Quantum Computing Circuits

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Introduction

This is a tutorial on the use of Quantum`Computing` *Mathematica* add-on to generate and work with Quantum Computing Circuits.

Load the Package

First load the Quantum`Computing` package. Write:
Needs["Quantum`Computing`"];
then press at the same time the keys SHIFT-ENTER to evaluate. *Mathematica* will load the package. The semicolon prevents *Mathematica* from printing the welcome message:

```
Needs["Quantum`Computing`"]
```

```
Quantum`Computing` Version 2.2.0. (June 2010)
A Mathematica package for Quantum Computing
  in Dirac bra-ket notation and plotting of quantum circuits
by José Luis Gómez-Muñoz

Execute SetComputingAliases[] in order to use
  the keyboard to enter quantum objects in Dirac's notation
SetComputingAliases[] must be executed again in each new notebook that is created
```

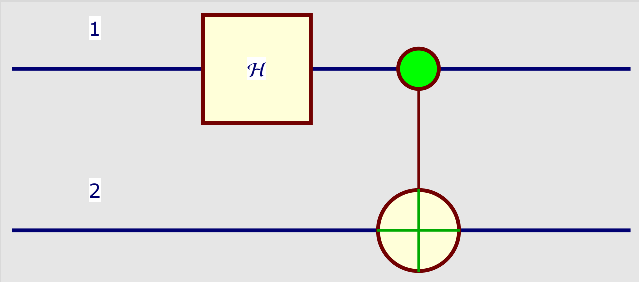
In order to use the keyboard to enter quantum objects write:
SetComputingAliases[ ];
then press at the same time the keys SHIFT-ENTER to evaluate. The semicolon prevents *Mathematica* from printing the help message. Remember that SetComputingAliases[ ] must be evaluated again in each new notebook:

```
SetComputingAliases[];
```

Simple Quantum Computing Circuits

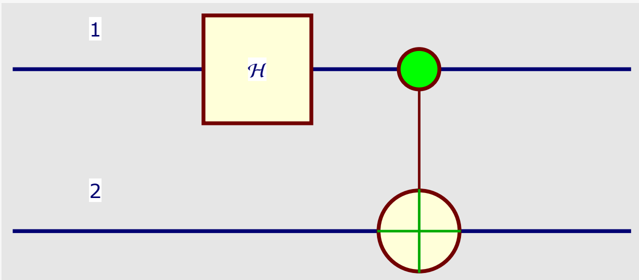
In order to plot a simple quantum circuit, press the keys:
QuantumPlot[[ESC]cnot[ESC] [ESC]on[ESC] [ESC]hg[ESC]]
Then press the [TAB] key several times to select the first "place holder" □, and press the keys:
1[TAB]2[TAB]1
then press at the same time the keys SHIFT-ENTER to evaluate:

$\texttt{QuantumPlot}\left[\mathcal{C}^{\{\hat{1}\}}\left[\mathcal{NOT}_{\hat{2}}\right]\cdot\mathcal{H}_{\hat{1}}\right]$



Quantum Circuits can be used exactly the same way as the Dirac expressions that were used to generate them.
As an example, write:
QuantumEvaluate[ ]
then **copy-paste** the circuit **inside** the brackets. Place the cursor to the right of the circuit and press the keys:
[ESC]on[ESC] [ESC]qqket[ESC]
Then press the [TAB] key one or several times to select the first "place holder" □, and press the keys:
0[TAB]1[TAB]0[TAB]2
then press at the same time the keys SHIFT-ENTER to evaluate:

$\texttt{QuantumEvaluate}[$



$\cdot\ \left|0_{\hat{1}}, 0_{\hat{2}}\right\rangle]$

$$\frac{\left|0_{\hat{1}}, 0_{\hat{2}}\right\rangle}{\sqrt{2}}+\frac{\left|1_{\hat{1}}, 1_{\hat{2}}\right\rangle}{\sqrt{2}}$$

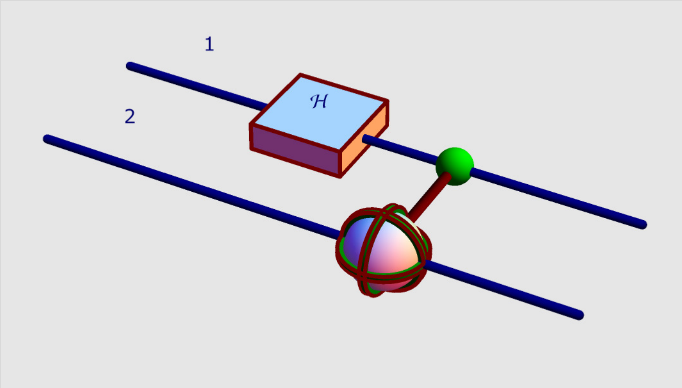
It is the same result that is obtained with the original Dirac expression, press the keys:
QuantumEvaluate[[ESC]cnot[ESC] [ESC]on[ESC] [ESC]hg[ESC] [ESC]on[ESC][ESC]qqket[ESC]]
Then press the [TAB] key several times to select the first "place holder" □, and press the keys:
1[TAB]2[TAB]1[TAB]0[TAB]1[TAB]0[TAB]2
then press at the same time the keys SHIFT-ENTER to evaluate:

$\texttt{QuantumEvaluate}\left[\mathcal{C}^{\{\hat{1}\}}\left[\mathcal{NOT}_{\hat{2}}\right]\cdot\mathcal{H}_{\hat{1}}\cdot\ \left|0_{\hat{1}}, 0_{\hat{2}}\right\rangle\right]$

$$\frac{\left|0_{\hat{1}}, 0_{\hat{2}}\right\rangle}{\sqrt{2}}+\frac{\left|1_{\hat{1}}, 1_{\hat{2}}\right\rangle}{\sqrt{2}}$$

In order to plot **in 3D** a simple quantum circuit, press the keys:
QuantumPlot**3D**[[ESC]cnot[ESC] [ESC]on[ESC] [ESC]hg[ESC]]
Then press the [TAB] key several times to select the first "place holder" □, and press the keys:
1[TAB]2[TAB]1
then press at the same time the keys SHIFT-ENTER to evaluate:

QuantumPlot3D$\left[\mathcal{C}^{\{\hat{1}\}}\left[\mathcal{NOT}_{\hat{2}}\right]\cdot\mathcal{H}_{\hat{1}}\right]$

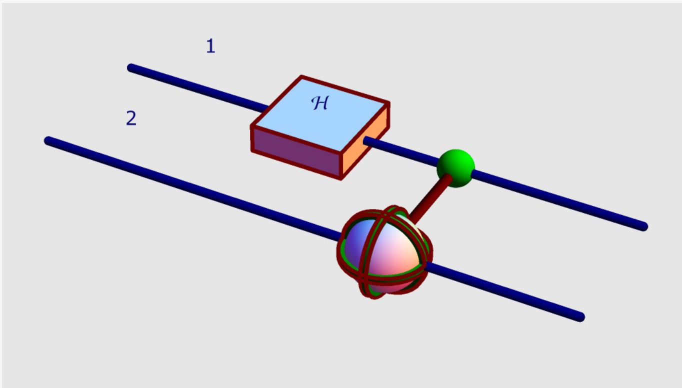


Quantum Circuits can be used exactly the same way as the Dirac expressions that were used to generate them.
As an example, write:

QuantumMatrixForm[ ]

then **copy-paste** the circuit from the *Mathematica* output **inside** the brackets. Finally press at the same time the keys SHIFT-ENTER to evaluate:

QuantumMatrixForm[



]

$$\begin{pmatrix} \frac{1}{\sqrt{2}} & 0 & \frac{1}{\sqrt{2}} & 0 \\ 0 & \frac{1}{\sqrt{2}} & 0 & \frac{1}{\sqrt{2}} \\ 0 & \frac{1}{\sqrt{2}} & 0 & -\frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} & 0 & -\frac{1}{\sqrt{2}} & 0 \end{pmatrix}$$

The same result is obtained from the original Dirac expression:

QuantumMatrixForm$\left[C^{\{\hat{1}\}}\left[\mathcal{NOT}_{\hat{2}}\right]\cdot\mathcal{H}_{\hat{1}}\right]$

$$\begin{pmatrix} \frac{1}{\sqrt{2}} & 0 & \frac{1}{\sqrt{2}} & 0 \\ 0 & \frac{1}{\sqrt{2}} & 0 & \frac{1}{\sqrt{2}} \\ 0 & \frac{1}{\sqrt{2}} & 0 & -\frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} & 0 & -\frac{1}{\sqrt{2}} & 0 \end{pmatrix}$$

Remember that QuantumMatrixForm is only for display purposes. For actual *Mathematica* calculations, QuantumMatrix must be used:

QuantumMatrix$\left[C^{\{\hat{1}\}}\left[\mathcal{NOT}_{\hat{2}}\right]\cdot\mathcal{H}_{\hat{1}}\right]$

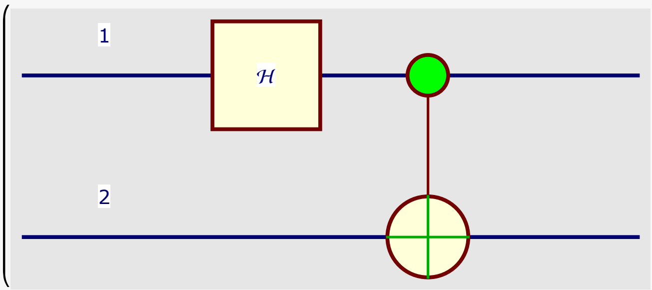
$$\left\{\left\{\frac{1}{\sqrt{2}},0,\frac{1}{\sqrt{2}},0\right\},\left\{0,\frac{1}{\sqrt{2}},0,\frac{1}{\sqrt{2}}\right\},\left\{0,\frac{1}{\sqrt{2}},0,-\frac{1}{\sqrt{2}}\right\},\left\{\frac{1}{\sqrt{2}},0,-\frac{1}{\sqrt{2}},0\right\}\right\}$$

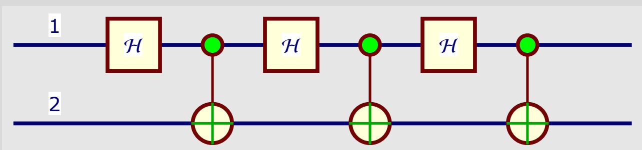
This is a Determinant, calculated from **QuantumMatrix,** not from QuantumMatrixForm

Det$\left[\textbf{QuantumMatrix}\left[C^{\{\hat{1}\}}\left[\mathcal{NOT}_{\hat{2}}\right]\cdot\mathcal{H}_{\hat{1}}\right]\right]$

-1

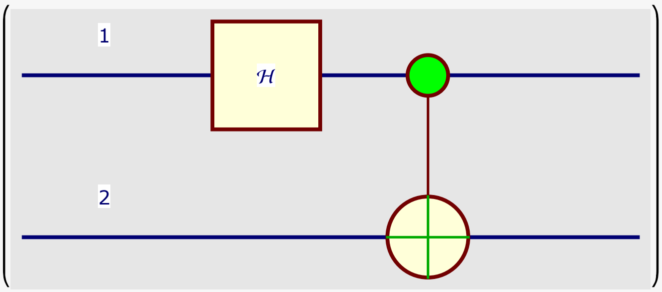
This is a **normal power** of a Quantum Circuit. Press [ESC]po[ESC] for the **normal power** template and **copy-paste** the circuit from a previous *Mathematica* output. Write a **3** in the exponent:

QuantumPlot[()^3]

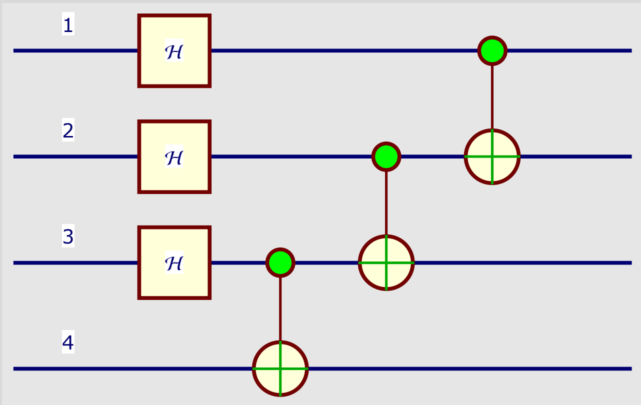


This is a **tensor power** of a Quantum Circuit. Press [ESC]tpow[ESC] for the **tensor power** template and **copy-paste** the circuit from the *Mathematica* output. Write a **3** in the exponent:

QuantumPlot[

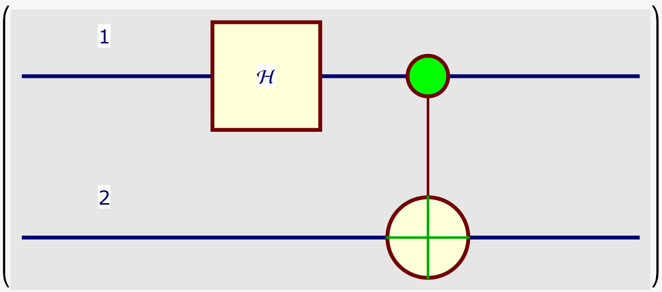


$^{\otimes 3}$]



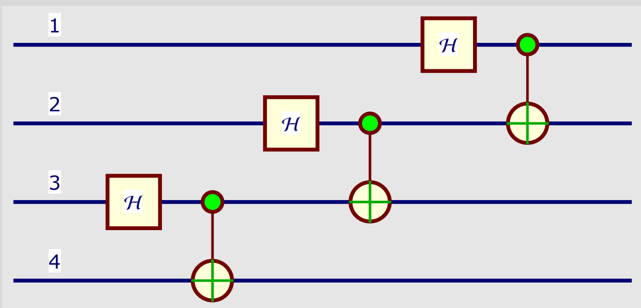
The option QuantumGateShifting→False can be used to show the circuit in another, equivalent form (the arrow → can be entered by pressing [ESC]->[ESC])

