# Would you let HAL-320 be your captain today?

ICAPS'22 Workshop on Reliable Data-Driven Planning and Scheduling

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Dear passengers, welcome in 2059.

I'm HAL-320, your new captain. John fell asleep, so I'm just taking over the commands to fly you back home.

Keep calm and enjoy your flight!


Well... Keep calm, we're not still there 😅
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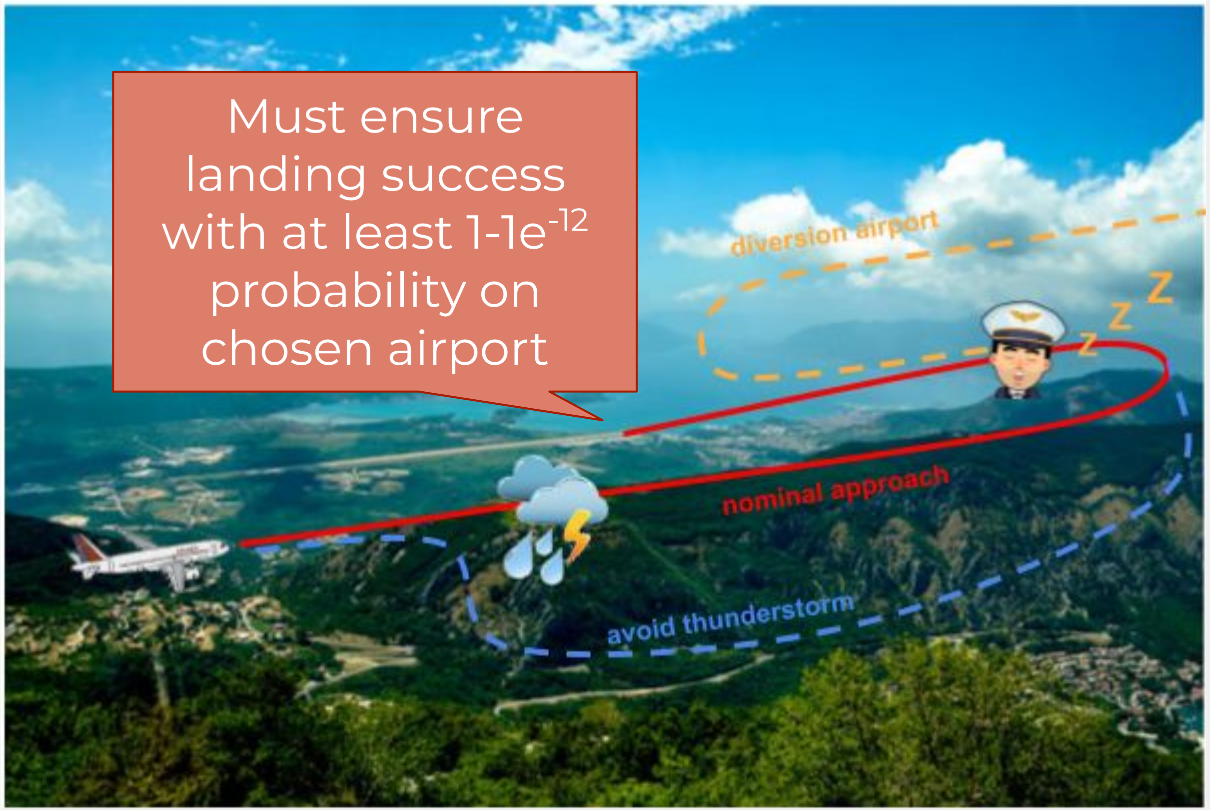
# A typical use case: airport diversion strategy

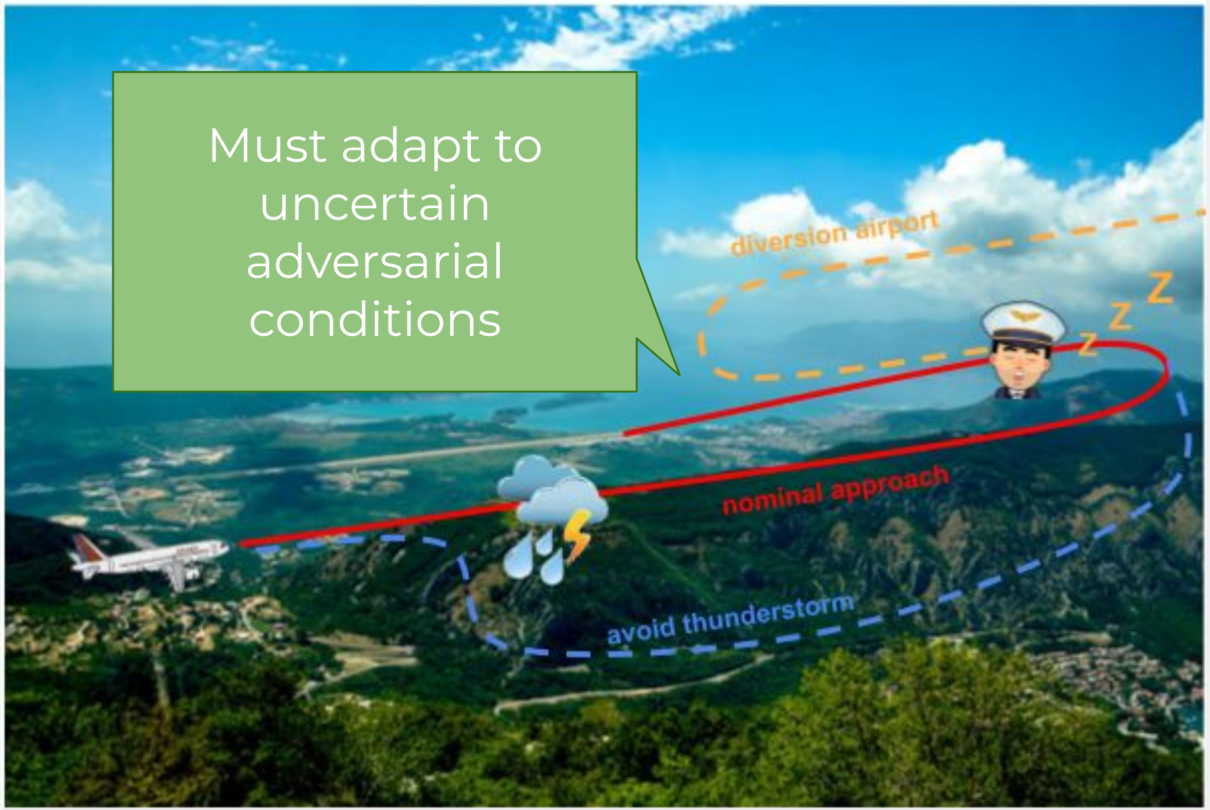



Autonomous system to take over the pilot as a last resort

Must ensure:

✈ Safety

# A typical use case: airport diversion strategy

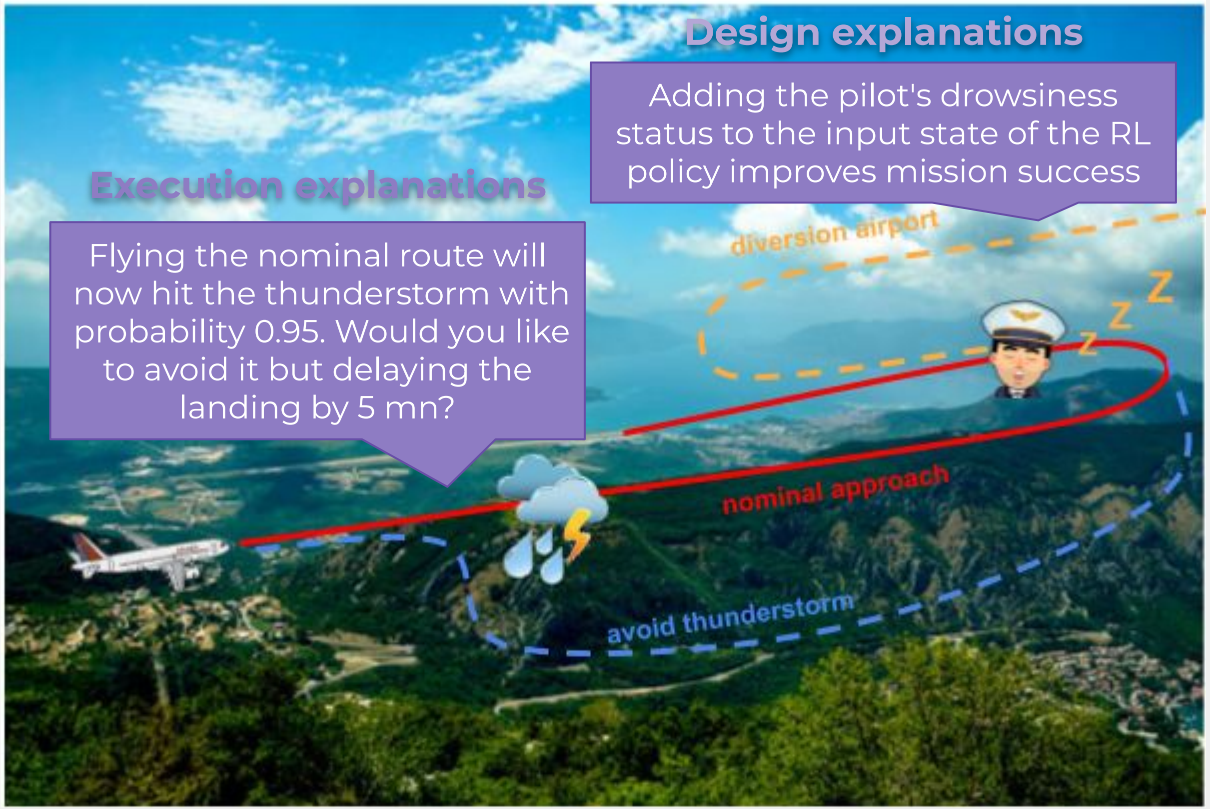



Autonomous system to take over the pilot as a last resort

Must ensure:

- ✈ Safety
- ✈ Robustness

# A typical use case: airport diversion strategy




Autonomous system to take over the pilot as a last resort

Must ensure:

