, then copied and pasted into the Linkage program.
	Ctrl+A	Select all links, connectors, and all other elements.
		Show a list of all elements with each element being selectable using a checkbox. See the Selecting Elements section for more information.
		Add a single lone connector.
		Add a single lone anchor.
		Add a link with two connectors.
		Add a link with an anchor and a connector.
		Add a link with a rotating input anchor and a connector.
		Add a linear actuator link.
		Add a link with three connectors.

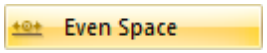
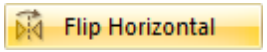
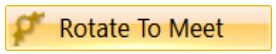
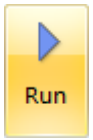
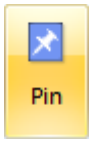
What You See	Keyboard	Action
		Add a guideline. Guidelines are lines used for aligning and positioning elements. Other elements snap to these lines and to the intersections of these lines during drag/positioning and rotate operations.
		Add a drawing point.
		Add a drawing line.
		Add a drawing polygon. It starts as a square but you can modify it to be any shape, have more points, and even have concave sections.
		Add a measurement line. **When two connectors are selected in the mechanism, the ends of this measurement line are moved to the locations of those connectors and are then automatically fastened to them. When the mechanism simulates, the measurement line ends will move if those connectors move and the measurement will change appropriately.**
		Add an angle measurement polyline. The angle polyline has three points and shows the angle between the two line segments. **When three connectors are selected in the mechanism, the points of the angle measurement element are moved to the locations of those connectors and are fastened to them. When the mechanism simulates, the angle measurement element will move if those connectors move and the measurement will change appropriately.**
		Add a gear.
		Add a drawing circle.

What You See	Keyboard	Action
		Add a spline. A spline can be used as a cam by creating a sliding connector as the “follower”. A spline does not need to be closed (continuous) to use it as a cam if the cam is never moved to where the follower moves off the end of the spline.
	A	Add a connector to the selected link. A link can have any number of connectors. A single link must be selected to add a connector to it.
	L	Create a link between all selected connectors.
	J	Join all selected connectors. This causes all the selected connectors to become a single connector. **The location of the final connector is the location of the last selected connector (the one with the red selection dot). Older versions of the software would find an average point between all the selected connectors for the final location.** If a connector on a locked link will move during the Join operation, **the entire link is moved**. It is not possible to join two or more connectors that are on locked links that are connected because that would change the shape of one of those locked links. It is not possible to join a sliding connector to other connectors if the sliding connector is not the last selected connector unless it is already in the same location as the last selected connector. Two or more sliding connectors cannot be joined to each other unless they are already at the same location.
	B	Change all the selected links into a single link.
	S	Slide one connector between two others. Select three connectors or select one connector and one link (that has only two connectors) to use this feature. If selecting three connectors, two of the connectors must be part of the same link and the third must not be part of that link. The order of selection does not matter. The connector that is not on the same link as the others (or is not the selected link) will become the sliding connector and will slide on a line between the two other connectors. Note that the line can be turned into a curve by setting the appropriate property of the sliding connector.

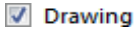
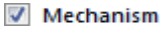
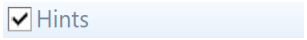
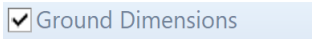
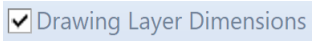
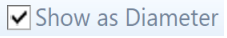
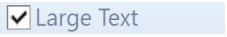
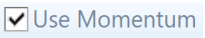
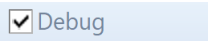
What You See	Keyboard	Action
	T	Turns one connector into two or more connectors depending on the number of links that share the connector. This is a way to separate the links from each other. They become disconnected. If the selected connector is a sliding connector, it is changed into a regular connector and no longer follows the slide path. If two meshed gears are selected then they are separated/disconnected and treated as two unmeshed gears.
	F	Fasten all of the selected elements on the drawing layer to the selected link in the mechanism, or fasten the selected gears to the selected link. Fastened drawing elements are moved during simulation with the link to which they are fastened. Fastened elements are drawn identical to non-fastened elements when they are not selected, and the effects of fastening can only be seen during simulation. When elements are selected and there are fastened elements fastened to them or they are fastened to other elements, dashed line boxes are drawn around the unselected-but-fastened elements. Fastened gears rotate with the link that they are fastened to. Or the link is moved as the fastened gear is rotated. Fastened splines rotate with the link that they are fastened to. Splines can also be fastened to input anchor connectors.
	U	Unfasten the selected elements.
	K	Lock the selected links so they cannot change size or shape and, for selected connectors, so they cannot be moved. **If all selected elements are already locked, this will unlock all of them!**
	P	Change the properties for the selected element. The rotation speed of a connector and the visual appearance of a link are a few of the properties that can be set for these elements. This button is only available when a single element in the mechanism is selected.
	Ctrl+Z	Undo the last action.
	Ctrl+Y	Redo the last action that was undone.

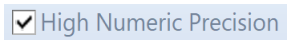
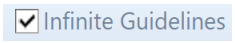
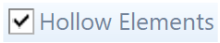
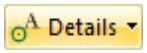
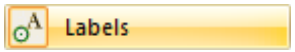
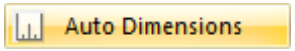
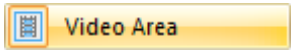
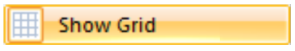
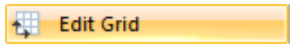
What You See	Keyboard	Action
		Show the align menu. This menu contains alignment and adjustment functions that can be performed on the selected links and connectors.
		Set the ratio of the two selected gears (or pulleys/sprockets). The ratio for pulleys/sprockets can also be used as the size of the pully/sprockets. Ratio values can also be entered into the tool bar dimension text box.
		Set the angle between two selected connectors around the third selected connector. Angles are entered in degrees using polar coordinates with positive degree values changing counter-clockwise as they get bigger. Angle values can also be entered into the tool bar dimension text box. **The angle of one selected connector relative to the other, can also be set this way. Zero degrees is directly to the right of the first selected connector (polar coordinate space in mathematics and not compass coordinate space on a map). In this case, only two connectors need to be selected. This feature is not available in the tool bar dimension text box.**
		Rotate all selected elements around a center point by the set number of degrees. Angles are entered in degrees using polar coordinates with positive degree values moving being counter-clockwise as they get bigger. Angle values can also be entered into the tool bar dimension text box using a number followed by an asterisk (there is no way to type in a little “degrees” circle so the asterisk is the character for “degrees”).
		Scale the selected elements using a percentage value. Entering 100% results in no change to size of the selected elements. Scale values can also be entered into the tool bar dimension text box. Entering 110% would result in a 10% increase in size and entering 90% would result in a 10% decrease in size. Scale values can also be entered into the toolbar dimension text box using a number followed by a percent sign.

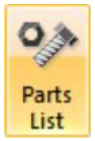
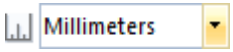
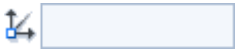
What You See	Keyboard	Action
		Set the distance between two selected connectors or set the length of the selected link (when it has only two connectors). Lengths and distances are entered using inches or millimeters based on the unit selection in the tool bar. Length and distance values can also be entered into the tool bar dimension text box. You can select and change two links at the same time if they have no more than two connectors each and also share one of those connectors. When the length is set, they both change length by moving the shared connector to the appropriate new location. **Note that when a sliding connector is moved to a distance from another connector, it is moved along the slide path. This might cause the requested length to be ignored if the length would place the sliding connector off the path.**
		Set the location of the selected connector. Coordinates are entered in inches or millimeters based on the unit selection in the tool bar. Coordinate values can also be entered into the tool bar dimension text box using two numbers separated by a comma.
		Align the three selected connectors to form a right triangle. The third selected connector is rotated around the second to the correct location.
		Align the four selected connectors to form a rectangle. The third selected connector is rotated around the second to the correct location to form a right triangle and the fourth connector is moved into position to form the rectangle.
		Align the four selected connectors to form a parallelogram. The fourth selected connector is moved into position to form the parallelogram.
		Align the selected connectors along a horizontal line. The first selected connector is left in place and the rest of the selected connectors are aligned to it.
		Align the selected connectors along a vertical line. The first selected connector is left in place and the rest of the selected connectors are aligned to it.
		Align the selected connectors in a line. The first and last selected connectors are left in place and the rest of the selected connectors are aligned between them.

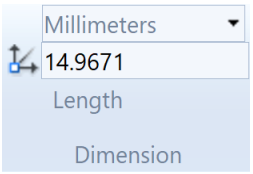
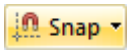
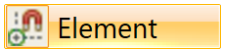
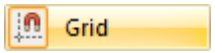
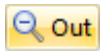
What You See	Keyboard	Action
		Align the selected connectors in a line (just like the Line Up feature) and space them evenly along that line. The first and last selected connectors are left in place and the rest of the selected connector are aligned between them.
		Flip the selected elements horizontally. Rotating anchor direction is reversed when flipping the anchor.
		Flip the selected elements vertically. Rotating anchor direction is reversed when flipping the anchor.
		Rotate two of the four selected connectors around the other connectors – the potential new location of the two rotated connectors is shown as a circle with some arrows pointing to it whenever four connectors are selected, if there is a point where the two connectors can meet.
	R	Run the mechanism in real time while showing the animation in the window. All movement is automatic based on the speeds set for the various input elements. The button changes to become the Stop button when the simulation is running.
	R	Stop the simulation and reset it to its original condition. The Run button changes to be the Stop button while running the simulation in any way. This is not a separate button as it was in earlier versions of the software.
		Stop the simulation. The position of all links and connectors at the moment that the simulation is stopped becomes their new position.
		Interactively run the mechanism in real time while showing the animation in the window. All inputs and actuators are controlled manually. No input or actuator will move more than a few times the configured speed to ensure that the simulation is accurate.
	Q	Manually run the mechanism in real time while showing the animation in the window. The entire mechanism is controlled manually. The mechanism will not move more than twice as fast as when running automatically to ensure that the simulation is accurate.

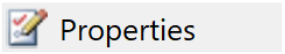
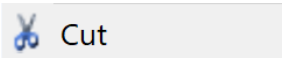
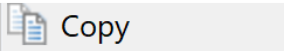
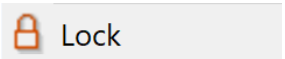
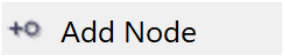
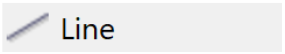
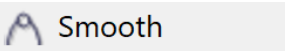
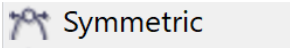
What You See	Keyboard	Action
		Run the simulation for half of a cycle with no animation and then pause. This is only available if all inputs have the same number of cycles and revolutions per minute. The RPM or CPM of the inputs may get lowered temporarily to get exactly half of one cycle. For instance, an input with 15.1 RPM would need a fractional number of steps in the simulator to rotate 180 degrees so the RPM during this operation would be adjusted to 15 exactly. When completed, the simulator will be paused to show the elements in their half-cycle positions. If the simulation is unpaused without stopping then the temporary RPM and CPM values are still in effect and only get rest to the real values once the simulation is stopped. **This feature is experimental and has not been tested with inputs that have start angles, limit angles or other complex settings.**
		Run the simulation for one cycle with no animation. This is only available if all inputs have the same number of cycles and revolutions per minute. The RPM or CPM of the inputs may get lowered temporarily to get exactly half of one cycle. For instance, an input with 15.1 RPM would need a fractional number of steps in the simulator to rotate 360 degrees so the RPM during this operation would be adjusted to 15 exactly. When completed, the simulation is stopped since the mechanism returned to the starting position at the end of the single cycle. **This feature is experimental and has not been tested with inputs that have start angles, limit angles or other complex settings.**
		Run and animate the simulation ten times faster than normal.
	→	Step the simulation forward one step.
	Space	Pause the simulation and allow stepping forward and backward. If the simulation is not running, it is started and paused immediately. **This button changes to look like a Run button when the simulation is paused.** When the simulation is paused, the Stop button will stop the simulation. The Run Fast button will also start the simulation running if it is paused.
	Space	Run the simulation. This is how the Pause button looks once the simulation is paused. Any of the Run buttons, such as the Run Fast button, can be used to resume the simulation.

What You See	Keyboard	Action
	←	Step the simulation backward one step.
		In the View panel, check this option to display the drawing layer. In the Edit panel, check this option to allow editing of the drawing layer.
		In the View panel, check this option to display the mechanism layer. In the Edit panel, check this option to allow editing of the mechanism layer.
	H	Show the hint lines for making right angles, rectangles, parallelograms, and other types of alignment changes. More information is available later in the Alignment section.
		Show the dimensions of all links, etc., in the document.
		Include ground dimensions when showing dimensions.
		Show circle and gear diameters when dimensions are shown. If unchecked, the radius is shown.
		Use a larger font for all text.
		Causes new links to be inserted as solid links. When not selected, new links are inserted in the standard line style.
		Causes the simulator to apply a fixed momentum to connectors during simulation. This is for helping simulate mechanisms like locomotive drive wheel connecting rods that are fully functional. This setting keeps the driven end of the connecting rod from simply oscillating instead of rotating all of the way around.
		Enables debugging mode (for me the developer). The effect of this will change in different versions of the program, but at this time, it changes the labels to show internal numbering of the elements in the mechanism. And it sometimes will show calculated RPM and speed values for various links and connectors.

What You See	Keyboard	Action
		Enables 6 digits of precision after the decimal point for numbers that represent positions, distances, and lengths. Using the mouse and having connectors and other points land on pixels on the screen can cause position, length, and distance numbers to have a large number of digits after the decimal point. Typically, only 4 of those digits are shown. This option only affects the precision of the numbers shown and it is always possible to enter more digits for more precise positioning. Keep in mind that after precisely positioning an element, subsequent mouse actions, even those that might position something at the same visible location, could cause the entered position to be lost. Most values that are only entered as text will appear with the precision of the previously entered values and are not affected by this option or any other precision limitation.
		Infinite guidelines allow snapping to guidelines beyond the ends of the visible segments. When this is disabled, snapping only happens when near the visible guideline segments.
		Disables filling elements like links, gears, etc., with a light fill color. This is useful for printing where saving toner is important. Color printers might also not draw the fill color very well due to its lightness.
		Motion path marks are at intervals along the motion path and are closer together or further apart depending on the speed of the connector that made the motion path.
		Show a menu of various details to show or hide. The items in that menu are shown below.
		Show labels that identify links, connectors, PRM, and other information.
	D	Show the dimensions of all links in the document.
	V	Show the video area that is captured when recording a video of a simulation.
		Show or hide the grid.
		Change the grid from automatic to manual and set the spacing of the lines.

What You See	Keyboard	Action
		Display the mechanism as a Parts List. The Parts List contains the links and connectors of the mechanism separated from each other and rotated to a horizontal position. Links with more than two connectors get rotated so that their longest side is along the bottom if the link in relationship to the screen, image, printout, etc.
		Select the measurement units for the mechanism. This is saved with the mechanism and set whenever a mechanism is loaded from a file or from the sample gallery.
		The following different values are seen and can be set using this edit control in the tool bar. The last selected connector is moved when the value is changed in a way that affects just a single connector. **Coordinates:** The x and y coordinates of a single selected connector are shown and can be set. Enter coordinates in the form “x,y”. **Length/Distance:** The distance between two selected connectors are shown and can be set by entering a single numeric value. The distance between two selected connectors can be set using a percentage value to alter the current distance as per the percentage. Enter a number followed immediately by a percent sign like this: “12%”. **Note that when a sliding connector is moved to a distance from another connector, it is moved along the slide path. This might cause the requested length to be ignored if the length would place the sliding connector off the path.** **Angle:** The angle between three selected connectors is shown and can be set by entering the number of degrees as a single numeric value. *The angle cannot be set if it could cause a sliding connector to be moved.* **Ratio:** The ratio of two gears can be set by entering two numeric values in the form “a:b”. The first value is the value representing the size of the first selected gear. The second value applies to the second selected gear. This is a ratio for gears and the gear sizes are determined by the distance between them. Use the Ratio button in the Align menu to create a chain. Once set to be a chain, the ratio of the chain sprockets can be changed using this box. **Scale:** The overall size, or scale, of a set of selected elements can be changed by entering a percentage like this: “120%”. Scaling like this is done if more than two connectors are selected or if a combination of connectors and links are selected. **Rotation:** The selected elements can be rotated by entering an angle followed by an asterisk (*) (Note that the letter ‘d’ would work in past versions but sometimes causes the auto-dimensions to display instead. Just use the asterisk now). Setting this will rotate the selected elements by the given value. Setting it a second time with the same or any other value will rotate the elements again by the specified amount. There are also menu items in the Align menu to do these operations.

