Toward Self-Adaptive Software Employing Model Predictive Control

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What is Model-Predictive Control?

"Model predictive control has had a major impact on industrial practice, with thousands of applications world-wide."

[Seborg+2011]

Idea of Model-Predictive Control (MPC):

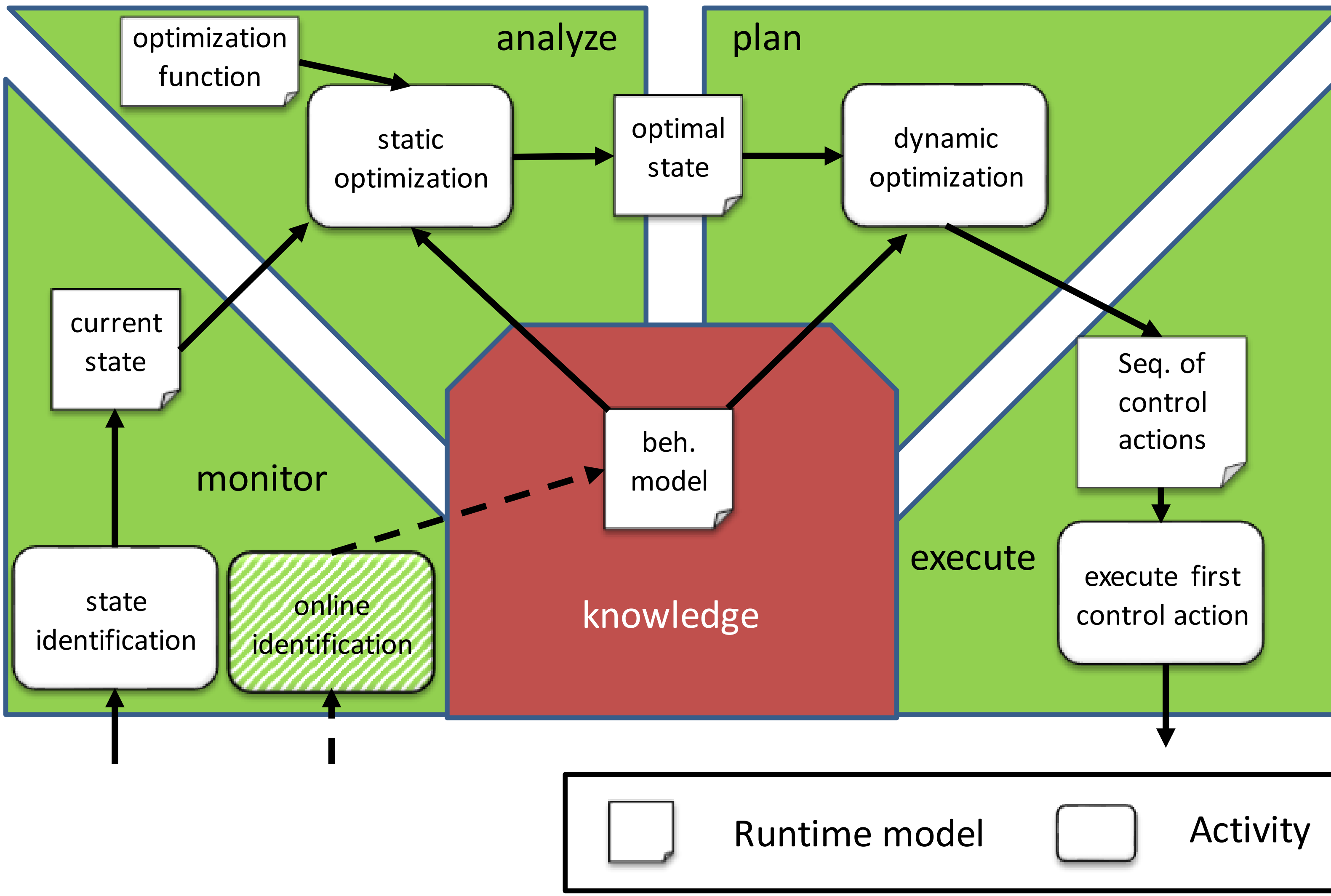
- Make required control decision based on **predictions** for a **model** of the controlled process by solving a related optimization problem (e.g., maximizing a profit function, minimizing a cost function, maximizing a production rate) at runtime.
- Usually MPC is running on top of simpler controllers (e.g., PID) that control the subsystems of the process according to the control inputs from MPC (hierarchical control).