- Safety
- Robustness
- Explainability

# Diversion management based on Probabilistic Flight Planning

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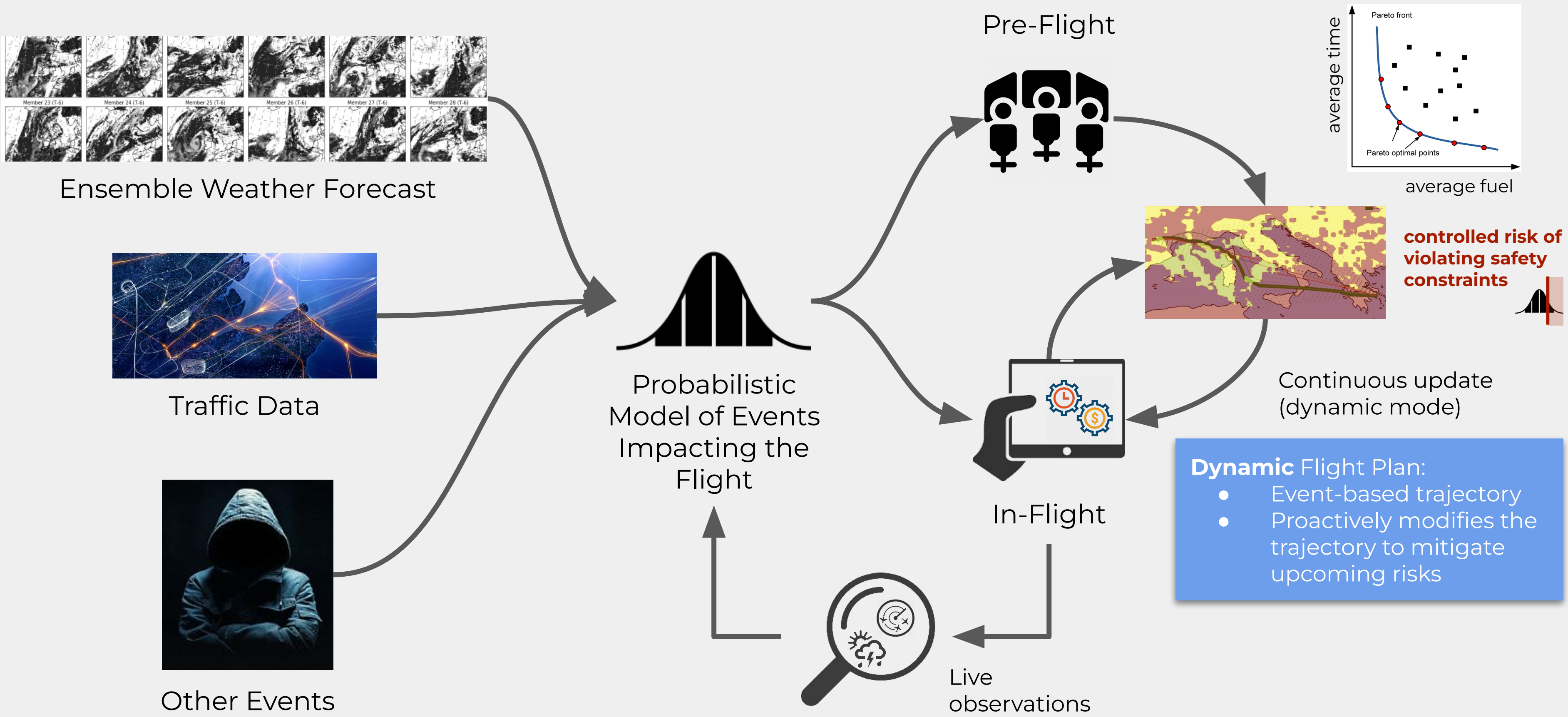

# DONUT project: benchmarking of two complementary flight planning algorithms

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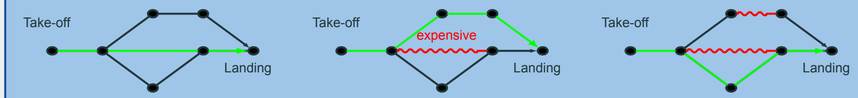
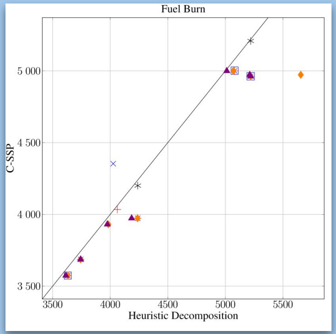
## CSSP - Constrained Stochastic Shortest Path

***Optimal and Heuristic Approaches for Constrained Flight Planning under Weather Uncertainty.*** *F. Geißer, G. Povéda, F. Trevizan, M. Bondouy, F. Teichteil-Königsbuch, S. Thiébaux. ICAPS 2020*

Iterative algorithm based on **LP** and **column generation**

**No use of heuristics** due to simulation-based aircraft performance model



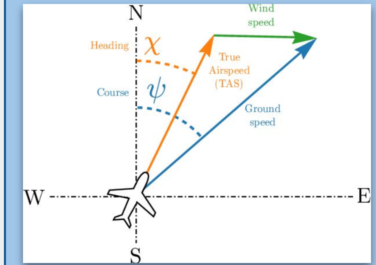




- ➕ Satisfy constraints by construction
- ➕ Robust by construction
- ➕ Handle waypoint graph

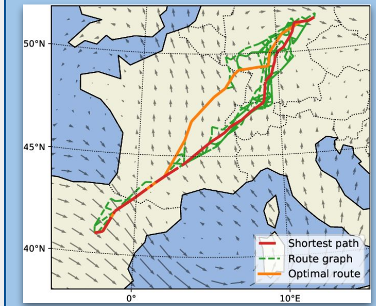
- ➖ Computationally expensive
- ➖ Simplified weather and transition model
- ➖ Cannot handle continuous variables

## Parallel Robust Optimal Control

***Probabilistic 4D Flight Planning in Structured Airspaces through Parallelized Simulation on GPUs.*** *D. Arribas, E. Andrés-Enderiz, M. Soler, A. Jardines, J. García-Heras. Computer Science, 2020*




Uses **Augmented Random Search** and **Optimal Control** to produce waypoint-constrained continuous trajectories evaluated on a set of **probabilistic weather scenarios**




- ➕ Use continuous aircraft performance model
- ➕ Robust by construction

- ➖ Not optimal
- ➖ A posteriori projection on discrete waypoints

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# No approach ruling all the others out

| | Aircraft Dynamics | Aircraft Systems | Airways Graph | Weather Model | ATC Model |
|---|---|---|---|---|---|
| Search/Planning methods (e.g. CSSP) | ⭐☆☆☆☆ | ⭐⭐⭐⭐☆ | ⭐⭐⭐⭐⭐ | ⭐⭐☆☆☆ | ⭐⭐⭐⭐⭐ |
| Simulation-based methods (e.g. RL, EA, MCTS) | ⭐⭐⭐⭐☆ | ⭐⭐⭐⭐⭐ | ⭐⭐☆☆☆ | ⭐⭐⭐⭐☆ | ⭐⭐⭐⭐☆ |
| Control-based methods (e.g. ROC, MPC) | ⭐⭐⭐⭐⭐ | ⭐⭐☆☆☆ | ⭐⭐⭐☆☆ | ⭐⭐⭐⭐☆ | ⭐⭐☆☆☆ |

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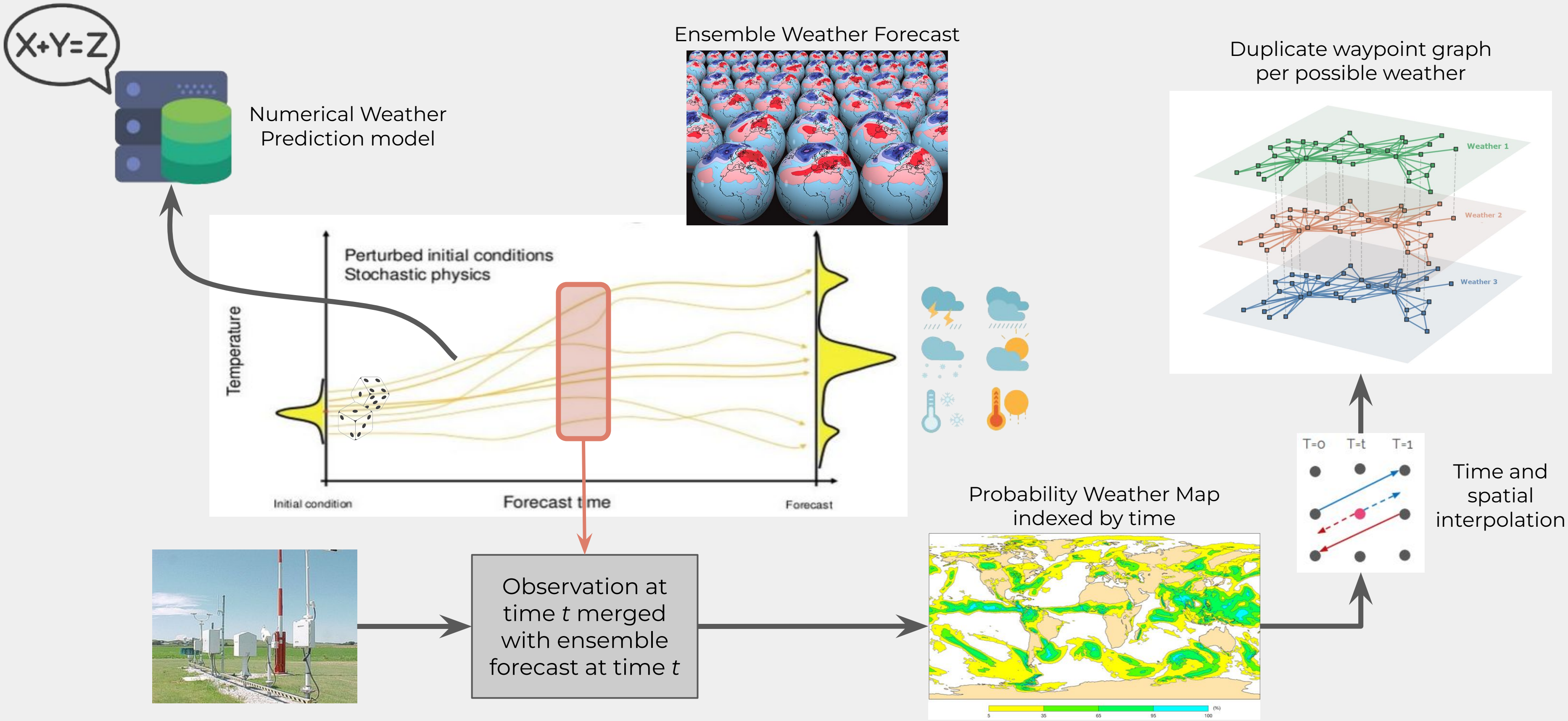
# A complex probabilistic weather model