What You See	Keyboard	Action
		When a value is displayed in the dimensions text box, the type of value is shown below it. It could be “Length”, “Distance”, “Angle”, “Scale”, “Ratio”, or “X, Y Coordinates”.
		Show a menu of snap options including the Auto Join option. Snapping to guidelines is always turned on so there’s no way to disable guide line snapping.
		When selected, snap connectors to align with other connectors, ends of lines, and points, while dragging selected elements.
		When selected, snap connectors to align with an invisible grid while dragging selected elements. *The grid size is picked automatically based on the zoom level.*
		Enables the automatic joining of connectors (makes them into one) when one is dropped directly on another. The Element Snap must be on or this feature will not be enabled. Once joined, there will be only a single connector possibly shared by multiple links. A Split operation will be needed to break the connector into two or more separate connectors. *Connectors that are not part of a link cannot be auto joined.*
		Zoom and pan the window so that the document is centered and is as big as possible in the window. The nearest standard zoom level is used and the mechanism may appear smaller than expected because of this.
	+	Zoom in to show the mechanism larger.
	-	Zoom out to show the mechanism smaller.
		Show program copyright and version information.
		Open the User Guide document. The User Guide is a PDF document. It’s this very PDF document that you are reading now!

What You See	Keyboard	Action
		The right-click context-specific menu may have an option to show the properties of the selected element.
		The right-click context-specific menu may have an option to cut the selected element.
		The right-click context-specific menu may have an option to copy the selected element.
		The right-click context-specific menu may have an option to lock the selected element. If the element is already locked, this option will show a highlight and selecting this option will unlock the element.
		The right-click context-specific menu may have an option to add a node to a spline at the selected position.
		The right-click context-specific menu may have an option to convert the segment of the selected spline into a straight line.
		The right-click context-specific menu may have an option to convert the segment of the selected spline into a curve. Curves are defined as cubic Bezier curves with a start point, end point, and two control points. The control points are shown as arrows at the ends of dotted lines. The start and end points are the nodes of the spline on either end of the curve.
		The right-click context-specific menu may have an option to set a spline node to be smooth. A smooth node restricts the positions of the control points around it so that curves and lines pass smoothly through the node point. Note that it is not possible to have a smooth node if the segment on either side of it are straight lines.
		The right-click context-specific menu may have an option to set a spline node to be symmetric. A symmetric node restricts the positions of the control points around it so that curves and lines pass smoothly through the node point. IN addition to being smooth, the control points are always forces to be equidistant from the node. Note that it is not possible to have a symmetric node if the segment on either side of it are straight lines.
		The right-click context-specific menu may have an option to set a spline node to be a cusp. A cusp node can have a sharp point with the control points on either side going in any direction out from the node.
		The right-click context-specific menu may have an option to delete a spline node. The selected node is deleted and the spline shape may change as a result.

Keyboard

See the menu and Tool Bars section above to see most keyboard shortcuts. Below are other keyboard shortcuts **that don't have tool bar buttons or menu items** to do the same things:

Keys	Action
C	Deprecated and won't work in the future. See "L" to make a link between two selected connectors.
Control-D	Duplicates the selected elements by copying and pasting them in one action. If you rotate or move the duplicates and then duplicate those elements, the movement or rotation is also applied to the newly duplicated elements. The rotation center is not updated and is the same as for the previous rotation. Only movements and rotations are saved in this way, and they are only automatically applied to duplicate elements if no other operations, including selection of elements, have taken place after the duplication operation.
E	Select the link that holds both selected connectors. Only the first two selected connectors are used. Nothing happens if only one connector, or none, are selected.
G	Change the selected connectors into anchors.
Ctrl+F1	Toggle the tool bar visibility. If the tool bar is hidden, only the tabs are shown and the tool bar pops up when a tab it clicked.
Delete	Delete the selected elements.
Tab	Select the next element in the mechanism after the element currently selected.
Shift-Tab Control-Tab	Select the previous element in the mechanism before the element currently selected.
←	Nudge the selected elements to the left one screen pixel when editing. Step the simulation one step backward while simulating.
→	Nudge the selected elements to the right one screen pixel when editing. Step the simulation one step forward while simulating.
↑	Nudge the selected elements up one screen pixel when editing.
↓	Nudge the selected elements down one screen pixel when editing.

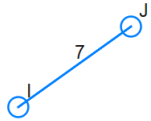
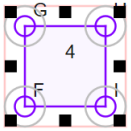
Keys	Action
Shift ←	Nudge the selected elements to the left five screen pixels when editing. Step the simulation backward 10 steps while simulating.
Shift →	Nudge the selected elements to the right five screen pixels when editing. Step the simulation forward 10 steps while simulating.
Shift ↑	Nudge the selected elements up five screen pixels when editing.
Shift ↓	Nudge the selected elements down five screen pixels when editing.
Escape	Unselect/deselect all selected elements and delete any motion path drawn by connectors.

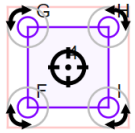
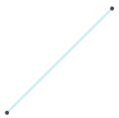
Mechanism Window

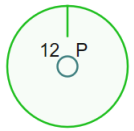
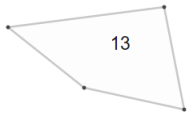
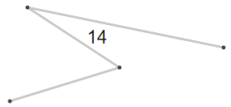
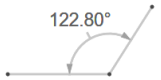
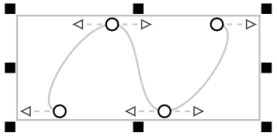
The mechanism with links and connectors is visible in the window along with various other pieces of information. Everything that may be seen in the window is described in the following table.

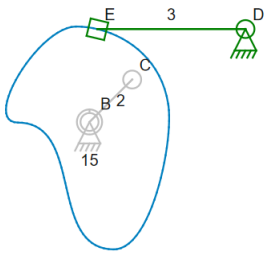
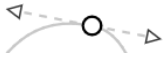
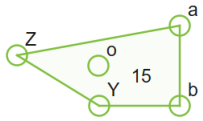
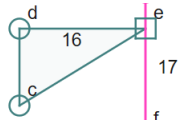
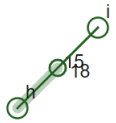
The first six things in this table are important to understand. You cannot design a mechanism without recognizing links and connectors.

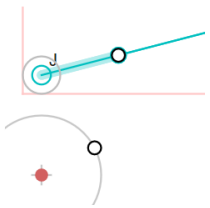
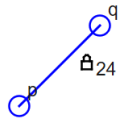
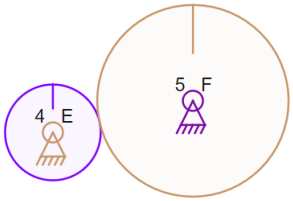
What You See	What It Means
	An individual connector represents the connection of one link to another or the place where a link could be connected. The connector is shown as a circle around the point of connection. A connector can exist without any links but it doesn't do anything. When labels are enabled, and a name has not been given to the connector, a letter will be shown near the connector for identification. Connectors will usually be the same color as the link to which they belong or black if they connect two or more links together.
	An anchor is a connector that is attached to the "ground." The location of this connector will not change during a simulation. Links connected to this anchor can rotate around it freely when the mechanism is simulated.

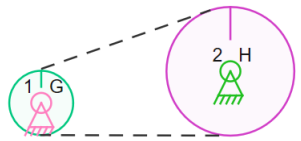
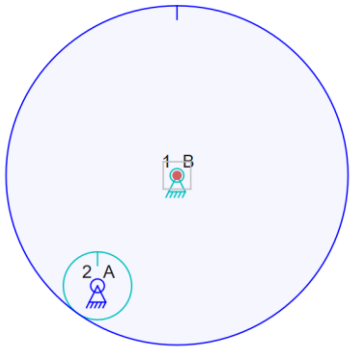
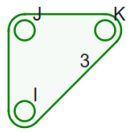
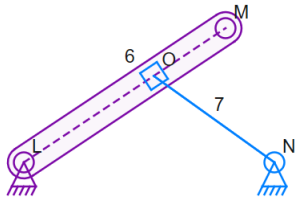
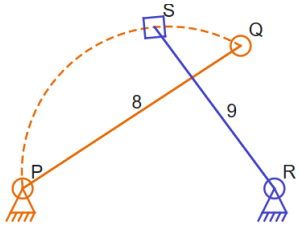
What You See	What It Means
	A rotating anchor rotates all of the links that are connected to it. The RPM of the rotation is shown below the anchor and can be set by double-clicking or right-clicking on the connector, or selecting it and clicking on the **Properties** button in the toolbar, and then typing in a new RPM value. Positive RPM values are for clockwise rotation. Negative RPM values are for counter-clockwise rotation.
	A rotating anchor that has a rotation limit will show an arc that represents the limit. In the case to the right, the limit is 180 degrees. If the RPM is set to a negative value, that arc would start at the top of the anchor and be drawn left and down.
	A sliding connector is a connector that slides between two other connectors on another link. The sliding connector is shown as a square when it has been set to slide between other links. A sliding connector may also be stationary or appear stationary while the other link defined by the other two connectors slides through this sliding connector. An anchor can also be a sliding connector.
	A link is a set of two or more connectors that are a single part in the mechanism. When labels are enabled and a name has not been given to the link, a number will be shown near the middle of the link.
	A ground link might be visible in the Parts List if there is no other link connecting all of the anchors to each other.
	Grab handles for stretching, or scaling, and resizing the selected elements of the mechanism will be shown as small black boxes around the selected elements. Clicking on one of the selected elements without dragging the selection will cause the rotate controls to appear. Clicking and dragging one of the grab handles allows the selected elements to be resized. Dragging a corner grab handle will maintain the aspect ratio of the resized elements. These handles are not shown for a single selected connector since they cannot affect it.

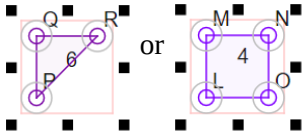
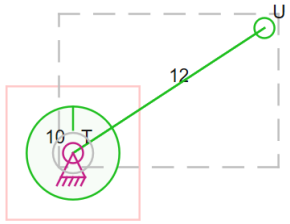
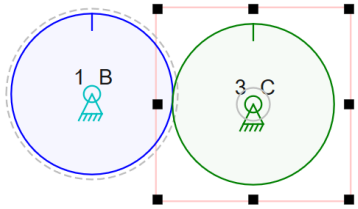
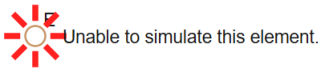
What You See	What It Means
	Rotation controls are shown as small arrows at the corners of the area containing the selected elements. These appear if an already selected set of links or connectors is clicked again (without the shift or control keys pressed). There is also a center mark that can move moved to change the point of rotation. Clicking and dragging one of the arrows allows the selected elements to be rotated. The center mark will snap to other connectors as it is moved near them. It does not snap to any other locations. These controls are shown for a single selected connector since the rotation center can be moved off of the connector and it can be rotated around that center point.
	When two or more connectors are at the same **screen location**, there is an extra arc draw to show this overlap. Two or more connectors at the same screen location don't connect links together, they are simply at the same location visually. When two links *are* connected, there is only a single connector at the connection point. This arc is not shown during the simulation.
	A point is a reference marker and is not part of the mechanism or simulation. A point will show up as a cross or plus sign when it is not part of a line. Points can be manipulated just like connectors.
	A line is a reference marker and is not part of the mechanism or simulation. A line is two points connected together. Lines can be manipulated just like links. Lines can even have points added to them and they behave just like links with more than two connectors.
	Guidelines are always a pale blue color. They have no labels. When elements are dragged or rotated, they can snap to be on a guideline if they get close enough. Elements will also snap to the intersection of two guidelines when close enough to that intersection point during a drag operation. If grid snapping is enabled, elements can snap to the intersection of guidelines and grid lines when dragging. Gridlines are part of the drawing layer but remain visible when the drawing layer visibility is turned off. The snapping line of a guideline can extend past the end of the visible Guideline segment if the Infinite Guidelines option is enabled.
	A point can have a circle drawn around it at a specified radius.

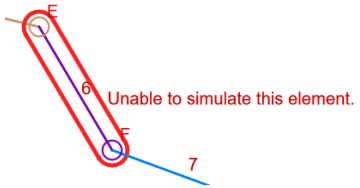
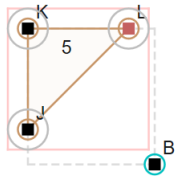
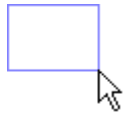
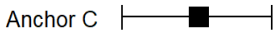
What You See	What It Means
	A gear appears as a circle that is colored like a link. The connector label appears in the typical label position. The link also has a label that is shown to the left of the connector label. There is a line drawn on the gear to help show movement during the simulation.
	A drawing line can be a polygon if there are three or more points. Drawing lines are edited just like links, with new points being added when the “A” button is pressed and selected when the mouse pointer is moved inside of the polygon and the left button is clicked. The polygon has no function other than to show some extra lines in the drawing. The drawing line, polygon, or the points on the line, can all be fastened to elements in the mechanism, so they move during simulation.
	A polyline is just a drawing line with three or more points that also has the “polyline” option selected. It is drawn as a series of individual lines and the entire element is not closed like a polygon.
	A measurement line is a reference marker and is not part of the mechanism or simulation. This is identical to a plain reference line except for the measurement that is displayed and the style of the ends of the line are specific to measuring things. There is little visual difference between a measurement line and an automatic dimension line, except that measurement lines can be drawn anywhere and are always visible. Measurement lines are actually polylines and can have more than two points in a series. Select a measurement line and click the Add button or tap the “A” key to add another point.
	A measurement line (see above) can be set to show angles instead of lengths. There must be at least three points on the line to show any measurements. Select a measurement line and click the Add button or tap the “A” key to add another point.
	A spline has curves, lines, and other features and has control points that can be moved and edited when the spline is selected. The default (dropped in) spline has 4 nodes and 3 visible segments. The last segment to make a continuous (closed) shape can be displayed by “closing” the spline using the “closed” option in the spline properties.
	An unselected spline can have almost any shape. The image to the left is an unselected spline.

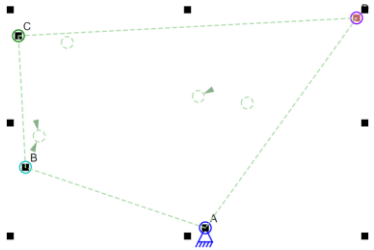
What You See	What It Means
	A spline can be used as a cam and will have one or more sliding connectors sliding on it. This is also an example of a closed spline. A closed spline is a spline that has no beginning or end.
	The spline control points consist of nodes and control points for curves. The nodes are the points between individual curves or lines. The control points are only shown and used for editing curves. A node with a curve segment on either side of it will appear with two arrows pointing out from it and the arrows can be used to change the shape of the individual segments.
	A link can have as many connectors as needed. When there are three or more connectors, the link will be shaded a light color similar to the line color of the link. The numeric identifier will be shown close to the center of the link. A connector within the area of a link that is part of that link will not have a line of any sort showing it as part of the link. It will simply be within the link area and if not connected to some other link, will be shown in the link color.
	A link can have regular connectors as well as sliding connectors. Once a connector is set to slide between other connectors (on another link), that connector is drawn as a square and is aligned with the path on which it slides. Sliding connectors can also have a curved path between two connectors and also can be set to slide on a spline.
	A linear actuator changes length during the simulation and any attached links will be moved appropriately. The CPM, or cycles per minute, shown below the link ID number and can be set by double-clicking or right-clicking on the link, or selecting the link and clicking on the **Properties** button in the toolbar, and then entering a new value for CPM. Positive CPM values are for actuators that get longer when they start moving. Negative CPM values are for actuators that get shorter when they start moving. The small circle on the actuator is the throw distance knob. The throw distance knob can be dragged to change the throw distance (the amount of travel of the actuator). The throw distance knob does not remain selected after it is released.

