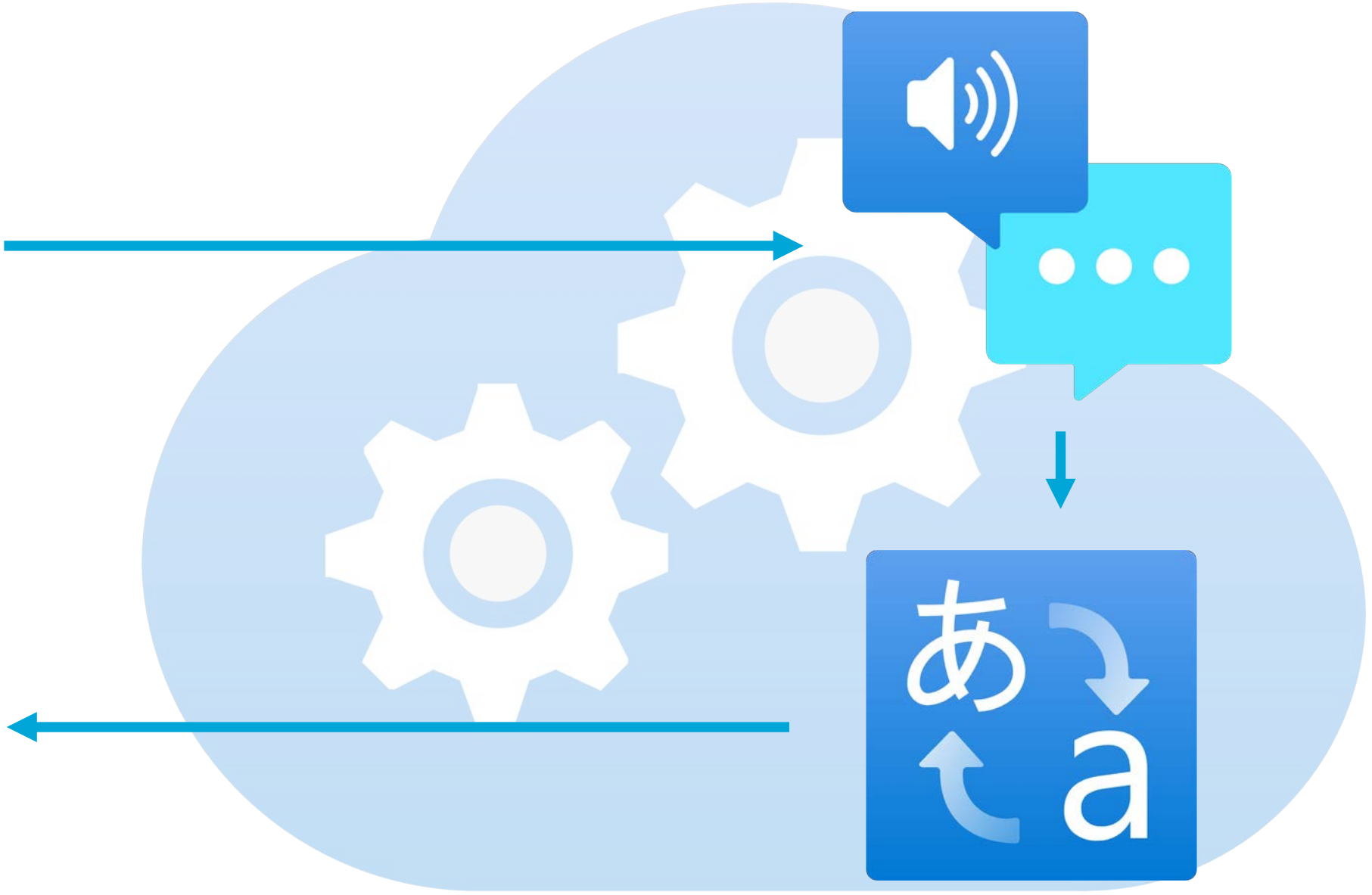
# Algorithms find solutions, so what's the problem?

**Mathijs de Weerdt, June 7, 2023**

TU Delft


TU Delft



But we aren’t using algorithms for finding the solution to some very relevant problems.

TU Delft

# Outline

1. What is an algorithm?
2. What is the problem?
3. How can we address this?

TU Delft

*efficient*

**algorithm = recipe to be executed by a computer**

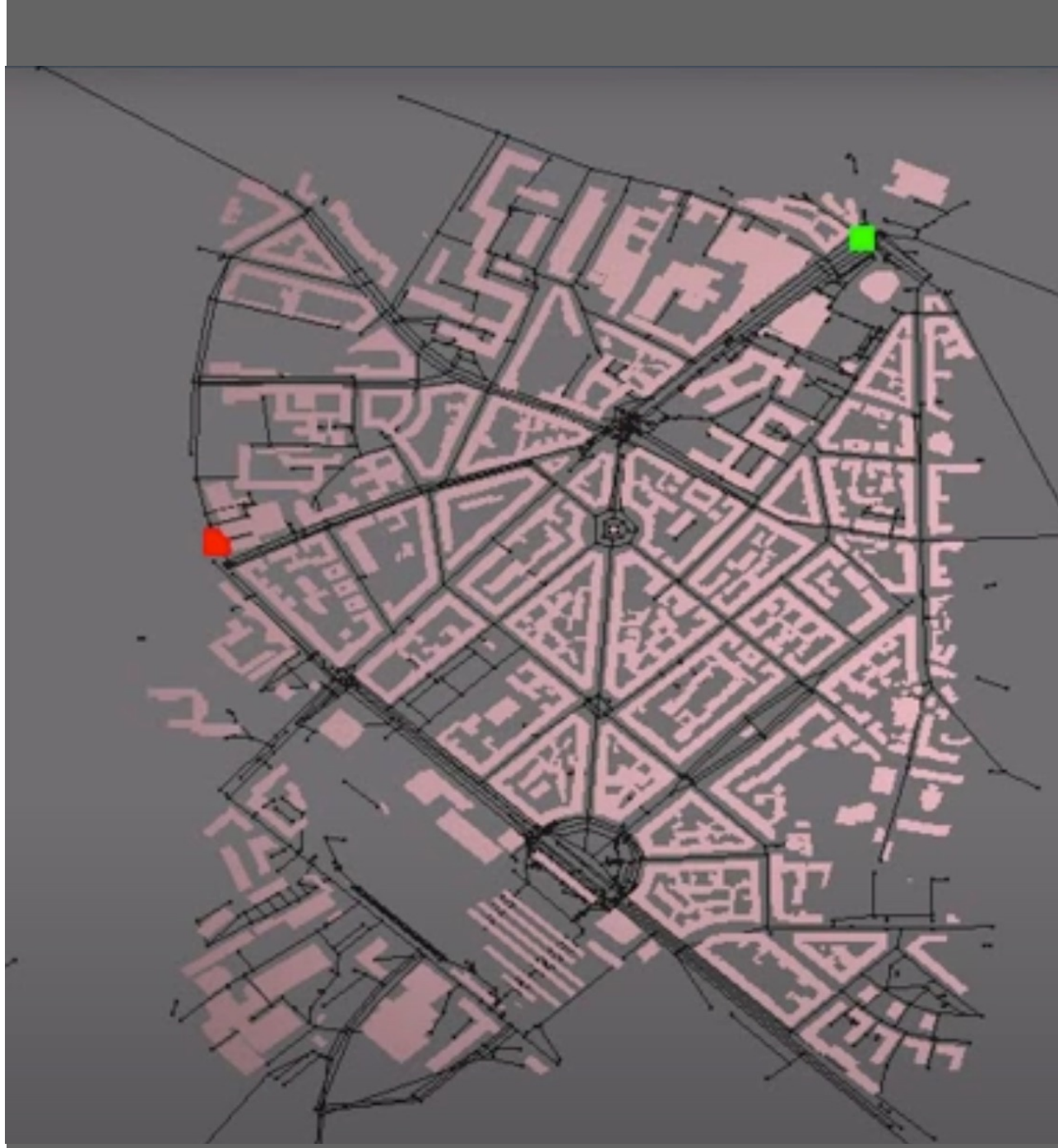
# Dijkstra's algorithm (1959)

""The question of whether a computer can think is no more interesting than the question of whether a submarine can swim."

— Edsger W. Dijkstra

TU Delft

```
function DIJKSTRA(V, E)
    d[v] ← ∞ for all v ∈ V
    d[s] ← 0 for start vertex
    while V is not empty do
        m ← arg min_{v∈V} d[v]
        Remove m from V
        if d[m] = ∞ then
            return ∞
        for every e ← (m, u) ∈ E do
            if d[m]+w(e) < d[u] then
                d[u] ← d[m]+ w(e)
    return d
```



http://www.danielkoitzsch.de/blog/2015/11/06/visual-comparison-of-dijkstra-and-a-star/

TU Delft

```
function DIJKSTRA(V, E)
    d[v] ← ∞ for all v ∈ V
    d[s] ← 0 for start vertex
    while V is not empty do
        m ← arg min_{v∈V} d[v]
        Remove m from V
        if d[m] = ∞ then
            return ∞
        for every e ← (m, u) ∈ E do
            if d[m]+w(e) < d[u] then
                d[u] ← d[m]+ w(e)
    return d
```

http://www.danielkoitzsch.de/blog/2015/11/06/visual-comparison-of-dijkstra-and-a-star/

TU Delft

```
function DIJKSTRA(V, E)
    d[v] ← ∞ for all v ∈ V
    d[s] ← 0 for start vertex
    while V is not empty do
        m ← arg min_{v∈V} d[v]
        Remove m from V
        if d[m] = ∞ then
            return ∞
        for every e ← (m, u) ∈ E do
            if d[m]+w(e) < d[u] then
                d[u] ← d[m]+ w(e)
    return d
```

http://www.danielkoitzsch.de/blog/2015/11/06/visual-comparison-of-dijkstra-and-a-star/

TU Delft

**function** DIJKSTRA($V, E$)
    $d[v] \leftarrow \infty$ for all $v \in V$
    $d[s] \leftarrow 0$ for start vertex
    **while** V is not empty **do**
        $m \leftarrow \arg\min_{v \in V} d[v]$
        Remove $m$ from $V$
        **if** $d[m] = \infty$ **then**
            **return** $\infty$
        **for** every $e \leftarrow (m, u) \in E$ **do**
            **if** $d[m]+w(e) < d[u]$ **then**
                $d[u] \leftarrow d[m]+ w(e)$
    **return** $d$

http://www.danielkoitzsch.de/blog/2015/11/06/visual-comparison-of-dijkstra-and-a-star/

