

- video of Justin's robot standing

- (turning around from a chair)
- hej Justin! Yours stands, very nice!
- and you people? how is your robot balancing?
- hello, I am Steffi, and today we are finishing our learning how to make a robot balance on its wheels

# Making robots balance

## Part 3



# What are we doing today?

- today we recap the P controller, and what it means
- we then add two more ingredients to our 'artificial brain' that we are putting into our robot: the I controller and D controller
- by mixing these three ingredients we will get our 'final' brain, a PID controller, a brain that is used practically everywhere, in the whole world

# Our purposes

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- have fun

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- understand the world a bit better

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- have fun
- understand the world a bit better
- see that math is useful



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- recall what is the “P controller”
- introduce the “I and D controllers”

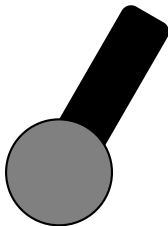
# What is going to happen in today's part

- recall what is the “P controller”
- introduce the “I and D controllers”
- connect I and D with useful math concepts

## Connecting things

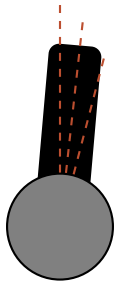
- let's recall what the P controller was, and how we arrived to it

## Towards the P controller: our first heuristic



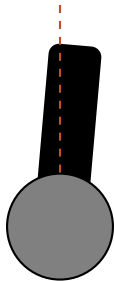
⇒ spin the wheels as fast as possible clockwise

## Towards the P controller: our second heuristic



⇒ depending on the zone, spin the wheels more or less fast

## The P (i.e., proportional) controller



$\Rightarrow$  speed of the wheels =  $P \cdot$  angular error

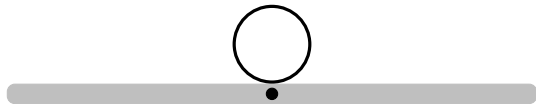


Remember:  $P$  is a design choice!

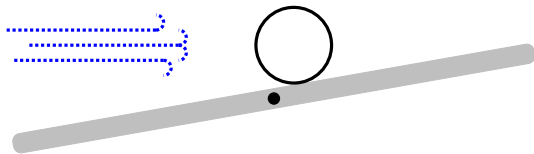
- $P$  small implies a 'gentle' control action
- $P$  big implies an 'aggressive' control action

- but our brain is not complete if we make it only using the P ingredient
- let me show you what I mean using another example (also to show how ubiquitous control is)
- assume that I want to balance a ball on a board, and make the ball stay at the center of the board
- my control action, that is, what I can do, is to move the board in this way
- what is a P controller here? it is that depending on how far the ball is from the center, I tilt more or less
- now remember: I may be more or less aggressive, that means choosing P bigger or smaller
- but pretend to be in the open space now, and that there is some wind that is keeping blowing and pushing just a tiny bit the ball that I am balancing
- what happens? let's have some wind assistant here: wind assistant, may you disturb me a bit?
- so the wind pushes, and the P controller reacts
- the wind makes a force, and the P controller makes a force too
- whenever the two forces are equal, then we get an equilibrium
- but at the equilibrium the ball is not at the point where I would like it to be
- somehow the P controller by itself is not "smart enough" to realize that there is this disturbance, and eliminate it
- let's see this through an animation

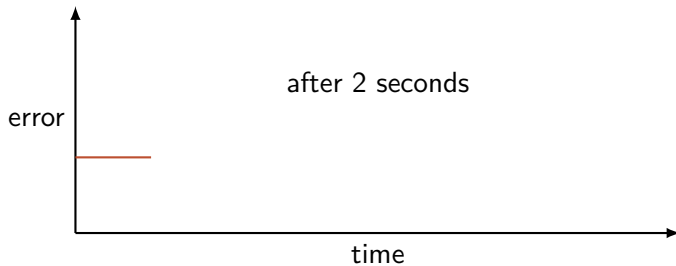
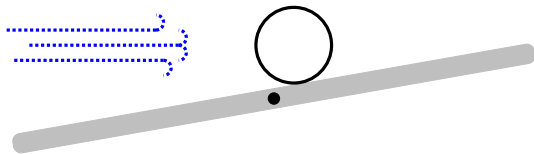
No wind = no problems



