Real Time Control of a Quadcopter

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Technische Universität München

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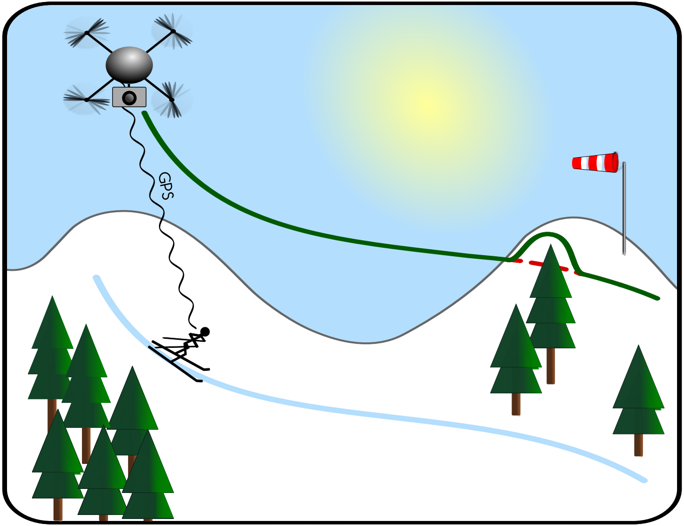
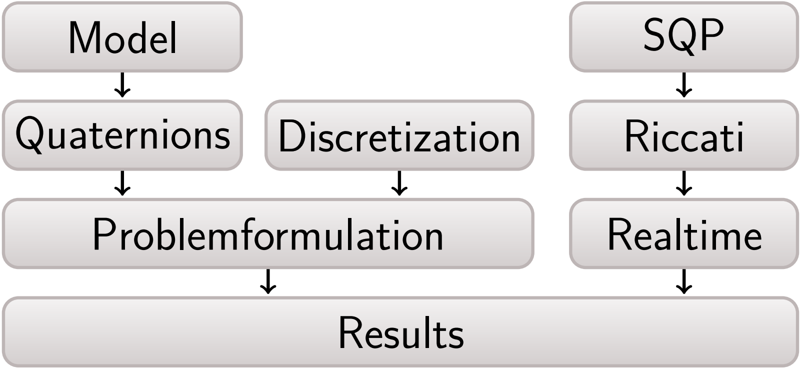
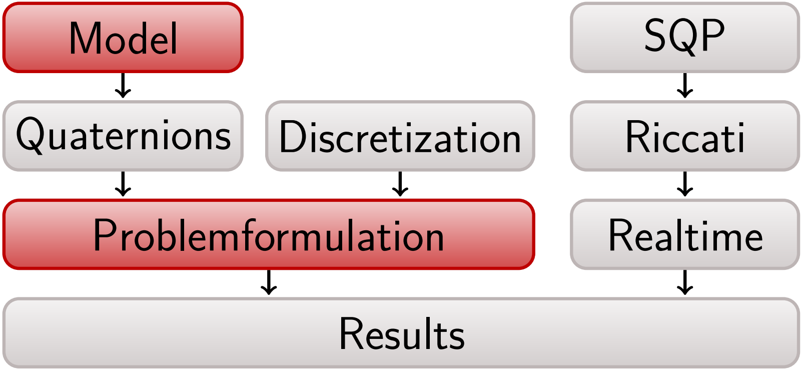
Motivation




Model
SQP
Quaternions
Discretization
Riccati
Problemformulation
Realtime
Results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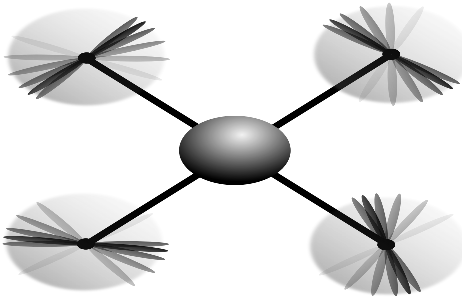
Optimal Control Formulation

$$\min_{x,u} J(x,u) \quad \text{s.t.} \quad \begin{aligned} \tilde{h}(x,u) &= 0 \\ \dot{x}(t) &= f(x(t),u(t)) \end{aligned}$$

