Model Predictive Control for online Motion Planning

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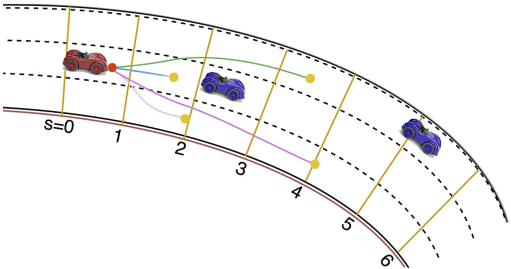
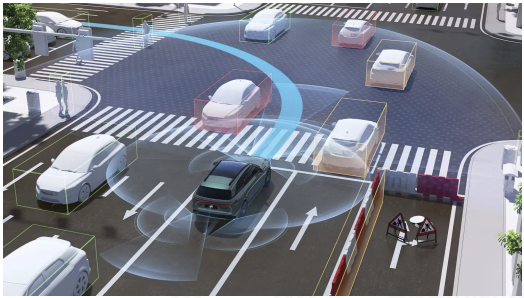
Outline

Motivation



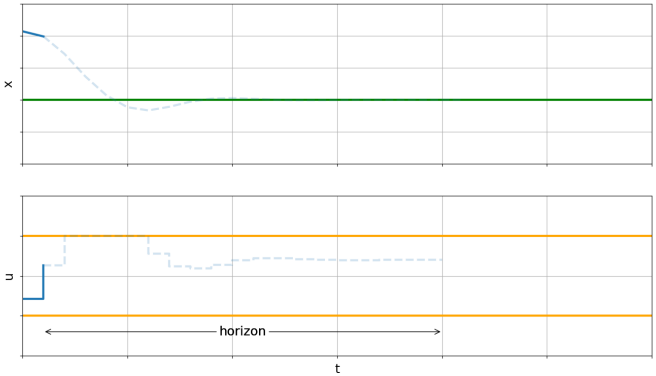
Source: Hui [2018]



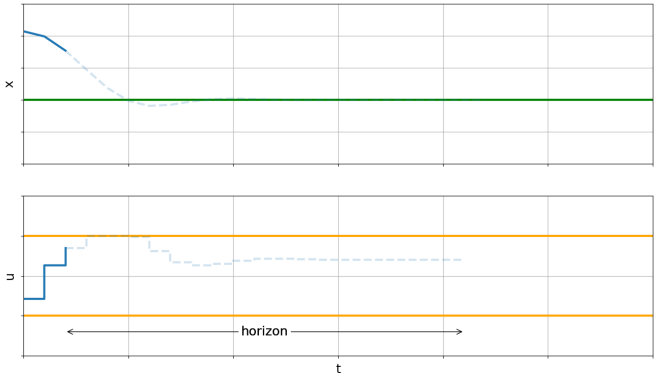
Source: ResearchInChina [2024]

MPC

- Model Predictive Control
- predict system into future
- optimize actions $\mathbf{u} = [u_0, u_1, ..., u_n]$
- only apply first action u_0
- recompute often
- react to inaccuracies



Adapted from Fiedler et al. [2023]



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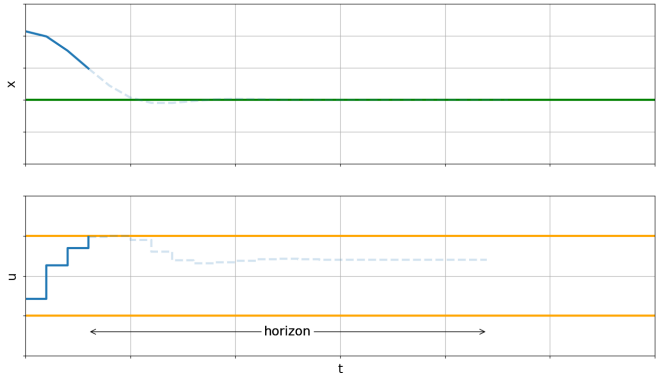

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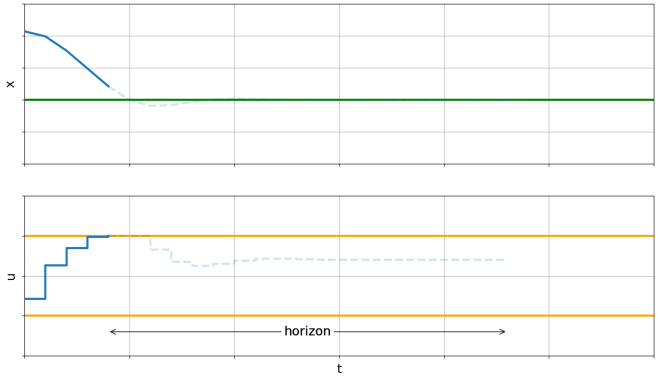

