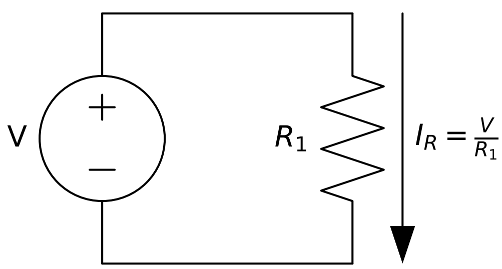
In [ ]:
```python
import matplotlib.pyplot as plt

from PySpice.Probe.Plot import plot
from PySpice.Spice.Library import SpiceLibrary
from PySpice.Spice.Netlist import Circuit
from PySpice.Unit import *
from ipywidgets import *
from IPython.display import display, Math, Latex
import schemdraw
import schemdraw.elements as elm

%matplotlib inline
%config InlineBackend.figure_format = 'svg'
```

In [ ]:
```python
with schemdraw.Drawing() as d:
    d.config(inches_per_unit=2, unit=2)
    # d += (d1 := elm.Dot())
    d += (s1 := elm.Line())
    # d += (d2 := elm.Dot())
    d += (s2 := elm.Resistor().label('$R_1$', fontsize=30).down())
    # d += (d3 := elm.Dot())
    d += (s3 := elm.Line().left())
    # d += (d4 := elm.Dot())
    d += (s4 := elm.SourceV().label('V', fontsize=30).up())
    d += elm.CurrentLabel(top=True).at(s2).label(r'$I_R=\frac{V}{R_1}$', loc="bot", fontsize=30).down()

    # d += elm.LoopCurrent([d1, d2, d3, d4], direction='cw').label('$Current$', fontsize=30)
```

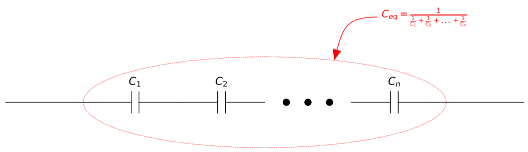


In [ ]:
```python
with schemdraw.Drawing() as d:
    d.config(inches_per_unit=2, unit=2)
    d += (c1 := elm.Capacitor().label(['+', '$V_c(t)$', '-'], loc="bot", fontsize=30))
    d += elm.CurrentLabel(length=1).at(c1).label(r'$I_c(t)= C. \frac{dV_c(t)}{dt}$', loc='top', fontsize=30)
    d += (c1 := elm.Inductor().at((8, 0)).label(['+', '$V_l(t)$', '-'], loc="bot", fontsize=30))
    d += elm.CurrentLabel(length=1).at(c1).label(r'$I_l(t)= \frac{1}{L} \int_0^t V_l(t)dt + I_0$', loc='top', fontsize=30)
```

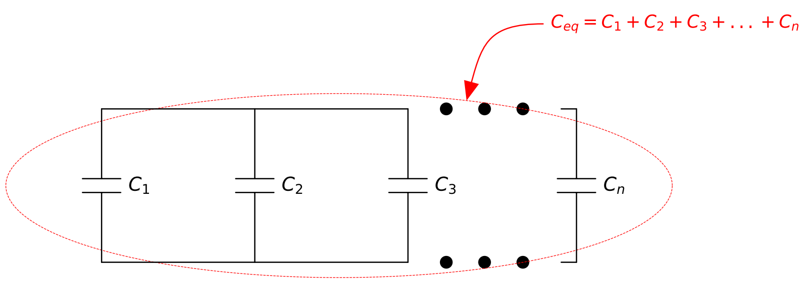
In [ ]:
```python
with schemdraw.Drawing() as d:
    d.config(inches_per_unit=2, unit=2)
    d += (c1 := elm.Capacitor().label([r'$V_c(t)=\int^t_0 I_c(t) dt + V_0$'], loc="bot", fontsize=30))
    d += elm.CurrentLabel(length=1).at(c1).label(r'$I_c(t)$', loc='top', fontsize=30)
    d += (c1 := elm.Inductor().at((8, 0)).label([r'$V_l(t)=L.\frac{dI_l(t)}{dt}$'], loc="bot", fontsize=30))
    d += elm.CurrentLabel(length=1).at(c1).label(r'$I_l(t)$', loc='top', fontsize=30)
```