QuantumPlot[

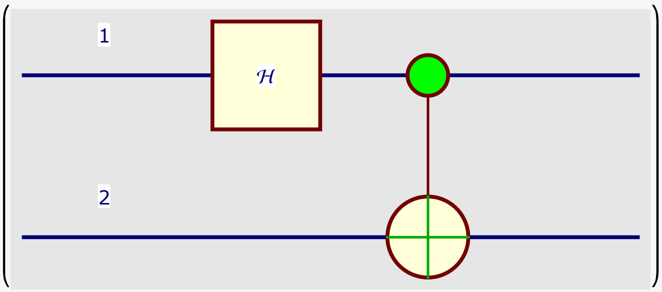


$^{\otimes 3}$,

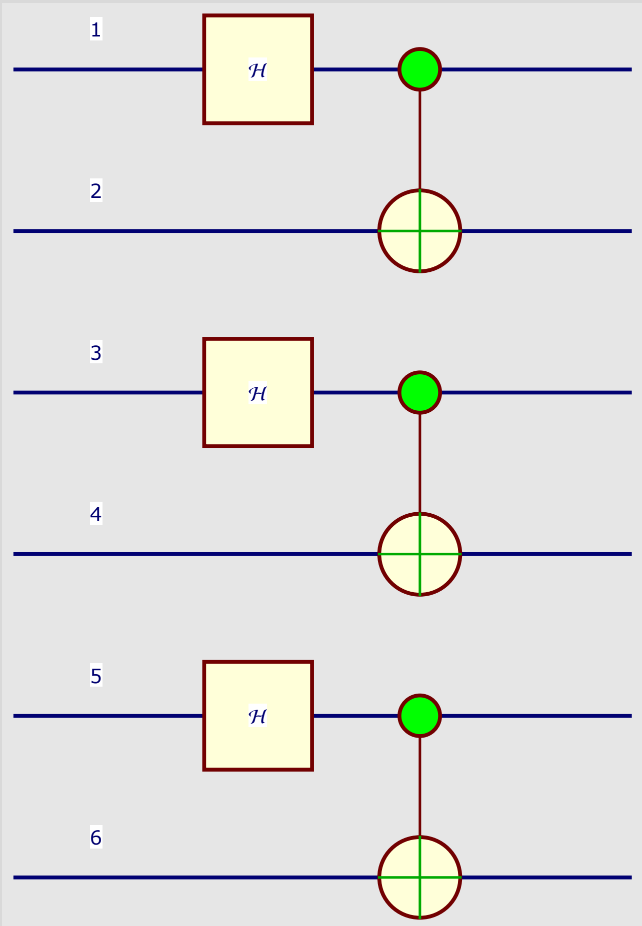
QuantumGateShifting → False]



Here is another tensor power of the circuit, where the "exponent" is actually a list that defines the first qubit for each "factor":

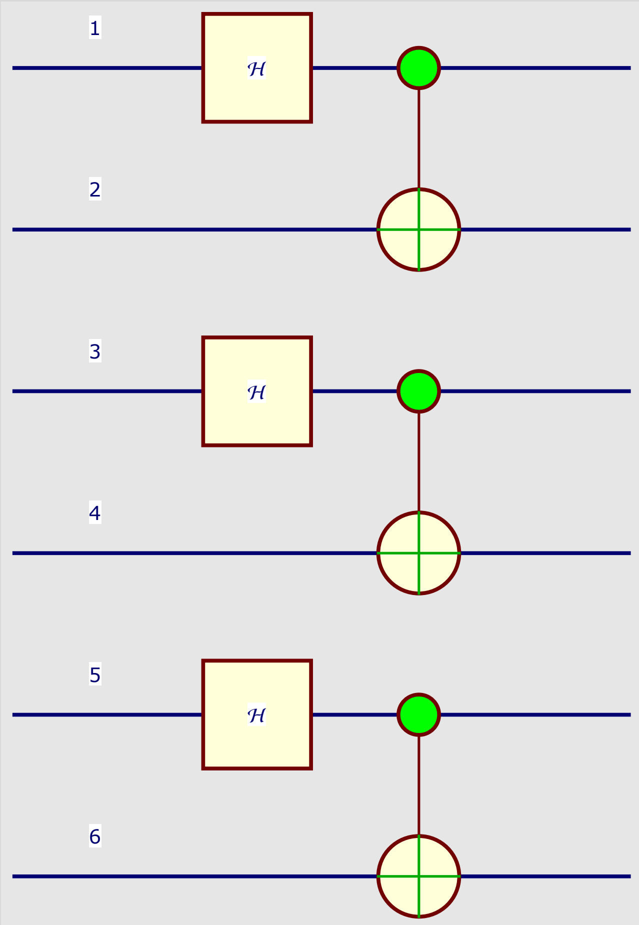
```
QuantumPlot[
```



```
]⊗{1,3,5}
```



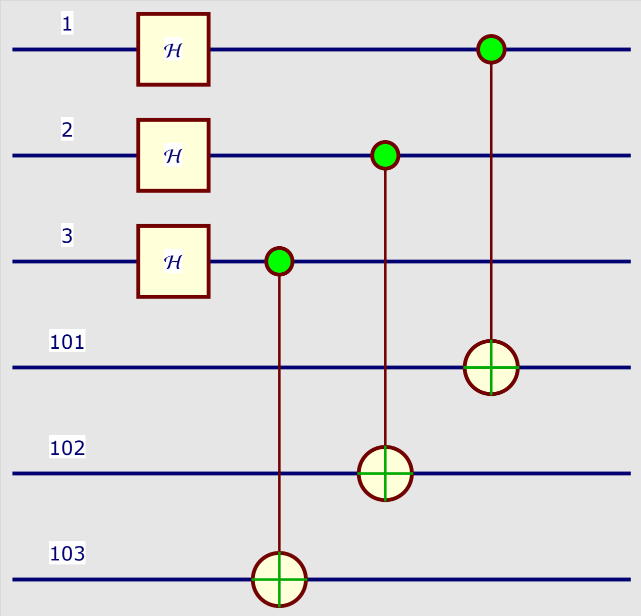
This is the same circuit obtained from the Dirac expression:

$\texttt{QuantumPlot}\left[\left(\mathcal{C}^{\{\hat{1}\}}\left[\mathcal{NOT}_{\hat{2}}\right]\cdot\mathcal{H}_{\hat{1}}\right)^{\otimes\{1,3,5\}}\right]$



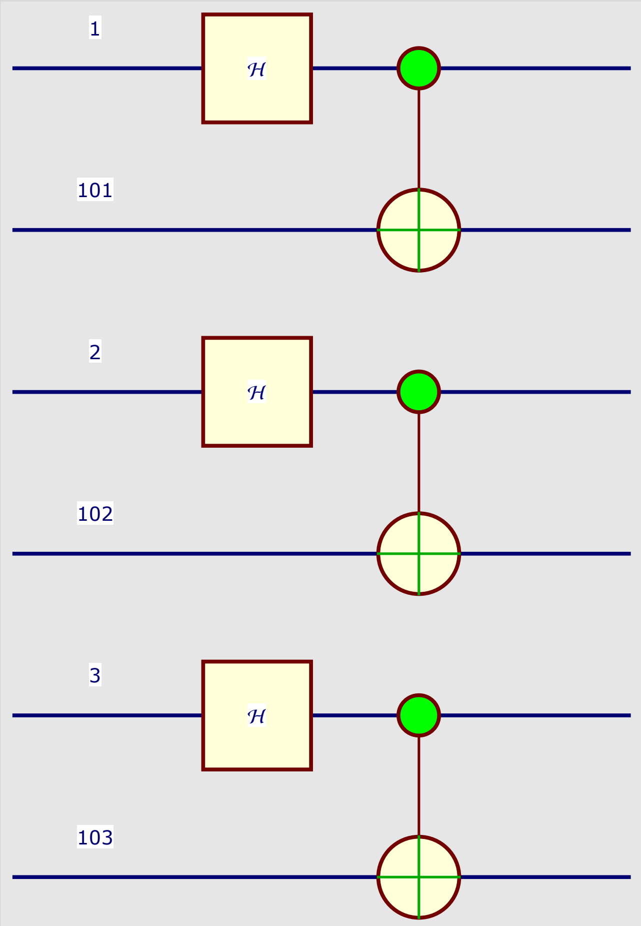
This circuit is similar to the previous one, but it looks different with the default qubit order:

$$\text{QuantumPlot}\left[\left(\mathcal{C}^{\{\hat{1}\}}\left[\mathcal{NOT}_{1\hat{0}1}\right]\cdot\mathcal{H}_{\hat{1}}\right)^{\otimes^3}\right]$$



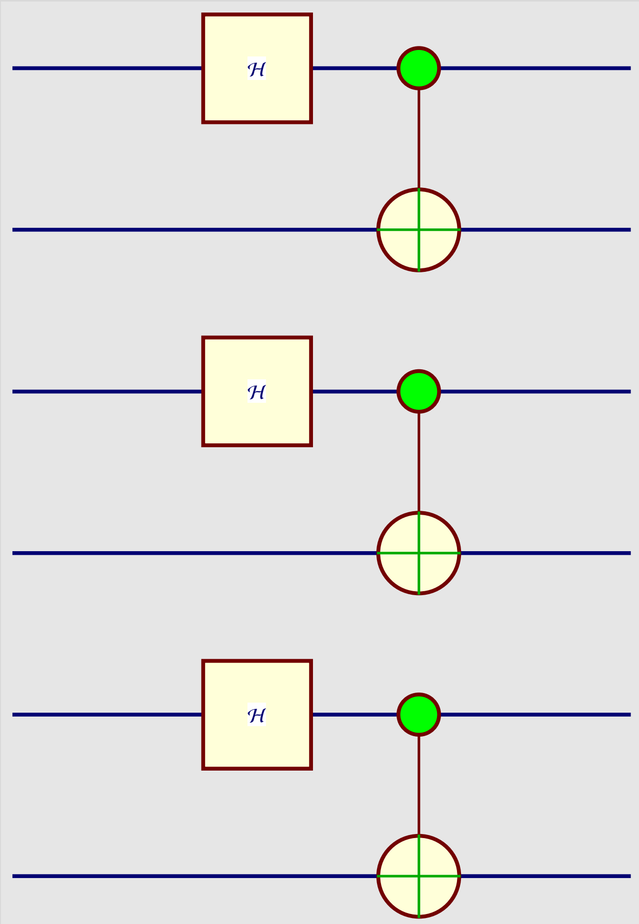
Using the option QubitList we can rearrange the circuit:

```
QuantumPlot[(C^{1̂}[NOT_{1̂01}] · H_{1̂})^{⊗3},
 QubitList → {1, 101, 2, 102, 3, 103}]
```



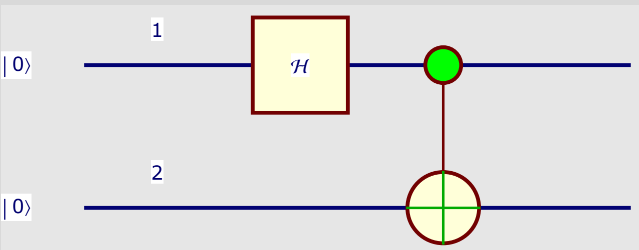
The qubit labels can be hidden using the option QubitLabels:

$$\text{QuantumPlot}\left[\left(\mathcal{C}^{\{\hat{1}\}}\left[\mathcal{NOT}_{\widehat{101}}\right]\cdot\mathcal{H}_{\hat{1}}\right)^{\otimes 3},\right.$$
$$\text{QubitList}\to\{1,101,2,102,3,103\},$$
$$\left.\text{QubitLabels}\to\text{False}\right]$$



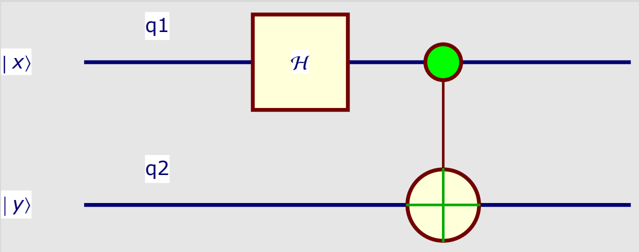
In order to plot a quantum circuit with initial (nonentangled) values for the qubits, press the keys:
QuantumPlot[[ESC]cnot[ESC] [ESC]on[ESC] [ESC]hg[ESC] [ESC]on[ESC][ESC]qqket[ESC]]
Then press the [TAB] key several times to select the first "place holder" □, and press the keys:
1[TAB]2[TAB]1[TAB]0[TAB]1[TAB]0[TAB]2
then press at the same time the keys SHIFT-ENTER to evaluate:

$$\text{QuantumPlot}\left[\mathcal{C}^{\{\hat{1}\}}\left[\mathcal{NOT}_{\hat{2}}\right]\cdot\mathcal{H}_{\hat{1}}\cdot\ \left|0_{\hat{1}},0_{\hat{2}}\right\rangle\right]$$



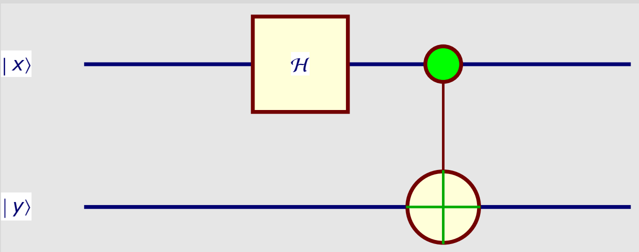
Qubit labels and initial qubit values do not need to be numbers:

$$\texttt{QuantumPlot}\left[\mathcal{C}^{\{\hat{q1}\}}\left[\mathcal{NOT}_{\hat{q2}}\right]\cdot\mathcal{H}_{\hat{q1}}\cdot\left|\mathbf{x}_{\hat{q1}},\ \mathbf{y}_{\hat{q2}}\right\rangle\right]$$



Use the option QubitLabels->False in order to have the plot without the qubit labels:

$$\texttt{QuantumPlot}\left[\mathcal{C}^{\{\hat{q1}\}}\left[\mathcal{NOT}_{\hat{q2}}\right]\cdot\mathcal{H}_{\hat{q1}}\cdot\left|\mathbf{x}_{\hat{q1}},\ \mathbf{y}_{\hat{q2}}\right\rangle,\ \texttt{QubitLabels}\rightarrow\texttt{False}\right]$$