TU Delft

**function** DIJKSTRA($V, E$)
    $d[v] \leftarrow \infty$ for all $v \in V$
    $d[s] \leftarrow 0$ for start vertex
    **while** V is not empty **do**
        $m \leftarrow \arg\min_{v \in V} d[v]$
        Remove $m$ from $V$
        **if** $d[m] = \infty$ **then**
            **return** $\infty$
        **for** every $e \leftarrow (m, u) \in E$ **do**
            **if** $d[m]+w(e) < d[u]$ **then**
                $d[u] \leftarrow d[m]+ w(e)$
    **return** $d$

http://www.danielkoitzsch.de/blog/2015/11/06/visual-comparison-of-dijkstra-and-a-star/

TU Delft

# Data = ingredients

- structured (e.g. a map)
- unstructured:
  - patterns trained and used (machine learning)
  - collected by the algorithm itself (reinforcement learning)

TU Delft

# An example with a *lot of* data: large language models

e.g. ChatGPT: GPT-4 was trained on 570 gigabytes of data

**570 000 000 000** bytes (characters)

thick book

TU Delft

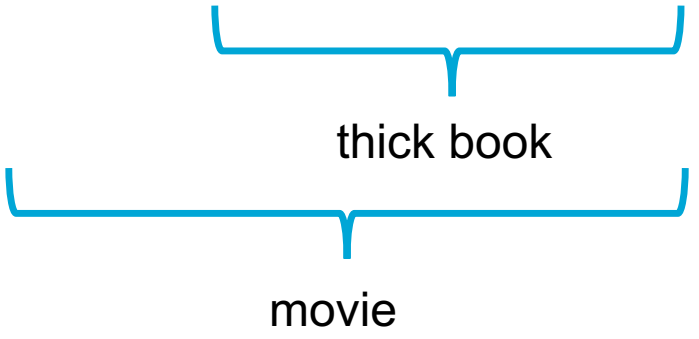
https://blog.invgate.com/chatgpt-statistics
https://www.easytechjunkie.com/how-big-is-the-internet.htm

# An example with a *lot of* data: large language models

“all” data on the internet estimated to be 5 billion gigabytes (by former CEO of Google, Eric Schmidt, interview in 2023)

**5 000 000 000 000 000 000**

bytes
(characters)




TU Delft

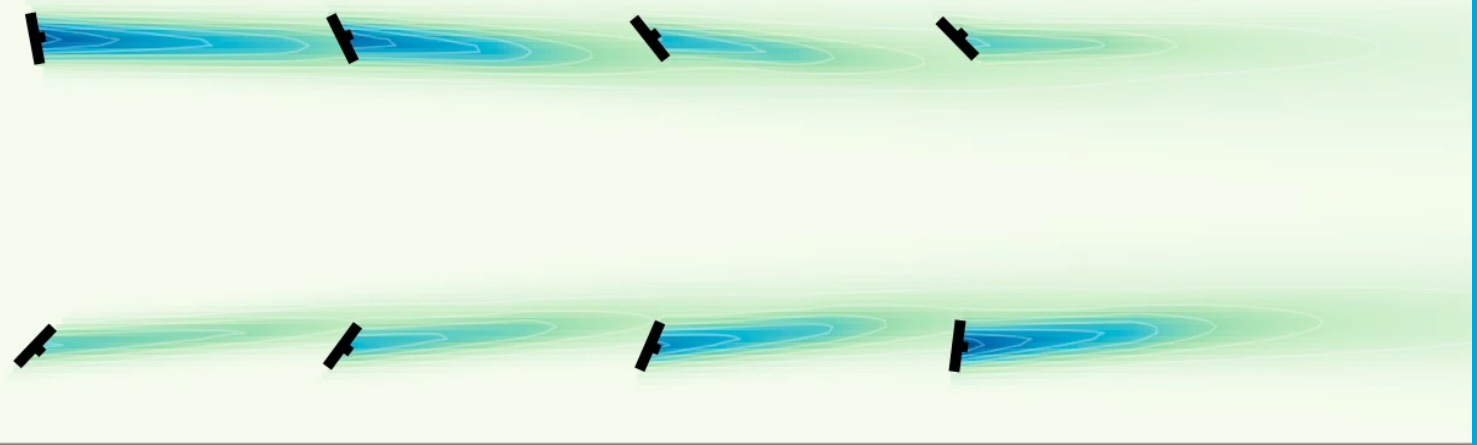
https://www.easytechjunkie.com/how-big-is-the-internet.htm

# The quality of the ingredients counts!

```
function Dijkstra(V, E)
    d[v] ← ∞ for all v ∈ V
    d[s] ← 0 for start vertex
    while V is not empty do
        m ← arg min_{v∈V} d[v]
        Remove m from V
        if d[m] = ∞ then
            return ∞
        for every e ← (m, u) ∈ E do
            if d[m]+w(e) < d[u] then
                d[u] ← d[m]+ w(e)
    return d
```

TU Delft


Wind farm



# Wind farm wake control

Greg Neustroev

https://github.com/AlgTUDelft/wind-farm-env

Greg Neustroev, S. Andringa, R. Verzijlbergh, MdW (2022), **Deep Reinforcement Learning for Active Wake Control**, In *AAMAS 2022* p.944-953

# Algorithms should be used for problems that matter!

Many of these are **planning or scheduling** problems!

- train shunting/path finding
- energy system investments
- heat network control
- efficient (bio)manufacturing

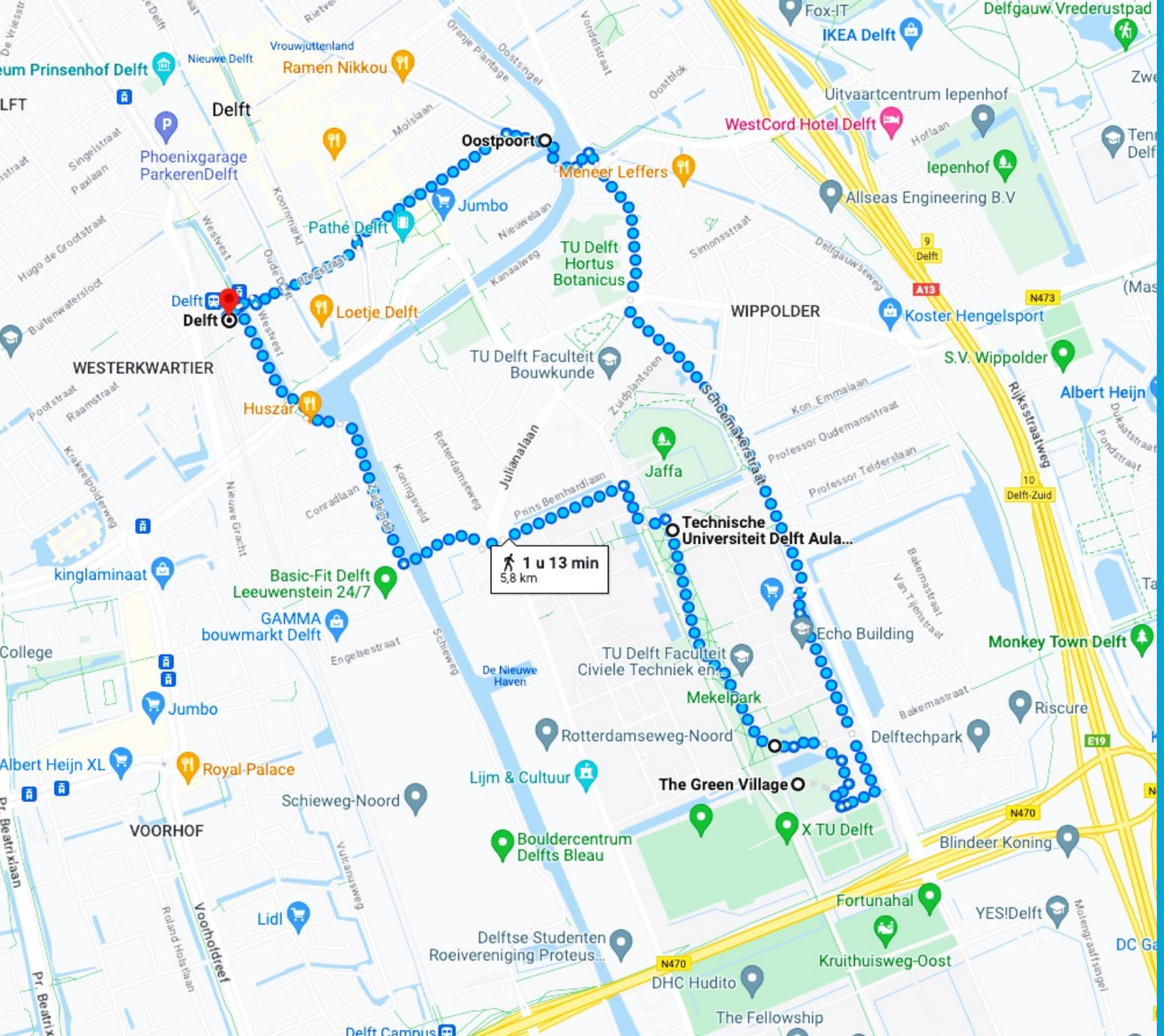
# Planning & Scheduling Methods in Practice

*Surprisingly little use of such algorithmic insights in practice!*

- “the majority of derived mathematical solutions have not been used in practice by manufacturing businesses” (Jackson et al., 2004)
- “**Spreadsheet application** still dominates enterprise resource planning and advanced planning systems” (De Man, Strandhagen, 2018)
- “most schedulers prefer the use of a simulation-based software or **manual decision**, which result to suboptimal solutions” (Georgiadis et al., 2019)

