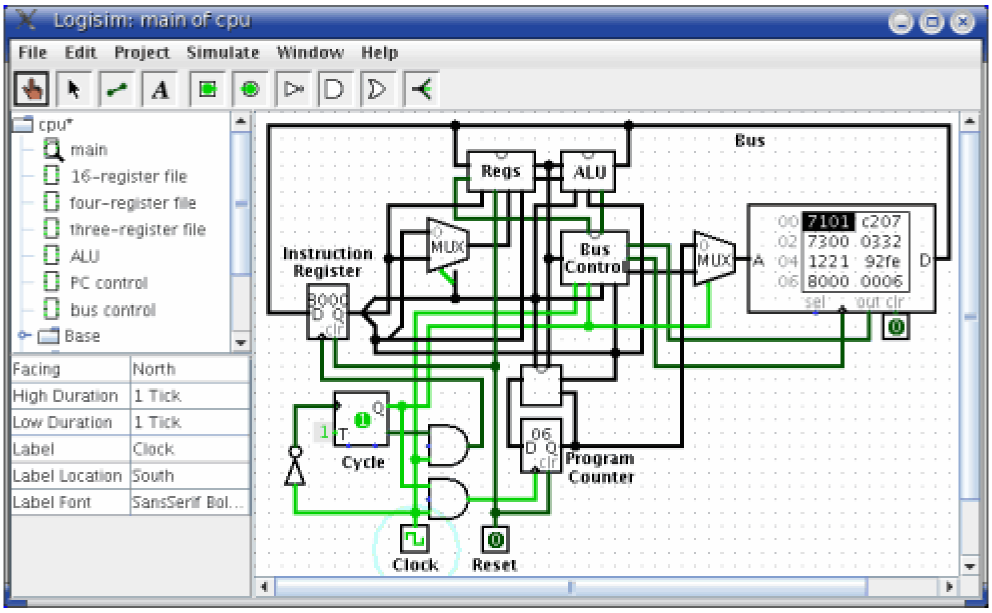
The Guide to Being a Logisim User



Facing	North
High Duration	1 Tick
Low Duration	1 Tick
Label	Clock
Label Location	South
Label Font	SansSerif Bol...

Logisim is an educational tool for designing and simulating digital logic circuits. With its simple toolbar interface and simulation of circuits as they are built, it is simple enough to facilitate learning the most basic concepts related to logic circuits. With the capacity to build larger circuits from smaller subcircuits, and to draw bundles of wires with a single mouse drag, Logisim can be used (and is used) to design and simulate entire CPUs for educational purposes.

Students at colleges and universities around the world use Logisim for a variety of purposes, including:

- A module in general-education computer science surveys
- A unit in sophomore-level computer organization courses
- Over a full semester in upper-division computer architecture courses

The Guide to Being a Logisim User, which you are reading now, is the official reference for Logisim's features. Its first part is a sequence of sections introducing the major parts of Logisim. These sections are written so that they can be read ``cover to cover'' to learn about all of the most important features of Logisim.

The remaining sections are a motley bunch of reference materials and explanations of some of the lesser corners of Logisim.

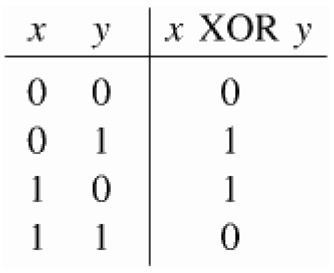
Beginner's tutorial

Next: Step 0: Orienting yourself

Welcome to Logisim!

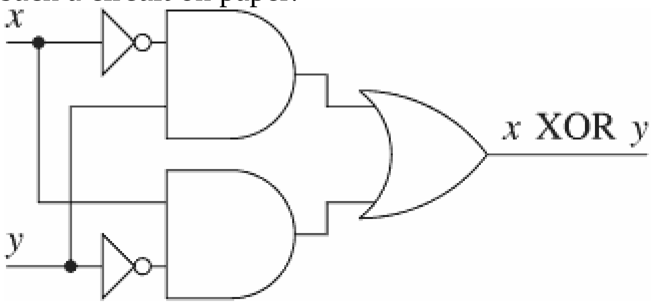
Logisim allows you to design and simulate digital circuits. It is intended as an educational tool, to help you learn how circuits work.

To practice using Logisim, let's build a XOR circuit - that is, a circuit that takes two inputs (which we'll call *x* and *y*) and outputs 1 if the inputs are the same and 0 if they are different. The following truth table illustrates.



x	y	x XOR y
0	0	0
0	1	1
1	0	1
1	1	0

We might design such a circuit on paper.



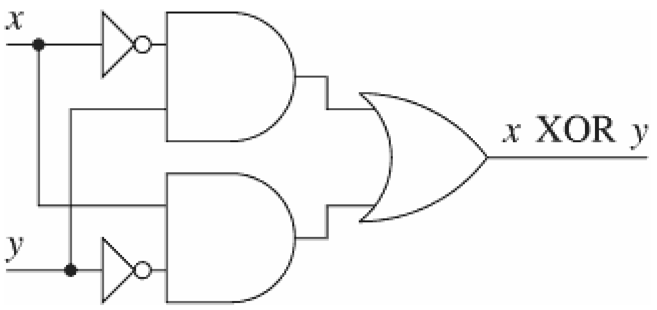
But just because it's on paper doesn't mean it's right. To verify our work, we'll draw it in Logisim and test it. As an added bonus, we'll get a circuit that's looks nicer than what you probably would draw by hand.

Enjoy your circuit-building!

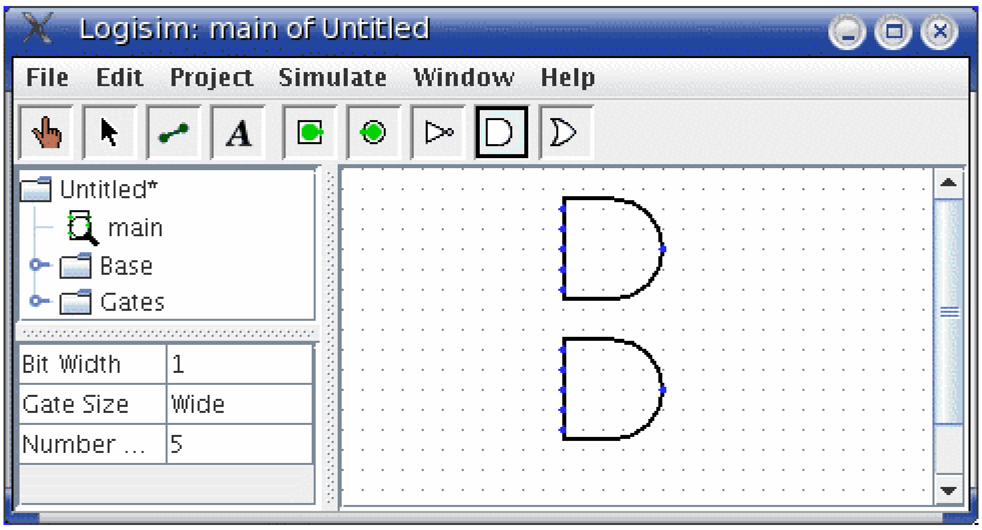
Next: Step 2: Adding wires

Step 1: Adding gates

Recall that we're trying to build the following circuit in Logisim.



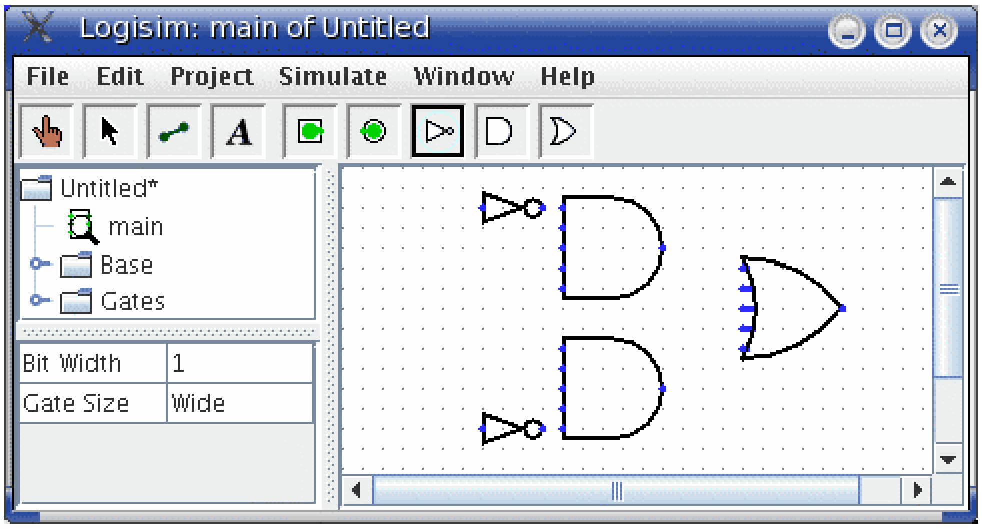
Building a circuit is easiest by inserting the gates first as a sort of skeleton for connecting wires into the circuit later. The first thing we're going to do is to add the two AND gates. Click on the AND tool in the toolbar (, the next-to-last tool listed). Then click in the editing area where you want the AND gates to go. Be sure to leave plenty of room for stuff on the left.


Logisim: main of Untitled
File Edit Project Simulate Window Help
Untitled*
main
Base
Gates

Bit Width	1
Gate Size	Wide
Number ...	5

Notice the five dots on the left side of the AND gate. These are spots where wires can be attached. It happens that we'll just use two of them for our XOR circuit; but for other circuits, you may find that having more than two wires going to an AND gate is useful.

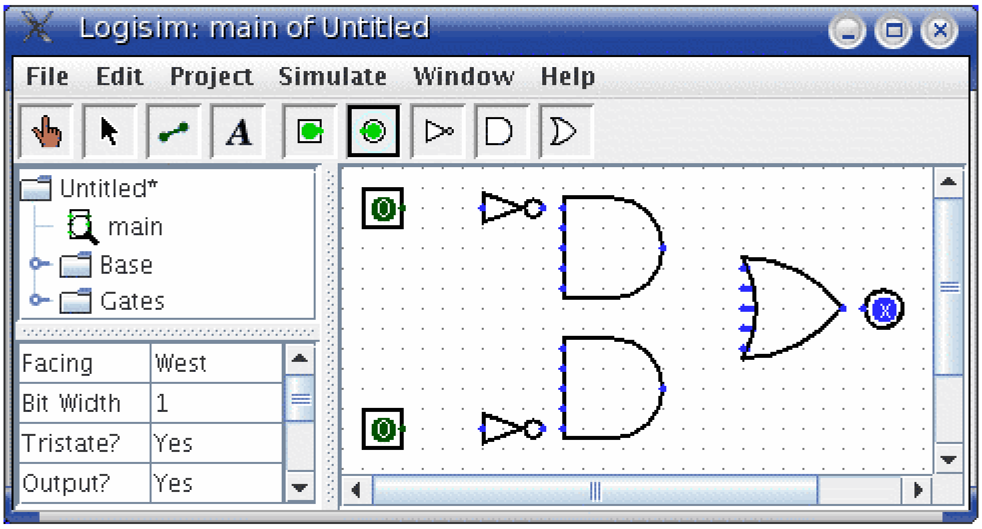
Now add the other gates. First click on the OR tool (); then click where you want it. And select the NOT tool () and put those two gates into the canvas.


Logisim: main of Untitled
File Edit Project Simulate Window Help
Untitled*
main
Base
Gates

Bit Width	1
Gate Size	Wide

I left a little space between the NOT gates and the AND gates; if you want to, though, you can put them up against each other and save yourself the effort of drawing a wire in later.

Now we want to add the two inputs *x* and *y* into the diagram. Select the input pin (🟩), and place the pins down. You should also place an output pin (●) next to the OR gate's output. (Again, though I'm leaving a bit of space between the OR gate and the output pin, you might choose to place them right next to each other.)


Logisim: main of Untitled
File Edit Project Simulate Window Help
Untitled*
main
Base
Gates
0
0
x

Facing	West
Bit Width	1
Tristate?	Yes
Output?	Yes

If you decide you don't like where you placed something, then you can right-click (or control-click) anything in the canvas to view a pop-up menu. Choose Delete. You can also rearrange things using the select tool ( ).

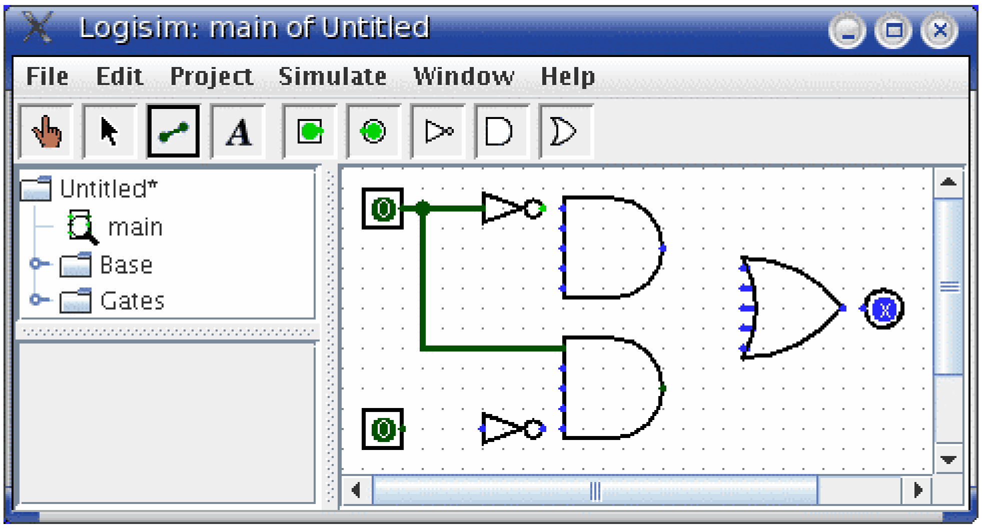
Next: Step 2: Adding wires

Next: Step 3: Adding text

Step 2: Adding wires

After you have all the components blocked out on the canvas, you're ready to start adding wires. Select the wiring tool (). Then start dragging from one position to another in the canvas area, and a wire will start to appear between the two points.