You can also have the Dirac notation for the circuit:

$$\texttt{QuantumEvaluate}\left[\mathcal{C}^{\{\hat{1}\}}\left[\mathcal{NOT}_{\hat{2}}\right]\cdot\mathcal{H}_{\hat{1}}\right]$$

$$\frac{\left|0_{\hat{1}},0_{\hat{2}}\right\rangle\cdot\left\langle 0_{\hat{1}},0_{\hat{2}}\right|}{\sqrt{2}}+\frac{\left|1_{\hat{1}},1_{\hat{2}}\right\rangle\cdot\left\langle 0_{\hat{1}},0_{\hat{2}}\right|}{\sqrt{2}}+\frac{\left|0_{\hat{1}},1_{\hat{2}}\right\rangle\cdot\left\langle 0_{\hat{1}},1_{\hat{2}}\right|}{\sqrt{2}}+\frac{\left|1_{\hat{1}},0_{\hat{2}}\right\rangle\cdot\left\langle 0_{\hat{1}},1_{\hat{2}}\right|}{\sqrt{2}}+\frac{\left|0_{\hat{1}},0_{\hat{2}}\right\rangle\cdot\left\langle 1_{\hat{1}},0_{\hat{2}}\right|}{\sqrt{2}}-\frac{\left|1_{\hat{1}},1_{\hat{2}}\right\rangle\cdot\left\langle 1_{\hat{1}},0_{\hat{2}}\right|}{\sqrt{2}}+\frac{\left|0_{\hat{1}},1_{\hat{2}}\right\rangle\cdot\left\langle 1_{\hat{1}},1_{\hat{2}}\right|}{\sqrt{2}}-\frac{\left|1_{\hat{1}},0_{\hat{2}}\right\rangle\cdot\left\langle 1_{\hat{1}},1_{\hat{2}}\right|}{\sqrt{2}}$$

TraditionalForm gives a format closer to the the format used in papers and textbooks:

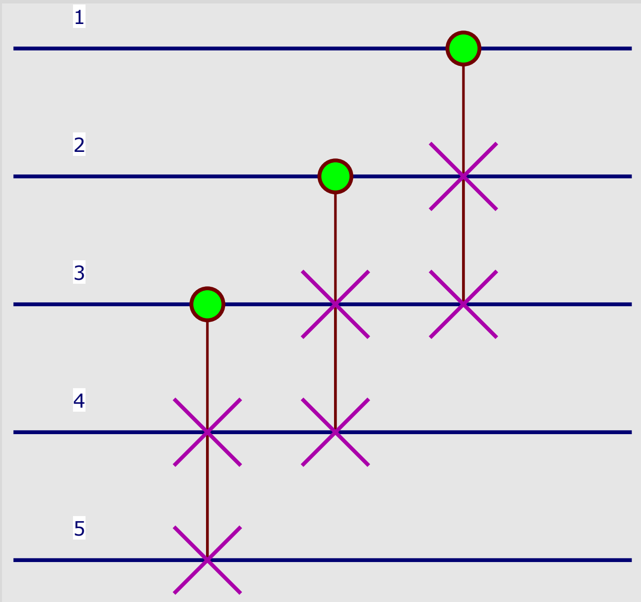
$$\texttt{TraditionalForm}\left[\texttt{QuantumEvaluate}\left[\mathcal{C}^{\{\hat{1}\}}\left[\mathcal{NOT}_{\hat{2}}\right]\cdot\mathcal{H}_{\hat{1}}\right]\right]$$

$$\frac{|00\rangle\langle 00|}{\sqrt{2}}+\frac{|11\rangle\langle 00|}{\sqrt{2}}+\frac{|01\rangle\langle 01|}{\sqrt{2}}+\frac{|10\rangle\langle 01|}{\sqrt{2}}+\frac{|00\rangle\langle 10|}{\sqrt{2}}-\frac{|11\rangle\langle 10|}{\sqrt{2}}+\frac{|01\rangle\langle 11|}{\sqrt{2}}-\frac{|10\rangle\langle 11|}{\sqrt{2}}$$

In order to plot the circuit of a tensor product of FREDKIN gates, press the keys:
QuantumPlot[[ESC]tprod[ESC]]
Then press the [TAB] key one or more times to select the first "place holder" □, and press the keys:
j[TAB]1[TAB]3[TAB]
Then press the keys:
[ESC]fred[ESC]
Then press the [TAB] key one or more times to select the first "place holder" □, and press the keys:
j [TAB] j+1[TAB]j+2
then press at the same time the keys SHIFT-ENTER to evaluate:

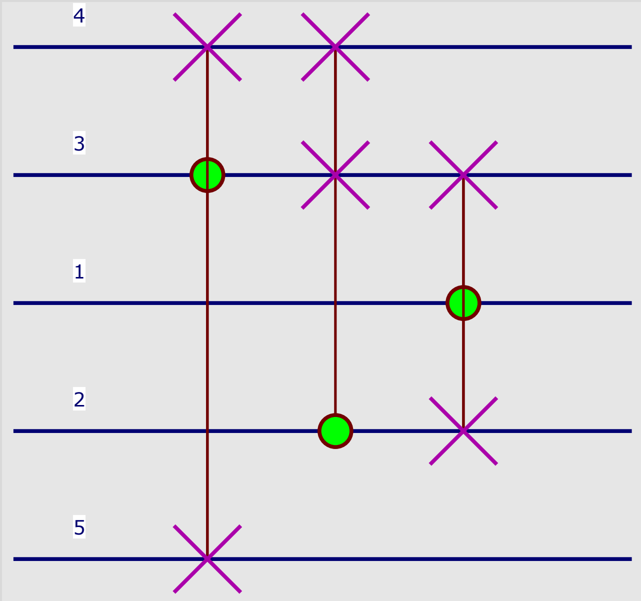
```
QuantumPlot[⊗_{j=1}^{3} 𝓕𝓡𝓔𝓓𝓚𝓘𝓝_{ĵ, ĵ+1, ĵ+2}]
```

$$\text{QuantumPlot}\left[\bigotimes_{j=1}^{3} \mathcal{FREDKIN}_{\hat{j},\widehat{j+1},\widehat{j+2}}\right]$$



Use the option QubitList in order to have the plot with some (or all) wires in a differente order. Press the keys [ESC]qb[ESC] in order to enter the qubit template:

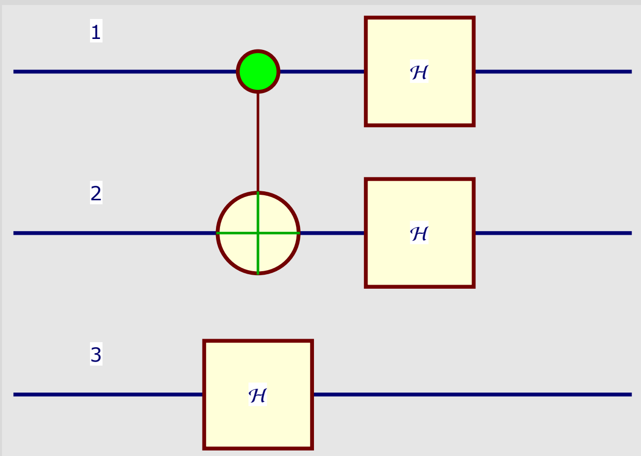
$$\texttt{QuantumPlot}\left[\bigotimes_{j=1}^{3} \mathcal{FREDKIN}_{\hat{j},\,\widehat{j+1},\,\widehat{j+2}},\ \texttt{QubitList} \to \{\hat{4},\ \hat{3}\}\right]$$



The Notation $\mathcal{H}_{\{\hat{q1},\,\hat{q2}\}}$ for Plotting Quantum Gates in the Same Column

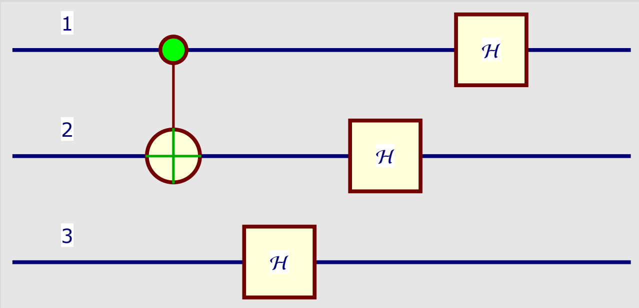
Notice that the three Hadamard gates are not in a column:

$$\texttt{QuantumPlot}\left[\left(\mathcal{H}_{\hat{1}}\right)^{\otimes 3} \cdot \mathcal{C}^{\{\hat{1}\}}\left[\mathcal{NOT}_{\hat{2}}\right]\right]$$



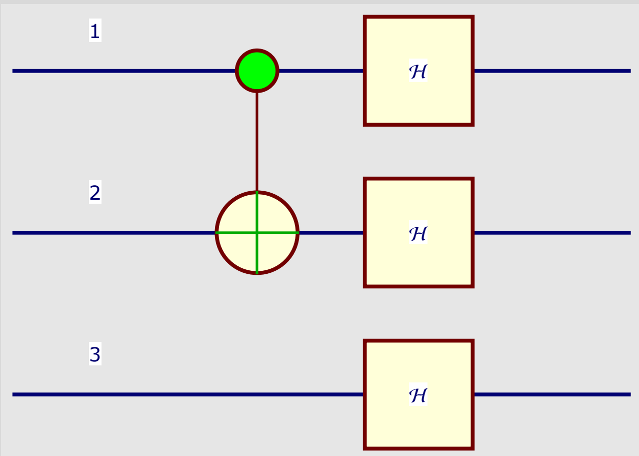
Notice that the Hadamard gates are not in a column:

$$\texttt{QuantumPlot}\left[\left(\mathcal{H}_{\hat{1}}\right)^{\otimes 3}\cdot \mathcal{C}^{\{\hat{1}\}}\left[\mathcal{NOT}_{\hat{2}}\right],\ \texttt{QuantumGateShifting}\rightarrow\texttt{False}\right]$$



There is a notation that allows to have all the $\mathcal{H}$ gates in the same column.
Press the keys [ESC]hggg[ESC] for the template:

$$\texttt{QuantumPlot}\left[\mathcal{H}_{\{\hat{1},\hat{2},\hat{3}\}}\cdot \mathcal{C}^{\{\hat{1}\}}\left[\mathcal{NOT}_{\hat{2}}\right]\right]$$



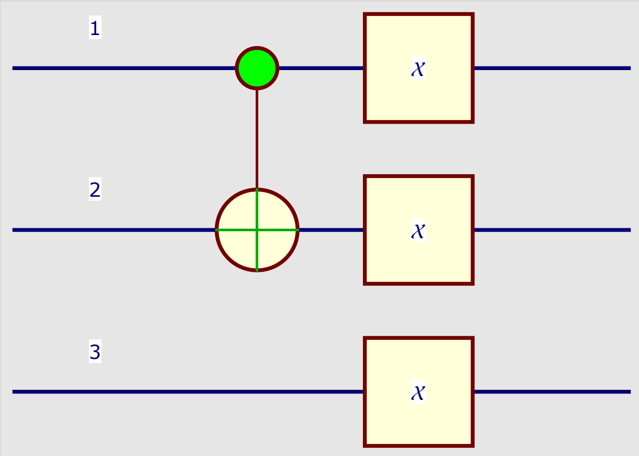
These two notations evaluate to the same Dirac expression, the only diference is whether gates will be plotted in the same column or not in a quantum circuit:

$$\texttt{QuantumEvaluate}\left[\mathcal{H}_{\{\hat{1},\hat{2},\hat{3}\}}\right] == \texttt{QuantumEvaluate}\left[\left(\mathcal{H}_{\hat{1}}\right)^{\otimes 3}\right]$$

```
True
```

There is a notation that allows to have all the $\mathcal{X}$ gates in the same column.
Press the keys [ESC]xggg[ESC] for the template:

QuantumPlot$\left[\mathcal{X}_{\{\hat{1},\hat{2},\hat{3}\}} \cdot \mathcal{C}^{\{\hat{1}\}}\left[\mathcal{NOT}_{\hat{2}}\right]\right]$



These two notations evaluate to the same Dirac expression, the only diference is whether gates will be plotted in the same column or not in a quantum circuit:

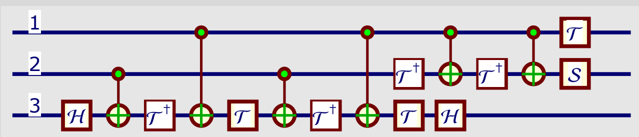
QuantumEvaluate$\left[\mathcal{X}_{\{\hat{1},\hat{2},\hat{3}\}}\right]$ == QuantumEvaluate$\left[\left(\mathcal{X}_{\hat{1}}\right)^{\otimes 3}\right]$

```
True
```

Textbook Examples

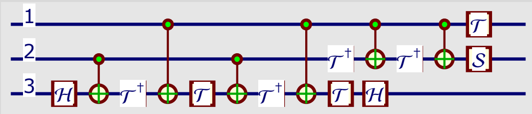
It is a textbook exercise to show that the following circuit is equivalente to a Toffoli (controlled-controlled-not) gate. **Press [ESC]her[ESC] for the "Hermitian Conjugate" $(\square)^{\dagger}$ template**:

QuantumPlot$\left[\mathcal{T}_{\hat{1}} \cdot \mathcal{S}_{\hat{2}} \cdot \mathcal{C}^{\{\hat{1}\}}\left[\mathcal{NOT}_{\hat{2}}\right] \cdot \left(\mathcal{T}_{\hat{2}}\right)^{\dagger} \cdot \mathcal{C}^{\{\hat{1}\}}\left[\mathcal{NOT}_{\hat{2}}\right] \cdot \left(\mathcal{T}_{\hat{2}}\right)^{\dagger} \cdot \mathcal{H}_{\hat{3}} \cdot \mathcal{T}_{\hat{3}} \cdot \right.$
$\left. \mathcal{C}^{\{\hat{1}\}}\left[\mathcal{NOT}_{\hat{3}}\right] \cdot \left(\mathcal{T}_{\hat{3}}\right)^{\dagger} \cdot \mathcal{C}^{\{\hat{2}\}}\left[\mathcal{NOT}_{\hat{3}}\right] \cdot \mathcal{T}_{\hat{3}} \cdot \mathcal{C}^{\{\hat{1}\}}\left[\mathcal{NOT}_{\hat{3}}\right] \cdot \left(\mathcal{T}_{\hat{3}}\right)^{\dagger} \cdot \mathcal{C}^{\{\hat{2}\}}\left[\mathcal{NOT}_{\hat{3}}\right] \cdot \mathcal{H}_{\hat{3}}\right]$

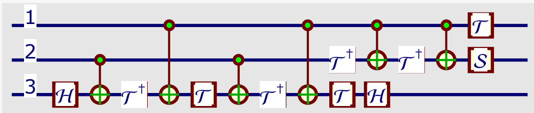


Use the option **ImageSize → {250, Automatic}** to have a smaller version of the circuit.
Press the keys [ESC]->[ESC] ("Escape","Minus","Grater Than","Escape") in order to enter the arrow →

