acados

A rapid prototyping tool for NMPC

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How things were until now

www.acadotoolkit.org

Key Properties of ACADO Toolkit [Houska et al 2009]

- Open Source (LGPL)
- **A**utomatic **C**ontrol **A**nd **D**ynamic **O**ptimization
- User friendly interface close to mathematical syntax

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- User friendly interface close to mathematical syntax

Multiplatform support

- C++: Linux, OS X, Windows
- MATLAB

ACADO developers (past and current)

Moritz Diehl
Scientific advisor

Hans Joachim Ferreau
Main developer

Boris Houska
Main developer

Filip Logist
Multi-objective optimization

Rien Quirynen
Code generation

Dries Telen
Optimal Experimental Design

Mattia Valerio
Multi-objective optimal control

Milan Vukov
Code generation for MPC & MHE

ACADO Code Generation Toolkit

Pro

- Easy to use,

Con

- ... but codebase difficult to maintain

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ACADO Code Generation Toolkit

Pro

- Easy to use,
- Fast NMPC/MHE solvers,
- Interfaced to external solvers,
- Comes with own AD,

Con

- ... but codebase difficult to maintain
- ... but with a lot of global data
- ... but hard coupling with new ones
- ... but not compatible with CasADi

Code generation

Mathematical Formulation

$$\begin{aligned} \min_{x,u} \quad & \int_0^T x^2 + u^2 \mathrm{d}t \\ & \dot{x} = f(x,u) \\ \text{s.t.} \quad & x(0) = x_0 \\ & -1 \leq u \leq 1 \, . \end{aligned}$$

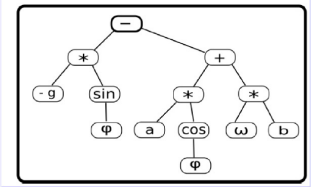
ACADO Syntax

```
DifferentialState    x;
Control              u;

DifferentialEquation f;
f << dot(x) == u + ...;

ocp.minLagrangeTerm( x*x+u*u );
ocp.subjectTo( f );
ocp.subjectTo( -1 <= u <= 1 );
```

Symbolic Structure Detection



Algorithm

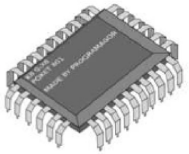
- **Multiple Shooting**
- **Real-Time Gauss Newton**
- **Online Active Set Strategy**

Optimized C-Code

```
r[1] = a[15]*c[17] + a[16]*c[19] + ... ;
r[2] = sin(a[1]*a[2]) + a[4] + ... ;
r[3] = cos(r[1])/exp(c[4])+ r[1] +... ;
```

Customized Solver Implemented on Chip/FPGA:

Measurement x_0



Optimal Decision u*

Code generation

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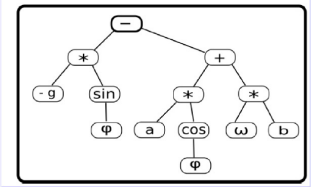

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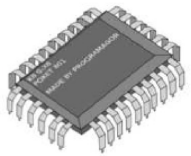

Optimal Decision u*

But is codegen really necessary?

Code generation

Why code generation?

- eliminate computations
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- no dynamic memory
- code reorganization, ...

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But code generation

- increases code size
- creates unreadable code
- only really makes sense at the bottleneck $\rightarrow$ linear algebra

A different idea

Instead of code-generated code, we want

- maintainable,
- extensible,
- fast code,
- with efficient linear algebra kernels,
- available from MATLAB and Python.

$\longrightarrow$ acados

Interfaces

The structure of acados is based on internal interfaces:

- OCP QP interface,
- condensing interface,
- integrator interface,
- AD interface,
- Hessian regularization interface,
- ...

If a solver sticks to a certain interface, it can be swapped quickly for another one

$$\rightarrow \text{Rapid Prototyping}$$

Status

As of now: one NMPC example in C99 with

- Model: [Chen&Allgoewer 1998]
- Integrator: Runge-Kutta 4
- Condensing: N^2
- QP solver: qpOASES3.0

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$0.63\,\mathrm{ms}$ per iteration,
only 2x slower than ACADO code generated code,
not bad for first 'plain vanilla' attempt ☺

Codebase

Located at `https://github.com/acados/acados`

- Completely written in `C99`
- Each interface has its own header file
- Data passed around by pointers to `structs`

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TODO:

- Interface with CasADi (and thus MATLAB/Python)
- Use BlasFEO's (former HPMPC) customly optimized linear algebra
- Implement many more new solvers
- Real-life examples
- ...