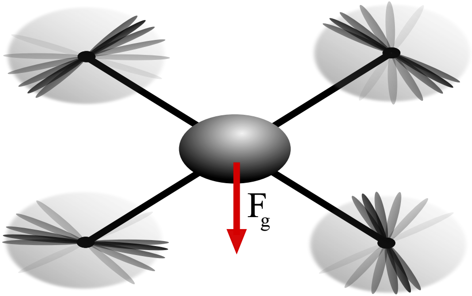
x : state

u : control

Model



Model



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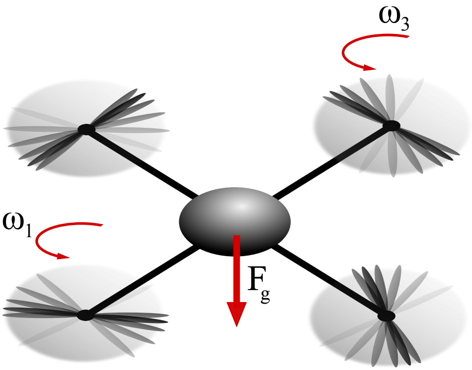
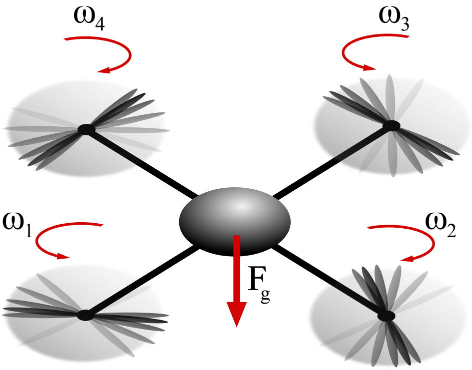
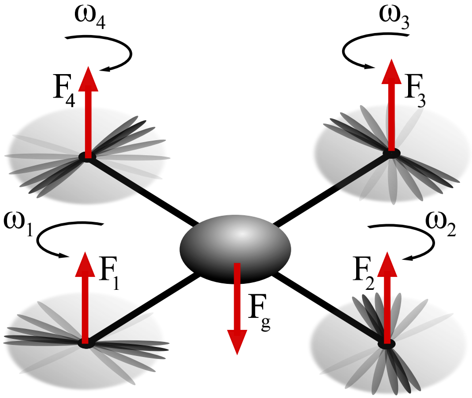