In [ ]:
```python
with schemdraw.Drawing() as d:
    d.config(inches_per_unit=2, unit=2)
    d += (s0 := elm.Line())
    d += (c1 := elm.Capacitor().label('$C_1$', fontsize=32))
    d += (c2 := elm.Capacitor().label('$C_2$', fontsize=32))
    d += (c3 := elm.DotDotDot())
    d += (c4 := elm.Capacitor().label('$C_n$', fontsize=32))
    d += (s0 := elm.Line())

    d += (series_equivelent := elm.Encircle(([c1, c2, c3, c4]), pady=.8).linestyle('--').linewidth(1).color('red'))
    d += elm.Annotate().at(series_equivelent.NNE).delta(dx=1, dy=1).label(r'$C_{eq}=\frac{1}{\frac{1}{C_1}+\frac{1}{C_2}+...+\frac{1}{C_
```

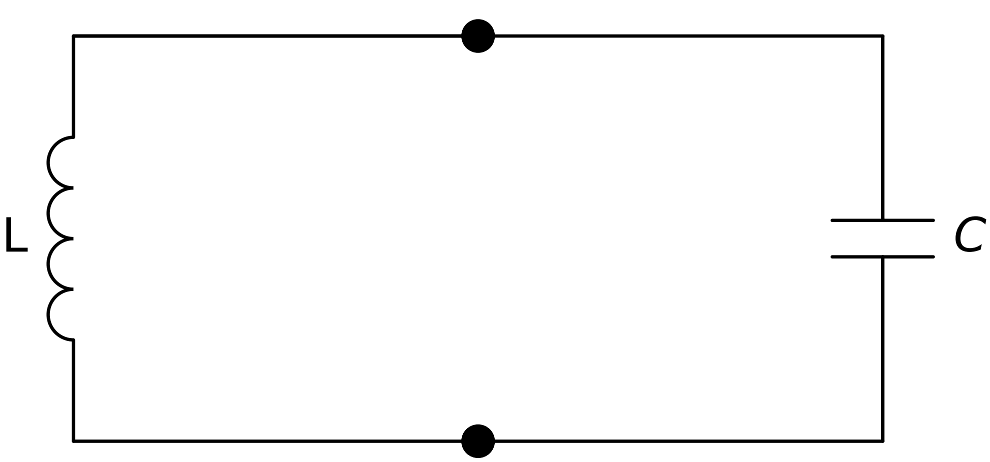
```
    # d += elm.LoopCurrent([d1, d2, d3, d4], direction='cw').label('$Current$', fontsize=30)
```



In [ ]:
```
with schemdraw.Drawing() as d:
    d.config(inches_per_unit=2, unit=2)
    d.push()
    d += (c1 := elm.Capacitor().down().label('$C_1$', loc='bot', fontsize=32))
    d.pop()
    d += (l1 := elm.Line().right())
    d.push()
    d += (c2 := elm.Capacitor().down().label('$C_2$', loc='bot', fontsize=32))
    d.pop()
    d += (l1 := elm.Line().right())
    d.push()
    d += (c3 := elm.Capacitor().down().label('$C_3$', loc='bot', fontsize=32))
    d.pop()
    d += (l1 := elm.DotDotDot().right())
    d.push()
    # d += (l1 := elm.Capacitor().down())
    d.pop()
    d += (l1 := elm.Line().right().length(0.2))
    d += (c4 := elm.Capacitor().down().label('$C_n$', loc='bot', fontsize=32))
    d += (l1 := elm.Line().left().length(0.2))
    d += (l1 := elm.DotDotDot().left())
    d += (l1 := elm.Line().left())
    d += (l1 := elm.Line().left())
    d += (series_equivelent := elm.Encircle(([c1, c2, c3, c4]), padx=1).linestyle('--').linewidth(1).color('red'))
    d += elm.Annotate().at(series_equivelent.NNE).delta(dx=1, dy=1).label(r'$C_{eq}=C_1+C_2+C_3+...+C_n}$', fontsize=30).color('red')


    # d += elm.LoopCurrent([d1, d2, d3, d4], direction='cw').label('$Current$', fontsize=30)
```

