Seluxit Case Study

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In Collaboration With:

seluxit

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The Case Study

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What do we need to consider?

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What do we need to consider?

- External environment
- Doors opening and closing
- Pipes heating a room may influence other rooms
- Constraints on the number of open valves

The Case Study

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- Every 15 minutes there is a reading of the room temperatures.
- Every 15 minutes a Bang-Bang controller operates the valves.

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What is our goal?

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Synthetize a near to optimal controller

Stochastic Hybrid Game for Floor Heating

The floor heating for n rooms and m doors is a *stochastic hybrid game*

$$\mathcal{G}_{n,m} = (\mathcal{C}, \mathcal{U}, X, \mathcal{F}, \delta)$$

- $\mathcal{C}$ is a controller with controllable modes $V = \{v_1, \ldots, v_n\}$,
- $\mathcal{U}$ is the environment with uncontrollable modes $D = \{d_1, \ldots, d_m\}$,
- $X = \{T_1, \ldots, T_n\}$ is a finite set of continuous (real-valued) variables,
- $\mathcal{F}_{v,d} : \mathbb{R}_{>0} \times \mathbb{R}^X \rightarrow \mathbb{R}^X$ is the flow-function for each $v \in V$ and $d \in D$,
- δ is a family of density functions, indicating the switching among uncontrollable modes D.

Thermodynamics

The evolution of the room temperatures $\mathcal{F}_{v,d}$ are the solutions to the following differential equations:

$$\frac{d}{dt} T_i(t) = \sum_{j=1}^{n} A^d_{i,j}(T_j(t) - T_i(t)) + B_i(T_{\text{env}}(t) - T_i(t)) + H^v_{j,i} \cdot v_j \; dt$$

Where:

- A^d represents the heat exchange coefficients among the different rooms given the door configuration d,
- B represents the heat exchange coefficients between the environment and each room,
- H^v represents the heat exchange coefficients among each pipe and the rooms it heats given the valve configuration v,

Optimal Controlling

Given strategy σ^H, $\mathcal{G}_{n,m} \upharpoonright \sigma^H$ is a stochastic process.

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Synthesize a near-optimal strategy σ^H which minimizes the expected distance

$$\sigma^H = \mathrm{argmin}_{\sigma} \mathbb{E}^{\mathcal{G}}_{\sigma,H}(\mathrm{dist})$$

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Distance measure the integrated deviation of the current room temperatures wrt. the target temperatures.

$$\text{dist} = \int_0^H \sum_i^n (T_i^g - T_i(t))^2 \cdot W_i \, dt$$

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- Infinite state space with non-linear continuous dynamics.
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- There are 2^{11} choices for the controller every 15 minutes.
- The temperature of a room is tightly connected to the temperatures of the other rooms.
- Opening one valve can influence several rooms.

Our Approach

Online Synthesis

Compute a strategy for the near future.

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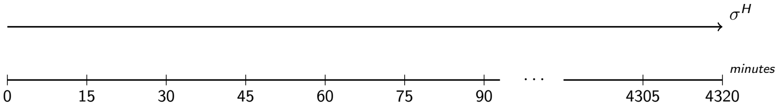
Compositional Synthesis

Synthesis for subsets of the controllable actions.

This talk

Online Synthesis

For n rooms, a Horizon H of 3 days and controlling every 15 min.



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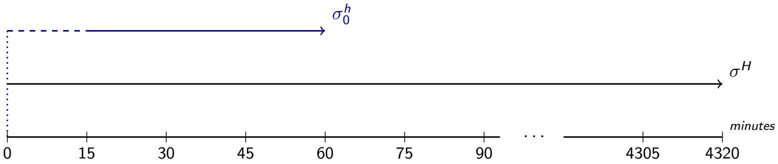
Compute a strategy σ^h for the next 45 min.