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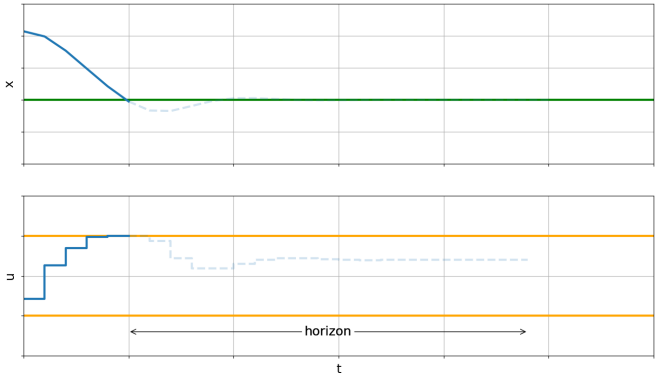

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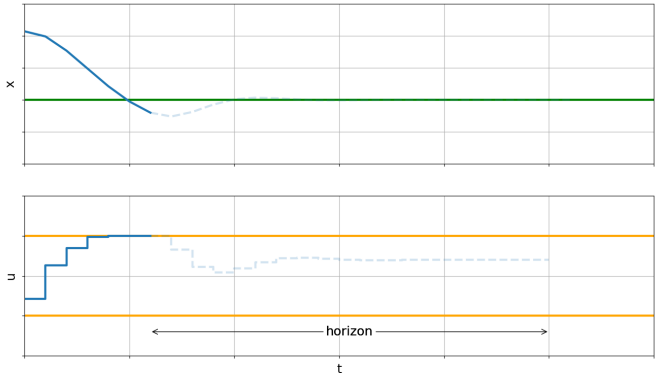

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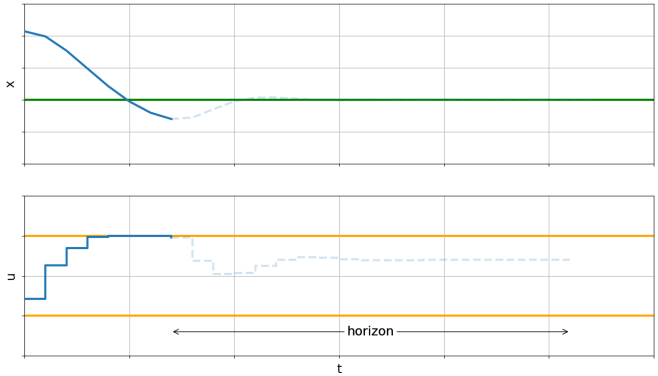

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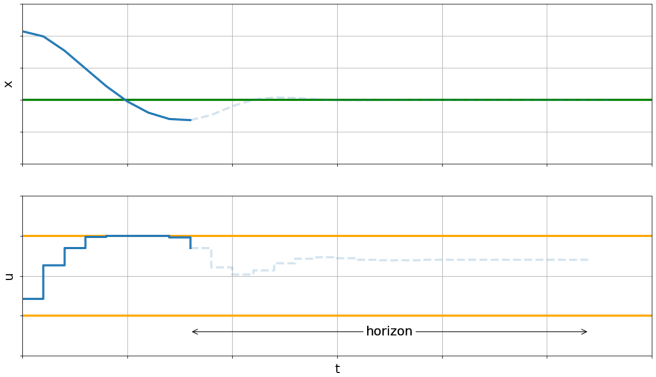


Adapted from Fiedler et al. [2023]

MPC: Definition

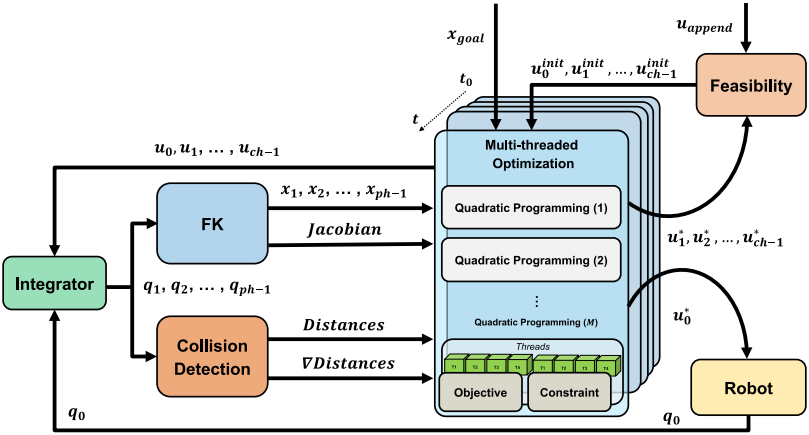
$$
\begin{aligned}
\min_{\mathbf{u}} \quad & l_{terminal}(x_N) + \sum_{k=0}^{N-1} l_{stage}(x_k, u_k) \\
\text{s.t.} \quad & x_{k+1} = f(x_k, u_t) && \forall k \in \{0, ..., N-1\} \\
& g_{state}(x_k) \leq 0 && \forall k \in \{0, ..., N-1\} \\
& g_{input}(u_k) \leq 0 && \forall k \in \{0, ..., N-1\}
\end{aligned} \tag{1}
$$

