

# Embedded Nonlinear MPC Software

Moritz Diehl

Systems Control and Optimization Laboratory  
Department of Microsystems Engineering and Department of Mathematics  
University of Freiburg, Germany

ELO-X Short Course  
July 20, 2022





## Algorithmic Ingredients:

- ▶ Basic linear algebra subroutines (BLAS)
- ▶ Algorithmic Differentiation (AD)
- ▶ Numerical Integration
- ▶ Quadratic Programming (QP)
  
- ▶ Nonlinear Programming (NLP)
- ▶ Nonlinear Optimal Control (NOC)
- ▶ Nonlinear Model Predictive Control (NMPC)
- ▶ Mixed Integer Optimal Control (MIOC)
- ▶ Nonsmooth Optimal Control



## Algorithmic Ingredients:

- ▶ Basic linear algebra subroutines (BLAS)
- ▶ Algorithmic Differentiation (AD)
- ▶ Numerical Integration
- ▶ Quadratic Programming (QP)
  
- ▶ Nonlinear Programming (NLP)
- ▶ Nonlinear Optimal Control (NOC)
- ▶ Nonlinear Model Predictive Control (NMPC)
- ▶ Mixed Integer Optimal Control (MIOC)
- ▶ Nonsmooth Optimal Control

## Software:

- ▶ Eigen, BLASFEO, ...
- ▶ ADOL-C, ACADO, CasADi, ...
- ▶ SUNDIALS, DAESOL, ACADO Integrators, ...
- ▶ CPLEX, OOQP, OSQP, qpOASES, qpDUNES, HPIPM, ...
  
- ▶ KNITRO, SNOPT, IPOPT, ...
- ▶ MUSCOD-II, ACADO, AWEbox, ...
- ▶ AutoGenU, GRAMPC, ACADO Code Generation, acados, ...
  
- ▶ MS-MINTOC, pycombina, ...
- ▶ NOSNOC, ...

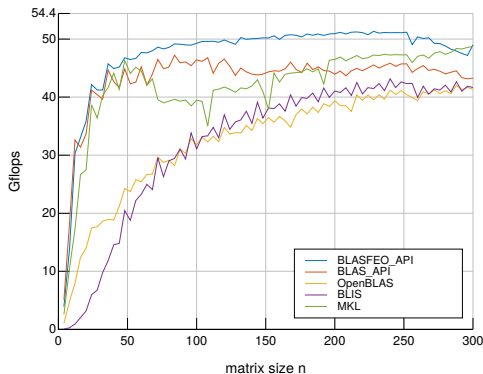


- ▶ Basic Linear Algebra Subroutines For Embedded Optimization
- ▶ open-source<sup>1</sup>, permissive BSD-2 license, by Gianluca Frison (MOSEK/Uni Freiburg)
- ▶ aim: provide high-performance linear algebra for embedded optimization applications
  - ▶ optimize performance for dense matrices fitting in cache
    - ▶ special focus on performance for small matrices
    - ▶ coded in C plus explicit vectorization using assembly
    - ▶ optimal register blocking
    - ▶ enhanced cache usage
  - ▶ no code-generation but rather library of routines
- ▶ two interfaces
  - ▶ standard BLAS API
    - ▶ standard column-major matrix format, high-performance for small to large matrices
  - ▶ BLASFEO own API
    - ▶ special panel-major matrix format further enhancing small-scale performance

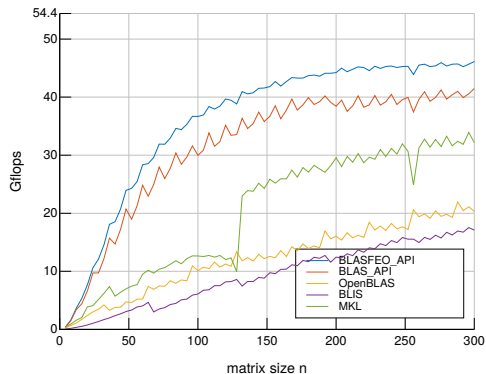
---

<sup>1</sup><https://github.com/giaf/blasfeo>

# BLASFEO – Selected Benchmarks



(a) dgemm\_nt (matrix multiplication)



(b) dpotrf\_l (Cholesky factorization)

**Figure:** Performance of BLASFEO (BLASFEO\_API and BLAS\_API), OpenBLAS 0.3.4, MKL 2019.1.144 and BLIS 0.5.0 on one core of an Intel Core i7 4810MQ (Haswell architecture).