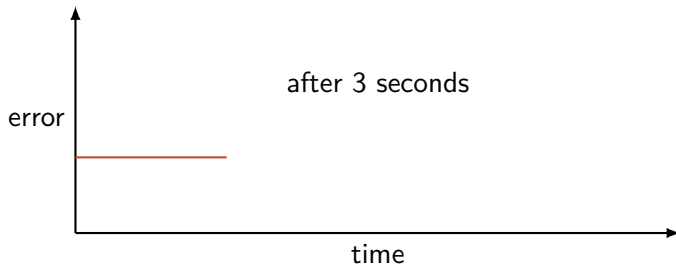
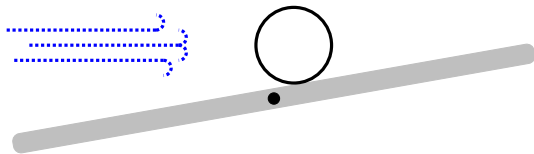
Some wind = some problems



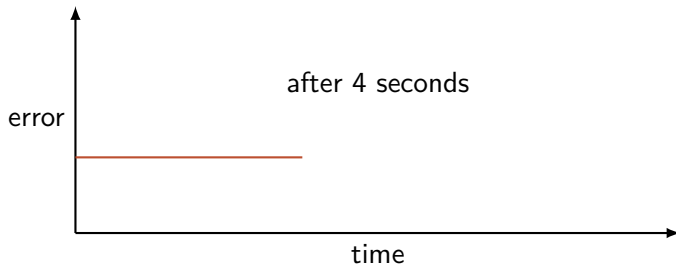
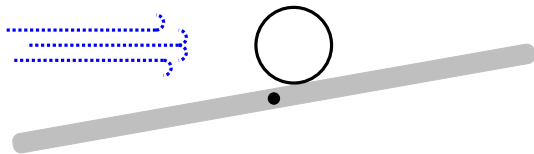
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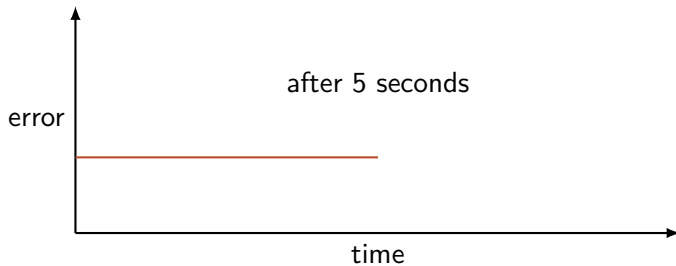
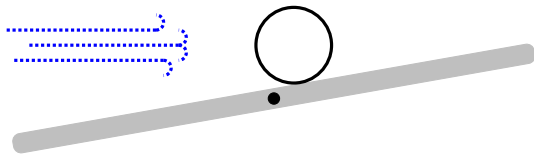
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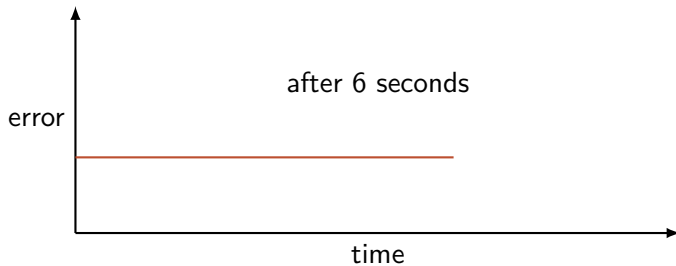
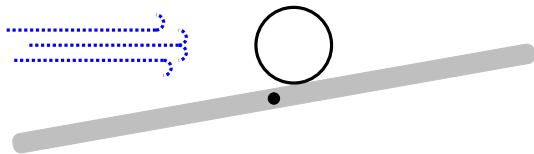


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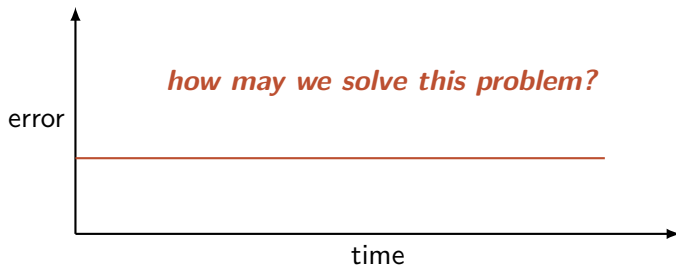
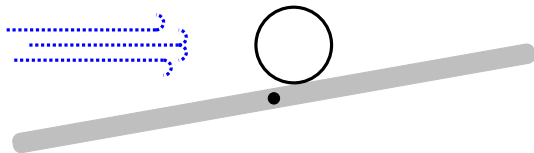




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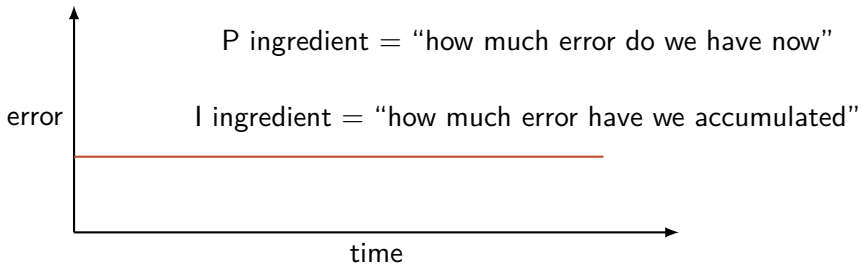
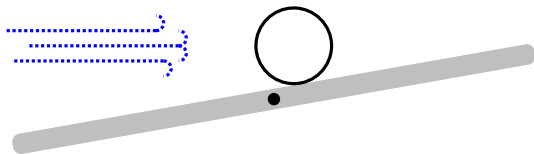


Discussion time!



- got some intuition? shared it with your friends?
- let's see if we have the same idea!
- let's see if you discovered the I controller by yourself!

The I (integral) ingredient: tilt not only proportionally to the current error, but also keep in mind the past history!



- but, as before, how do we design  $I$ ?
- to understand we should ask ourselves: what is the effect of having different  $I$ s?
- if I put  $I =$  a tiny tiny number, what is going to happen?
- if I put  $I =$  a huge number, what is going to happen?
- let's have a chat all together, and see what we think about this

## Discussion time!

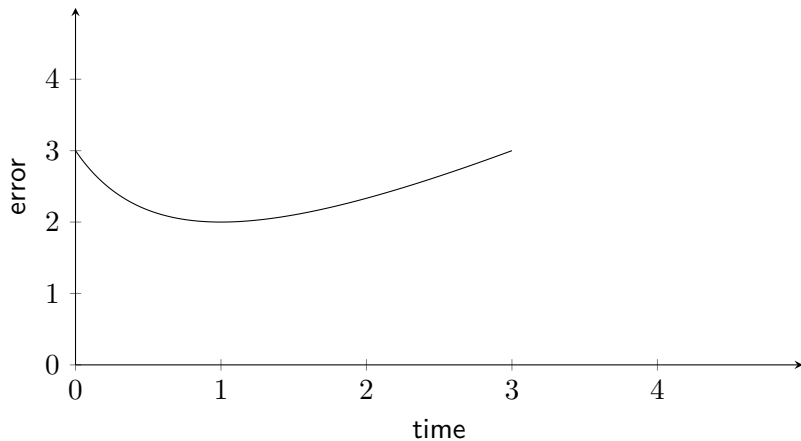
- if I put  $I =$  a tiny tiny number, what is going to happen?
- if I put  $I =$  a huge number, what is going to happen?

- good! So, the effects of choosing  $I$  are kind of similar as before for  $P$ , but not quite the same: the bigger  $I$ , the more we use the past to decide what to do now
- uhm, using the past errors to decide what to do now. . . and may we also use the future errors to decide what to do now? Can we forecast which errors we are going to make in the future?

- (this may be too much) 4 seconds of Sofie dressed like a magician making faces like she is trying to predict the future



## Predicting the future errors



The D (derivative) ingredient: tilt not only proportionally to the current error and keeping in mind the past history, but also forecasting what is going to happen in the future!

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$$\text{my action} = P \cdot \text{current error} + I \cdot \text{area of past error} + D \cdot \text{slope of current error}$$

- let's make a summary:
- P is how much I react to the current error
- I is a memory term: if I have been making errors for some time, then compensate for them
- D is trying to compensate for what I think the error will be in the next future. But watch out, predicting the future is a challenging thing, and the D term may make your brain quite nervous; try later on to put D big and you will see

I and D, two concepts that you will encounter in the future!



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- and now I leave you with playing with the robot; choose different  $P$ s, different  $I$ s, and different  $D$ s, and see what happens
- my proposal: try now to disturb the robot by gently poking it, placing it on a different surface, or attaching some weight to it! let's see who finds the PID combination that resists the most!

→ “manual for the students”, section “experimenting with the PID controller”

- so, now I let you do, and close this series video - I hope you liked it and that in the why you learned something about the most common automatic control strategy, the PID controller!
- please feel free to keep in touch, and good luck with all your wonderful projects!
- bye!

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- any Easter egg you would like to add :)