Safe and Near-Optimal Gate Control: A Case Study from the Danish West Coast

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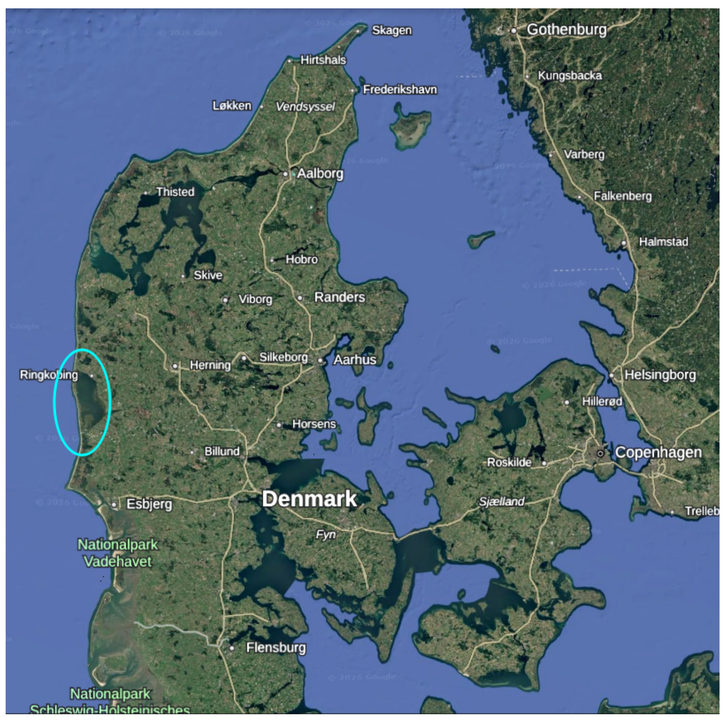
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Interreg North Sea
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Case Study

At Hvide Sande on the Danish west coast, the Danish Coastal Authority (DCA) controls sluices in order to manage the water levels of Ringkøbing Fjord, a 290 km^2 basin.

Given access to the current water levels and a forecast of the wind speed and sea level, we want to ensure safe sluice operation while also meeting performance criteria.



Our Approach

We use UPPAAL STRATEGO to model the system as a *network of stochastic hybrid automata*, consisting of the controller options, the effects of the fjord's water level based on the sluice state, and boats requesting passage. The water levels are given by *ordinary differential equations*.

UPPAAL STRATEGO performs *reinforcement learning with partition refinement*, resulting in a control strategy in the form of a decision tree.

The learning depends on the sea weather forecast; thus, the learned strategy is only valid up to a *horizon*. For each forecast a new control strategy is computed, resulting in an *online approach* which adapts to concrete conditions, including the state of the fjord.

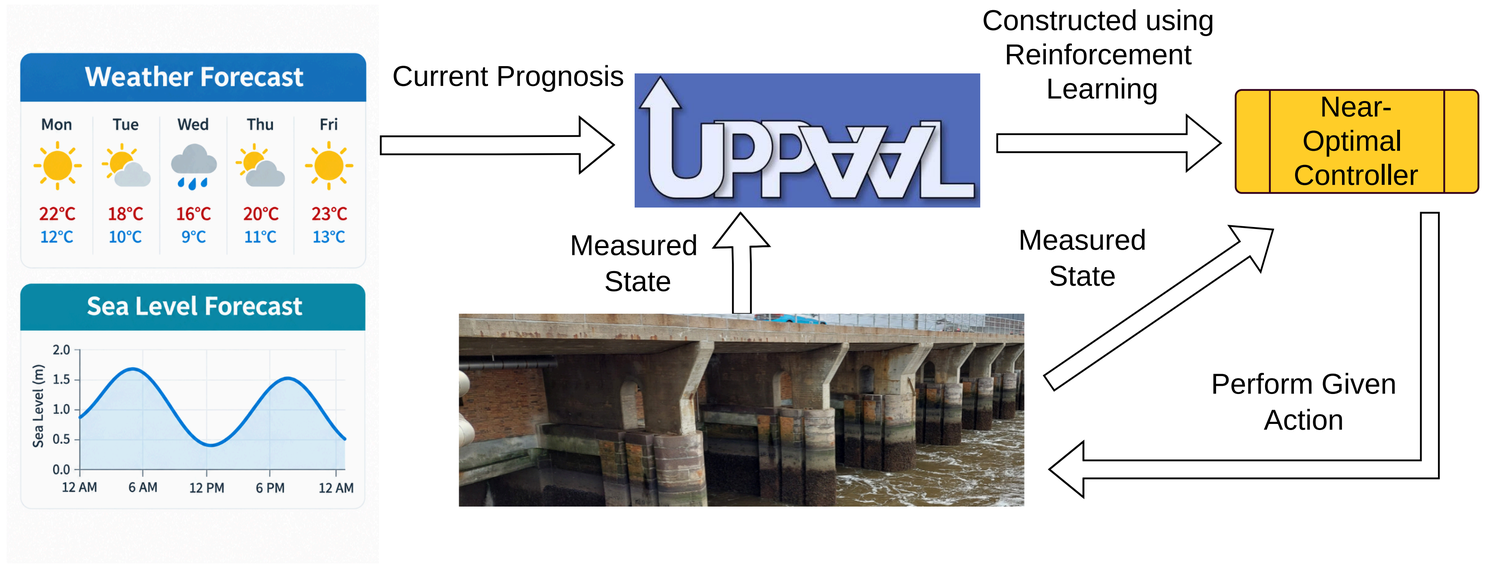
Requirements on Safety & Performance

Three safety requirements and three performance requirements for the controller.