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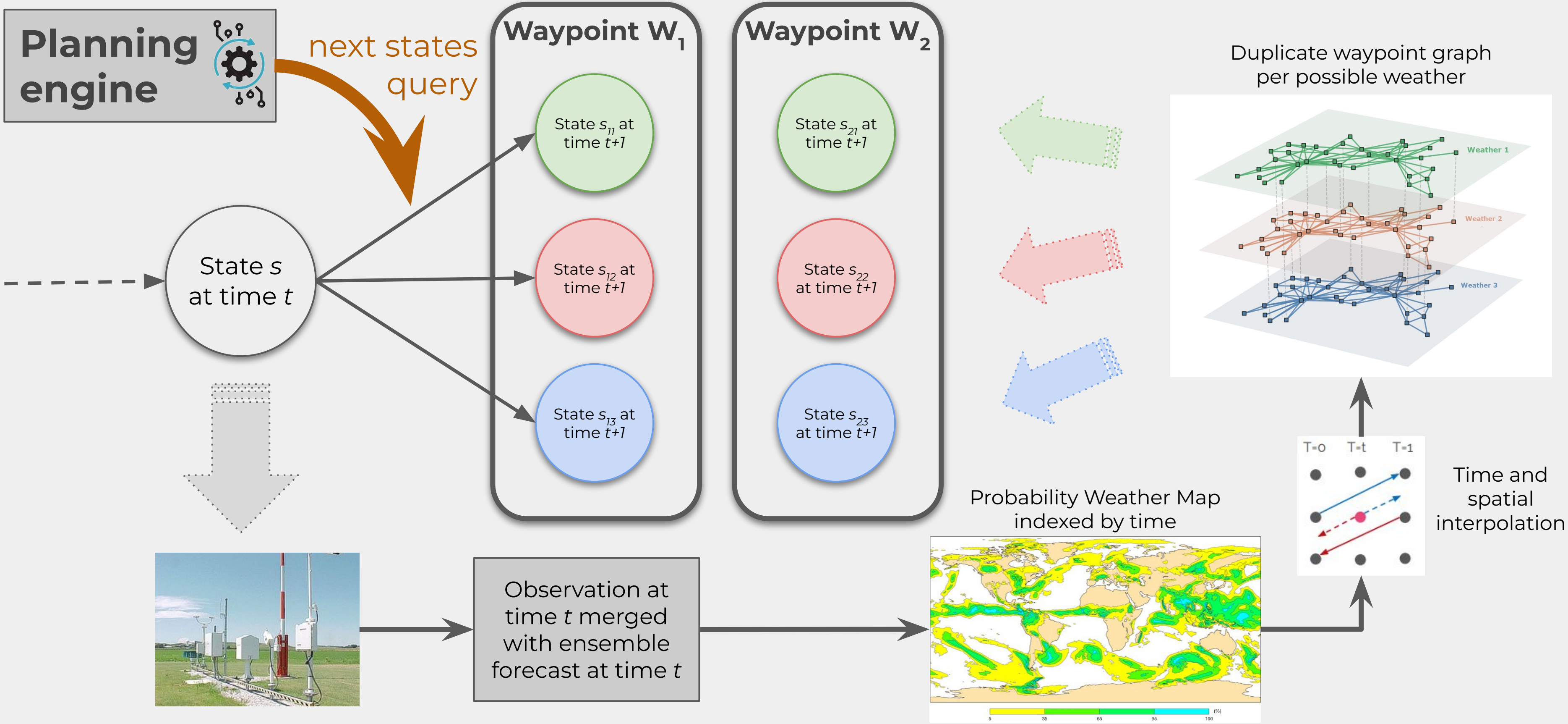
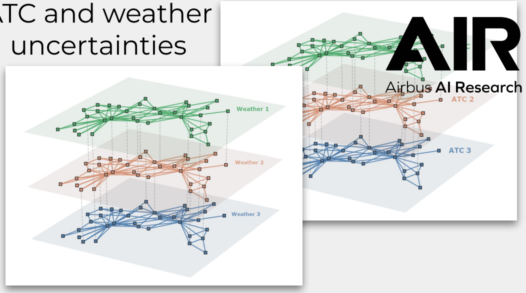
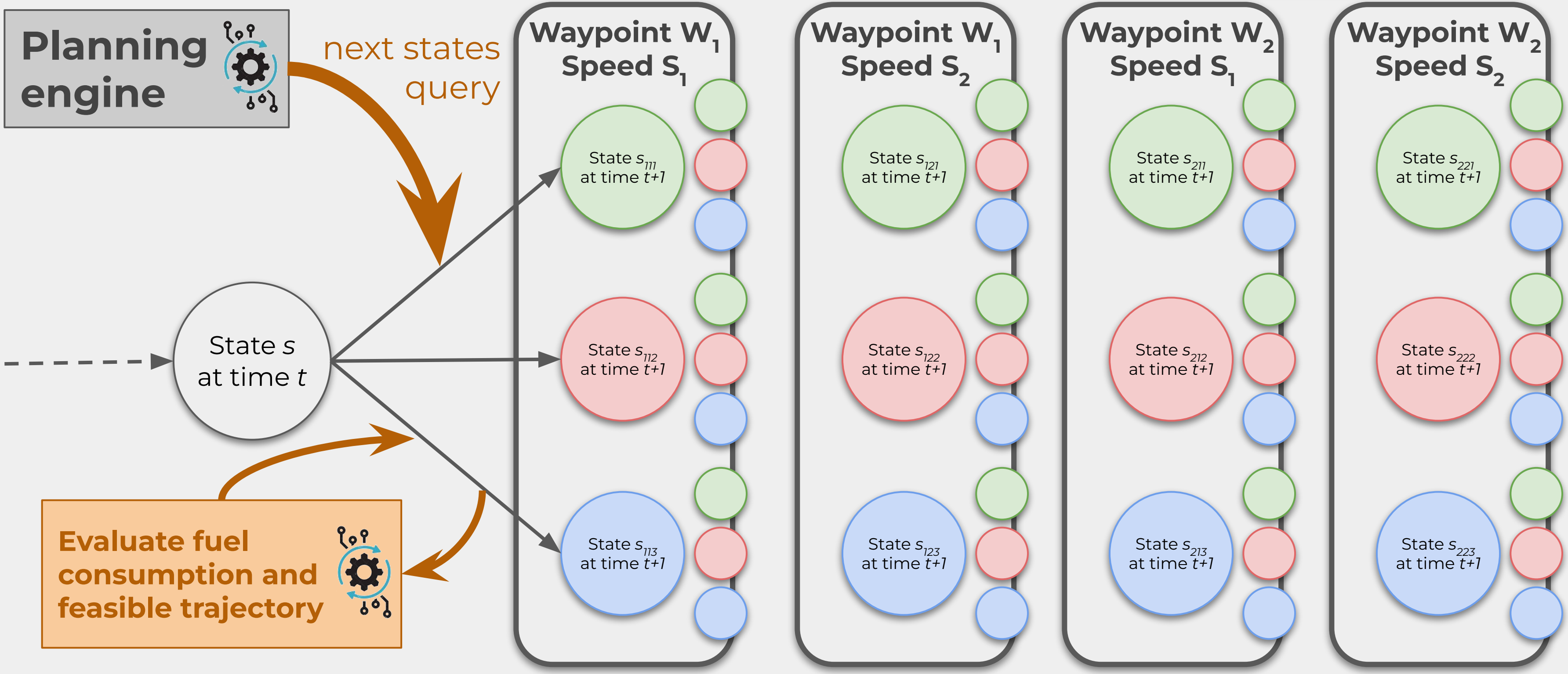
# A complex probabilistic weather model



ATC and weather uncertainties



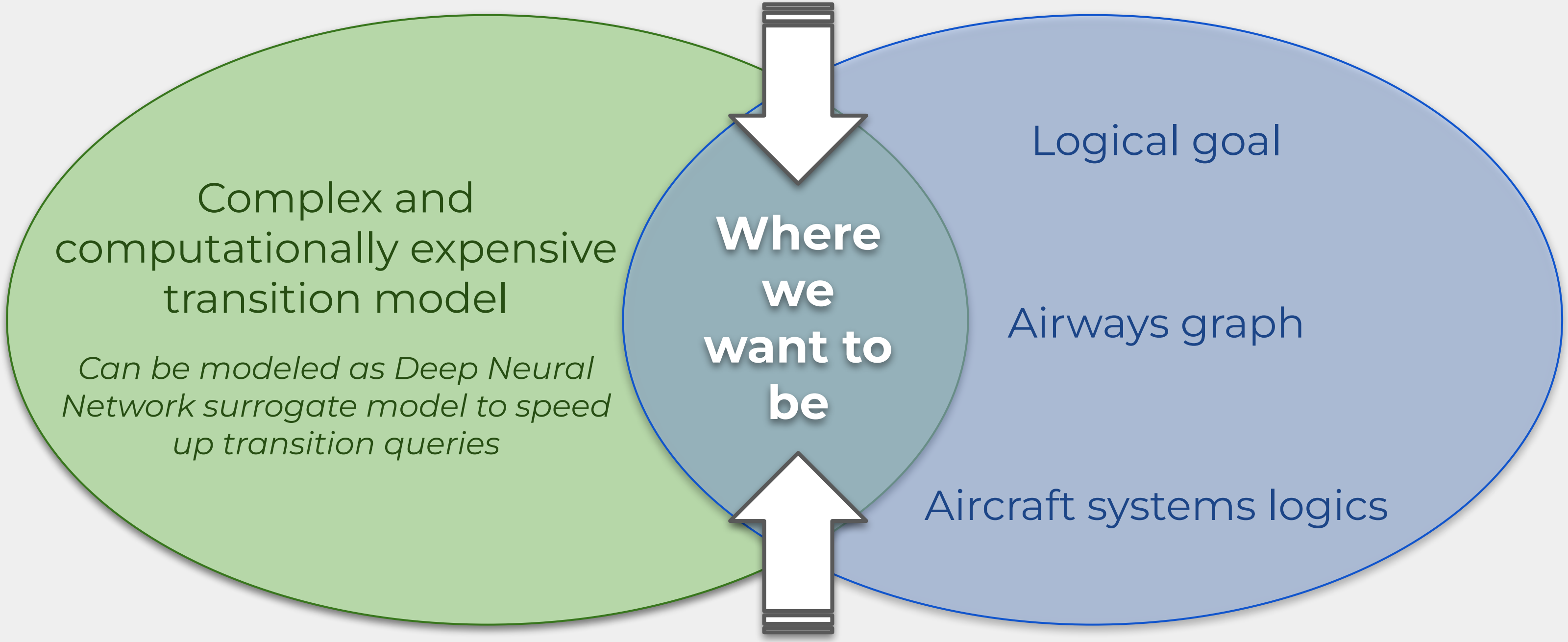

# The full transition model story



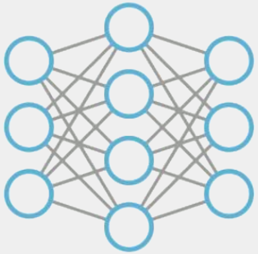
# No free lunch: need for hybrid planning method