QuantumPlot$\left[\mathcal{T}_{\hat{1}} \cdot \mathcal{S}_{\hat{2}} \cdot \mathcal{C}^{\{\hat{1}\}}\left[\mathcal{NOT}_{\hat{2}}\right] \cdot \left(\mathcal{T}_{\hat{2}}\right)^{\dagger} \cdot \mathcal{C}^{\{\hat{1}\}}\left[\mathcal{NOT}_{\hat{2}}\right] \cdot \left(\mathcal{T}_{\hat{2}}\right)^{\dagger} \cdot \mathcal{H}_{\hat{3}} \cdot \mathcal{T}_{\hat{3}} \cdot \mathcal{C}^{\{\hat{1}\}}\left[\mathcal{NOT}_{\hat{3}}\right] \cdot \left(\mathcal{T}_{\hat{3}}\right)^{\dagger} \cdot \mathcal{C}^{\{\hat{2}\}}\left[\mathcal{NOT}_{\hat{3}}\right] \cdot \mathcal{T}_{\hat{3}} \cdot \mathcal{C}^{\{\hat{1}\}}\left[\mathcal{NOT}_{\hat{3}}\right] \cdot \left(\mathcal{T}_{\hat{3}}\right)^{\dagger} \cdot \mathcal{C}^{\{\hat{2}\}}\left[\mathcal{NOT}_{\hat{3}}\right] \cdot \mathcal{H}_{\hat{3}}\right.$, **ImageSize → {250, Automatic}**]



This is the Truth-Table of the circuit (write **QuantumTableForm[ ]** and **copy-paste** the circuit from the previous calculation inside the brackets). Notice that only the two last rows of the table are different from the table of an identity:

QuantumTableForm[]

	Input	Output
0	$\lvert 0_{\hat{1}}, 0_{\hat{2}}, 0_{\hat{3}}\rangle$	$\lvert 0_{\hat{1}}, 0_{\hat{2}}, 0_{\hat{3}}\rangle$
1	$\lvert 0_{\hat{1}}, 0_{\hat{2}}, 1_{\hat{3}}\rangle$	$\lvert 0_{\hat{1}}, 0_{\hat{2}}, 1_{\hat{3}}\rangle$
2	$\lvert 0_{\hat{1}}, 1_{\hat{2}}, 0_{\hat{3}}\rangle$	$\lvert 0_{\hat{1}}, 1_{\hat{2}}, 0_{\hat{3}}\rangle$
3	$\lvert 0_{\hat{1}}, 1_{\hat{2}}, 1_{\hat{3}}\rangle$	$\lvert 0_{\hat{1}}, 1_{\hat{2}}, 1_{\hat{3}}\rangle$
4	$\lvert 1_{\hat{1}}, 0_{\hat{2}}, 0_{\hat{3}}\rangle$	$\lvert 1_{\hat{1}}, 0_{\hat{2}}, 0_{\hat{3}}\rangle$
5	$\lvert 1_{\hat{1}}, 0_{\hat{2}}, 1_{\hat{3}}\rangle$	$\lvert 1_{\hat{1}}, 0_{\hat{2}}, 1_{\hat{3}}\rangle$
6	$\lvert 1_{\hat{1}}, 1_{\hat{2}}, 0_{\hat{3}}\rangle$	$\lvert 1_{\hat{1}}, 1_{\hat{2}}, 1_{\hat{3}}\rangle$
7	$\lvert 1_{\hat{1}}, 1_{\hat{2}}, 1_{\hat{3}}\rangle$	$\lvert 1_{\hat{1}}, 1_{\hat{2}}, 0_{\hat{3}}\rangle$

We can see that is identical the Truth-Table of the Toffoli gate:
QuantumTableForm[[ESC]toff[ESC]]
Then press the [TAB] key one or more times to select the first "place holder" □, and press the keys:
1 [TAB] 2 [TAB] 3
then press at the same time the keys SHIFT-ENTER to evaluate. Notice that only the two last rows of the table are different from the table of an identity:

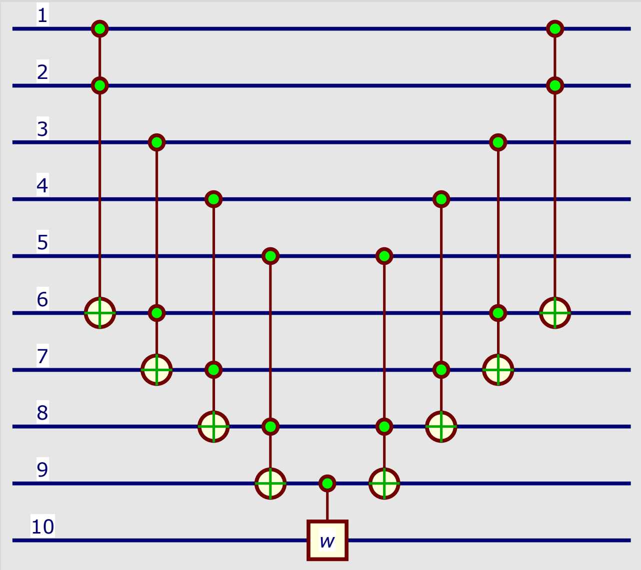
QuantumTableForm$\left[\mathcal{TOFFOLI}_{\hat{1},\hat{2},\hat{3}}\right]$

	Input	Output
0	$\lvert 0_{\hat{1}}, 0_{\hat{2}}, 0_{\hat{3}}\rangle$	$\lvert 0_{\hat{1}}, 0_{\hat{2}}, 0_{\hat{3}}\rangle$
1	$\lvert 0_{\hat{1}}, 0_{\hat{2}}, 1_{\hat{3}}\rangle$	$\lvert 0_{\hat{1}}, 0_{\hat{2}}, 1_{\hat{3}}\rangle$
2	$\lvert 0_{\hat{1}}, 1_{\hat{2}}, 0_{\hat{3}}\rangle$	$\lvert 0_{\hat{1}}, 1_{\hat{2}}, 0_{\hat{3}}\rangle$
3	$\lvert 0_{\hat{1}}, 1_{\hat{2}}, 1_{\hat{3}}\rangle$	$\lvert 0_{\hat{1}}, 1_{\hat{2}}, 1_{\hat{3}}\rangle$
4	$\lvert 1_{\hat{1}}, 0_{\hat{2}}, 0_{\hat{3}}\rangle$	$\lvert 1_{\hat{1}}, 0_{\hat{2}}, 0_{\hat{3}}\rangle$
5	$\lvert 1_{\hat{1}}, 0_{\hat{2}}, 1_{\hat{3}}\rangle$	$\lvert 1_{\hat{1}}, 0_{\hat{2}}, 1_{\hat{3}}\rangle$
6	$\lvert 1_{\hat{1}}, 1_{\hat{2}}, 0_{\hat{3}}\rangle$	$\lvert 1_{\hat{1}}, 1_{\hat{2}}, 1_{\hat{3}}\rangle$
7	$\lvert 1_{\hat{1}}, 1_{\hat{2}}, 1_{\hat{3}}\rangle$	$\lvert 1_{\hat{1}}, 1_{\hat{2}}, 0_{\hat{3}}\rangle$

Another textbook example. In order to enter the "controlled-controlled not" gates press the keys [ESC]ccnot[ESC]. For the "tensor product" press the keys [ESC]tprod[ESC]. For an arbitrary controlled gate press the keys [ESC]cgate[ESC]. For the arbitrary gate w, press the keys [ESC]qg[ESC]

```
SetQuantumGate[w, 1];
QuantumPlot[
```

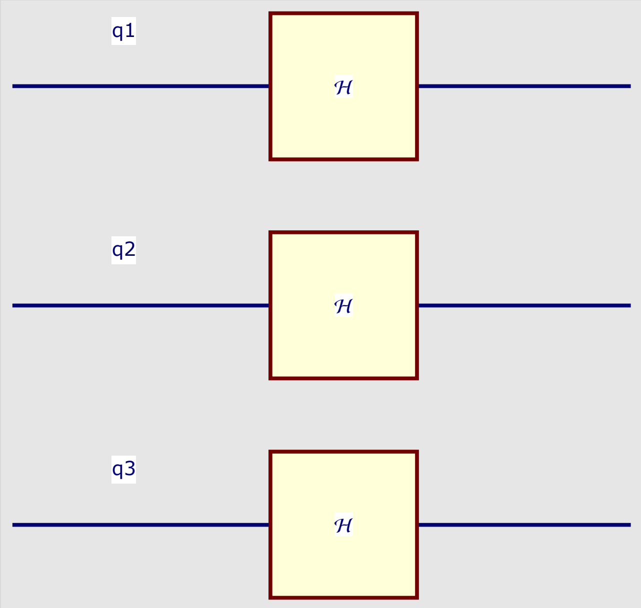
$$C^{\{\hat{1},\hat{2}\}}\left[\mathcal{NOT}_{\hat{6}}\right] \cdot \left(\bigotimes_{j=1}^{3} C^{\{\widehat{j+2},\widehat{j+5}\}}\left[\mathcal{NOT}_{\widehat{j+6}}\right]\right) \cdot C^{\{\hat{9}\}}\left[\mathbf{w}_{\widehat{10}}\right] \cdot \left(\bigotimes_{j=1}^{3} C^{\{\widehat{6-j},\widehat{9-j}\}}\left[\mathcal{NOT}_{\widehat{10-j}}\right]\right) \cdot C^{\{\hat{1},\hat{2}\}}\left[\mathcal{NOT}_{\hat{6}}\right]\Big]$$



Quantum Register Notation

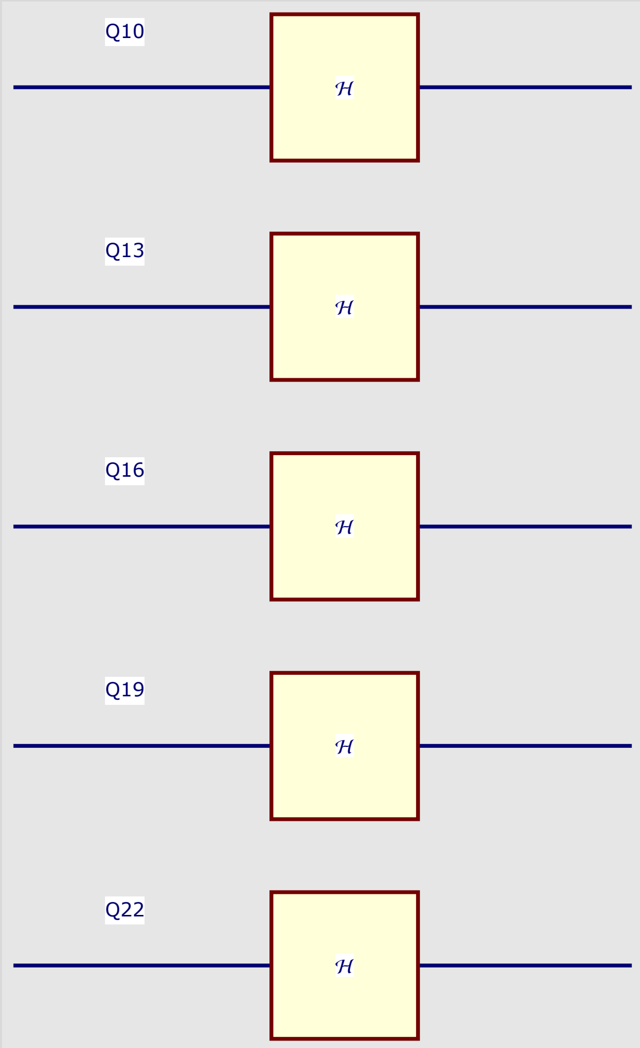
Press [ESC]hn[ESC] [TAB] [ESC]qr[ESC] to use the "quantum register" template in the Hadamard gate:

```
QuantumPlot[𝓗_{𝓡egister[3, "q"]}]
```



Press [ESC]hn[ESC] [TAB] [ESC]qr[ESC] to use the "quantum register" template in the Hadamard gate:

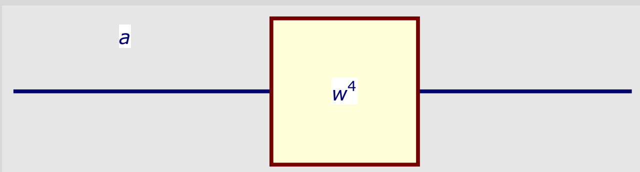
```
QuantumPlot[ℋ_Register[10,22,3,"Q"]]
```



Powers of Quantum Gates in Circuits

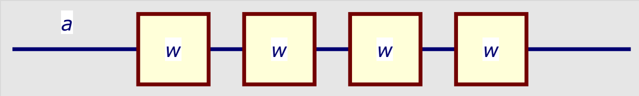
The power of a gate is by default shown as a single block. Press the keys [ESC]qg[ESC] in order to obtain the gate template $\square_{\hat{\square}}$

```
SetQuantumGate[w, 1];
QuantumPlot[w_â^4]
```



Integer powers of gates are shown as several gates if the option GatePowers is set to True. Press the keys [ESC]qg[ESC] in order to obtain the gate template $\square_{\hat{\square}}$

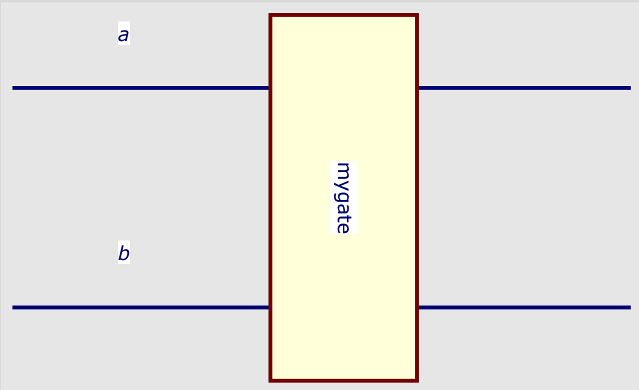
```
SetQuantumGate[w, 1];
QuantumPlot[w_â^4, QuantumGatePowers → False]
```



