

# Grand Prix Grand Prix

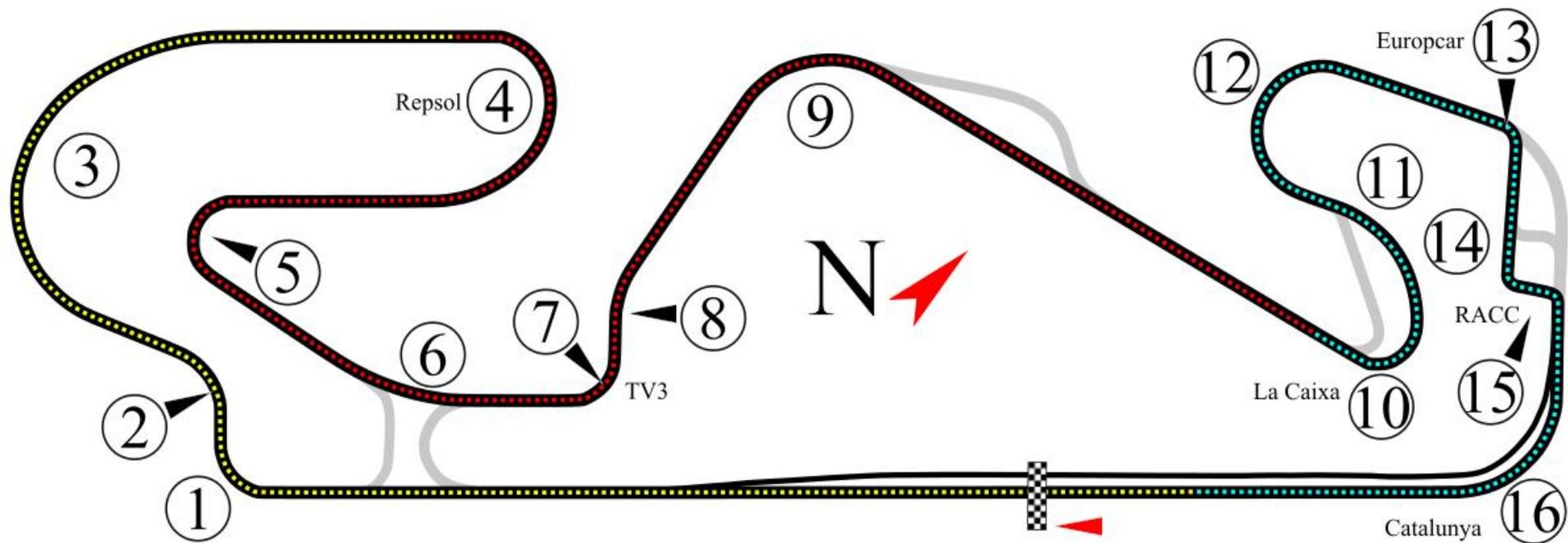
Racing Car(~~s~~) around a track safely, By Evan Lohn