**Simulation-based methods**

**Search-based methods**

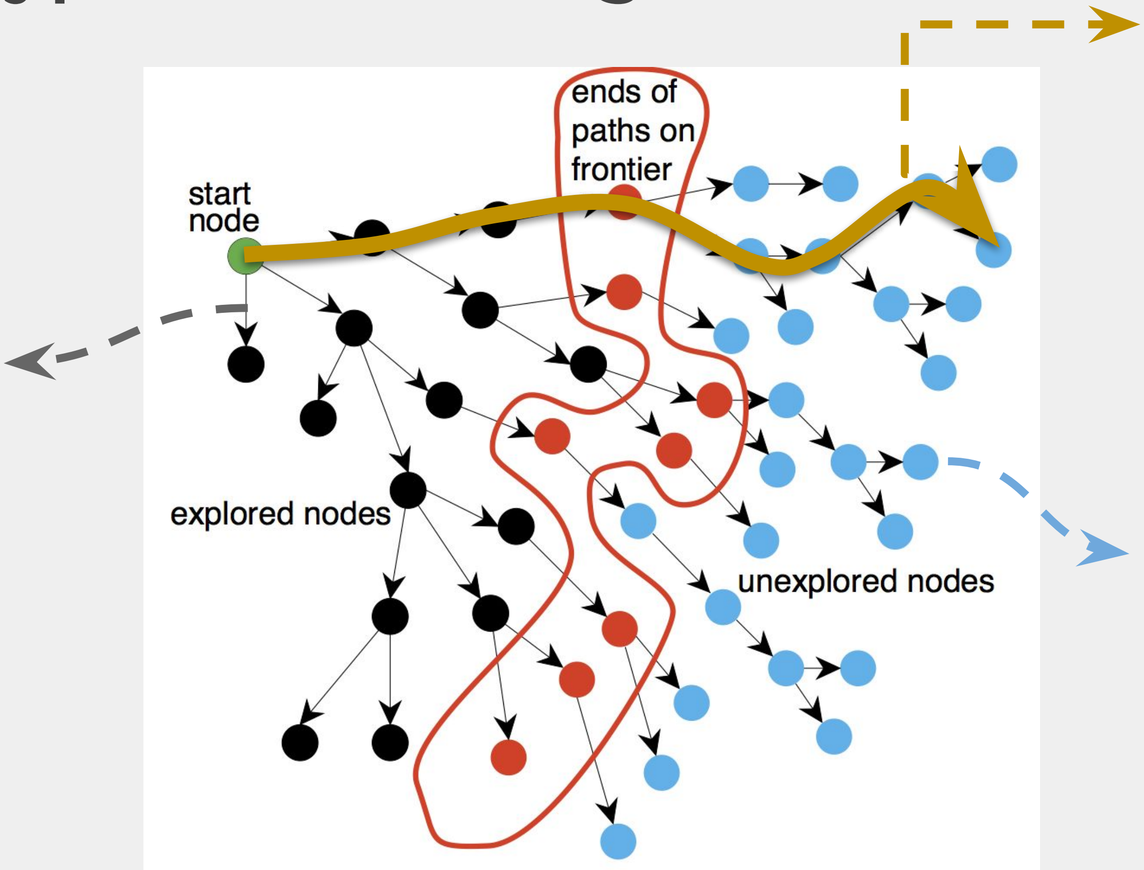


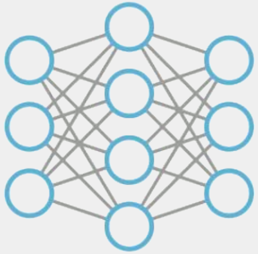
# Possible hybridizations of deep learning with a typical search algorithm



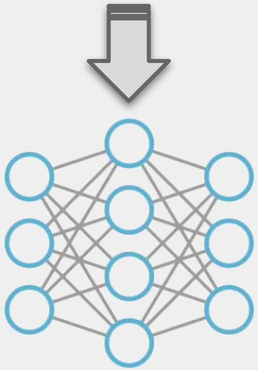
Surrogate model of transitions

*(aircraft performance evaluation, weather & ATC prediction)*



Surrogate model of the solver



Heuristic function

*(learned from previous solved instances of the search problem)*

# Another example of hybridization: stochastic manufacturing task scheduling

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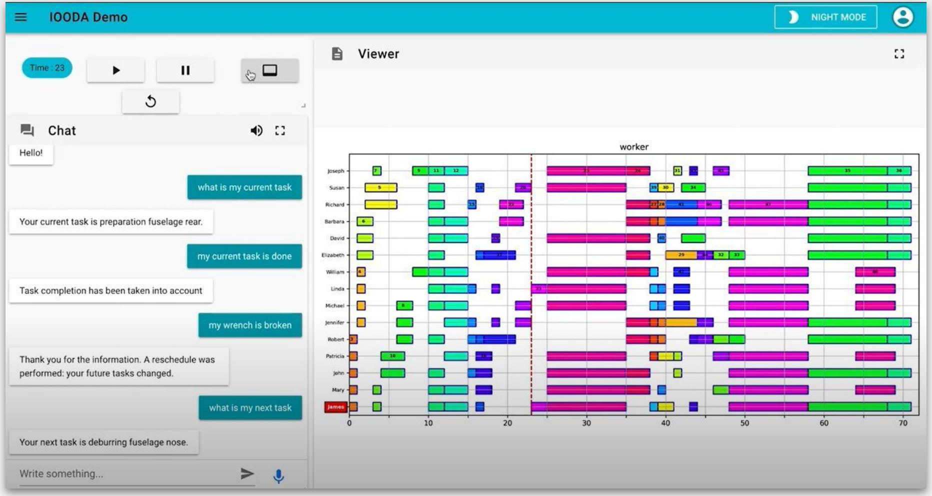
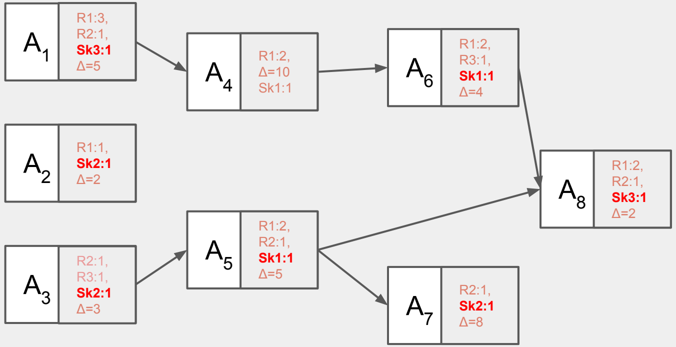
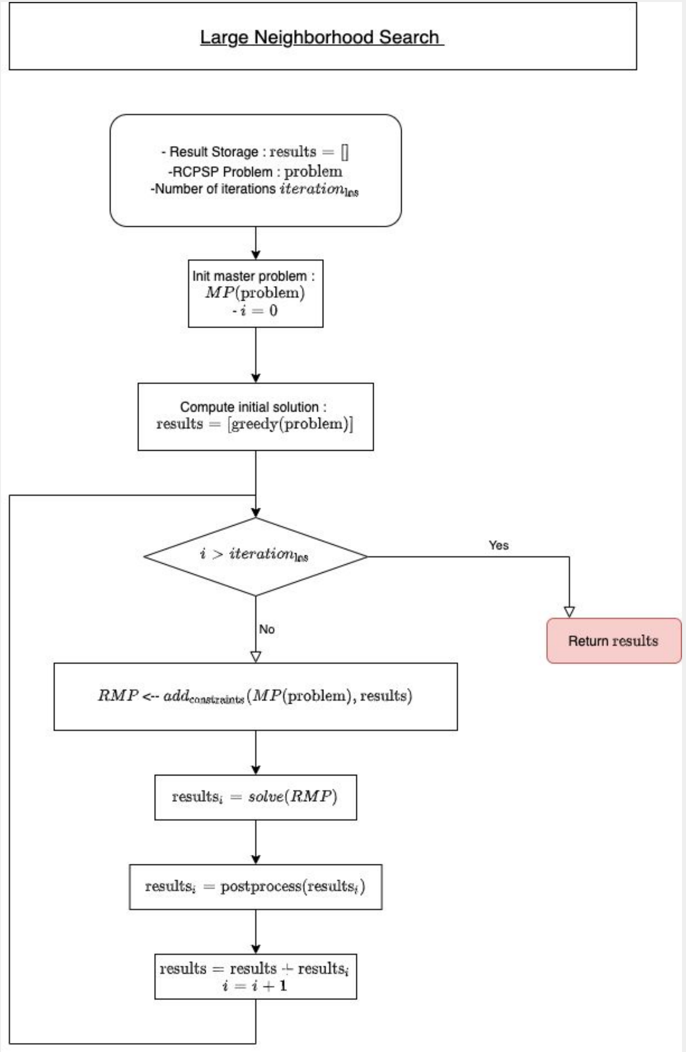
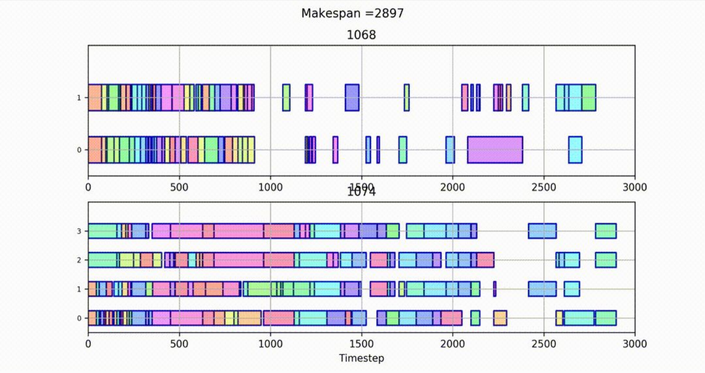
Stochastic Multi-Skill Multi-Mode Resource Constrained Project Scheduling Problem with Time-Constrained Precedence Constraints