## So what’s the problem?

TU Delft




# Traveling Salesman

find the shortest route via *a number of* locations

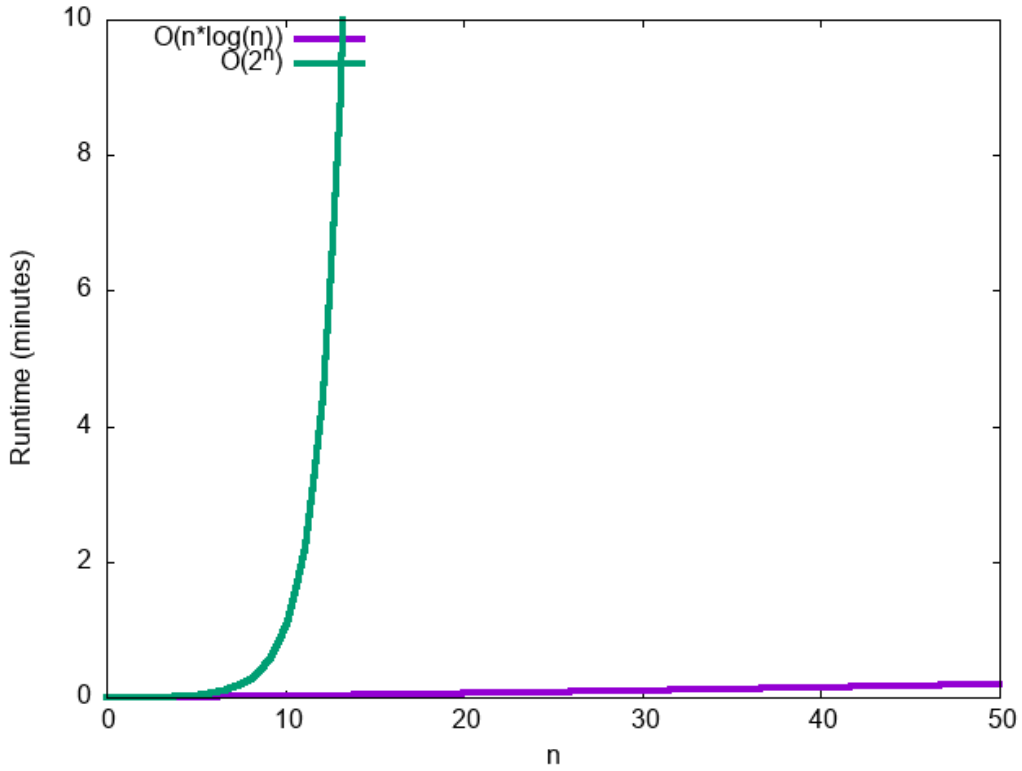
~~Traveling Salesman~~
Package delivery

find the shortest route via
*a number of* locations

# Problem complexity

Time needed for the computation (runtime)

Input size of the problem: n




$2^n$


https://josephpp.medium.com/the-second-half-of-the-chess-board-are-we-truly-ready-for-the-digital-revolution-ahead-c710b25f7119

# P (easy)

P is the class of problems that can be solved in polynomial time.

Examples

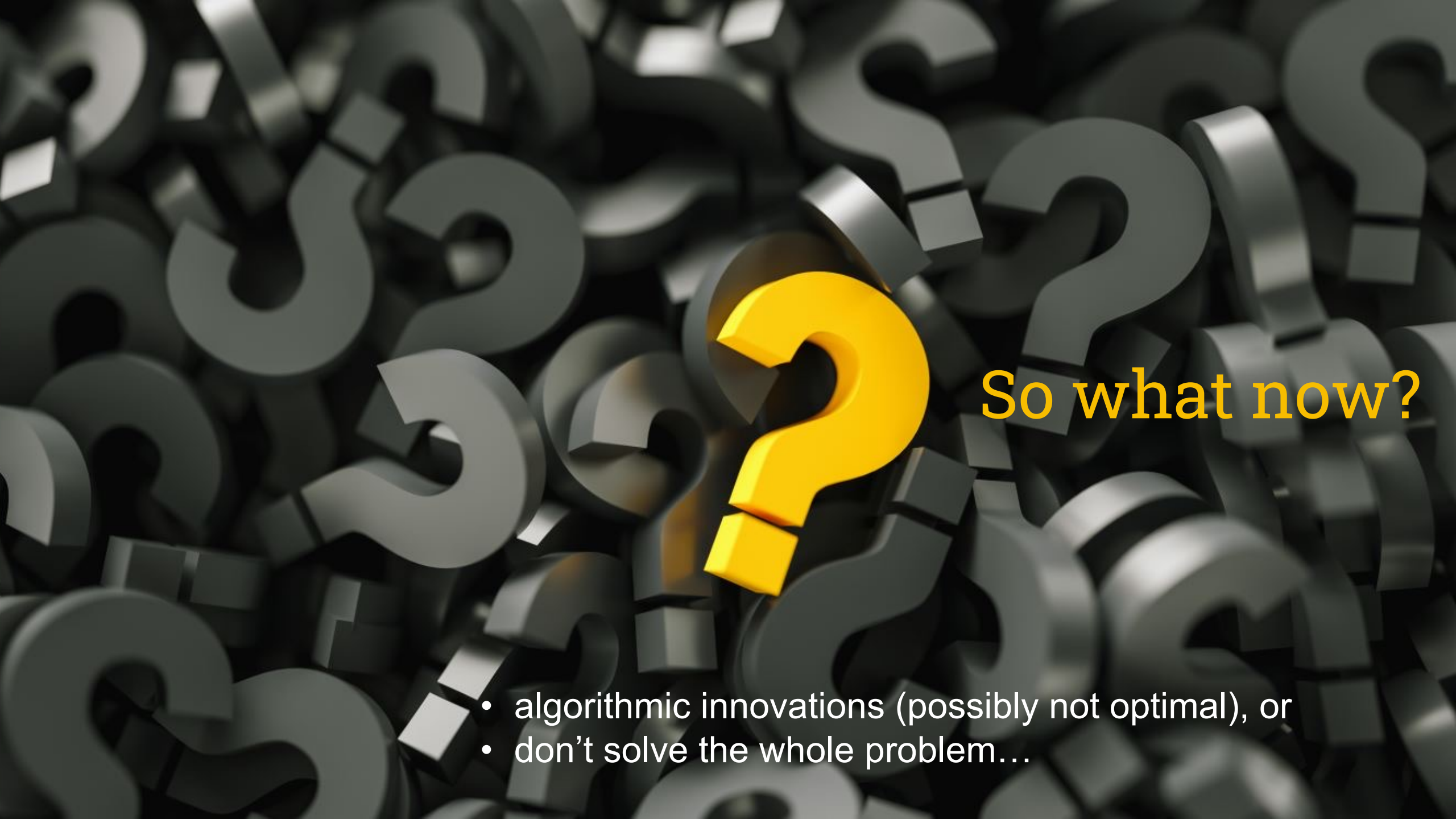
- Shortest path
- Scheduling with unit processing times

# NP (-hard)

NP-hard are those problems for which we have no polynomial-time algorithms.

Examples

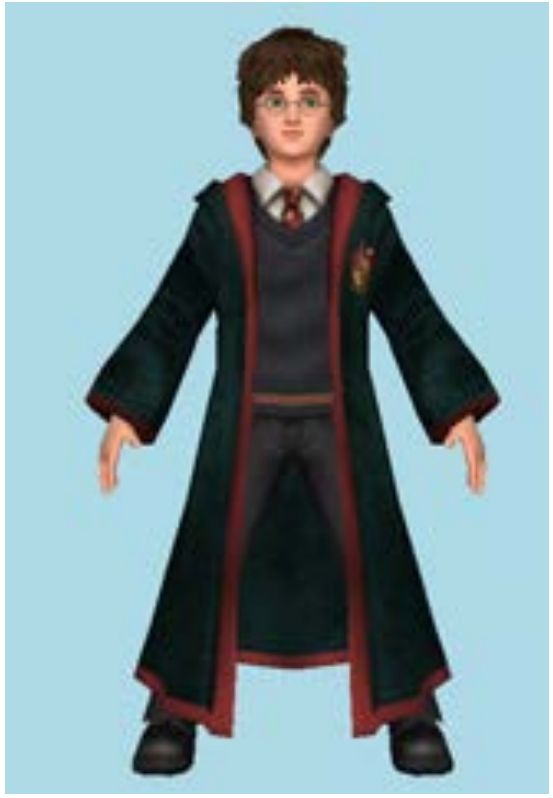
- Traveling salesman problem
- Scheduling with arbitrary processing times, release times and deadlines



# So what now?

- algorithmic innovations (possibly not optimal), or
- don’t solve the whole problem…

# Choosing the right model:



TU Delft

https://commons.wikimedia.org/wiki/File:HPMOR_fan_art.jpg
https://www.cgtrader.com/3d-models/character/man/lego-harry-potter
https://rigmodels.com/model.php?view=Harry%20Potter__94ZJU28BNQ1Q23OONR109WZ6B
https://rigmodels.com/model.php?view=Harry-Potter-3d-model__REQ0I1Y8QAPMNSVWG3ALT7WF5

# Choosing the right model requires…

algorithmic understanding

1. what is computational challenging?
2. which algorithm to use?

*and* expertise on the domain

1. what's important for (in)feasibility?
2. what can we fix later?

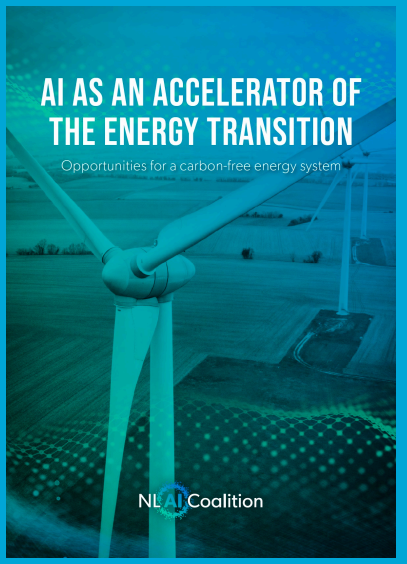
# How to address this?