Wires in Logisim must be horizontal or vertical. To connect the upper input to the NOT gate and the AND gate, then, I added three different wires.

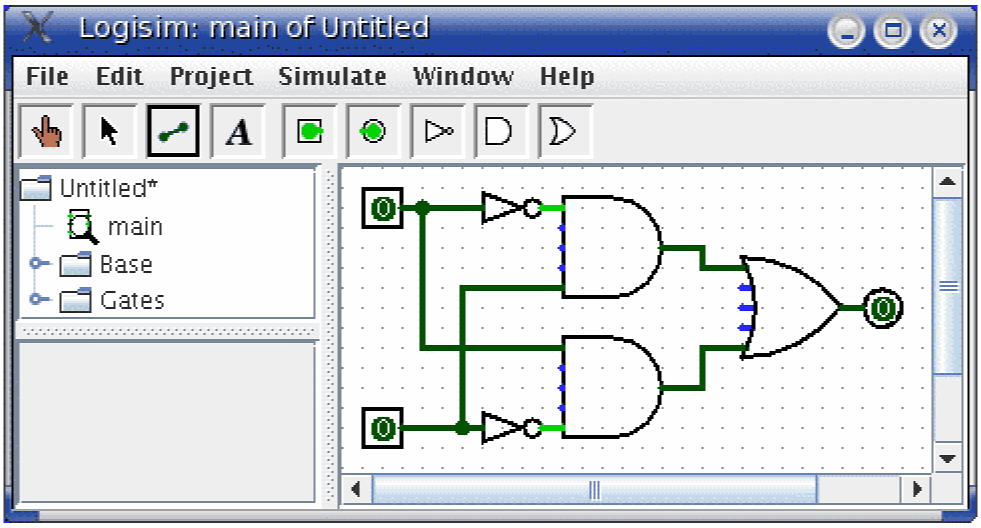

Logisim: main of Untitled
File Edit Project Simulate Window Help
Untitled*
main
Base
Gates
0
0
x

Logisim automatically connects wires to the gates and to each other. This includes automatically drawing the circle at a *T* intersection as above, indicating that the wires are connected.

As you draw wires, you may see some blue or gray wires. Blue in Logisim indicates that the value at that point is ``unknown", and gray indicates that the wire is not connected to anything. This is not a big deal temporarily. But by the time you finish your circuit, none of your wires should be blue or gray. (The unconnected legs of the OR gate will still be blue: That's fine.)

If you do have a blue or a gray wire after you think everything ought to be connected, then something is going wrong. It's important that you connect wires to the right places. Logisim draws little dots on the components to indicate where wires ought to connect. As you proceed, you'll see the dots turn from blue to light or dark green.

Once you have all the wires connected, all of the wires you inserted will themselves be light or dark green.



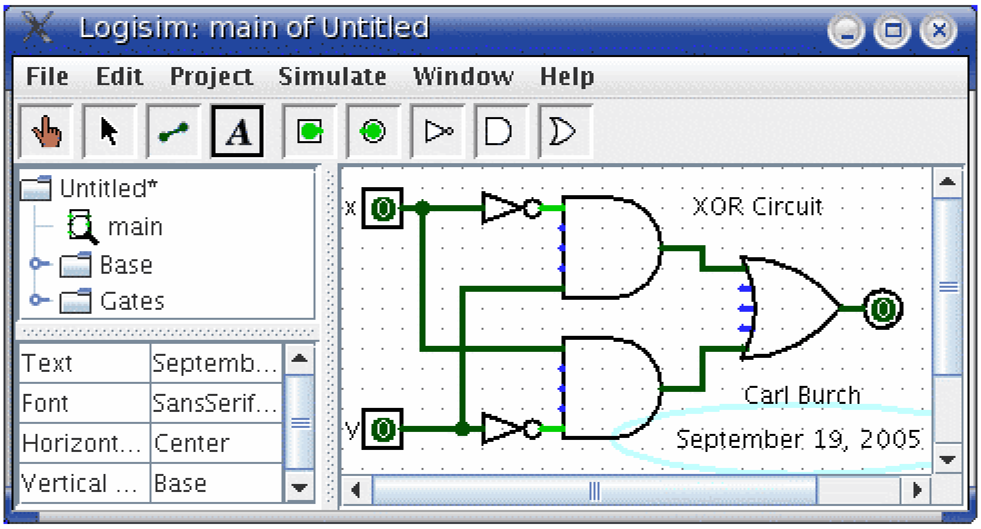
Next: Step 3: Adding text

Next: Step 4: Testing your circuit

Step 3: Adding text

Adding text to the circuit isn't necessary to make it work; but if you want to show your circuit to somebody (like a teacher), then some labels help to to communicate the purpose of the different pieces of your circuit.

Select the text tool (***A***). You can click on an input pin and start typing to give it a label. (It's better to click directly on the input pin than to click where you want the text to go, because then the label will move with the pin.) You can do the same for the output pin. Or you could just click any old place and start typing to put a label anywhere else.



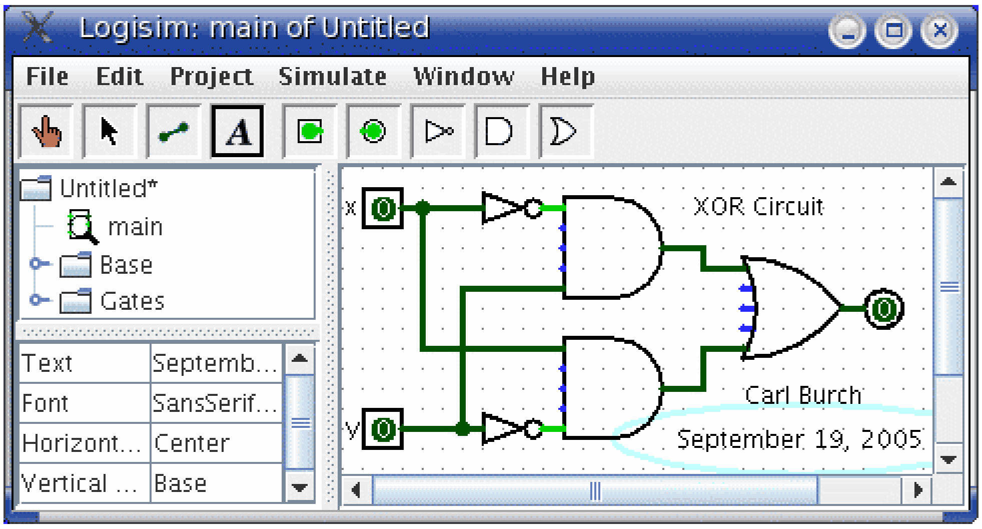
Text	Septemb...
Font	SansSerif...
Horizont...	Center
Vertical ...	Base

Next: Step 4: Testing your circuit

Next: *User's Guide*

Step 4: Testing your circuit

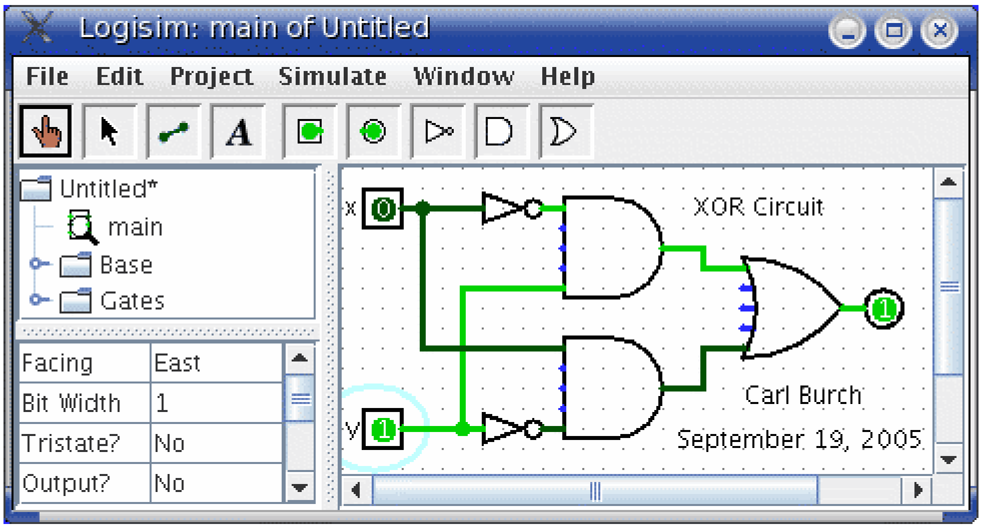
Our final step is to test our circuit to ensure that it really does what we intended. Logisim is already simulating the circuit. Let's look again at where we were.



Text	Septemb…
Font	SansSerif…
Horizont…	Center
Vertical …	Base

Note that the input pins both contain 0s; and so does the output pin. This already tells us that the circuit already computes a 0 when both inputs are 0.

Now to try another combination of inputs. Select the poke tool ( ) and start poking the inputs by clicking on them. Each time you poke an input, its value will toggle. For example, we might first poke the bottom input.



Facing	East
Bit Width	1
Tristate?	No
Output?	No

When you change the input value, Logisim will show you what values travel down the wires by drawing them light green to indicate a 1 value or dark green (almost black) to indicate a 0 value. You can also see that the output value has changed to 1.

So far, we have tested the first two rows of our truth table, and the outputs (0 and 1) match the desired outputs.

x	y	x XOR y
0	0	0
0	1	1
1	0	1
1	1	0

By poking the switches through different combinations, we can verify the other two rows. If they all match, then we're done: The circuit works!

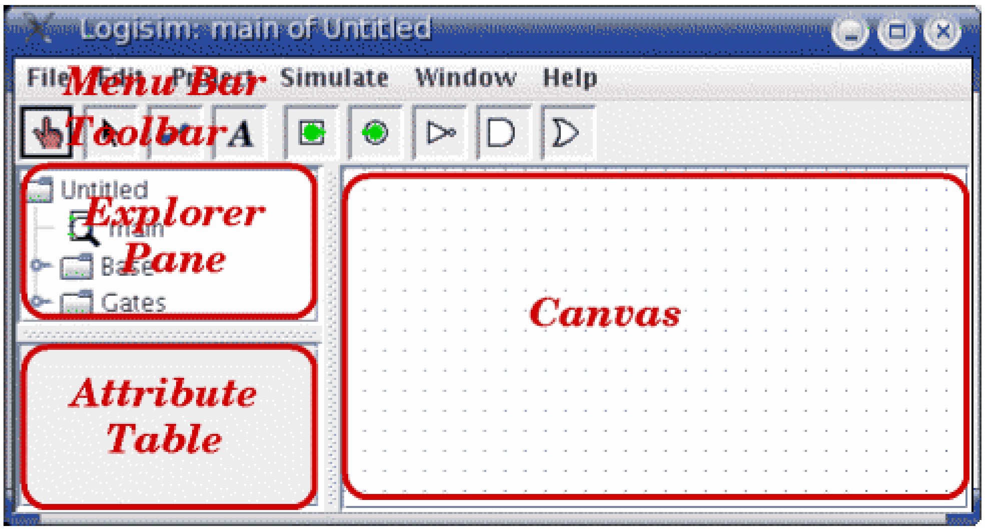
To archive your completed work, you might want to save or print your circuit. The File menu allows this, and of course it also allows you to exit Logisim. But why quit now?

Now that you are finished with tutorial, you can experiment with Logisim by building your own circuits. If you want to build circuits with more sophisticated features, then you should navigate through the rest of the help system to see what else you can do. Logisim is a powerful program, allowing you to build up and test huge circuits; this step-by-step process just scratches the surface.