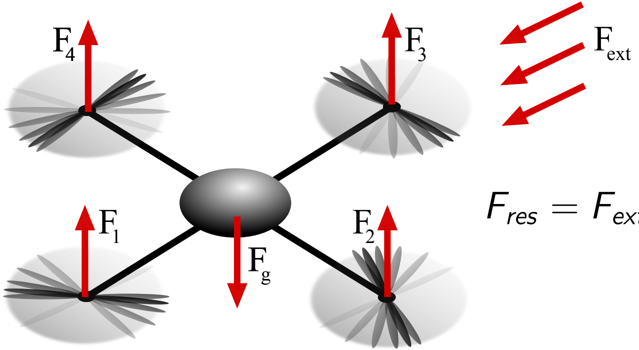
Model



Model

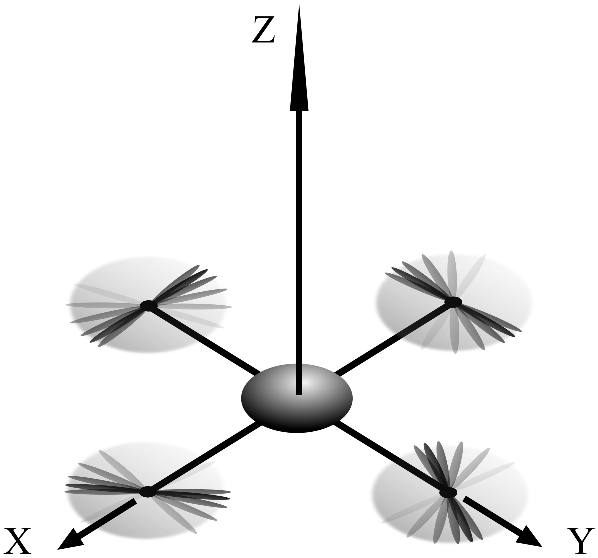


Forces

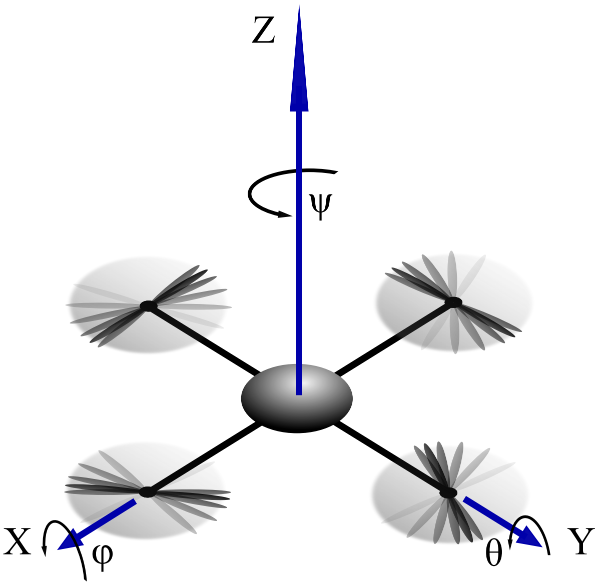


$$F_{res} = F_{ext} + F_g + \sum_{i=1}^{4} F_i$$

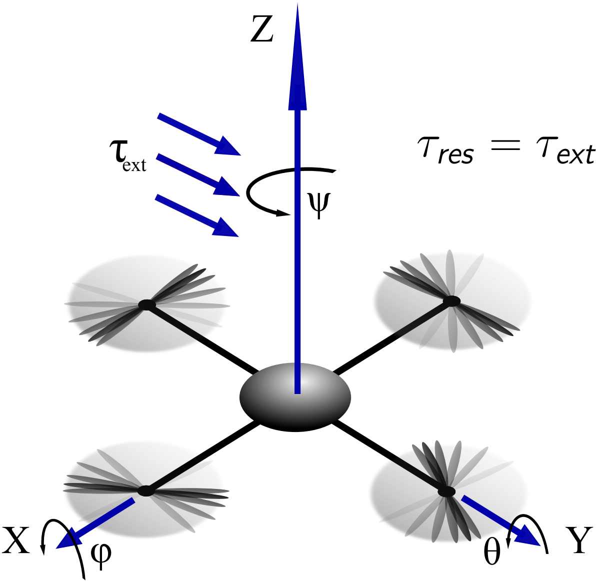
Torques



Torques



Torques



$$\tau_{res} = \tau_{ext} + \tau_{\psi} + \tau_{\varphi} + \tau_{\theta}$$

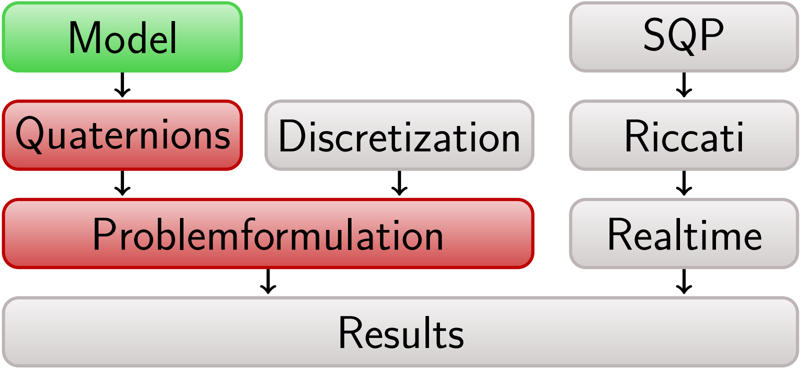
Obtain ODE

$$\left.\begin{array}{l} F_{res} = F_{ext} + F_g + \sum_{i=1}^{4} F_i \\ \tau_{res} = \tau_{ext} + \tau_\psi + \tau_\varphi + \tau_\theta \end{array}\right\} \quad \Rightarrow \quad \dot{x}(t) = f(x(t), u(t))$$

Obtain ODE

$$\left.\begin{array}{r}F_{res} = F_{ext} + F_g + \sum_{i=1}^{4} F_i \\ \tau_{res} = \tau_{ext} + \tau_\psi + \tau_\varphi + \tau_\theta\end{array}\right\} \quad \Rightarrow \quad \dot{x}(t) = f(x(t), u(t))$$

$$\left.\begin{array}{c}\tilde{h}(x,u) = 0 \\ \dot{x}(t) = f(x(t), u(t))\end{array}\right\} \Rightarrow h(x,u) = 0$$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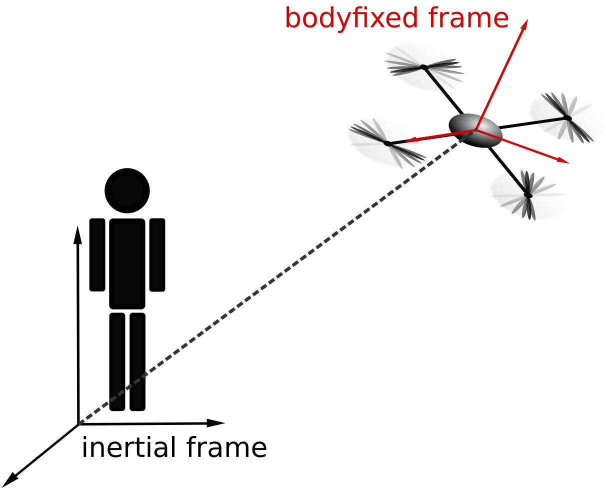
Copter Rotation