Capabilities:

- Can handle complex MIMO processes
- Can realize different optimization goals
- Can handle constraints on the control inputs and process outputs/state
- Can compensate loss of actuators (determine control structure + check for ill-conditioning)
- Can be combined with online identification

Remark: also named **moving horizon control** or **receding horizon control**

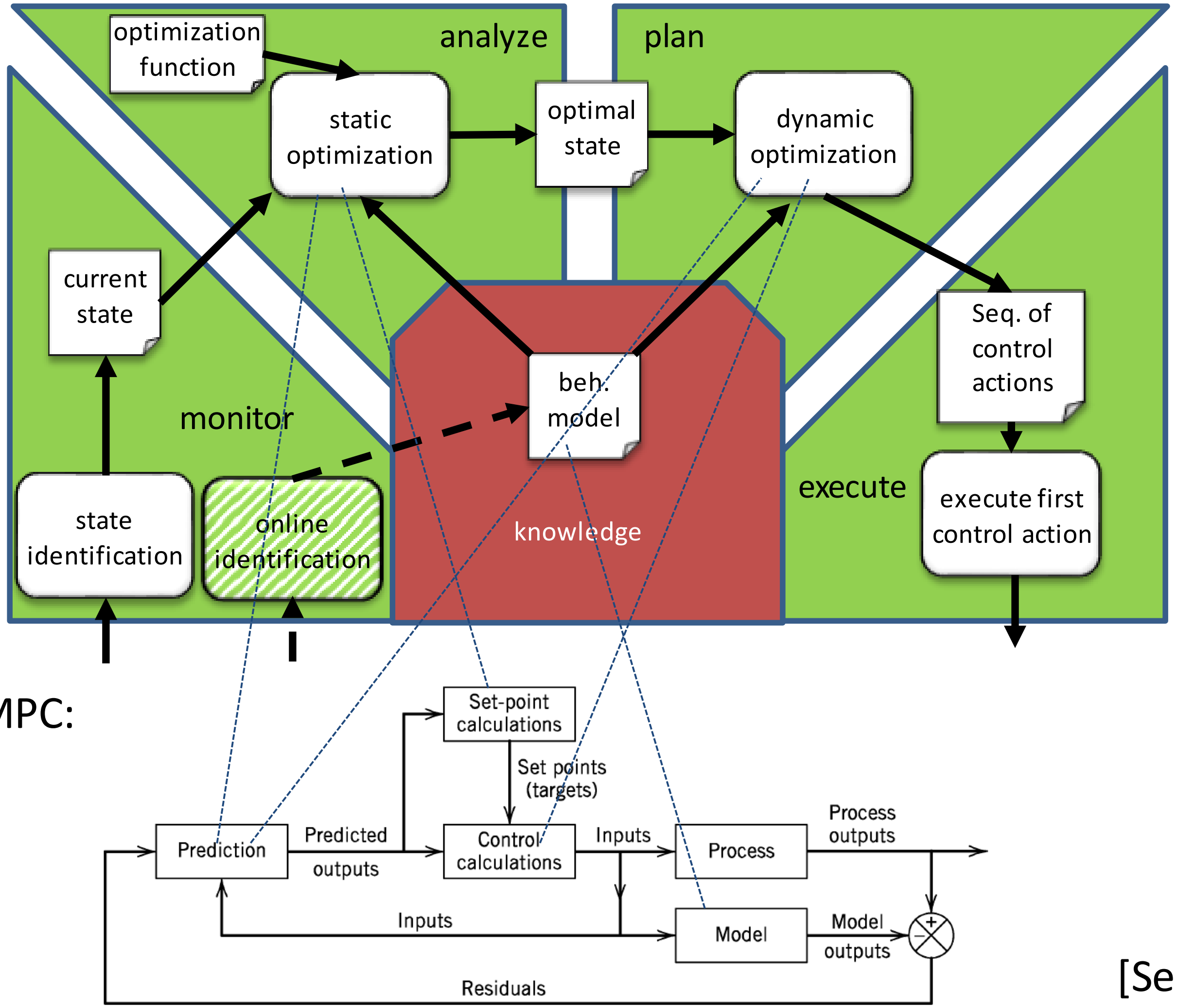
Advanced MPC in Terms of MAPE-K



Mapping Advanced MPC to classical MPC

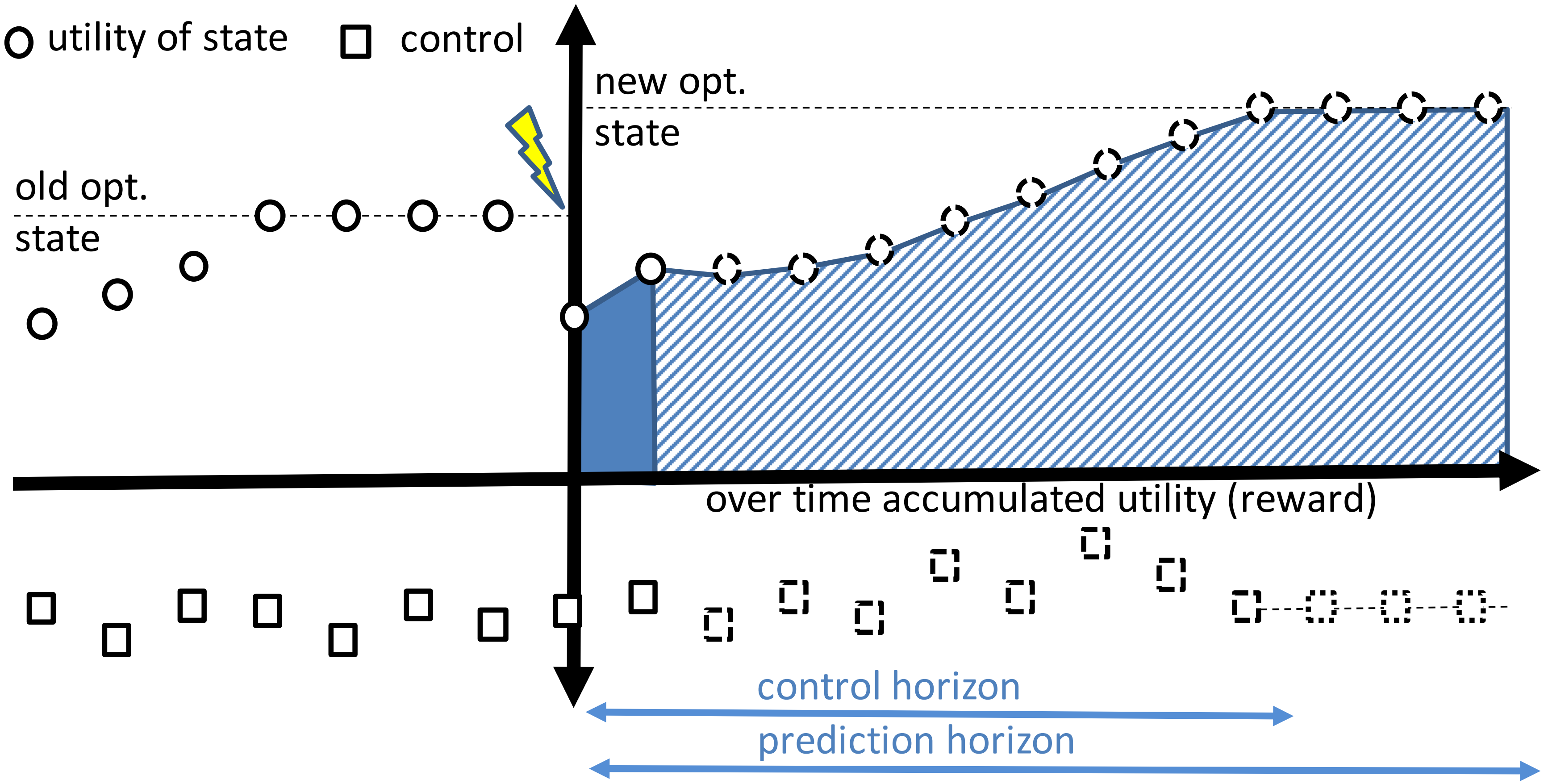
Advanced MPC:

Classical linear MPC:



[Seborg+2011]

