Planning and Scheduling in Aerospace Applications with Simulators Only

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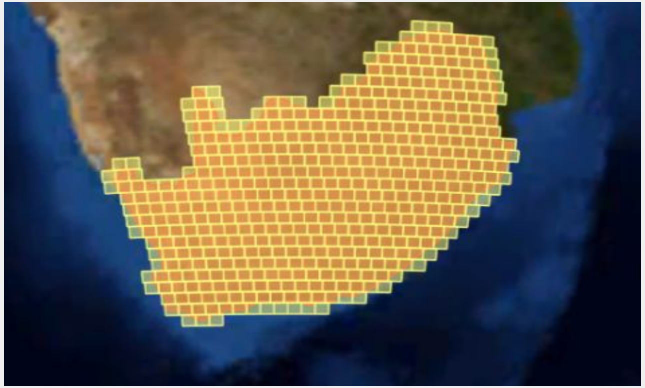
What is common to all those applications?



- 1 request = hundreds of meshes
- 5000+ requests
- Probabilistic cloud coverage forecast
- Decide next priority change for each request
- Minimize average delays

Earth-observation satellite priority request planning under uncertain cloud coverage

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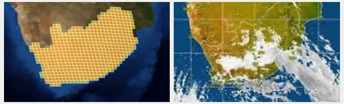

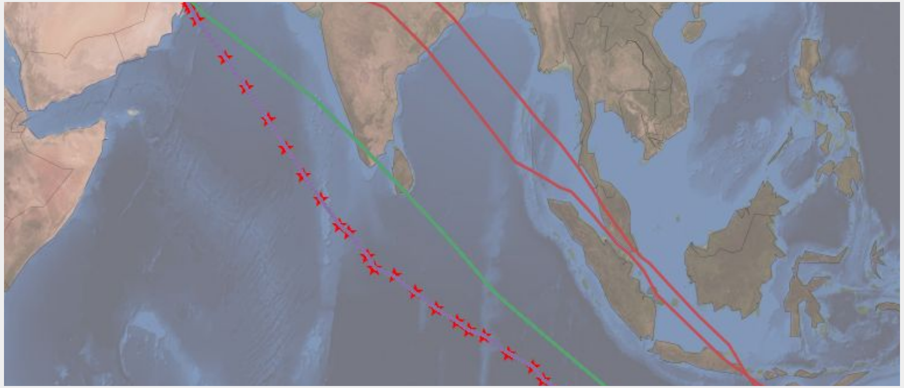

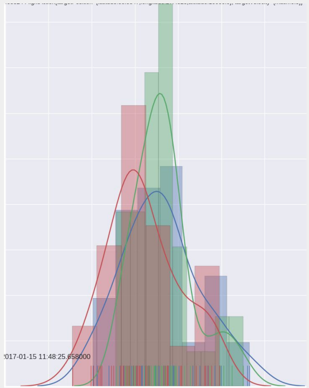

- Probabilistic extreme weather and traffic congestion forecast
- Decide next 4D waypoint to go to
- Minimize average fuel burn and flight time
- Ensure minimal fuel reserve and arrival time window constraints

Safe probabilistic flight planning under uncertain weather and traffic

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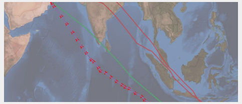
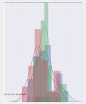