Next: *User's Guide*

Libraries and Attributes

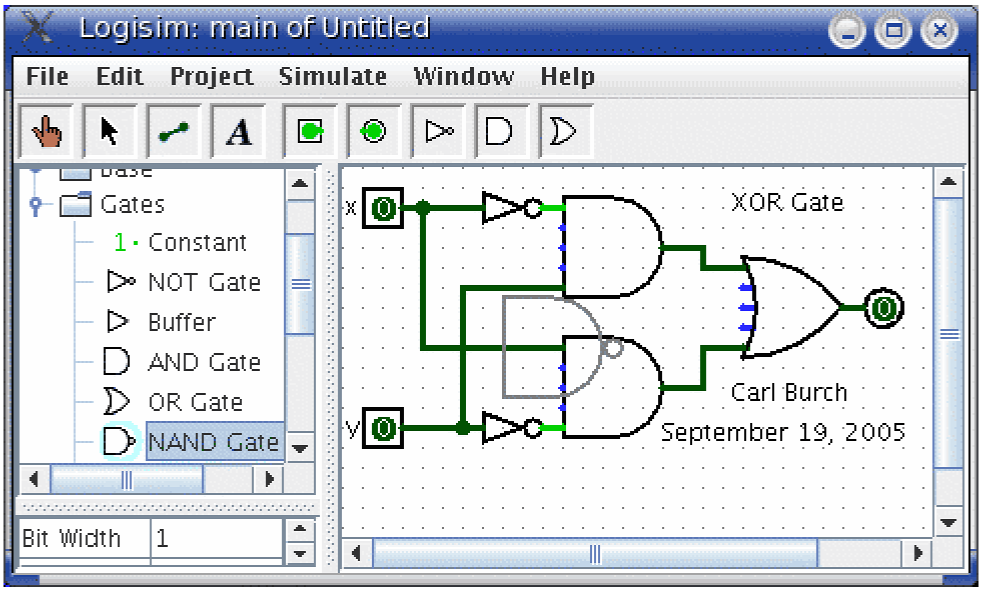
In this section, we'll examine how to use the other two major regions of the Logisim window, the *explorer pane* and the *attribute table*.



Next: The explorer pane.

The explorer pane

Libraries contain components that can be dropped into circuits. They are displayed as folders in the explorer pane; to access a library's components, you have only to double-click the corresponding folder. Below, I have opened the Gates library and selected the NAND tool from it. You can see that Logisim now stands ready to add NAND gates into the circuit.



If you look through the choices in the Gates library, you'll notice that there was no need for us to develop a XOR circuit earlier: It's built into Logisim.

When you create a project, it automatically includes the Base and Gates libraries. But Logisim includes many other libraries, too: To load one, go to the Project menu, in the Load Library submenu, and choose Built-in Library.... A dialog box will appear allowing you to choose which libraries you want to add. If you choose Plexers, for example, then you will be able to add multiplexers, demultiplexers, and decoders. You can load as many libraries as you like.

In the Load Library submenu, you can see that Logisim has three categories of libraries.

- **Built-in libraries** are libraries that are distributed with Logisim. These are documented in the *Library Reference*.
- **Logisim libraries** are projects built within Logisim and saved to the disk. You can develop a set of circuits in a single project (as described in the Subcircuits section of this guide) and then use that set of circuits as a library for another projects.
- **JAR libraries** are libraries that are developed in Java but not distributed with Logisim. You can download JAR libraries that others have written, or you can write your own as described in the JAR Libraries section of this guide. Developing a JAR library is much more difficult than developing a Logisim library, but the components can be much fancier, including things like attributes and interaction with the user. The built-in libraries (other than Base)

were written using the same API as JAR libraries can use, so they aptly demonstrate the range of functionality that the JAR libraries can support.

When loading a JAR library, Logisim will prompt you to select the JAR file, and then it will prompt you to type a class name. This class name should be provided by whoever distributed the JAR file to you.

To remove a library, choose Unload Library... from the Project menu. Logisim will prevent you from unloading libraries that contain components used in a circuit, that appear in the toolbar, or that are mapped to a mouse button.

Incidentally, a library technically contains tools, not components. Thus, in the Base library you'll find the Poke Tool (), the Select Tool ( ), and other tools that don't correspond directly to individual components. Most libraries, though, contain only tools for adding individual components; all built-in libraries other than the Base library are like this.

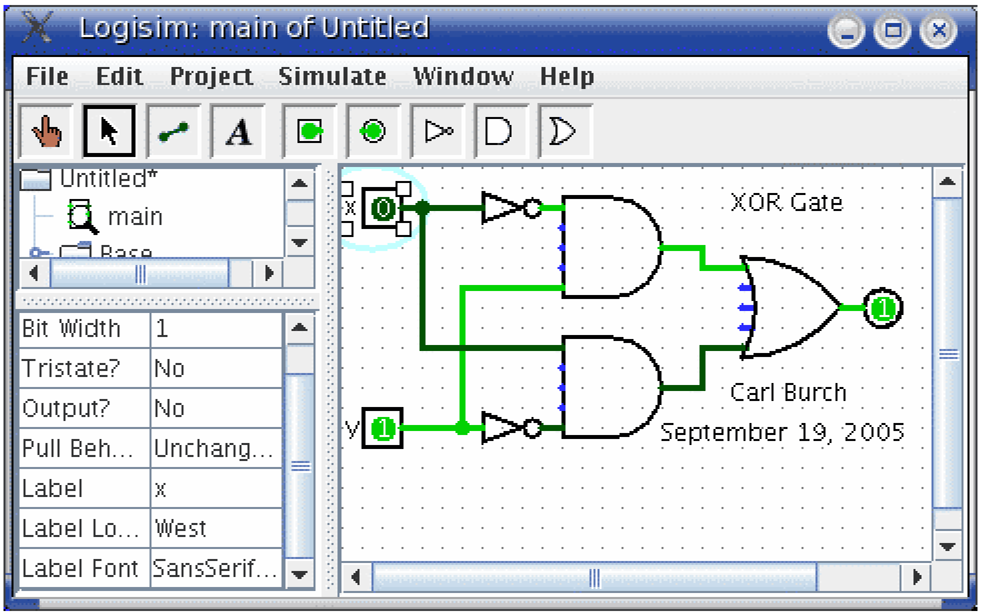
Next: The attribute table.

The attribute table

Many components have **attributes**, which are properties for configuring how the component behaves or appears. The **attribute table** is for viewing and displaying a component's attribute values.

To select which component's attributes you wish to view, click the component using the Select tool ( ). (You can also right-click (or control-click) the component and choose Show Attributes from the popup menu. Also, manipulating a component via the Poke tool () or the Text tool (A) will display that component's attributes.)

The below screen shot demonstrates what things look like after selecting the upper input of our XOR circuit and scrolling down to view the Label Font attribute.


Logisim: main of Untitled
File Edit Project Simulate Window Help
Untitled*
main
Base
XOR Gate
Carl Burch
September 19, 2005

Bit Width	1
Tristate?	No
Output?	No
Pull Beh...	Unchang...
Label	x
Label Lo...	West
Label Font	SansSerif...

Note the pale teal (i.e., light blue) oval surrounding the pin, called a **halo**: This indicates whose attributes are displayed in the attribute table.

To modify an attribute value, click on the value. The interface for modifying the attribute will depend on which attribute you are changing; in the case of the Label Font attribute, a dialog box will appear for selecting the new font; but some attributes (like Label) will allow you to edit the value as a text field, while others (like Label Location) will display a drop-down menu from which to select the value.

Each component type has a different set of attributes; to learn what they mean, go to the relevant documentation in the Library Reference.

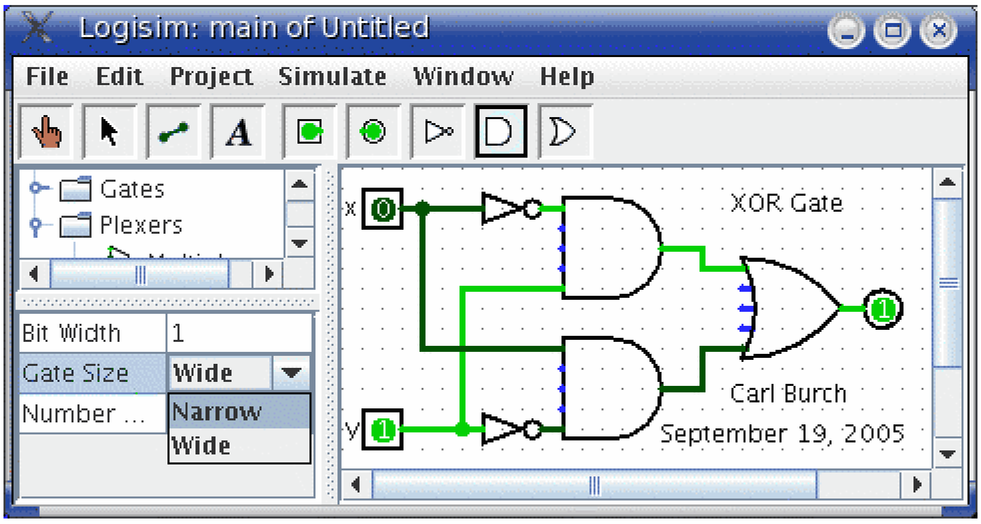
Some components have attribute values that cannot be changed. One example of this is the AND gate's Gate Size attribute: As soon as you create an AND gate, is size is fixed. If you want an AND gate of a different size, then you'll need to change the attributes for the tool, which we'll discuss next.

Next: Tool attributes.

Tool attributes

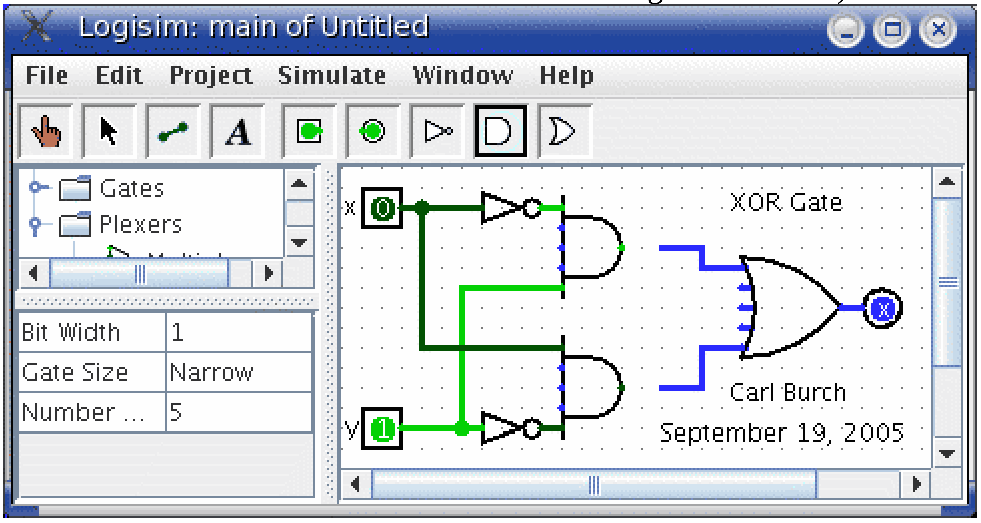
Every tool for adding components to a circuit also has a set of attributes, which are imparted to the components created by the tool, although the components' attributes may be changed later without affecting the tool's attributes. When you select a tool, Logisim will change the attribute table to display that tool's attributes.

For example, suppose we want to create smaller AND gates. We've already seen that an AND gate's Gate Size attribute is not editable. But the Gate Size attribute *is* editable for the AND gate *tool*: To view and edit this attribute, click the tool's icon in the toolbar (or the explorer pane), and change its Gate Size attribute.


Logisim: main of Untitled
File Edit Project Simulate Window Help
Gates
Plexers
XOR Gate
Carl Burch
September 19, 2005
x
y
0
1
1

Bit Width	1
Gate Size	Wide
Number ...	Narrow
	Wide

Now, we can delete the two existing AND gates and add two new AND gates in their place. This time, they will be narrow. (If you chose to reduce the number of inputs to 3, the AND gate would not have vertical extension on the left side. But you'd also have to rewire the circuit so that the wires hit the AND gate's left side.)


Logisim: main of Untitled
File Edit Project Simulate Window Help
Gates
Plexers
XOR Gate
Carl Burch
September 19, 2005
x
y
0
1
X

Bit Width	1
Gate Size	Narrow
Number ...	5

With some tools, the icon reflects some of the attributes' values. One example of this is with the Pin tool, whose icon faces the same way as its Facing attribute says.

The tools in the toolbar each have a separate attribute set from the corresponding tools in the explorer pane. Thus, even though we changed the toolbar's AND tool to create narrow AND gates, the AND tool in the Gates library will still create wide AND gates unless you change its attributes too.

In fact, the input pin and output pin tools in the default toolbar are both instances of the Base library's Pin tool, but the three attribute sets are different. The icon for the Pin tool is drawn as a circle or a square depending on the value of its ``Output?'' attribute.

Logisim provides a handy shortcut for changing the Facing attribute that controls the direction in which many components face: Typing an arrow key while that tool is selected automatically changes the direction of the component.

Next: *User's Guide*.

Subcircuits

As you build circuits that are more and more sophisticated, you will want to build smaller circuits that you can use multiple times in larger circuits. In Logisim, such a smaller circuit that is used in a larger circuit is called a **subcircuit**.

