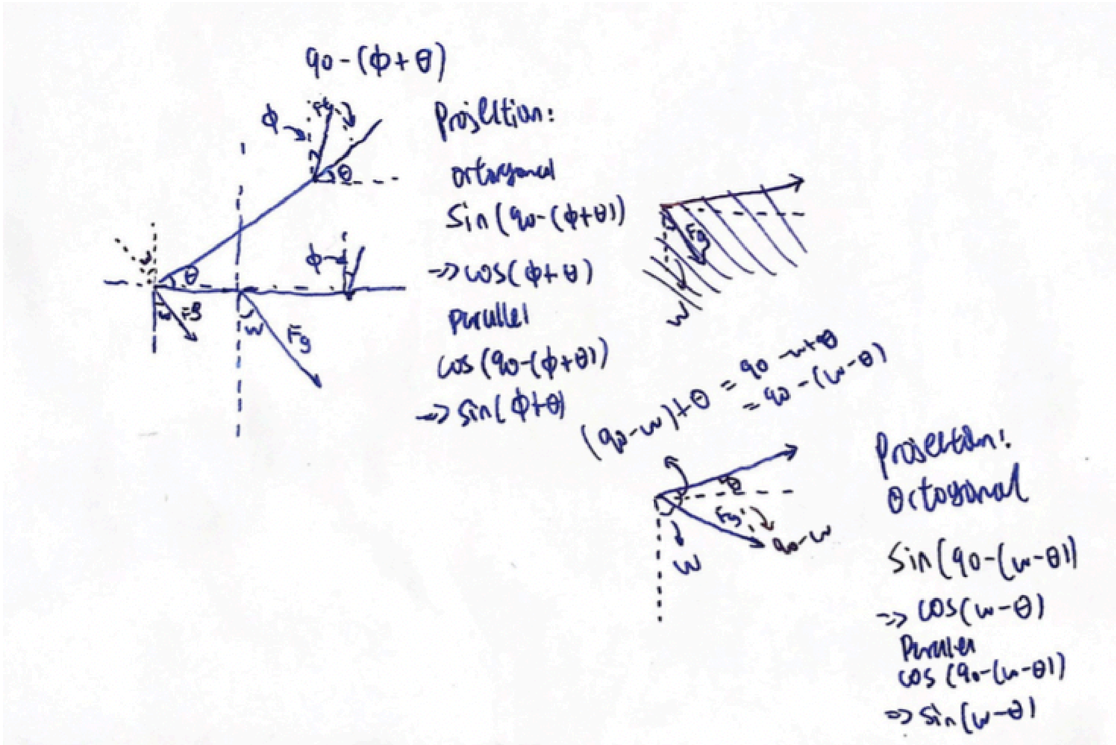
Let's draw a picture of this situation!



We first set up the basic assumptions and variables.

```
GRAV <- 9.8 # gravity (m/s^2)
MASS <- 3.11*10^(-5) # mass (kg)
I_CM <- 9.85*10^(-5) # roational inertia at the centre of gravity (kg m^2)
L1 <- 0.0017 # distance from rotation point to CoM (m)
L2 <- 0.0034 # distance from rotation point to tension (m)
PHI <- pi/6 # angle of Ft relative to floor (orthogonal) (rad)
FT <- 5*10^(-4) # tension force (N)
OMEGA <- 0 # angle of line orthogonal to floor relative to gravity (rad) (because shifted axis)
```

Additionally, we set the time interval and seed values for time and theta (distance from flat):

```
dt <- 0.0001
t_max <- 1

vx <- 0
vy <- 0

x <- 0
y <- 0

theta <- 0
thetadot <- 0
time <- 0
```

Great. Let's start generating the table! We essentially write a for loop to appends to a few different vectors. Variables appended with `c` reflect the column vectors that we will put together.

```
cTime = NULL
cTheta = NULL
cDDTheta = NULL
cDTheta = NULL
cTorqueNet = NULL
cAccelX = NULL
cAccelY = NULL
cVelX = NULL
cVelY = NULL

cPosX = NULL
cPosY = NULL

cPosPX = NULL
cPosPY = NULL

cFFriction = NULL
cFNormal = NULL

# debugging values
cFNetY = NULL
cFTensionPhiComponent = NULL
cFGravityPhiComponent = NULL

cMuStatic = NULL
cKERot = NULL
cKETrans = NULL
```