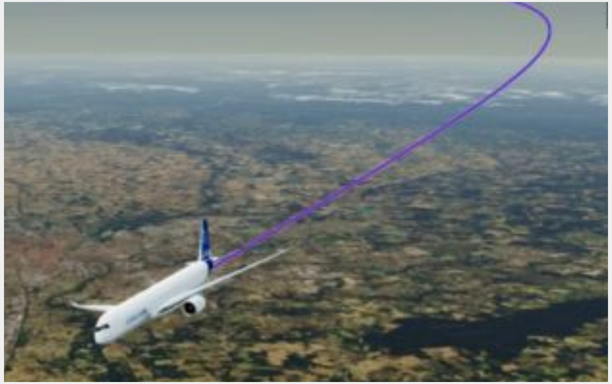
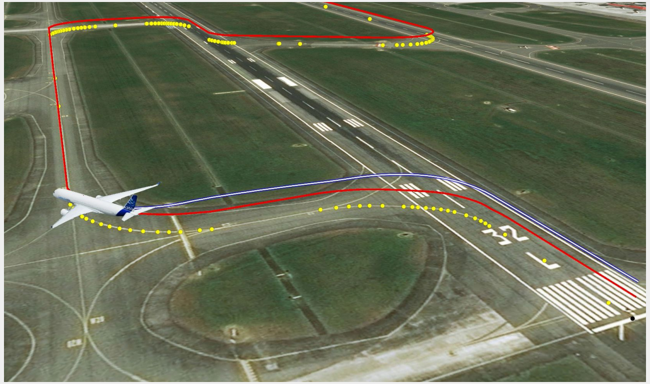

- Observe aircraft sensor outputs
- Decide of next control action to perform on aircraft actuators
- Discrete/continuous hybrid action and state spaces
- Nonlinear dynamics governed by many coupled subsystems

In-flight and on-ground aircraft control

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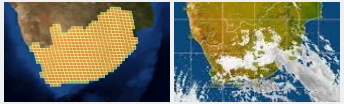

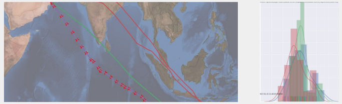

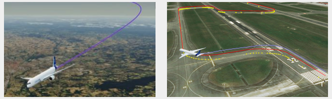

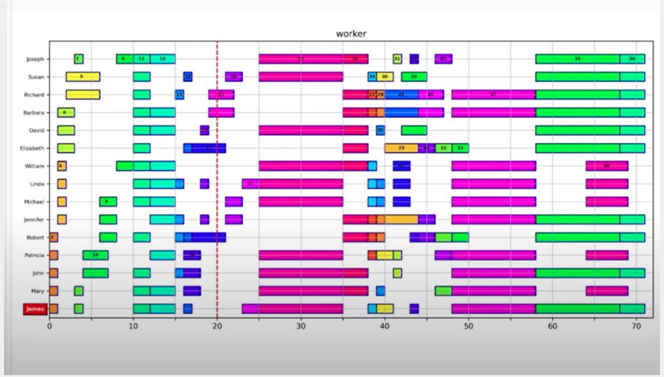

- Visual-based and speech-driven robotic assistance to blue collars
- Workflow scheduling under uncertainty to advise white collars
- End-to-end decision-making assistance with coupled control and scheduling

Manufacturing task and workflow optimisation

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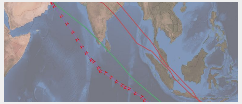
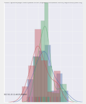
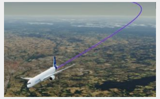
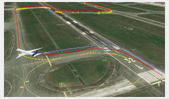

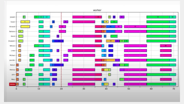

1. They all are control, or planning or scheduling applications 😊

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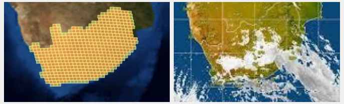

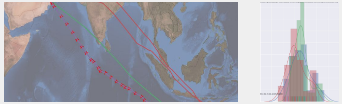

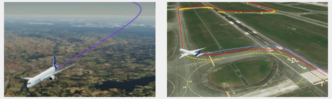

1. They all are control, or planning or scheduling applications 😊
2. There is no model of the transition function, but only simulators
    a. Satellite motion and orbital physics simulation
    b. Aircraft physics and performance simulation
    c. Robot motion simulation
    d. Manufacturing workflow simulation
    e. Weather simulation

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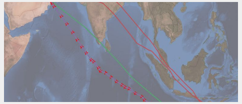
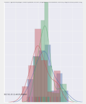
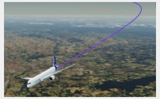
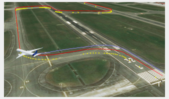

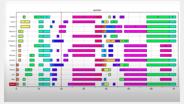

1. They all are control, or planning or scheduling applications 😊
2. There is no model for the transition function, but only simulators
3. Huge simulation times to compute single transition step:
   a. ~100 milliseconds for aircraft dynamics
   b. ~1 second for aircraft performance
   c. ~ 10 seconds for satellites