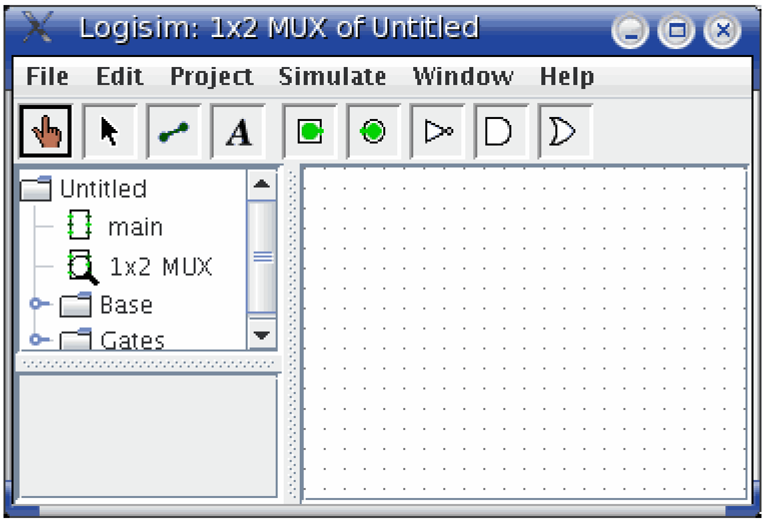
If you're familiar with computer programming, you're familiar with the subprogram concept (called *subroutines*, *functions*, or *methods* in different languages). The subcircuit concept is analogous to the concept in computer programming, and it is used for the same purposes: To break a large job into bite-sized pieces, to save the effort of defining the same concept multiple times, and to facilitate debugging.

Next: Creating circuits.

Creating circuits

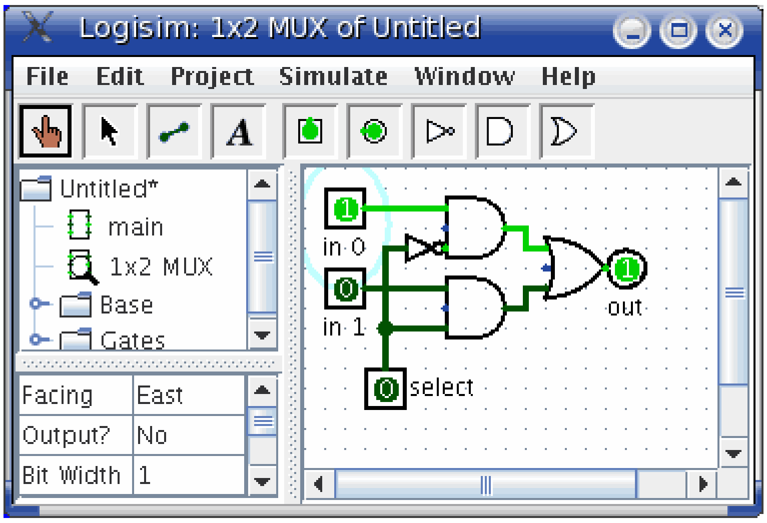
Every Logisim project is actually a library of circuits. In its simplest form, each project has only one circuit (called "main" by default), but it is easy to add more: Select Add Circuit... from the Project menu, and type any name you like for the new circuit you want to create.

Suppose we want to build a 1x2 multiplexer named "1x2 MUX." After adding the circuit, Logisim will look like this.



In the explorer pane, you can now see that the project now contains two circuits, "main", and "1x2 MUX." Logisim draws a magnifying glass over the icon of the circuit currently being viewed; the current circuit name also appears in the window's title bar.

After editing the circuit to appear like a 1x2 multiplexer, we might end up with the following circuit.

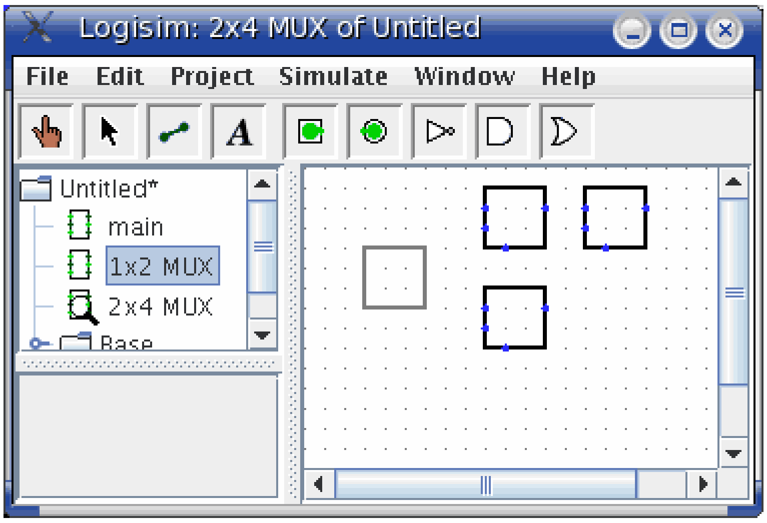

Logisim: 1x2 MUX of Untitled
File Edit Project Simulate Window Help
Untitled*
main
1x2 MUX
Base
Gates
in 0
in 1
select
out

Facing	East
Output?	No
Bit Width	1

Next: Using subcircuits.

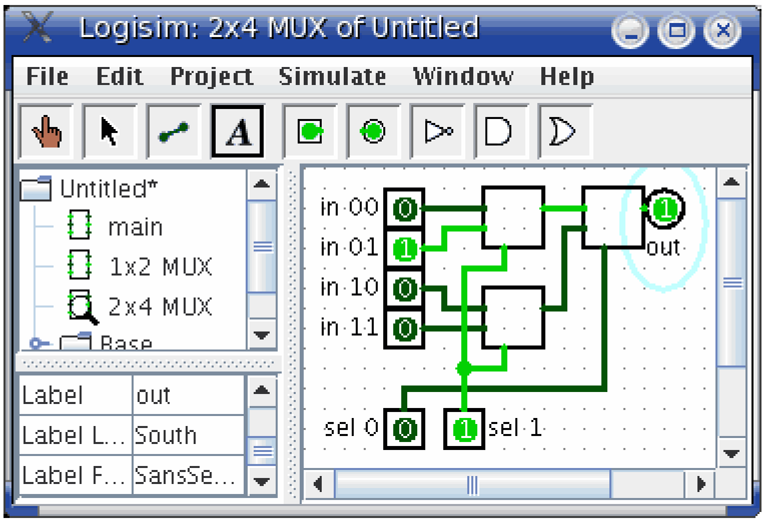
Using subcircuits

Now suppose we want to build a 2x4 multiplexer using instances of our 1x2 multiplexer. Of course, we would first create a new circuit, which we'll call "2x4 MUX." To add 1x2 multiplexers into our circuit, we click the 1x2 MUX circuit *once* in the explorer pane to select it as a tool, and then we can add copies of it, represented as boxes, by clicking within the canvas.


Logisim: 2x4 MUX of Untitled
File Edit Project Simulate Window Help
Untitled*
main
1x2 MUX
2x4 MUX
Base

If you click the 1x2 MUX circuit *twice* in the explorer pane, then the window would switch to editing the 1x2 MUX circuit instead.

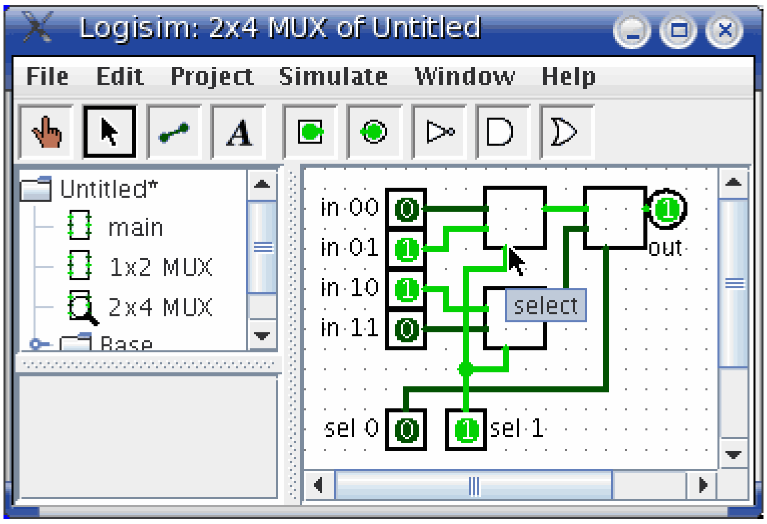
After building up the circuit, we end up with the following.


Logisim: 2x4 MUX of Untitled
File Edit Project Simulate Window Help
Untitled*
main
1x2 MUX
2x4 MUX
Base
in 00
in 01
in 10
in 11
out
sel 0
sel 1

Label	out
Label L...	South
Label F...	SansSe...

Our circuit for a 2x4 multiplexer uses three copies of the 1x2 multiplexer, each drawn as a box with pins along the side. The pins on this box correspond to the input and output pins in the 1x2 MUX circuit. The two pins on the west side of the box correspond to the two pins that face east in the 1x2 MUX circuit; the pin on the box's east side corresponds to the 1x2 MUX's west-facing pin (which happens to be an output pin); and the pin on the box's south side corresponds to the 1x2 MUX's north-facing pin. The order of the two pins on the box's west side correspond to the same top-down ordering that appears in the subcircuit. (If there were several pins on the box's north or south side, they would correspond to the same left-right order in the subcircuit.)

If the pins in the subcircuit's layout have labels associated with them, then Logisim will display that label in a **tip** (that is, a temporary text box) when the user hovers the mouse over the corresponding location of the subcircuit component. (If you find these tips irritating, you can disable them via the Project Options window's Canvas tab.)



Several other components will display these tips, too: For some of the pins of a built-in flip-flop, for example, hovering over it explains what that pin does.

Incidentally, every pin to a circuit must be either an input or an output. Many manufactured chips have pins that behave as an input in some situations and as an output in others; you cannot construct such chips within Logisim.

Logisim will maintain different state information for all subcircuits appearing in a circuit. For example, if a circuit contains a flip-flop, and that circuit is used as a subcircuit several times, then each subcircuit's flip-flop will have its own value when simulating the larger circuit.

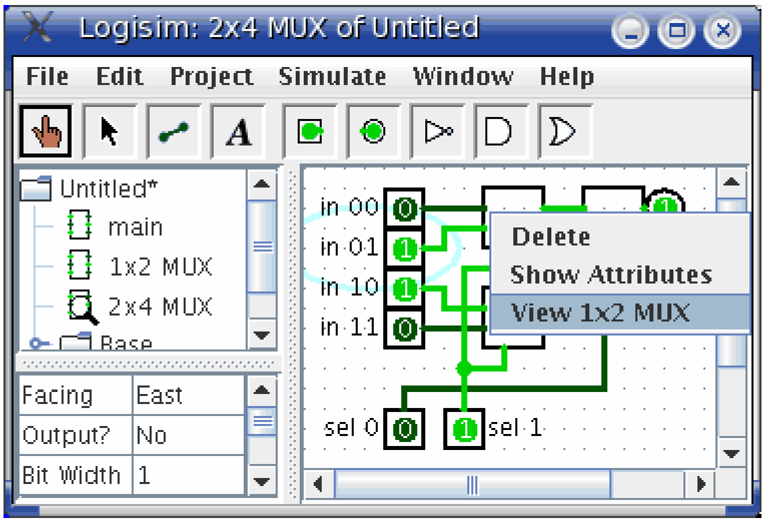
Now that we have the 2x4 multiplexer defined, we can now use it in other circuits. Logisim has no limits on how deeply circuits can be nested - though it will object to nesting circuits within themselves!

Note: There's nothing wrong with editing a circuit that is being used as a subcircuit; in fact, this is quite common. Be aware, though, that any changes to a circuit's pins (adding, deleting, or moving them) will rearrange them also in the containing circuit. Thus, if you change any pins in a circuit, you will also need to edit any circuits using it as a subcircuit.

Next: Debugging subcircuits.

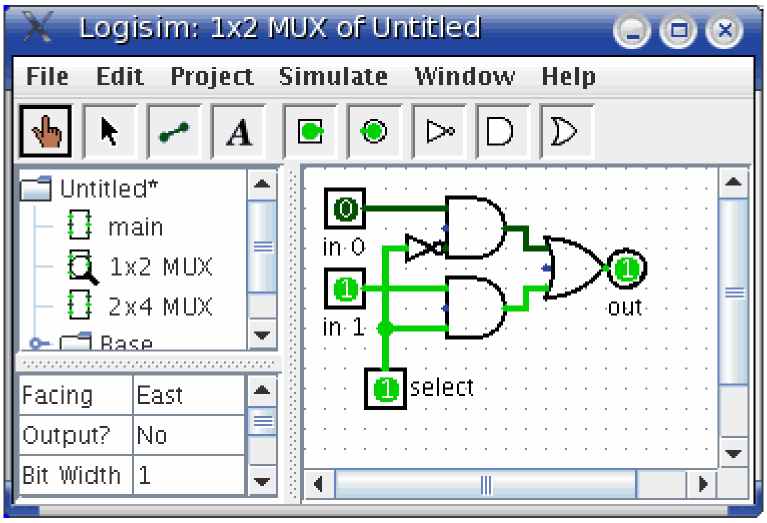
Debugging subcircuits

As you test larger circuits, you will likely find bugs. To nail down what's going wrong, exploring what's going on in the subcircuits while running the overall circuit can help. From viewing the overall circuit, you can do this by bringing up the subcircuit's popup menu (right-click or control-click its box). Then choose the View option.



Facing	East
Output?	No
Bit Width	1

After choosing this, the view will switch to the subcircuit.


Logisim: 1x2 MUX of Untitled
File Edit Project Simulate Window Help
Untitled*
main
1x2 MUX
2x4 MUX
Base
in 0
in 1
select
out
0
1
1
1

Facing	East
Output?	No
Bit Width	1

Notice that the pins' values in the subcircuit match the values being sent to them in its containing circuit.