Awesome. Let's now run a lovely little for loop to actually populate the values recursively.

```
for (i in 0:(t_max/dt)) {
    # We first populate the time column with the time, theta column with theta
    cTime[i] = time

    # Given the theta value, we calculate the net torque and set that
    I_ROT <- I_CM + MASS * L1^2 # we calculate I_ROT using
# the Parallel axis theorem

    torque <- L2 * FT * cos(theta + PHI) - L1 * MASS * GRAV * cos(theta - OMEGA)
    cTorqueNet[i] = torque
    # Now that we know the net torque, we could know how much the angular
    # acceleration is by just dividing out the rotational inertia
    thetadotdot <- torque/I_ROT
    cDDTheta[i] = thetadotdot
    # We could also multiply the theta acceleration by time to get the
    # velocity at that point
    thetadot <- dt*thetadotdot + thetadot
    cDTheta[i] = thetadot

    # we then tally the theta value
    theta <- dt*thetadot + theta
    cTheta[i] = theta

    # We could therefore component-ize the acceleration in theta, times
```

```
    # the length of the object until com, to figure the acceleratinos
    # of the com
    ax <- -1 * L1 * sin(theta) * thetadotdot
    cAccelX[i] = ax
    ay <- L1 * cos(theta) * thetadotdot
    cAccelY[i] = ay # @mark isn't sin and cos backwards?

    # "position prime": calculated positino
    cPosPX[i] = cos(theta)*L1
    cPosPY[i] = sin(theta)*L1

    # We also tally the components seperately for velocity
    vx <- ax*dt + vx
    vy <- ay*dt + vy

    # We finally tally the positions as well
    x <- vx*dt + x
    y <- vy*dt + y

    cPosX[i] = x
    cPosY[i] = y

    # Based on these accelerations, we therefore could calculate the relative
    # force of friction and normal force by subtracting the force in that direction
    # out of net
    ffriction <- FT*sin(PHI) + MASS*GRAV*sin(OMEGA)-MASS*ax
    fnormal <- MASS*ay-FT*cos(PHI)+MASS*GRAV*cos(OMEGA)

    cFNetY[i] = MASS*ay
    cFTensionPhiComponent[i] = FT*cos(PHI)
    cFGravityPhiComponent[i] = -MASS*GRAV*cos(OMEGA)

    cFFriction[i] = ffriction
    cFNormal[i] = fnormal

    # Then, we calculate the energies
    cKERot[i] = 0.5 * I_ROT * thetadot^2
    cKETrans[i] = 0.5 * MASS * (vx^2+vy^2)

    # Dividing the friction force by the normal force, of course, will result in
    # the (min?) friction coeff
    cMuStatic[i] = ffriction/fnormal

    # We incriment the time and also increment theta by multiplying the velocity
    # by dt to get change in the next increment
    time <- dt + time
}
```

We now put all of this together in a dataframe.

```
rotating_link <- data.frame(cTime,
    cTheta,
    cDTheta,
    cDDTheta,
```

```
    cTorqueNet,
    cAccelX,
    cAccelY,
    cPosX,
    cPosY,
    cPosPX,
    cPosPY,
    cFFriction,
    cFNormal,
    cMuStatic,
    cKERot,
    cKETrans)

names(rotating_link) <- c("time",
  "theta",
  "d.theta",
  "dd.theta",
  "net.torque",
  "accel.x",
  "accel.y",
  "pos.x",
  "pos.y",
  "pos.p.x",
  "pos.p.y",
  "friction.force",
  "normal.force",
  "friction.coeff",
  "ke.rot",
  "ke.trans")
```