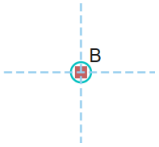
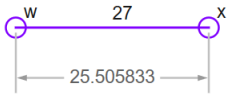
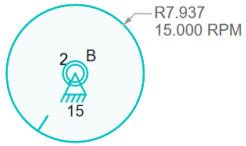
What You See	What It Means
	Linear actuators, circles, and some other elements have control knobs. The control knobs are little circles that appear when the element is selected. When the element is selected, the control knob can be dragged with the mouse. A small dot appears inside of the control knob circle when the control knob is selected. The control knob on actuators controls the throw distance. The control knob on circles controls the radius. Control knobs on splines control the shape of the spline segments. Some control knobs will snap in the same way that connectors snap while they are being dragged. Turn on and off the various snapping options using the Snap menu in the tool bar.
	A selected connector shows with a small square or dot in the middle of it. A connector is selected by clicking on it with the left mouse button. Multiple connectors and links can be selected by holding the Control or Shift key while clicking on each with the left mouse button. The last selected connector will be a red color square or dot but all previous selected connectors will be shown with a black square or dot in them. Some operations may treat the first or last selected connector in a special way depending on the operation. If the order of more than two selected connectors is important than there may be other hint markings or lines to show this. For instance, if three connectors are selected and the Hints view option is enabled then an angle radius arc will be shown around the second selected connector.
	A connector that draws while the mechanism is animating or simulating will show a tiny pencil icon and the label will be in a different location from the label on a non-drawing connector.
	A link that is lock will be show a little padlock icon before the label. A locked link cannot change size or shape, but can be rotated.
	Gears that are connected to each other (having a ratio set) will be drawn touching each other and at sizes appropriate to the gear ratio that was set.

What You See	What It Means
	Gears that are connected to each other (having a ratio set) and set to use a chain/belt connection will be drawn not touching each other, at sizes appropriate to the gear ratio that was set, and with dotted lines showing where the chain or belt would go. The size of the gears is arbitrary, except for the ratio, because the distance between the gears does not change the ratio.
	Internal gear pairs are drawn with the larger of the two gears outside of the smaller gear. It is not possible to have a 1:1 ratio with planetary gears. The small gear runs on the inside of the larger gear. It is possible to create some planetary gear mechanisms using internal gears.
	Links can be drawn as solid looking objects in addition to the regular drawing style. A border is drawn outside of the connectors and around them.
	The path of a slidingconnector is drawn as a dotted line when the path is inside of a solid looking link or between connectors on a link that are not adjacent to each other.
	The path of a sliding connector can be curved in some situations. The path is always drawn as a dotted line.

What You See	What It Means
	A selected link shows with a red or grey rectangle around it. A link is selected by clicking within the link with the left mouse button. A link is not automatically selected when one of the connectors of the link is selected. Multiple links and connectors can be selected by holding the Control key or Shift key while clicking on each with the left mouse button. The last selected link will be surrounded by a red rectangle but all previous selected links will be shown with grey rectangles. Some operations may treat the last selected link in a special way depending on the operation. Each connector of a selected link has a circle drawn around it to help identify which connectors are part of the selected links.
	A grey dashed box appears around an element when you select another element that is fastened to it. For drawing elements, the link they are fastened to may be any place else in the mechanism. The grey dashed box might appear if any of a set of elements is selected. This indicates that one or more of the selected elements is fastened to, or has elements fastened to it.
	A grey dashed circle appears around a gear when you select another gear that meshes with it.
	A connector that cannot be properly moved during simulation will be shown with a set of red lines around it if the simulation is running. Only the first failing connector, or the first few failing connectors, will show these marks. The error marking will not appear during editing. Links cannot stretch or shrink, and a mechanism is not guaranteed to work properly when simulated. Simulation done without animation will not cause this information to be shown. If the mechanism cannot move past a specific position due to limitations in the mechanism, the mechanism will appear stuck with these indicators shown until the simulation is stopped.

What You See	What It Means
	Any link that cannot be properly moved during simulation will be shown with a red outline around it if the animation is running. Only the first failing link, or the first few failing links, will show the error outline. The error outline will not appear during editing. Links cannot stretch or shrink, and a mechanism is not guaranteed to work properly when simulated. Simulation done without animation will not cause this information to be shown. If the mechanism cannot move past a specific position due to limitations in the mechanism, the mechanism will appear stuck with these indicators shown until the simulation is stopped.
	When stretching one or more selected elements, a dotted line will appear showing the actual area of the mechanism being stretched. Stretching is done based on the locations of the connectors that are selected or are part of selected links. This is not the same area that is enclosed by the grey box around each of the selected elements even though the grab handles are draw along the edges of that larger box.
	Select a group of connectors and links by drawing a box around them. Draw the box starting in an empty location in the window or the element under the mouse cursor will be selected instead of the selection box being drawn. Only the center point of connectors is used to determine what is selected. The circles, triangles, text, and any other graphics are ignored during this type of selection and need not be enclosed in the selection box to have the associated connector or link become selected.
	During an interactive simulation, controls are shown in the bottom of the window. Each control consists of a text label, a line representing the range of movement of the input or actuator, and a control box. The box can be moved anywhere between the sides of the range indicator line and part of the mechanism will move to match its position. For a rotating anchor, moving the control box from the far left to the far right of the range indicator line will rotate the input one complete revolution. For a linear actuator, moving the box from the far left to the far right of the range indicator line will move the actuator from its shortest length to its longest length. This is only1/2 of a complete cycle but allows the full range of the actuator to be used.
	Connectors can be configured to draw a motion path. The motion path remains visible after a simulation run has stopped. This allows manual editing of the mechanism based on the path. The path may have marks or dots along it to show the speed of the connector if the Motion Path Marks option is enabled.

What You See	What It Means
	The greenish dashed lines, circles, and arrows, are all hints that show the results of various alignment and other operations. The hints for three selected elements will also show an angle arc as a hint to what part of the selected elements will change if the angle is changed.
	This is a hint circle. It shows a destination location for a selected connector or point when various types of alignment operations are performed. The arrow is pointing at the circle from the connector or point that is moved during the operation. For three selected elements, this shows the destination for the third selected element during a Right-Angle operation. For four selected elements, this shows the destination for the fourth element during a Parallelogram operation. You can click on this hint circle to perform the Right-Angle or Parallelogram operation.
	This is a hint circle. It shows the destination for two connectors and/or point elements when a Rotate to Meet operation is performed. The two arrows point at the circle from the two elements that will be moved. You can click on this hint circle to perform the Rotate and Meet operation.
	This is a hint circle. A pair of circles with no arrows and two small lines will show the new locations for the third and fourth selected connector and/or point elements when a Rectangle operation is performed. You can click on either hint circle to perform the Rectangle operation.
	This is a hint circle. This circle with a line though it will show the new locations for the third and possibly fourth selected connector and/or point elements when a Perpendicular operation is done for three or four selected connector and/or point elements. The line shows the direction of a perpendicular line through the midpoint between the first and second selected elements. You can click on either hint circle, if there is more than one, to perform the Perpendicular operation.

What You See	What It Means
	Hints are shown whenever a selected connector is snapped to align with some other connector or the grid. The connector snap hint is drawn between the connector that is snapped and the unselected connector used for alignment. There are separate hint lines for horizontal and vertical alignments. Snap hints are even shown when a connector or other element is snapping to the position it was in before it was dragged away.
	Hints are shown whenever a selected connector is snapped to align with some other connector or grid. The grid hint line is drawn to the edge of the window through the connector that is snapped. There are separate hint lines for horizontal and vertical alignments.
	When the grid is displayed, it is drawn as light blue lines. The grid will set itself to a size appropriate for the zoom level and can also be set to a specific size.
	Automatic dimensions for links are shown offset from the link and are aligned using the pair of adjacent connectors that are furthest apart.
	Automatic dimensions for circles and gears. Gears will show an RPM value when a simulation is running.
	A blue box on the screen that is centered and is of a 16:9 size ratio represents the area used for saving a video of the mechanism simulation. This is a different shade of blue from the shade used for the mouse selection box. Anything outside of this area is not captured in the video. There is an option on the Preferences panel to show an area for 720 and 1080 video sizes.
	When there are no elements of the mechanism available for showing dimensions, and when dimensions are enabled, this ruler will appear to show the current zoom and dimensions in the window.

Grid

There are two types of grids in the Linkage program. One is an automatic grid, which is the grid you will see if you show the grid and have not set your own grid spacings. The automatic grid gets smaller and smaller as you zoom out until it is “too small”. When it gets too small, it changes spacing and becomes large again.

This grid is useful when you are first creating a mechanism and just need a simple alignment feature. The automatic grid is generated so that it is an even number of units in size or a consistent fraction of the unit size (2 per unit, 10 per unit, etc.).

The manual grid can be set with separate horizontal and vertical spacings and can be set to any reasonable value. Click on the Edit Grid button to open the grid settings dialog box to set these values.

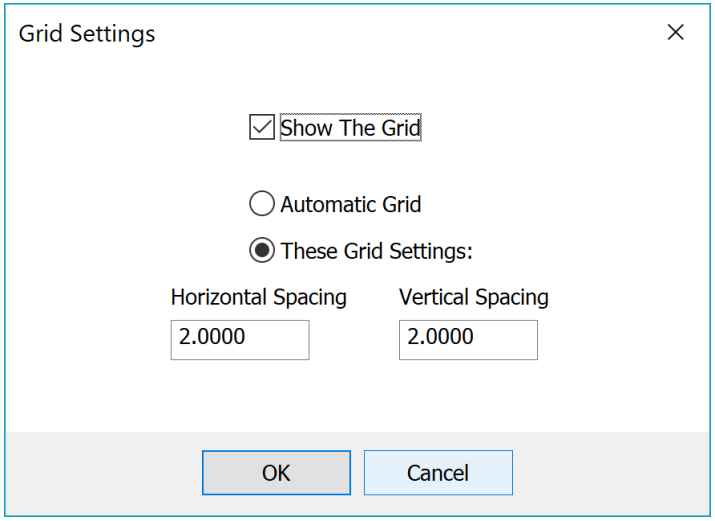


Figure 10. Grid Settings

When the manual grid settings cause the grid lines to be closer together than the element snap distance, the grid is not displayed but the snap feature will still work.

Selection	**Meaning**
Show the Grid	Show the grid by checking this box. The grid can also be shown and hidden by clicking the Show Grid button in the **Detail** menu in the View section of the tool bar.
Automatic Grid	The automatic grid changes spacing depending on the zoom level.
These Grid Settings	The manual grid requires a horizontal spacing and a vertical spacing.
Horizontal Spacing	The horizontal distance between the vertical lines in the grid.
Vertical Spacing	The vertical distance between the horizontal lines in the grid.

Background Images

The Linkage program can display an image as a background for a mechanism. There is a Background tab on the tool bar that has an Open button and a Transparency slider. The background image feature is quite limited, and the image is always shown at a specific size and centered on the 0,0 coordinates of the mechanism. Making the image more transparent makes the image lighter since the background behind it is white. Once an image is loaded, it the image data is saved with the mechanism and the original file need not exist.

Background images are not affected by Undo operations!

The background Image feature is still a Beta test feature and may not work exactly as needed. It may also cause memory usage problems if the background is changed often or if mechanisms with backgrounds are opened and closed numerous times.

Alignment and Hints

Connectors and Points can be aligned to each other in a variety of ways. When two or more connectors and points are selected, green lines, circles, and arrows, show hints about what alignment feature are available. To see a complete list of alignment options, look in the menus and Tool Bars section earlier in this document. The action of each alignment option is described there. Hint lines and circles are described below.

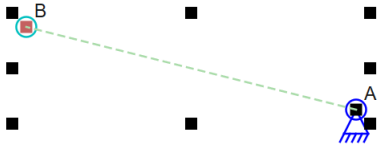


Figure 11. Two Element Hints

In Figure 11, two connectors are selected. A line is drawn between them to show that they can be linked together (forming a link with two connectors). They can also be aligned vertically or horizontally, as well as being aligned in other ways described elsewhere.

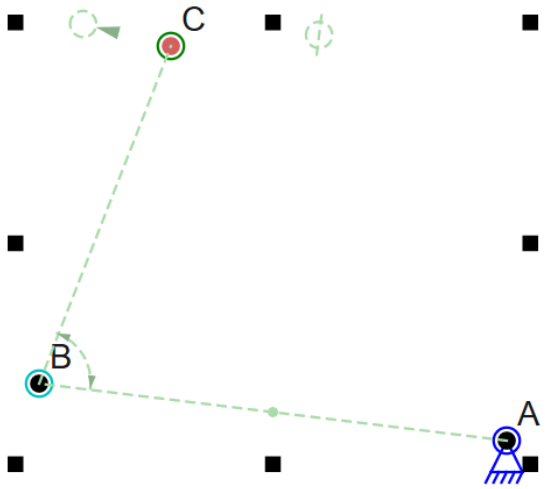


Figure 12. Three Element Hints

In Figure 12, three connectors are selected. The two dotted lines and the angle marking at the second selected connector shows that the angle can be set. The circle and arrow closest to connector C shows where C will move to if the Right-Angle alignment is used. The further circle with a line through it shows the result of a Perpendicular alignment where C is moved to be aligned at a right-angle from the midpoint between A and B.

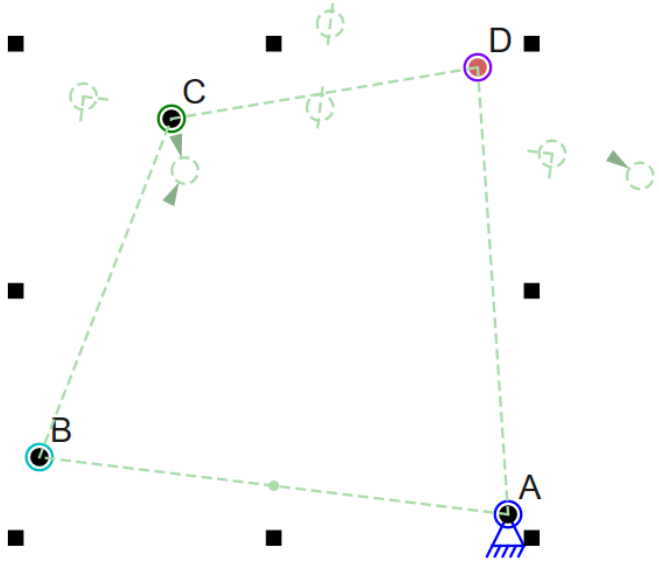


Figure 13. Four Element Hints

In Figure 13, four connectors are selected, and hints are shown for a variety of configurations. The circle with two arrows on it shows the new location of both B and C, if they are rotated around A and D respectively, to meet each other. This is handy for rotating two links to meet without changing their lengths. The circle with a single arrow shows the new location of D if the selected elements are aligned into a Parallelogram. The circles without arrows but with a small right angle set of lines, show the new C and D locations if the selections are aligned into a rectangle. The two circles with lines through them show the result of a Perpendicular alignment where C and D are moved to be aligned at a right-angle from the midpoint between A and B

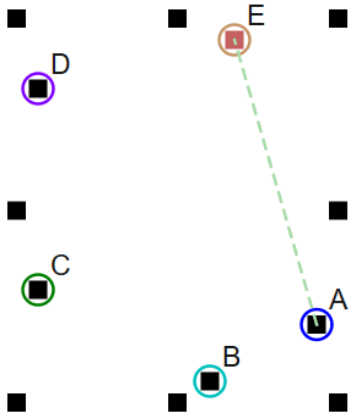


Figure 14. Five Selected Connectors

When five or more connectors and points are selected, the only hint line that is drawn is the hint for lining up the elements with the first and last shown at the ends of the hint line. The line represents that alignment of all the connectors if the Line Up and Even Spacing features are used. The new positions of the other connectors not at the ends of the line are not shown in this hint.