## In my own research

TU Delft

## Supporting others

EnergySHR




NL AI Coalitie

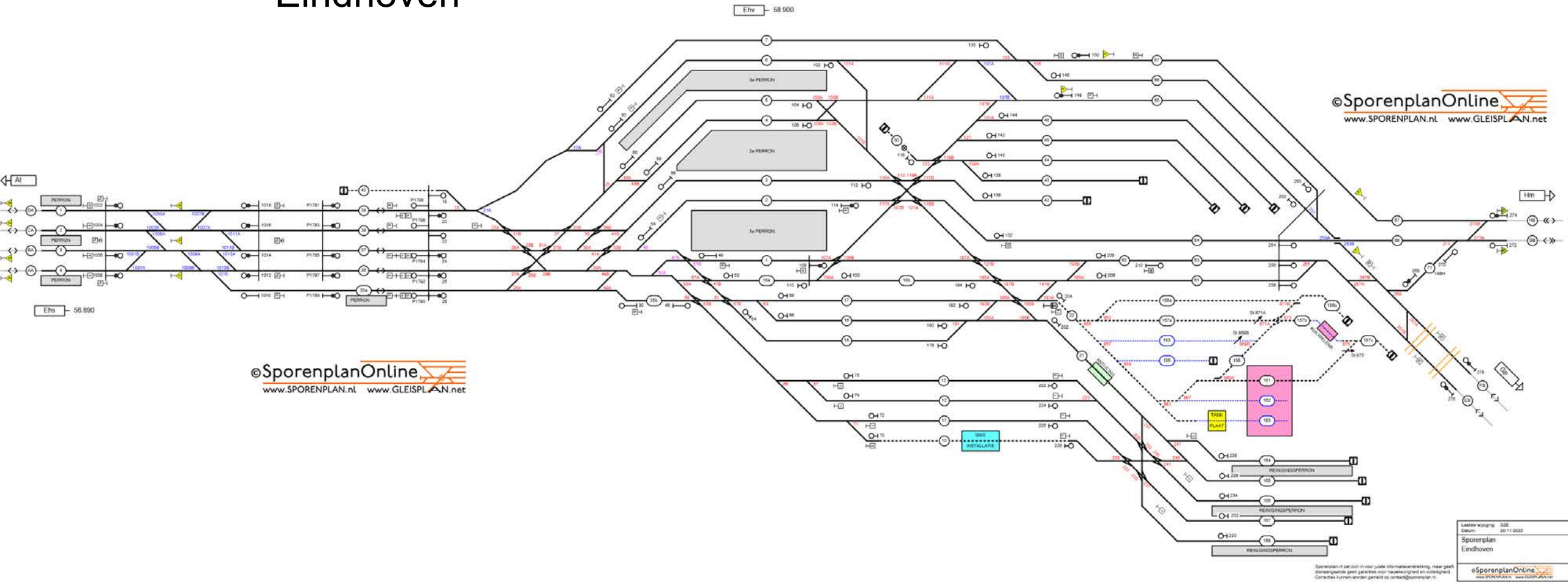
# Shunting at railway hubs

https://nieuws.ns.nl/media-archief/

TU Delft

# Shunting at railway hubs

## Eindhoven



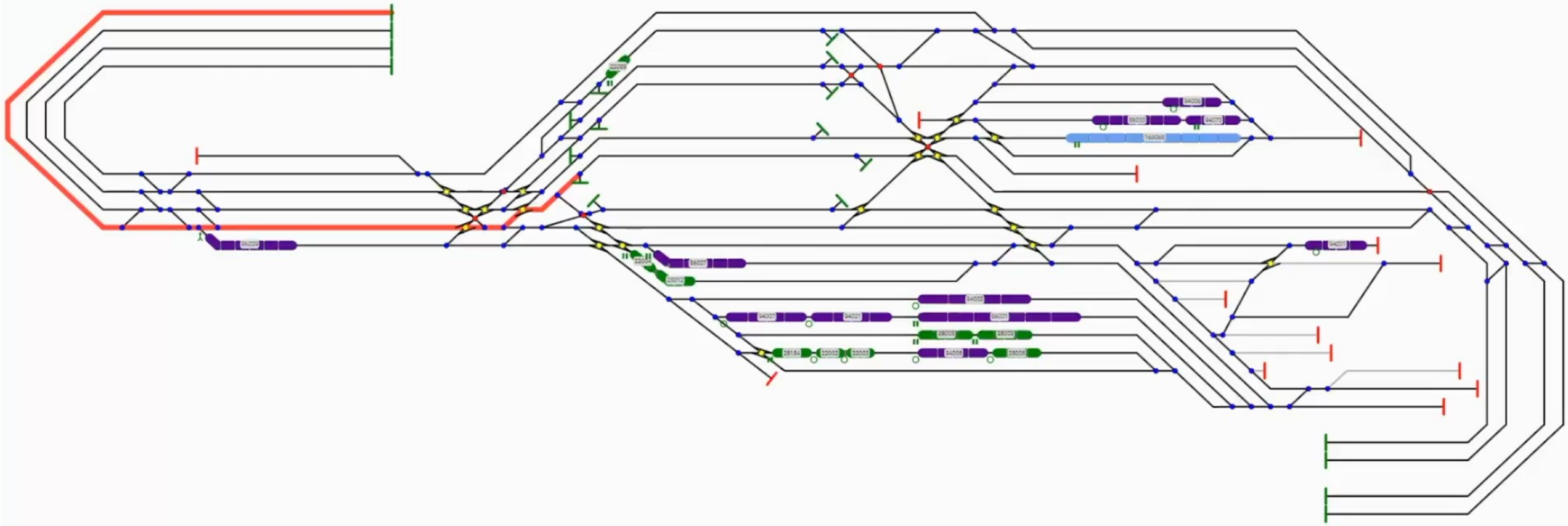

TU Delft


https://commons.wikimedia.org/wiki/File:15-Puzzle.jpg

TU Delft

V

# Eindhoven

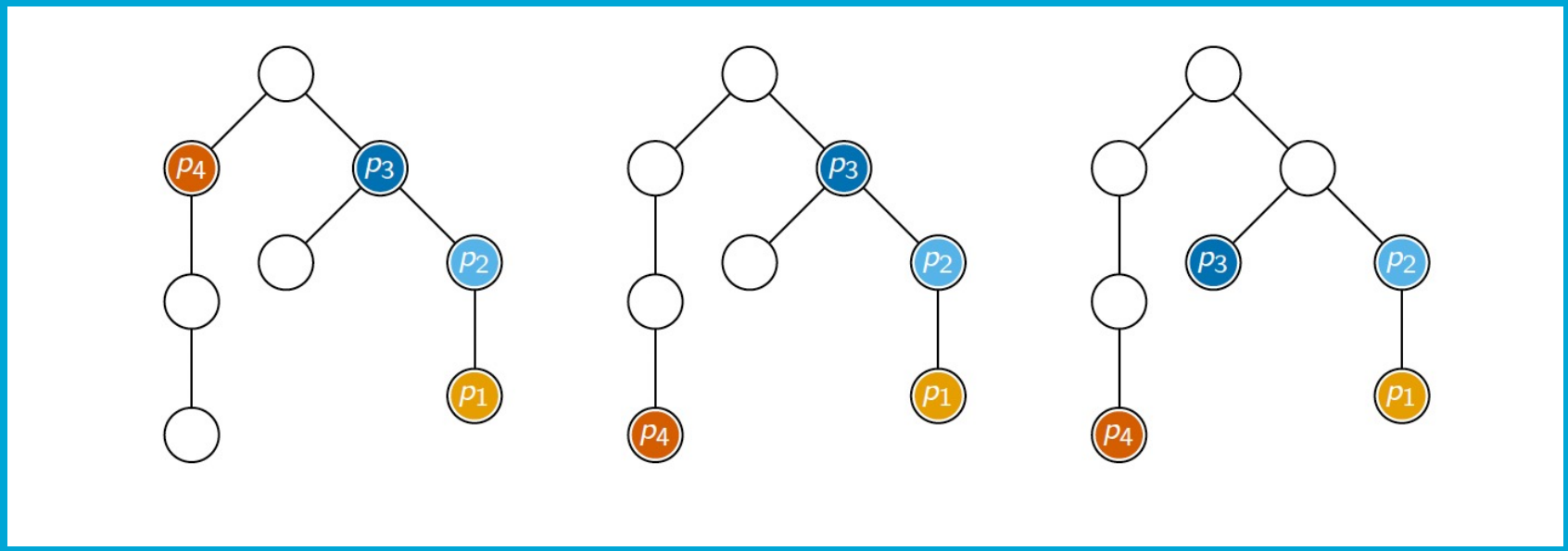


made by NS & Utrecht University

1.1.21:24:00

# Using a more simple model can help!

Issa Hanou



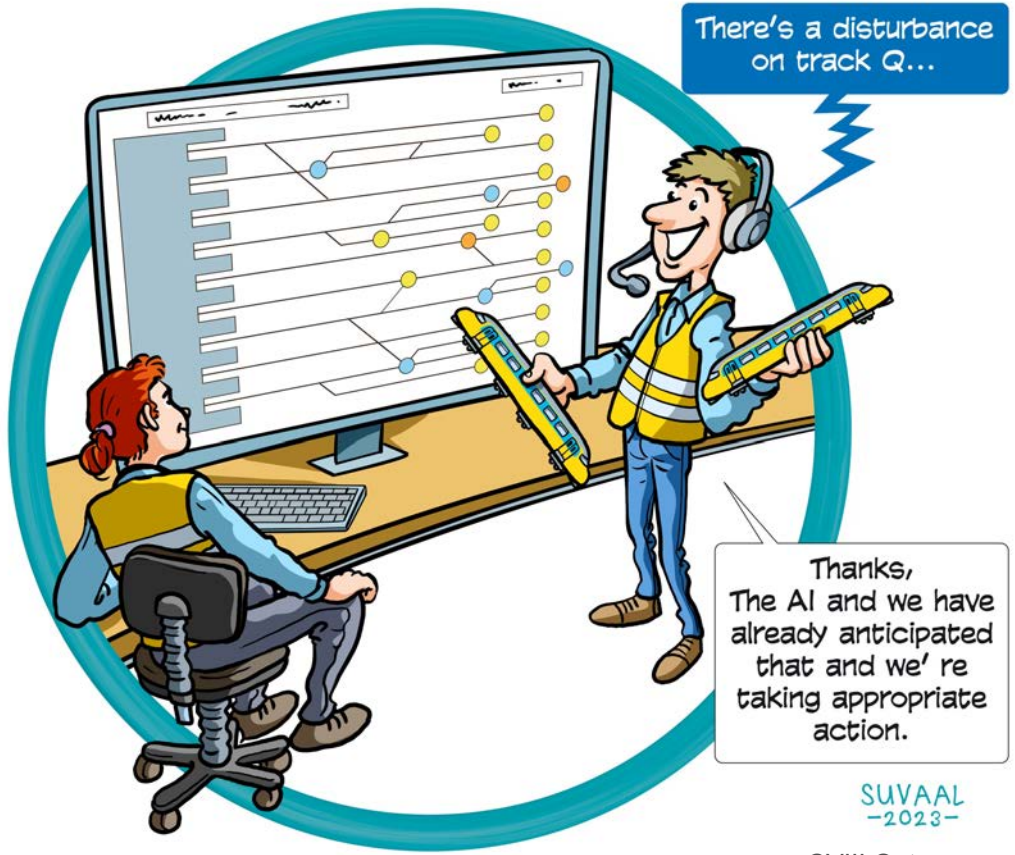

Issa Hanou, MdW, J. Mulderij. Moving Trains Like Pebbles: a Feasibility Study on Tree Yards. *ICAPS* 2023.