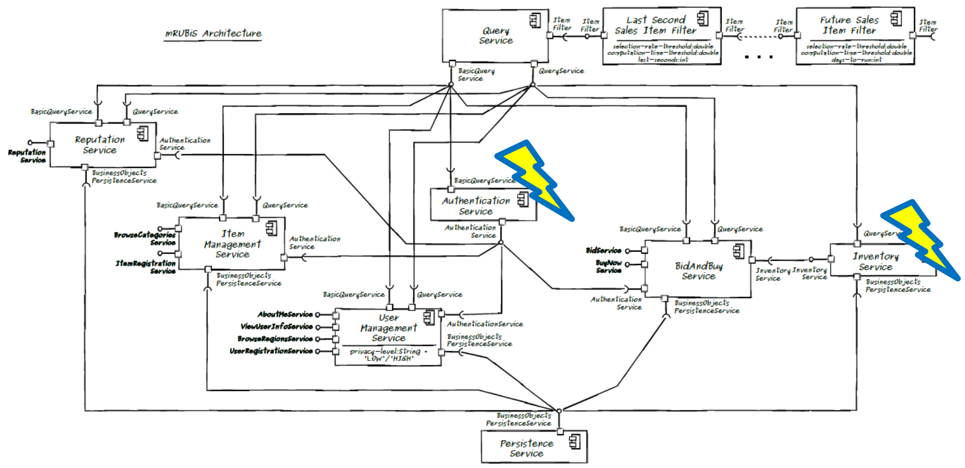
Finite Receding Horizons in MPC



- (prediction horizon – control horizon) * sampling time ≈ settling time (horizons = number of considered steps)
- Sequence decision problem (agents)

Example: Self-Repair

- Failures of different types:
  - Various exceptions
  - Crash of a component
  - ...
- Multiple repair strategies for each failure type:
  - Restart the component
  - Redeploy the component
  - Replace the component
  - ...



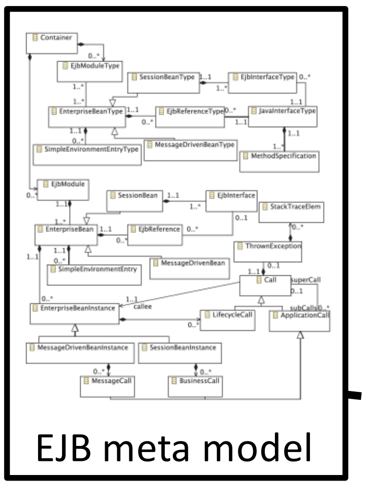
1. Which strategy should be applied to repair a specific failure?
2. If there are multiple failures, which one should be repaired first?