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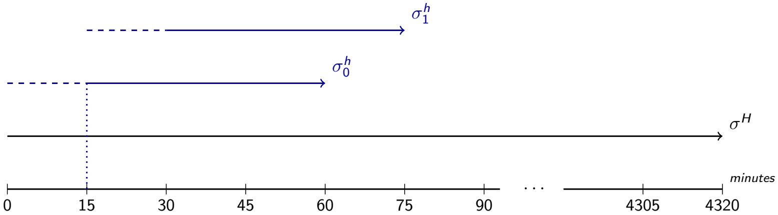

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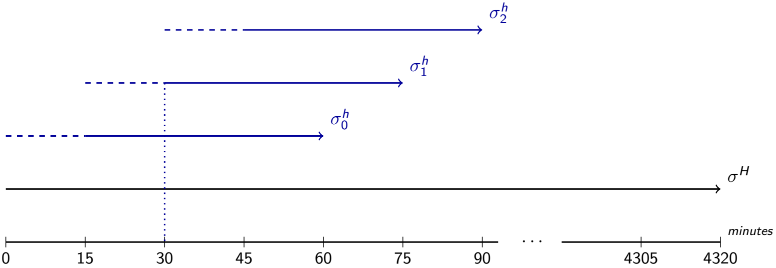

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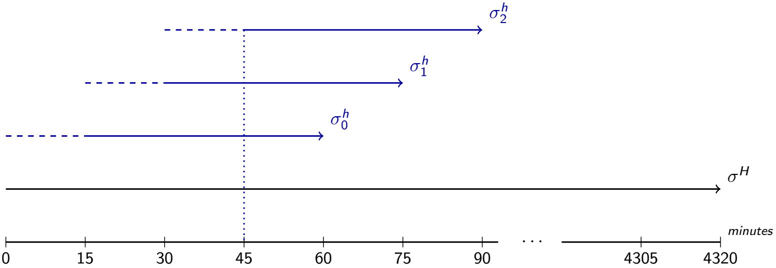
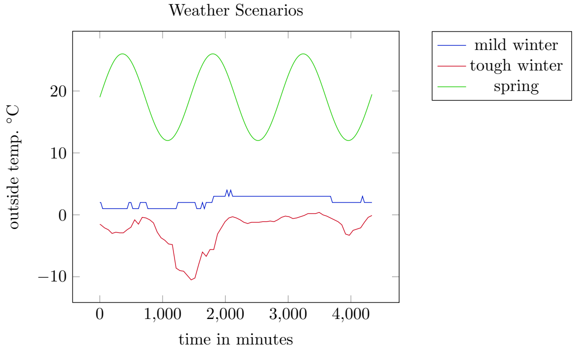


For n rooms for the online and offline controllers there are 2^{3n} vs. 2^{288n} decisions.

Scenarios



Situation

- Vacation: $T(0)$ about 14 °C and T^g about 22 °C.
- Stability: $T(0) = T^g$ about 22 °C.

Controllers

- Bang-Bang

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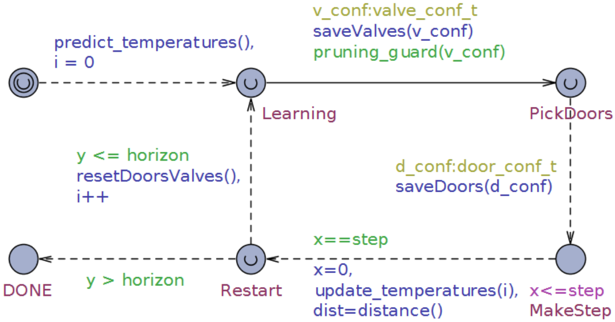

Results for 5 Rooms

Scenario	Controller	dist	Time (sec.)
mild winter vacation	Bang-Bang	62704	< 1
	Bang-Bang-Cap-Aware	39755	< 1
	Brute-Force	38072	~ 4.3
	STRATEGO-ON	36449	~ 99.3
tough winter vacation	Bang-Bang	248367	< 1
	Bang-Bang-Cap-Aware	155090	< 1
	Brute-Force	138034	~ 5.9
	STRATEGO-ON	137071	~ 111.9
mild winter stability	Bang-Bang	24834	< 1
	Bang-Bang-Cap-Aware	18405	< 1
	Brute-Force	17289	~ 5.8
	STRATEGO-ON	16717	~ 148.3
tough winter stability	Bang-Bang	199688	< 1
	Bang-Bang-Cap-Aware	121776	< 1
	Brute-Force	108403	~ 4.5
	STRATEGO-ON	106944	~ 139.5
spring stability	Bang-Bang	4297	< 1
	Bang-Bang-Cap-Aware	4297	< 1
	Brute-Force	3878	~ 5.9
	STRATEGO-ON	3784	~ 181.5

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What about 11 rooms?