Quaternions

$$q = a + \mathrm{i}b + \mathrm{j}c + \mathrm{k}d \qquad a, b, c, d \in \mathbb{R}$$

$$\Leftrightarrow$$

$$q = \begin{pmatrix} a \\ b \\ c \\ d \end{pmatrix} \in \mathbb{R}^4$$

Quaternions

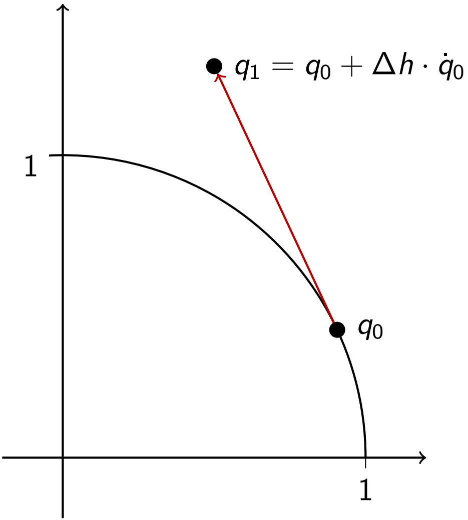
$$q = a + \mathrm{i}b + \mathrm{j}c + \mathrm{k}d \qquad a, b, c, d \in \mathbb{R}$$

$$\Leftrightarrow$$

$$q = \begin{pmatrix} a \\ b \\ c \\ d \end{pmatrix} \in \mathbb{R}^4$$

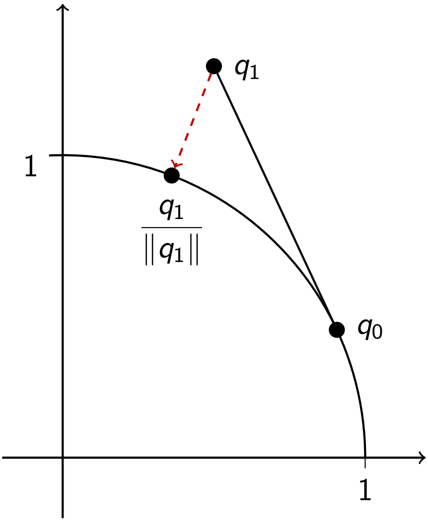
represent rotation $\quad \Leftrightarrow \quad \|q\| = 1 \quad \Leftrightarrow \quad q \in \mathcal{S}^3$