Gates of two qubits

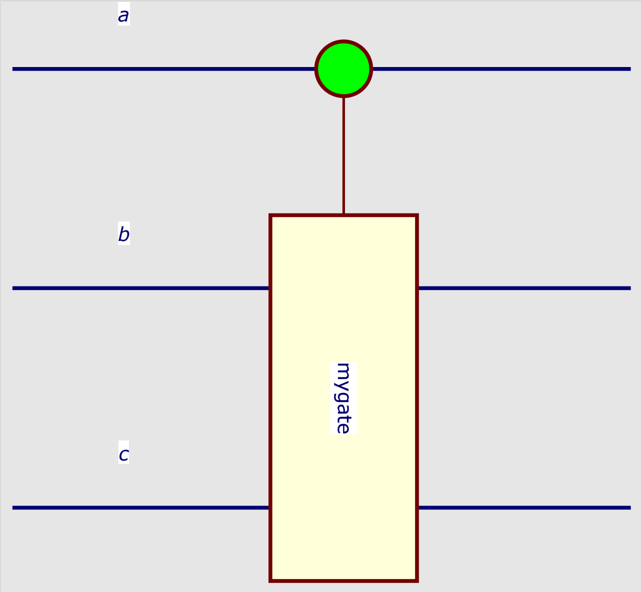
Here is a gate of two qubits. Press the keys [ESC]qqg[ESC] in order to obtain the gate template $\square_{\hat{\square},\hat{\square}}$

```
SetQuantumGate[mygate, 2];
QuantumPlot[mygate_â,b̂]
```



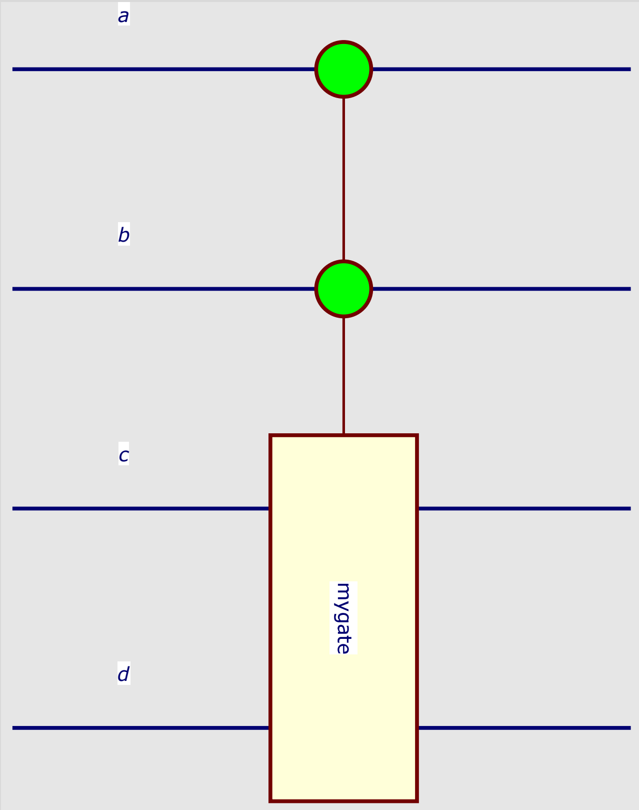
This is a controlled gate. Press the keys [ESC]cgate[ESC] in order to obtain the controlled gate template. Press the keys [ESC]qqg[ESC] in order to obtain the gate template $\square_{\hat{\square},\hat{\square}}$

```
SetQuantumGate[mygate, 2];
QuantumPlot[C^{â}[mygate_{b̂,ĉ}]]
```



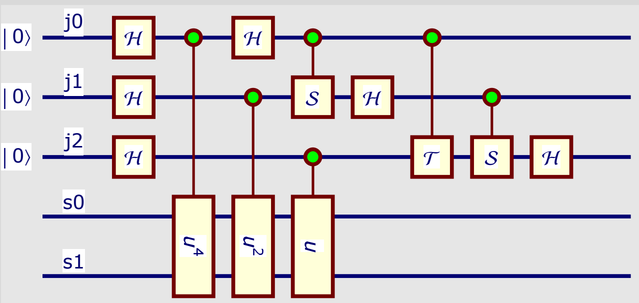
This is a controlled gate. Press the keys [ESC]ccgate[ESC] in order to obtain the controlled-controlled gate template $C^{\{\hat{\square},\hat{\square}\}}[\square]$. Press the keys [ESC]qqg[ESC] in order to obtain the gate template $\square_{\hat{\square},\hat{\square}}$

```
SetQuantumGate[mygate, 2];
QuantumPlot[C^{â,b̂}[mygate_{ĉ,d̂}]]
```



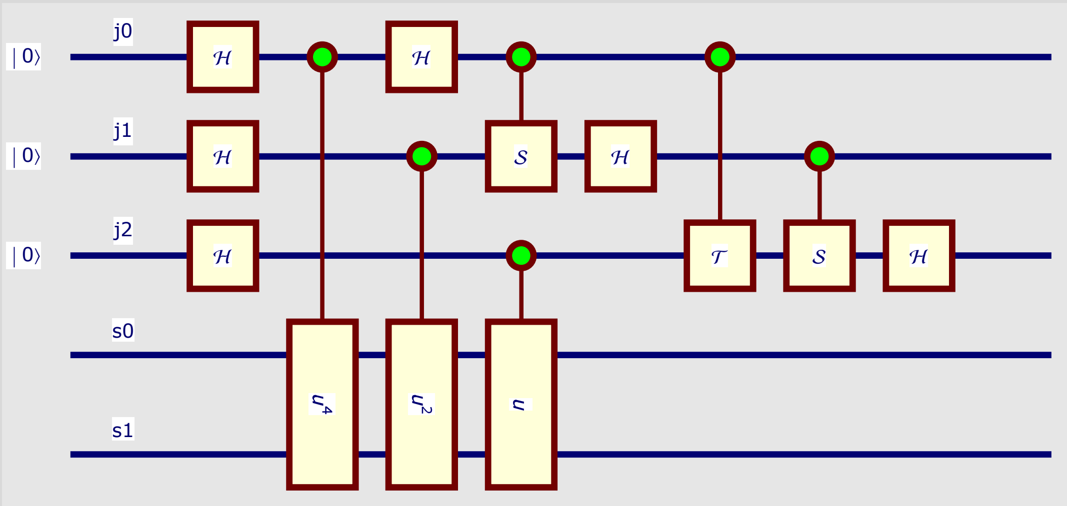
This circuit shows controlled gates of two qbits, powers of gates, and initial values for some of the qubits:

```
SetQuantumGate[u, 2];
QuantumPlot[
  H_ĵ2 · C^{ĵ1}[S_ĵ2] · C^{ĵ0}[T_ĵ2] · H_ĵ1 · C^{ĵ0}[S_ĵ1] · H_ĵ0 ·
   C^{ĵ2}[u_{ŝ0,ŝ1}] · C^{ĵ1}[u_{ŝ0,ŝ1}^2] · C^{ĵ0}[u_{ŝ0,ŝ1}^4] · H_ĵ2 · H_ĵ1 · H_ĵ0 · | 0_ĵ0, 0_ĵ1, 0_ĵ2〉]
```



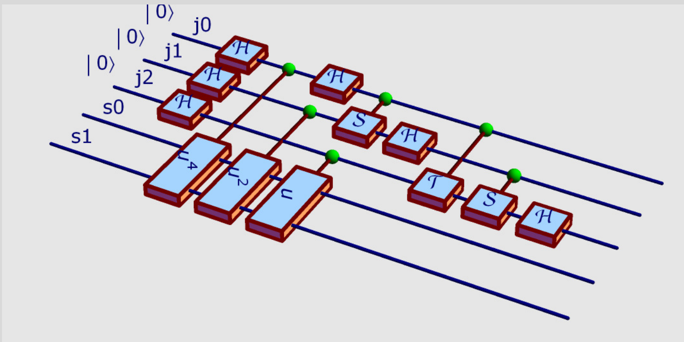
Use the option **ImageSize → {500, Automatic}** to have a larger version of the circuit:

```
SetQuantumGate[u, 2];
QuantumPlot[
 𝓗_ĵ2 · C^{ĵ1}[𝓢_ĵ2] · C^{ĵ0}[𝓣_ĵ2] · 𝓗_ĵ1 · C^{ĵ0}[𝓢_ĵ1] · 𝓗_ĵ0 · C^{ĵ2}[u_{ŝ0,ŝ1}] · C^{ĵ1}[u_{ŝ0,ŝ1}^2] ·
  C^{ĵ0}[u_{ŝ0,ŝ1}^4] · 𝓗_ĵ2 · 𝓗_ĵ1 · 𝓗_ĵ0 · |0_ĵ0, 0_ĵ1, 0_ĵ2⟩, ImageSize → {500, Automatic}]
```



A 3D-version of the circuit

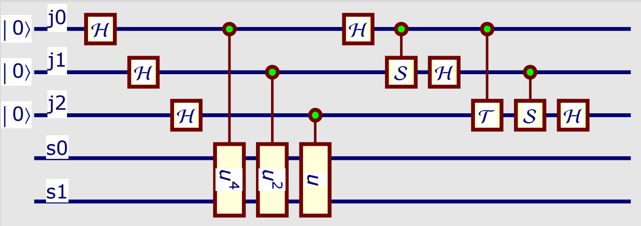
```
SetQuantumGate[u, 2];
QuantumPlot3D[
 𝓗_ĵ2 · C^{ĵ1}[𝓢_ĵ2] · C^{ĵ0}[𝓣_ĵ2] · 𝓗_ĵ1 · C^{ĵ0}[𝓢_ĵ1] · 𝓗_ĵ0 ·
  C^{ĵ2}[u_{ŝ0,ŝ1}] · C^{ĵ1}[u_{ŝ0,ŝ1}^2] · C^{ĵ0}[u_{ŝ0,ŝ1}^4] · 𝓗_ĵ2 · 𝓗_ĵ1 · 𝓗_ĵ0 · |0_ĵ0, 0_ĵ1, 0_ĵ2⟩]
```



Same circuit with QuantumGateShifting→False

```
SetQuantumGate[u, 2];
QuantumPlot[
```

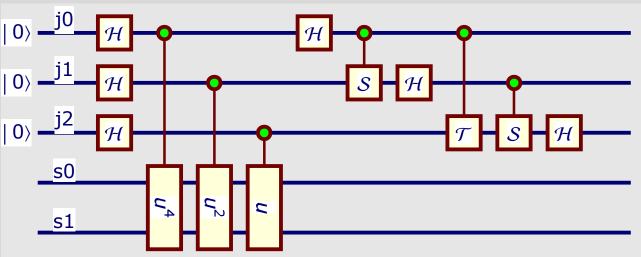
$$\mathcal{H}_{\hat{j2}} \cdot \mathcal{C}^{\{\hat{j1}\}}\left[\mathcal{S}_{\hat{j2}}\right] \cdot \mathcal{C}^{\{\hat{j0}\}}\left[\mathcal{T}_{\hat{j2}}\right] \cdot \mathcal{H}_{\hat{j1}} \cdot \mathcal{C}^{\{\hat{j0}\}}\left[\mathcal{S}_{\hat{j1}}\right] \cdot \mathcal{H}_{\hat{j0}} \cdot \mathcal{C}^{\{\hat{j2}\}}\left[\mathbf{u}_{\hat{s0},\hat{s1}}\right] \cdot \mathcal{C}^{\{\hat{j1}\}}\left[\mathbf{u}_{\hat{s0},\hat{s1}}{}^{2}\right] \cdot \mathcal{C}^{\{\hat{j0}\}}\left[\mathbf{u}_{\hat{s0},\hat{s1}}{}^{4}\right] \cdot \mathcal{H}_{\hat{j2}} \cdot \mathcal{H}_{\hat{j1}} \cdot \mathcal{H}_{\hat{j0}} \cdot \left|0_{\hat{j0}}, 0_{\hat{j1}}, 0_{\hat{j2}}\right\rangle, \textbf{QuantumGateShifting} \to \textbf{False}\Big]$$



Same circuit with QuantumGateShifting→False **AND the use of the template** $\mathcal{H}_{\{\hat{\square},\hat{\square},\hat{\square}\}}$ **for plotting the three Hadamard gates in the same column,** see the gates next to the ket and compare with the circuit above. The $\mathcal{H}_{\{\hat{\square},\hat{\square},\hat{\square}\}}$ template can be entered y pressing the keys [ESC]hggg[ESC]

```
SetQuantumGate[u, 2];
QuantumPlot[
```

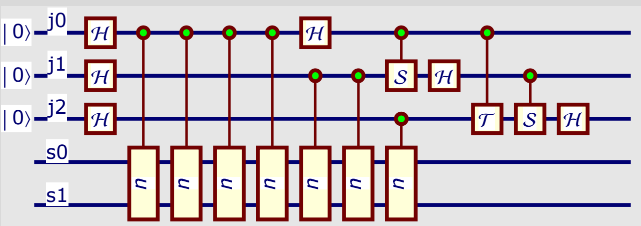
$$\mathcal{H}_{\hat{j2}} \cdot \mathcal{C}^{\{\hat{j1}\}}\left[\mathcal{S}_{\hat{j2}}\right] \cdot \mathcal{C}^{\{\hat{j0}\}}\left[\mathcal{T}_{\hat{j2}}\right] \cdot \mathcal{H}_{\hat{j1}} \cdot \mathcal{C}^{\{\hat{j0}\}}\left[\mathcal{S}_{\hat{j1}}\right] \cdot \mathcal{H}_{\hat{j0}} \cdot \mathcal{C}^{\{\hat{j2}\}}\left[\mathbf{u}_{\hat{s0},\hat{s1}}\right] \cdot \mathcal{C}^{\{\hat{j1}\}}\left[\mathbf{u}_{\hat{s0},\hat{s1}}{}^{2}\right] \cdot \mathcal{C}^{\{\hat{j0}\}}\left[\mathbf{u}_{\hat{s0},\hat{s1}}{}^{4}\right] \cdot \mathcal{H}_{\{\hat{j0},\hat{j1},\hat{j2}\}} \cdot \left|0_{\hat{j0}}, 0_{\hat{j1}}, 0_{\hat{j2}}\right\rangle, \textbf{QuantumGateShifting} \to \textbf{False}\Big]$$



Same circuit with QuantumGatePowers→False

```
SetQuantumGate[u, 2];
QuantumPlot[
```