While in the subcircuit, you can change it however you want; any changes to pins' values will be propagated within the containing circuit. (If you attempt to toggle a pin using the Poke Tool, Logisim will pop up a dialog box asking whether you want to create a new state; responding Yes will divorce the state viewed with the subcircuit from the outer circuit's state, while responding No will cancel the toggle request.)

Once you have completed viewing and/or editing the parent circuit either by double-clicking it in the explorer pane, or via the Go Out To State submenu of the Simulate menu.

Next: Logisim libraries.

Logisim libraries

Every Logisim project is automatically a library that can be loaded into other Logisim projects: Just save it into a file and then load the library within another project. All of the circuits defined in the first project will then be available as subcircuits for the second. This feature allows you to reuse common components across projects and to share favorite components with your friends (or students).

Each project has a designated "main circuit," which can be changed to refer to the current circuit via the Set As Main Circuit option in the Project menu. The *only* significance of this is that the main circuit is the one that is displayed when you first open the project. The default name of the circuit in a newly created file ("main") has no significance at all, and you can feel free to delete or rename that circuit.

With a loaded Logisim library, you are allowed to view circuits and manipulate their states, but Logisim will prevent you from altering them.

If you want to alter a circuit in a loaded Logisim library, then you need to open it separately within Logisim. As soon as you save it, the other project should automatically load the modified version immediately; but if it does not, you can right-click the library folder in the explorer pane and select Reload Library.

Next: *User's Guide*.

Wire bundles

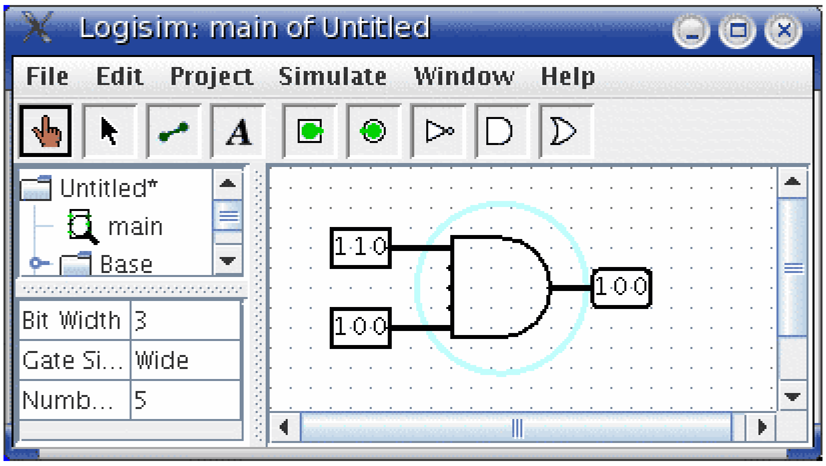
In simple Logisim circuits, most wires carry only one bit; but Logisim also allows you to create wires that bundle together multiple bits. The number of bits traveling along a wire is that wire's **bit width**.

Next: Creating bundles.

Creating bundles

Every input and output on every component in the circuit has a bit width associated with it. Many of Logisim's built-in components include attributes allowing you to customize the bit widths of their inputs and outputs.

The below screen shot illustrates a simple circuit for finding the bitwise AND of two three-bit inputs; each pin has its Bit Width attribute customized for dealing with three-bit data, as with the pictured AND gate attributes.

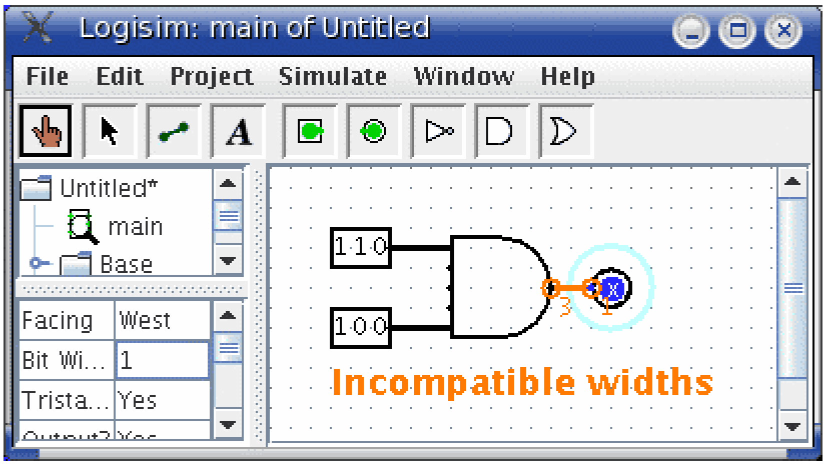


Logisim: main of Untitled
File Edit Project Simulate Window Help
Untitled*
main
Base
110
100
100

Bit Width	3
Gate Si...	Wide
Numb...	5

Notice that the input and output pins are drawn with three bits, and the output is the bitwise AND of the inputs.

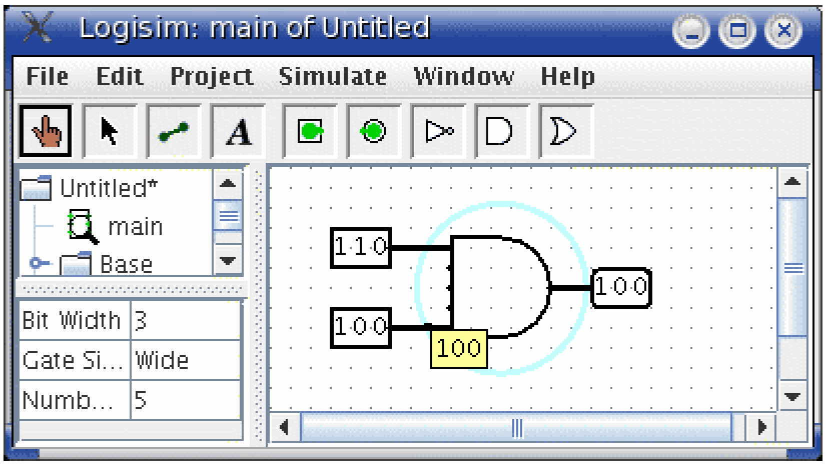
For components, all inputs and outputs must have their bit widths defined. In contrast, a wire's bit width is undefined: Instead, the wire's width adapts to the components to which it is attached. If a wire connects two components demanding different bit widths, Logisim will complain of ``Incompatible widths" and indicate the offending locations in orange. In the below, the output pin's Bit Width attribute has been changed to 1, and so Logisim complains that the wire cannot connect a three-bit value to a one-bit value.


Logisim: main of Untitled
File Edit Project Simulate Window Help
Untitled*
main
Base
110
100
3
1
Incompatible widths

Facing	West
Bit Wi...	1
Trista...	Yes

Wires that connect incompatible locations (drawn in orange) do not carry values.

For single-bit wires, you can see at a glance what value it is carrying because Logisim colors the wire light or dark green depending the value. It does not display values for multi-bit wires: They are simply black. You can, though, probe a wire by clicking it using the poke tool (👆).


Logisim: main of Untitled
File Edit Project Simulate Window Help
Untitled*
main
Base
110
100
100
100

Bit Width	3
Gate Si...	Wide
Numb...	5

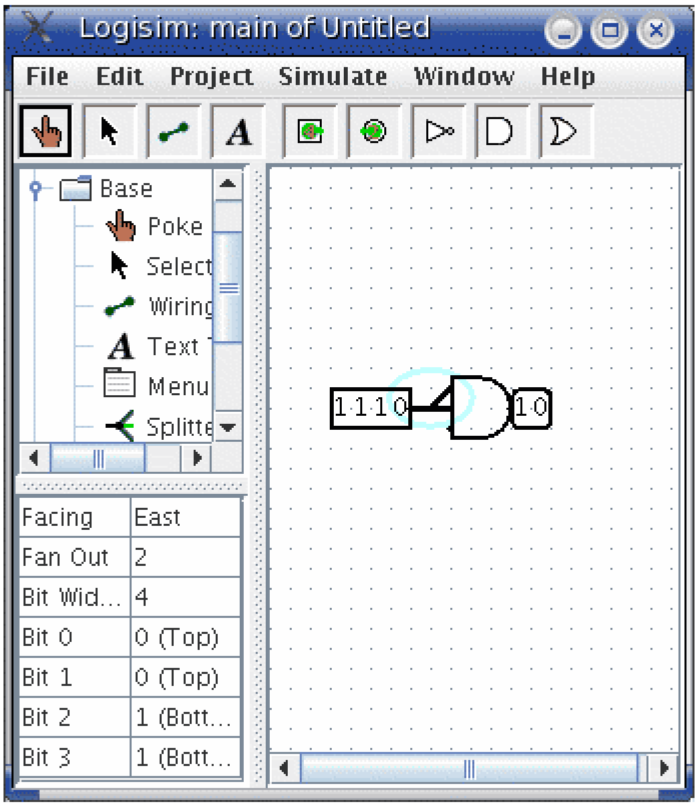
This probing feature is helpful for debugging circuits using wire bundles.

Next: Splitters.

Splitters

When you work with multi-bit values, you will often want to route different bits in different directions. The Base library's splitter tool (allows you to accomplish this.

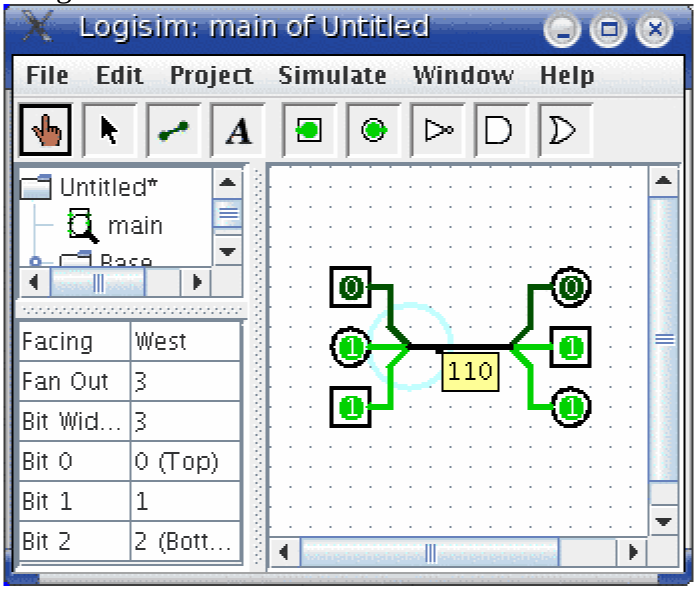
For example, suppose we want to build a circuit taking an eight-bit input and outputting the AND of its two nibbles (the upper four bits and the lower four bits). We will have an eight-bit value coming from the input pin, and we want to split that into two four-bit values. In the below circuit, we have used a splitter to accomplish this.



Logisim: main of Untitled
File Edit Project Simulate Window Help
Base
Poke
Select
Wiring
Text
Menu
Splitte
1110
10

Facing	East
Fan Out	2
Bit Wid...	4
Bit 0	0 (Top)
Bit 1	0 (Top)
Bit 2	1 (Bott...
Bit 3	1 (Bott...

In this example, the splitter happens to actually split an incoming value into multiple outgoing values. But splitters can also combine multiple values into a single value. In fact, they are non-directional: They can send values one way at one time and another way later, and they can even do both at the same time, as in the below example where two values are fed rightward and the middle value feeds leftward.



Logisim: main of Untitled
File Edit Project Simulate Window Help
Untitled*
main
Base
0
1
1
110
0
1
1

Facing	West
Fan Out	3
Bit Wid...	3
Bit 0	0 (Top)
Bit 1	1
Bit 2	2 (Bott...

The key to understanding splitters is their attributes. In the following, the term *split end* refers to one of the multiple wires on one side, while the term *combined end* refers to the single wire on the other side.

- The **Facing** attribute tells where the split ends should be relative to the combined end. This cannot be changed once a splitter is dropped into the circuit.

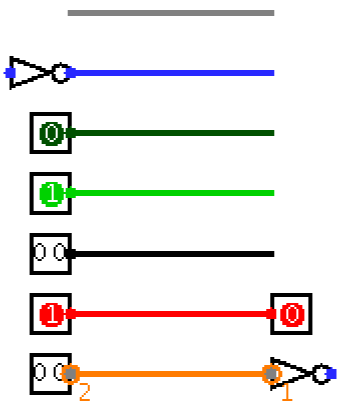
- The **Fan Out** attribute specifies how many split ends there are. This also cannot be changed once a splitter is dropped into the circuit.
- The **Bit Width** attribute specifies the bit width of the combined end.
- The **Bit *x*** attribute says which split end corresponds to bit *x* of the combined end. If multiple bits correspond to the same split end, then their relative ordering will be the same as in the combined end. Logisim splitters cannot have a bit from the combined end correspond to multiple split ends.

Note that any change to the Fan Out or Bit Width attributes will reset all Bit *x* attributes so that they will distribute the bits of the combined value as evenly as possible among the split ends.

Next: Wire colors.

Wire colors

We are now in a position to summarize the full rainbow of colors that Logisim wires can take on. The following little circuit illustrates all of them at once.