Drift Correction

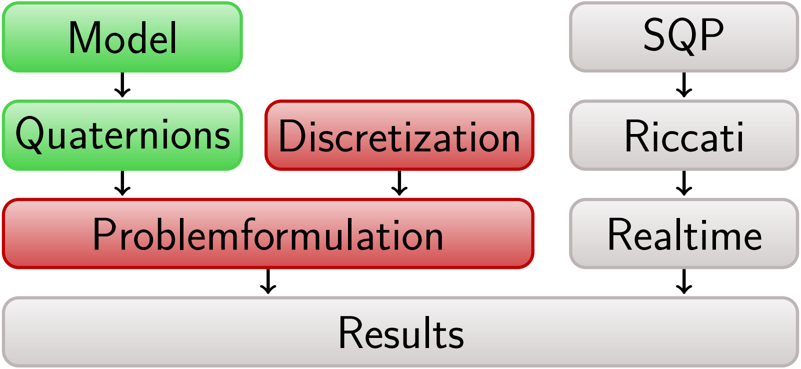


$$\dot{q}(t) = \tilde{f}(q(t))$$

Drift Correction



$$\dot{q}(t) = \tilde{f}(q(t)) - \lambda(q(t))$$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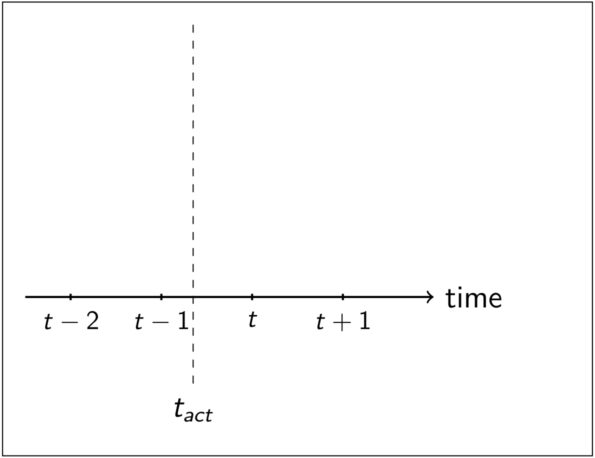
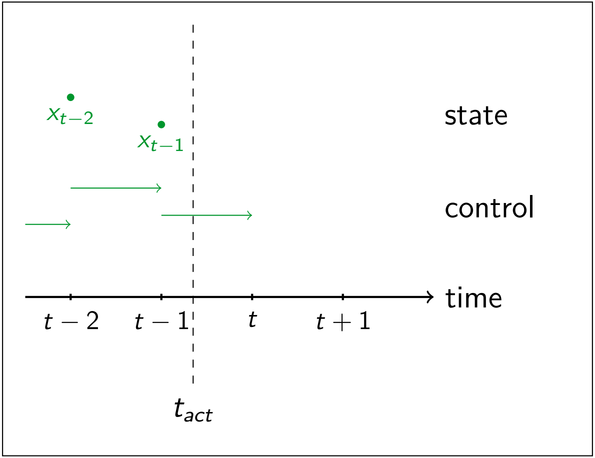
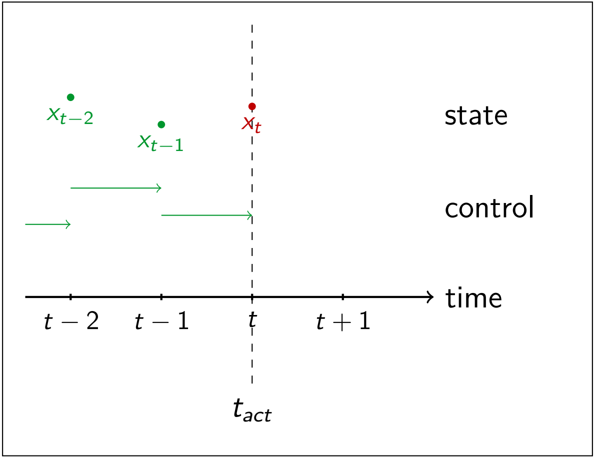
Setting



Setting



Setting



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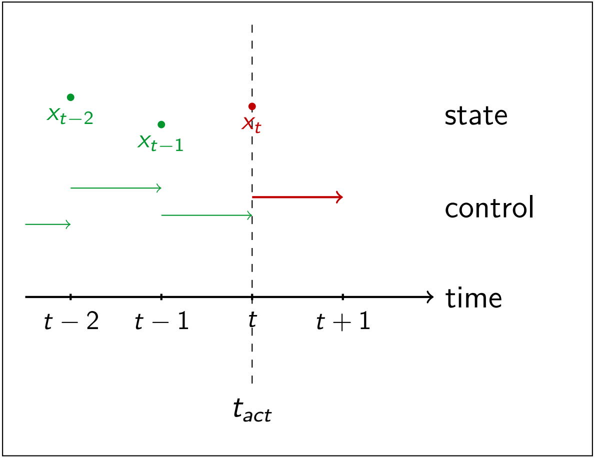
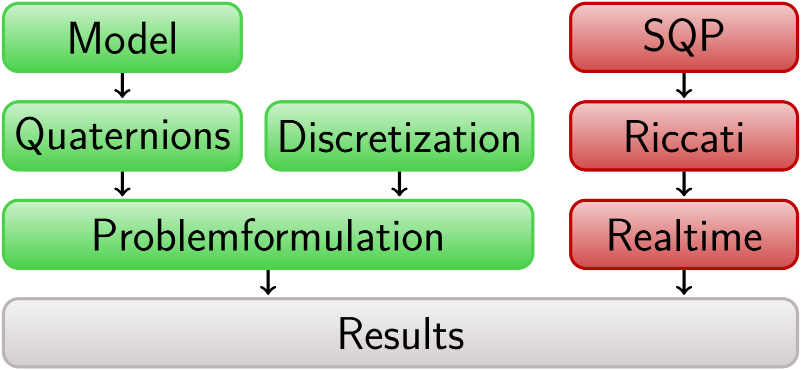


Discrete Problem

$$\min_{x,u} \sum_{i=t}^{t+N} J_i(x_i, u_i) \qquad \text{s.t.} \quad h_i(x_i, u_i) = 0 \quad i = t, \ldots, t+N$$