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  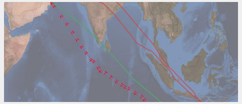 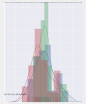 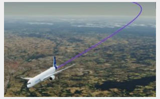 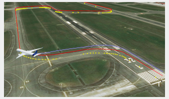  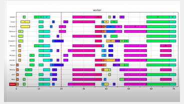

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2. There is no model for the transition function, but only simulators
3. Huge simulation times to compute single transition step
4. Cannot simulate from random state
    a. Weather prediction models are deterministic but sampled on different random initial weather conditions
    b. Physics simulator cannot quickly warm-start from any given random state

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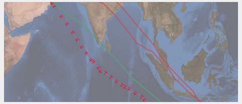
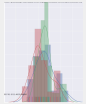
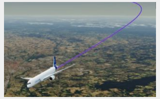
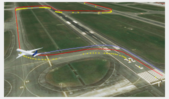
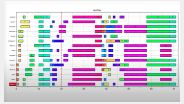
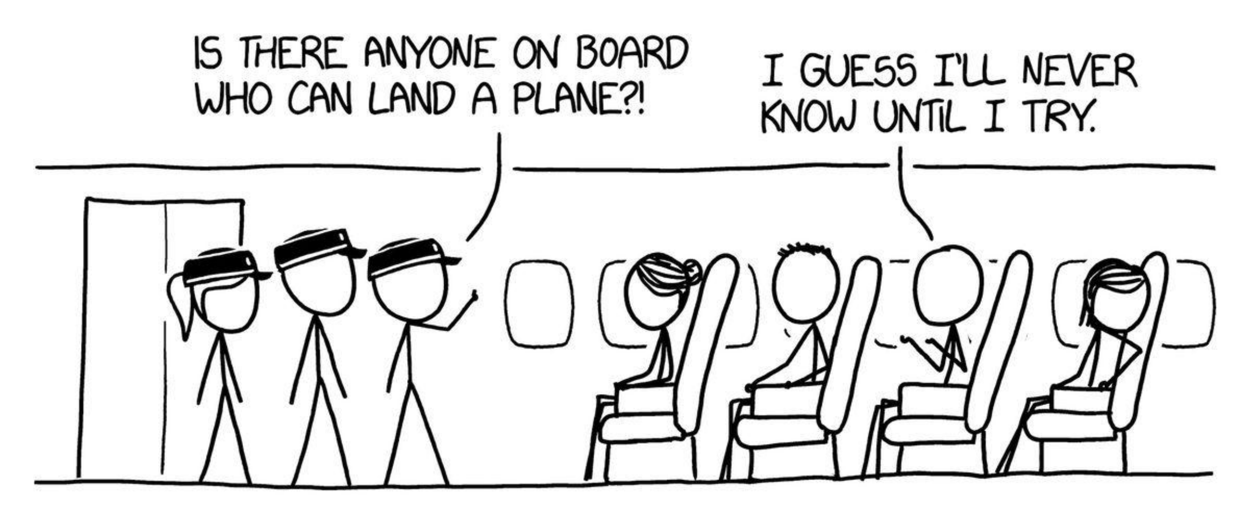
       

1. They all are control, or planning or scheduling applications 😊
2. There is no model for the transition function, but only simulators
3. Huge simulation times to compute single transition step
4. Cannot simulate from random state
5. No obvious heuristics (neither informative nor admissible)
    a. Complex state space topology
    b. No relaxed transition graph model

This is the end?

Most research works on planning and scheduling assume ~~white-box transition function models~~, ~~quick generation of transitions from random search states~~ and ~~heuristics availability or computability~~.