Let's import some visualization tools, etc.

```
library(tidyverse)
```

Let's first see the head of this table:

```
head(rotating_link)
```

```
1e-04 2.9059380176551e-10 1.9372920117422e-06 0.00968646005829307 9.54117186351211e-07 -4.785202931781
1.64669820990982e-05 -7.97533822000296e-23 4.94009463001366e-13 0.0017 4.94009463001367e-13
0.00025 -0.000128232189769076 -1.94958848047598 1.8484036034639e-16 1.68662452673712e-22
2e-04 5.81187603505943e-10 2.90593801740433e-06 0.0096864600566213 9.54117186186541e-07 -9.570405861498
1.64669820962562e-05 -2.39260146573936e-22 9.88018925960103e-13 0.0017 9.88018925960103e-13
0.00025 -0.000128232189769076 -1.94958848047598 4.15890810719562e-16 3.79490518461272e-22
3e-04 9.68646005787513e-10 3.8745840228157e-06 0.00968646005411363 9.54117185939536e-07 -1.595067643078
1.64669820919932e-05 -5.5827367525568e-22 1.64669820983877e-12 0.0017 1.64669820983877e-12
0.00025 -0.000128232189769076 -1.94958848047598 7.39361441130349e-16 6.74649810461973e-22
4e-04 1.45296900857678e-09 4.8432300278927e-06 0.00968646005077009 9.54117185610197e-07 -2.392601463619
1.64669820863092e-05 -1.11654735029939e-21 2.47004731458053e-12 0.0017 2.47004731458053e-12
0.000250000000000001 -0.000128232189769076 -1.94958848047598 1.1552522514671e-15 1.05414032857393e-21
5e-04 2.03415661183196e-09 5.81187603255177e-06 0.00968646004659066 9.54117185198522e-07 -3.349642047333
1.64669820792041e-05 -2.00978523007641e-21 3.45806624011433e-12 0.0017 3.45806624011433e-12
0.000250000000000001 -0.000128232189769077 -1.94958848047597 1.66356324158625e-15 1.51796207266616e-21
```

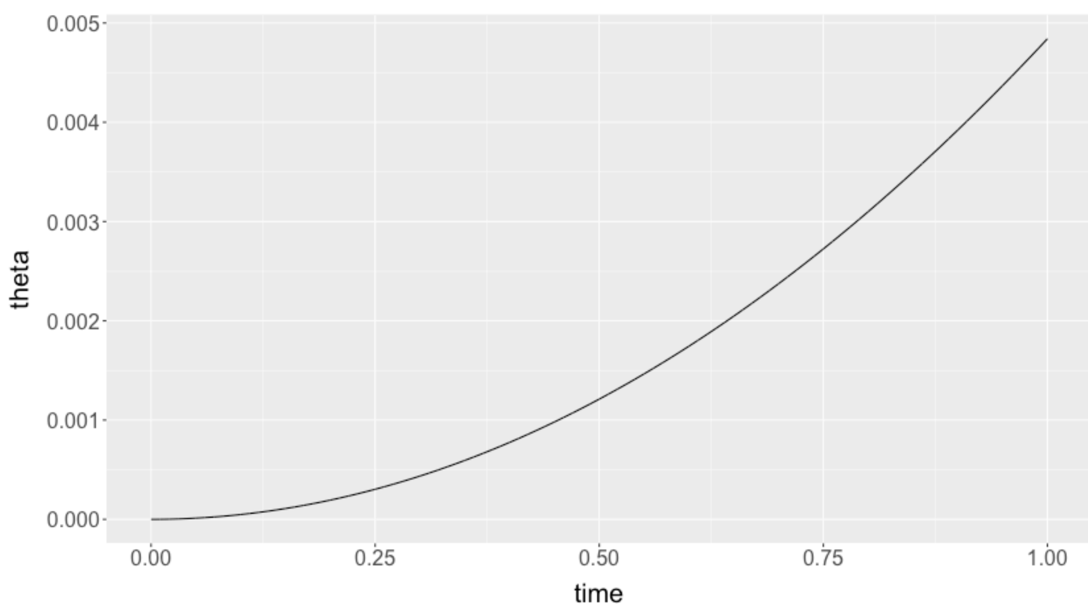
```
6e-04 2.71220881550289e-09 6.7805220367093e-06 0.00968646004157534 9.54117184704513e-07 -4.4661893936821
1.64669820706781e-05 -3.34964204922164e-21 4.61075498635491e-12 0.0017 4.61075498635491e-12
0.000250000000000001 -0.000128232189769077 -1.94958848047597 2.26429441131234e-15 2.06611504257856e-21
```