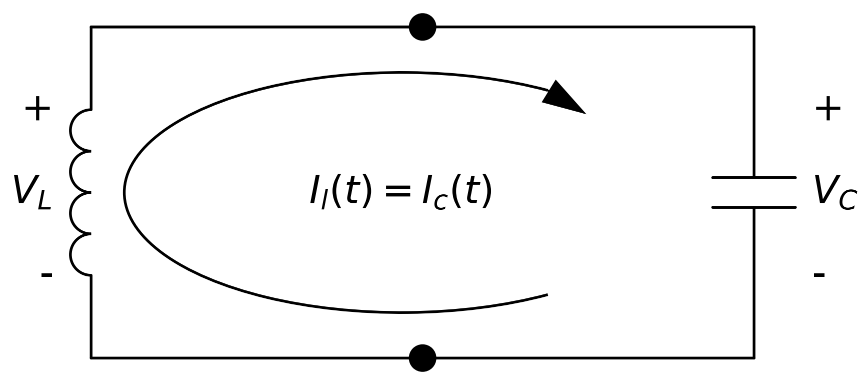


In [ ]:
```
with schemdraw.Drawing() as d:
    d.config(inches_per_unit=2, unit=2)
    d += (s1 := elm.Line())
    d += (d1 := elm.Dot())
    d += (s2 := elm.Line())
    d += (c1 := elm.Capacitor().down().label(f'$C$', loc="bot", fontsize=30))
    d += (s3 := elm.Line().left())
    d += (d2 := elm.Dot())
    d += (s4 := elm.Line().left())
    d += (l1 := elm.Inductor().up().label(f'L', loc="top", fontsize=30))
    d += (s5 := elm.Line().right())
    # d += elm.LoopCurrent([d1, c1, d2, l1], direction='cw').label('$I(t)$', fontsize=30)
```



In [ ]:
```python
display(Math(r"\text{Using Kerckhoffs's Voltage law}"))
with schemdraw.Drawing() as d:
    d.config(inches_per_unit=2, unit=2)
    d += (s1 := elm.Line())
    d += (d1 := elm.Dot())
    d += (s2 := elm.Line())
    d += (c1 := elm.Capacitor().down().label(['+','$V_C$','-'], loc="bot", fontsize=30))
    d += (s3 := elm.Line().left())
    d += (d2 := elm.Dot())
    d += (s4 := elm.Line().left())
    d += (l1 := elm.Inductor().up().label(['-','$V_L$','+'], loc="top", fontsize=30))
    d += (s5 := elm.Line().right())
    d += elm.LoopCurrent([d1, c1, d2, l1], direction='cw').label(r'$I_l(t)=I_c(t)$', fontsize=30)
display(Math(r"$V_L+V_C=0$"))
display(Math(r"$I_l(t)=I_c(t)$"))
```

Using Kerckhoffs's Voltage law



$V_L + V_C = 0$

$I_l(t) = I_c(t)$

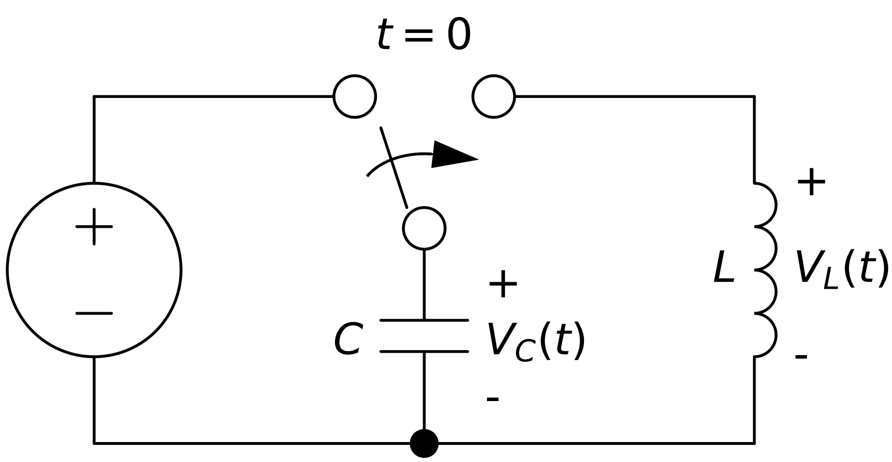
In [ ]:
```python
# # display(Math(r"\text{Sum of all currents entering a node must be equal to 0}"))
# with schemdraw.Drawing() as d:
#     d.config(inches_per_unit=2, unit=2)
#     d += (s1 := elm.Line())
#     d += (d1 := elm.Dot().label('n0', fontsize=30))
#     d += elm.CurrentLabelInline(direction='in', ofst=0.8).at(d1).label(r'$I_l(t)$', fontsize=30)
#     d += elm.CurrentLabelInline(direction='in', ofst=-1.1).at(d1).label(r'$I_c(t)$', fontsize=30)
#     d += (s2 := elm.Line())
#     d += (c1 := elm.Capacitor().down().label(f'$C$', loc="bot", fontsize=30))
#     d += (s3 := elm.Line().left())
#     d += (d2 := elm.Dot().label('n1', fontsize=30, loc='bot'))
#     d += elm.CurrentLabelInline(direction='out', ofst=0.8).at(d2).label(r'$I_l(t)$', fontsize=30)
#     d += elm.CurrentLabelInline(direction='out', ofst=-1.1).at(d2).label(r'$I_c(t)$', fontsize=30)
#     d += (s4 := elm.Line().left())
#     d += (l1 := elm.Inductor().up().label(f'L', loc="top", fontsize=30))
#     d += (s5 := elm.Line().right())
#     # d += elm.LoopCurrent([d1, c1, d2, l1], direction='cw').label('$I(t)$', fontsize=30)
```