Connectors and Points

Connectors and points are elements of a mechanism that represent the connection location of links and lines. Note that drawing points are functionally similar to connectors and drawing lines are functionally similar to links – the only difference is that points and lines do not act as mechanical components of a mechanism and they are drawn differently. For the rest of this description, you can safely assume that lines are like links and points are like connectors. A link by itself will have two or more connectors. Once two links or lines are connected together, they will share a common connector. This means that when two connectors are selected and then joined to be a single connector, they become a single connector with the properties of that single connector and the connector then mechanically connects the links; The two connectors become one.

Drawing elements and splines can be fastened to connectors. If the connector is not an input connector then the fastened elements move as the connector moves but do not rotate as the connector rotates. This is because connectors that are not inputs are meant to “spin” freely. Or rather, elements on them can spin freely. Since drawing elements and splines don’t behave link links in the simulation, they won’t spin at all when they are fastened to a connector that appears to rotate as it moves. An element fastened to a rotating input connector will rotate around it as it rotates in the same way a link that has a rotating input connector will rotate as the input rotates.

Connector and Point Properties

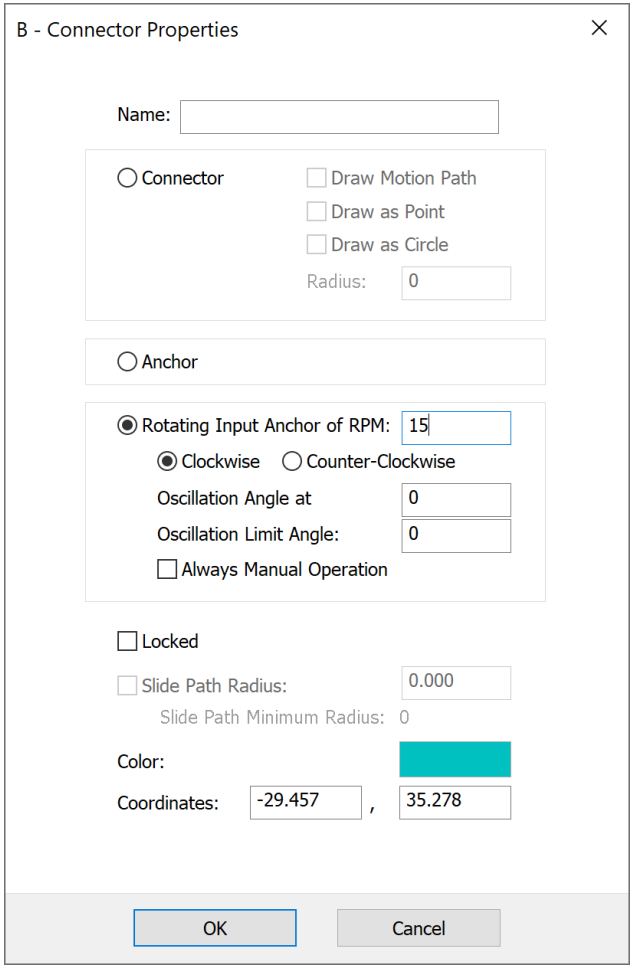


Figure 15. Connector Properties

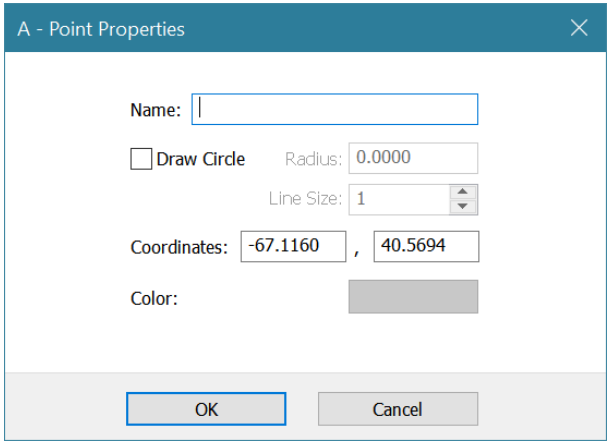


Figure 16. Point Properties

The connector properties dialog box in Figure 15 shows what settings are available for connectors. Figure 16 shows the point properties. Double-click or right click on a connector to show the Connector Properties or click on the Properties button. The different settings are:

Selection	**Meaning**
Name	This is the name of the connector. It will be displayed after the connector identifier when labels are enabled.
Connector	The connector can connect links together so that they rotate around the connector. A connector can be part of a single link with no connections or it can connect two or more links together.
Draw Motion Path	When the Draw Motion Path property is set for a connector, the connector causes a line to be drawn along the path taken by the connector during simulation. The line, which is more accurately a curve, is drawn in a light grey as the simulation is run and remains visible until the mechanisms is changed in some way that could make the path invalid.
Draw as Point	Connectors that do not connects link together can be drawn as a point using this option. This allows links to be used as mechanical parts and also as drawing elements that define the shape of the final part.
Anchor	The anchor is a connector attached to the “ground”. The ground is like one large link that is the base for all other connections in the mechanism.
Rotating Anchor	A rotating anchor provides rotational movement to selected parts of the mechanism. When simulated or animated, any links that connect to this anchor will rotate at the given RPM.

Selection	Meaning
RPM	The revolutions per minute can be set for rotating anchors.
Clockwise Counter-Clockwise	These two buttons allow for the selection of the direction of rotation. Note that older version of the software used a negative RPM value to create a counterclockwise input. A negative value is no longer used in this dialog box to create a counterclockwise input but the negative number still appears in the mechanism as a quick way to show an input that rotates counterclockwise.
Oscillation Limit Angle	The angle for how far around the input can rotate. If this is set to zero, the input rotates around 360 degrees continuously and does not oscillate. If this is set to any positive value, it is the number of degrees to rate before changing direction and rotating back to the starting position.
Oscillation Start Angle	The angle where the movement starts if an oscillation angle is set. This value is set automatically when the mechanism is pinned.
Always Manual Operation	When the AMO property is set for a rotating anchor, movement of the anchor is controlled manually during all simulations. When this property is not set, the rotating anchor rotates automatically during simulation.
Draw Circle	Draw a circle of the given radius around the point on the drawing layer as a reference marker.
Radius (for Draw Circle)	The drawing circle radius can be entered. A value of zero will disable the circle drawing.
Line Size (for Draw Circle)	The thickness of the lines used for drawing a circle can be set from 1 to 4. This is not available for drawing the point marking.
Slide Path Radius	The path of a sliding connector can be curved when simple sliding connector configurations are used. The radius can be entered as a positive or negative value to set both the radius and the direction of the arc. If the path appears on the wrong side of a link, change the radius from positive to negative or vice-versa.
Slide Path Minimum Radius	The minimum allowed radius is shown for the slide path. A slide path cannot have a radius that is less than half the distance between the limit connectors.
Color	The color of the connector or point can be set by clicking on the color box.
Coordinates	The x and y coordinates in Millimeters or Inches are shown in two edit boxes. If either or both are changed then the connector will move to the given coordinates when the OK button is pressed.

Links and Lines

Links and lines are elements of a mechanism Links represent physical elements of machinery such as the frame of a truck, the floor of a factory, the lever of the gas pedal of a car, and anything else that would have a physicality such that other things could be attached to it in various ways. Your upper arm has a bone in it that is a link from your shoulder to your elbow. In the Linkage program, there are also special links such as actuators that can change length but otherwise still behave link other typical links. Keep in mind that a link can have more than two connectors and it is often much more descriptive to create a link in the shape of a triangle than to create a triangle using three separate links. Lines are like links when editing them but have no effect on the simulation.

Drawing elements and splines that are fastened to a link will move and rotate as the link rotates. Gears can be fastened to links and also rotate as the link rotates but this feature is deprecated and it is better to simply add more connectors to a gear since it is itself a link that can have any number of connectors in addition to its “gearing”.

Link and Line Properties

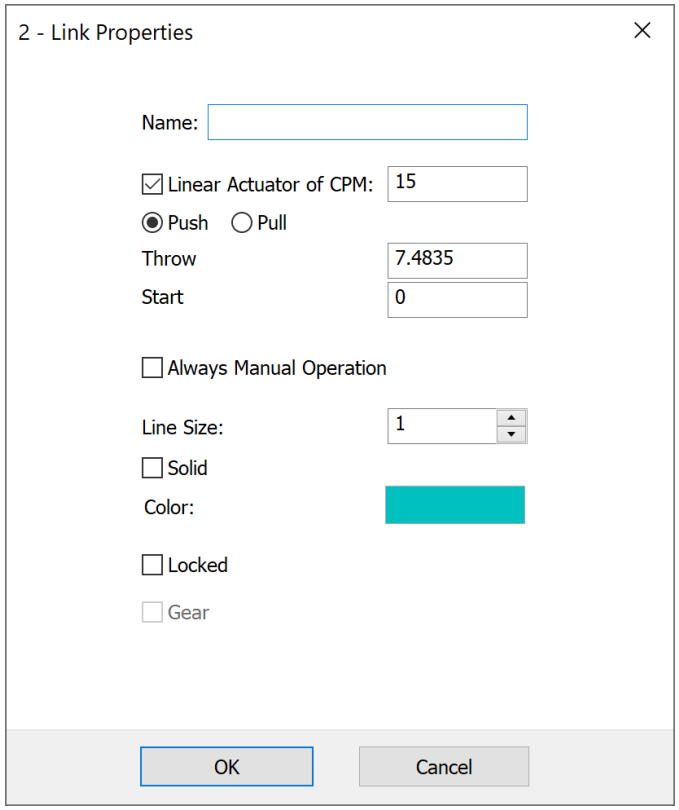


Figure 17. Link Properties

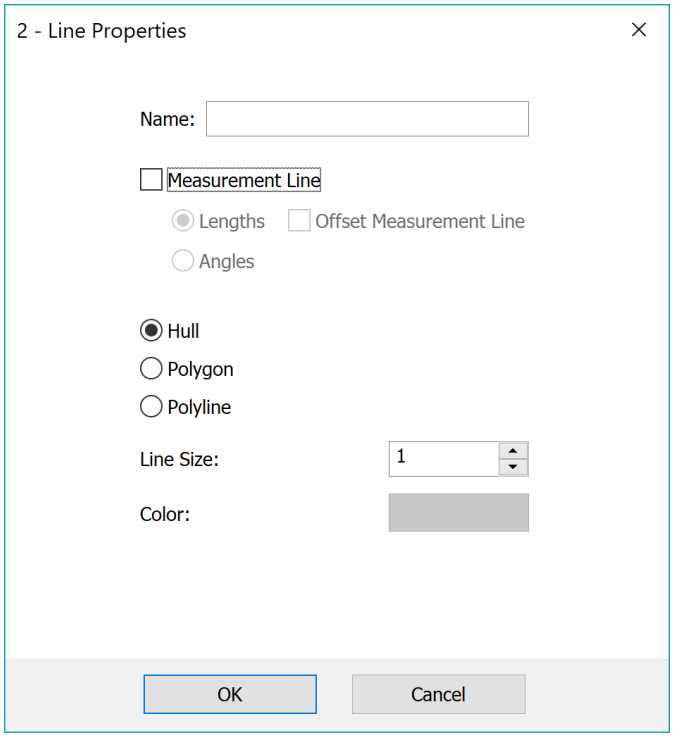


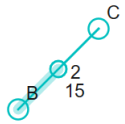
Figure 18. Line Properties

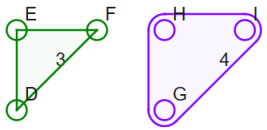
The Link Properties dialog box in Figure 17 shows the settings that are available for links. Figure 18 shows the line properties. Double-click or right click on a link to show the Link Properties or click on the Properties button.

The link properties is shown if more than one element is selected and one of them is a link. This makes it easy to change the visual style of all of the selected links without worrying about having other elements selected.

The different settings are:

Selection	**Meaning**
Name	This is the name of the link. It will be displayed after the link identifier when labels are enabled.

Selection	Meaning
Actuator	A link can be a linear actuator if this option is selected. A linear actuator moves during simulation. The movement is linear like the hydraulic piston on a tractor scoop. The movement is continuous throughout the simulation. **Only links with two connectors can be actuators.**  Actuators are shown with two different size lines and a small circle shows the throw distance, or total movement distance, of the actuator. The throw circle can be dragged to a new position to change the throw distance once the actuator is selected.
CPM	The cycles per minute can be set for an actuator. One cycle is the movement from the start position to the end position and then back again. Enter only positive values. **For "Always Manual Operation", this value is the maximum CPM that the actuator can have. The actuator will move up to this CPM to get to the manual operation position.**
Push Pull	The two buttons allow for the selection of the starting actuator direction. A "Pushing" actuator gets longer when it first starts moving whereas a "pulling" actuator gets shorter when it first starts moving. Note that older version of the software used a negative CPM value to create a "pull" actuator. A negative value is no longer used to create a "pull" actuator but the negative number still appears in the mechanism as a quick way to show an actuator that is a "pulling" actuator.
Throw Distance	The throw distance is the distance of travel for a linear actuator.
Start Position	The starting position of the actuator. This cannot be negative and should not be entered larger than the throw distance. Pinning the mechanism will set this value automatically at which time the value could be up to twice the throw distance if the actuator was moving through the second half of its cycle.
Always Manual Operation	When the AMO property is set for an actuator link, movement of the actuator is controlled manually during all simulations. When this property is not set, the actuator moves automatically during simulation. Set the CPM value to the maximum CPM that is allowed when using AMO.
Measurement Line	A line on the drawing layer can be displayed as a plain line with dots at the ends or as a measurement line with measurement information (length or angle). The measurement line, like all lines, can be a polyline made from connected line segments. Unlike simple lines, they cannot be closed polygons or hull shapes.

Selection	Meaning
Lengths	This option causes measurement lines to display their length for each segment.
Angles	This option causes measurement lines to show the angle between segments. There must be at least two segments to show the angle between them.
Offset Measurement Line	When this is selected, the measurement of a measurement line is drawn off center.
Hull	This sets the drawing line to look like a polygon when there are three or more points. A drawing line is just a link and can have more than two points. The Hull is the shape of the outer points of the polygon with points skipped if they would make the shape have concave parts to it. In other words, if you follow the hull shape clockwise around the polygon, all bends are to the right – there are no left turns at all.
Polygon	This sets the drawing line to look like a polygon when there are three or more points. A drawing line is just a link and can have more than two points. This includes all points (unlike the Hull) and the polygon might appear like an hourglass or other odd shape depending on the locations of the various points.
Polyline	This sets the drawing line to look like a polyline (a set of lines between the points with a specific start and end point) when there are three or more points. A drawing line is just a link and can have more than two points. When this is selected, the drawing line is not drawn like a typical link and is not a closed hull or polygon.
Line Size	The thickness of the lines used for drawing the link can be set from 1 to 4.
Solid	Links are normally drawn as single lines from one connector to another or as a polygon between the connectors. Making a link solid will cause the lines to be drawn outside of the connector circles and will give the impression that the link of a solid material. Actuators can be drawn solid but there will always be two lines between the connectors with one line wider to show the throw distance for the actuator.  A solid link (link 4) is shown here next to a non-solid link (link 3).

Selection	Meaning
Color	The color of the link or line can be set by clicking on the color box. Gears that are fastened to links will take the color of the link and not the color set here.
Locked	The Lock check box shows if the selected link is locked. A locked link cannot change shape or size.
Gear	The Gear check box shows if the selected link is a gear. This control is disabled since this setting cannot be changed.

Splines

A spline is a set of segments that can be curves or lines and are drawn and simulated as a continuous element. A spline can be "closed" making the start point and end points the same point. The segments of a spline are called segments and the points between them are called "nodes." While segments can be straight lines or curves, the nodes can have properties such as "smooth" , "symmetrical" , and "cusp" . These node properties affect how the segments are manipulated and drawn on both sides of the node.

Splines can be used as cams. A cam is typically a circular sort of shape with bumps on it. The connector that moves along the surface of the cam shape is normally called a "follower" but in the Linkage software, it is a sliding connector since it has the property of never being able to move away from the outer shape of the cam (unlike many real-world cams). Even though a typical cam is a circular sort of shape with bumps, it can also be a long set of segments that do not circle back to themselves. In this case, the cam works the same but can, of course, only move in a way that doesn't cause the sliding connector to slide "off the end" of the cam shape. If the cam doesn't move in a way that causes the sliding connector to move past its limits, a cam can have any shape that can be drawn using lines and curves.