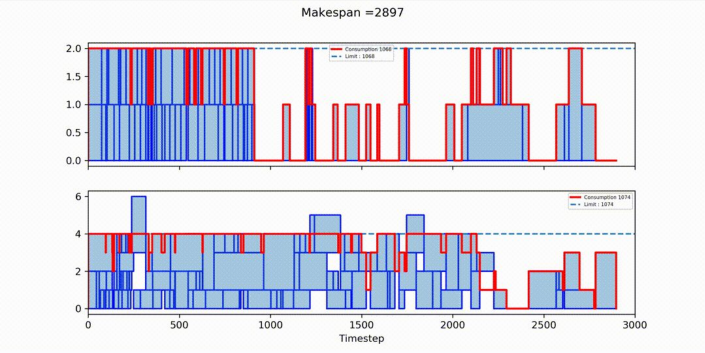


# Solving extended RCPSPs with Large Neighborhood Search



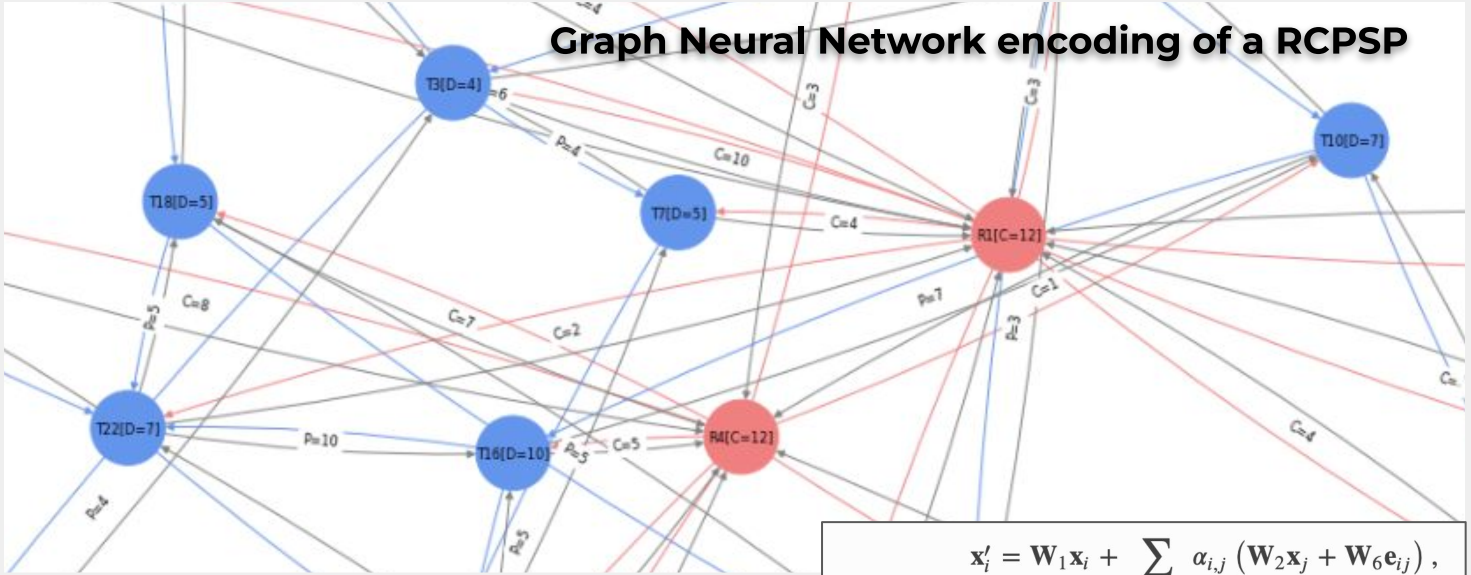




👍 Scales to large industrial problems (thousands of multi-mode tasks with multi-skilled workers and temporal precedence constraints)

👎 But does not handle uncertainty

# Towards uncertainty and adaptivity handling with Graph Neural Networks




e_ij

precedence
[0, 1, 0, 0, 0]

resource
[1, 0, 0, 0, #consumed]

reverse link
(to propagate information in both ways)
pre.: [0, 0, 0, 1, 0]
res.: [0, 0, 1, 0, #consumed]

[0, 1, 0, duration]

[1, 0, #resources, 0]

x_i

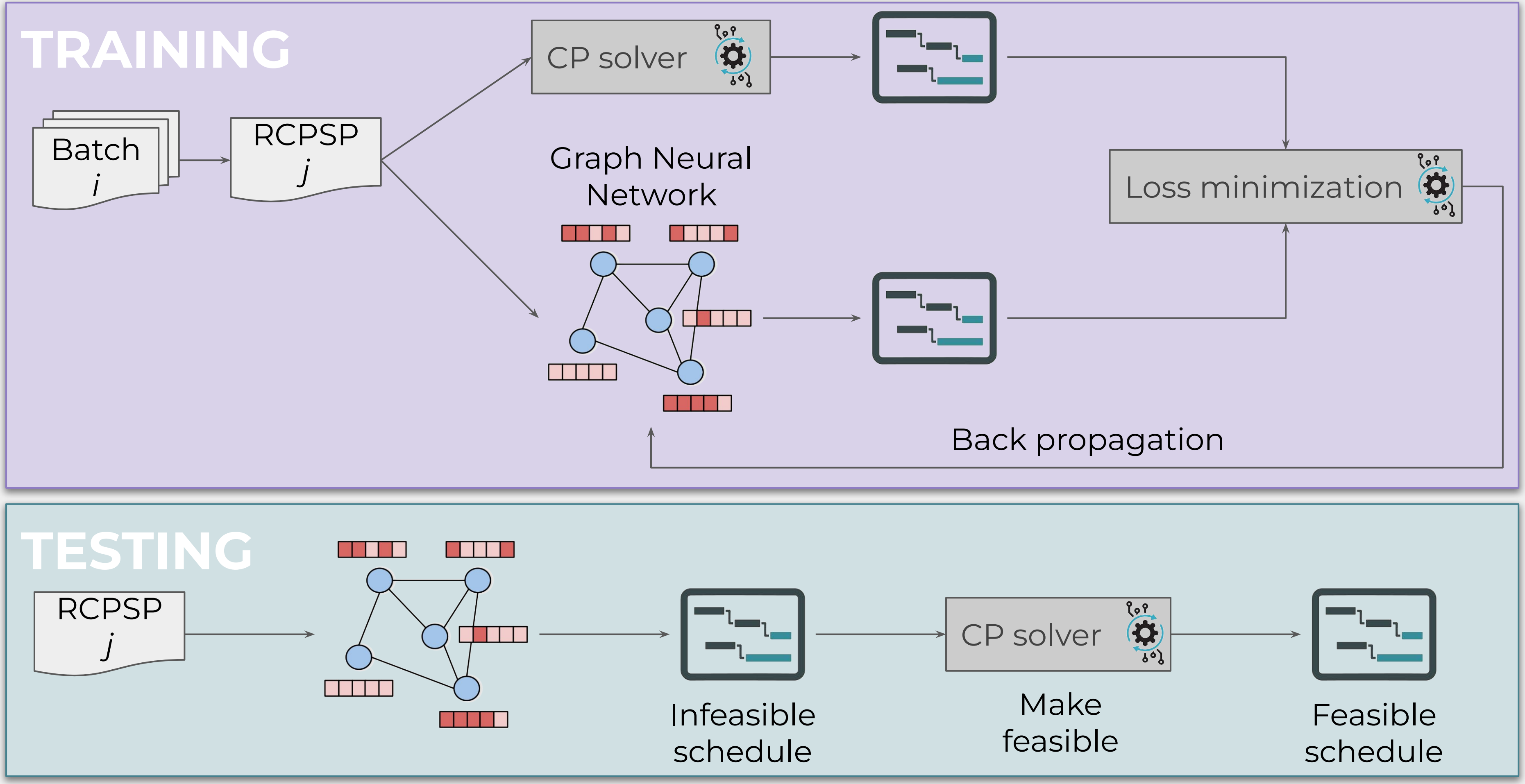
Currently using [TransformerConv](TransformerConv) as NN layers:

$$\mathbf{x}'_i = \mathbf{W}_1 \mathbf{x}_i + \sum_{j \in \mathcal{N}(i)} \alpha_{i,j} \left( \mathbf{W}_2 \mathbf{x}_j + \mathbf{W}_6 \mathbf{e}_{ij} \right),$$

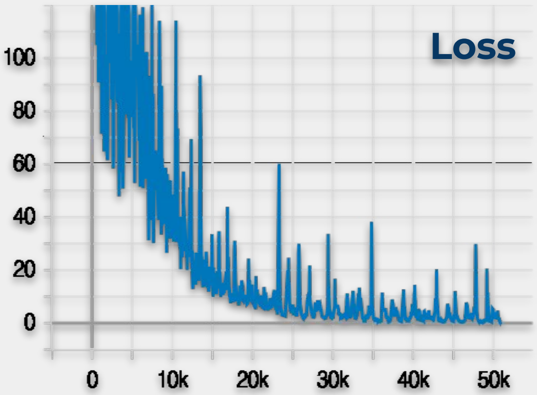
where the attention coefficients $\alpha_{i,j}$ are now computed via:

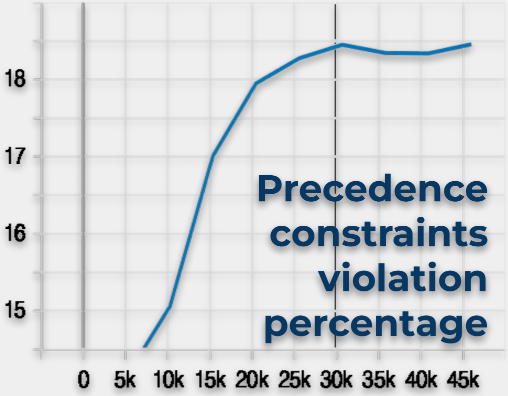
$$\alpha_{i,j} = \mathrm{softmax}\left( \frac{(\mathbf{W}_3 \mathbf{x}_i)^\top (\mathbf{W}_4 \mathbf{x}_j + \mathbf{W}_6 \mathbf{e}_{ij})}{\sqrt{d}} \right)$$

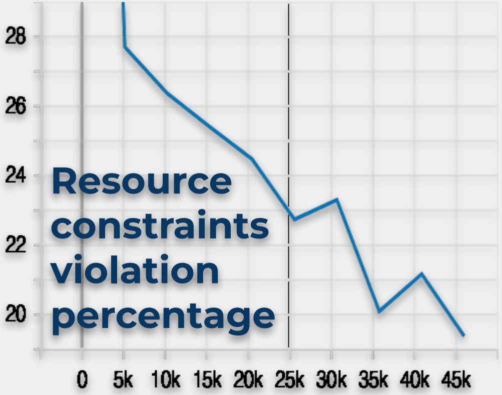
# Hybridizing CP+GNN (supervised learning from CP solution examples)

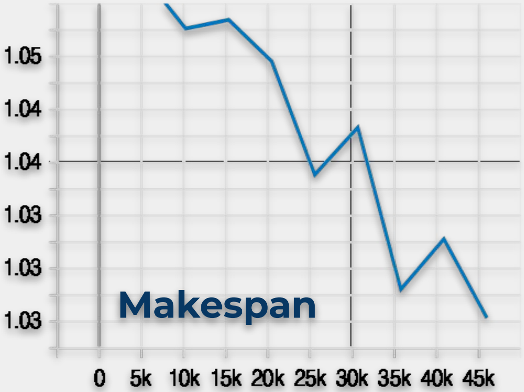


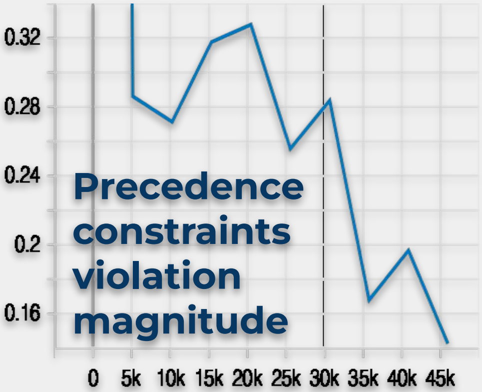
# CP + GNN : *training* statistics
## (80% of 2040 RCPSP instances)

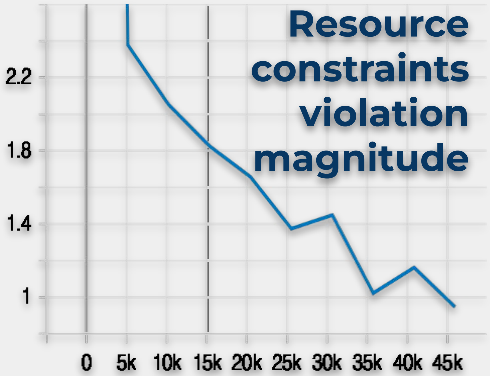


# CP + GNN : *testing* statistics (20% of 2040 RCPSP instances)

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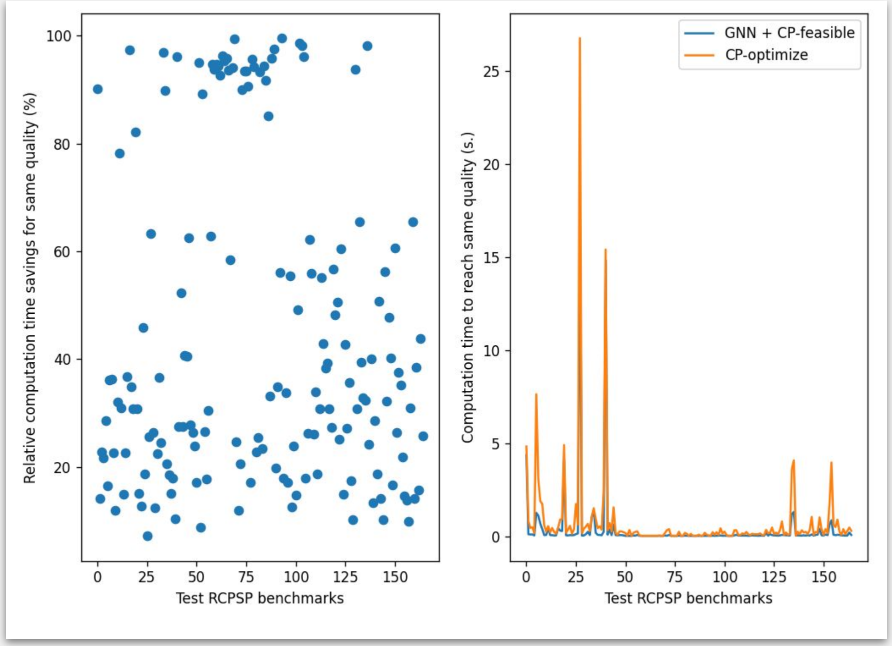
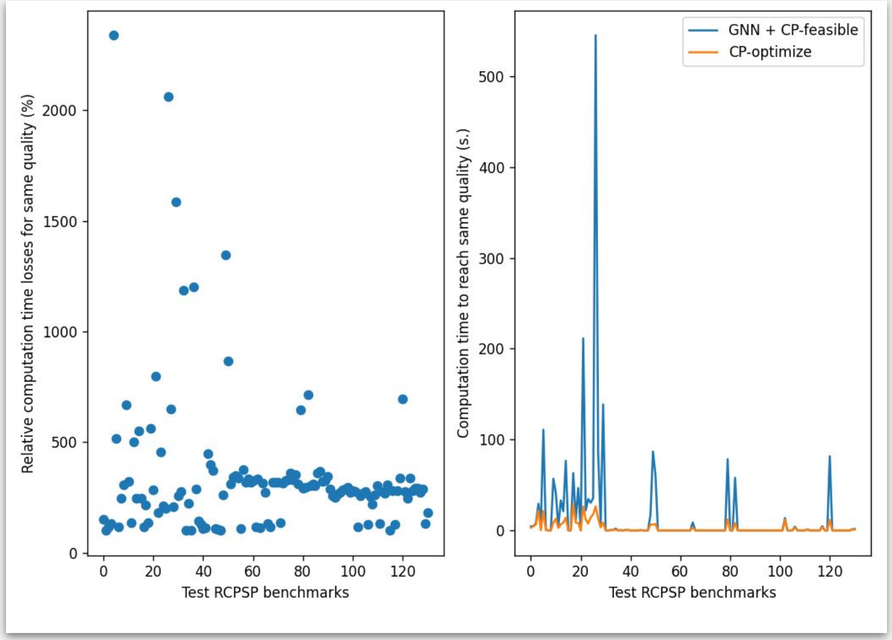
Protocol: evaluate vanilla CP solver time to get same quality solution as GNN+CP solver, then compare with GNN+CP solver time ⇒ ***Does warm-starting CP with GNN solution help?***




👍 Benchmarks where warm-starting the CP solver with the GNN inferred solution **helps**




👎 Benchmarks where warm-starting the CP solver with the GNN inferred solution **harms**

# Possible hybridizations of deep learning with a Constraint Programming solver

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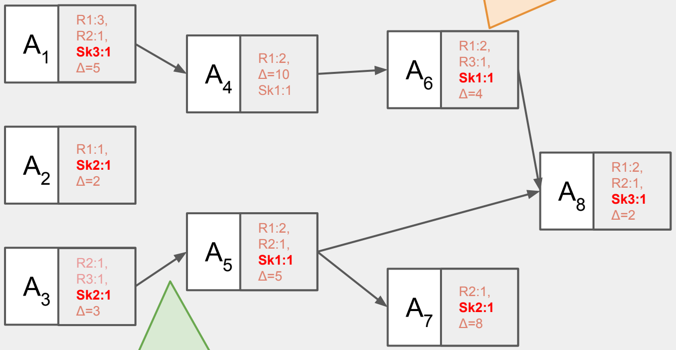
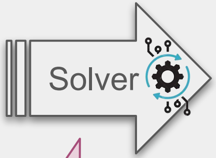
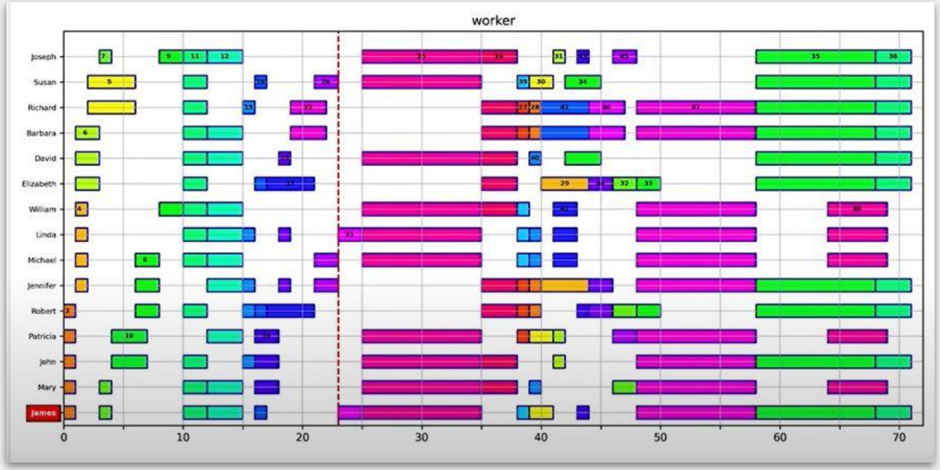
Learn task duration and resource uncertainties