Before we start graphing, let's set a common graph theme.

```
default.theme <- theme(text = element_text(size=20), axis.title.y = element_text(margin = margin(t = 0,
```

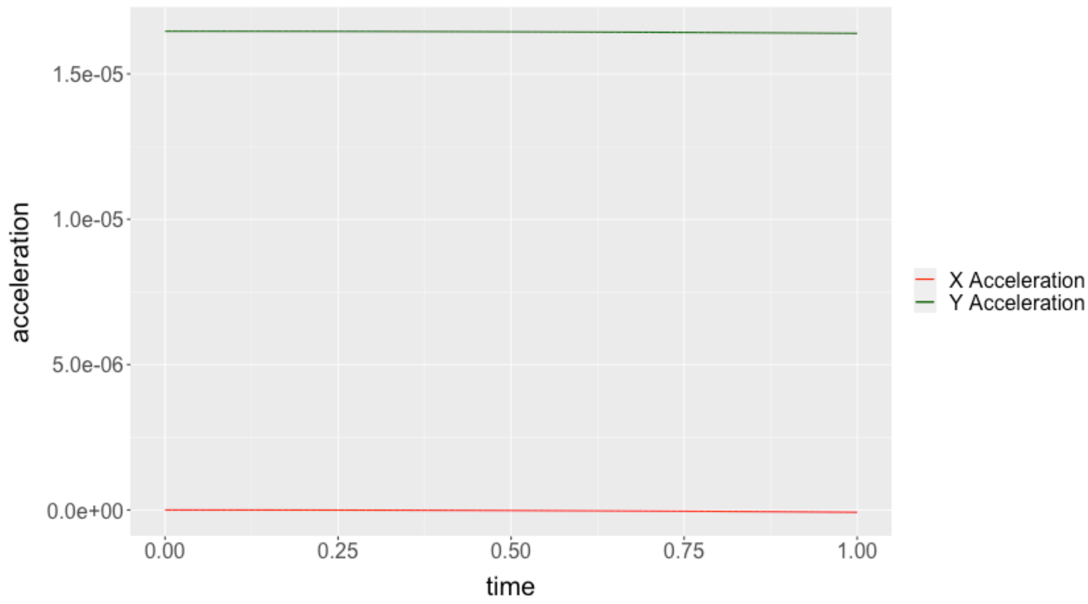
Cool! We could first graph a function for theta over time.

```
rotating_link %>% ggplot() + geom_line(aes(x=time, y=theta)) + default.theme
```



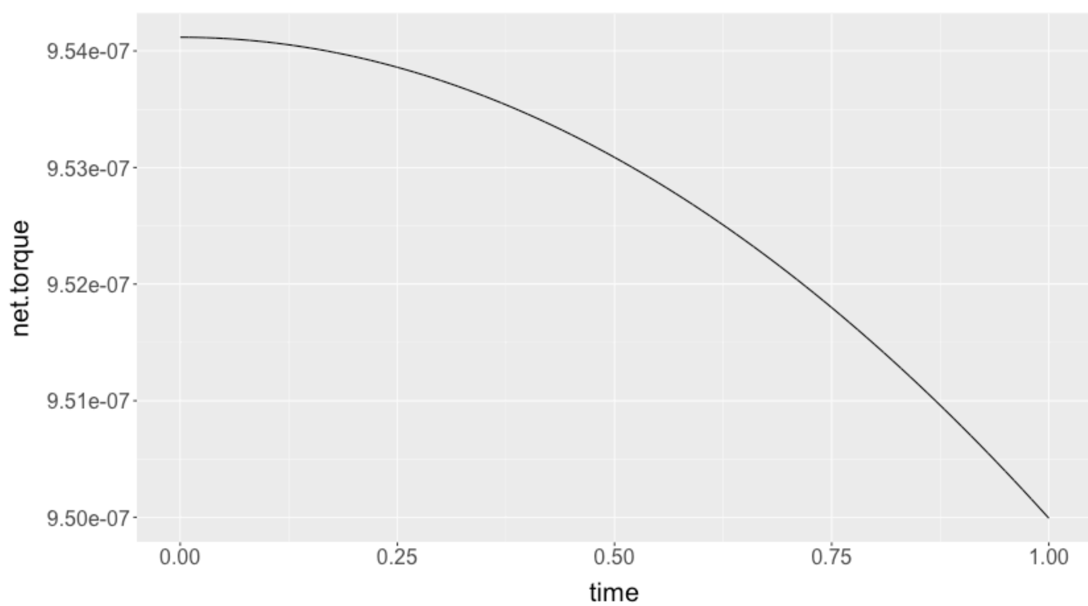
And, similarly, we will graph `ax` and `ay` on top of each other:

```
rotating_link %>% ggplot() + geom_line(aes(x=time, y=accel.x, colour="X Acceleration")) + geom_line(aes
```