# Example: RAIL lab – LPT Robust (2023-2027)

ICAI Lab, Scientific directors: Marjan van den Akker (UU), Mathijs de Weerdt (TU Delft)

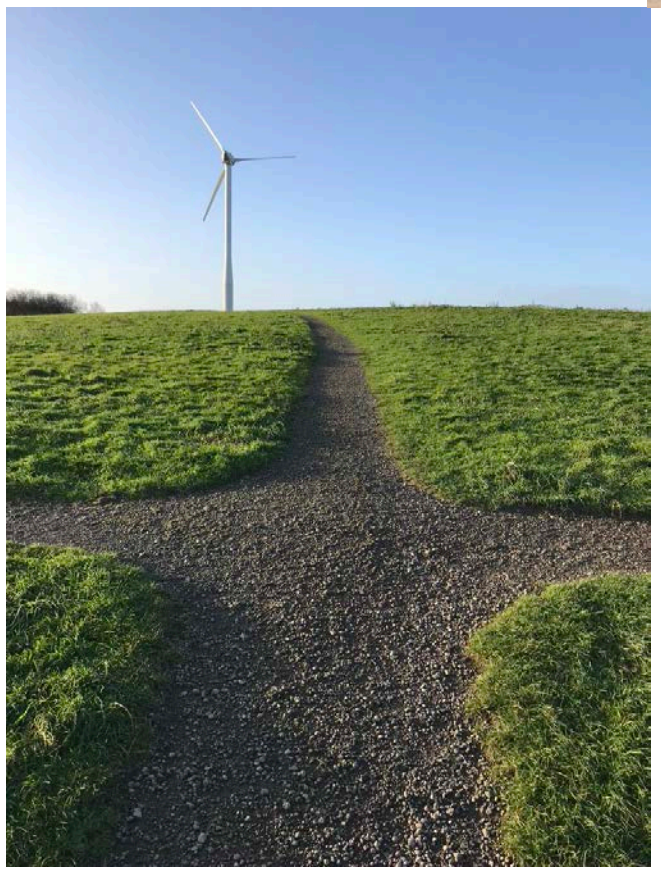
Five PhD projects:

1. Cooperation between human and AI planners
2. Robust planning
3. Quickly reacting to changes and disruptions
4. Supporting strategic decisions regarding the infrastructure capacity
5. Learning from previous situations and produce recognizable plans




CVIII Ontwerpers

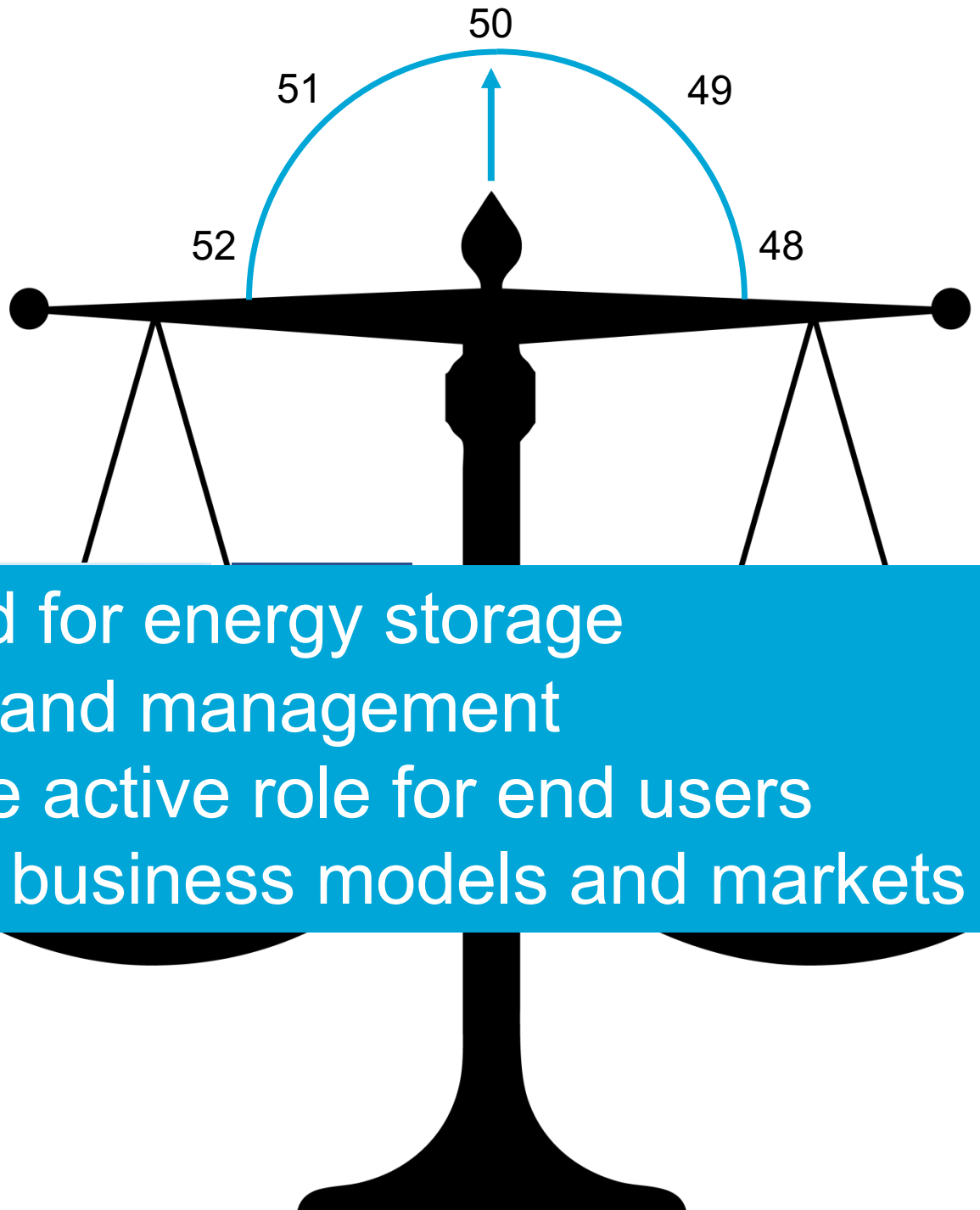
Supported by the DelftRail institute



- not completely controllable,
- variable,
- not perfectly predictable

TU Delft

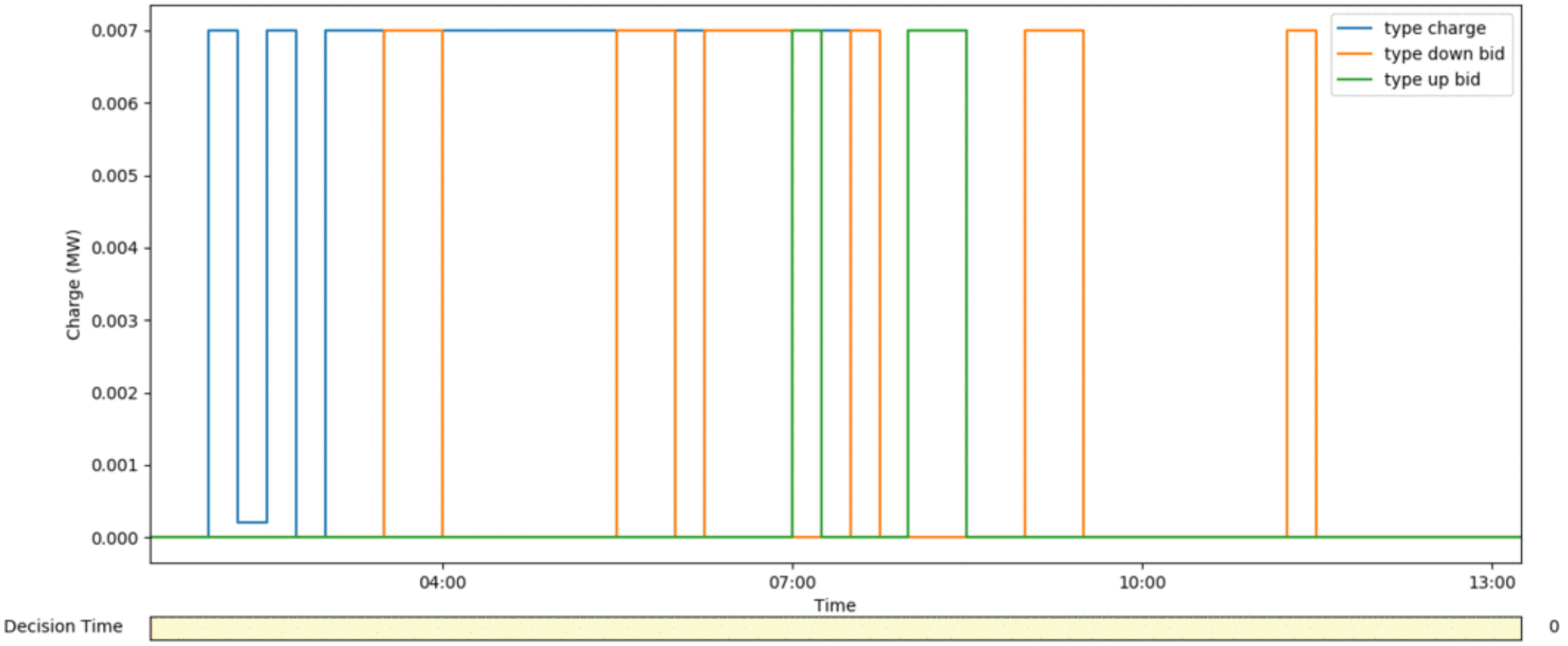
**supply** **demand**




- need for energy storage
- demand management
- more active role for end users
- new business models and markets