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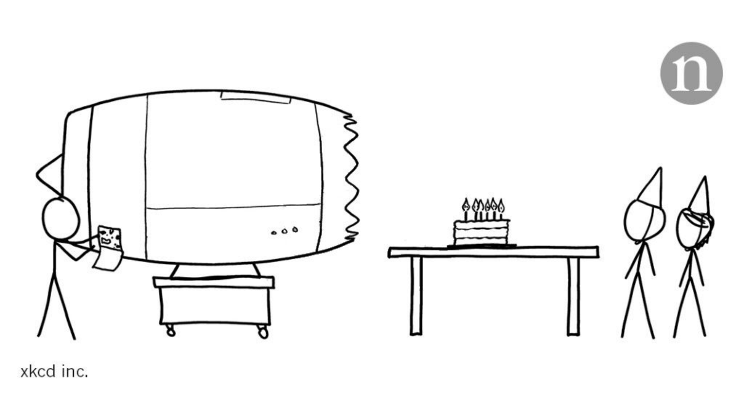
The issue is not the problem but the way we look upon it!



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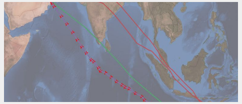
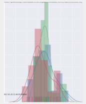
There are solutions 😅

- Use approximate transition models
- Or rollout simulation-based approaches

Example #1: approximate model





Probabilistic flight planning under uncertain weather and traffic

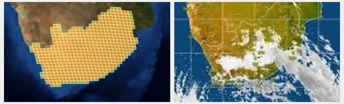
- Generating the aircraft and weather state at the next flight waypoint requires:
  - Simulation of aircraft's allowed speed and altitude at next waypoint, and of aircraft's fuel consumption

    Complex differential equation integration approximated with **simple tabular BADA model**
  - Simulation of possible weathers at the next waypoint

    No Markovian local model of probabilistic weather forecast ⇒ **statistical approximation loosing spatio-temporal coherency**
- **Approximate** $\mathbb{P}\left(s_{t+1}=s' \mid s_t=s, a_t=a\right)$ ⇒ solve search and OR techniques

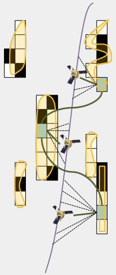
***Optimal and Heuristic Approaches for Constrained Flight Planning under Weather Uncertainty* (Geißer et al., ICAPS 2020)**

Example #2: meta-heuristics and rollouts



EO-satellite mission planning under uncertain cloud coverage

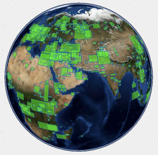
Generating the satellite and environment state at the decision point requires:



- Simulation of satellite's flight dynamics and images acquisition
- Simulation of possible cloud coverages at the next decision point

Several seconds of simulation per step even for simplest models

No Markovian and local model of probabilistic weather forecast ⇒ **must rollout weather scenarios**



Huge branching factor (≅3^{5000}) out of reach of search algorithms

Run **parallel rollouts** each optimizing for given weather scenario static priorities using **genetic algorithm** (to tackle high combinatorics & complex evaluation)

Evolutionary approaches to dynamic earth observation satellites mission planning under uncertainty **(Povéda et al., GECCO 2019)**

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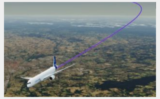
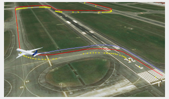
Example #3: meta-heuristics and rollouts

Synthetizing aircraft flying and taxiing controllers

- Generating the aircraft state at the next time point requires:
  - Simulation of aircraft's subsystems dynamics from differential equations
  - Simulation cannot be warm-started from random search state

Continuous states and actions ⇒ **no complete search tree**

No Markovian transition function ⇒ can only **rollout full state trajectory** from initial state

- Run **Rollout Iterated Width** search with state feature encoding that handles continuous state variables and favours exploration of novel states (i.e. curiosity) by dynamically counting state variable values expansions

Boundary Extension Features for Width-Based Planning with Simulators on Continuous-State Domains **(Teichteil, Ramirez & Lipovetzky, IJCAI 2020)**

Take-home messages

- Features of aerospace planning & scheduling problems:
  - **Black-box transition model** based on simulators
  - **CPU-demanding simulations** for each single step
  - **Cannot warm-start simulation** from random search state
  - **No informative nor easily computable heuristics**
  - **Huge branching factors**

- Not discussed: **sparse reward structure** (challenging for RL)
- **Need for simulation-based search algorithms**