# Why (Race)Car Safety?

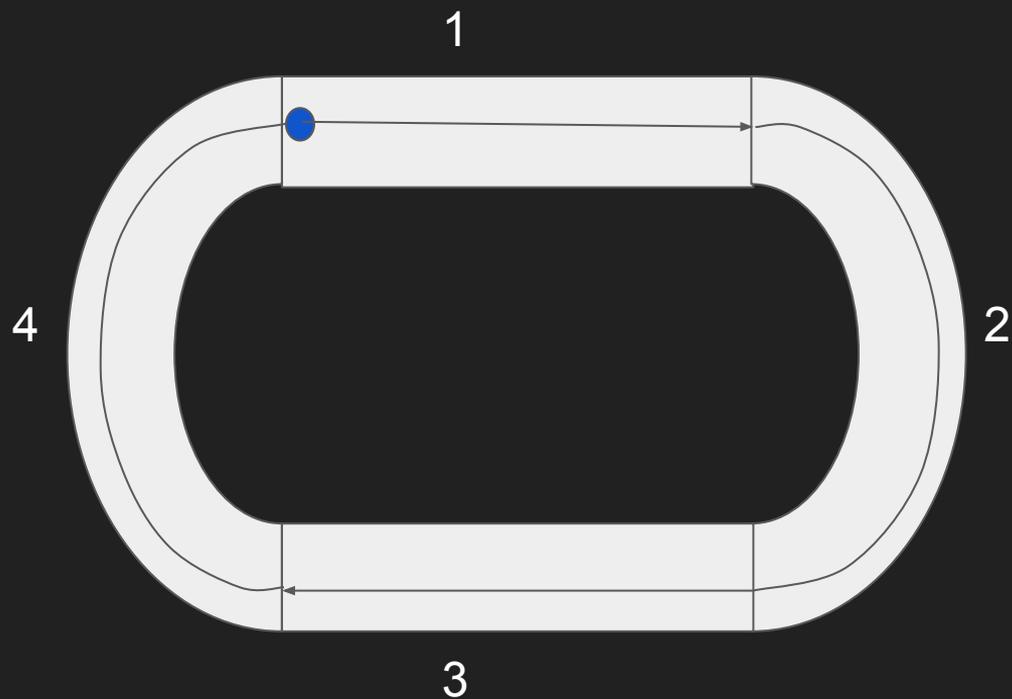


# How to Model a Racetrack?

F1 Catalunya 2021



# Full tracks



# Straight segments

Parameters:

- Starting Line,
- Goal Line,
- Track width

Inbounds(x,y): (simple case)

$\text{minX} < x < \text{maxX} \ \&\&$

$\text{minY} < y < \text{maxY}$



# Curve Segments

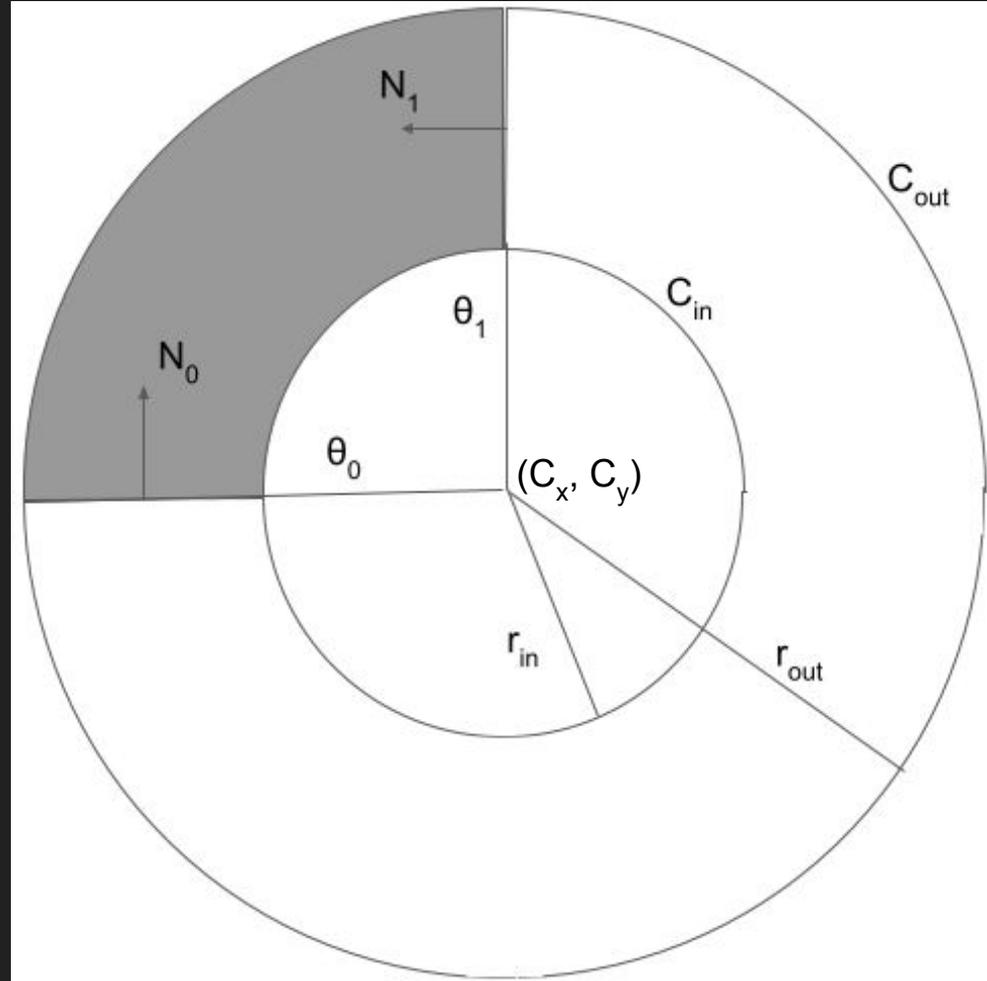
Parameters:  $C_x, C_y, r_{in}, r_{out}, \theta_0, \theta_1$