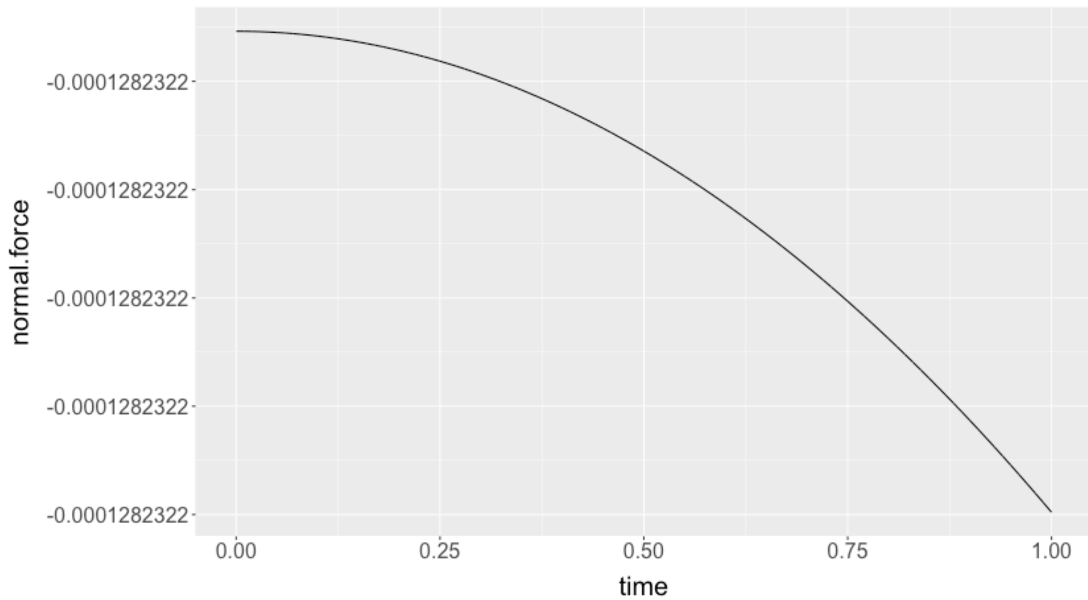
Let's also plot torque as well.

```
rotating_link %>% ggplot() + geom_line(aes(x=time, y=net.torque)) + default.theme
```



And. **Most importantly!** Let's plot the normal force.

```
rotating_link %>% ggplot() + geom_line(aes(x=time, y=normal.force)) + default.theme
```