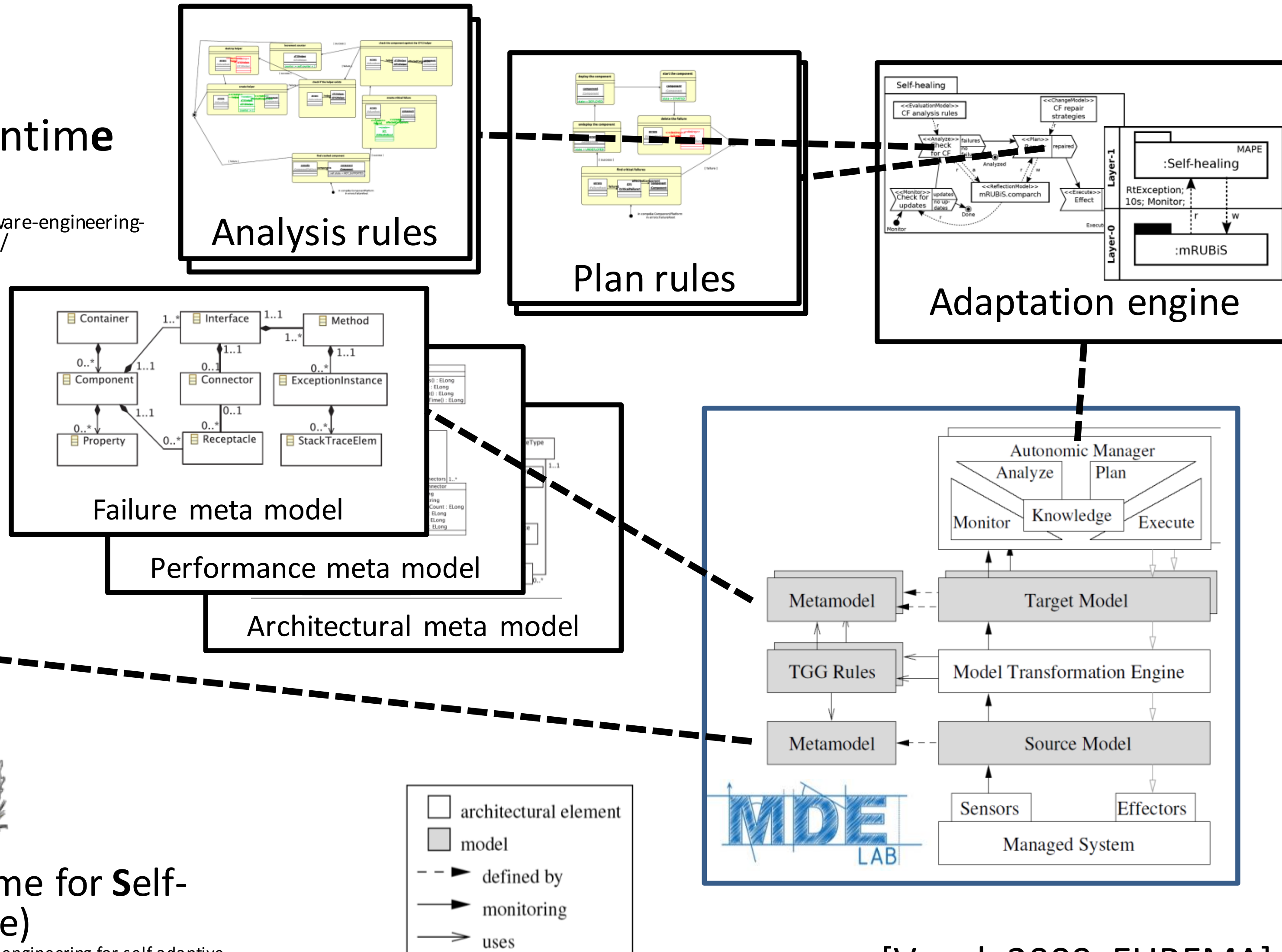
Example: MAPE-K with EUREMA & MORISIA

EUREMA

(**E**xec**u**table **R**untime **Mega**models)

mdelab.de/mdelab-projects/software-engineering-for-self-adaptive-systems/eurema/





MORISIA

(**Mo**dels at **R**unt**i**me for **S**elf-Adapt**i**ve Softw**a**re)

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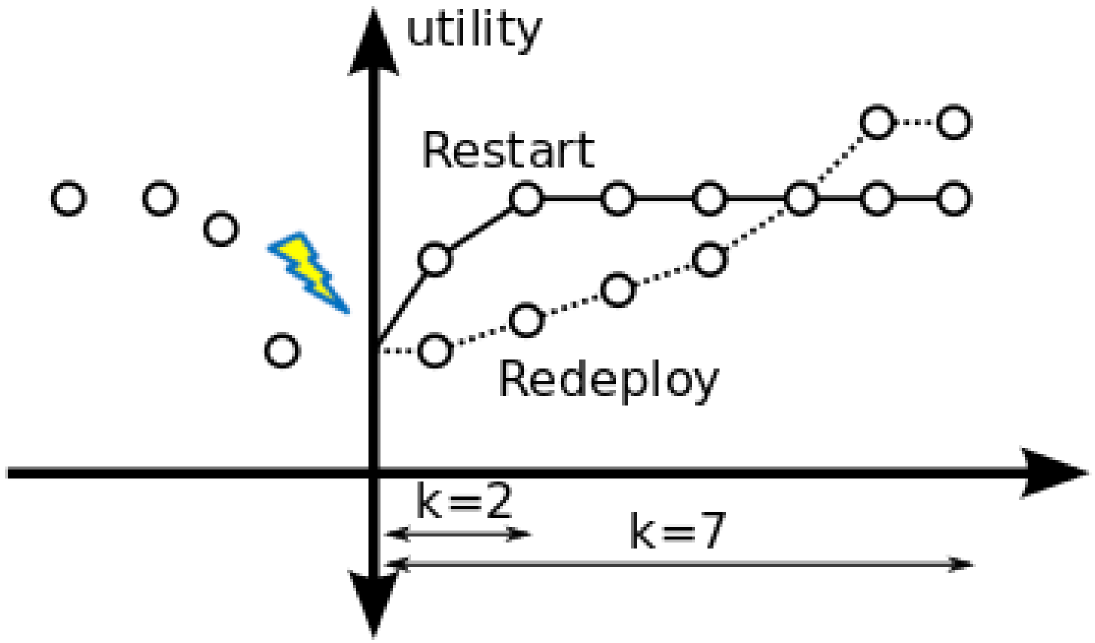
[Vogel+2009, EUREMA]