Inbounds(x,y):

$r_{in} < \text{distFrom}(C_x, C_y, x, y) < r_{out} \ \&\&$

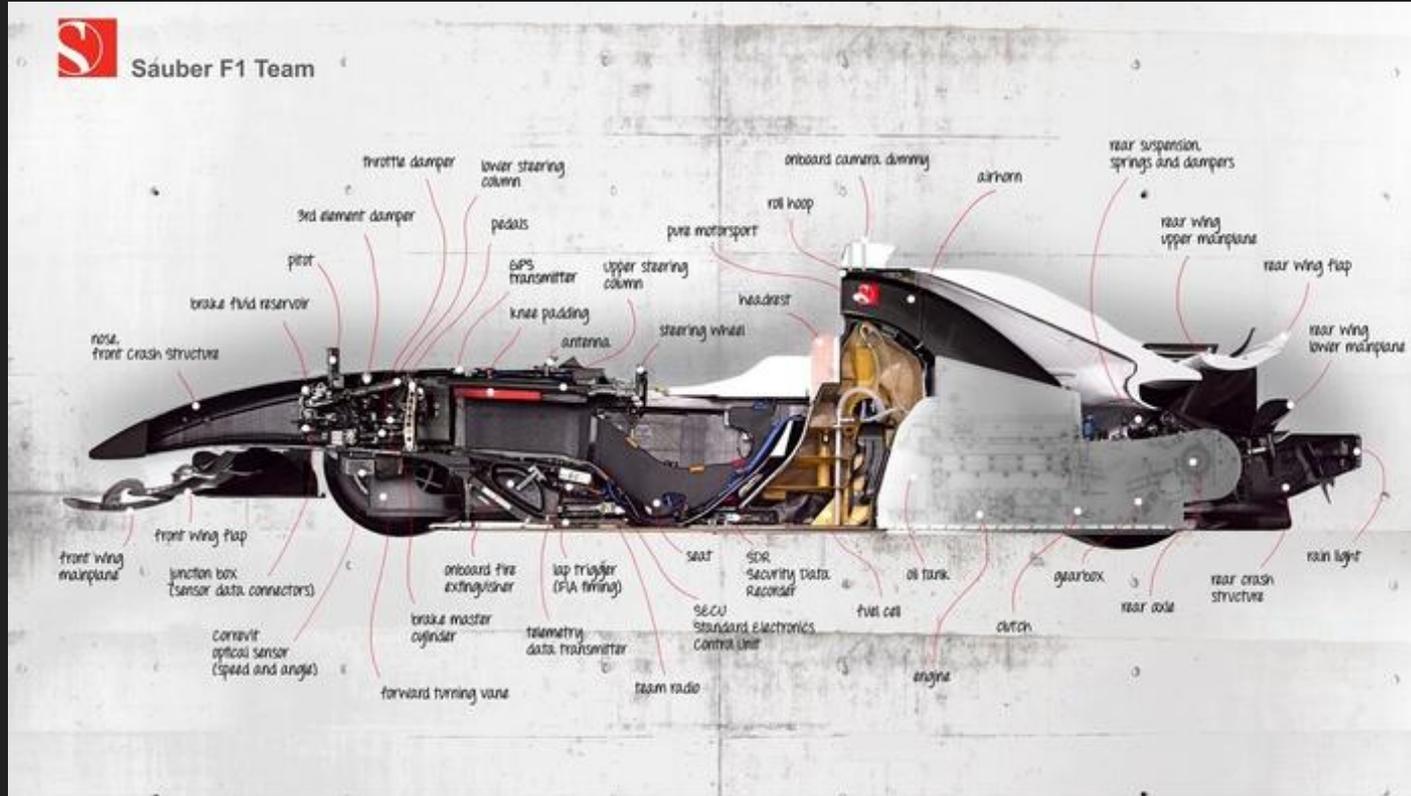
$\langle \text{vecFrom}(C_x, C_y, x, y), N_0 \rangle \geq 0 \ \&\&$