TU Delft

# Scheduling what to bid & when to charge



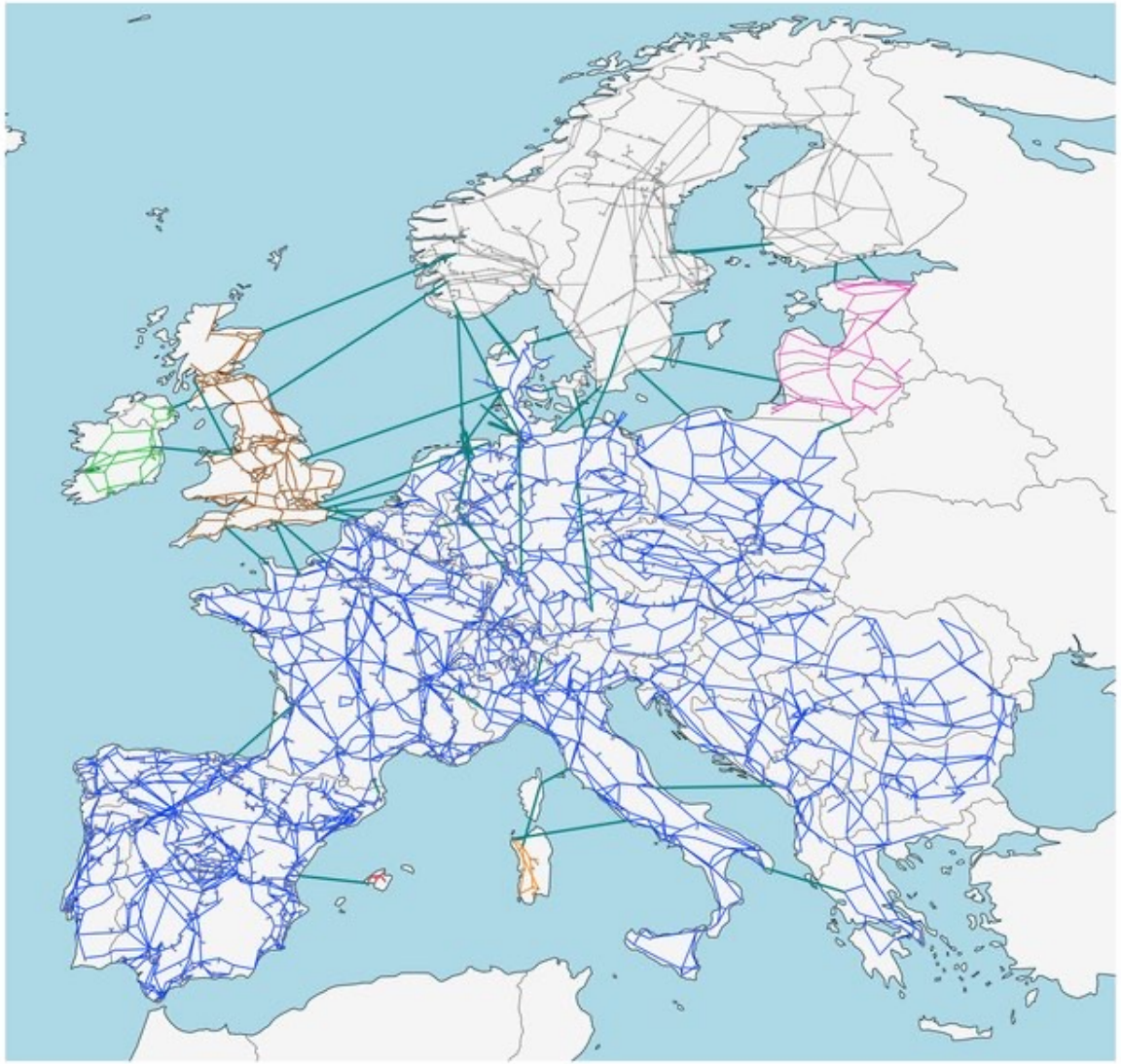

Koos
van der Linden

https://github.com/AlgTUDelft/B-FELSA

Koos van der Linden, Natalia Romero, MdW. Benchmarking Flexible Electric Loads Scheduling Algorithms, In *Energies* (2023) Volume 14 p.1-16.

# Optimal Investments in and Operation of the Energy System

- whole of Europe
- 20+ million constraints
- no optimal solution after a week
- just for the power system…



Hofmann, F.; Schlott, M.; Kies, A.; Stöcker, H. Flow Allocation in Meshed AC-DC Electricity Grids. *Energies* **2020**, *13*, 1233.

TU Delft

# NextGenOpt (2023-2027)

## Next Generation Sector-Coupling Models for Optimal Investments and Operation

Work in a team with algorithmic & domain expertise

Core aims:

- also **use algorithms to find models** with a good trade-off between accuracy and computation
- and to allow **making trade-offs interactively with the user**

Maaike Elgersma

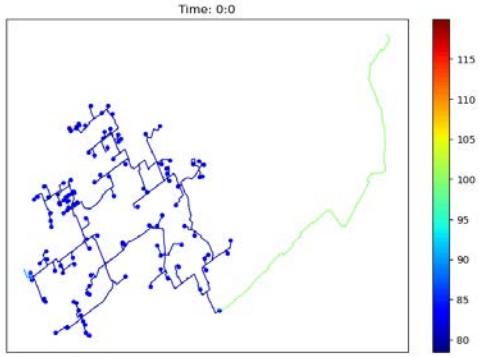
Greg Neustroev

TU Delft · Utrecht University · TNO innovation for life · PBL Netherlands Environmental Assessment Agency