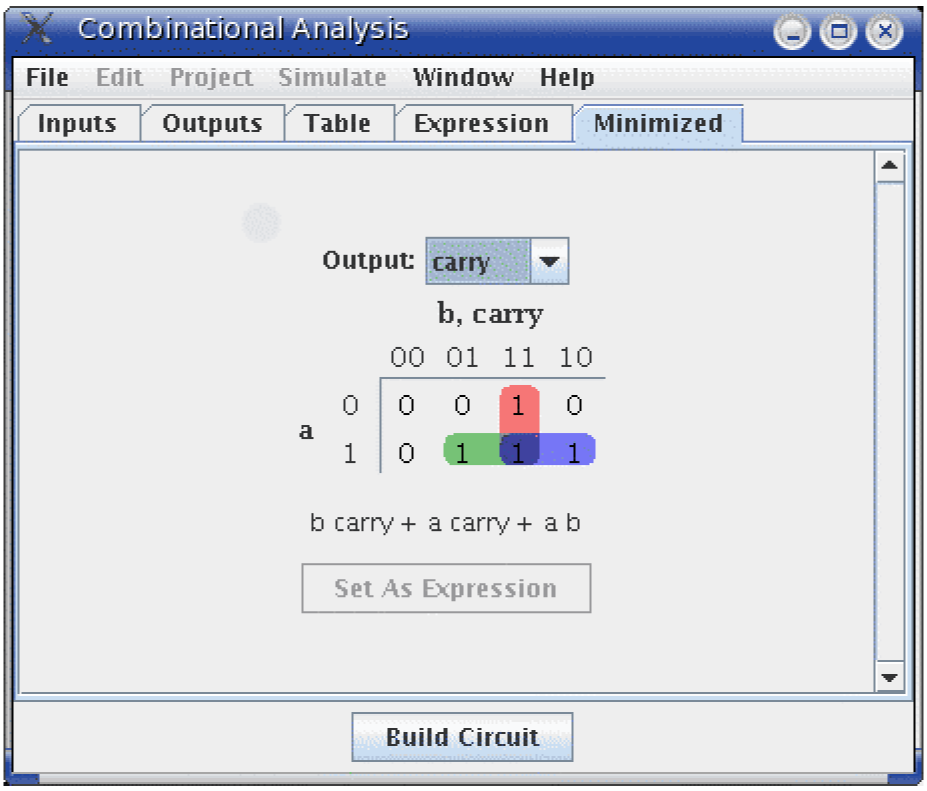


- **Gray:** The wire's bit width is unknown. This occurs because the wire is not attached to any components' inputs and outputs. (All inputs and outputs have a defined bit width.)
- **Blue:** The wire is for carrying a one-bit value, but the value it is carrying is not known. In the above example, this is occurring because the NOT gate's input is unknown, and so its output is also unknown.
- **Dark green:** The wire is carrying a one-bit 0 value.
- **Bright green:** The wire is carrying a one-bit 1 value.
- **Black:** The wire is carrying a multi-bit value. Some or all of the bits may not be specified.
- **Red:** The wire is carrying an error value. This usually arises because conflicting values on the wire. (The other possibility would be that a library component is programmed to emit an error value for another reason; in the built-in libraries, though, error values arise only from propagating other error values.) In the above example, we have one input pin placing a 0 on the wire and another placing a 1 on the wire, causing a conflict. Multi-bit wires will turn red when any of the bits carried are error values.

- **Orange:** The components attached to the wire do not agree in bit width. An orange wire is effectively "broken": It does not carry values between components.

Next: *User's Guide*.

Combinational analysis


Combinational Analysis
File Edit Project Simulate Window Help
Inputs Outputs Table Expression Minimized
Output: carry
b, carry
a
Set As Expression
Build Circuit

		00	01	11	10
a	0	0	0	1	0
	1	0	1	1	1

b carry + a carry + a b

All circuits fall into one of two well-known categories: In a **combinational circuit**, all circuit outputs are a strict *combination* of the current circuit inputs, whereas in a **sequential circuit**, some outputs may depend on past inputs (the *sequence* of inputs over time).

The category of combinational circuits is the simpler of the two. Practitioners use three major techniques for summarizing the behavior of such circuits.

- logic circuits
- Boolean expressions, which allow an algebraic representation of how the circuit works
- truth tables, which list all possible input combinations and the corresponding outputs

The *Combinational Analysis* module of Logisim allows you to convert between these three representations in all directions. It is a particularly handy way of creating and understanding circuits with a handful of one-bit inputs and outputs.
Opening Combinational Analysis
Editing the truth table

Next: Opening Combinational Analysis.

Opening Combinational Analysis

The bulk of the Combinational Analysis module is accessed through a single window of that name allowing you to view truth tables and Boolean expressions. This window can be opened in two ways.

Via the Window menu

Select Combinational Analysis, and the current Combinational Analysis window will appear. If you haven't viewed the window before, the opened window will represent no circuit at all.

Only one Combinational Analysis window exists within Logisim, no matter how many projects are open. There is no way to have two different analysis windows open at once.

Via the Project menu

From a window for editing circuits, you can also request that Logisim analyze the current circuit by selecting the Analyze Circuit option from the Project menu. Before Logisim opens the window, it will compute Boolean expressions and a truth table corresponding to the circuit and place them there for you to view.

For the analysis to be successful, each input must be attached to an input pin, and each output must be attached to an output pin. Logisim will only analyze circuits with at most eight of each type, and all should be single-bit pins. Otherwise, you will see an error message and the window will not open.

In constructing Boolean expressions corresponding to a circuit, Logisim will first attempt to construct a Boolean expressions corresponding exactly to the gates in the circuit. But if the circuit uses some non-gate components (such as a multiplexer), or if the circuit is more than 100 levels deep (unlikely), then it will pop up a dialog box telling you that deriving Boolean expressions was impossible, and Logisim will instead derive the expressions based on the truth table, which will be derived by quietly trying each combination of inputs and reading the resulting outputs.

After analyzing a circuit, there is no continuing relationship between the circuit and the Combinational Analysis window. That is, changes to the circuit will not be reflected in the window, nor will changes to the Boolean expressions and/or truth table in the window be reflected in the circuit. Of course, you are always free to analyze a circuit again; and, as we will see later, you can replace the circuit with a circuit corresponding to what appears in the Combinational Analysis window.

Limitations

Logisim will not attempt to detect sequential circuits: If you tell it to analyze a sequential circuit, it will still create a truth table and corresponding Boolean expressions, although these will not accurately summarize the circuit behavior. (In fact, detecting sequential circuits is *provably impossible*, as it would amount to solving the Halting Problem. Of course, you might hope that Logisim would make at least some attempt - perhaps look for flip-flops or cycles in the wires - but it does not.) As a result, the Combinational Analysis system should not be used indiscriminately: Only use it when you are indeed sure that the circuit you are analyzing is indeed combinational!

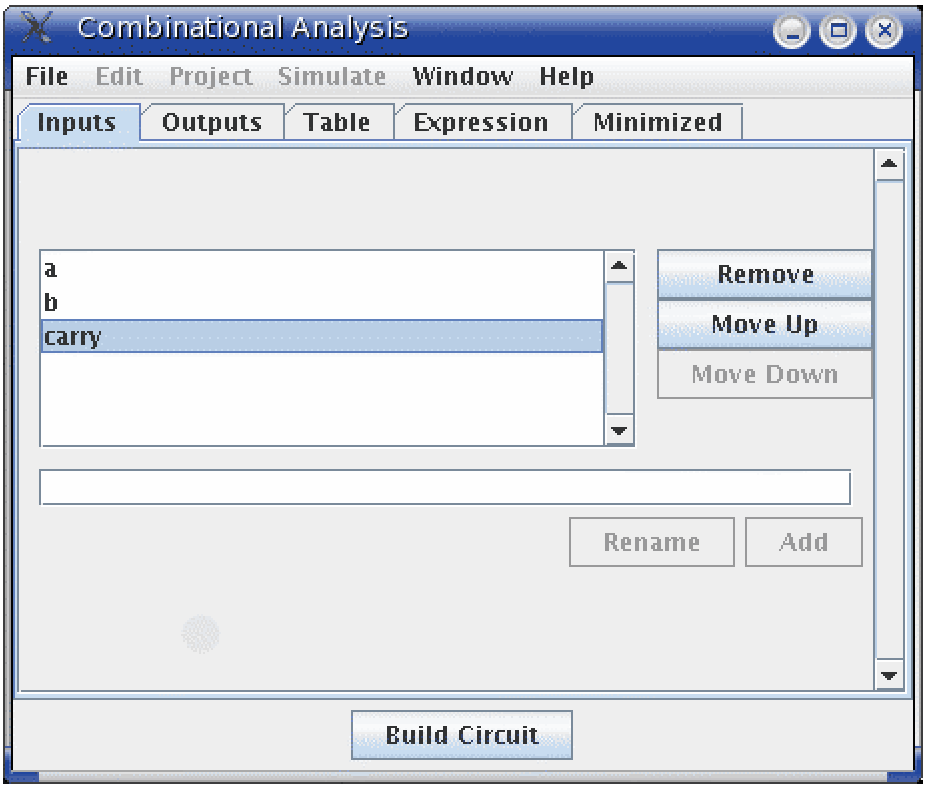
Logisim will make a change to the original circuit that is perhaps unexpected: The Combinational Analysis system requires that each input and output have a unique name that conforming to the rules for Java identifiers. (Roughly, each character must either a letter or a digit, and the first character must be a letter. No spaces allowed!) It attempts to use the pins' existing labels, and to use a list of defaults if no label exists. If an existing label doesn't follow the Java-identifier rule, then Logisim will attempt to extract a valid name from the label if at all possible.

Incidentally, the ordering of the inputs in the truth table will match their top-down ordering in the original circuit, with ties being broken in left-right order. (The same applies to the ordering of outputs.)

Next: Editing the truth table.

Editing the truth table

On opening the Combinational Analysis window, you will see that it consists of five tabs.



This page describes the first three tabs, Inputs, Outputs, and Table. The next page of the guide describes the last two tabs, Expression and Minimized.

The Inputs and Outputs tabs

The Inputs tab allows you to view and edit the list of inputs. To add new inputs, type it in the field at the pane's bottom, and click Add. If you want to rename an existing input, select it in the list in the pane's upper left region; then type the name and click Rename.

To remove an input, select it from the list and click Remove. You can also reorder the inputs (which affects the order of columns in the truth table and in the generated circuit) using the Move Up or Move Down buttons on an input.

All actions affect the truth table immediately.

The Outputs tab works in exactly the same way as the Inputs tab, except of course it works with the list of outputs instead.

The Table tab

The only item under the Table tab is the current truth table, diagrammed in the conventional order, with inputs constituting the columns on the left and outputs constituting the columns on the right.

You can edit the current values appearing in the output columns by clicking on the value of interest. The values will cycle through 0, 1, and *x* (representing a "don't care"). As we'll see on the next page, any don't-care values allow the computation of minimized expressions some flexibility.

You can also navigate and edit the truth table using the keyboard. And you can copy and paste values using the clipboard. The clipboard can be transferred to any application supporting tab-delimited text (such as a spreadsheet).

If the truth table is based on an existing circuit, you may see some pink squares in the output columns with "!!" in them. These correspond to errors that occurred while calculating the value for that row - either the circuit seemed to be oscillating, or the output value was an error value (which would be pictured as a red wire in the Logisim circuit). Hovering your mouse over the entry should bring up a tool tip describing which type of error it was. Once you click on the error entry, you will be in the 0-1-*x* cycle; there is no way to go back.

Next: Creating expressions.

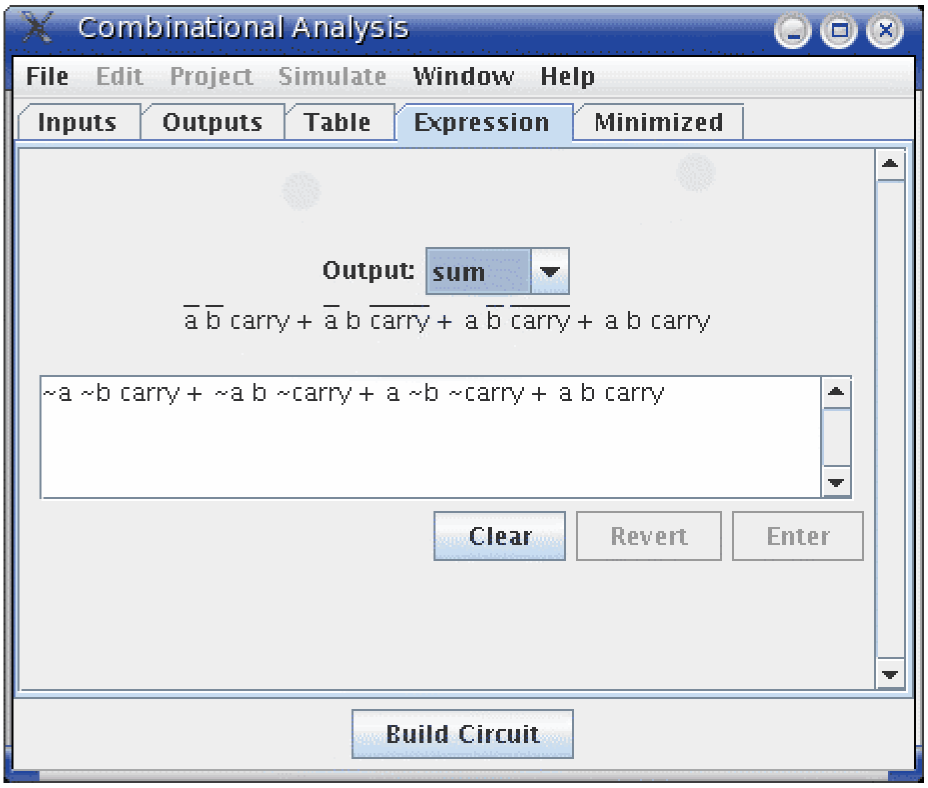
Creating expressions

For each output variable, the Combinational Analysis window maintains two structures - the relevant column of the truth table, and a Boolean expression - specifying how each output relates to its input. You can edit either the truth table or the expression; the other will automatically change as necessary to keep them consistent.