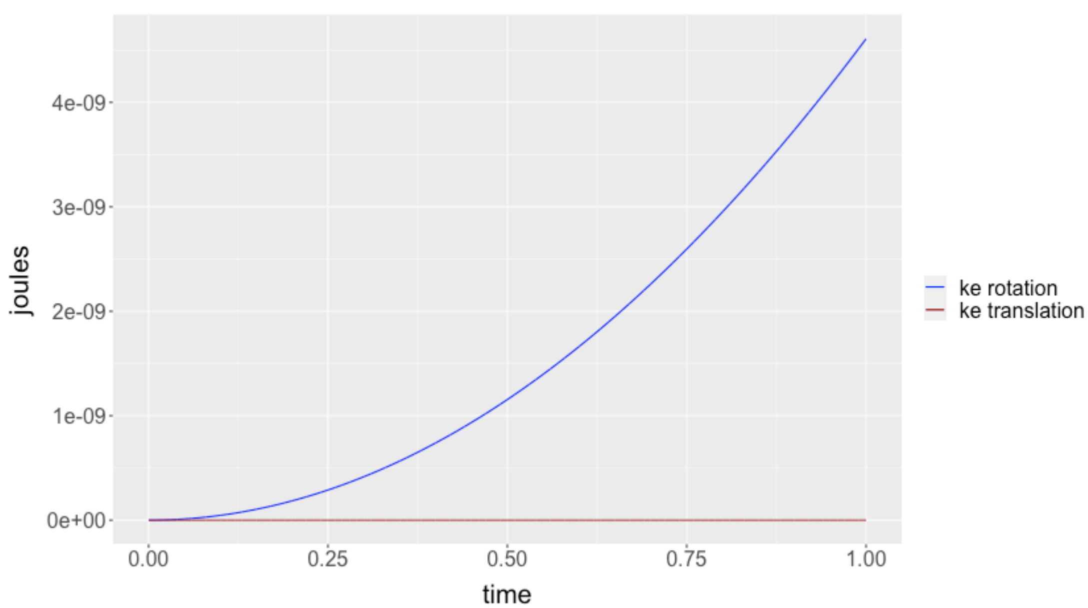


Obviously, after the normal force becomes negative, this graph stops being useful.

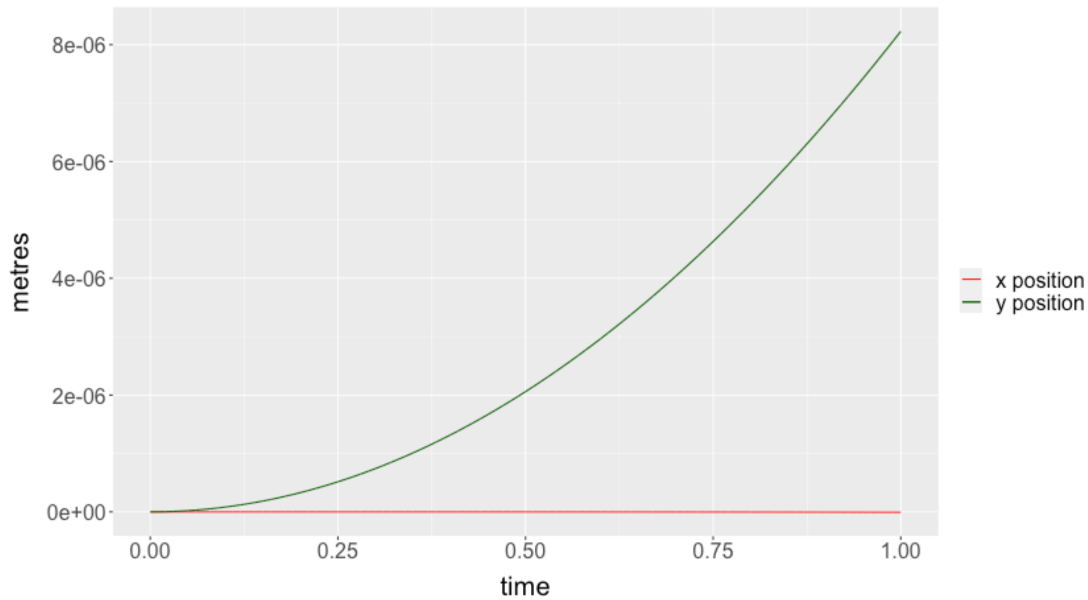
Theta dot atop theta:

We finally, plot KE rotation and translation

```
rotating_link %>% ggplot() + geom_line(aes(x=time, y=ke.rot, colour="ke rotation")) + geom_line(aes(x=t
```

