- 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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- have fun
- understand the world a bit better

Our purposes

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

What is going to happen in today's part

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- recall what is the "P controller"

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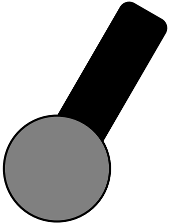
What is going to happen in today's part

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

Connecting things

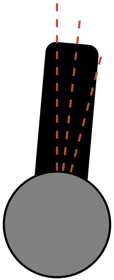
- let's recall what the P controller was, and how we arrived to it

Towards the P controller: our first heuristic



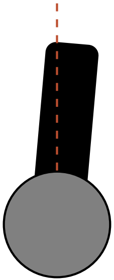
$\Longrightarrow$ spin the wheels as fast as possible clockwise

Towards the P controller: our second heuristic



$\Longrightarrow$ depending on the zone, spin the wheels more or less fast

The P (i.e., proportional) controller



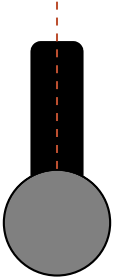
$\Longrightarrow$ speed of the wheels $= P\cdot$ angular error

Remember: P is a design choice!

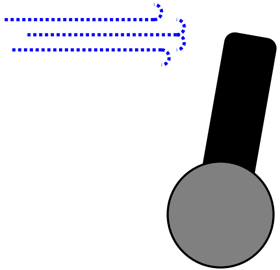
- P small implies a 'gentle' control action
- P big implies an 'aggressive' control action

- but our brain is not complete if we make it only using the P ingredient
- let me show you what I mean:
- the “P controller” brain we put inside the robot makes the wheels move so that the robot stays upright
- what is the P controller doing, actually? well, the more tilted the robot is, the more the wheels push
- 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 robot
- you can simulate it by using a hairdryer – try!
- anyway, what happens with the wind? 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 robot is not perfectly vertical, and thus it is not how I would like it to be
- somehow the “P controller” brain by itself is not “smart enough” to realize that there is this wind that is disturbing, and thus it cannot eliminate its effects
- let’s see this through an animation

No wind = no problems



Some wind = some problems



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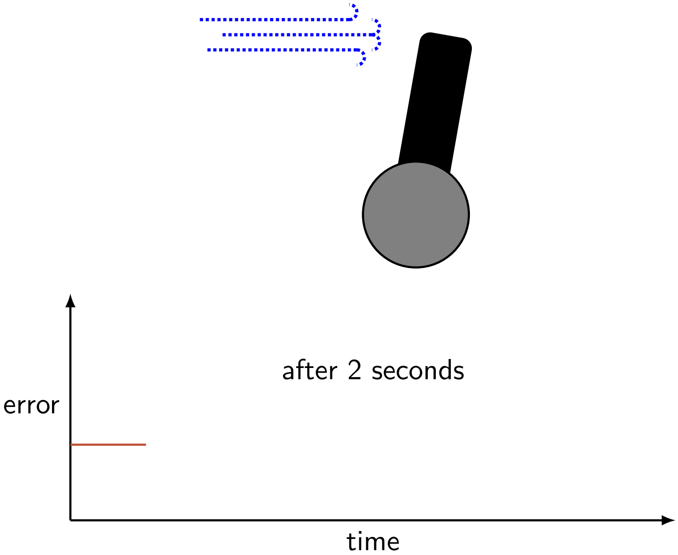

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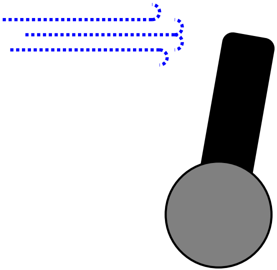

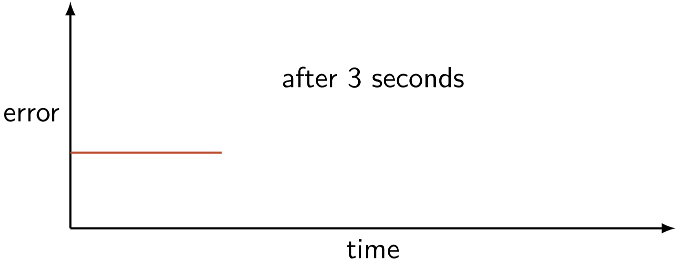

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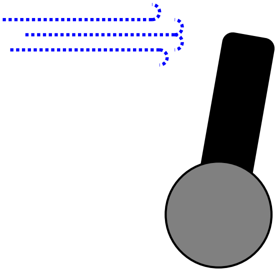

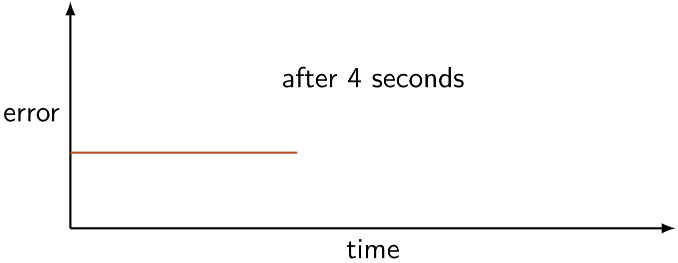

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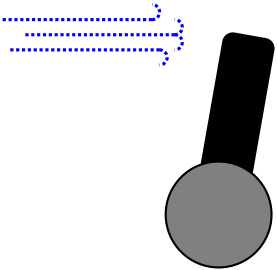

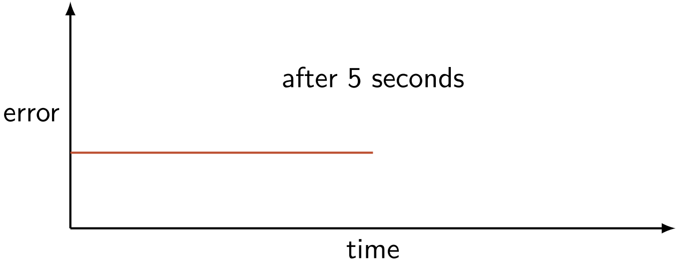

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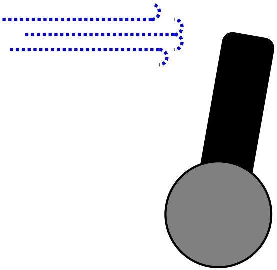
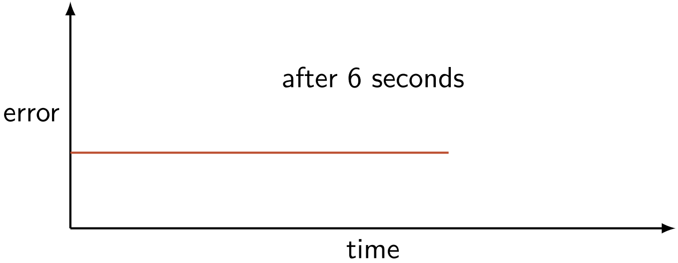
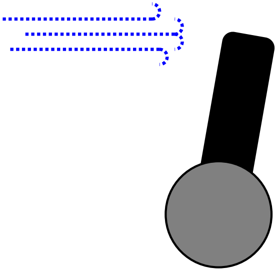
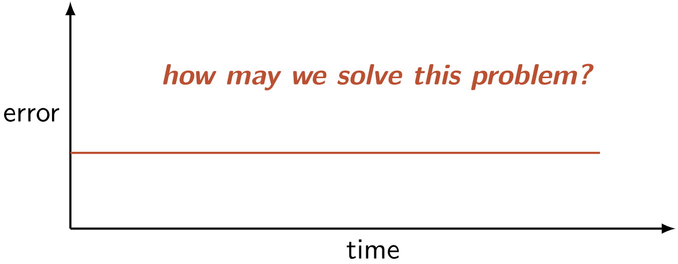




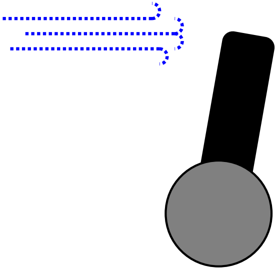
Discussion time!





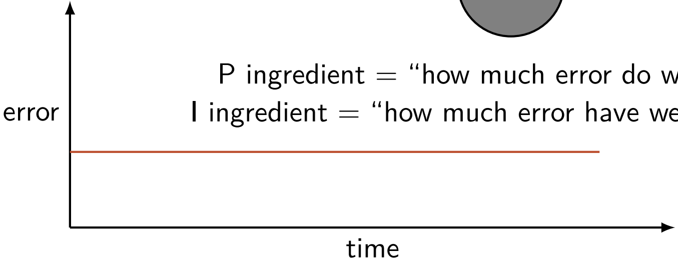
- got some intuition? shared it with your friends?
- let's see if we have the same idea!
- let's see if you discovered the I controller by yourself!

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



P ingredient = “how much error do we have now”

I ingredient = “how much error have we accumulated”



- but, as before, how do we design I?
- to understand we should ask ourselves: what is the effect of having different Is?
- 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

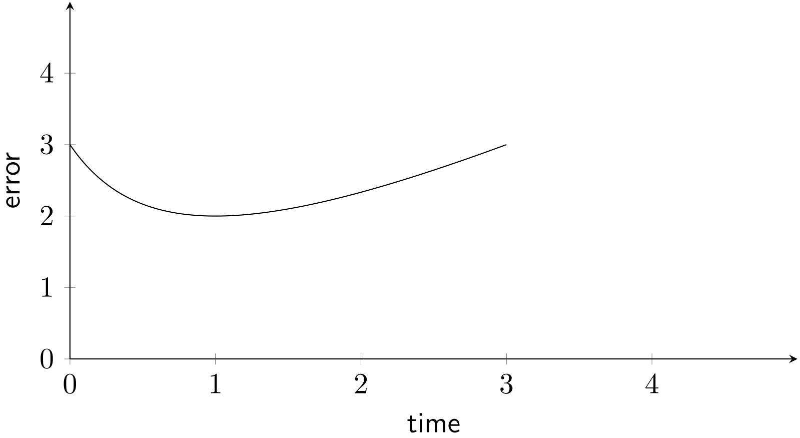
Discussion time!

- 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: consider how fast the error is changing!

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my action = $P \cdot$ current error

The D (derivative) ingredient: consider how fast the error is changing!

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

The D (derivative) ingredient: consider how fast the error is changing!

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

- 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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- I = area = "integral". Symbol: $\int e(t)dt$
- D = slope = "derivative". Symbol: $\frac{d}{dt}e(t)$

- and now I leave you with playing with the robot; choose different Ps, different Is, and different Ds, 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!

Making robots balance

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- any Easter egg you would like to add :)