As we will see on the next page, the Boolean expressions are particularly useful because the Combinational Analysis window will use these when told to build a circuit corresponding to the current state.

You can view and edit the expressions using the window's last two tabs, the Expression tab and the Minimized tab.

The Expression tab



$\overline{a}\ \overline{b}\ carry + \overline{a}\ b\ \overline{carry} + a\ \overline{b}\ \overline{carry} + a\ b\ carry$

```
~a ~b carry + ~a b ~carry + a ~b ~carry + a b carry
```

The Expression tab allows you to view and edit the current expression associated with each output variable. You can select the output expression you want to view and edit using the selector labeled "Output:" at the pane's top.

Just below the selector will appear the expression formatted in a particularly common notation, where an OR is represented as addition, an AND is represented as multiplication, and a NOT is denoted with a bar above the portion affected by the NOT.

The text pane below this displays the same information in ASCII form. Here, a NOT is represented with a tilde ('~').

You can edit the expression in the text pane and click the Enter button to make it take effect; doing this will also update the truth table to make it correspond. The Clear button clears the text pane, and the Revert button changes the pane back to representing the current expression.

Note that your edited expression will be lost if you edit the truth table.

In addition to multiplication and addition standing for AND and OR, an expression you type may contain any of C/Java logical operators, as well as simply the words themselves.

highest precedence	~ !	**NOT**
	(none) & &&	**AND**
	^	**XOR**

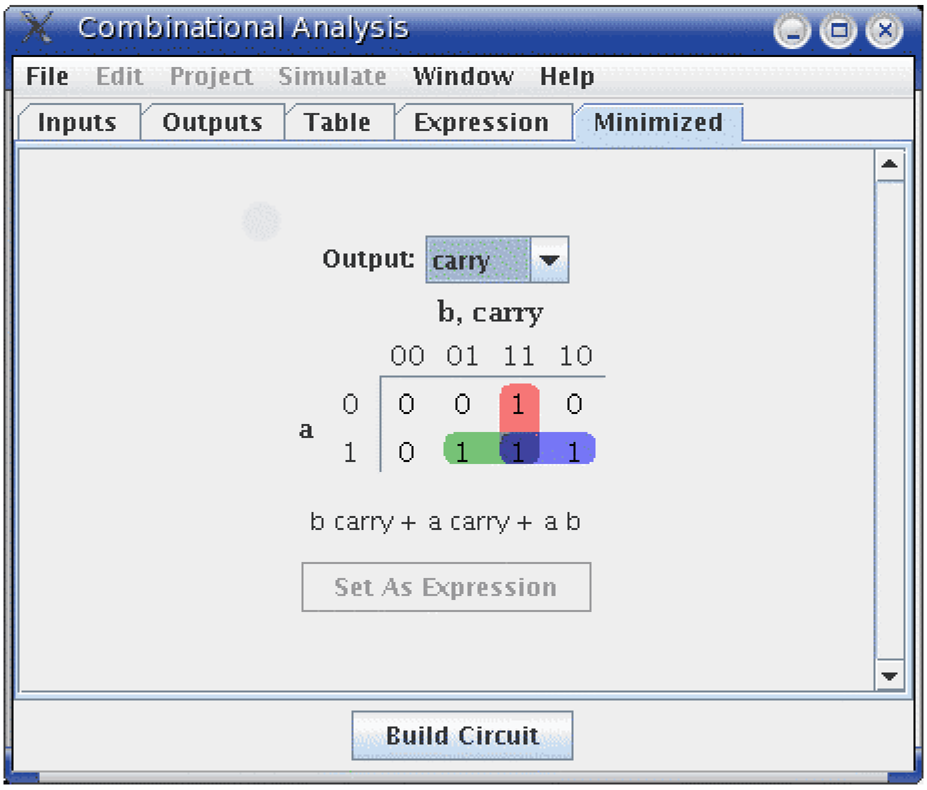
lowest precedence	`+	||`	**OR**

The following examples are all valid representations of the same expression. You could also mix the operators.

```
~a (b + c)
!a && (b || c)
NOT a AND (b OR c)
```

In general, parentheses within a sequence of ANDs (or ORs or XORs) do not matter. (In particular, when Logisim creates a corresponding circuit, it will ignore such parentheses.)

The Minimized tab



Output: carry

a \ b, carry	00	01	11	10
0	0	0	1	0
1	0	1	1	1

b carry + a carry + a b

The final tab displays a minimized sum-of-products expression corresponding to a column of the truth table. You can select which output's minimized expression you want to view using the selector at top.

If there are four or fewer inputs, a Karnaugh map corresponding to the variable will appear below the selector. You can click the Karnaugh map to change the corresponding truth table values. The Karnaugh map will also display the currently selected terms for the minimized expression as solid semitransparent rounded rectangles.

Below this is the minimized expression itself, formatted as in the Expression tab's display. If there are more than four inputs, the Karnaugh map will not appear; but the minimized expression will still be computed. (Logisim uses the Quine-McCluskey algorithm to compute the minimized expression. This is equivalent to a Karnaugh map, but it applies to any number of input variables.)

The Set As Expression button allows you to select the minimized expression as the expression corresponding to the variable. This will generally not be necessary, as edits to the truth table result in using the minimized expression for the changed column; but if you enter an expression through the Expression tab, this can be a convenient way to switch to the corresponding minimized expression.

Next: Generating a circuit.

Generating a circuit

The Build Circuit button will construct a circuit whose gates correspond to the currently chosen expressions for each output. The circuit's inputs and outputs will be displayed in top-down order corresponding to how they appear under the Inputs and Outputs tabs. Generally speaking, the constructed circuit will be attractive; and, indeed, one application of Logisim's Combinational Analysis module is to beautify poorly drawn circuits. Still, as with any automatic formatting, it will not express the structural details that a human-drawn circuit would.

When you click the Build Circuit button, a dialog box will appear prompting you to choose which project where you want the circuit and the name you wish to give it. If you type the name of an existing circuit, then that circuit will be replaced (after Logisim prompts you to confirm that you really want to do this).

The Build Circuit dialog includes two options. The Use Two-Input Gates Only option specifies that you want all gates constructed to have two inputs. (NOT gates, of course, constitute an exception to this rule.) The Use NAND Gates Only option specifies that you would like it to translate the circuit into one using only NAND gates. You can select both options if you want to use only two-input NAND gates.

Logisim cannot construct a NAND-only circuit for an expression containing any XOR operators. This option will therefore be disabled if any outputs' expressions contain XORs.

Next: *User's Guide*.

Memory components

The RAM and ROM components are two of the more useful components in Logisim's built-in libraries. However, because of the volume of information they can store, they are also two of the most complex components.

Documentation about how they work within a circuit can be found on the RAM and ROM pages of the *Library Reference*. This section of the *User's Guide* explains the interface allowing the user to view and edit memory contents.

Next: Poking memory.

Poking memory

You can manipulate the contents of memory using the Poke Tool, but the interface for this is severely limited by space constraints: For more than the simplest editing, you will probably find the integrated hex editor far more convenient.

Nonetheless, to view and edit values within the circuit, the Poke Tool has two modes of operation: You can edit the address displayed, and you can edit an individual value.

To edit the address displayed, click outside the display rectangle. Logisim will draw a red rectangle around the top address.

- Typing hexadecimal digits will change the top address accordingly.
- Typing the Enter key will scroll down one line.
- Typing the Backspace key will scroll up one line.
- Typing the space bar will scroll down one page (four lines).

To edit a particular value, click the value within the display rectangle. Logisim will draw a red rectangle around that address.

- Typing hexadecimal digits will change the value at the address currently being edited.
- Typing the Enter key will move to editing the value just below it in the display (down one line).
- Typing the Backspace key will move to editing the value at the previous address.
- Typing the space bar will move to editing the value at the following address.

Next: Pop-up menus and files.

Pop-up menus and files

The pop-up menu for memory includes four options in addition to the options common to all components:

- Edit Contents: Bring up a hex editor for editing the contents of memory.
- Clear Contents: Resets all values in memory to 0.
- Load Image...: Resets all values in memory based on the values found in a file using the format described below.
- Save Image...: Stores all values in memory into a file using the format described below.

The file format used for image files is intentionally simple; this permits you to write a program, such as an assembler, that generates memory images that can then be loaded into memory. As an example of this file format, if we had a 256-byte memory whose first five bytes were 2, 3, 0, 20, and -1, and all subsequent values were 0, then the image would be the following text file.

```
v2.0 raw
02
03
00
14
ff
```

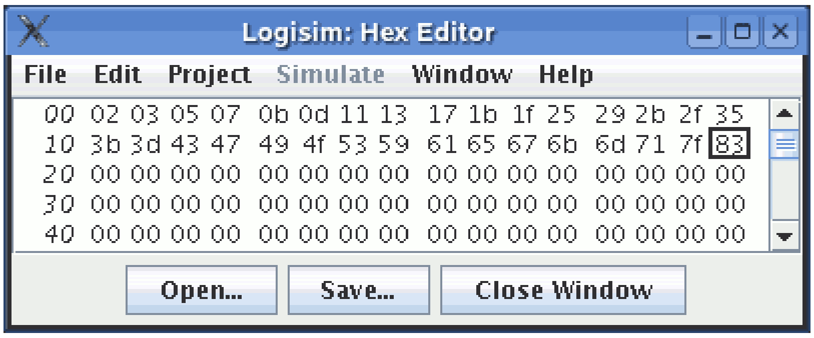
The first line identifies the file format used (currently, there is only one file format recognized). Subsequent values list the values in hexadecimal, starting from address 0; you can place several such values on the same line. Logisim will assume that any values unlisted in the file are zero.

The image file can use run-length encoding; for example, rather than list the value `00` sixteen times in a row, the file can include `16*00` rather than repeat 00 sixteen times. Notice than the number of repetitions is written in base 10. Files produced by Logisim will use run-length encoding for runs of at least four values.

Next: Hex editor.

Hex editor

Logisim includes an integrated hex editor for viewing and editing the contents of memory. To access it, bring up a pop-menu for the memory component and select Edit Contents.... For ROM components, which have the memory contents as part of the attribute value, you can alternatively access the hex editor by clicking the corresponding attribute value.



```
00  02 03 05 07  0b 0d 11 13  17 1b 1f 25  29 2b 2f 35
10  3b 3d 43 47  49 4f 53 59  61 65 67 6b  6d 71 7f 83
20  00 00 00 00  00 00 00 00  00 00 00 00  00 00 00 00
30  00 00 00 00  00 00 00 00  00 00 00 00  00 00 00 00
40  00 00 00 00  00 00 00 00  00 00 00 00  00 00 00 00
```

The numbers in italics at left display memory addresses, written in hexadecimal. The other numbers display values starting from that memory address; the hex editor may display four, eight, or sixteen values per line, depending on what fits in the window. To help with counting, each group of four values has a larger space between.

You can navigate through memory using the scroll bar or using the keyboard (the arrow keys, home, end, page up, and page down). Typing hexadecimal characters will alter the currently selected value.

You can select a range of values by dragging the mouse, shift-clicking the mouse, or navigating through memory with the keyboard while depressing the shift key. Values may be copied and pasted using the Edit menu; the clipboard can also be transferred into other applications.

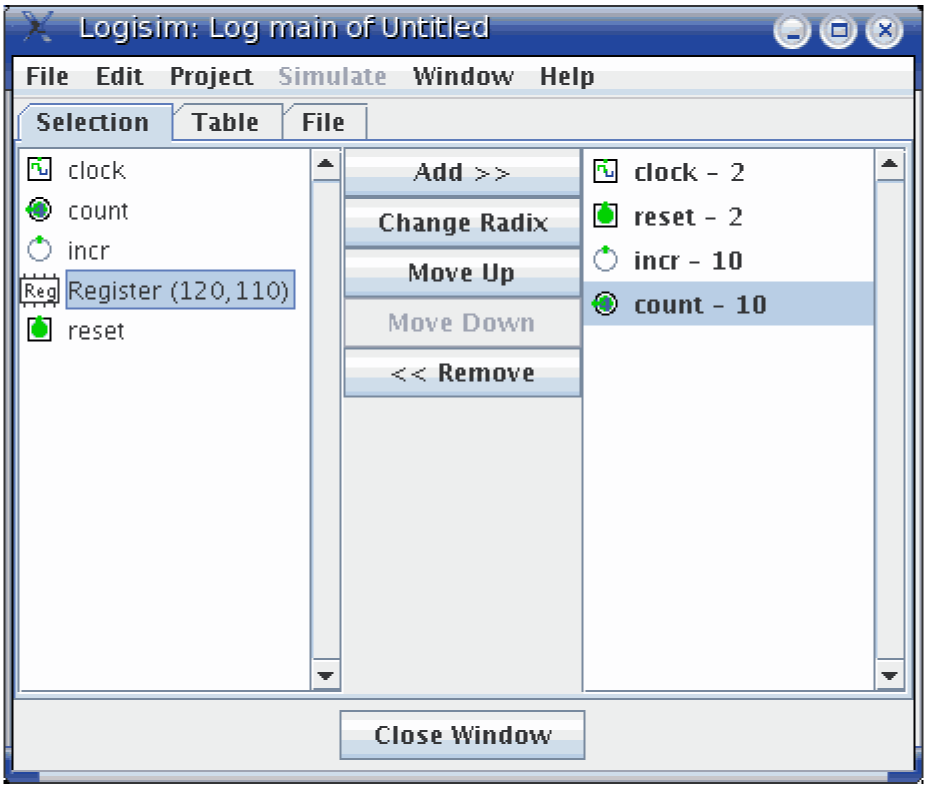
Next: *User's Guide*.