$J_i(x_i, u_i)$ discretized goal function

$h_i(x_i, u_i)$ equality constraints at time i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The Lagrangian

$$L(y) = \sum_{i=t}^{t+N} J_i(x_i, u_i) + \sum_{i=t}^{t+N} \lambda_i^T h_i(x_i, u_i)$$

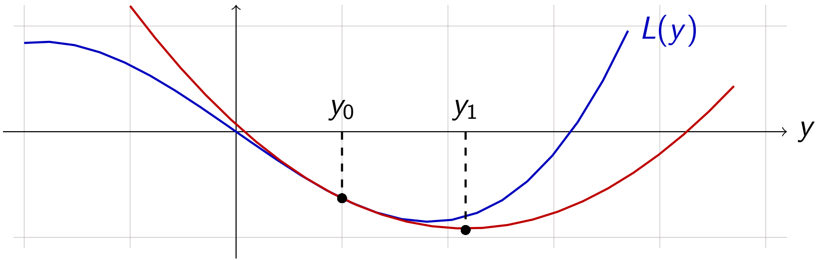
$$y := (\lambda, x, u)$$

$$y^* \text{ optimal} \quad \Leftrightarrow \quad \nabla_y L(y^*) = 0$$

The SQP Method

Find y^*:

$$y_1 = y_0 + s$$
$$\min_s \frac{1}{2} s^T \nabla^2 L(y_0) s + \nabla L(y_0)^T s$$



Quasi Newton-Method

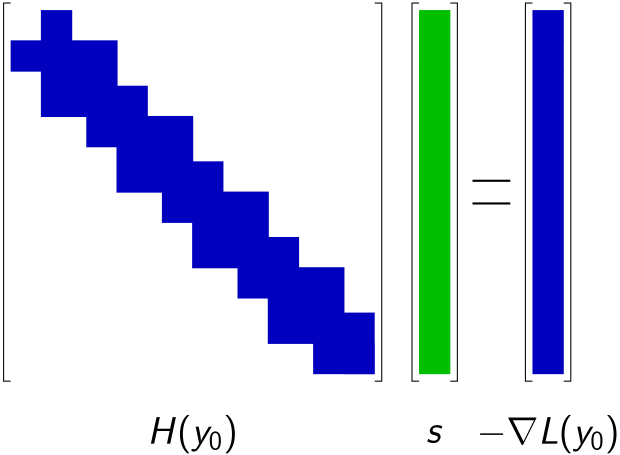
Find s with:

$$\nabla L(y_0) + \nabla^2 L(y_0) s = 0$$

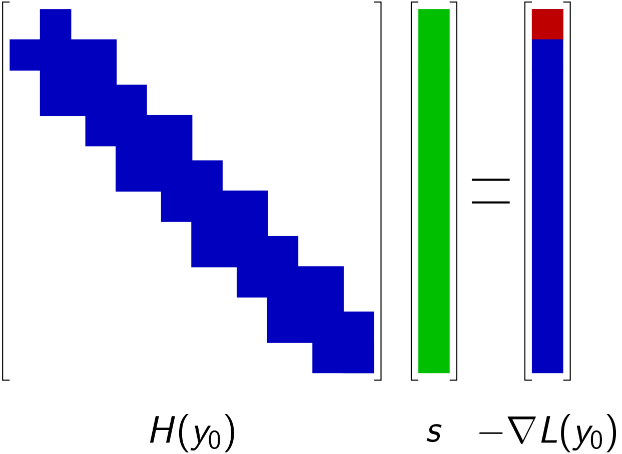
Approximate $\nabla^2 L(y_0)$ and solve:

$$H(y_0) s = -\nabla L(y_0)$$

Riccati Recursion



Riccati Recursion



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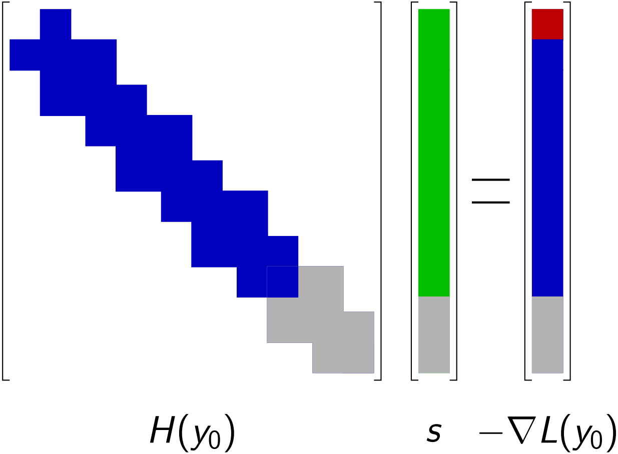