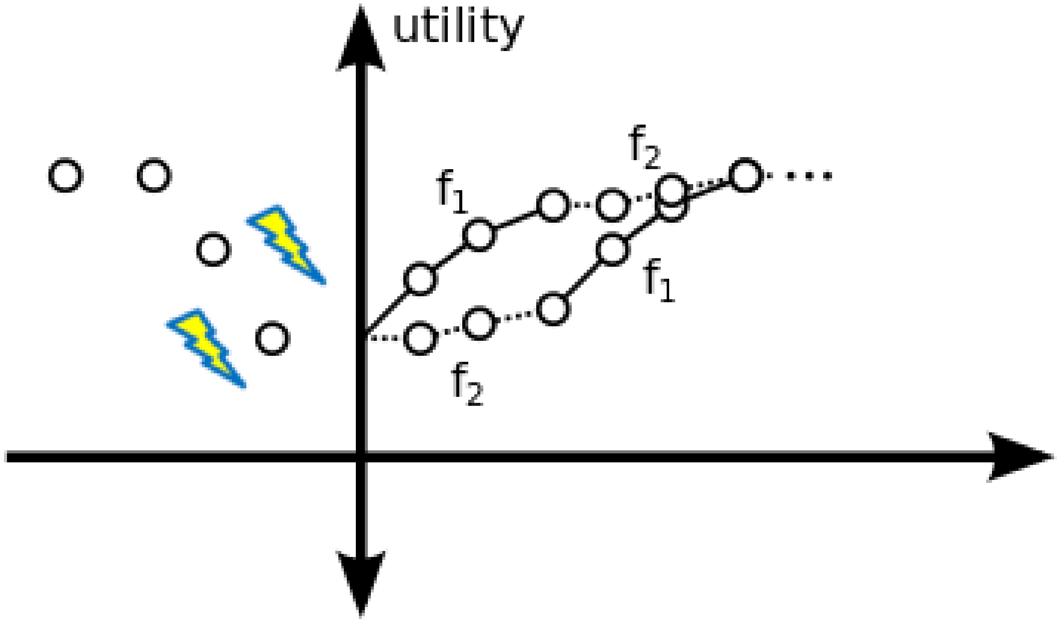
Example: Analysis & Plan - Which strategy to apply?



k: number of prediction steps

- Predicting two steps, **Restart** appears to be the better strategy
- Predicting seven steps, **Redeploy** appears to be better (e.g., using a different node with more resources)
- Short vs. long term (steady state **utility** dominates **reward**)

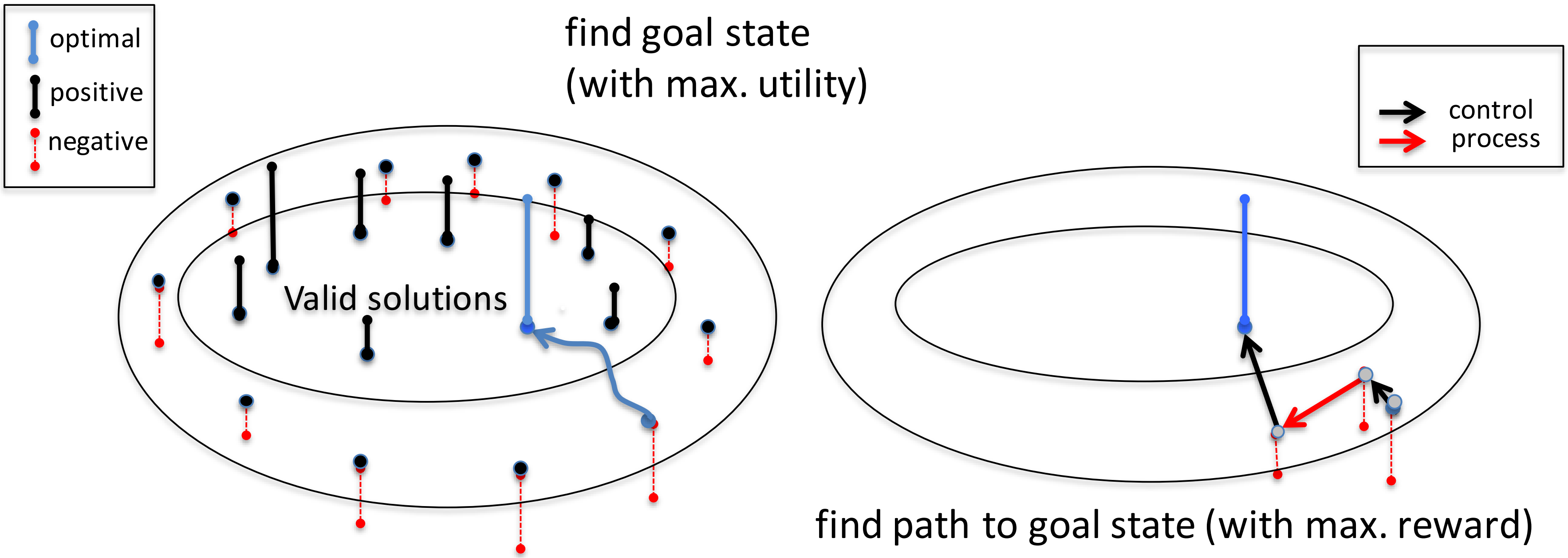
Example: Analysis & Plan – Which failure to repair first?