In [ ]:
```python
display(Math(r'\text{Assuming the following initial conditions:}'))
display(Math(r'$\text{Capacitor is initially charged }$'))
# display(Math(r'$\text{Current is flowing through the circuit:   }I_0 = 0$'))
# display(Math(r'$\text{Voltage accross both elements is equal:  } V_l(t) = V_c(t) = V(t)$'))

with schemdraw.Drawing() as d:
    d.config(inches_per_unit=2, unit=2)
    d += (V1 := elm.SourceV())
    d += elm.Line().right(d.unit*.75)
    d += (S1 := elm.SwitchSpdt2(action='close').up().anchor('b').label('$t=0$', loc='rgt',fontsize=32))
    d += elm.Line().right(d.unit*.75).at(S1.c)
    d += elm.Inductor().down().label('$L$', fontsize=32).label(['+','$V_L(t)$','-'], loc='bot', fontsize=32)
    d += elm.Line().to(V1.start)
    d += elm.Capacitor().at(S1.a).toy(V1.start).label('$C$', fontsize=32).label(['+','$V_C(t)$','-'], fontsize=32, loc='bot').dot()
# display(Math(r'$\mathscr{L}\{C.\frac{dV(t)}{dt}+\frac{1}{L} \int_0^tV(t)dt\}=0$'))
display(Math(r"\text{Kerckhoffs's Voltage law}"))
display(Math(r'$V_C(t)+V_L(t)=0$'))
display(Math(r"\text{Substituting Voltages}"))
display(Math(r'$\frac{1}{C} \int_0^tI_C(t)dt+L.\frac{dI_L(t)}{dt}=0$'))
display(Math(r"\text{Converting to second order}"))
display(Math(r'$\frac{d}{dt}(\frac{1}{C} \int_0^tI_C(t)dt+L.\frac{dI_L(t)}{dt})=0$'))
display(Math(r'$\frac{I_C(t)}{C}+L.\frac{d^2I_L(t)}{dt^2}=0$'))
display(Math(r"\text{Using the fact that } I_C(t)=I_L(t)"))
display(Math(r'$\frac{I_L(t)}{C}+L.\frac{d^2I_L(t)}{dt^2}=0$'))
display(Math(r"\text{Dividing by L }"))
display(Math(r'$\frac{1}{LC}I_L(t)+\frac{d^2I_L(t)}{dt^2}=0$'))

display(Math(r"\text{One possible solution is}"))
display(Math(r'$I_L(t) = I_0\cos(\frac{t}{\sqrt{LC}})$'))
display(Math(r"\text{To see if it is lets plug it in to the second order equation...}"))
display(Math(r"\text{But FIRST we need the first and second derivative...}"))
display(Math(r'$I_L(t) = I_0\cos(\frac{t}{\sqrt{LC}})$'))
display(Math(r'$\frac{dI_L(t)}{dt} = -I_0 \frac{1}{\sqrt{LC}} \sin(\frac{t}{\sqrt{LC}})$'))
```

```
display(Math(r'$\frac{d^2I_L(t)}{dt^2} = -I_0 \frac{1}{LC} \cos(\frac{t}{\sqrt{LC}})$'))
display(Math(r"\text{Plugging in...}"))
display(Math(r'$\frac{1}{LC}I_L(t)+\frac{d^2I_L(t)}{dt^2}=0$'))
display(Math(r'$\frac{1}{LC}I_0\cos(\frac{t}{\sqrt{LC}})+(-I_0 \frac{1}{LC} \cos(\frac{t}{\sqrt{LC}}))=0$'))
display(Math(r"\text{So we ARE right...}"))
display(Math(r'$I_L(t) = I_0\cos(\frac{t}{\sqrt{LC}})$'))

display(Math(r"\text{What about the Voltage?...}"))
display(Math(r"\text{Let's use the fact that we know that the voltage accross the inductor is } V_L(t)=L.\frac{dI_l(t)}{dt}"))
display(Math(r"\text{Substituting the first derivative of current}"))
display(Math(r'$\frac{dI_L(t)}{dt} = -I_0 \frac{1}{\sqrt{LC}} \sin(\frac{t}{\sqrt{LC}})$'))
display(Math(r'$V_L(t)=-L.I_0 \frac{1}{\sqrt{LC}} \sin(\frac{t}{\sqrt{LC}})$'))
display(Math(r"\text{Simplifying}"))
display(Math(r'$V_L(t)=-I_0 \sqrt{\frac{L}{C}} \sin(\frac{t}{\sqrt{LC}})$'))

# display(Math(r'$\mathscr{L}\{C.\frac{dV_c(t)}{dt}+\frac{1}{L} \int_0^tV_l(t)dt+I_0\}=\mathscr{L}\{0\}$'))
# display(Math(r"\text{Applying initial conditions}"))
# display(Math(r'$\mathscr{L}\{C.\frac{dV(t)}{dt}+\frac{1}{L} \int_0^tV(t)dt\}=\mathscr{L}\{0\}$'))
```