Learn constraints from example schedules

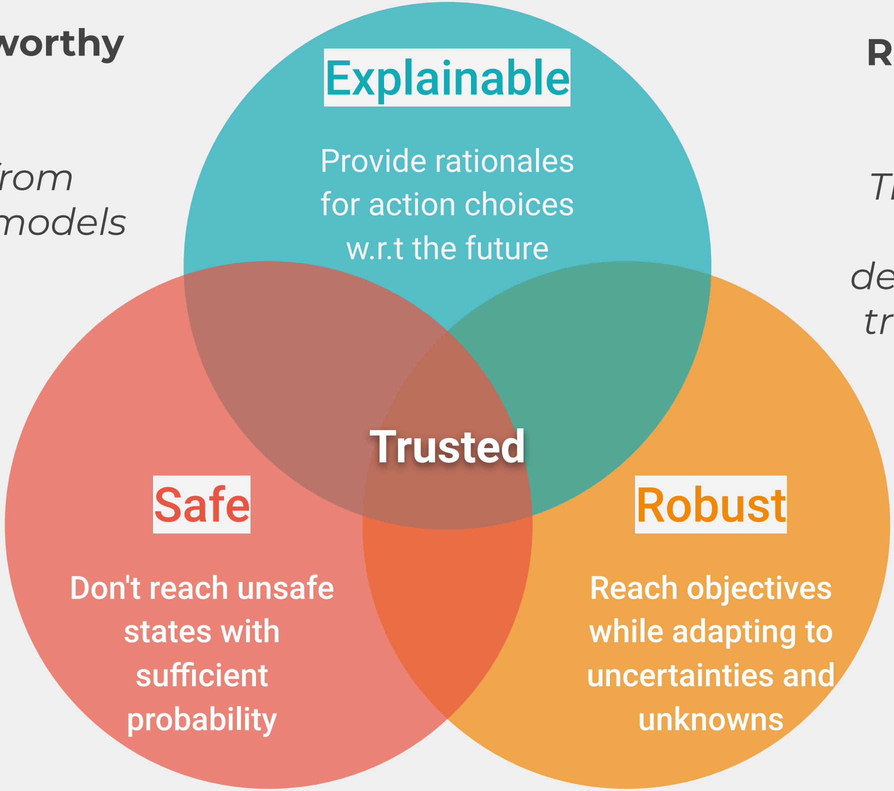
Learn surrogate model of the CP solver and warm-start it with the inferred solution

Learn human schedules to warm-start the CP solver

# Trustable decision-making systems

**Different from trustworthy deep learning:**

*valid independently from using deep learning models in decision-making*




**Relying on deep learning adds to the complexity:**

*Trustworthy properties for deep learning-based decision-making rest upon trustworthy deep learning properties*

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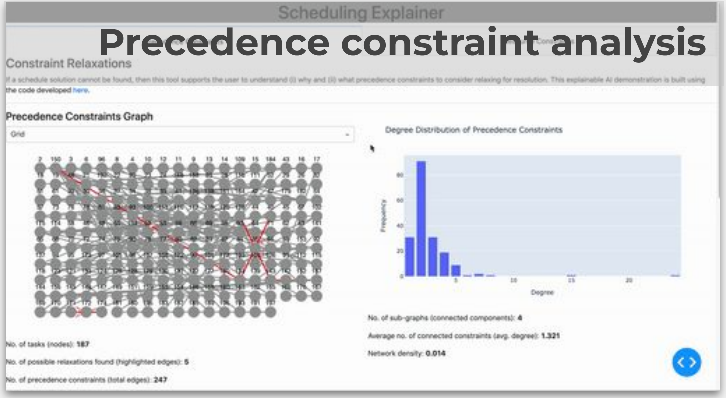
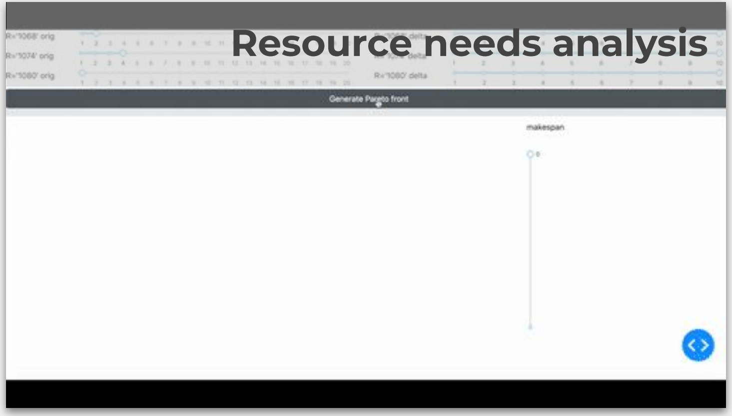
# Explaining manufacturing schedules

- ✅ Precedence constraints analysis
- ✅ Resource needs analysis
- ✅ Feature importance analysis of embedded deep learning models
- ❌ Runtime task choice explanation



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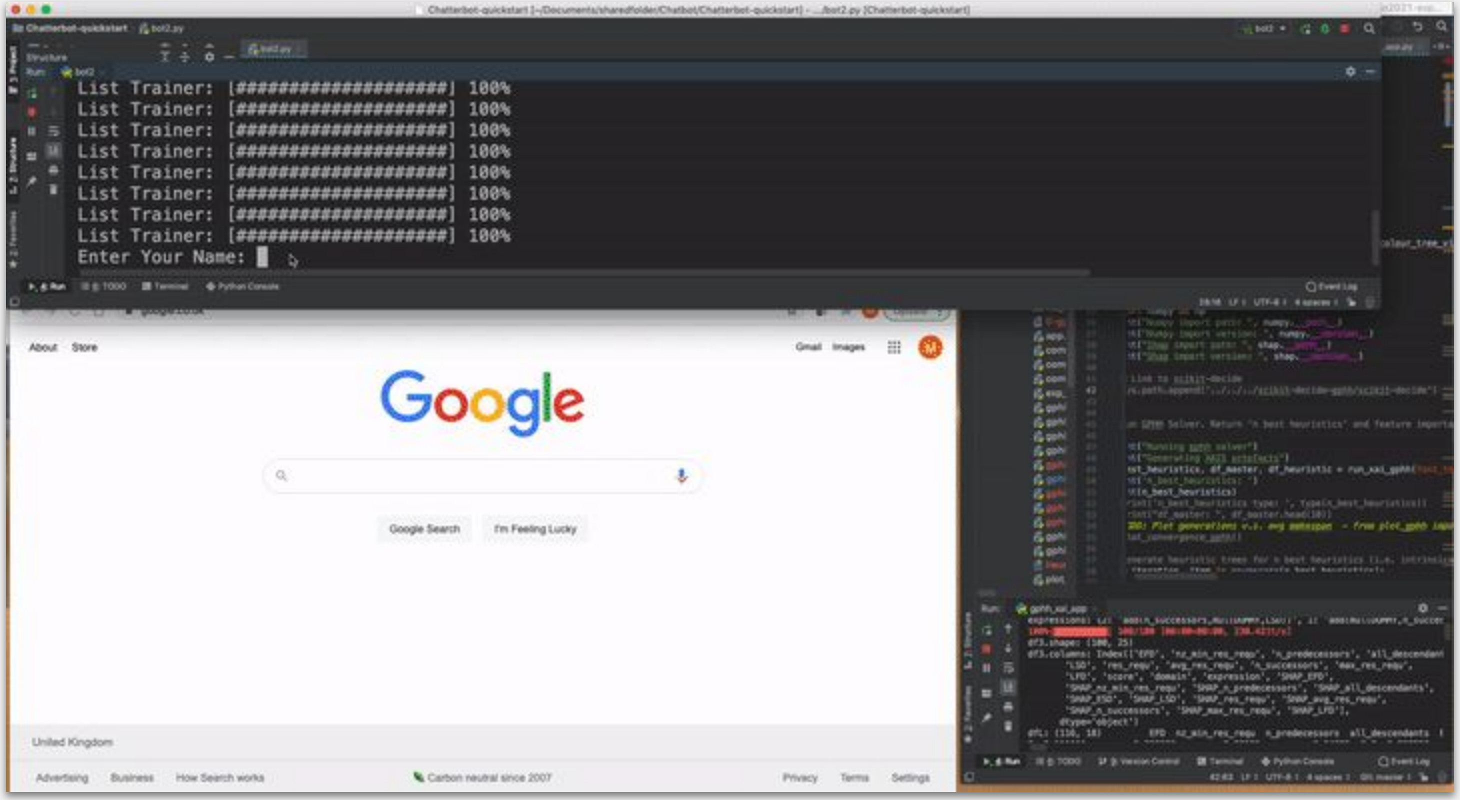
# NLP-based chatbot for schedule explanation