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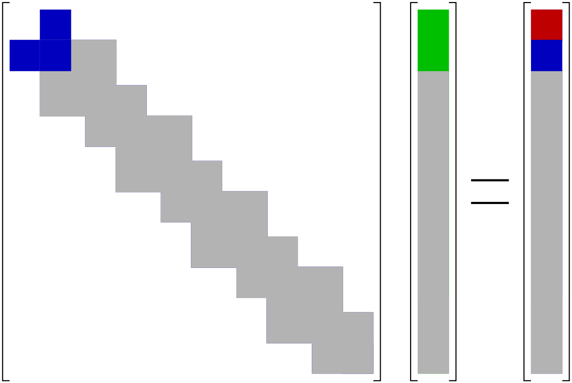
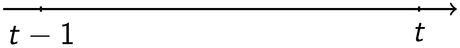


$H(y_0)$ $\quad s \quad -\nabla L(y_0)$

Summary

What happens in interval $[t-1, t]$?



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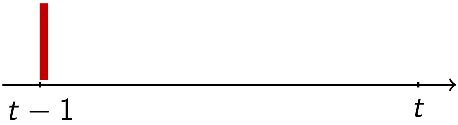
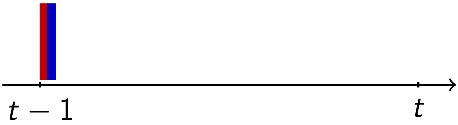


1. calculate control u_{t-1} (Riccati Part II)

Summary

What happens in interval $[t-1, t]$?



1. calculate control u_{t-1} (Riccati Part II)
2. calculate y (Riccati Part II)

Summary

What happens in interval $[t-1, t]$?

1. calculate control u_{t-1} (Riccati Part II)
2. calculate y (Riccati Part II)
3. prepare u_t (Newton & Riccati Part I)

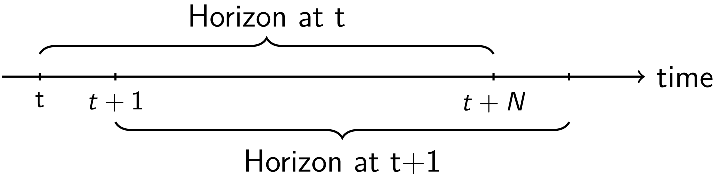
Summary

What happens in interval $[t-1, t]$?

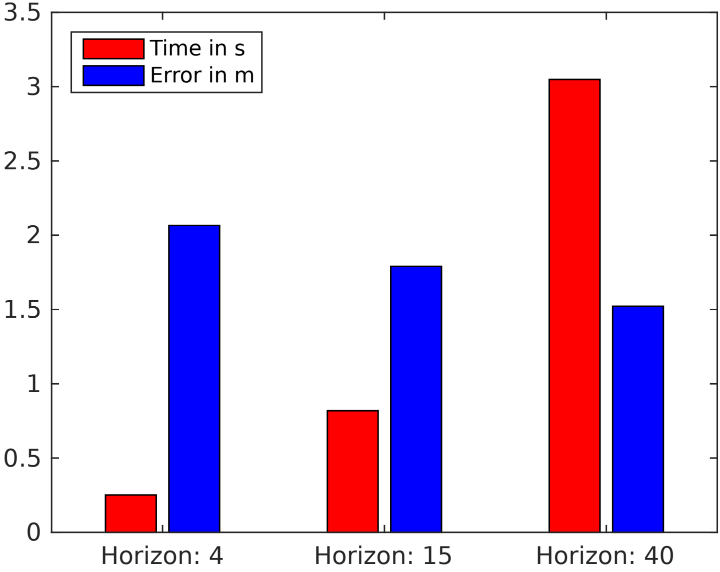
1. calculate control u_{t-1} (Riccati Part II)
2. calculate y (Riccati Part II)
3. prepare u_t (Newton & Riccati Part I)

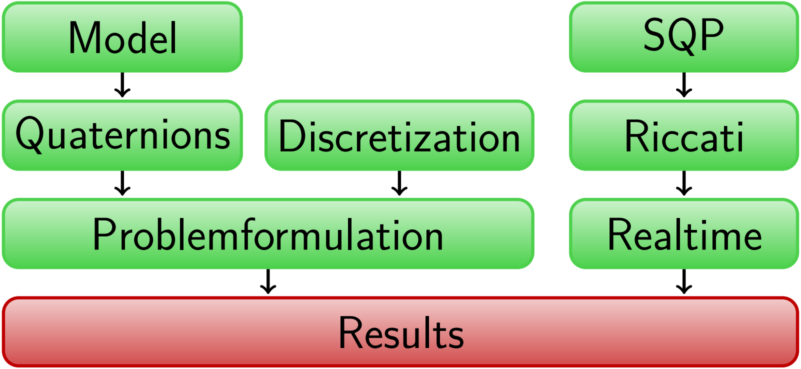
$\Rightarrow$ with horizon 18 this is 28% faster