Logging

In testing a large circuit, and for documenting a circuit's behavior, a log of past circuit behavior. This is the purpose for Logisim's logging module, which allows you to select components whose values should be logged; optionally, you can specify a file into which the log should be placed.

Note: The logging module is in alpha phase; it may be buggy, and it is subject to significant changes in the future. While bug reports and suggestions are welcome for all of Logisim, they are particularly welcome concerning this relatively new feature. If you do not send comments, then it will likely not change.

You can enter the logging module via the Logging... option from the Simulate menu. It brings up a window with three tabs.



We will discuss each of these tabs separately.
The Selection tab
The Table tab
The File tab

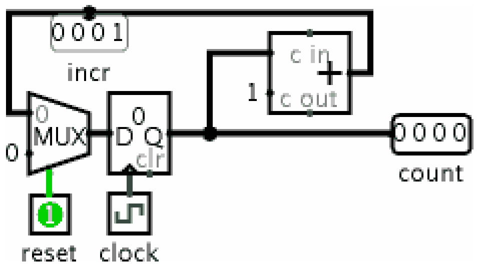
Each project has only one logging window; when you switch to viewing another circuit within the project, the logging window switches automatically to logging the other circuit instead. That is, it does this unless you are moving up or down within the same simulation, in which case the logging module does not change.

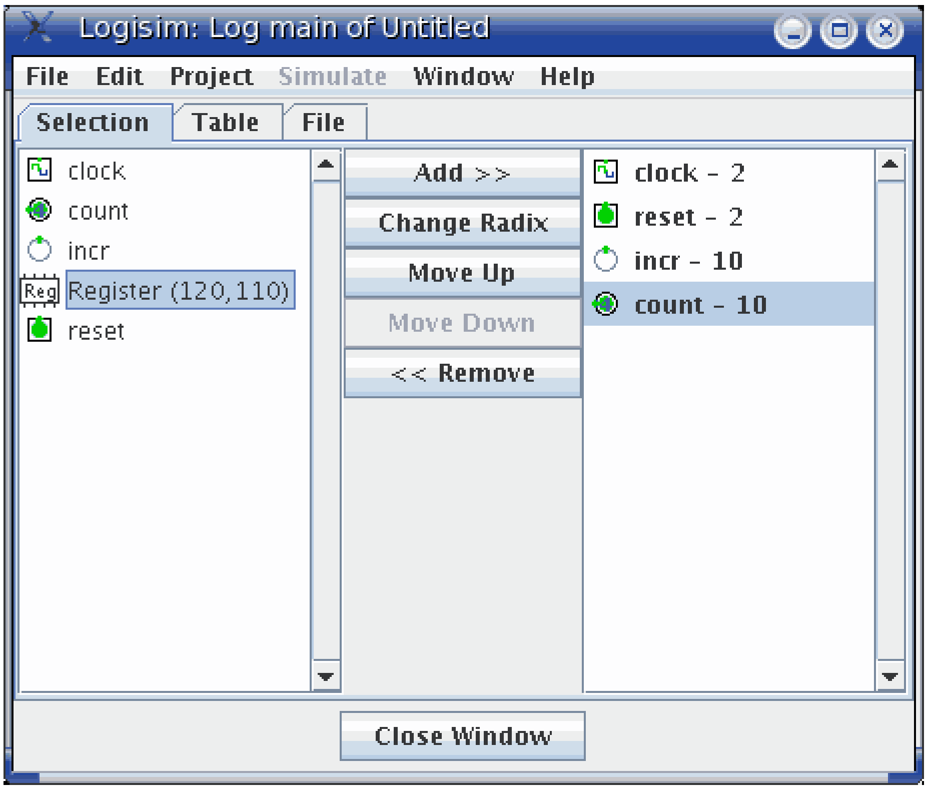
Note that when the logging module switches to logging another simulation, it will cease any logging into a file. Should you switch back to the simulation again, it will remember the configuration for that simulation, but you will need to re-enable the file logging manually.

Next: The Selection tab.

The Selection tab

The Selection tab allows you to select which values should be included in the log. The window below corresponds to the following circuit.





The tab is divided into three vertical areas. The first (leftmost) is a list of all components in the circuit whose values can be logged. Among the built-in libraries, the following types of components support logging.

Base library: Pin, Probe, and Clock components
Memory library: All components
For components with labels associated with them, their names correspond to the labels; other components' names specify their type and their location within the circuit. Any subcircuits will also appear in the list; they cannot be selected for logging, but eligible components within them can be. Note that the RAM component requires you to choose which memory address(es) should be logged; it allows logging only for the first 256 addresses.

The last (rightmost) vertical area lists those components that have been selected. Also, it indicates the radix (base) in which the component's multi-bit values will be logged; the radix does not have a significant effect on one-bit values.

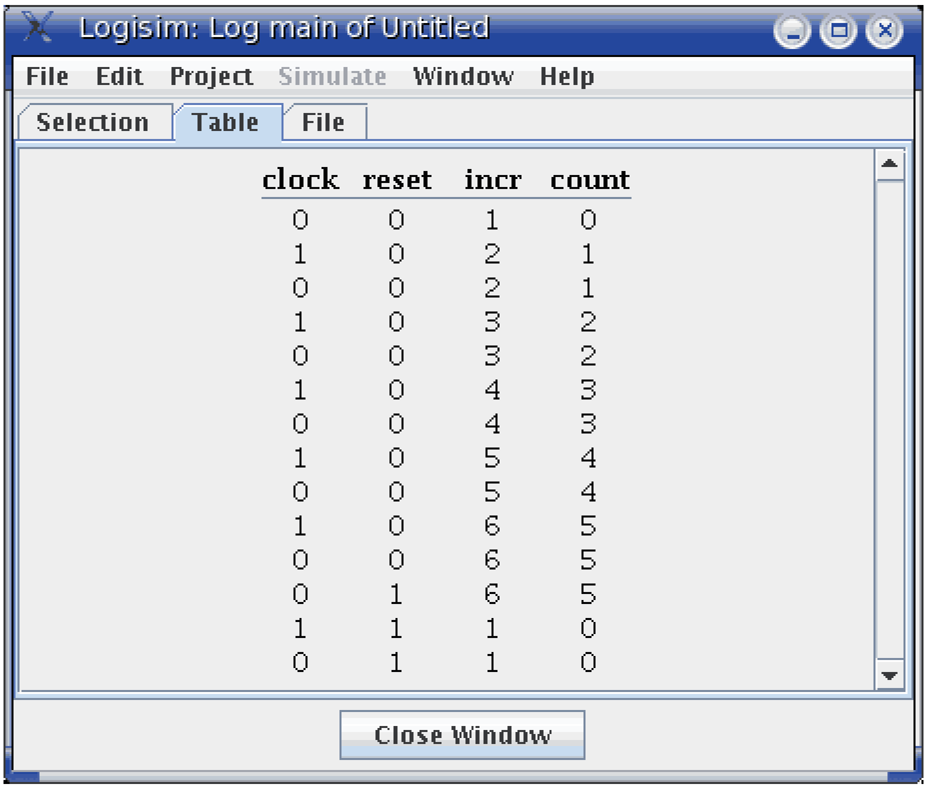
The middle column of buttons allows the manipulation of the items within the selection.

- **Add** adds the currently selected item(s) on the left side into the selection.
- **Change Radix** cycles the radix for the currently selected component in the selection between 2 (binary), 10 (decimal), and 16 (hexadecimal).
- **Move Up** moves the currently selected component in the selection forward one spot.
- **Move Down** moves the currently selected component in the selection back one spot.
- **Remove** removes the currently selected component in the selection.

Next: The Table tab.

The Table tab

The Table tab displays the current log graphically.


Logisim: Log main of Untitled
File Edit Project Simulate Window Help
Selection Table File
Close Window

clock	reset	incr	count
0	0	1	0
1	0	2	1
0	0	2	1
1	0	3	2
0	0	3	2
1	0	4	3
0	0	4	3
1	0	5	4
0	0	5	4
1	0	6	5
0	0	6	5
0	1	6	5
1	1	1	0
0	1	1	0

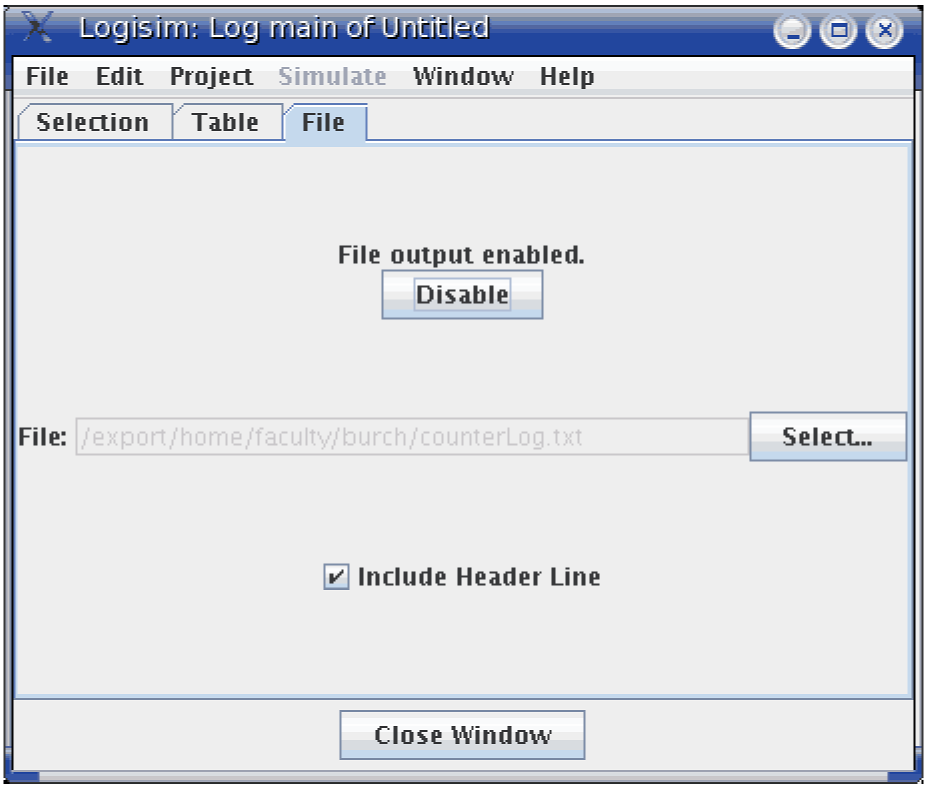
The table contains a column for each component in the selection. Each row in the selection displays a snapshot of the simulation after a propagation of values has completed. Any duplicate rows are not added into the log. Note that only the most recent 400 rows are displayed. Some rows may have empty entries if the corresponding component was not in the selection at the time that the row was computed.

The displayed table is for review only; it is not interactive.

Next: The File tab.

The File tab

The File tab allows you to specify a file into which the log should be placed.


Logisim: Log main of Untitled
File Edit Project Simulate Window Help
Selection Table File
Disable
Select...
Close Window

File output enabled.

File: /export/home/faculty/burch/counterLog.txt

☑ Include Header Line

At the top is an indicator of whether file logging is in progress and a button for enabling or disabling it. (Note that you cannot enable it until a file is selected below.) The button allows you to pause and restart file entry. When you switch in the project window to viewing another simulation, the file logging is automatically halted; if you return to the original one and want logging to continue, you will need to re-enable the file logging manually using the button at top.

In the middle is an indicator of what file is being logged to. To change it, use the Select... button. On selecting a file, file logging will automatically start. If you select a pre-existing file, Logisim will ask whether you want to overwrite the file or append the new entries onto the end.

At bottom you can control whether a header line should be placed into the file indicating which items are in the selection. If header lines are added, then a new header line will be placed into the file whenever the selection changes.

File format

Entries are placed into the file in tab-delimited format corresponding closely to what appears under the Table tab. (One difference is that any header lines will give the full path to components lying in subcircuits.) The format is intentionally simple so that you can feed it into another program for processing, such as a Python/Perl script or a spreadsheet program.

So that a script can process the file at the same time as Logisim is running, Logisim will flush the new records onto the disk every 500 ms. Note that Logisim may also intermittently close and later re-open the file during the simulation, particularly if several seconds have elapsed without any new records being added.