Explore the strategies for the different failures (f_1 and f_2):

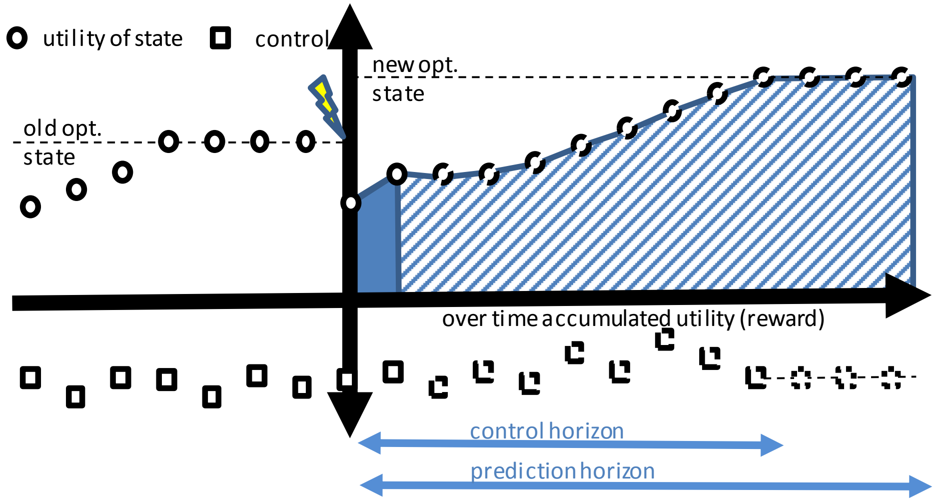
- Steady state **utility** is the same but order matters considering the **reward**
- Repair the failure first whose repairing improves most the reward (f_1)

Utility-Based View of the Solution Space



- **Analysis:** Check whether the current state is optimal concerning its **utility**
  - **Static optimization**: Check whether a better optimal solution state exists. (side-effect is that we also have one optimal/satisficing goal state)
- **Planning:** Find a path with optimal **reward** leading to the chosen solution
  - **Dynamic optimization**: what is the optimal path to the chosen solution state
  - Trivial in case solution space can be easily configured

Cases for the Selection of the Horizons



- Solution space is not fragmented (you can compensate “failures” ...)
  ➔ (small) finite horizon may be sufficient
- No or unlikely interference with process behavior
  ➔ usually 0 settling time ➔ prediction horizon = control horizon
- Multiple control inputs feasible in one control step
  ➔ receding horizon may be skipped or “reduced”

...