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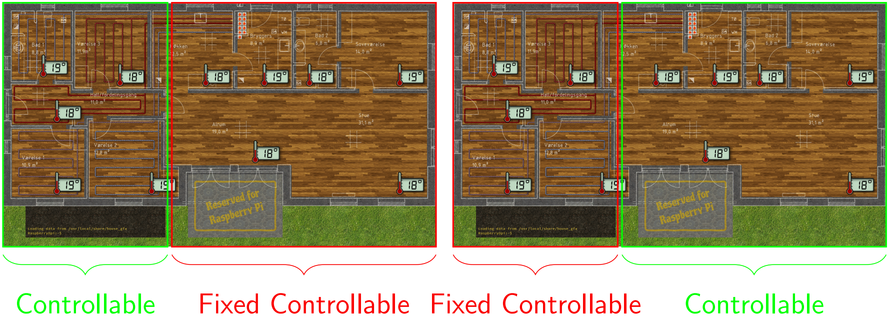
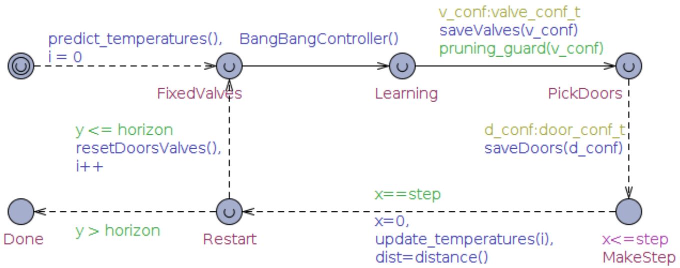


Compositional Synthesis



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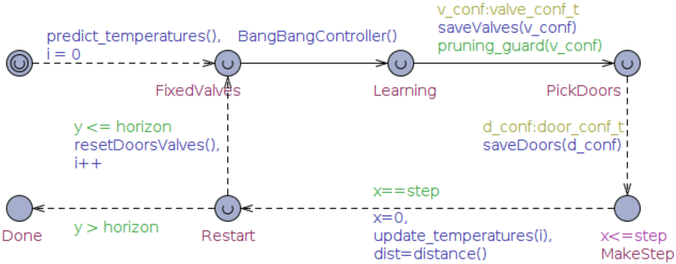


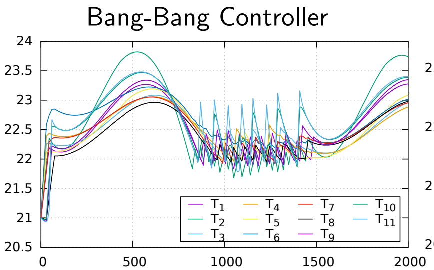
Reduction in size:

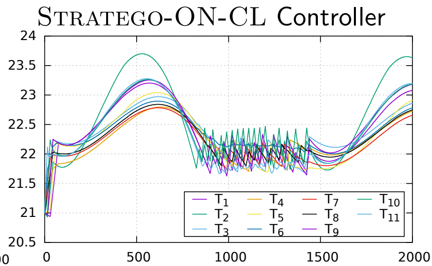
$$(2^{5h} + 2^{6h}) \text{ vs. } 2^{11h} \text{ decision choices}$$

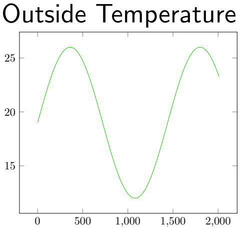
Results for 11 Rooms

Scenario	Controller	dist	Time (sec.)
mild winter vacation	Bang-Bang	53550	< 1
	Bang-Bang-Cap-Aware	31718	< 1
	Brute-Force	35210	~ 237
	STRATEGO-ON-CL	29456	~ 834
tough winter vacation	Bang-Bang	163635	< 1
	Bang-Bang-Cap-Aware	82250	< 1
	Brute-Force	78170	~ 307
	STRATEGO-ON-CL	66399	~ 811
mild winter stability	Bang-Bang	9654	< 1
	Bang-Bang-Cap-Aware	9430	< 1
	Brute-Force	9219	~ 305
	STRATEGO-ON-CL	8978	~ 833
tough winter stability	Bang-Bang	82849	< 1
	Bang-Bang-Cap-Aware	37099	< 1
	Brute-Force	34366	~ 234
	STRATEGO-ON-CL	34117	~ 814
spring stability	Bang-Bang	4493	< 1
	Bang-Bang-Cap-Aware	4419	< 1
	Brute-Force	2761	~ 259
	STRATEGO-ON-CL	2649	~ 875

Simulation for Spring







Simulation for Winter Vacation