$\langle \text{vecFrom}(C_x, C_y, x, y), N_1 \rangle \geq 0$



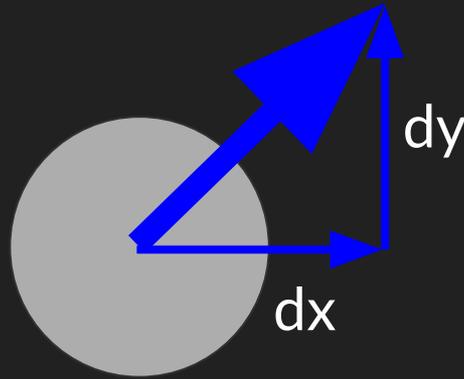
How to Model a Racecar?

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# How to Model a Racecar?

$(x, y, dx, dy, v, a)$



# How to Model a Racecar?

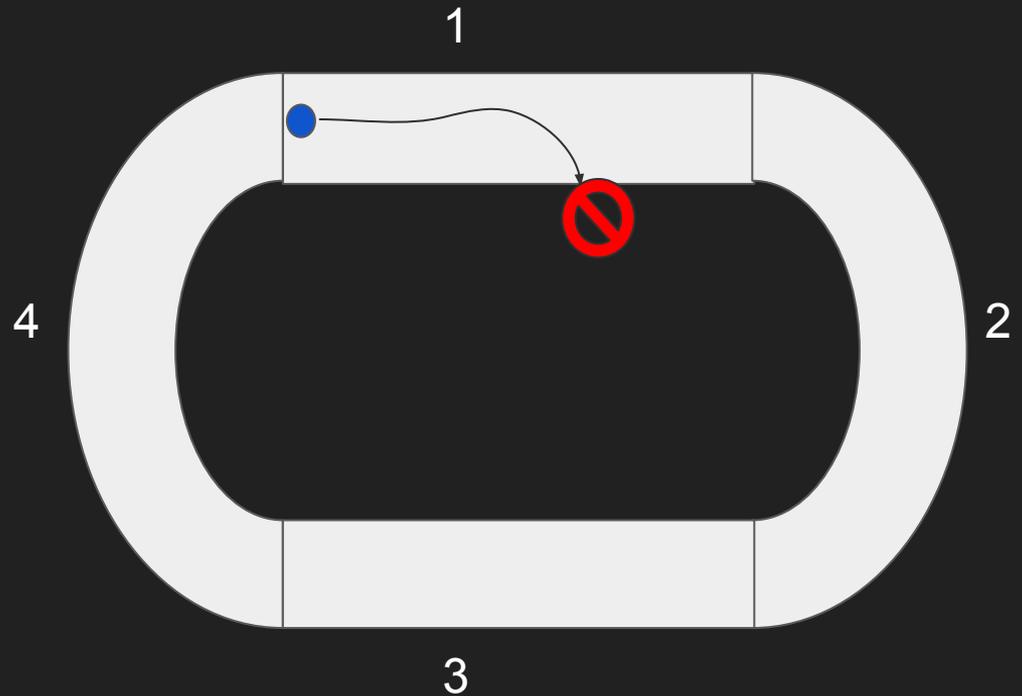
- Dynamics
  - Turning speed  $s$ , acceleration  $a$
  - $dx' = s * dy$ ,  $dy' = -s * dx$
  - $x' = v * dx$ ,  $y' = v * dy$
  - $v' = a$
- Racecar radius?

# Reality Check

- Track
  - Varying width?
- Car
  - Tire slipping?
  - Tire wear?
  - Max turning radius?
  - Oh my!
- Fundamental limitations

# Proofs about Entire Tracks

Goal: Never Crash!