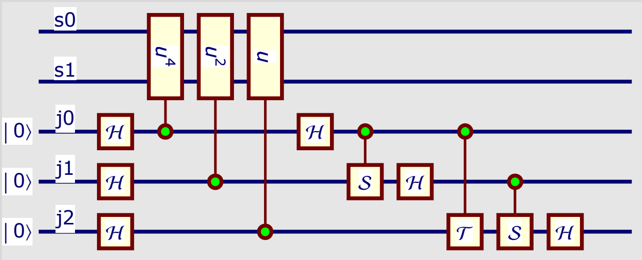
$$\mathcal{H}_{\hat{j2}} \cdot \mathcal{C}^{\{\hat{j1}\}}\left[\mathcal{S}_{\hat{j2}}\right] \cdot \mathcal{C}^{\{\hat{j0}\}}\left[\mathcal{T}_{\hat{j2}}\right] \cdot \mathcal{H}_{\hat{j1}} \cdot \mathcal{C}^{\{\hat{j0}\}}\left[\mathcal{S}_{\hat{j1}}\right] \cdot \mathcal{H}_{\hat{j0}} \cdot \mathcal{C}^{\{\hat{j2}\}}\left[\mathbf{u}_{\hat{s0},\hat{s1}}\right] \cdot \mathcal{C}^{\{\hat{j1}\}}\left[\mathbf{u}_{\hat{s0},\hat{s1}}{}^{2}\right] \cdot \mathcal{C}^{\{\hat{j0}\}}\left[\mathbf{u}_{\hat{s0},\hat{s1}}{}^{4}\right] \cdot \mathcal{H}_{\hat{j2}} \cdot \mathcal{H}_{\hat{j1}} \cdot \mathcal{H}_{\hat{j0}} \cdot \left|0_{\hat{j0}}, 0_{\hat{j1}}, 0_{\hat{j2}}\right\rangle, \textbf{QuantumGatePowers} \to \textbf{False}\Big]$$



Same circuit with qubit order specified by QubitList

```
SetQuantumGate[u, 2];
```

$$\texttt{QuantumPlot}\Big[\mathcal{H}_{\hat{j}2} \cdot \mathcal{C}^{\{\hat{j}1\}}\left[\mathcal{S}_{\hat{j}2}\right] \cdot \mathcal{C}^{\{\hat{j}0\}}\left[\mathcal{T}_{\hat{j}2}\right] \cdot \mathcal{H}_{\hat{j}1} \cdot \mathcal{C}^{\{\hat{j}0\}}\left[\mathcal{S}_{\hat{j}1}\right] \cdot \mathcal{H}_{\hat{j}0} \cdot \mathcal{C}^{\{\hat{j}2\}}\left[\mathbf{u}_{\hat{s}0,\hat{s}1}\right] \cdot \mathcal{C}^{\{\hat{j}1\}}\left[\mathbf{u}_{\hat{s}0,\hat{s}1}{}^{2}\right] \cdot \mathcal{C}^{\{\hat{j}0\}}\left[\mathbf{u}_{\hat{s}0,\hat{s}1}{}^{4}\right] \cdot \mathcal{H}_{\hat{j}2} \cdot \mathcal{H}_{\hat{j}1} \cdot \mathcal{H}_{\hat{j}0} \cdot \left|0_{\hat{j}0}, 0_{\hat{j}1}, 0_{\hat{j}2}\right\rangle, \texttt{QubitList} \to \{\hat{s}0, \hat{s}1, \hat{j}0, \hat{j}1, \hat{j}2\}\Big]$$

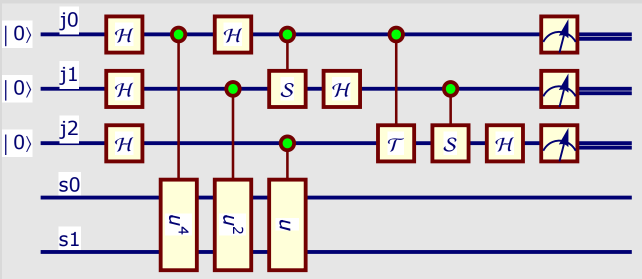


Measuring Meters

Next circuit shows how plot Measuring Meters in a quantum circuit.
Notice that **QubitMeasurement** has **not** the same syntaxis as a quantum gate:

```
SetQuantumGate[u, 2];
```

$$\texttt{QuantumPlot}\Big[\texttt{QubitMeasurement}\Big[\mathcal{H}_{\hat{j}2} \cdot \mathcal{C}^{\{\hat{j}1\}}\left[\mathcal{S}_{\hat{j}2}\right] \cdot \mathcal{C}^{\{\hat{j}0\}}\left[\mathcal{T}_{\hat{j}2}\right] \cdot \mathcal{H}_{\hat{j}1} \cdot \mathcal{C}^{\{\hat{j}0\}}\left[\mathcal{S}_{\hat{j}1}\right] \cdot \mathcal{H}_{\hat{j}0} \cdot \mathcal{C}^{\{\hat{j}2\}}\left[\mathbf{u}_{\hat{s}0,\hat{s}1}\right] \cdot \mathcal{C}^{\{\hat{j}1\}}\left[\mathbf{u}_{\hat{s}0,\hat{s}1}{}^{2}\right] \cdot \mathcal{C}^{\{\hat{j}0\}}\left[\mathbf{u}_{\hat{s}0,\hat{s}1}{}^{4}\right] \cdot \mathcal{H}_{\hat{j}2} \cdot \mathcal{H}_{\hat{j}1} \cdot \mathcal{H}_{\hat{j}0} \cdot \left|0_{\hat{j}0}, 0_{\hat{j}1}, 0_{\hat{j}2}\right\rangle, \{\hat{j}0, \hat{j}1, \hat{j}2\}\Big]\Big]$$



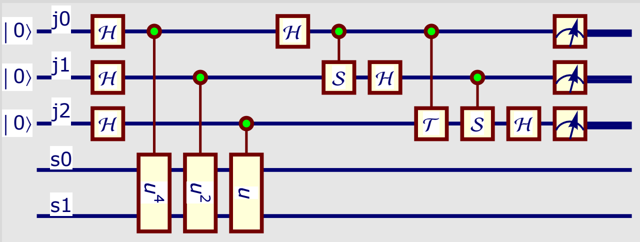
Same circuit with QuantumGateShifting→False **AND the use of the template** $\mathcal{H}_{\{\hat{\square},\hat{\square},\hat{\square}\}}$ **for plotting the three Hadamard gates in the same column,** see the gates next to the ket and compare with the circuit above. The $\mathcal{H}_{\{\hat{\square},\hat{\square},\hat{\square}\}}$ template can be entered y pressing the keys [ESC]hggg[ESC]

SetQuantumGate[u, 2];

QuantumPlot[QubitMeasurement[

$$\mathcal{H}_{\hat{j2}} \cdot \mathcal{C}^{\{\hat{j1}\}}\left[\mathcal{S}_{\hat{j2}}\right] \cdot \mathcal{C}^{\{\hat{j0}\}}\left[\mathcal{T}_{\hat{j2}}\right] \cdot \mathcal{H}_{\hat{j1}} \cdot \mathcal{C}^{\{\hat{j0}\}}\left[\mathcal{S}_{\hat{j1}}\right] \cdot \mathcal{H}_{\hat{j0}} \cdot \mathcal{C}^{\{\hat{j2}\}}\left[\mathbf{u}_{\hat{s0},\hat{s1}}\right] \cdot \mathcal{C}^{\{\hat{j1}\}}\left[\mathbf{u}_{\hat{s0},\hat{s1}}{}^{2}\right] \cdot \mathcal{C}^{\{\hat{j0}\}}\left[\mathbf{u}_{\hat{s0},\hat{s1}}{}^{4}\right] \cdot$$

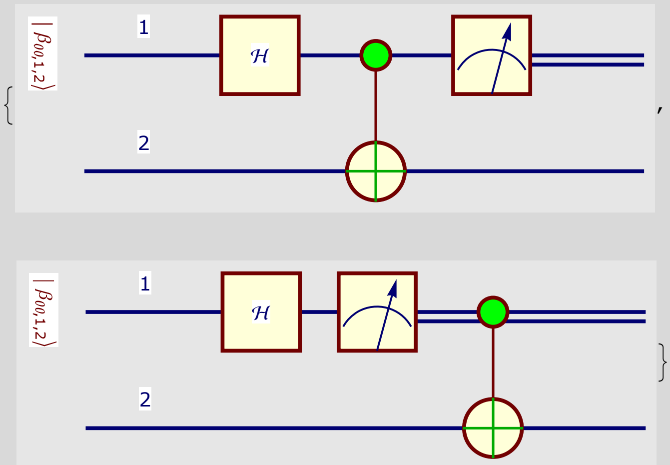
$$\mathcal{H}_{\{\hat{j0},\hat{j1},\hat{j2}\}} \cdot \left| 0_{\hat{j0}}, 0_{\hat{j1}}, 0_{\hat{j2}} \right\rangle, \{\hat{j0}, \hat{j1}, \hat{j2}\}\Big], \texttt{QuantumGateShifting} \rightarrow \texttt{False}\Big]$$



Controlled gates commute with measurements in their control qubit. This means these two circuits are equivalent:

$$\left\{\texttt{QuantumPlot}\left[\texttt{QubitMeasurement}\left[\mathcal{C}^{\{\hat{1}\}}\left[\mathcal{NOT}_{\hat{2}}\right] \cdot \mathcal{H}_{\hat{1}} \cdot \left|\mathcal{B}_{00,\hat{1},\hat{2}}\right\rangle, \{\hat{1}\}\right]\right],\right.$$

$$\left.\texttt{QuantumPlot}\left[\mathcal{C}^{\{\hat{1}\}}\left[\mathcal{NOT}_{\hat{2}}\right] \cdot \texttt{QubitMeasurement}\left[\mathcal{H}_{\hat{1}} \cdot \left|\mathcal{B}_{00,\hat{1},\hat{2}}\right\rangle, \{\hat{1}\}\right]\right]\right\}$$



It can be seen that both circuits are equivalent by writting QuantumEvaluate instead of QuantumPlot:

$\{\texttt{QuantumEvaluate}[\texttt{QubitMeasurement}[\mathcal{C}^{\{\hat{1}\}}[\mathcal{NOT}_{\hat{2}}]\cdot\mathcal{H}_{\hat{1}}\cdot\ |\ \mathcal{B}_{00,\hat{1},\hat{2}}\rangle,\ \{\hat{1}\}]],$
$\texttt{QuantumEvaluate}[\mathcal{C}^{\{\hat{1}\}}[\mathcal{NOT}_{\hat{2}}]\cdot\texttt{QubitMeasurement}[\mathcal{H}_{\hat{1}}\cdot\ |\ \mathcal{B}_{00,\hat{1},\hat{2}}\rangle,\ \{\hat{1}\}]]\}$

{

Probability	Measurement	State
$\frac{1}{2}$	$\{\{0_{\hat{1}}\}\}$	$\mid 0_{\hat{1}}\rangle\otimes\left(\frac{\mid 0_{\hat{2}}\rangle}{\sqrt{2}}+\frac{\mid 1_{\hat{2}}\rangle}{\sqrt{2}}\right)$
$\frac{1}{2}$	$\{\{1_{\hat{1}}\}\}$	$\mid 1_{\hat{1}}\rangle\otimes\left(-\frac{\mid 0_{\hat{2}}\rangle}{\sqrt{2}}+\frac{\mid 1_{\hat{2}}\rangle}{\sqrt{2}}\right)$
Probability	Measurement	State

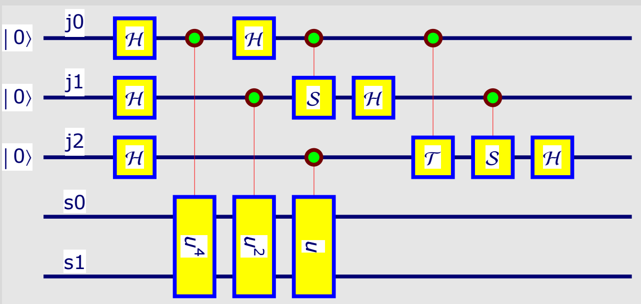
,

Probability	Measurement	State
$\frac{1}{2}$	$\{\{0_{\hat{1}}\}\}$	$\mid 0_{\hat{1}}\rangle\otimes\left(\frac{\mid 0_{\hat{2}}\rangle}{\sqrt{2}}+\frac{\mid 1_{\hat{2}}\rangle}{\sqrt{2}}\right)$
$\frac{1}{2}$	$\{\{1_{\hat{1}}\}\}$	$\mid 1_{\hat{1}}\rangle\otimes\left(-\frac{\mid 0_{\hat{2}}\rangle}{\sqrt{2}}+\frac{\mid 1_{\hat{2}}\rangle}{\sqrt{2}}\right)$
Probability	Measurement	State

}

Use of Circuit Options

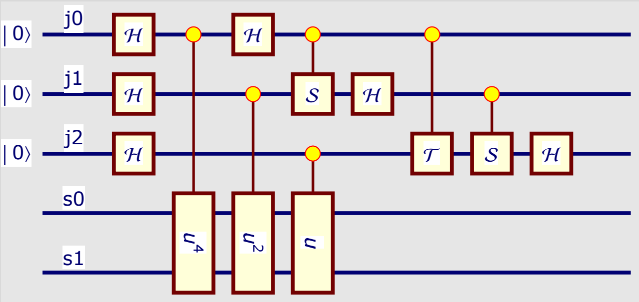
$\texttt{SetQuantumGate[u, 2];}$
$\texttt{QuantumPlot}[$
$\mathcal{H}_{\hat{j2}}\cdot\mathcal{C}^{\{\hat{j1}\}}[\mathcal{S}_{\hat{j2}}]\cdot\mathcal{C}^{\{\hat{j0}\}}[\mathcal{T}_{\hat{j2}}]\cdot\mathcal{H}_{\hat{j1}}\cdot\mathcal{C}^{\{\hat{j0}\}}[\mathcal{S}_{\hat{j1}}]\cdot\mathcal{H}_{\hat{j0}}\cdot\mathcal{C}^{\{\hat{j2}\}}[\mathbf{u}_{\hat{s0},\hat{s1}}]\cdot\mathcal{C}^{\{\hat{j1}\}}[\mathbf{u}_{\hat{s0},\hat{s1}}{}^{2}]\cdot\mathcal{C}^{\{\hat{j0}\}}[\mathbf{u}_{\hat{s0},\hat{s1}}{}^{4}]\cdot$
$\mathcal{H}_{\hat{j2}}\cdot\mathcal{H}_{\hat{j1}}\cdot\mathcal{H}_{\hat{j0}}\cdot\ |\ 0_{\hat{j0}},\ 0_{\hat{j1}},\ 0_{\hat{j2}}\rangle,\ \texttt{QuantumConnectionStyle}\to\texttt{Directive[Red, Thin]},$
$\texttt{QuantumGateStyle}\to\texttt{Directive[Yellow, EdgeForm[\{Blue\}]]}]$



```
SetQuantumGate[u, 2];
QuantumPlot[
```