Splines can be fastened to links and to rotating input connectors. In both cases, the spline will move and rotate to match the movement and rotation of the link or connector to which it is fastened. If a spline is fastened to a non-input connector, there is no way to simulate it mechanically and it will just move but not rotate relative to the connector. Using a spline in this way is not typical but not disallowed.

A spline is considered a drawing element on the drawing layer unless a connector is made to slide on it. A spline that has a sliding connector on it is then a mechanism element on the mechanism layer. This allows splines to be used for both mechanical parts and as simple drawing elements to define the outer shape of elements.

Splines that are drawing elements are not shown in the parts list at this time. A plan is in place to allow drawing elements to show in the parts list in a future version of the Linkage program. But since drawing elements, like mechanism elements, are shown when printed or when an image is created, parts can be made to match the drawing elements shapes using printouts and image exports.

Spline Properties

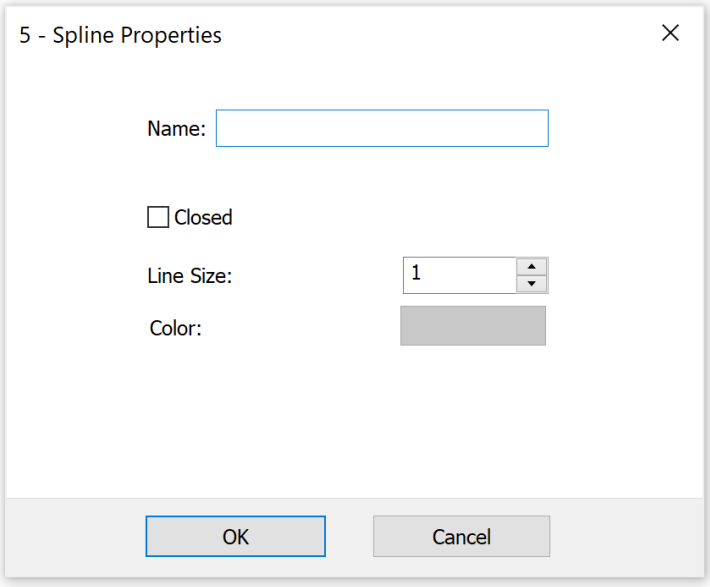


Figure 19, Spline Properties

The Spline Properties dialog box in Figure 19 shows the settings that are available for splines. Splines can be used as cams using these same properties. Double-click or right click on a spline to show the Spline Properties or click on the Properties button. The properties are for the overall spline shape; select the spline and then use the right-click to show a context menu to modified the properties of individual nodes and segments.

The different settings are:

Selection	Meaning
Name	This is the name of the spline. It will be displayed after the spline identifier when labels are enabled.
Closed	When the spline is closed, it forms a continuous shape. When it is not closed, the shape is open and cannot be filled in. A rotating cam typically needs to be closed but an open spline can also be used as a cam if the movement oscillates so that the follower (sliding connector) doesn't move past the end of the spline.
Line Size	The thickness of the lines used for drawing the link can be set from 1 to 4.

Selection	Meaning
Color	The color of the link or line can be set by clicking on the color box. Gears that are fastened to links will take the color of the link and not the color set here.

Spline Node and Segment Properties

The cam node and segment properties are only available through a right-click context menu. Right click on a segment or node to show the appropriate menu.

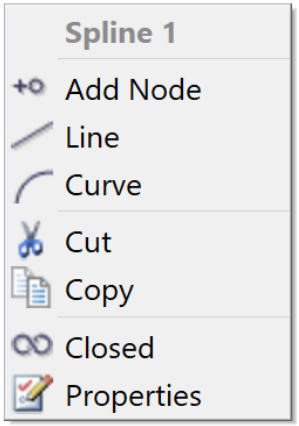


Figure 20. Segment Context Menu

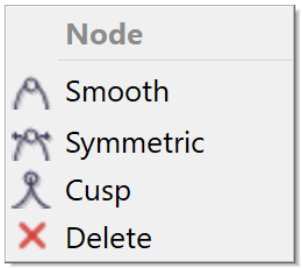


Figure 21. Node Context Menu

Figure 22 and Figure 23 show the context menus that appear when you right click on a spline. The options in the segment menu include options that apply to the entire spline as well as to the segment The node menu only contains options for the selected node.

Spline context menu items are:

Selection	Meaning
Add Node	This option adds a node at the location where the segment is selected. A temporary selected node is displayed at the selection point to show where the new node would be placed.
Line	Convert the segment to a line segment.
Curve	Convert the segment to a curved segment. Cubic Bezier curves are used for curved segment. There will be a control point connected with a dotted line to each end of the curve.
Cut	Copy the spline to the clipboard then delete it from the mechanism. This is the same “Cut” that is available in the toolbar and when using the Ctrl-X key combination.
Copy	Copy the spline to the clipboard. This is the same “Copy” that is available in the toolbar and when using the Ctrl-C key combination.
Closed	This is a toggle used to open and close the spline. A closed spline has no start or end node and the spline follows a continuous path (like a circle). When the spline is not closed, there are separate start and end nodes. Open splines can be used as cams as long as the cam follower sliding connector cannot end up moving past the ends of the spline.
Properties	The properties option opens the properties dialog box for the spline.
Smooth	A node is smooth when the control points for the curves on either side of the node are lined up through the node. When a node is smooth, moving one of the control points next to the node will automatically move the other adjacent control point to keep the curves smooth. If one of the segments is a line, the control point will be limited to moving along a continuation of the line through the node. It is not possible to have a smooth node if there is a line on both sides.
Symmetric	Symmetric nodes are smooth nodes with the additional restriction that the control points on each side of the node are always the same distance from the node. Moving one of the control points will automatically move the other control point to keep the control points lined up through the node and also to keep them the same distance from the node.
Cusp	A node is a cusp when there is no limit to where the control points can be on either side of the node. A cusp is essentially a node that allows the segments on either side to form a sharp point (or a dull point, but a point nonetheless). Note that a node with a line segment on one side will not have a control point on that side but the other control point is still not limited. A node with two line segments will always be a cusp.

Simple Cam Tutorial

Splines can be dropped into the mechanism from the right-click element gallery. A closed spline can be fastened to a link and used as a cam with a sliding connector acting as the cam follower.

This tutorial is less detailed than the first mechanism tutorial. Refer to that tutorial if any of these steps seem confusing.

1. Add a link on a rotating input connector using the popup element gallery.

Figure 22. Cam Tutorial Simple Rotating Link

2. Add a spline.

Figure 23. Cam Tutorial Newly Inserted Spline

3. **Close the spline,** move it to be near or around the link.

4. Shape the spline to the desired cam shape.

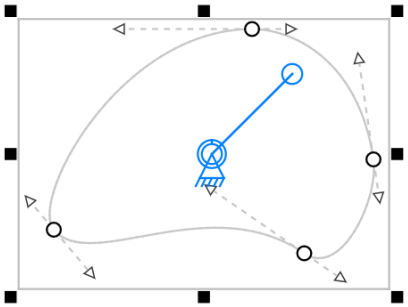


Figure 24. Cam Tutorial Spline Shaped and Positioned

5. Select both the spline and the link and click the “Fasten” button.

   Note that it is also possible in version 3.16.8 to fasten the spline to an input anchor connector and the spline (the cam) will rotate with the rotation of the input. A separate link is no longer needed.

6. Run the simulation as a quick test. The spline should move as if it is part of the link.

7. Add a link on an anchor. This is not an input anchor. Move the new link into position near the top right area of the spline.

8. Select both the connector on the end of that new link and the spline. When both are selected, click the “Slide” button.

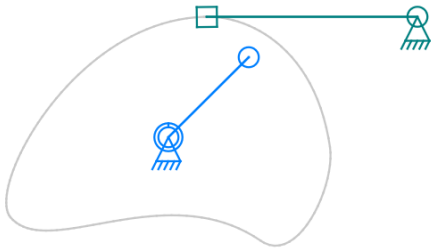


Figure 25. Cam Tutorial Finished Cam

9. Ensure that the connector appears as a square and is automatically positioned on the spline. Drag it around and see how it is “stuck” on the spline shape.

10. Run the simulation and the sliding connector will follow the spline shape as the spline rotates. This cam can be used as the basis for other more interesting cam mechanisms. An error message will appear if the follower/slider cannot reach the cam at some point during the simulation.

Curved Sliding Connector Paths

Sliding connectors can have curved paths. The Curve is an arc between the two limit connectors.

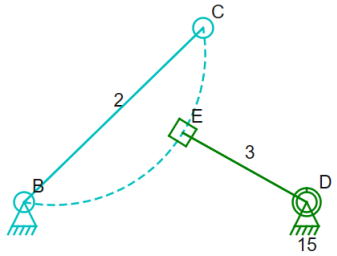


Figure 26. Curved Sliding Connector Path

The configuration of the connections in Figure 26 and in Figure 28 have sliding connectors that are used to position the links. These are the valid types of connections that can be made using sliding connectors on curved paths. Many other variations of these types of mechanisms can be designed.

Figure 29 shows the type of curved path that **cannot** be simulated. Although the invalid curved paths would work in a physical world, the simulator algorithm necessary to handle this situation has not yet been implemented.

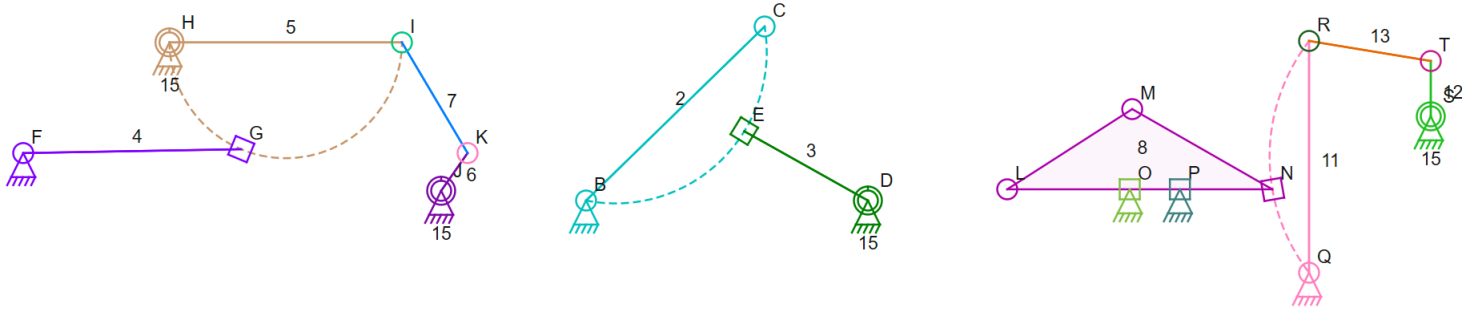


Figure 27. Valid Sliding Connector Curved Paths

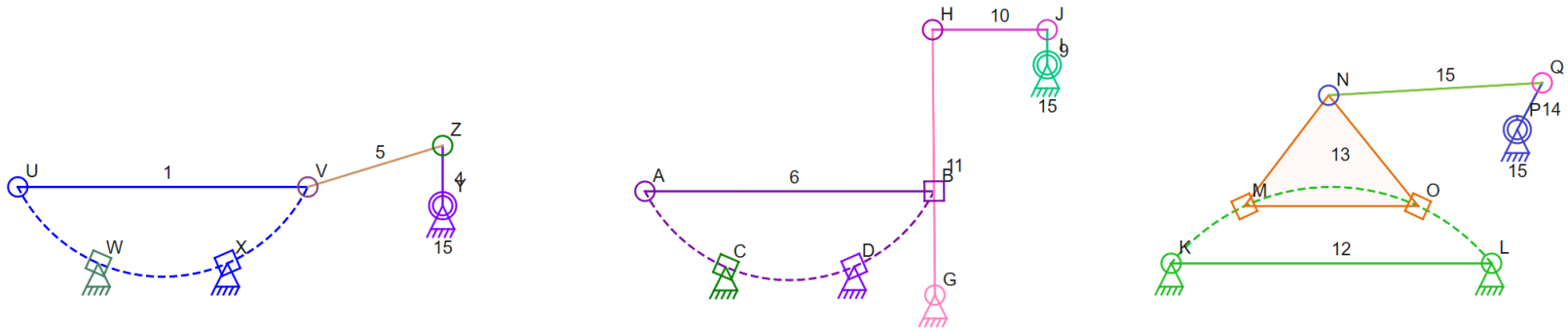


Figure 28. More Valid Sliding Connector Curved Paths

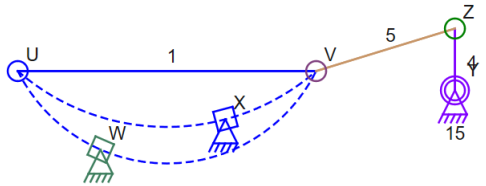


Figure 29. Invalid Sliding ConnectorCurved Path

Locked Elements

Links and anchors (anchor connectors) can be locked and cannot change shape or size, and in the case of anchors, cannot change location. The lock is set by selecting the element and clicking on the Lock button in the tool bar. To unlock an element, open the link properties box for the link and uncheck the Locked checkbox or open the connector properties box for the anchor and uncheck the Locked checkbox.

When any connector of a locked link is moved, all the connectors of the locked link are moved (unless an anchor is locked). Rotating one or more connectors of a locked link will rotate all the connectors together. Locked links are not resized or stretched and any resize or stretching actions are ignored for locked links. Locked links with locked anchors will not move or change in any way. Locked links cannot be rotated around a locked anchor even though the locked anchor doesn't get moved – it just works this way.

When an anchor is locked, the location of the anchor cannot be changed in any way.

Gears and Chains

Gear and chain connections can be simulated in the Linkage program. A chain connection is just a special type of gear connection and the "sprockets" are still called "gears." If you are designing a mechanism that uses belts and pulleys then the word "gear" applies to the pulleys and the word "chain" applies to the belt. The naming of these elements doesn't change how they function.

Gear Ratio

The gear ratio in the Linkage program is not the same as a typical gear ratio where the first number is the relative speed or rotations of the input gear and the second number is the speed or rotations of the output gear. The Linkage program does not keep track of which gear is the input and which is the output. Instead, the first number is the relative size of the first selected gear and the second number is the relative size of the second selected gear. If the gears are selected in the opposite order, the numbers would be displayed in the opposite order.

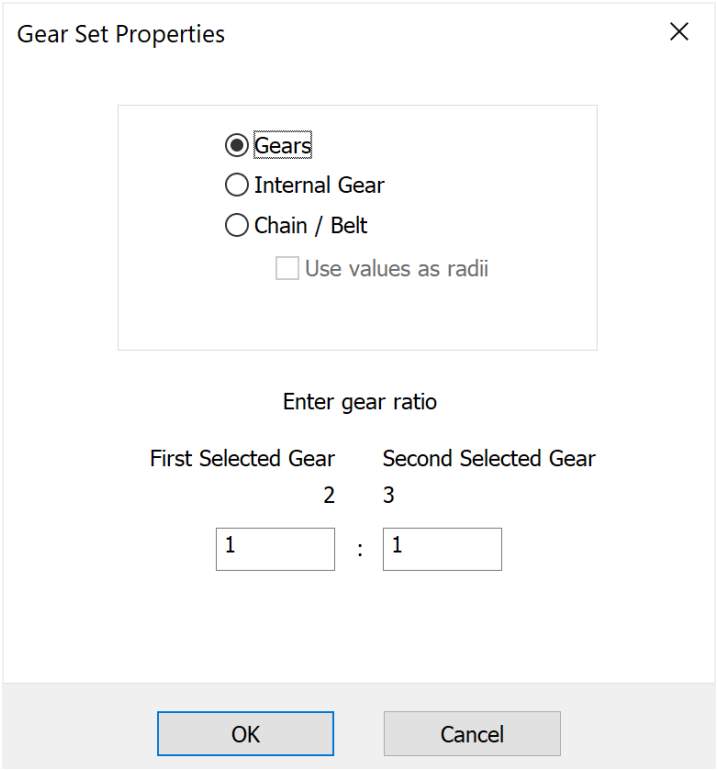


Figure 30. Gear Ratio

The different gear ratio settings are:

Selection	**Meaning**
Chain / Belt	Selecting the Chain/belt option results in the gears (pulleys or sprockets in real life) being displayed smaller than if they were gears to allow for some space between them. The size, aside from the sizes being appropriate for the ratio, is arbitrary and does not reflect any real-life size requirements like it does with gears. The simulator turns one gear the same direction as the other.
First Selected Gear	The label for the first selected gear is shown over the input box for that gear.
Second Selected Gear	The label for the second selected gear is shown over the input box for that gear.