Assuming the following initial conditions:

Capacitor is initially charged



Kerckhoffs's Voltage law

$V_C(t) + V_L(t) = 0$

Substituting Voltages

$$\frac{1}{C}\int_0^t I_C(t)dt + L.\frac{dI_L(t)}{dt} = 0$$

Converting to second order

$$\frac{d}{dt}(\frac{1}{C}\int_0^t I_C(t)dt + L.\frac{dI_L(t)}{dt}) = 0$$

$$\frac{I_C(t)}{C} + L.\frac{d^2I_L(t)}{dt^2} = 0$$

Using the fact that $I_C(t) = I_L(t)$

$$\frac{I_L(t)}{C} + L.\frac{d^2I_L(t)}{dt^2} = 0$$

Dividing by L

$$\frac{1}{LC}I_L(t) + \frac{d^2I_L(t)}{dt^2} = 0$$

One possible solution is

$$I_L(t) = I_0\cos(\frac{t}{\sqrt{LC}})$$

To see if it is lets plug it in to the second order equation...

But FIRST we need the first and second derivative...

$$I_L(t) = I_0\cos(\frac{t}{\sqrt{LC}})$$

$$\frac{dI_L(t)}{dt} = -I_0\frac{1}{\sqrt{LC}}\sin(\frac{t}{\sqrt{LC}})$$

$$\frac{d^2I_L(t)}{dt^2} = -I_0\frac{1}{LC}\cos(\frac{t}{\sqrt{LC}})$$

Plugging in...

$$\frac{1}{LC}I_L(t) + \frac{d^2I_L(t)}{dt^2} = 0$$

$$\frac{1}{LC}I_0\cos(\frac{t}{\sqrt{LC}}) + (-I_0\frac{1}{LC}\cos(\frac{t}{\sqrt{LC}})) = 0$$

So we ARE right...

$$I_L(t) = I_0\cos(\frac{t}{\sqrt{LC}})$$

What about the Voltage?...

Let's use the fact that we know that the voltage accross the inductor is $V_L(t) = L.\frac{dI_l(t)}{dt}$