Category	Id	Requirement
Safety	S.1	The fjord water level must be between 0.00 m and 0.25 m DVR90
	S.2	Allow water into the fjord only when the wind speed is above 8 m/s
	S.3	The gates are closed when the water levels differ by more than 1 m
Performance	P.1	Enable fish migration
	P.2	Minimize the number of operations (wear and tear)
	P.3	Minimize the waiting time for boat passage

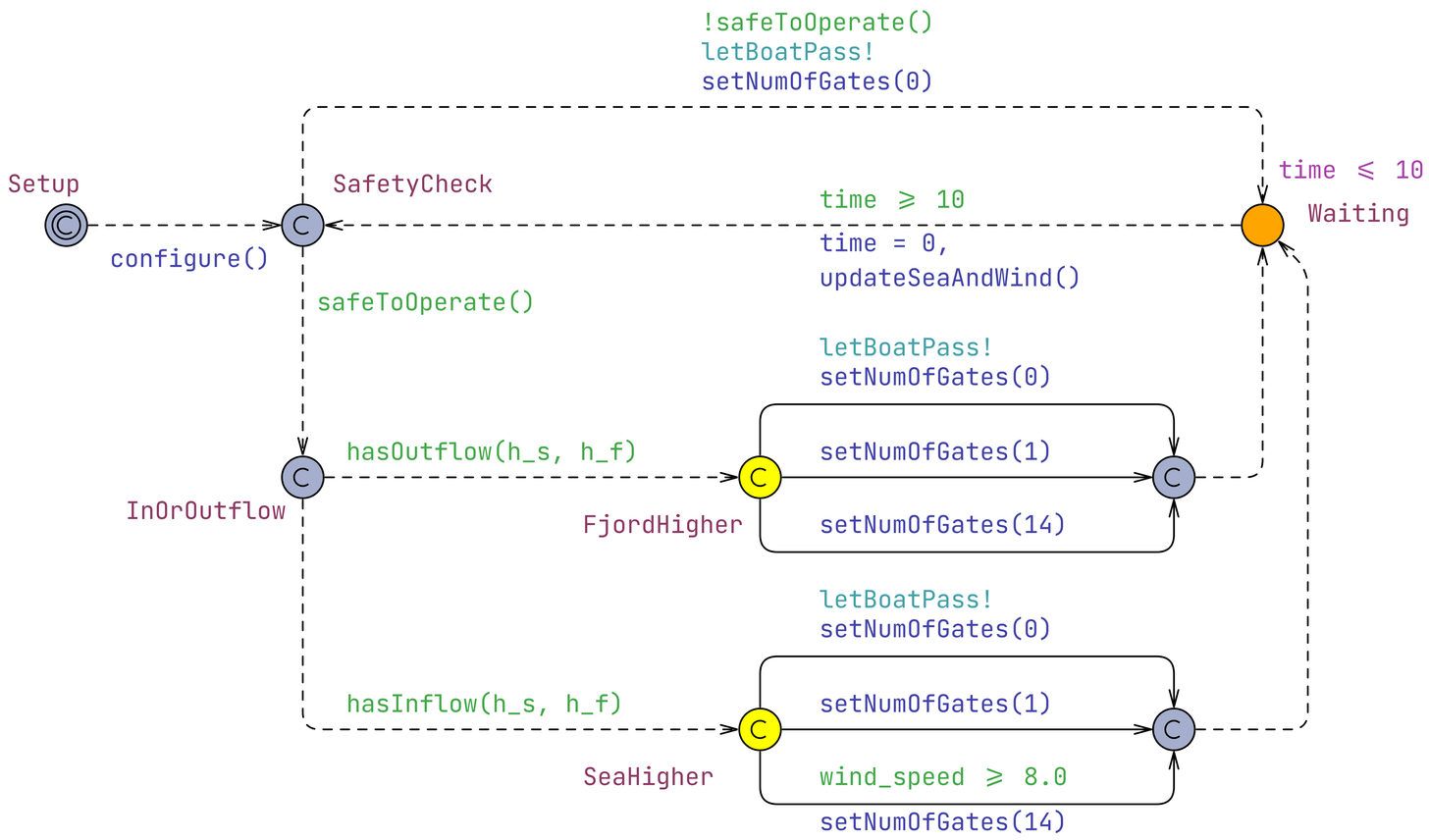
Constructing and Evaluating Safe and Near-Optimal Strategies

A 72h forecast arrives every 6 hours. UPPAAL STRATEGO learns a control strategy for the next 24 hours. The strategy is executed until the next forecast. Look-ahead time guards against high fluctuations in the sea water level.



Considered Scenarios	Controller	Safety	Fish Migration	Max Waiting Time [min]	Gate Operations
Normal Water Levels					
	Baseline	63.2%	95.70%	8.95 ± 0.18	26.15 ± 0.92
	Ours	100%	99.05%	8.87 ± 0.23	40.30 ± 0.00
Low Water Levels					
	Baseline	82.03%	99.62%	9.00 ± 0.24	36.14 ± 0.93
	Ours	100%	99.50%	8.83 ± 0.23	37.36 ± 1.17
High Water Levels					
	Baseline	76.9%	95.62%	8.89 ± 0.24	26.42 ± 0.91
	Ours	100%	96.41%	8.81 ± 0.24	32.43 ± 0.75

Controller Options in UPPAAL STRATEGO



Ongoing Research

- Pareto frontier of dominant controllers over various learning weight combinations.
- Safety shield from UPPAAL COSHY.