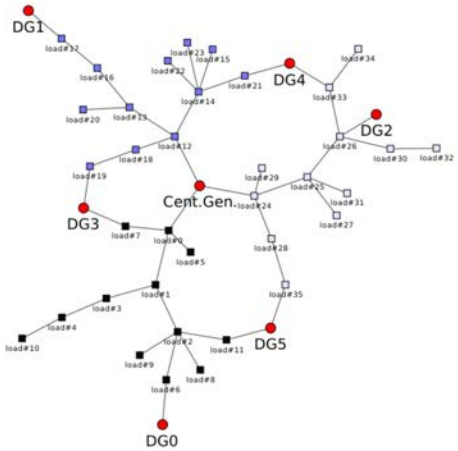
# Other projects

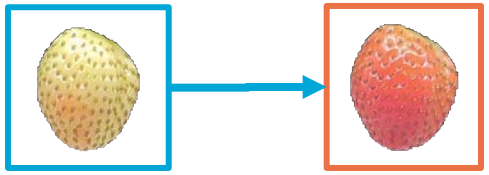
AI4b.io

https://github.com/ftbv/grid-penguin




by Jichen Wu



DSM

with the grid

Flex Technologies

DCpportunities

Delphy

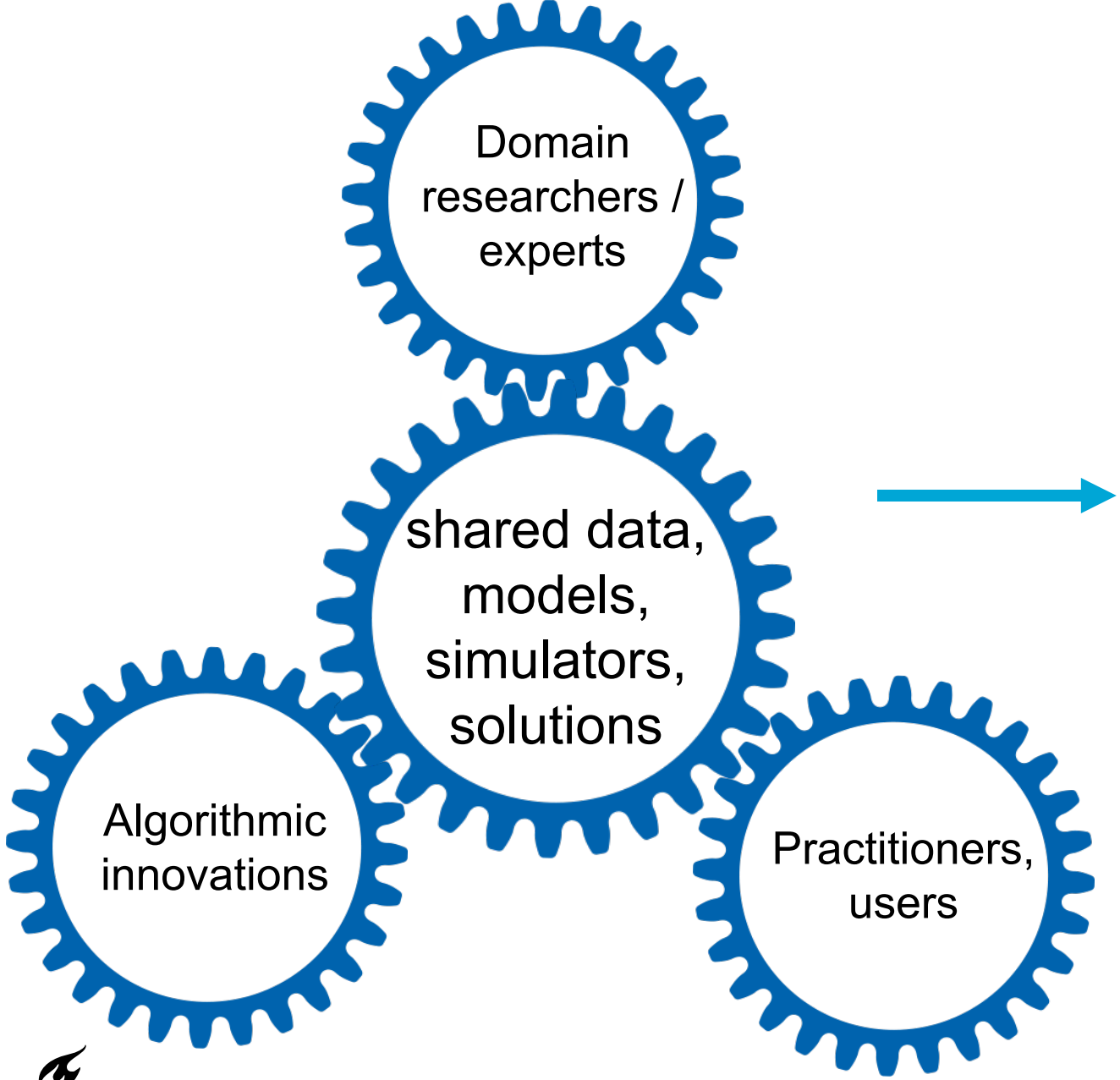
Birds.ai

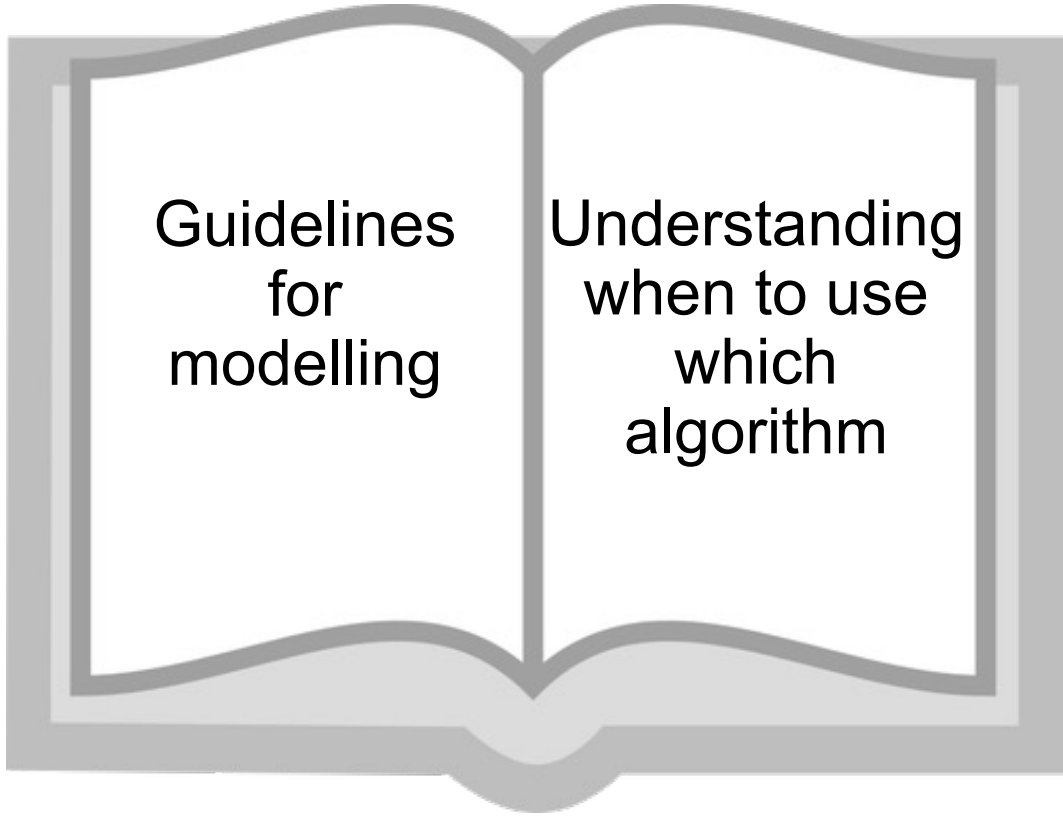
Kim van der Houten

Ksenija Stepanovic

Grigorii Veviurko

Junhan Wen


Domain researchers / experts
shared data, models, simulators, solutions
Algorithmic innovations
Practitioners, users


Guidelines for modelling
Understanding when to use which algorithm

TU Delft

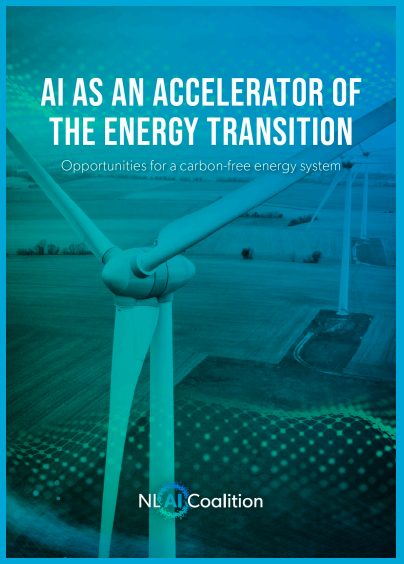
# How to address this?

## In my own research

TU Delft

## Supporting others

EnergySHR




NL AI Coalitie

AI, Data & Digitalisation
By Convergence

# Center for Energy System Intelligence

co-chaired with Yashar Ghiassi-Farrokhfal (RSM)

## EnergySHR

Sharing data and code by and for researchers

- For practitioners: to benefit more directly from new algorithms
- For researchers: working with real data; solving the right problems

Contact me (or Caroline Duterloo)!

TU Delft

Supported by the PowerWeb institute

Inspired by The Green Village: a living lab for sustainability and energy research

https://www.thegreenvillage.org

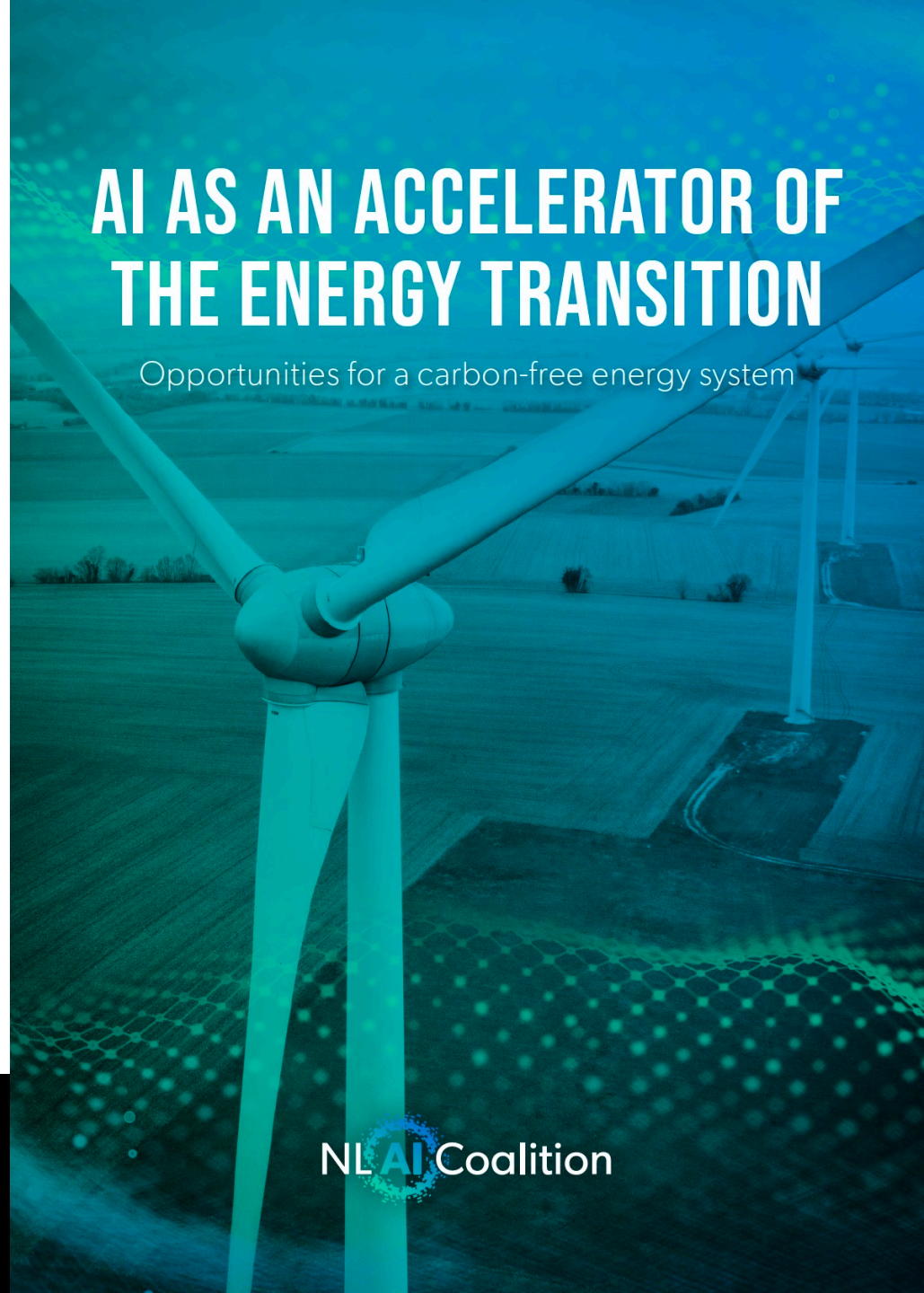
# NL AIC

- transfer of knowledge

  https://energie.ai-cursus.nl/home
- bringing together problem owners and AI expertise (researchers & developers)

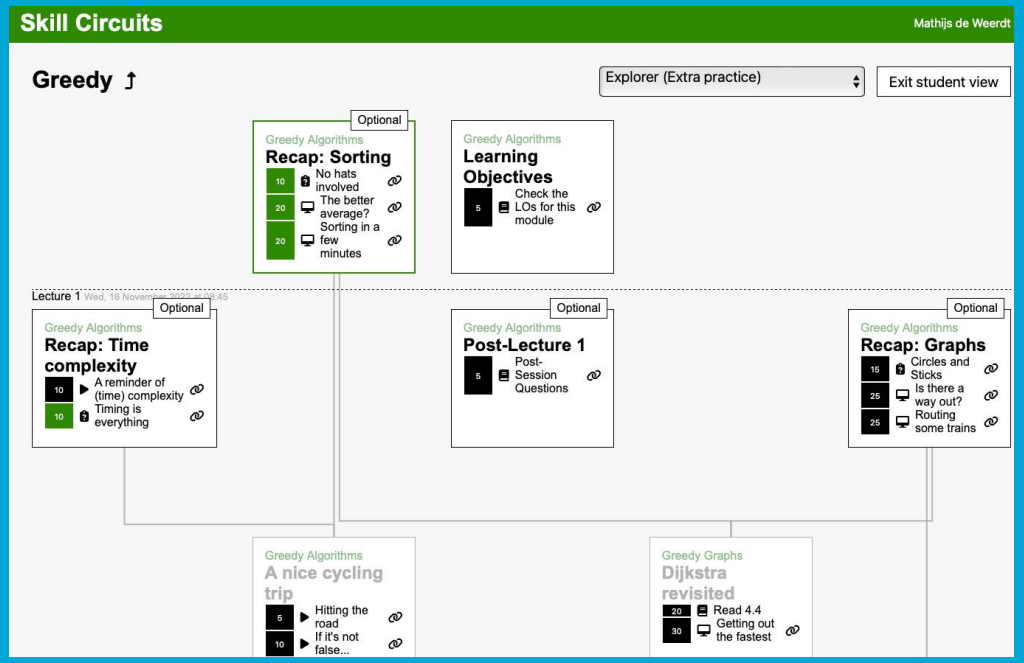
Contact me if you're looking for AI expertise!