Selection	Meaning
Ratio Numbers	The two text inputs are for the gear ratio numbers. Entering 1 in one box and a 1 in the other results in a 1:1 ratio and both gears will be the same size. The actual size will be determined by how far apart the gears are on in the mechanism. If a 1 is entered in the left box and a 2 is entered in the right box, the second selected gear will be shown two times bigger than the first selected gear. Again, the actual sizes will be determined by the distance between the gears.
Gears	Selecting the Gears option results in the gears being displayed touching each other. The simulator then turns one gear the opposite direction of the other gear. Teeth are not shown but there is a line shown on all gears to help visualize the rotation.
Internal Gears	Selecting the Internal Gears option results in the gears being displayed touching each other with the gear of the larger ratio number being an internal gear (teeth inside) and the other smaller gear being inside of it. The simulator then turns one gear the same direction as the other. Teeth are not shown but there is a line shown on all gears to help visualize the rotation.

Note that the ratio can be set using the dimension input box in the tool bar, but the Gear and Chain / Belt settings cannot be set there. The dimension input box also does not give a hint about which gear was selected first. For that, rely on the color of the selection box around the gears.

Simple planetary gear sets can be created by adding a “sun” gear and an internal “ring” gear on the same connector and then using a link and a “planet” gear between them.

Simple Gear Tutorial

This tutorial is less detailed than the first mechanism tutorial. Refer to that tutorial if any of these steps seem confusing.

1. Right click in the window to display the Element Popup Gallery.
2. Select the Gear element  .
3. The gear will be inserted into the mechanism at the point where the mouse was clicked.

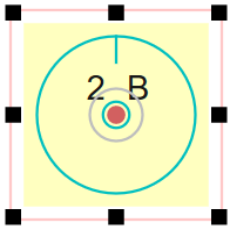


Figure 31. Gear Tutorial with a Single Gear

4. Click somewhere in the window that is not on the gear to unselect the gear and connector.
5. Click on the connector at the center of the gear and then click on the **Properties** button in the tool bar.
6. Change the property of the connector so that it is a rotating anchor. The default speed of 15 RPM is fine for now.

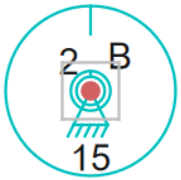


Figure 32. Gear Tutorial with a Single Gear on a Rotating Anchor

7. Repeat the above steps nearby in the window. This time make the connector an anchor, but not a rotating anchor.

Figure 33. Gear Tutorial with Two Gears

8. The mechanism should look something like that shown above. Now click on the let gear and then hold the Shift key and click on the right gear.

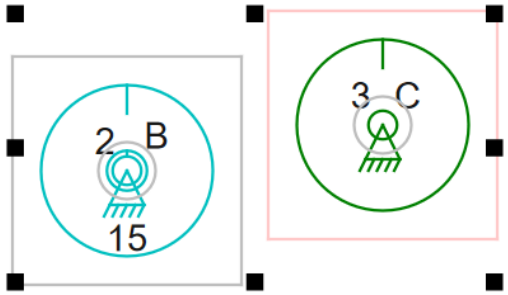


Figure 34. Gear Tutorial with Two Selected Gears

Notice that the second selected gear has a red rectangle. This hint will help when setting gear ratios later.

9. Click on the dimensions text box in the tool bar. Enter “1:2”. This sets the size of the second selected gear to be twice the size of the first selected gear. You can also find a **Gear Ratio** option in the **Align** menu that does the same thing and more!

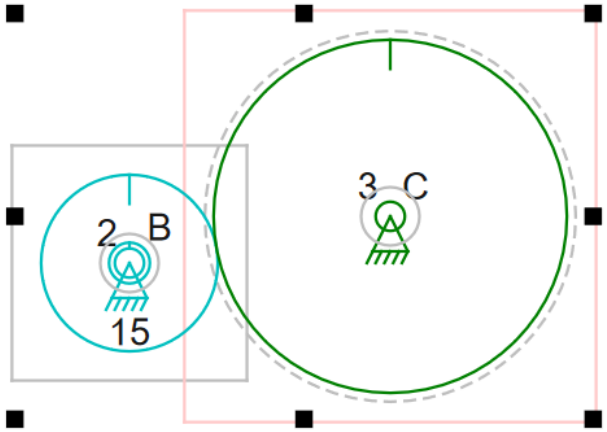


Figure 35. Gear Tutorial with a 1:2 Ratio

That’s it. Run the simulator and the second gear should turn at ½ the speed of the first, and in the opposite direction.

Gear Fastening

Some mechanisms might need to have a gear move a link that shares the gear center connector. **Normally, a gear can have more than one connector, so this is not typically needed.** But if it is needed, the gear can be fastened to a link. Select the gear and the link and then click on the **Fasten** button in the tool bar. Once

fastened, when the gear is turned by another gear, the link will move appropriately as if the gear and link are all one element. If the link is being moved, the action is similar and the gear is rotated to match the rotation of the link. In either case, the connector at the center of the gear does not need to be an anchor; It can be any connector and can move about in the mechanism taking the gear with it. To get the same result using just the gear, select the gear and click the “add” button or tap the “A” key to add a connector to the gear.

If a gear has an anchor connector, selecting just the gear and clicking on the **Fasten** button will fasten the gear to the anchor, thus keeping it from turning. This keeps the gear stationary even if the anchor is a rotating input! This is necessary for planetary gear drives and other gear mechanisms.

Sample gear mechanisms in the Linkage program show the various types of gear mechanisms that can be created.

Selecting Elements

The mouse and the Tab key may be used to select elements in various ways. These are described earlier in the Mouse Operations and Keyboard Operations. Additionally, elements may be selected using the Select Element dialog box shown in Figure 36.

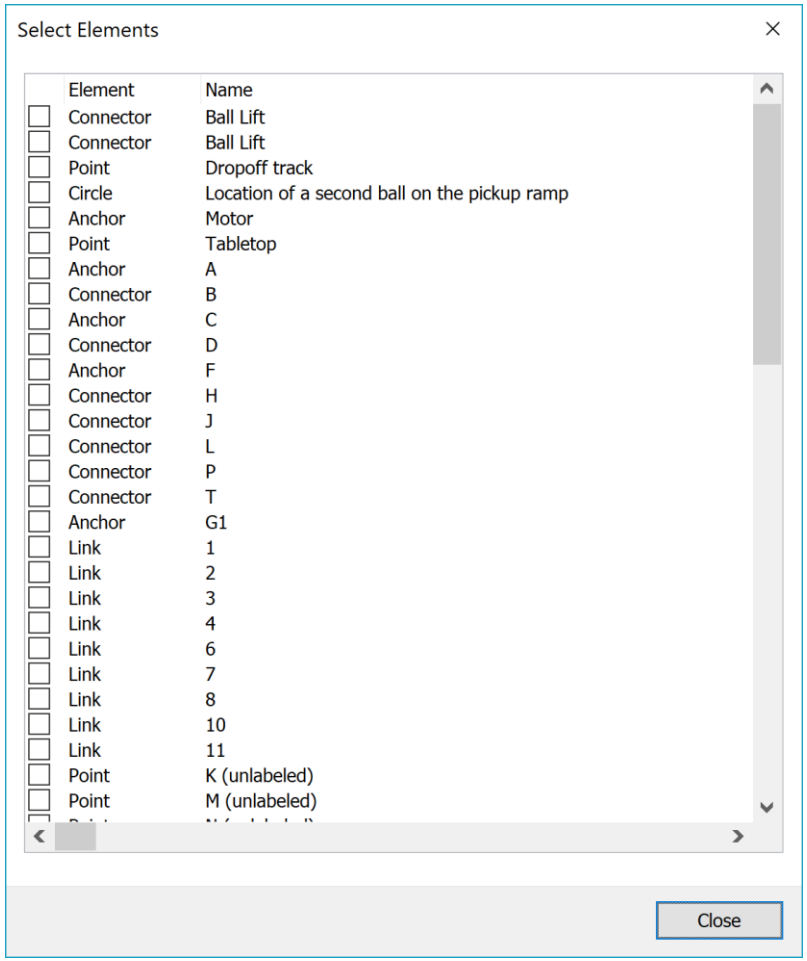


Figure 36. Select Elements Dialog Box

The Select Elements dialog box has a list of all elements in the mechanism drawing. Any elements that are already selected will be checked in the list. Checking and unchecking the boxes next to the element names will select and deselect them appropriately when the Select button is clicked.

Elements that were given a name are shown first. Then un-named connectors and links are listed before drawing elements. Measurement elements will be listed with their measurement (length or angle) instead of a name or label.

Each time the selection of changed for an element in this box, the mechanism drawing will change to show the selection change.

Dimensions

With Auto Dimensions enabled, the dimensions for all links, lines, circles, gears, etc., will be shown. The RPM of gears is also shown in addition to their radius or diameter.

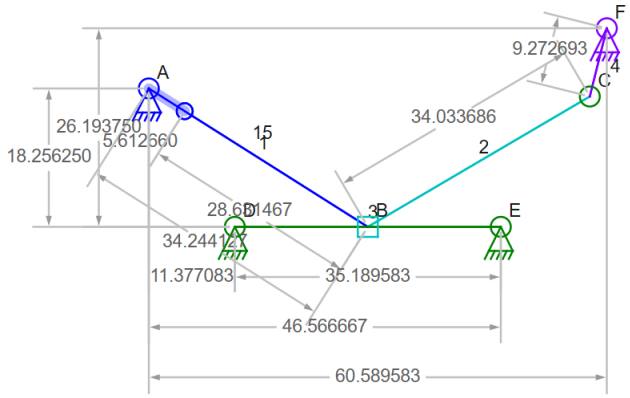


Figure 37. Link Dimensions

Dimensions for links will be drawn so that they are aligned to the link. The dimensions can then be used to manufacture a link without regard to the position of the link within the mechanism or on the page.

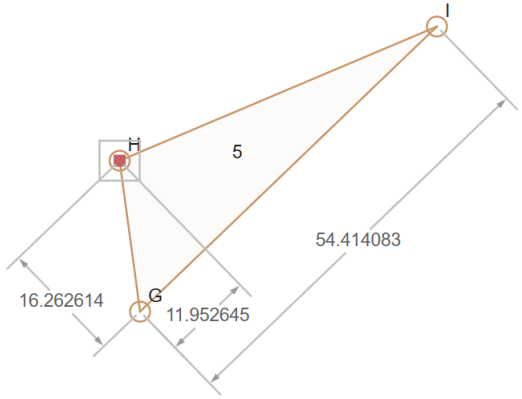


Figure 38. Three Connector Link Dimensions

Links that have three or more connectors are displayed with dimensions that are aligned to the longest adjacent pair of connectors. Figure 38 shows a three-connector link with this type of alignment. The dimensions show the locations of the connectors as offsets relative to the two used for alignment.

Anchors, also called ground connectors, include dimensions. These dimensions are show relative to the leftmost anchor and to the bottom most anchor. The anchors do not need to be part of a single link to see these dimensions. If there are only two anchors in the mechanism, then the distance between them diagonally is also shown since this might be a useful measurement. Figure 37 has anchors that are down with dimensions.

Dimensions are shown in the units that have been selected in the tool bar. The type of unit is saved with the mechanism.

Parts List

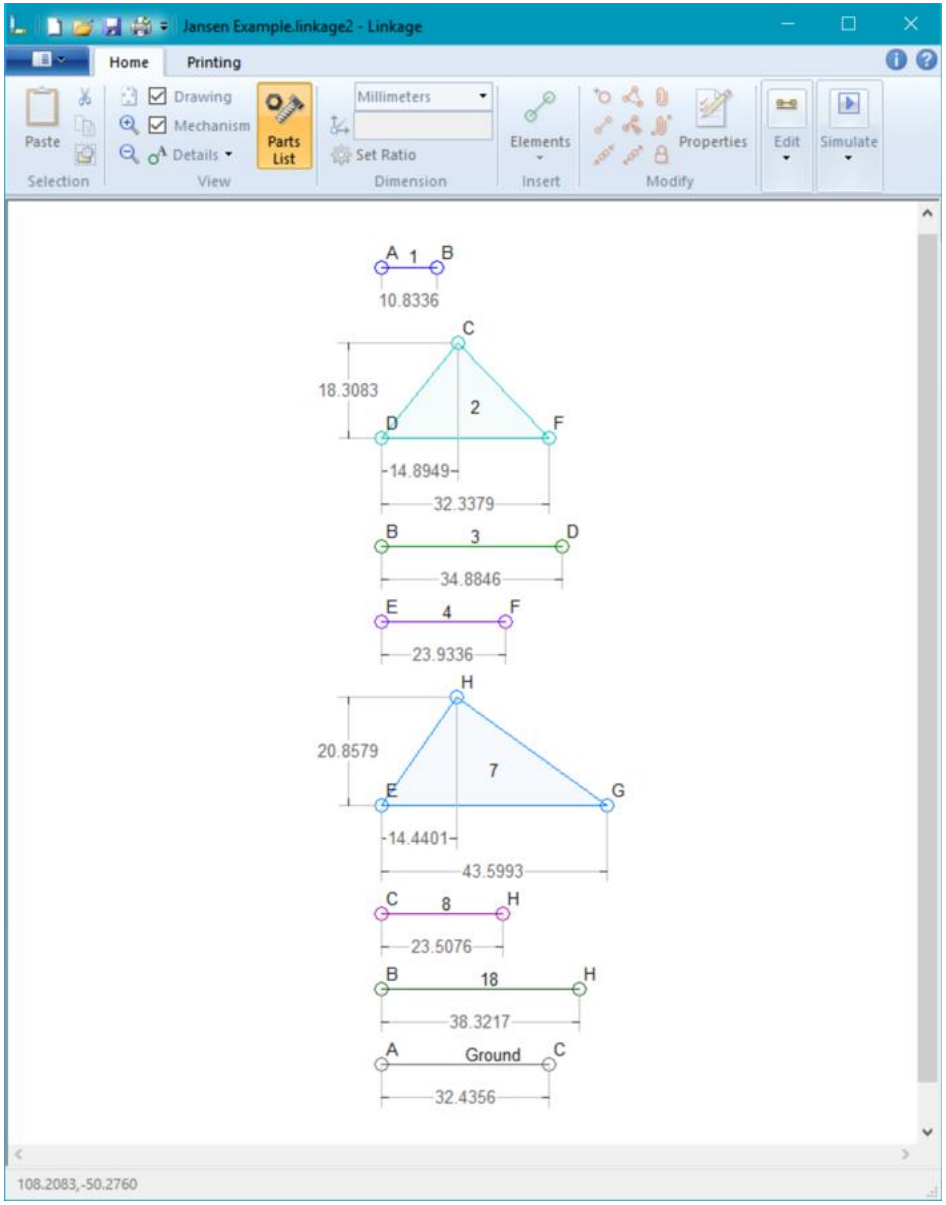


Figure 39. Parts List View (With Auto Dimensions On)

The Parts List view shows all the links of a mechanism separate and aligned in a vertical list. If Auto Dimensions are enabled, the links are separated enough to show the horizontal dimensions of all the connectors on the link. The mechanism cannot be altered in this view because link connections are not accessible. *Some editing of properties like color, etc. may be available in future versions of the program.* The image export, video export, printing, and other exporting features all use the Parts List if it is enabled.

Splines used as cams are shown in the parts list with the connector or link to which they are fastened.

Use the Parts List button in the toolbar to switch to and from the Parts List View.