Finite Horizon



Finite Horizon

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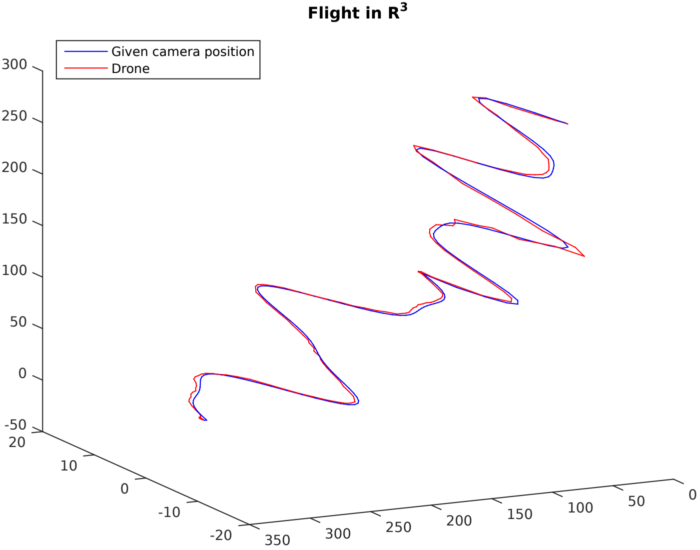
Following a Skier



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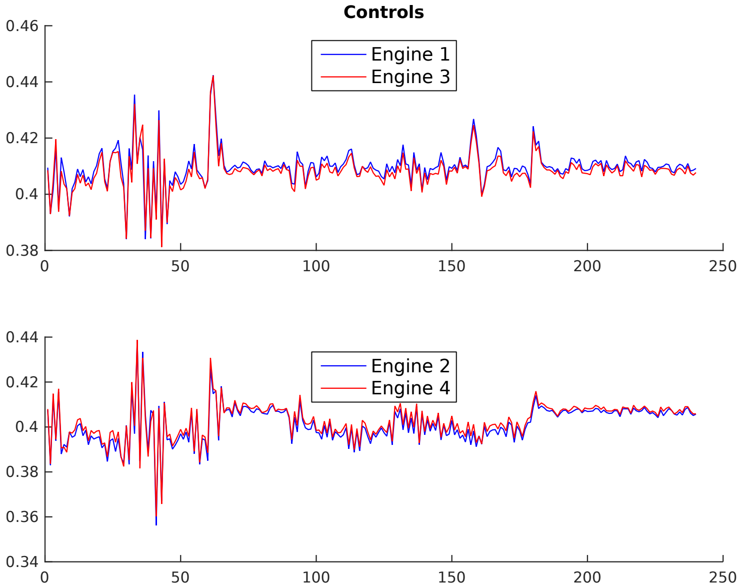

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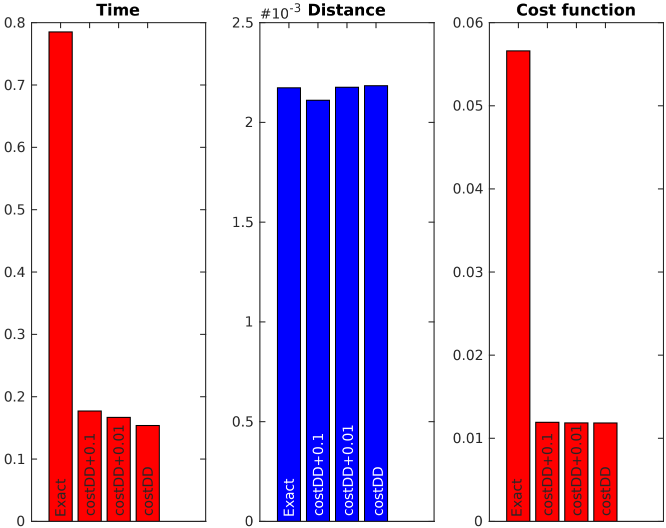

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What we have learned from the Project:

- you have to know your plan to ignore it
- MATLAB® is special
- tests are helpful - or drive you crazy
- loopings can be cheap, too
- keep your colorscheme
- keep calm and do case studies

Any Questions?