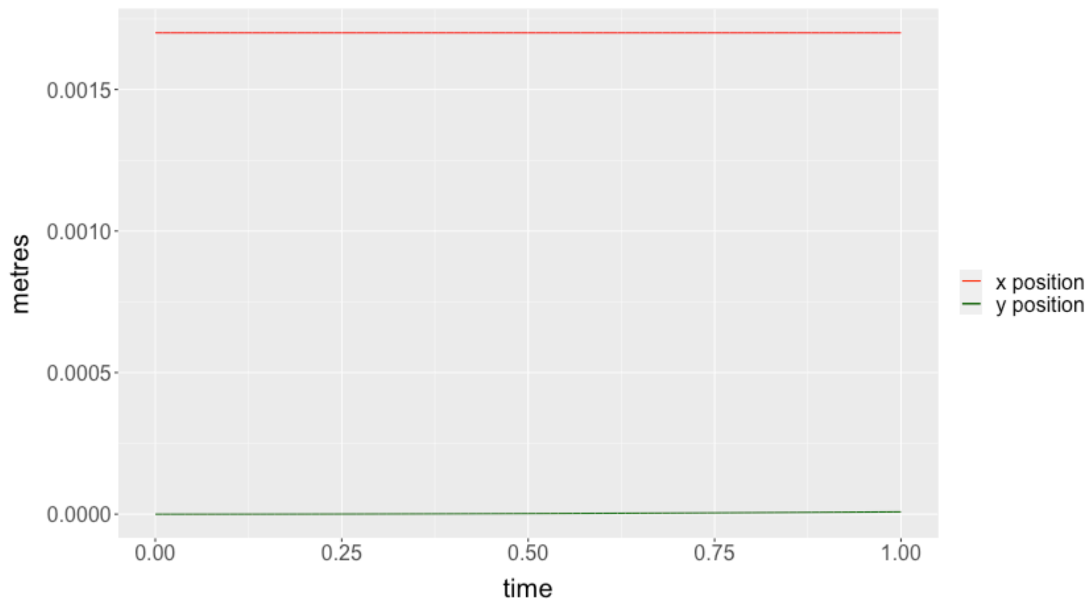



```
rotating_link %>% ggplot() + geom_line(aes(x=time, y=pos.x, colour="x position")) + geom_line(aes(x=tim
```

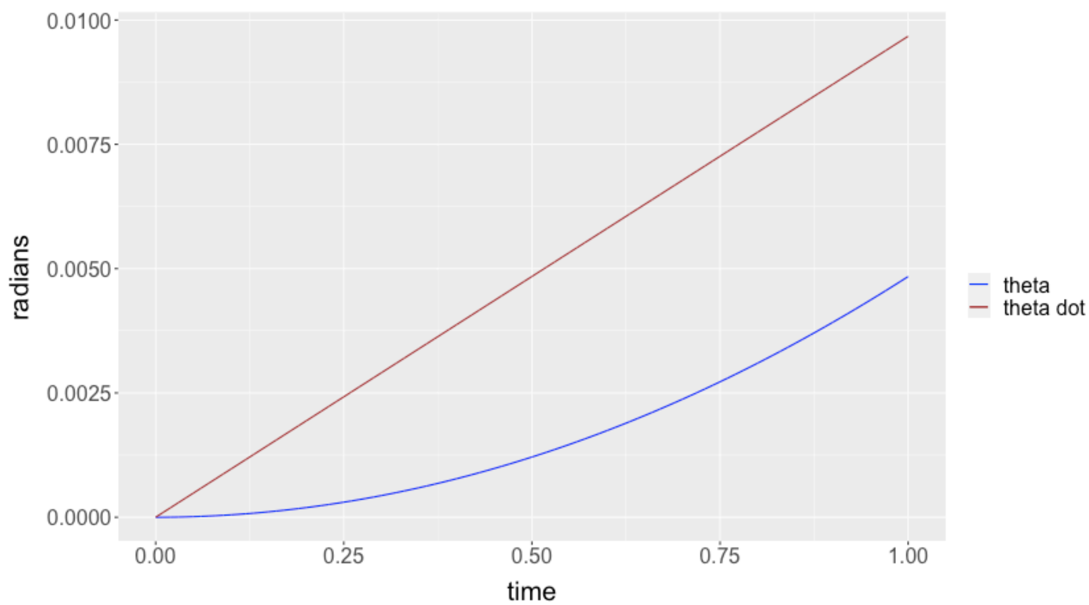


floor

```
rotating_link %>% ggplot() + geom_line(aes(x=time, y=pos.p.x, colour="x position")) + geom_line(aes(x=t
```




```
rotating_link %>% ggplot() + geom_line(aes(x=time, y=theta, colour="theta")) + geom_line(aes(x=time, y=
```




```
rotating_link %>% ggplot() + geom_line(aes(x=time, y=dd.theta, colour="thetadd")) + scale_colour_manual
```