Coordinates

The Linkage program uses the Cartesian coordinate system. The x coordinate increase to the right and the y coordinate increases upwards. New mechanisms start with 0,0 in the middle of the window. Angles are measured in degrees and are generally shown as an angle between two lines. Angles values are never shown as reflex angles. If an angle could be described as greater than 180 degrees, then it is sometimes displayed as a value from 0 to 180 measured in the opposite direction (negative). Angles can however be input as any degree value.

Coordinates can usually be entered with more decimal places than are shown. Most coordinates are displayed with three decimal places like 0.123 but more can be entered, and the higher accuracy is used for the coordinate until changed. There is also an option in the Preferences panel of the toolbar to display 6 digits after the decimal point.

Simulation (Run, Step, etc.)

The Run button, as well as a bunch of other buttons in the tool bar, simulate the mechanism in various ways. When a video is exported, the mechanism is simulated. **The simulator cannot run if there are no inputs or if all the inputs are actuators and none of them are anchored. A simulation will only work if the mechanism is not floppy and is predictable. It also cannot run in certain situations where the computations to simulate a complex set of links is beyond the capabilities of this software.** There are examples of invalid or too-complicated mechanism elsewhere in this document.

Other than a fully automatic simulation, there are also interactive and manual simulations. These types of simulations add manual controls to the window. For an interactive simulation, each input or actuator can be controlled manually. For manual simulations, the entire mechanism can be controlled manually.

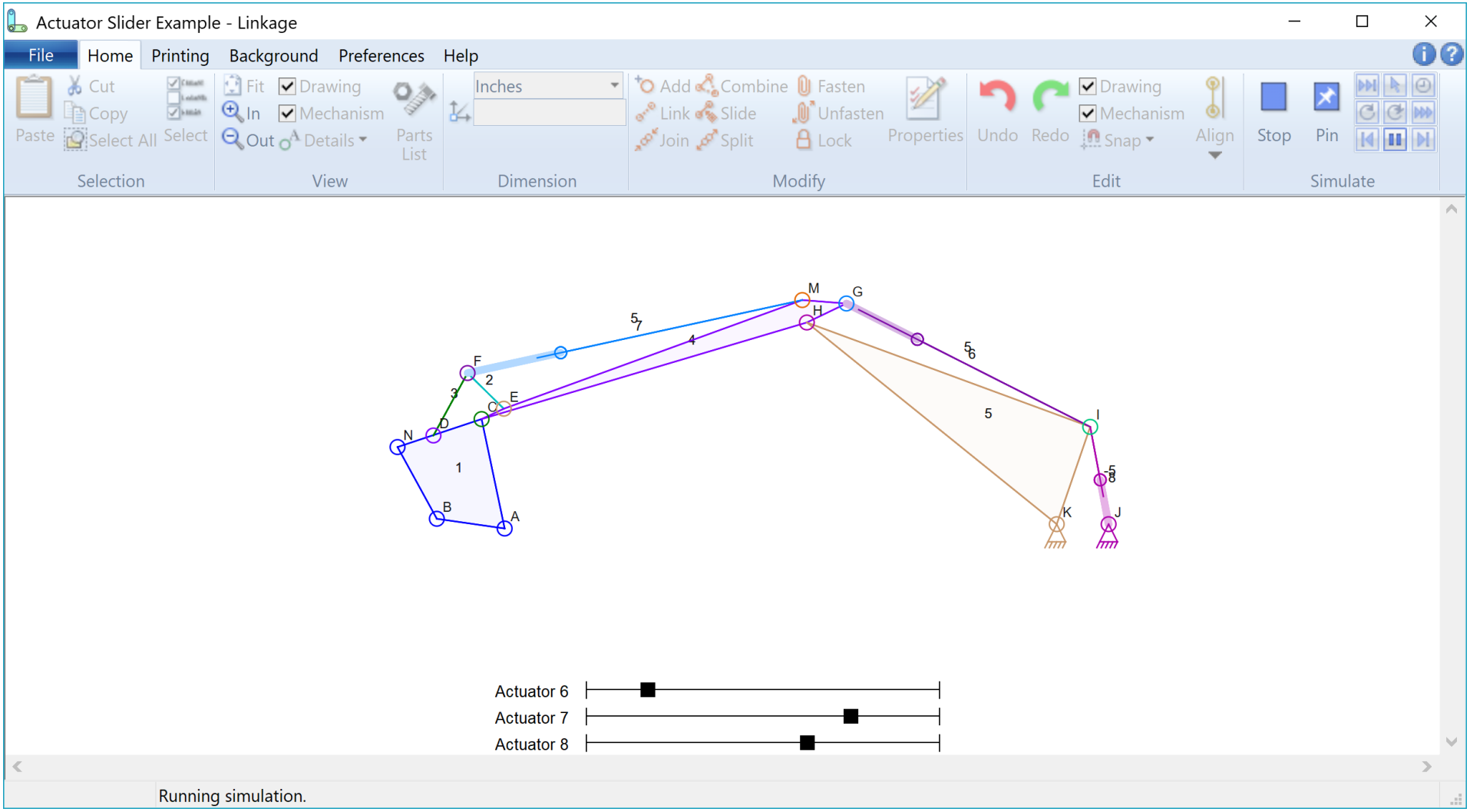


Figure 40. Interactive Simulation

For interactive simulations, each input and each actuator will be listed at the bottom of the window next to a sliding control as seen in Figure 40. Drag the handles (squares) side to side to move the associated input or actuator. The link or connector will be listed using the ID shown in the mechanism when labels are visible.

The manual simulation looks almost identical to the interactive simulation except that there is a single control at the bottom of the window for controlling the entire mechanism.

Manual Controls for Automatic Simulation

Individual connectors and links can be configured for manual control regardless of the type of simulation that is run. The controls will look the same as described earlier for *Interactive and Manual Simulations* but controls will only be shown for those elements that are set for manual control.

If a simulation is done that is not animated, the manual controls will not be moved during that simulation.

Status

The status bar will show some helpful information in some situations. During scaling, rotating, and other operations, the values related to the operation are shown. An element name or number of selected elements is shown when any elements are selected.

During the creation of a video, the status will show a message about the video capture. This can include the time that has passed in the simulation if a specific amount of time has been requested for the video capture.

Drawing during Simulation

Any or all the connectors can be set to draw while simulating. This allows for analysis of the linkage movement. The drawing option is selected by modifying the properties of the selected connector. Figure 41 shows a mechanism while simulating and grey curves are draw by the connectors as they move.

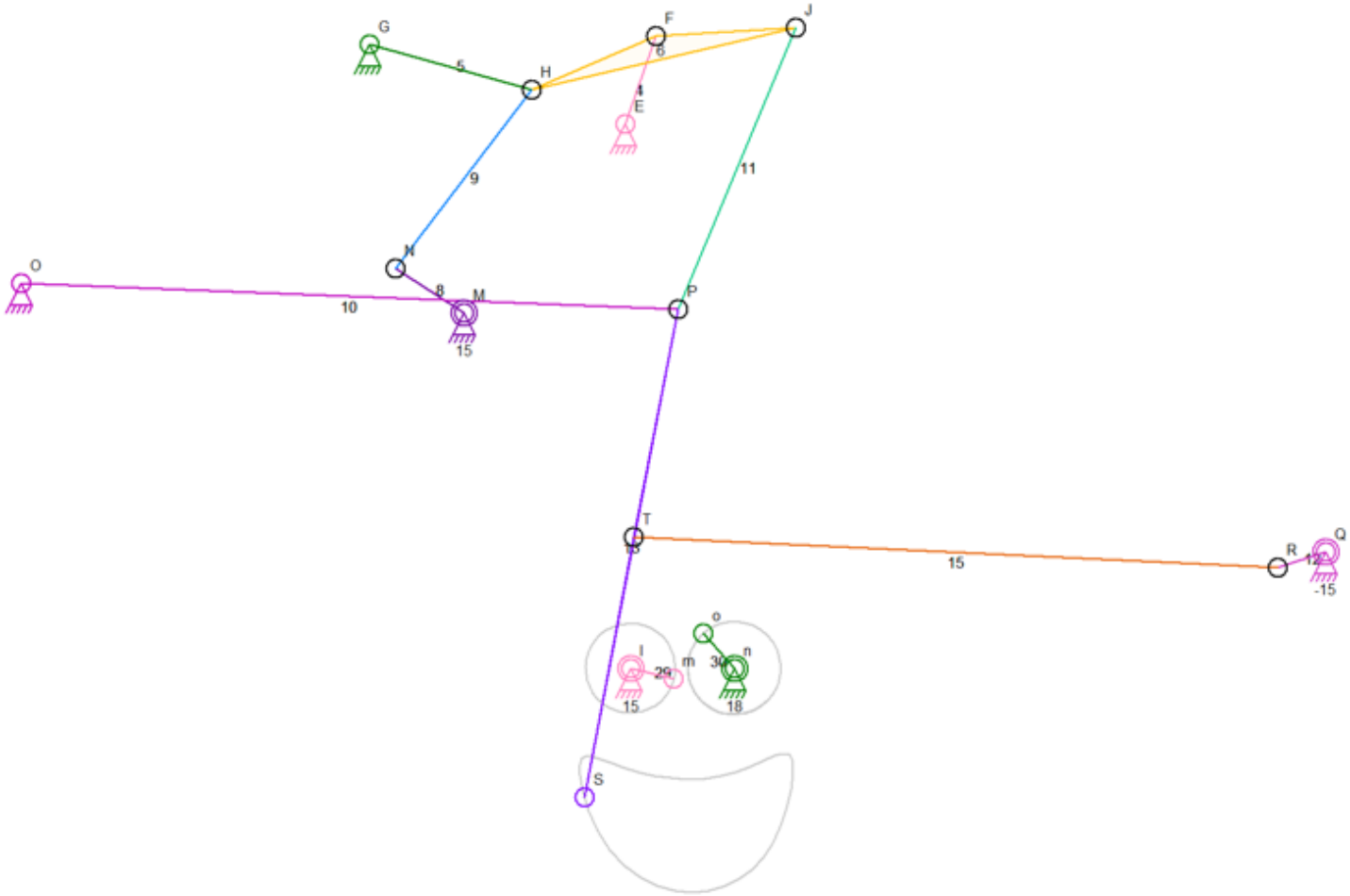


Figure 41. Smile Drawing Example

Exporting

Videos

The linkage program can run an animated simulation and save the animation in an AVI file. The compression algorithm used, or codec, can be selected when the simulation is about to be started.

The video is a copy of the image seen in the center area of the editor window except for manual controls at the bottom.

There are two different sets of settings controlling the video capture quality. There is an option in the Preferences panel to select the FHD Video Area. There is also a quality select available when the video length and encoder are selected. Here is a table describing how these option work together to determine the video quality:

Video Capture Area	Quality	Video Resolution and Quality
Not FHD Video Area	Standard Quality (Standard Speed)	1280x720 (720p) resolution with quality that matches the look of the image on the screen. This is the only set of options that produces 1280x720 video resolution.
Not FHD Video Area	Higher Quality (Slow)	1920x1080 (1080p) resolution with the mechanism scaled down. Lines are thinner, text is smaller, connector circles are smaller, as well as other similar changes to the mechanism from what is visible on the screen. Lines are smoother at this quality level, but the export process is very slow.
FHD Video Area	Standard Quality (Standard Speed)	1920x1080 (1080p) resolution with quality that matches the look of the image on the screen. This is the fastest full HD settings combination.
FHD Video Area	Higher Quality (Slow)	1920x1080 (1080p) resolution with the mechanism scaled down. Lines are **a lot** thinner, text is **a lot** smaller, connector circles are a **lot** smaller, as well as other similar changes to the mechanism from what is visible on the screen. Lines are smoother at this quality level, but the export process is very slow.

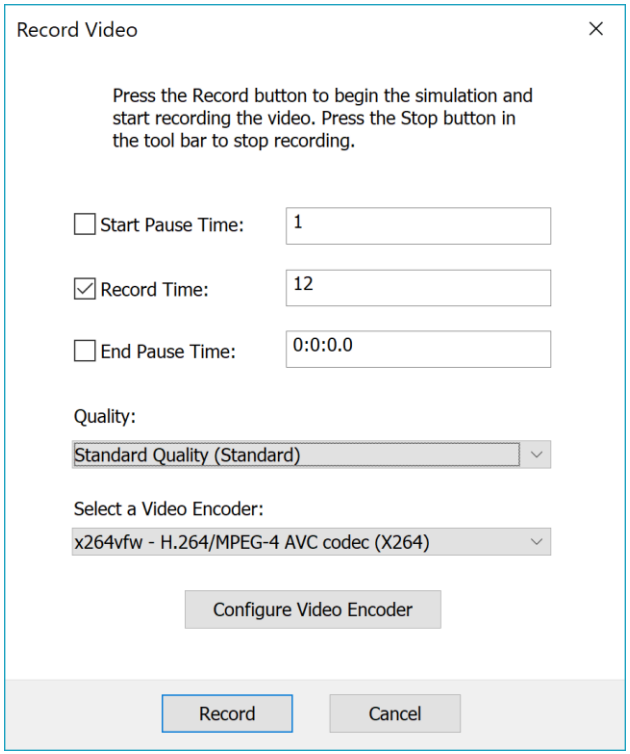


Figure 42. Video Export Options

The different video export settings are:

Selection	**Meaning**
Start Pause Time	How much time should be spent paused before starting the mechanism movement.
Record Time	How long should the mechanism be animated during the recording.
End Pause Time	How much time should be spent paused after mechanism movement is finished.
Quality	The quality of the exported video. The quality settings and their effects was described earlier in this section.
Select a Video Encoder	Pick the encoder to use for the video. The x264 video encoder creates mpeg4 videos within a Microsoft AVI file. It is the best free/shareware codec available that I have found so far.

Selection	Meaning
Configure Video Encoder	Open options that are specific to the selected video encoder. Please use the video encoder documentation to learn about the various video encoding options available.

Video Encoding

There is no built-in CODEC. A CODEC is an encoder/decoder that can both read and write video data. Interestingly, the format of encoded data is a separate thing from the format of the file containing the data. A .mov file created by some Apple software and other Macintosh products can contain MPEG video video data while the .avi file created by Microsoft software and other Windows products can also contain MPEG video data. There is a built-in CODEC in Windows that is quite terrible called “Microsoft Video 1 (MSVC)”. Videos created for various tutorial online were created using the X264 CODEC. The Video-For-Windows (VFW) version is needed so that the Linkage program can communicate with the CODEC properly. As of this writing, this link is where you can get the x264vfw CODEC:

https://sourceforge.net/projects/x264vfw/

You will need to install it and possibly configure it. The only configuration option that seems necessary to work with the Linkage program is the “One-Pass” option. Using the “Two-Pass” option will cause the Linkage program to output an empty file or possibly crash!

Images

A mechanism can be saved to an image file that is either a JPEG file or a PNG file. The size of the final image can be selected from a few choices, as can the relative size of connectors, text, and other parts of the picture. The margin can also be set to accommodate text, dimensions lines, and other parts of the image that might get cut off at the edge of the image.