NL AI Coalitie



# Education

## Students are all different




## Teach bachelor students about research

### More than 250 papers in less than 2 months

NEWS - 23 JULY 2021

**Vibrant groups full of creativity and interesting new research, but above all: a new generation of bachelor students ready for all the possible academic hurdles they will face during their master's. The new "Research Project" of the renewed Computer Science and Engineering curriculum is a great success! But what made that possible?**

#### A big change

You don't change a successful curriculum just like that. 'We thought about it very carefully,' says Mathijs de Weerdt, 'because a lot of what we were doing before also worked well'. Until a year ago, the bachelor students of Computer Science Engineering did their graduation research in groups of four at a company, to gain practical experience. 'That was an incredibly valuable experience and we didn't really want to give it up. But ultimately we also want to train scientists.' The group assignment at a company was therefore retained, but moved to the second year. And indeed, that went very well. In their third and final year of the bachelor's, the students now do a graduation assignment, in which they set up and complete a high-quality research project in two months, including a paper. 'That is quite a task, and it was a little exciting whether everyone would succeed.'

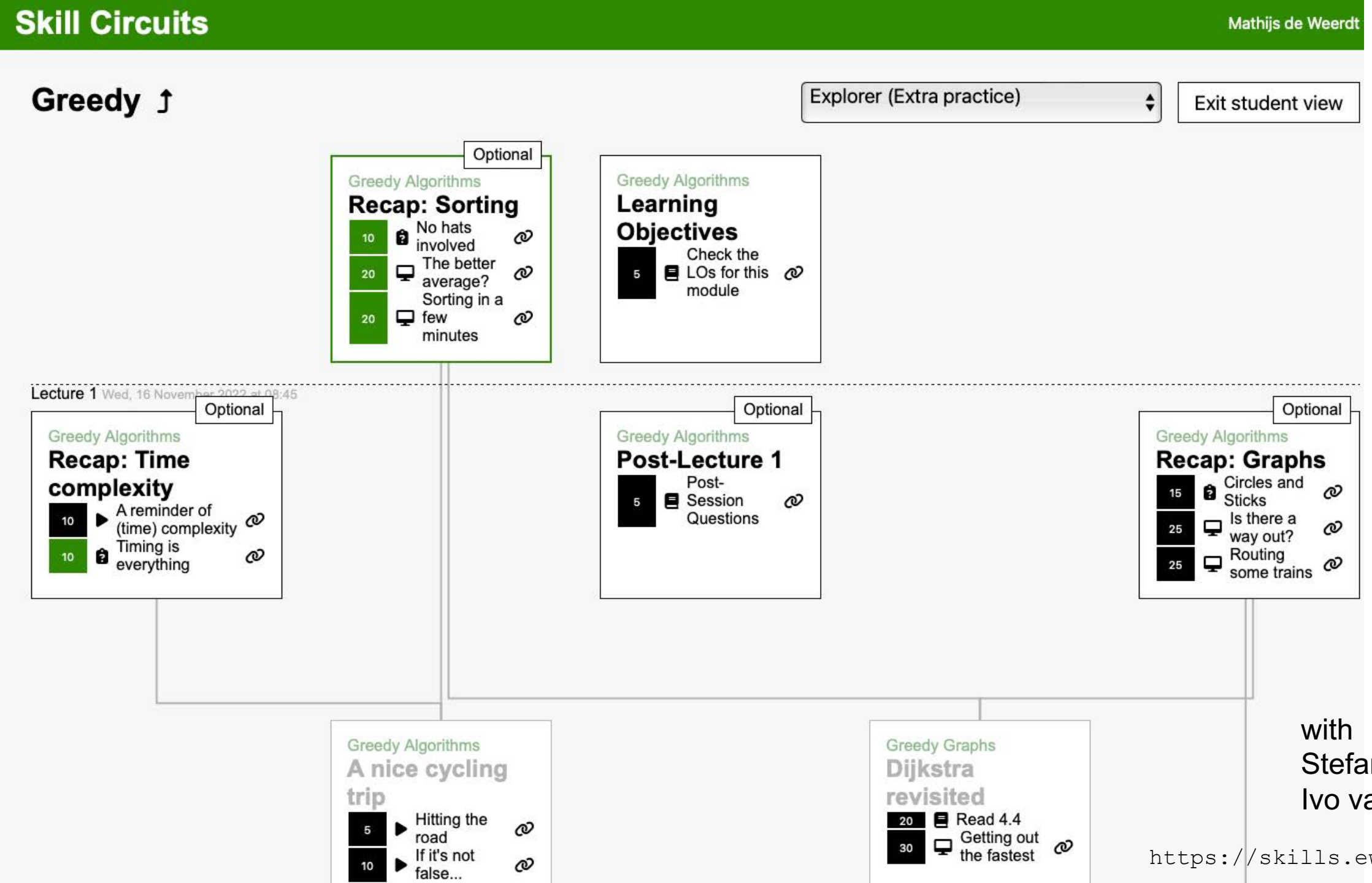
But they did: the 250 studies are full of interesting results, from programmes that enable a computer to defend itself better in a game of AI football to algorithms that automatically analyse web comics. 'Supervisors, including professors, were more than positively surprised by the quality', says Mathijs enthusiastically, 'some are even working on getting their research published.'


*Are you curious about all the results? Then click here.*

#### An unexpected puzzle

For Mathijs and his team there was also a major task: how do you ensure that all those students set up a good research project

TU Delft




with
Stefan Hugtenburg
Ivo van Kreveld

https://skills.ewi.tudelft.nl/

# Education: the bachelor research project

Challenge:

- experience research
- write a paper individually
- over 300 students per year, 60-90 projects

Next:

- connect CS students (more) to other disciplines
- allow other students to learn (more) about algorithms

Project Popularity

| Project | Popularity | In top 3 | In top 5 | In top 10 |
|---|---|---|---|---|
| 2582 - Cooperative AI for Overcooked! | 10.65 | 51 | 72 | 124 |
| 2440 - A Virtual Reality Game to Explore Hyperbolic Geometry | 11.98 | 38 | 56 | 84 |
| 2467 - Find biological markers for human disease and allergies | 11.77 | 37 | 63 | 87 |
| 2545 - Advances and Challenges in Traffic Forecasting with Deep Learning... | 12.62 | 31 | 41 | 67 |
| 2471 - Person identification using heart rate and activity from consumer... | 12.0 | 30 | 50 | 88 |
| 2439 - Comics Illustration Synthesizer using Deep Generative Models | 12.98 | 28 | 35 | 58 |
| 2466 - "We need to learn how to teach Machine Learning" | 12.67 | 28 | 45 | 65 |
| 2485 - Shining a light on Material Appearance | 12.78 | 26 | 39 | 63 |
| 2518 - Mining Software Testing Knowledge | 12.74 | 23 | 38 | 67 |
| 2524 - Combinatorial Optimisation for Scheduling (NP-Hard Algorithms) | 12.8 | 23 | 39 | 62 |
| 2539 - Revealing the Secret to Successful Virtual Meetings: How Personal... | 12.99 | 21 | 32 | 61 |
| 2520 - Github Mining: Discover the Descriptive Metrics of the Context in... | 13.06 | 20 | 33 | 59 |
| 2433 - Creation of Gang Territories and other Patterns | 13.23 | 19 | 31 | 52 |

https://projectforum.tudelft.nl/

TU Delft

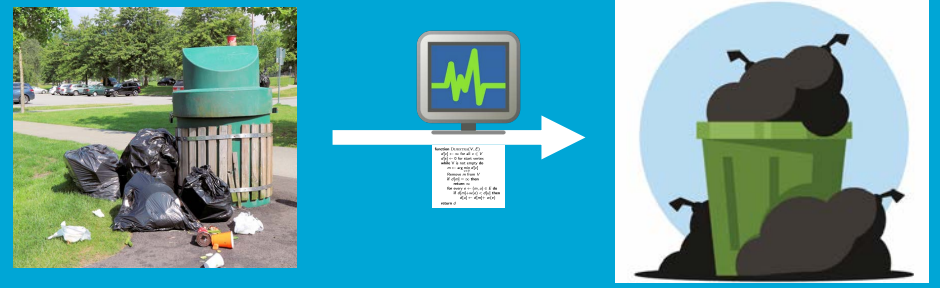
with Philipe Louchtch, Taico Aerts, Gosia Migut

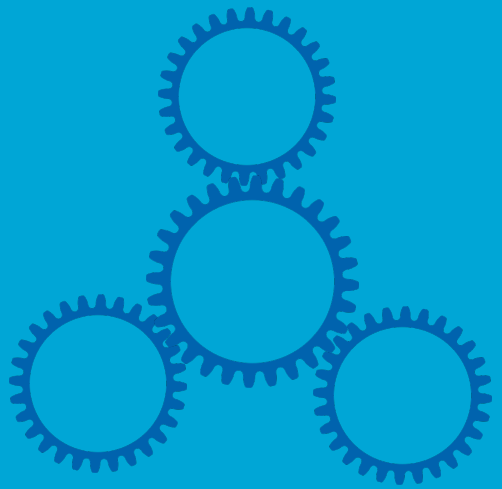
# Conclusion

Algorithmic insights *can* help solve society's problems.

But it is important that an algorithm

1. uses the right model
2. uses the right data
3. works in interaction with users





TU Delft

# Not alone

- My promotors: great to have you here!
- PhD students: current and former
- Post-docs, research software engineers
- Business developers, project support, etc.

Konstantin Sidorov

Ksenija Stepanovic

Issa Hanou

Maaike Elgersma

Koos van der Linden

Kim van der Houten

Grigorii Veviurko

Junhan Wen

TU Delft

# Not alone

- Other staff of the section Algorithmics
- All colleagues of the two departments
- My collaborators over the years
- Industry partners
- Could not mention all in this talk
- Fantastic to work with you!

**Anna Lukina**
safety and explainability of AI

**Matthijs Spaan**
planning under uncertainty

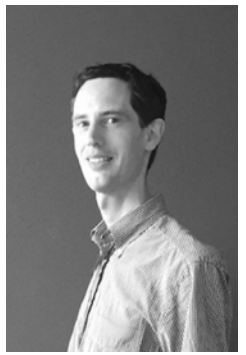
**Wendelin Böhmer**
deep RL

**Peter Bosman**
evolutionary intelligence

**Sicco Verwer**
learning interpretable models

**Sebastijan Dumančić**
probabilistic program synthesis

**Emir Demirović**
optimisation & ML



**Neil Yorke-Smith**
data-driven optimisation

TU Delft