# Proofs about entire tracks



# Proofs about entire tracks

Entry/Exit contracts

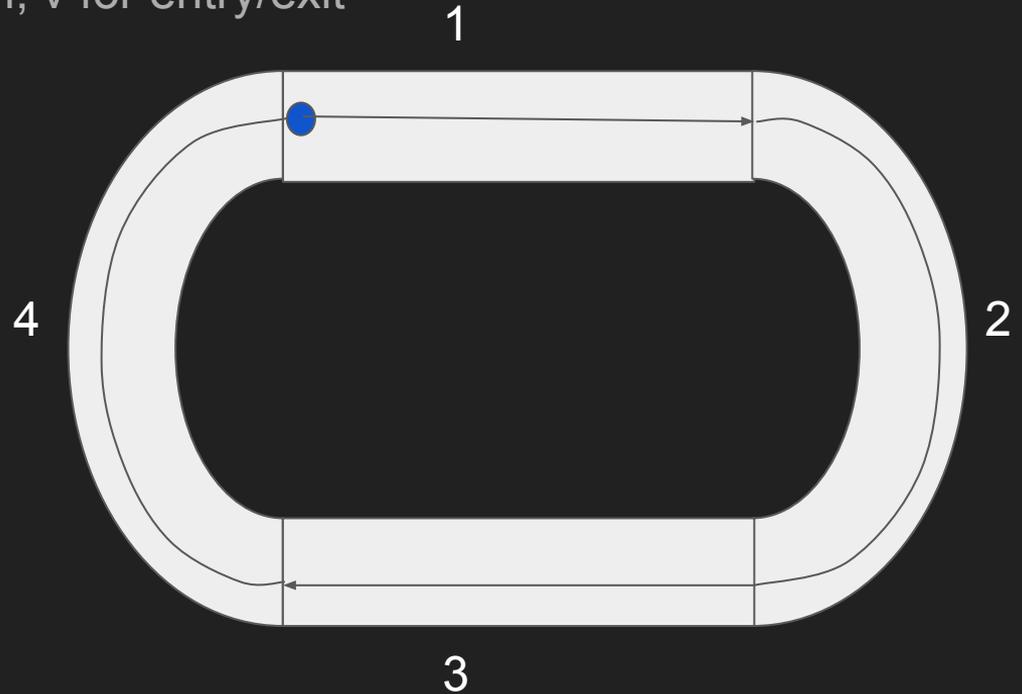
Proven per controller per track segment

# DL model

- Event-Driven
  - Pick controller based on position, pick dynamics, evolve!
  - Stop whenever! (For safety proof)
- Controllers set  $(s, a)$  ONCE for an entire track segment
  - pros/cons
- Main idea: use controller-segment proofs as lemmas to complete entire track proofs