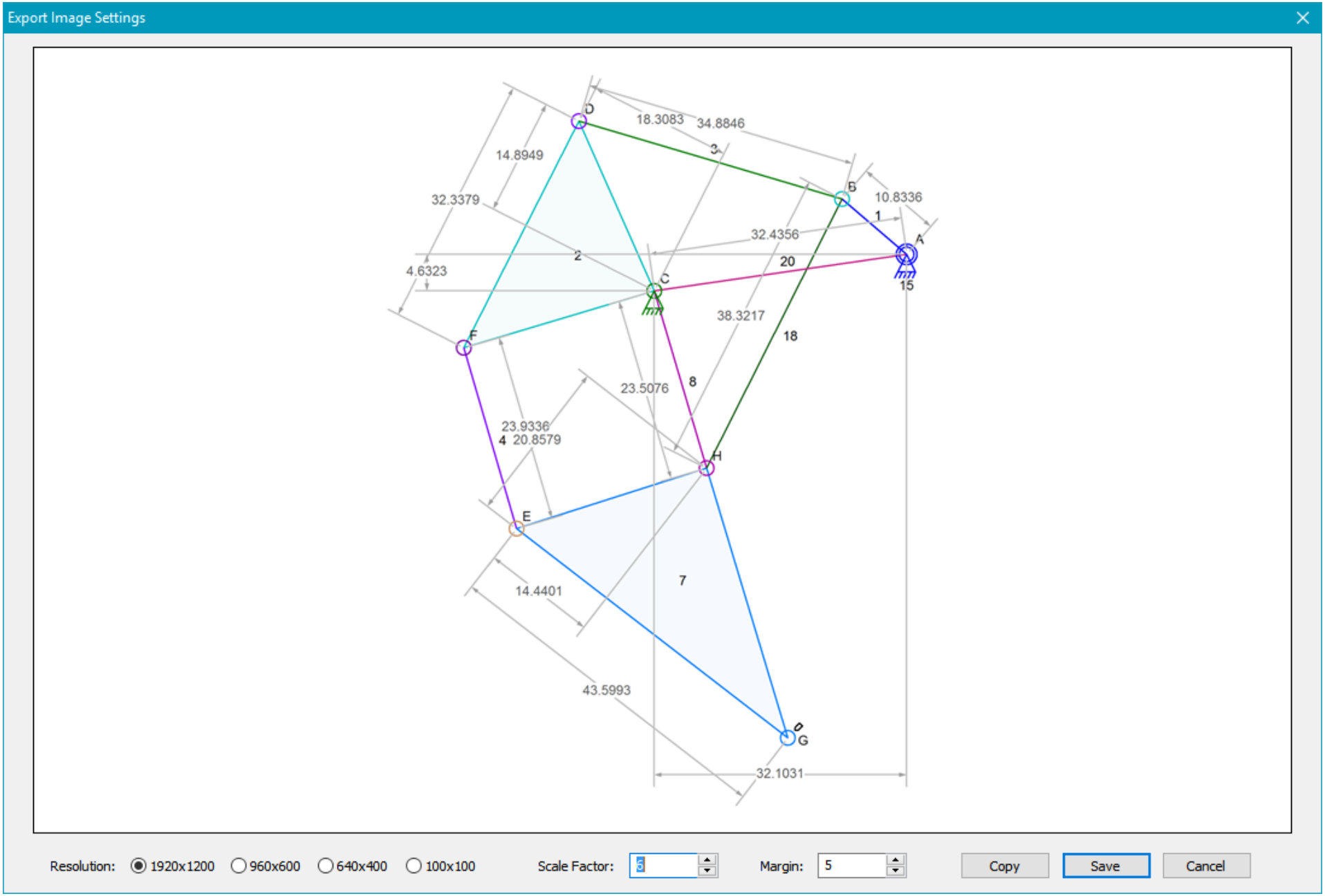


Figure 43. Export Image Settings

The Export Image Settings are set after selecting the Export-Image items in the **File** menu. There are a variety of image sizes to select from when exporting images. The Scale factor value controls the size of text, connector circles, line thickness, and dimension line positions. The Margin option controls the margin as a percentage of the image size. The Copy button will copy the image to the clipboard for pasting into other programs. Press the Save button to save the image to a file. The file extension .jpg or .png will determine the image file format.

DXF Files

There is a simplistic DXF file export available in the Linkage program. The files that are created may have missing elements. The format has not been developed with much effort and is really a test. You will see a warning about the feature being incomplete if you export a DXF file.

Motion Path

Path data of connectors that are set to show their motion path can be exported. The exported file is in CSV (Comma Separated Values) format. There is a preference to turn this off in order to use an older less flexible format. The anchors and the motion path connectors have their coordinates and speed listed in columns in the exported file. There are two header lines that show the names of the connectors and “X”, “Y”, and “SPEED” as column headings. Each line of the file represents a single step of the simulation which is 1/30th of a second of movement.

Printing

A set of printing options is available in the tool bar. The printing buttons are also available in the **File** menu, but the option for printing actual size is only in the tool bar.

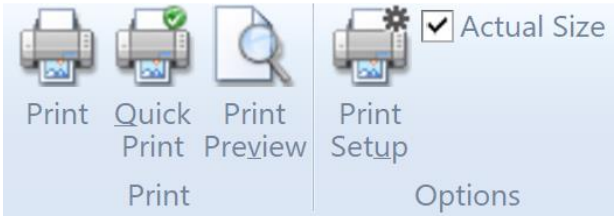


Figure 44. Printing Options in the Tool Bar

A mechanism can be printed to any supported printer. The mechanism is shrunk to fit the page if the **Actual Size** option is not checked. Labels, dimensions, and any other visual information that is seen on screen are also shown in the printed image. If the mechanism is printed actual size and it is larger than a sheet of paper, it will be printed on multiple sheets.

Note that the number of sheets needed for an Actual Size printout cannot be seen or selected before the print or print preview is started. Always use the print preview when printing actual size to get an idea of how much paper you will use. The orientation is picked automatically to use as little paper as possible when printing actual size.

File Format

The Linkage program stores data in files that normally have a .linkage2 extension. The content of the file is ASCII text in an XML format specific to the Linkage program. The files can be read using notepad or another text editor. The same format of data is also used when copying and pasting mechanisms or parts of mechanisms. This results in the clipboard containing text that could be pasted into or from a text editor.

The clipboard data and the data in files do not contain information about the simulation or the drawing information for connectors that draw during simulation.

The contents of the XML file can be modified by other programs and then used in the Linkage program.

Note that the numeric values for the positions of the elements is not inches or millimeters; The values are based on 96 units per inch.

Sliding Mechanism Tutorial

Sliding connectors are more complex than regular connectors. A sliding connector has a location on a link but also has a set of connectors on another link that define the slide path. This short tutorial shows how to create a sliding connection between links.

1. Create enough of a mechanism so that there are two links where one of the connectors on one of the links will slide on the other link. In the picture above, there are two links that each have an anchor. One of the anchors is an input.

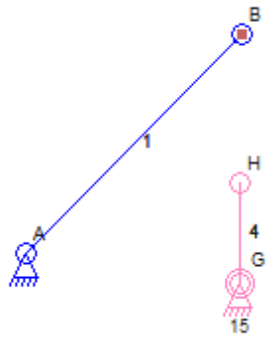


Figure 45. Starting Point for a Sliding Connection

2. Select the three connectors used for the sliding connection. Two of the connectors are on the same link and are the limits to the sliding connection. The third selected connector will be the one that slides. The order of selection does not matter.

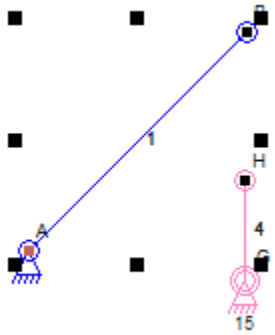


Figure 46. Selecting Connectors for a Sliding Connection

Only three connectors can be selected and two of them must be on one link and the third on another link. If the three selected connectors are all on the same link or if none of them is on the same link as another, a sliding connection cannot be made.

Notice that the Slide function is only available in the tool bar if the connection is possible.

3. Click on the Slide icon in the tool bar. The one connector is converted to be a sliding connector and is moved to the midpoint between the other two connectors.

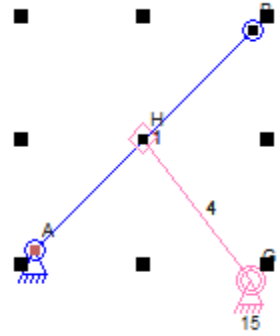


Figure 47. A Sliding Connection

Limitations

There are a few minor limitations, and some known bugs, in the Linkage program.

1. There is a minimal amount of momentum handled in the simulation. If any step in the simulation computes more than one possible position for an element, the position nearest the next expected position is used. Because the momentum handling is minimal, and because only visible positions of the elements are ever computed during the simulation, it is possible for a mechanism to become broken where some part has moved past an invalid position to a new but improper valid position. This is more likely to happen when running an interactive or manual simulation where the mechanism can be moved faster than normal. Very fast inputs and actuators can also cause this problem during a normal simulation.

   If there is a problem with momentum, try selecting or unselecting the "Momentum" option in the **Details** menu in the tool bar.

2. Linear actuators do not work like real-world hydraulic cylinders. It is possible to draw an actuator that looks unrealistic when compared to similar looking real-world counterparts. This is because there may be real world linear actuators that look and move differently from typical and well known hydraulic mechanisms. This is only a visual issue and does not affect functionality.

Figure 48. Odd Looking but Functional Linear Actuator

3. ~~The Join function cannot be used to join a sliding connector with a non-sliding connector due to a bug in the software. Use the Attach function to create a new link with the sliding connector as one of the two ends of the link.~~

4. A mechanism that has multiple rotating anchors all set to different RPM values could draw a very complex pattern for connectors that draw their motion path. This program has a limit to the amount of drawing data maintained and if the drawing connector does not get back to the initial starting position within the given amount of simulation time, the beginning part of the line/curve may begin to disappear when animating or not appear at all when simulating. Mechanisms of the required complexity to do this are not normally used in real-world situations.

5. Some sliding connector configurations that can work in real life cannot be simulated due to their complexity. Each different type of sliding connector configuration is a special case for the simulator and some special cases have been overlooked or require an iterative approach to simulation that cannot be handled.

   The example below cannot be properly simulated but is also not detected as incorrect due to there being three sliders. Many other unresolved configurations that involve multiple sliders also exist. This mechanism is not functional in real life.

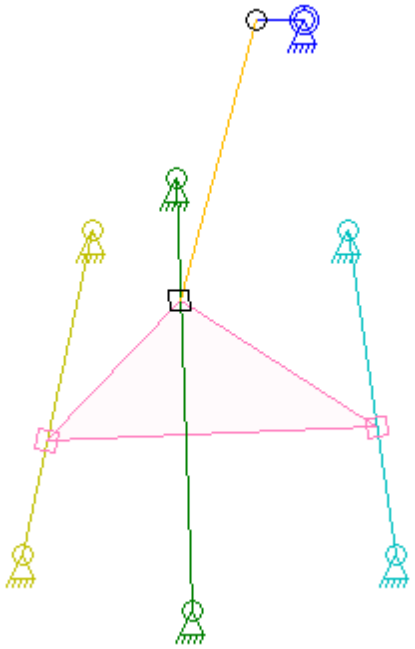


Figure 49. Three Sliders Cannot Be Simulated

6. Two sliders on two different links is not handled by the simulation.

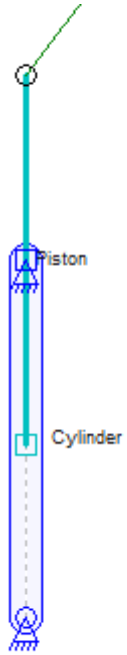


Figure 50. Two Sliders on Two Different Links

The mechanism in Figure 50 shows a link called “Cylinder” that has a sliding connector anchor at the top. There is also a “Piston” link with a sliding connector. The Cylinder sliding connector slides on the Piston link and the Piston sliding connector slides on the Cylinder link. The simulator does not handle this even though it is a perfectly rational mechanism. It is a special case that is not currently handled. **Note that this does not mean that you cannot have a link with two sliding connections; it only means that both sliding connectors need to be on the same link or both sliding connectors need to have the same slide path on another link.**

Customer Support

Linkage is not a commercial product. This is a personal project done out of my interest in mechanical simulations. If you want to get some help or want to provide feedback, feel free to contact me at rectorsquid@gmail.com and I will do what I can for you. Suggestions are always welcome.

Glossary

Actuator: Any device that creates linear movement and has an attachment point on each end. It can be driven by an electric motor, such as to turn a satellite dish, or by hydraulics, such as to lift the bucket on a loader or tractor.

Align: Adjust the locations of multiple elements. The Align menu in the tool bar also has options to set gear ratios and to scale or rotate the selected elements.

Anchor: A connector that is connected to the ground. Anchors do not move during the simulation.

Binding, Bind: A mechanism binds when an element is pushed or pulled beyond its reach and would need to stretch or compress in some way to keep working.

Buried: Any element that is visually or physically underneath another element is buried.

Cam: An element that has a sliding connector that slides along it. Typically, a cam will have a shape that is not a straight line and not a circular curve.

Cartesian: The name of the coordinate system used in this program.

Chain: In this program, the word chain is synonymous with "belt" and is the type of chain or belt used to drive a mechanism using pullies or sprockets.

Combine: Convert two or more separate elements into a single element.

Connect: Add a link between two connectors where there is not already a link.

Connector: An element of a mechanism that is the point where two or more links can connect to each other.

Coordinate: A 2-dimensional location in the mechanism. There are two numbers for a coordinate with the first being the horizontal location and the second being the vertical location.

CPM: Cycles Per Minute. The CPM defines the rate of movement of an actuator. This is not the change of length over time (speed), but rather the number of complete in-out cycles the actuator will make in a minute of time.

Cycle: The movement of an actuator from a fully retracted position, to fully extended then back to fully retracted.

Dimension: A measurement of part of an element or of any other thing in the mechanism or drawing.

DXF: A file format for representing drawings. AutoCAD and other software can read files of this format.

Element: Any object in the Linkage program, including links, connectors, drawing lines, gears, etc.

Export: save a representation of the mechanism in some form other than a Linkage file, such as an image, animation video, DXF file, etc.

Fasten: To attach two or more things together so that they move as a single element during the simulation.

Flip: To convert to a mirror image horizontally or vertically.

Gear: One of a set of toothed wheels that work together to transfer rotational movement from one element to another. The word "gear" can also be used to describe a "pully" in this software.

Guideline: A line drawn in the mechanism to use as a guide for aligning other elements.

Hint: Extra information displayed in the mechanism during editing to show what options might be available for aligning elements.

Hull: A polygon shape that has no concave "curves". It is a polygon that when followed clockwise, has changes in segments as right turns. Whenever a link or drawing line shape is drawn as a hull, some of the points of the shape might be drawn inside of the hull since they cannot be included in the outside hull shape.

JPEG: A file format for images that is compressed and some amount of detail is lost when saving the image.

Label: The name, number, or textual description of an element. Labels can also include non-editable information about speed or other features of an element.

Linear Actuator: *see **Actuator***.

Measurement Line: A drawing element that shows a line and the length of the line, or line segments and the angle between segments.

Mechanism: The entire drawing in the Linkage program. Alternatively, the mechanical part of the drawing whose movement can be simulated.

Motion Path: A drawing of the path taken by an element.

Nudge: Moving an element a small distance using the keyboard.

PNG: A file format for images.

Point: A single location in the 2-dimentional drawing space. Alternatively, an element that can be added to a mechanism to show a single location in the 2-dimentional drawing space, or the end of a drawing or measurement line in the mechanism.

Polyline: A set of line segments that are all connected in a series. Drawing line elements can be displayed as a polyline. Links of a mechanism cannot be displayed as a polyline.

Polygon: A set of line segments for form a closed shape. Drawing elements can be displayed as a polygon. Links of a mechanism are shown as a special form of polygon called a hull.

Properties: The information and data for a specific element.

Ratio: The quantitative relation between two amounts showing the number of times one value contains or is contained within the other. This is used to define the relationship of two gears or two pulleys in this program.

RPM: Revolutions Per Minute. The RPM defines the rate of movement of a rotating element. This is the number of complete rotations per minute of time.

Run: Simulate the mechanism and show the movement in real-time.

Scale: To change the size of something.

Slide: to move along a path.

Sliding Connector: A connector that makes a rotational connection as well as a connection to a path that it can follow. The path is always defined by two other connectors.

Snap: To move or rotate all elements automatically when a connector is close to s snap location.

Spline: An elements that is a set of lines and curves that are connected end-to-end. The curved sections are defined using cubic Bezier curves (curves with two control points separate from the end points). The line sections are just straight lines. The points where curves and lines connect to each other are called “nodes” and the lines and curves are called “segments.”

Split: Convert or change a connector into two or more connectors depending on how many links are connected at that location. Alternatively, to change a sliding connector to a regular connector and no longer follow a path. This can also separate two gears that were meshed.

Step: A single moment of time within the simulation. The simulation normally (as of this writing) runs at about 30 frames per second. One step is one frame so one step is $1/30^{th}$ of a second.

Throw: The distance an actuator travels from being fully retracted to fully extended and vice versa.

Units: The type of measurement values shown for measurements in the program. For instance, millimeters or inches.

Index