$\mathcal{H}_{\hat{j2}} \cdot \mathcal{C}^{\{\hat{j1}\}}\left[\mathcal{S}_{\hat{j2}}\right] \cdot \mathcal{C}^{\{\hat{j0}\}}\left[\mathcal{T}_{\hat{j2}}\right] \cdot \mathcal{H}_{\hat{j1}} \cdot \mathcal{C}^{\{\hat{j0}\}}\left[\mathcal{S}_{\hat{j1}}\right] \cdot \mathcal{H}_{\hat{j0}} \cdot \mathcal{C}^{\{\hat{j2}\}}\left[\mathbf{u}_{\hat{s0},\hat{s1}}\right] \cdot \mathcal{C}^{\{\hat{j1}\}}\left[\mathbf{u}_{\hat{s0},\hat{s1}}{}^{2}\right] \cdot \mathcal{C}^{\{\hat{j0}\}}\left[\mathbf{u}_{\hat{s0},\hat{s1}}{}^{4}\right] \cdot \mathcal{H}_{\hat{j2}} \cdot \mathcal{H}_{\hat{j1}} \cdot \mathcal{H}_{\hat{j0}} \cdot \left| 0_{\hat{j0}}, 0_{\hat{j1}}, 0_{\hat{j2}} \right\rangle$,

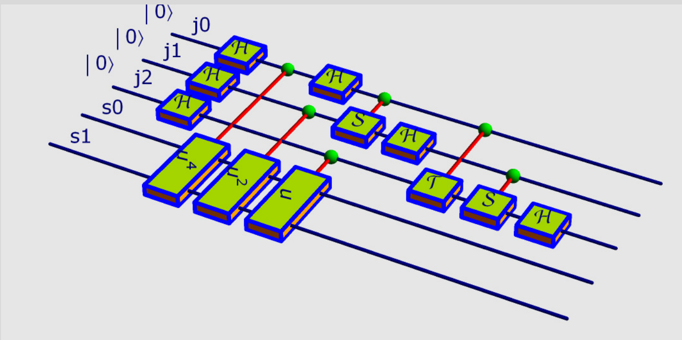
```
 QuantumControlStyle → Directive[Yellow, EdgeForm[{Red}]]
]
```




```
SetQuantumGate[u, 2];
QuantumPlot3D[
```

$\mathcal{H}_{\hat{j2}} \cdot \mathcal{C}^{\{\hat{j1}\}}\left[\mathcal{S}_{\hat{j2}}\right] \cdot \mathcal{C}^{\{\hat{j0}\}}\left[\mathcal{T}_{\hat{j2}}\right] \cdot \mathcal{H}_{\hat{j1}} \cdot \mathcal{C}^{\{\hat{j0}\}}\left[\mathcal{S}_{\hat{j1}}\right] \cdot \mathcal{H}_{\hat{j0}} \cdot \mathcal{C}^{\{\hat{j2}\}}\left[\mathbf{u}_{\hat{s0},\hat{s1}}\right] \cdot \mathcal{C}^{\{\hat{j1}\}}\left[\mathbf{u}_{\hat{s0},\hat{s1}}{}^{2}\right] \cdot \mathcal{C}^{\{\hat{j0}\}}\left[\mathbf{u}_{\hat{s0},\hat{s1}}{}^{4}\right] \cdot \mathcal{H}_{\hat{j2}} \cdot \mathcal{H}_{\hat{j1}} \cdot \mathcal{H}_{\hat{j0}} \cdot \left| 0_{\hat{j0}}, 0_{\hat{j1}}, 0_{\hat{j2}} \right\rangle$, `QuantumConnectionStyle → Directive[Red, Thin],`

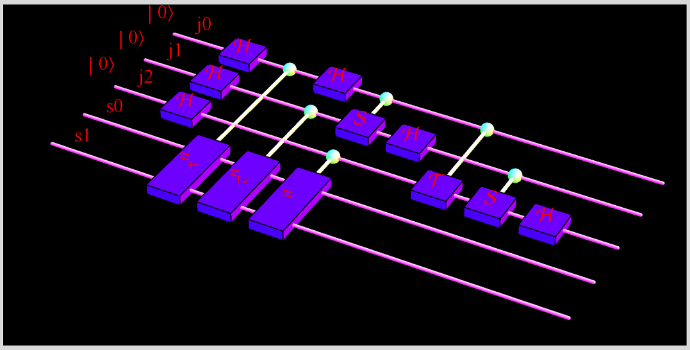
```
 QuantumGateStyle → Directive[Yellow, EdgeForm[{Blue, Thick}]]
]
```



```
SetQuantumGate[u, 2];
QuantumPlot3D[
```

$$\mathcal{H}_{\hat{j2}} \cdot C^{\{\hat{j1}\}}\left[\mathcal{S}_{\hat{j2}}\right] \cdot C^{\{\hat{j0}\}}\left[\mathcal{T}_{\hat{j2}}\right] \cdot \mathcal{H}_{\hat{j1}} \cdot C^{\{\hat{j0}\}}\left[\mathcal{S}_{\hat{j1}}\right] \cdot \mathcal{H}_{\hat{j0}} \cdot C^{\{\hat{j2}\}}\left[\mathbf{u}_{\hat{s0},\hat{s1}}\right] \cdot C^{\{\hat{j1}\}}\left[\mathbf{u}_{\hat{s0},\hat{s1}}{}^{2}\right] \cdot C^{\{\hat{j0}\}}\left[\mathbf{u}_{\hat{s0},\hat{s1}}{}^{4}\right] \cdot \mathcal{H}_{\hat{j2}} \cdot \mathcal{H}_{\hat{j1}} \cdot \mathcal{H}_{\hat{j0}} \cdot \left|0_{\hat{j0}}, 0_{\hat{j1}}, 0_{\hat{j2}}\right\rangle,$$

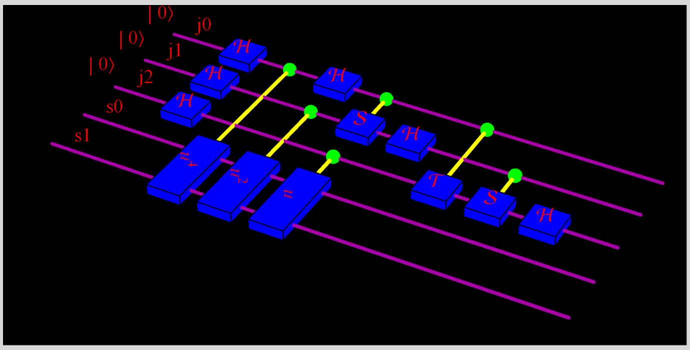
```
 QuantumBackground → Black,
 QuantumGateStyle → Directive[Glow[Blue]],
 QuantumConnectionStyle -> Directive[Glow[Yellow]],
 QuantumWireStyle → Directive[Glow[Darker[Magenta]]],
 QuantumControlStyle → Directive[Glow[Green]],
 QuantumTextStyle → Red
]
```



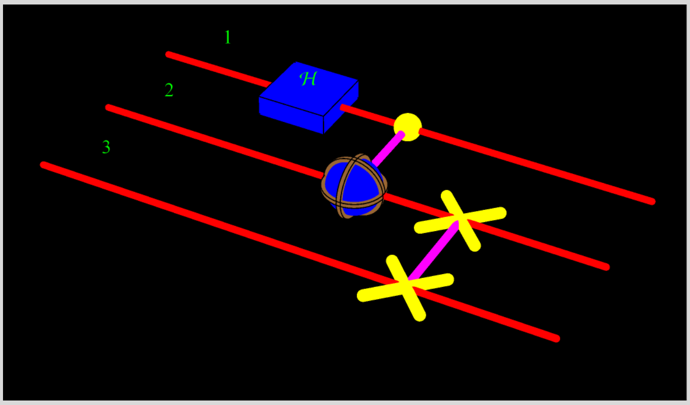

```
SetQuantumGate[u, 2];
QuantumPlot3D[
```

$$\mathcal{H}_{\hat{j2}} \cdot C^{\{\hat{j1}\}}\left[\mathcal{S}_{\hat{j2}}\right] \cdot C^{\{\hat{j0}\}}\left[\mathcal{T}_{\hat{j2}}\right] \cdot \mathcal{H}_{\hat{j1}} \cdot C^{\{\hat{j0}\}}\left[\mathcal{S}_{\hat{j1}}\right] \cdot \mathcal{H}_{\hat{j0}} \cdot C^{\{\hat{j2}\}}\left[\mathbf{u}_{\hat{s0},\hat{s1}}\right] \cdot C^{\{\hat{j1}\}}\left[\mathbf{u}_{\hat{s0},\hat{s1}}{}^{2}\right] \cdot C^{\{\hat{j0}\}}\left[\mathbf{u}_{\hat{s0},\hat{s1}}{}^{4}\right] \cdot \mathcal{H}_{\hat{j2}} \cdot \mathcal{H}_{\hat{j1}} \cdot \mathcal{H}_{\hat{j0}} \cdot \left|0_{\hat{j0}}, 0_{\hat{j1}}, 0_{\hat{j2}}\right\rangle,$$

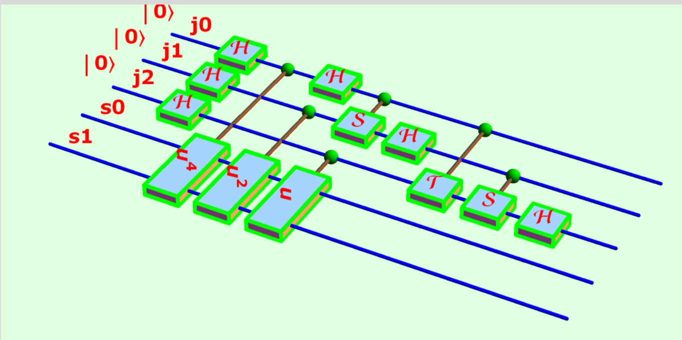
```
 QuantumBackground → Black,
 QuantumGateStyle → Directive[Glow[Blue]],
 QuantumConnectionStyle -> Directive[Glow[Yellow]],
 QuantumWireStyle → Directive[Glow[Darker[Magenta]]],
 QuantumControlStyle → Directive[Glow[Green]],
 QuantumTextStyle → Red,
 Lighting → None
]
```



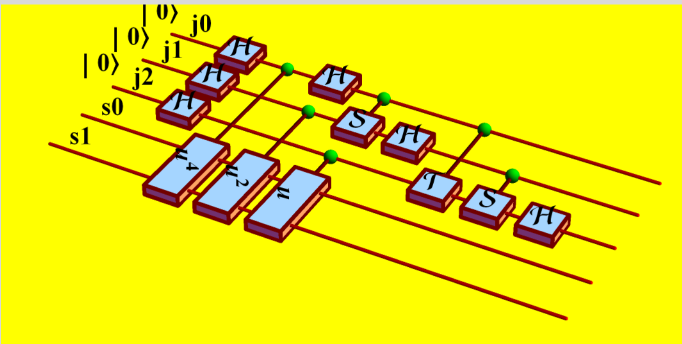
```
QuantumPlot3D[
  SWAP_{2̂,3̂} · C^{1̂}[NOT_{2̂}] · H_{1̂},
  QuantumBackground → Black,
  QuantumGateStyle → Directive[Glow[Blue]],
  QuantumConnectionStyle -> Directive[Glow[Magenta]],
  QuantumControlStyle → Directive[Glow[Yellow]],
  QuantumNotStyle → Directive[Glow[Brown]],
  QuantumWireStyle → Directive[Glow[Red]],
  QuantumTextStyle → Green,
  Lighting → None]
```



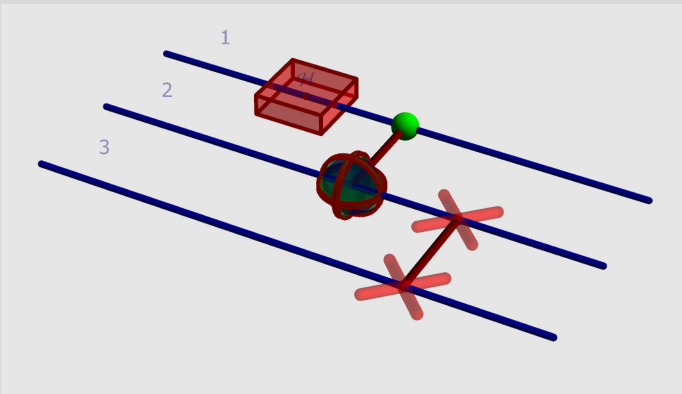

```
SetQuantumGate[u, 2];
QuantumPlot3D[
  H_{ĵ2} · C^{ĵ1}[S_{ĵ2}] · C^{ĵ0}[T_{ĵ2}] · H_{ĵ1} · C^{ĵ0}[S_{ĵ1}] · H_{ĵ0} · C^{ĵ2}[u_{ŝ0,ŝ1}] ·
   C^{ĵ1}[u_{ŝ0,ŝ1}^2] · C^{ĵ0}[u_{ŝ0,ŝ1}^4] · H_{ĵ2} · H_{ĵ1} · H_{ĵ0} · |0_{ĵ0}, 0_{ĵ1}, 0_{ĵ2}⟩,
  QuantumConnectionStyle → Brown, QuantumGateStyle →
   Directive[LightYellow, EdgeForm[Green]],
  QuantumWireStyle → Directive[Blue, Thick],
  QuantumBackground → LightGreen,
  QuantumTextStyle → Directive[Red, FontWeight → Bold, FontFamily → "Verdana"]
]
```



```
SetQuantumGate[u, 2];
QuantumPlot3D[
 ℋ_ĵ2 · C^{ĵ1}[𝒮_ĵ2] · C^{ĵ0}[𝒯_ĵ2] · ℋ_ĵ1 · C^{ĵ0}[𝒮_ĵ1] · ℋ_ĵ0 · C^{ĵ2}[u_{ŝ0,ŝ1}] ·
  C^{ĵ1}[u_{ŝ0,ŝ1}^2] · C^{ĵ0}[u_{ŝ0,ŝ1}^4] · ℋ_ĵ2 · ℋ_ĵ1 · ℋ_ĵ0 · |0_ĵ0, 0_ĵ1, 0_ĵ2⟩,
 QuantumTextStyle → Directive[Black, Medium, FontWeight → Bold],
 QuantumWireStyle → Directive[Red, Thick],
 QuantumBackground → Yellow
]
```




```
QuantumPlot3D[
 𝒮𝒲𝒜𝒫_{2̂,3̂} · C^{1̂}[𝒩𝒪𝒯_2̂] · ℋ_1̂,
 QuantumSwapStyle → Directive[Red, Opacity[0.4]],
 QuantumGateStyle → Directive[Opacity[0.4]]
]
```