Substituting the first derivative of current

$$\frac{dI_L(t)}{dt} = -I_0\frac{1}{\sqrt{LC}}\sin(\frac{t}{\sqrt{LC}})$$

$$V_L(t) = -L.I_0\frac{1}{\sqrt{LC}}\sin(\frac{t}{\sqrt{LC}})$$

Simplifying

$$V_L(t) = -I_0\sqrt{\frac{L}{C}}\sin(\frac{t}{\sqrt{LC}})$$

In [ ]:

```
display(Math(r'$V_L(t)=-I_0 \sqrt{\frac{L}{C}} \sin(\frac{t}{\sqrt{LC}})$'))
display(Math(r'$I_L(t) = I_0\cos(\frac{t}{\sqrt{LC}})$'))

def simulate(I0 = 1, L=0.05, C=0.05, R=0, show_voltage=True, show_current=True):
    circuit = Circuit('LCCircuit')
    circuit.L(1, 'node_01', circuit.gnd, L@u_mH)
    circuit.C(2, 'node_01', 'node_02', C@u_mF)
    circuit.R(1, 'node_02', circuit.gnd, R@u_Ohm)
    Tf =3@u_ms
    T = 0.1@u_ms
    simulator = circuit.simulator(temperature=25, nominal_temperature=25)
    simulator.initial_condition(node_01 = I0@u_V)
    analysis = simulator.transient(step_time=T/10, end_time=Tf)
    fig, ax1 = plt.subplots()
    a,b = -5e10,5e10
    if show_current:
        ax1.set_title(f'I(t)&V(t) @I0={I0}, C={C}, L={L}')
        ax1.set_xlabel('Time in ms')
        # ax1.ticklabel_format(style='sci', axis='x', scilimits=(0,0))
        ax1.plot(analysis.branches['l1'])
        ax1.set_ylabel('A')
        color = 'tab:blue'
        ax1.tick_params(axis='y', labelcolor=color)
        ax1.set_ylim(a,b)

    if show_voltage:
        ax2 = ax1.twinx()
        color = 'tab:red'
        ax2.plot(analysis['node_01'], 'r')
        ax2.tick_params(axis='y', labelcolor=color)
        ax2.set_ylabel('V')
        ax2.set_ylim(a,b)


interact(simulate, I0=(1,5,0.01), C=(0.1, 0.5, 0.01), L=(0.1, 0.5, 0.01), R=(0, 1, 0.01), show_voltage=True, show_current=True)
```

$$V_L(t) = -I_0\sqrt{\frac{L}{C}}\sin(\frac{t}{\sqrt{LC}})$$

$$I_L(t) = I_0\cos(\frac{t}{\sqrt{LC}})$$

```
interactive(children=(FloatSlider(value=1.0, description='I0', max=5.0, min=1.0, step=0.01), FloatSlider(value…
```

Out[ ]:

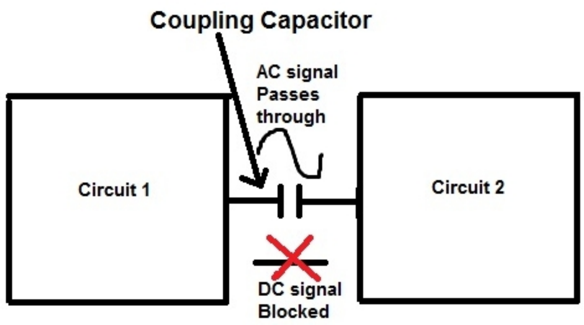
```
<function __main__.simulate(I0=1, L=0.05, C=0.05, R=0, show_voltage=True, show_current=True)>
```

In [ ]:

```
display(Math(r"\text{What else is a capacitor used for?}"))

from IPython.display import Image
from IPython.core.display import HTML
Image(url= "http://www.learningaboutelectronics.com/images/Couplingcapacitor.jpg")
```

What else is a capacitor used for?

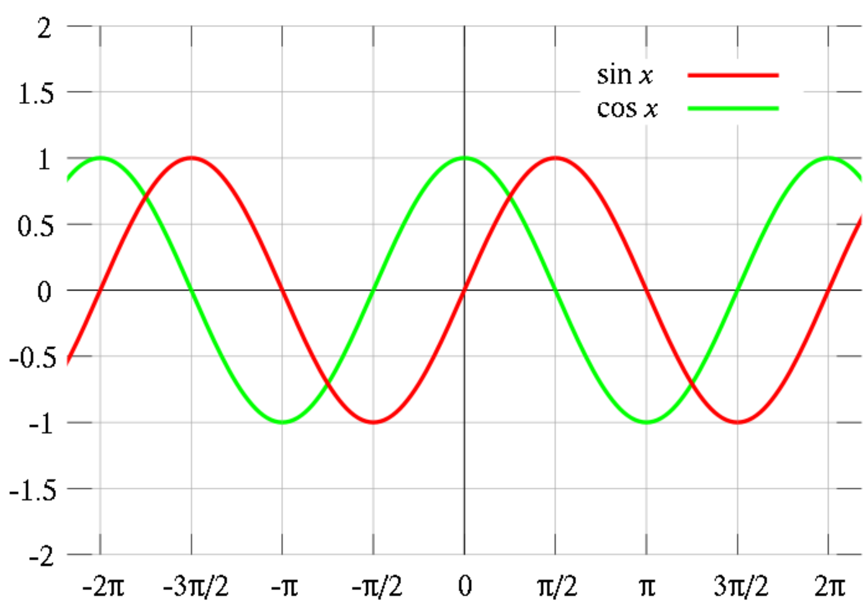
Out[ ]:



In [ ]:
```
display(Math(r"\text{What else is a capacitor used for?}"))

from IPython.display import Image
from IPython.core.display import HTML
Image(url= "https://upload.wikimedia.org/wikipedia/commons/thumb/3/38/Sine_cosine_plot.svg/800px-Sine_cosine_plot.svg.png?20090930212724
```

What else is a capacitor used for?