MPC: System Model

- linear system model $x_{k+1} = Ax_k + Bu_k$
- linear constrains
- quadratic loss function
- convex quadratic programming
- polynomial time

NMPC

- many systems are non-linear
  - forward kinematics
- Nonlinear Model Predictive Control
- many solvers
  - Sequential Quadratic Programming
- gradient information



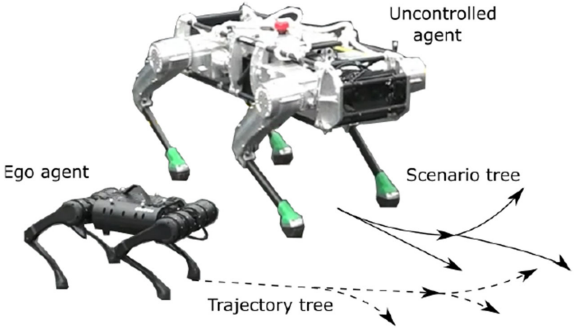
Source: Hu et al. [2021]

Warm start

- Convergence might take long time
- Good initial guess needed
- Shift prior result
- $[u_0, u_1, ..., u_{ch-1}]$
- $[u_1, ..., u_{ch-1}, u_{append}]$
- Append random input

Interactive Scenarios

- Interactive scenario
- other uncontrolled actors
- react to others
- robustness



Source: Chen et al. [2022]

Branch MPC

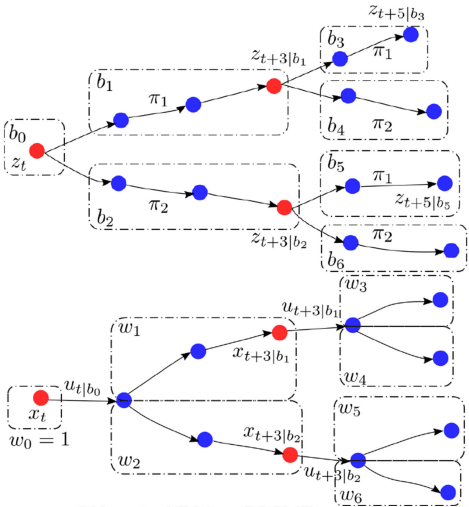
- probabilistic branches
- dependent on uncontrolled robot
- scenario tree
- x state of controlled robot
- z state of uncontrolled robot
- u input of controlled robot
- d input of uncontrolled robot

Policy definition

- finite set of policies π_i
  - maintain fixed speed
  - slow down
  - left lane change
  - right lane change
- feedback policies: $d = \pi_i(z)$
- multiple robots => exponential policies

Scenario Tree

- Branch every $M = 3$ nodes into $m = 2$
- define branch weight w_i
- trajectory tree
- Risk neutral
  - minimizes expectation of cost
- Risk aware
  - minimizes expectation of worst α percentile
  - tradeoff performance vs. robustness



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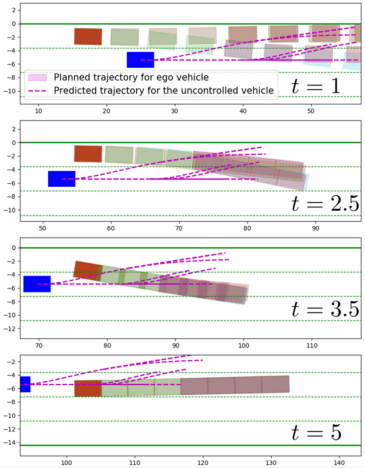
Branch MPC



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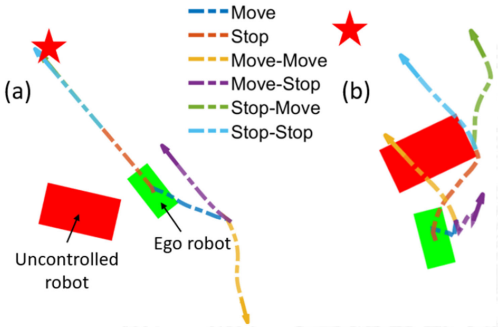

Source: Chen et al. [2022]

Conclusion

- linear vs nonlinear MPC
- real time
- reactive
- system model
- Branch MPC: robust

Bibliography

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