# Example Full track proof idea

- Simple controllers
- Prove exact position, orientation,  $v$  for entry/exit

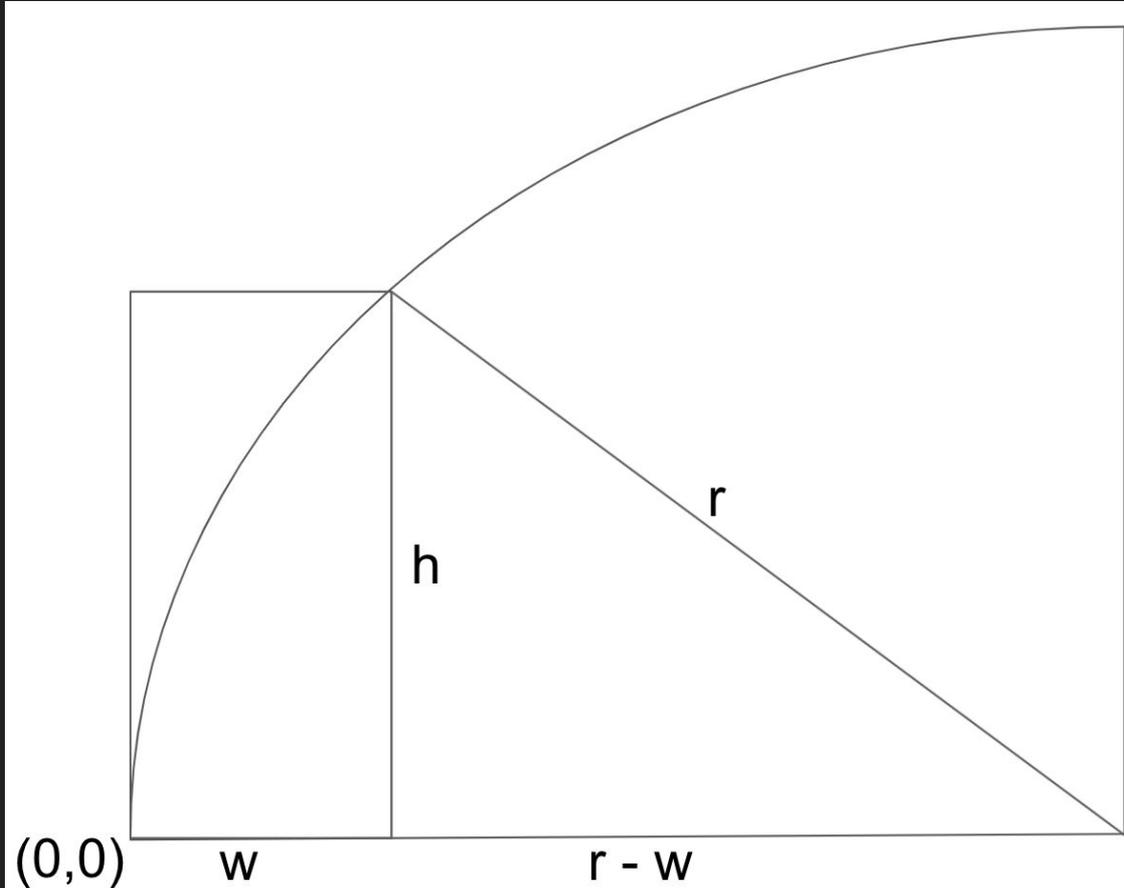


# More interesting controllers

- Acceleration!

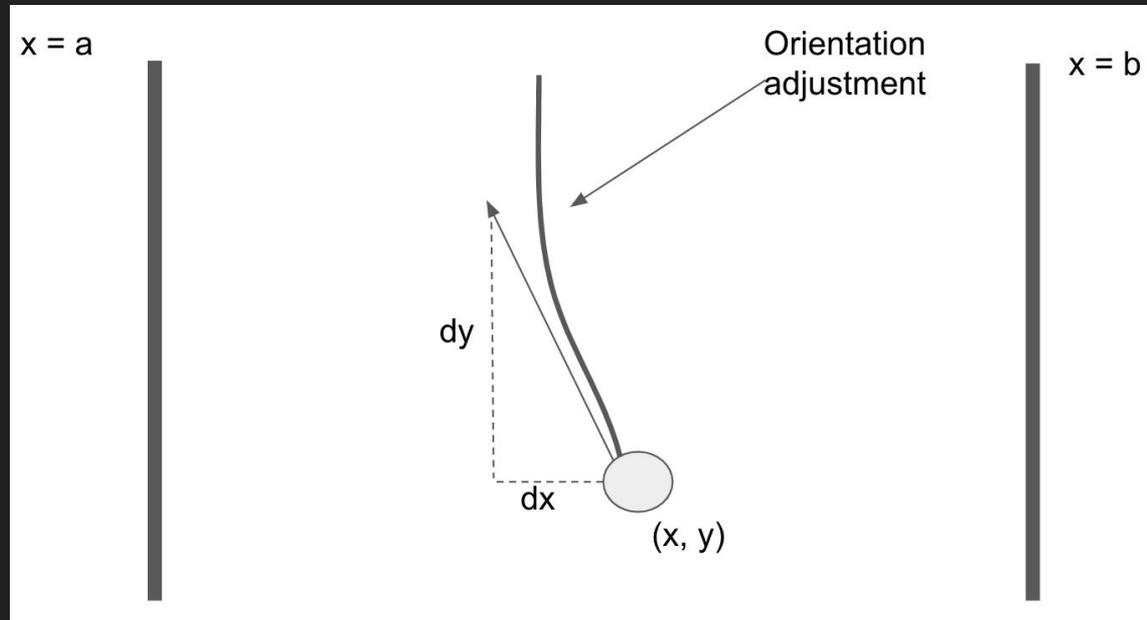
# More interesting controllers

- Acceleration!
- Slight turn



# More interesting controllers

- Acceleration!
- Slight turn
- Orientation adjustment



# Things I Actually Proved

- Simple straight controller (KeymaeraX)
- Simple curve controller (KeymaeraX)
- Acceleration straight controller (KeymaeraX)
- Variation of orientation adjustment controller (KeymaeraX)
- Maximum “slight turn” steering rate (math)  $s_{\max} = 2vw/(h^2 + w^2)$
- Exact orientation adjustment steering rate (math)
- No full track proofs