QuantumPlot has its own options, plus all the options of the standard *Mathematica* commands Plot and Plot3D. Following commands show a list of the options that are exclusive of QuantumPlot, together with their default value:

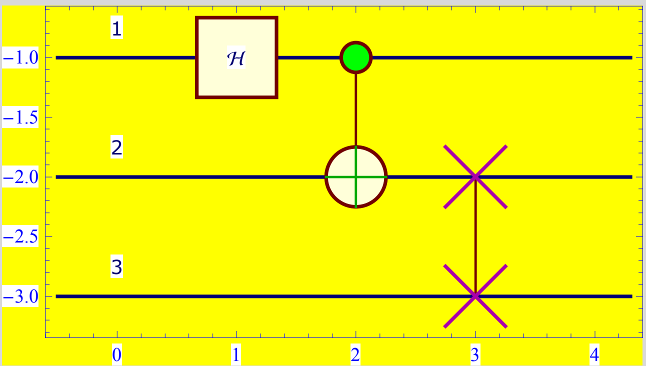
```
Select[Options[QuantumPlot], Characters[SymbolName[#[[1]]]][[1]] == "Q" &]
```

```
{QubitList → {}, QubitLabels → True,
 QuantumGatePowers → True, QuantumGateShifting → True,
 QuantumBackground → RGBColor[0.9, 0.9, 0.9], QuantumMeterStyle →
  Directive[RGBColor[0, 0, 4/9], Thickness[0.003], Arrowheads[Small]],
 QuantumWireStyle → Directive[RGBColor[0, 0, 4/9], Thickness[0.006]],
 QuantumConnectionStyle → Directive[RGBColor[4/9, 0, 0], Thickness[0.004]],
 QuantumNotStyle → Directive[RGBColor[0, 2/3, 0], Thickness[0.004]],
 QuantumControlStyle →
  Directive[RGBColor[0, 1, 0], EdgeForm[{RGBColor[4/9, 0, 0], Thickness[0.006]}]],
 QuantumSwapStyle → Directive[RGBColor[2/3, 0, 2/3], Thickness[0.006]],
 QuantumGateStyle →
  Directive[RGBColor[1, 1, 0.85], EdgeForm[{Thickness[0.006], RGBColor[4/9, 0, 0]}]],
 QuantumTextStyle → Directive[Small, RGBColor[0, 0, 4/9], FontFamily → Verdana],
 QuantumVerticalTextStyle → Directive[RGBColor[4/9, 0, 0], FontFamily → Verdana],
 QuantumPlot3D → False}
```

Use of Standard Graphics Options

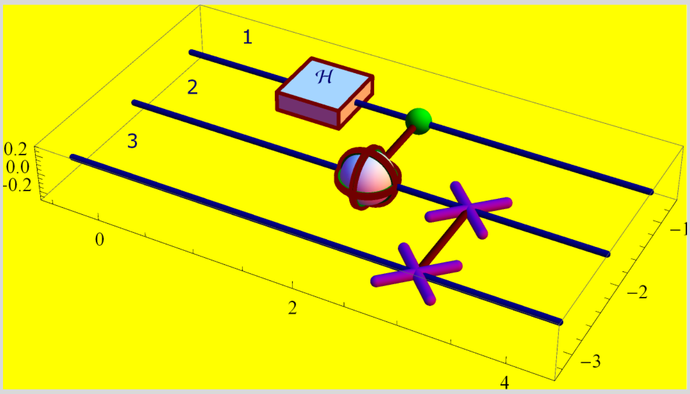
Standard *Mathematica* Graphics options can be used in a Quantum Circuit using the syntax:
QuantumPlot[*expression*,*options*]

```
QuantumPlot[
 SWAP_{2̂,3̂} · C^{1̂}[NOT_{2̂}] · H_{1̂}, Background → Yellow, Frame → True, FrameStyle → Blue]
```



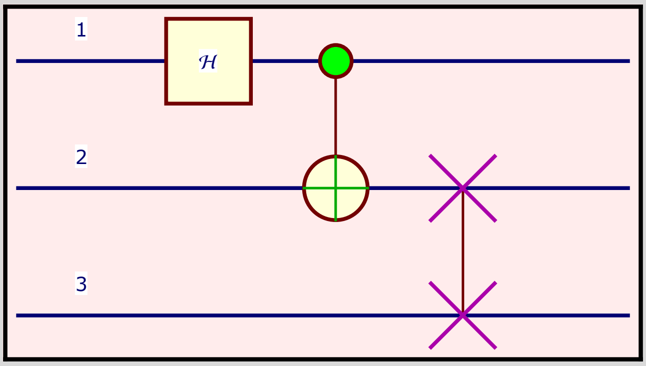
Standard *Mathematica* Graphics**3D** options can be used in a Quantum Circuit using the syntax:
QuantumPlot**3D**[*expression*,*options*]

```
QuantumPlot3D[
 SWAP₂̂,₃̂ · C^{1̂}[NOT₂̂] · H₁̂,
 Background → Yellow, Boxed → True, Axes → True]
```



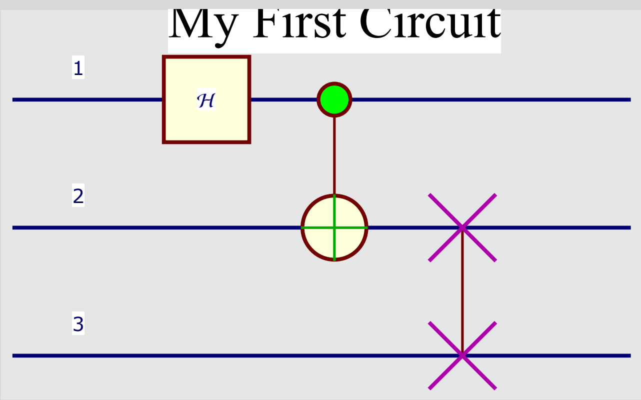
Standard *Mathematica* Graphics options can be used in a Quantum Circuit using the syntax:
QuantumPlot[*expression*,*options*]

```
QuantumPlot[
 SWAP₂̂,₃̂ · C^{1̂}[NOT₂̂] · H₁̂,
 Background → LightPink, Frame → True, FrameTicks → None, FrameStyle → Thick]
```



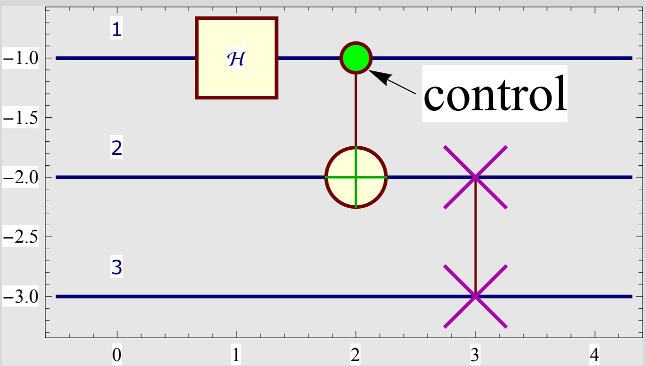
Standard *Mathematica* primitives can be combined Quantum Circuit using the syntax:
Show[QuantumPlot[*expression*],Graphics[{*primitives*}],*options*]

```
Show[QuantumPlot[
  𝒮𝒲𝒜𝒫_{2̂,3̂} · 𝒞^{1̂}[𝒩𝒪𝒯_{2̂}] · ℋ_{1̂}],
 Graphics[{Text[Style["My First Circuit", Large], {2, -0.4}]}], Frame → False]
```



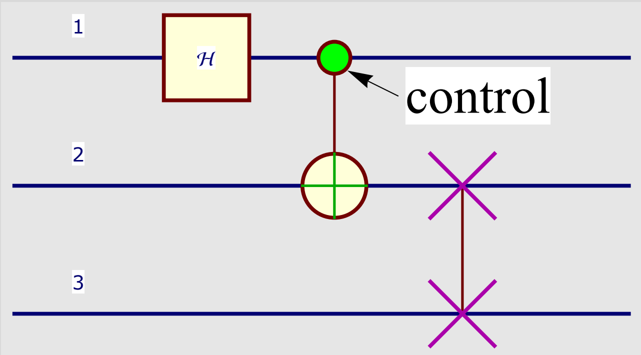
Standard *Mathematica* primitives can be combined Quantum Circuit using the syntax:
Show[QuantumPlot[*expression*],Graphics[{*primitives*}],*options*]

```
Show[
 QuantumPlot[
  𝒮𝒲𝒜𝒫_{2̂,3̂} · 𝒞^{1̂}[𝒩𝒪𝒯_{2̂}] · ℋ_{1̂}],
 Graphics[{
   Arrow[{{2.5, -1.3}, {2.1, -1.1}}],
   Text[Style["control", Large], {2.5, -1.3}, {-1.1, 0}]
  }], Frame → True]
```



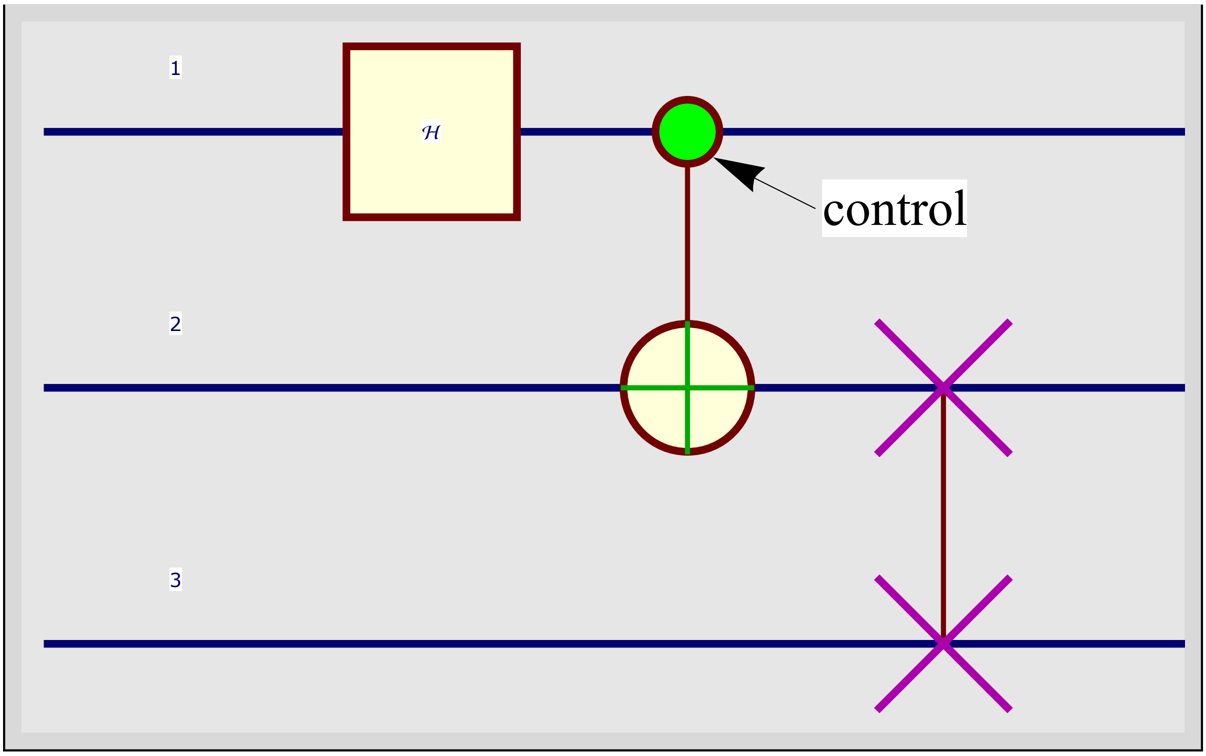
Standard *Mathematica* primitives can be combined Quantum Circuit using the syntax:
Show[QuantumPlot[*expression*],Graphics[{*primitives*}],*options*]

```
Show[
 QuantumPlot[
  SWAP_{2̂,3̂} · C^{1̂}[NOT_{2̂}] · H_{1̂}],
 Graphics[{
   Arrow[{{2.5, -1.3}, {2.1, -1.1}}],
   Text[Style["control", Large], {2.5, -1.3}, {-1.1, 0}]
  }], Frame → False]
```



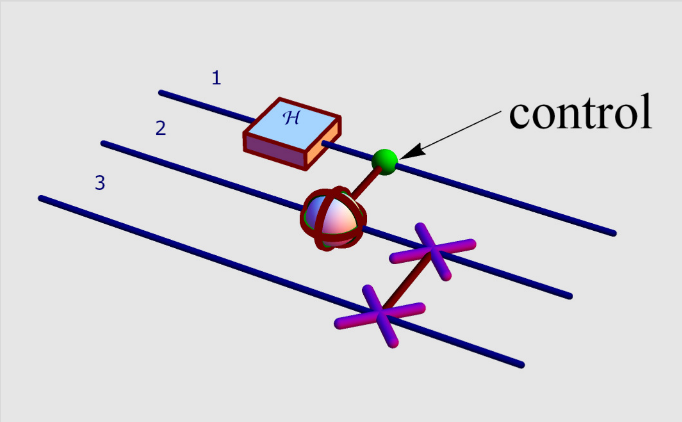
Standard *Mathematica* primitives can be combined Quantum Circuit using the syntax:
Show[QuantumPlot[*expression*],Graphics[{*primitives*}],*options*]

```
Show[
 QuantumPlot[
  SWAP_{2̂,3̂} · C^{1̂}[NOT_{2̂}] · H_{1̂}],
 Graphics[{
   Arrow[{{2.5, -1.3}, {2.1, -1.1}}],
   Text[Style["control", Large], {2.5, -1.3}, {-1.1, 0}]
  }], Frame → False, ImageSize → {600, Automatic}]
```



Standard *Mathematica* primitives can be combined Quantum Circuit using the syntax:
Show[QuantumPlot**3D**[*expression*],Graphics**3D**[{*primitives*}],*options*]

```
Show[
 QuantumPlot3D[
  𝒮𝒲𝒜𝒫_{2̂,3̂} · C^{1̂}[𝒩𝒪𝒯_{2̂}] · ℋ_{1̂}],
 Graphics3D[{
   Arrow[{{2.6, 0.3, 0}, {2.1, -0.9, 0}}],
   Text[Style["control", Large], {2.6, 0.3, 0}, {-1.1, 0}]
  }]]
```



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