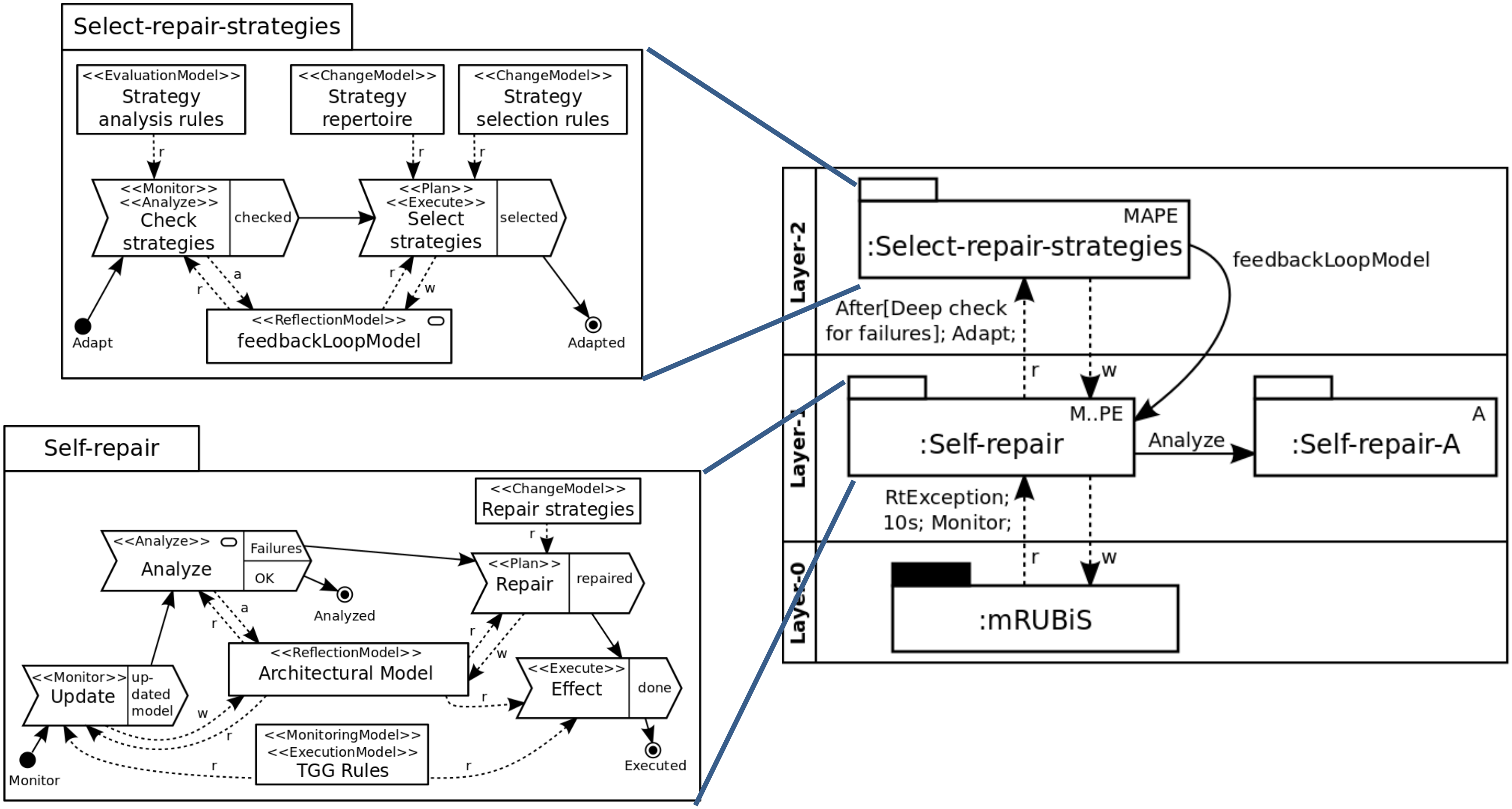
Beyond Classical and Advanced MPC

- **Infinite horizon** can lead to better results (if long term predictions are accurate), as it considered the steady state assuming optimal behavior, but it requires more resources.
- **Stochastic MPC** considers probabilities for process behavior and optimizes the **expected reward**.

Beyond advanced MPC:

- For **non-deterministic models** (e.g. PTA) the control inputs (strategy) requires to be safe (any or too high risk is avoided by excluding unsafe control options).
- Agents **learning the expected rewards** (not via state) leads to predict reward rather than process behavior.

Beyond MPC: Layered Architecture & Adapt



- Adapt MPC (monitor, analysis, plan, execute)? e.g., adapt rules, attention
- Adapt underlying controllers (omitted in the architecture)

Conclusions & Outlook

- MPC can handle many properties of complex process models typically present for **software** (MIMO, different optimization goals, constraints on the control inputs and process outputs/state, loss of actuators)
- Advanced MPC seems suitable as a **framework** to understand and fine-tune many approaches based on models and related predictions.
  - Can employ for a **variety of techniques** (simulation, optimization, search, synthesis, ...) and **models** (linear, non-linear, state space, probabilistic) ...
- The horizons for control and predictions result in a useful **design space** in many cases (depending on the characteristics of the state space).
  - Enlarging the control and prediction horizon can help to engineer **more accurate** solutions (infinite = optimal?)
  - Limitation of the control and prediction horizon (and also input blocking) can help to engineer **better scalable** solutions
- **But:** MPC with bad models of the process don't work!

References

[Calinescu+2011] Radu Calinescu, Lars Grunske, Marta Kwiatkowska, Raffaela Mirandola and Giordano Tamburrelli. Dynamic QoS Management and Optimization in Service-Based Systems. In IEEE Transactions on Software Engineering, Vol. 37(3):387-409, IEEE Computer Society, Los Alamitos, CA, USA, 2011.

[Seborg+2011] Dale E. Seborg, Thomas F. Edgar, Duncan A. Mellichamp, Francis J. Doyle III: Process Dynamics and Control (Third Edition), Wiley, 2011.

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