# Robustness: adapt to uncertainties

*(and you can't go without a simulator)*

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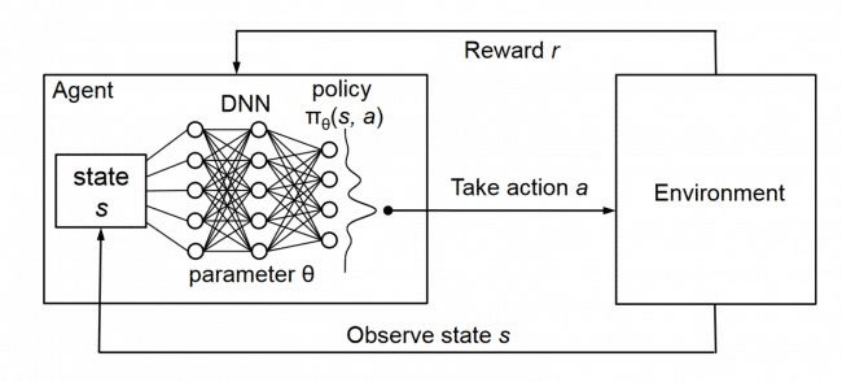
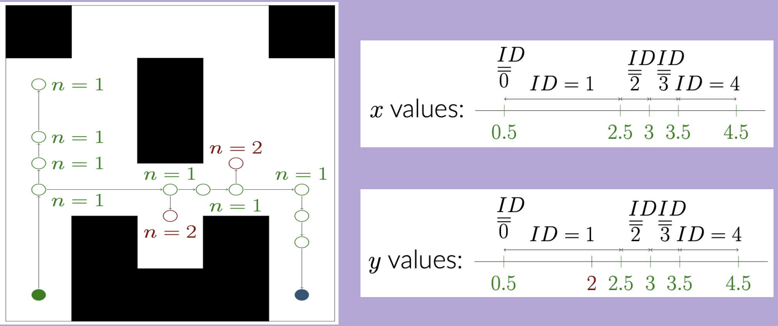
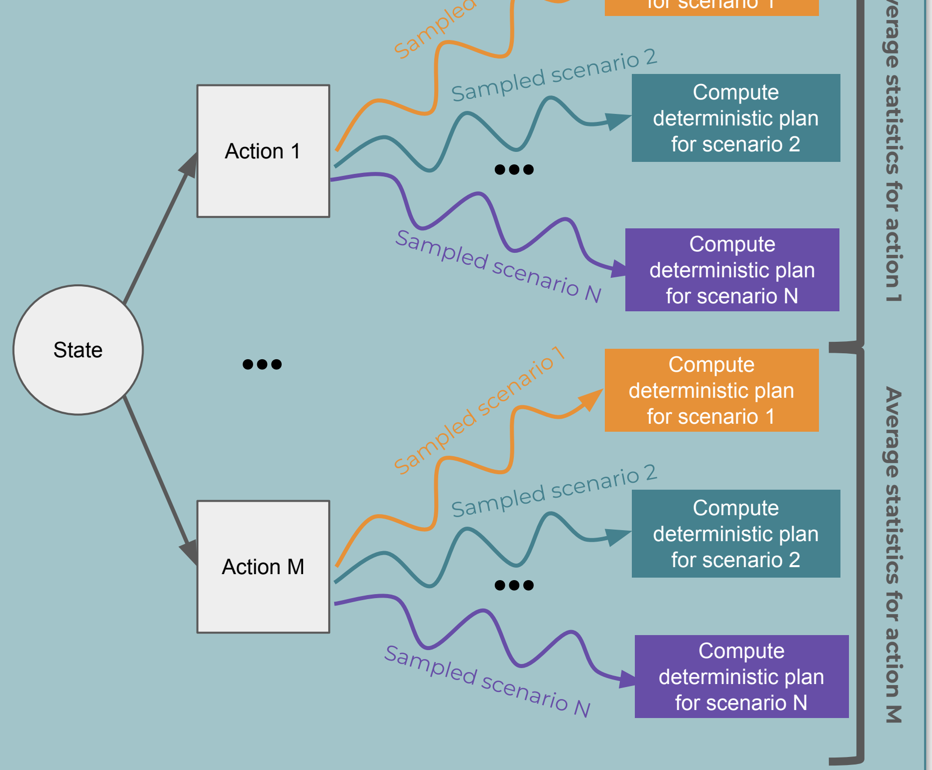
## Option 1 : Reinforcement Learning




## Option 2 : Width-Based Planning



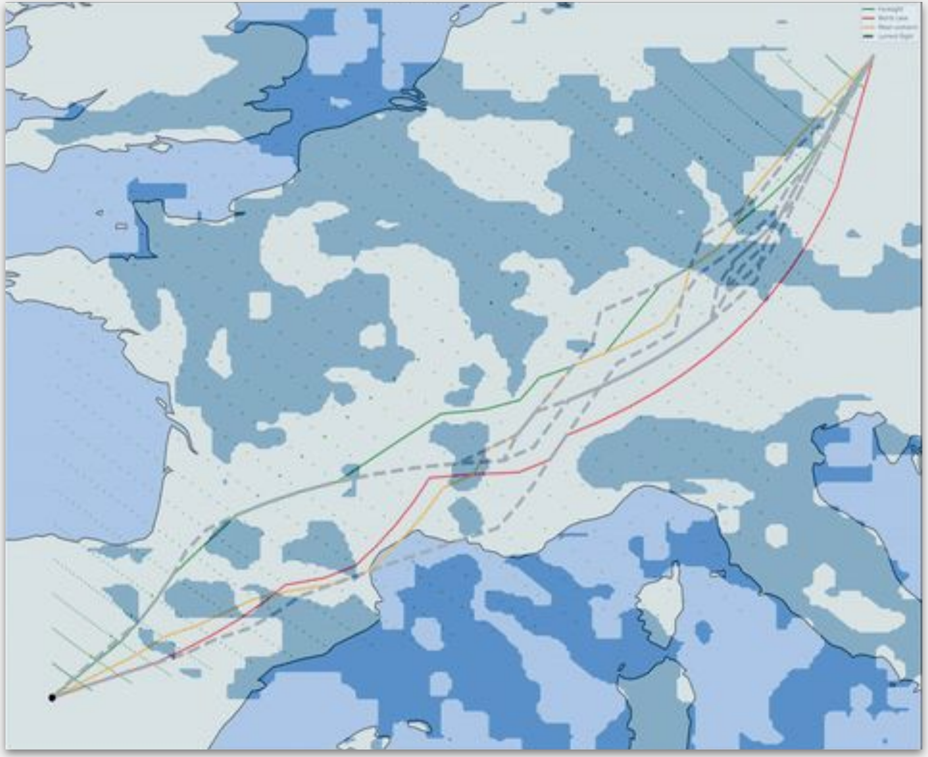

## Option 3 : Optimization In Hindsight



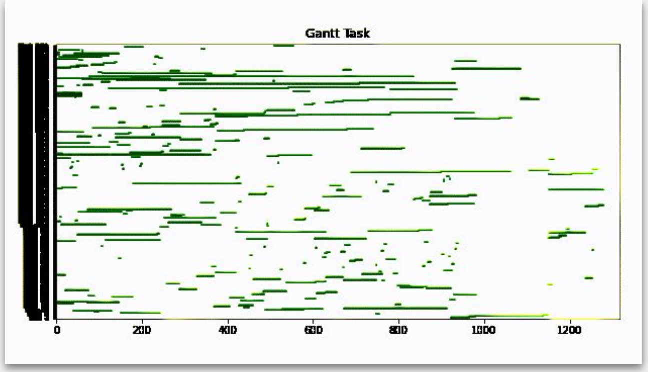
# Robustness: optimization in hindsight showcase

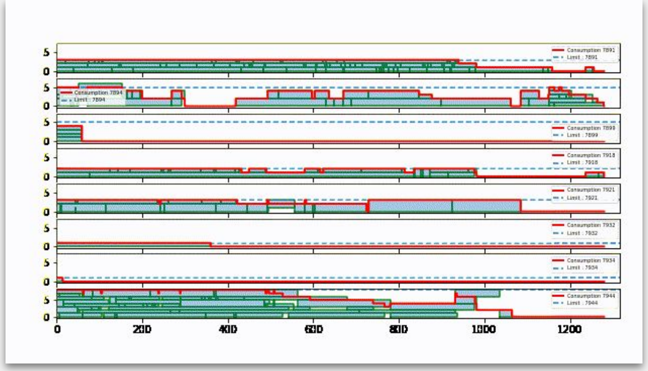


## Flight planning under uncertain convective areas



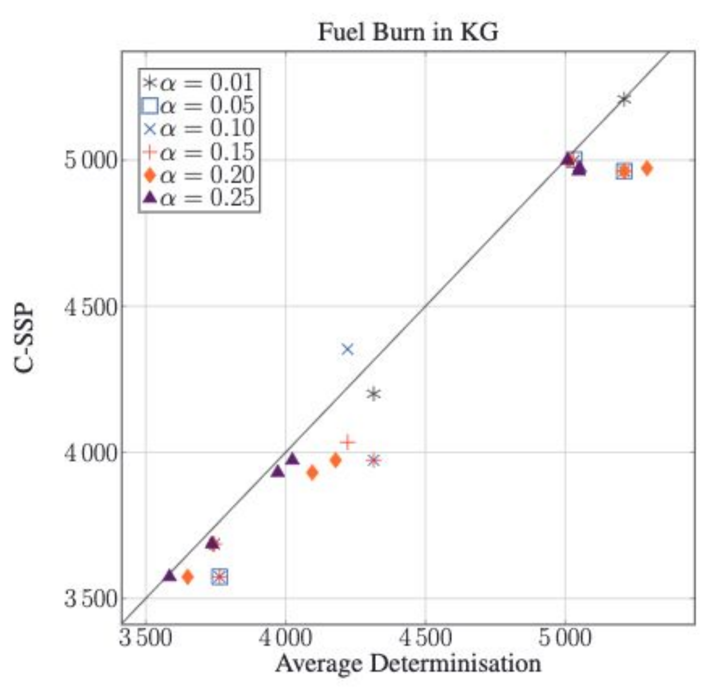
## Manufacturing scheduling under uncertain task durations



# Safety: HAL-320, don't crash the plane!

## *Example: maximum flight time in convective area*




***Optimal and Heuristic Approaches for Constrained Flight Planning under Weather Uncertainty***
*F. Geißer, G. Povéda, F. Trevizan, M. Bondouy, F. Teichteil-Königsbuch, S. Thiébaux. ICAPS 2020*

$$\min_{\vec{p}} \sum_{p_\pi} E[C_0|\pi]p_\pi \qquad \text{(LP1)}$$

$$\text{s.t.} \quad p_\pi \geq 0 \qquad \forall \pi \in \Pi_{det} \quad \text{(C1)}$$

$$\sum_{\pi} p_\pi = 1 \qquad \text{(C2)}$$

$$\sum_{p_\pi} E[C_i|\pi]p_\pi \leq u_i \qquad \forall i \in \{1, \cdots, k\} \quad \text{(C3)}$$

👍 Perfectly deals with flight time constraints that can be modeled in the LP

👎 Unable to capture fuel constraints because aircraft performance model is based on simulation engines

**How to solve C-SSPs with simulation-based transitions? With deep-learning surrogate models?**

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## So, HAL-320, how can I help you to be trusted?

1. Solve the *right* problem *efficiently*: hybridize search and deep learning
2. Explain: (i) algorithm parameter impact to system designers; (ii) algorithm online choices to end users
3. Be robust: proactively reasons about uncertainty while optimizing the plan or the schedule
4. Be safe: prove that the plan or schedule - be hybridized with deep learning or not - satisfy probabilistic constraints

# Acknowledgements

AIR
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Charles Gretton


Felipe Trevizan


Alexandre Arnold


Gérard Dupont

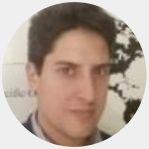

Manon Bondouy


Guillaume poveda


Sylvie Thiébaux


Florian Geisser


Daniel Gonzalez-Arribas


Santiago Quintana-Amate


Aniel Jardines


Javier Garcia Heras


Guillermo Gonzalez de Garibay

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Mark Hall


Nahum Alvarez


Olivier Régnier-Coudert


Manuel Soler Arnedo

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