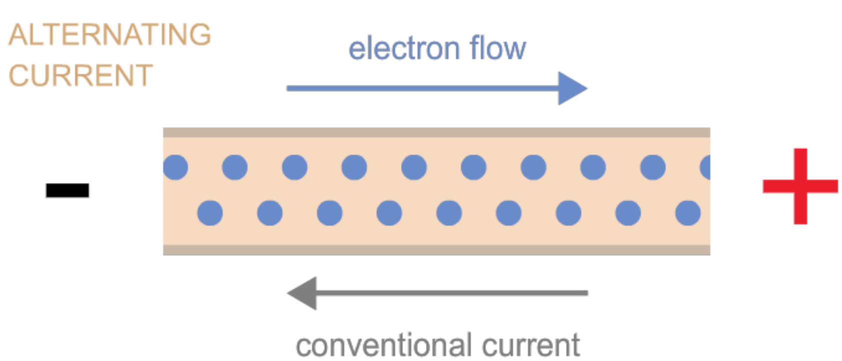
Out[ ]:



In [ ]:
```
display(Math(r"\text{What else is a capacitor used for?}"))

from IPython.display import Image
from IPython.core.display import HTML
Image(url= "https://serpmedia.org/scigen/images/electrons-ac%20copy.gif?crc=521762502")
```

What else is a capacitor used for?

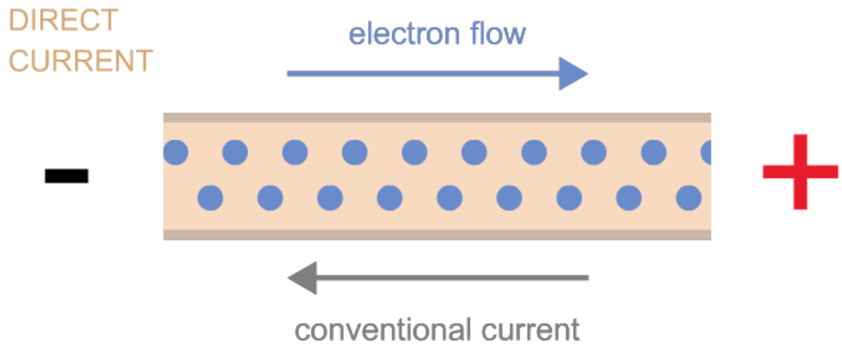
Out[ ]:



In [ ]:
```
display(Math(r"\text{What else is a capacitor used for?}"))

from IPython.display import Image
from IPython.core.display import HTML
Image(url= "https://serpmedia.org/scigen/images/electrons-dc%20copy.gif?crc=57018027")
```

What else is a capacitor used for?

Out[ ]:



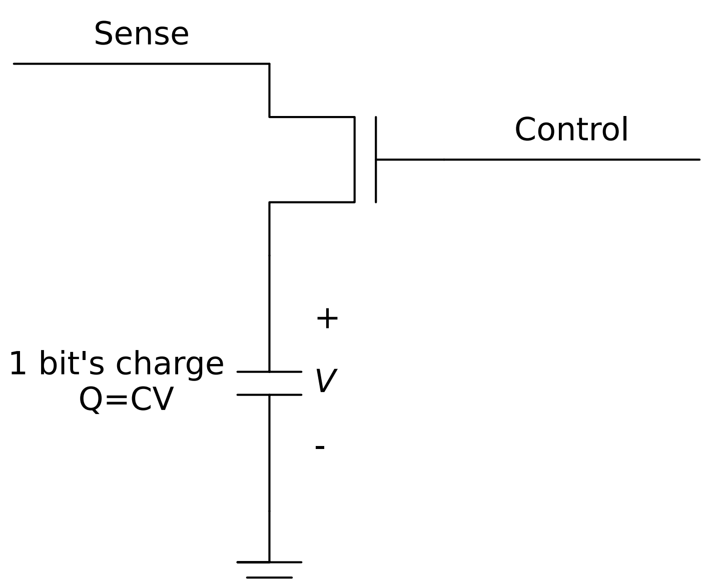
In [ ]:

```
display(Math(r"\text{What about something we use everyday?}"))
display(Math(r"\text{RAM}"))
display(Math(r"\text{Introducing the 1T1C DRAM Cell}"))
with schemdraw.Drawing() as d:
    d.config(inches_per_unit=2, unit=2)
    d += (s1 := elm.Line().label('Sense', fontsize=32))
    d += (t1 := elm.transistors.NFet())
    d += (s1 := elm.Line().at(t1.gate).label('Control', fontsize=32))

    d += (d1 := elm.Capacitor().down().at(t1.source).label("1 bit's charge\nQ=CV     ", fontsize=32).label(['+', '$V$', '-'], loc='bot',
    d += (d1 := elm.Ground())
    # d += (s2 := elm.Line())
    # d += (c1 := elm.Capacitor().down().label(f'$C$', loc="bot", fontsize=30))
    # d += (s3 := elm.Line().left())
    # d += (d2 := elm.Dot())
    # d += (s4 := elm.Line().left())
    # d += (l1 := elm.Inductor().up().label(f'L', loc="top", fontsize=30))
    # d += (s5 := elm.Line().right())
display(Math(r"\text{We read by setting control to high and comparing voltage of capacitor to some reference with a comparator?}"))
display(Math(r"\text{If V greater than comparator reference then value of bit is 1 else 0}"))
display(Math(r"\text{Why is it called (D)ynamic RAM? because you need to keep refreshing because charge in the capacitor leakse, you ref
display(Math(r"\text{What's the relationship between electrons and information here?}"))
display(Math(r"\text{Assuming Capacitance C=75fF}"))
display(Math(r"\text{Assuming V=3}"))
display(Math(r"\text{Q=10^-15 coulomb}"))
display(Math(r"\text{1 coulomb = 10^19 electrons}"))
display(Math(r"\text{So the capacitor needs ~1000 electrons to store 1 bit}"))
display(Math(r"\text{Can we make that a little more efficient?}"))
```

What about something we use everyday?

RAM

Introducing the 1T1C DRAM Cell



We read by setting control to high and comparing voltage of capacitor to some reference with a comparator?

If V greater than comparator reference then value of bit is 1 else 0

Why is it called (D)ynamic RAM? because you need to keep refreshing because charge in the capacitor leakse, you refresh by reading through the compar

What's the relationship between electrons and information here?

Assuming Capacitance C=75fF

Assuming V=3

Q=10^-15 coulomb

1 coulomb = 10^19 electrons

So the capacitor needs ~1000 electrons to store 1 bit

Can we make that a little more efficient?

In [ ]:

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from IPython.display import Image
from IPython.core.display import HTML
Image(url= "https://1.bp.blogspot.com/-yk5zuR9kJpI/V9ejT_lVGJI/AAAAAAAAfaU/_7fXsY8kzSQauGI5USPzzyVO5zLKI83UACLcB/s1600/generatoranimatio
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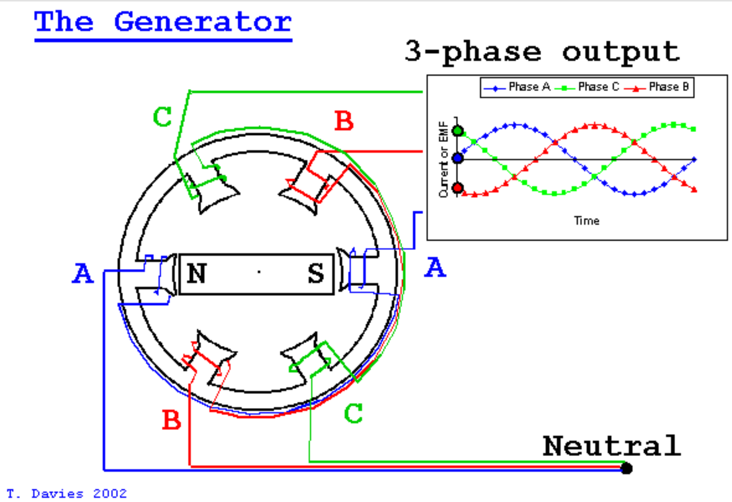
Out[ ]:



In [ ]: