

These slides are based on material I developed while working at the University of Bern. This version has been adapted for public educational use.

Objective

Understand
how can a
robot take a
decision



1

Understand
how robot deal
with
Uncertainty



2

Uncertainty

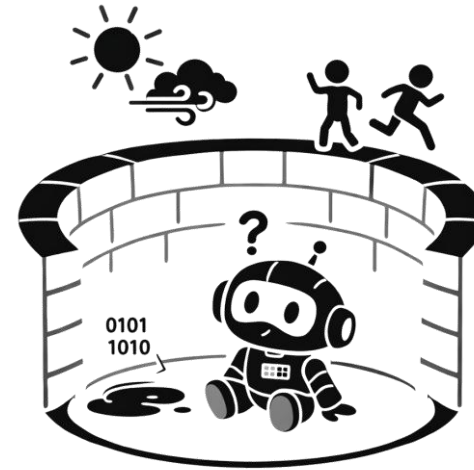
What is uncertainty

**The world is
not as
perfect as a
Model**

But for years, robots
worked in controlled
environments

**Robotic systems
think the way we
programmed them
to think.**

It's code they're not
able to adapt to new
case



*A robot is like a frog in a well,
it only knows what we **have taught him***

One of the definition

Uncertainty is the difference between the robot's *Internal Model* and the *Physical Reality*.

Type of Uncertainty

Aleatoric Uncertainty

Events that are inherently random and have no identifiable cause

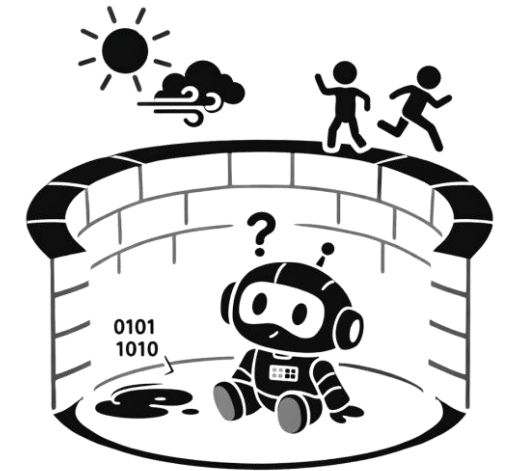
Human example

A gust of wind

Epistemic Uncertainty

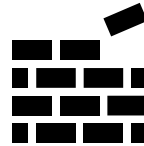
Events that occur unexpectedly due to missing knowledge.

Not knowing why, you have gum stuck to your shoe.



*A robot is like a frog in a well, it only knows what we **have taught him***

Steve the surveillance robot “suicide”



<https://edition.cnn.com/videos/tech/2017/07/18/steve-robot-drowns-on-the-job-social-media-reacts-orig-aa.cnn>

Aleatoric Uncertainty

Robot machine caused explosion at Fukushima



<https://spectrum.ieee.org/robotic-construction-machine-causes-explosion-at-fukushima>

Epistemic Uncertainty

Open world vs closed lab testing



<https://www.youtube.com/watch?v=FwhVtgyPgO0>

**XPeng's Humanoid Robot Lost Balance in Public
— Here's Why It Matters**

Open-world testing is more difficult because you cannot simply restart the test.

In Open world you often don't have access to Monitoring directly and cannot stop the robot if you **anticipate too much** it will fail

Open world vs closed lab testing

Is an engineer negligent if they don't test for an infinite "Open World"?

Yes, but to a certain degree

How can you predict how the user will use your product ?



The Missing Titanic Submarine Was Using A \$30 Video Game Controller

<https://www.forbes.com/sites/paultassi/2023/06/20/the-missing-titanic-submarine-was-using-a-30-video-game-controller/>

in **TRENDS**

Thieves are using the 'Game Boy' method to steal more cars than ever before

This Nintendo Game Boy look-alike works in seconds – and not just on Kia and Hyundai cars.

by **SARAH KENNEDY** | Published on July 8, 2024 10:39 am | 2 min read

<https://www.motorbiscuit.com/game-boy-method-steal-cars/>

Repurposing robots



Sell vacuum cleaner robot

<https://techxplare.com/news/2025-04-repurposed-roombas-scientists-domestic-robots.html>

Imagine the risks if similar repurposing happened with more dangerous robots.

Move objects in the room (e.g. move plants)

scanning the fridge and suggesting items to purchase

...



<https://www.youtube.com/watch?v=iBhO7VQUzP4>
will the robot shoot the human?

Open world vs closed lab testing

Is an engineer negligent if they don't test for an infinite "Open World"?

Yes, but to a certain degree

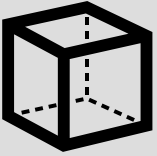
How can you be ready for every uncertainty ?

ISO norm can be a safety measure during the production but it's not enough

Source of doubt

A robot can have doubt of three things:

"I see something, but I don't know what it is"



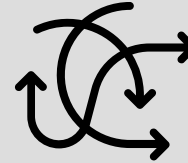
His Perception

"I see a person, but I don't know where they will go"



The environment

"I want to turn but I can't because the floor is slippery"



His Action

Source Uncertainty



Wind



Temperature



Weather

...

**Environment Uncertainty
& Perception Uncertainty**



Hardware failure

Sensor failure, bit flip,...



Software failure

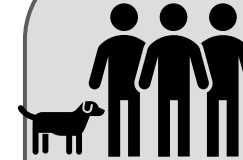
Bug, security breach,...



Mechanical failure

Broken part, friction,...

Robot Uncertainty



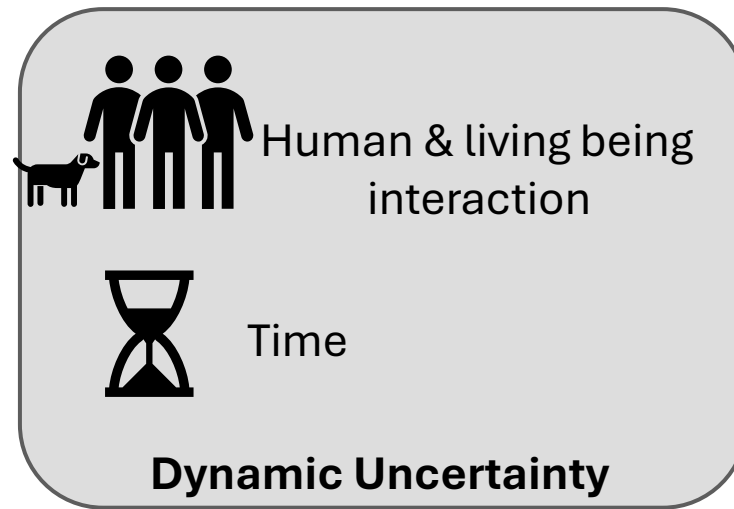
Human & living being
interactions



Time

Dynamic Uncertainty

Source Uncertainty



Dynamic Uncertainty



Now there are people and moving things

How can I predict what the human will do

It makes things unsure



https://www.youtube.com/watch?v=TSfbih_kfp8

Source Uncertainty



Hardware failure
Sensor failure, bit flip,...



Software failure
Bug, security breach,...

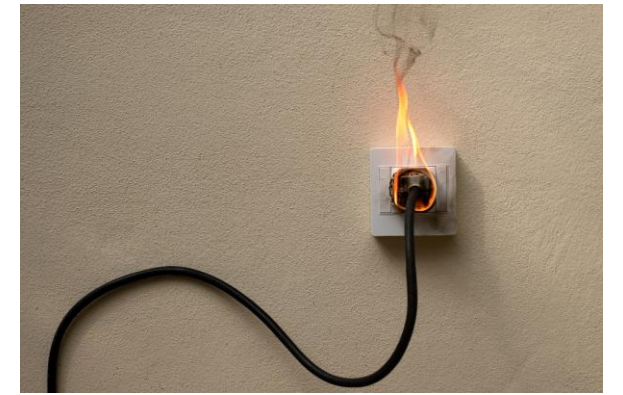


Mechanical failure
Broken part, friction,...

Robot Uncertainty

Failure Uncertainty - hardware

It's all the failure related to the electronics, the sensor , ...



And it represent a lot of failures :

Component is defective

The battery is dead

You plug it in and it creates a short circuit.

...

These failures are random because components operate are very small.

US-Boeing deal over crashes 'repugnant' - lawyer for victims' families

5 June 2025

Share Save

Adam Hancock
Business reporter, BBC News



Boeing struck a deal with the US Justice Department over crashes involving its 737 Max jets in 2018 and 2019

The Boeing crashed because the plane had the sensor giving the position defective

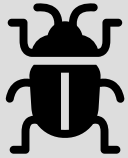
The autopilot acted based on incorrect data and caused the crash.

<https://www.bbc.com/news/articles/c5y57p8xnp5o>

Failure Uncertainty - software

This includes all failures related to software, such as:

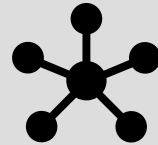
Software Bug
and crash



Bad decision



Hacking



AI error

How a Self-Driving Uber Killed a Pedestrian in Arizona

By TROY GRIGGS and DAISUKE WAKABAYASHI **UPDATED** MARCH 21, 2018

A woman was struck and killed on Sunday night by an autonomous car operated by Uber in Tempe, Ariz. It was believed to be the first pedestrian death associated with self-driving technology.

<https://www.nytimes.com/interactive/2018/03/20/us/self-driving-uber-pedestrian-killed.html>

The system had trouble to decide what to do because of a classification error and killed the pedestrian

Failure Uncertainty - software

Protesters develop novel way to build cone-sensus against driverless cars

San Francisco's Safe Street Rebel group are disabling autonomous taxis by placing a cone on the hood of the car



Waymo vehicles sit parked in a staging area in San Francisco, California. Photograph: Justin Sullivan/Getty Images

<https://www.theguardian.com/technology/2023/jul/07/san-francisco-autonomous-cars-protest-cone>

In Europe

Directive NIS2

Force a level of degree of security for company products
Company must tell when they are hacked

DORA rules

Force systems to be tested and give some level of test to be made

AI Act

Deals with AI security and transparency

...

Failure Uncertainty - mechanical

It's every phenomena that is cause by the mechanical part

Replace brake discs when they are too worn.

Put more oil in the gears

Change pieces that are damaged

Nowadays this kind of issue are predicted very easily

Usually, a technical control and good maintenance solve the issue

In 1984 , a worker died because a robot arm had an unexpected mechanical behavior, crushed by the arm

<https://www.cdc.gov/niosh/docs/85-103/default.html>

Failure Uncertainty mechanical

kind of failure that is quite regulate in the Europe and Switzerland

EU Machinery Directive (2006/42/EC)

sets essential health and safety requirements for machinery, including robots. It mandates risk assessments, safety measures, and regular maintenance to prevent accidents.

new Machinery Regulation (EU 2023/1230)

Extend the previous directive to AI driven machines. Ensuring robots are designed for safe maintenance

In Switzerland

VUV (Verordnung über die Verhütung von Unfällen und Berufskrankheiten)

It requires employers to ensure the safety of machinery, including robots, through regular maintenance, risk assessments, and compliance with technical standards.

ISO 10218

Failure Uncertainty Human parallels

What can make you have difficulties to move ?



An Injury

Hardware failure



Being sick and ill

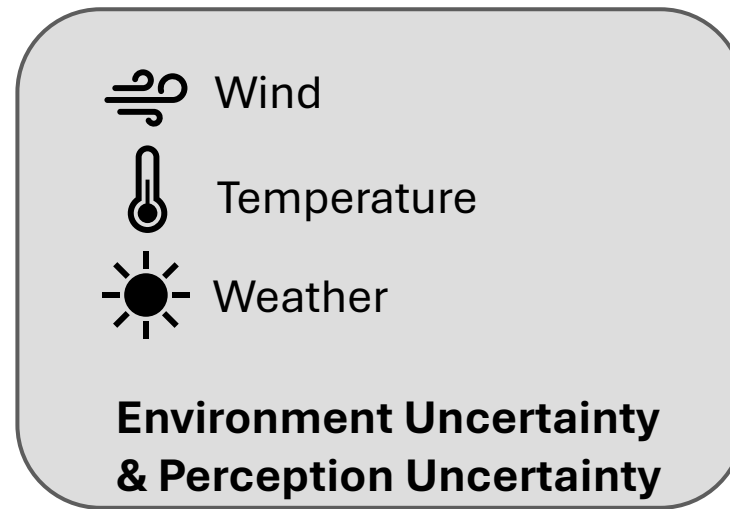
Software failure



Being old

Mechanical
failure

Source Uncertainty



It's the reason of most of the crash in
robotic and autonomous systems

Environment Uncertainty

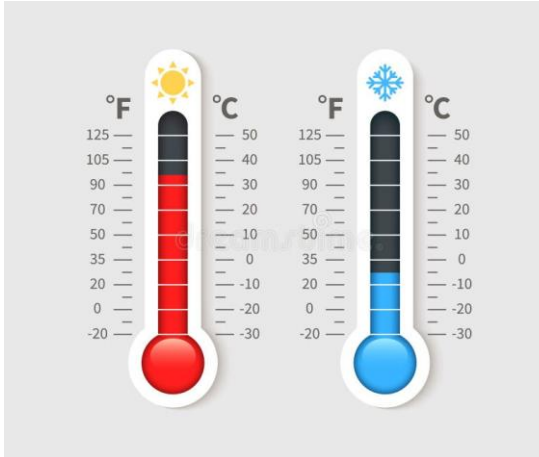


Can make the robot drift



Humidity increase the chance of failure of the robot

These are all the unexpected environmental conditions encountered during operation that can cause problems.



Cold can block the movement and hot heat up too much the robot causing failure



Can make the robot fail and even make him fall



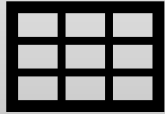
Can make crash the robot

Perception Uncertainty

**The perception
of a robot is
limited**



**Sensors have a
resolution limit**

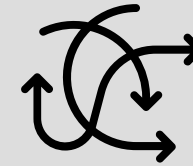


**Robots cannot fully
understand the world.**



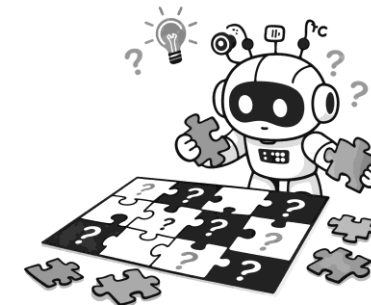
*We can see only what
we are able to do*

**And putting lot of sensors is also a
problem**



*Too much information
can reduce clarity.*

**The robot must still infer missing information
to act.**



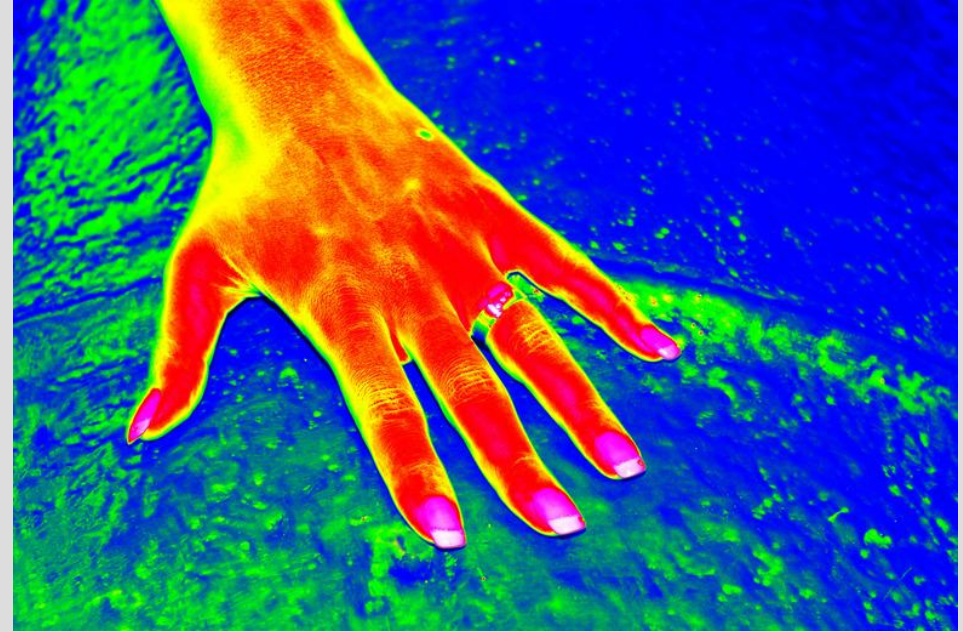
Perception Uncertainty Human example

Is the dress blue or green or even gold ?



https://en.wikipedia.org/wiki/The_dress

Sensor have a resolution limit

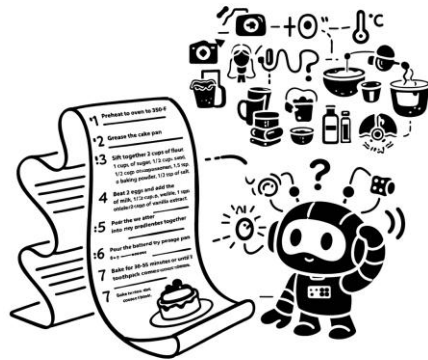


We cannot see infrared with our eyes

They don't permit to understand fully the environment

Perception Uncertainty Human example

Recipe for making a good dessert



First, before you even think about turning on the oven, you should conceptually prepare the preparation phase of the preparation phase. This means you must gather all ingredients, but also mentally categorize them into “structural ingredients,” “moisture contributors,” and “flavor modifiers,” even though you might still mix them together later anyway.

Step 0: Pre-Heating Considerations

You will eventually preheat the oven to 180°C (or maybe 175°C if your oven tends to behave aggressively, but not lower than 170°C unless altitude factors intervene, which we are not calculating right now). However, do not preheat yet, just be aware that preheating will occur soon.

Step 1: Ingredient Alignment

Collect the following, but place them on the counter in a left-to-right order that feels logical:

- 2 cups flour (preferably sifted, but if not sifted you should consider sitting now or later depending on texture philosophy)
- 1 cup sugar (white, unless you think brown sugar might add depth, which complicates moisture balance)
- 2 eggs (room temperature is recommended, although “room temperature” varies by room)
- 1/2 cup butter (soft but not melted, except partially melted butter is technically still usable)
- 1 teaspoon vanilla extract
- 1 teaspoon of baking powder
- A pinch of salt (define pinch according to finger size)
- About 1/2 cup of milk (adjust later if batter viscosity appears conceptually incorrect)

At this point, you might want to preheat the oven now, unless you feel you still need time to psychologically commit to baking.

Step 2: Structural Mixing Phase

Bring a bowl. Not too small, because expansion of batter volume is probabilistic but real.

1. Cream the butter and sugar until “light and fluffy.”
 - Light compared to what? Mostly compared to how it started.

- Fluffy meaning air is incorporated, though you cannot see all of it.
2. Add eggs one at a time.
 - Stir after each egg, but not excessively because overmixing may or may not matter yet.
3. Add vanilla while remembering that vanilla is mostly aroma chemistry.

Step 3: The Dry Ingredient Situation

In a separate bowl (unless you forgot, in which case you can improvise but results become unpredictable):

- Mix flour, baking powder, and salt.
- Optionally shift again even if already shifted because redundancy sometimes improves texture, or maybe not noticeably.

Step 4: Alternating Combination Sequence

Now combine wet and dry mixtures in alternating steps:

1. Add some flour mixture.
2. Add some milk.
3. Stir but not fully.
4. Repeat until everything is combined but also not overworked.

The better should be:

- Thick but pourable
- Smooth but not suspiciously smooth
- Slightly glossy but not liquid

If it doesn't look correct, adjust milk or flour into small philosophical increments.

Step 5: Pan Preparation Protocol

Before pouring batter, ensure your pan is:

- Greased
- Possibly lined with parchment
- Or both, which might be excessive but safer.

Pour batter into the pan but leave some vertical expansion margin (exact amount depends on cake optimism).

Step 6: Baking Window

Place in oven at the temperature you hopefully preheated earlier.

Bake for 25–35 minutes, though:

- Ovens differ.
- Pan depth matters
- Batter mood varies.

Check with a toothpick:

- If clean + cake is done
- If slightly crumbed + also possibly done
- If wet + definitely not done

Step 7: Cooling Strategy

Remove cake but do not immediately remove cake from pan unless you intend to risk structural collapse or steam dynamics. Wait about 10 minutes (give or take 3 minutes). Then transfer to a rack or any surface that allows air circulation but not falling.

Final Outcome Expectation

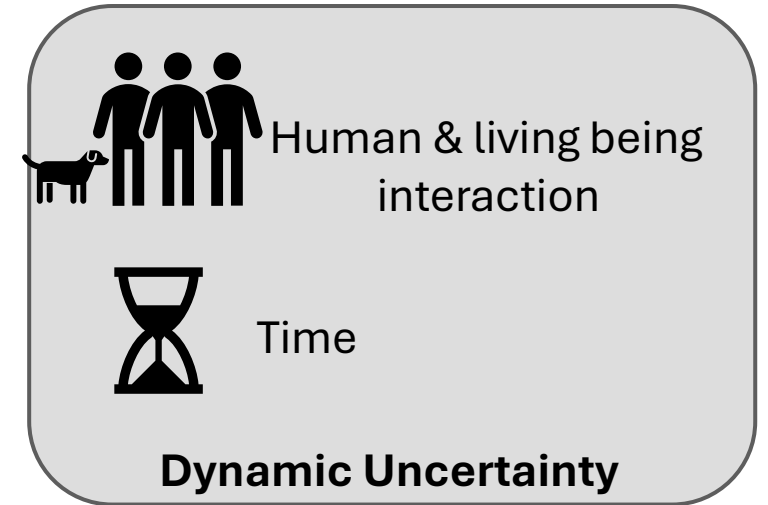
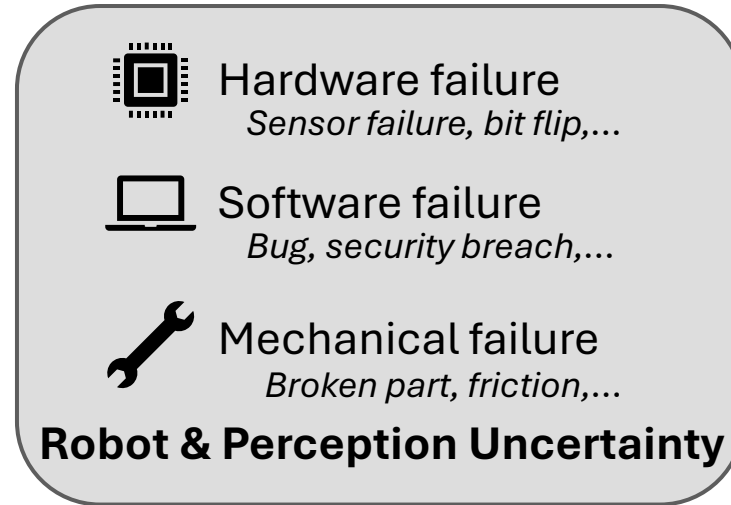
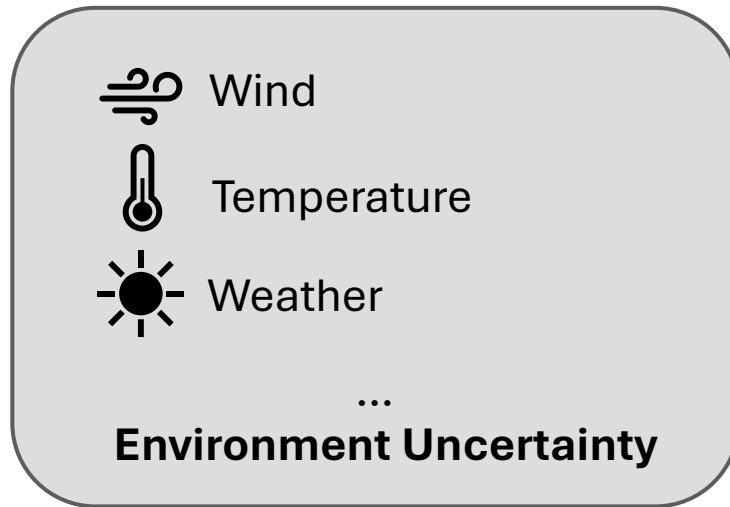
You should now have a cake, assuming:

- Measurements were approximately correct,
- Mixing intensity remained within acceptable thresholds,
- And the oven behaved thermally as predicted.

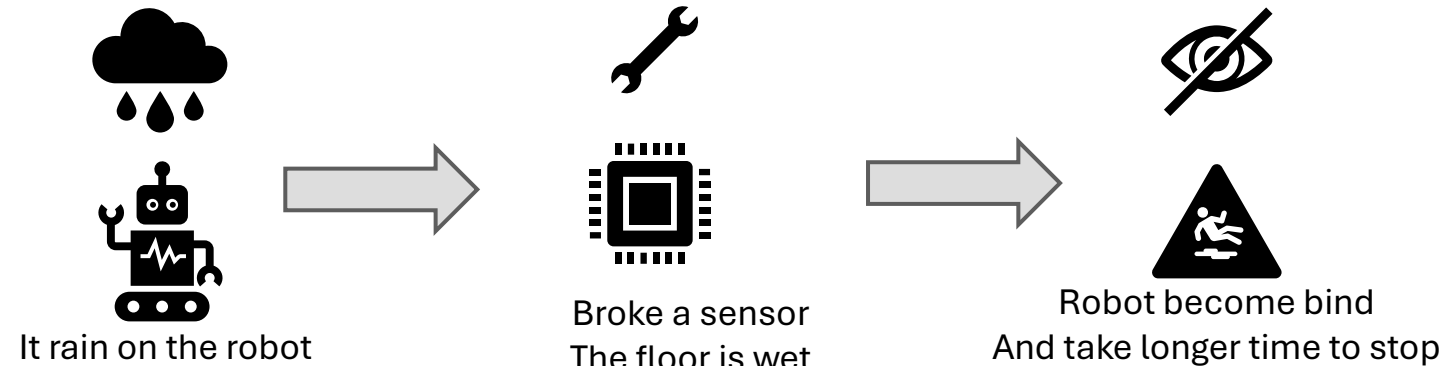
If the cake tastes good, you succeed. If not, adjustments can be made next time using lessons learned from this somewhat overly explained process.

Understanding all the requirements of this recipe takes time *and there is a lot of things not useful*

Source Uncertainty



And these sources of uncertainty are linked together and will cause problems together



Liability

Lots of safety to be
norm compliant

ISO 13850
ISO 10218-1/-2
ISO/TS 15066
IEC 60204-1
ISO 3691-4

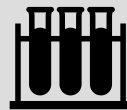
...



Lots of testing

ISO 12100
ISO 13849-1/-2
IEC 61508
ISO 26262
UL 4600
AI Act (UE)

...



Redundancy and
verification

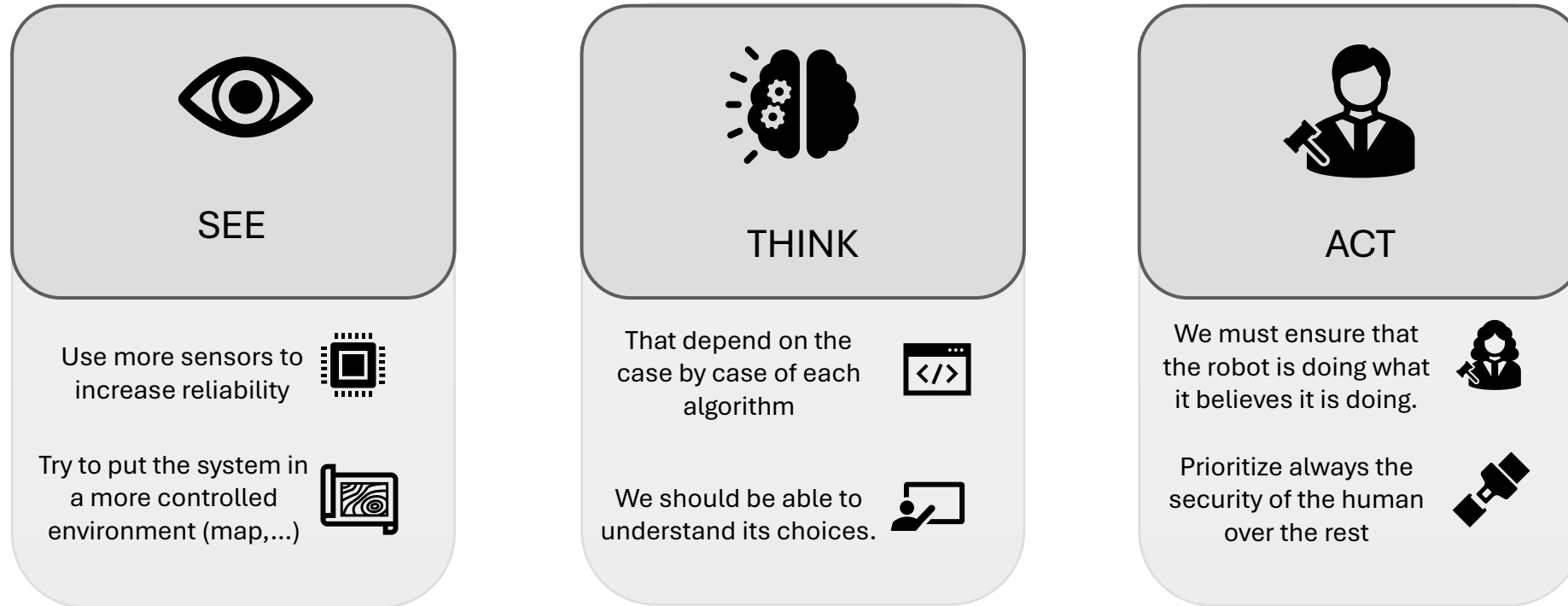
IEC 61508
ISO 26262
ISO 10218
ISO 21448
DO-178C + DO-254

...



Decision making

How it decide



It's the same things as us human or any living being



Some research try to look into other models of decision but it's still the safest

Reactive decision Making

It was the first decision making ever made

Main idea :

If there is an obstacle, then react

It's very simple to audit, the conditions are written in the code

But there is no nuance, it doesn't take the context into account



In this case, responsibility often lies with the designer, because they wrote the rules directly.

This decision making is still used in Automation industry

Planning based decision Making

Each action
has a cost

The goal would be
to optimize this
cost

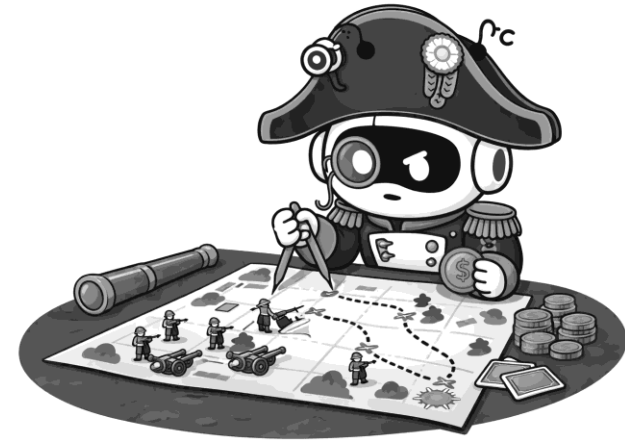
Simple example :

The robot compute a path to go to somewhere

There is a wall and two possible roads

He will choose the best road possible

The decision depends **on the cost function and the parameters used**

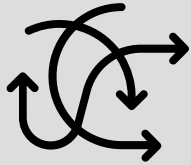


If the cost function is bad, the robot can take dangerous decisions

*It's still the option the most used in embedded system because it's
the safest*

Probabilistic decision Making

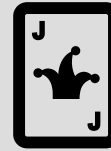
The robot acknowledges that uncertainty exists.



It considers this uncertainty as probability



It chooses the most probable best action given the uncertainty.



But is it very safe ?

How do we explain to the public that an accident happened due to “bad luck”?

Forecasting weather robot



<https://www.csem.ch/en/news/swiss-precision-at-the-heart-of-next-generation-weather-forecasting/>

AI and Black box decision Making

Train the neural Network robot over a large amount of data of similar situation

Then the robot do what he has to do

Problems of AI decision making :

Explainability

How the dataset was trained

Are new situations oversimplified by the model?

AI implication

Is it legal data

Does the dataset include enough diverse cases?

...

AI will change the Future

Meanwhile AI :



<https://www.youtube.com/shorts/WgQmPB6CgIM>

Strategy

Decision Strategy	Predictability	Most probable legal responsibility
Reactive	High	Engineer (Calculation Error)
Planning	Medium	Manufacturer (Cost/Benefit Bias)
Probabilistic	Low	Owner (Risk Tolerance Setting)
AI (Black Box)	Very Low	Unknown (The Transparency Crisis)

Vaccum Robot most critical Issue



To localize and decide you build a map collect personal information

And the vacuum cleaning robot are almost always connected to the wifi...

SUCK IT UP

Man Alarmed to Discover His Smart Vacuum Was Broadcasting a Secret Map of His House

"That's when I made my first mistake: I decided to stop it."

<https://futurism.com/robots-and-machines/robot-vacuum-broadcasting>

December 23, 2025

Roomba Knows Where You Hid Your Safe ... Now China Will Too

in LinkedIn

f Facebook

✕ X

✉ Send

🔗 Embed

<https://www.jdsupra.com/legalnews/roomba-knows-where-you-hid-your-safe-1061373/>

GDPR

General Data Protection Regulation

Scope :

Apply to every organisation,
systems,... that collect data

Application

May 25th, 2018, in EU
Using audit with independent company

Core principe :

processed lawfully, fairly and transparently.
collected for specific purpose,
minimized kept accurate and secure
retained only as long as necessary

Data subject right

Right to acces and edit the data
Right to be forgotten.

Safety vs Utility Trade-off

Utility

The robot must arrive on time, deliver the package and be profitable

Safety

The robot mustn't hurt anything or anybody

The truth

It's impossible to be 100 percent safe

Engineers try to reduce risk as much as possible by following standards, but some risk always remains.

That now the role of the law to tell where the risk is acceptable and what is not using the **Last clearance rule**

In industry they use the **risk assessment process**

Last clear chance Doctrine

asks if a party could have avoided the accident even if the other person was being negligent.

The scenario

A human is walking while looking at their phone (negligent).

The robot sees the human.

Robot Decision A: *Maintain its right of way (because it is "legal").*

Robot Decision B: *Swerve into a flower bed (protecting the human but damaging property).*



**Robots don't have
"mercy." They have
priorities**

Is the Engineer liable for not programming "Empathy" into the cost function?

Risk assessment process

People know it is dangerous and have implemented risk-assessment processes.

Hazard assessment

What problem could be dangerous to us where there are a robot ?

E.g. Environment hazard, sensor problem, energy issues...



Risk Assessment

For each Hazard what could it cause and how severe it is ?

E.g. How probable, How dangerous, ...



Safety Measures

What can be made as a safety measure in case of problem ?

E.g. Red Button for emergency stop in industry,...



Few law and recommendation implemented in the EU

It's mandatory to be able to trace decision of the robot

ISO 13482: 2014

framework for hazard identification, risk estimation, and risk reduction for personal-care / service robots

<https://publications.vtt.fi/pdf/science/2014/S69.pdf>

When ask human for help ?

Sometimes, asking a human to verify is the safest option.

When it is unsure about its perception

*Incoherent data on the
sensor*

Lost himself

Don't recognize object

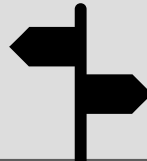


When he's not sure of his choice

*Two choice with the same pro
and con*

New situation

When there is legal risk



When it detects a failure.

Sensor failure

Bug

Robot stuck



It's called collaborative robotics (Cobots)

Robots that work with a human sometime waiting for his feedback

Cobots example



Unveiling Robojob's Game-Changing Cobot: See It In
Action! | EMO 2023

<https://www.youtube.com/watch?v=ExLdbJR2a5A>

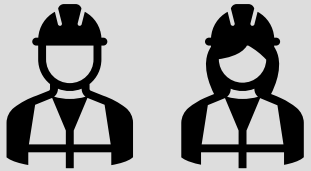
A small Exercise/Discussion

Exercise

There is some legal issue, and you try to know who is responsible



You are the jury who try to identify what to decide in each case



We provide the technical evidence.

Give your view on this scenarios and who is to blame for the accident

The ghost in the machine

Situation



Delivery Robot

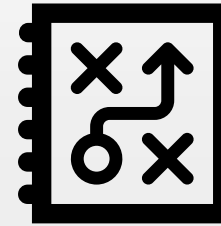


A busy sidewalk near a noisy construction site.



The robot detected a shadow and classified it as a person

Consequence



The robot is forced to move to avoid it



The cyclist is forced to avoid it and crash into a car parked

Technical expertise

The sensor detection was slightly dusty



The robot gave a beeping sound when he detect the pedestrian



The robot uses a small AI module to make its decision, which is then checked by deterministic code.

The AI was trained on a dataset from California (constant bright sun) it didn't recognize deep shadows

Discussion

So, in your opinion, who is responsible?

The engineer

Who coded the robot ?



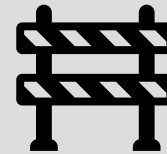
The Manufacturer

who didn't choose a better LIDAR ?



The company

for allowing the robot to in this kind of place ?



The pedestrians

To not being able to listen to the beeping sound



The over optimized drone



A pilot drives a drone in a warehouse to make the inventory



The drone crashed into expensive machinery



It's in winter, and to save cost the company decide to not heat up the warehouse



The pilot is a pro that has won multiple drone competition

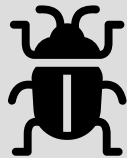
Is this a Design Defect or a Maintenance Error ?

Technical expertise

The warehouse was colder than usual (5°C). Lithium batteries provide less power in the cold.



There is no bug in the code



When the drone tried to accelerate to avoid a shelf, the battery couldn't provide the sudden "burst" of current required by the motors.

The "Health Monitor" software was calibrated for 20°C (standard lab temp). It "thought" it had 10 minutes of flight left, but it had 0.



Discussion

So, in your opinion, who is responsible?

The pilot

For flying with only 30% battery in cold weather



The Software Engineer

For the algorithm that didn't account for temperature-based battery discharge.



The company

For not heating the warehouse during in flight operation



The manufacturer

For failing to design a "Fail-Safe" (like a parachute) for flight over crowds.

