Slovak University of Technology in Bratislava
Institute of Information Engineering, Automation, and Mathematics

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Introduction to Machine Learning in Process Control

Applications of ML in Process Control

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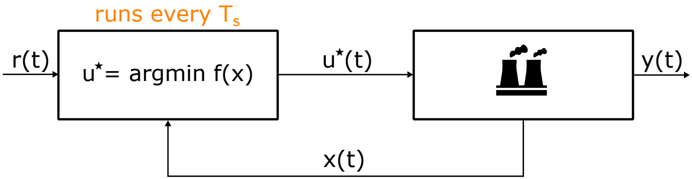
Speakers

- **Lecture**: Martin Klaučo, `martin.klauco@stuba.sk`
- **Exercises**: Patrik Valábek, `patrik.valabek@stuba.sk`

Comparison - MPC

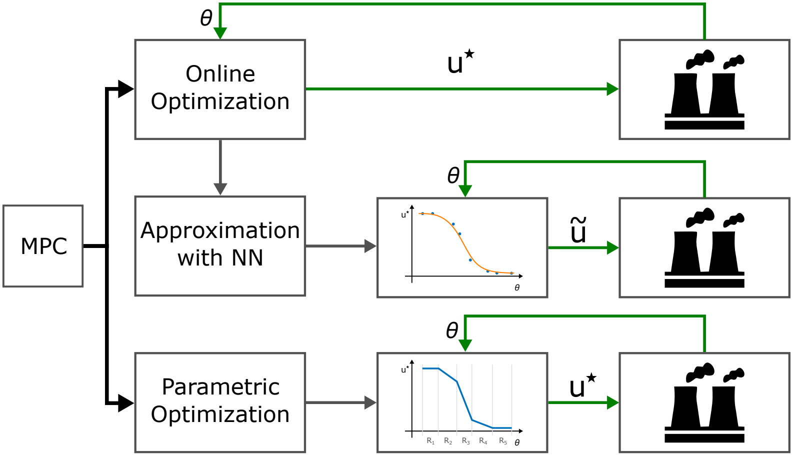


Holy Grail of Control

- Multiple-input Multiple-output Controllers
- Optimal control action (s.t. performance, contraints, etc.)
- Fast evaluation
- Low memory footprint

- $u^\star = f(\theta)$, where $f(\theta)$ is explicit function

Pros/Cons of MPC-based Control



Arbitrary problem size
Tunability
Online optimization

Fast execution
Tunability
Few kilobytes
Stability issues

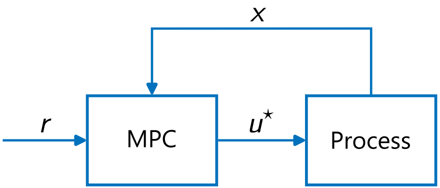
Fast execution
Tunability
Gigabytes
Small problems

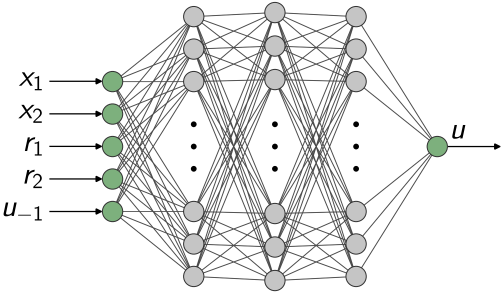
Training of Neural Network Control Law

Repeatedly solve MPC for
large pool of initial conditions

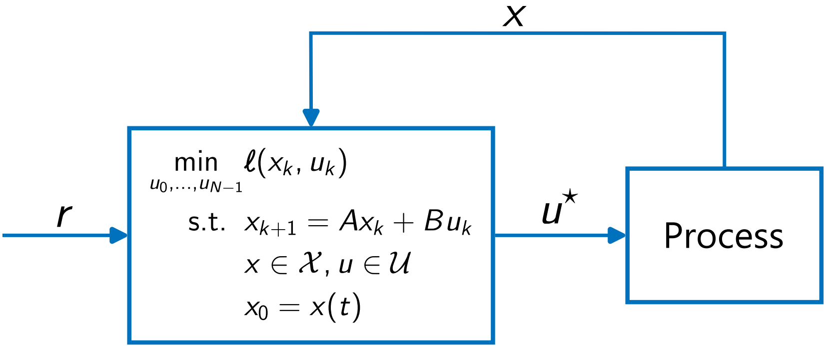
Train neural network
in offline mode

$$\min \left| u_{\mathrm{NN}} - u^{\star} \right|$$

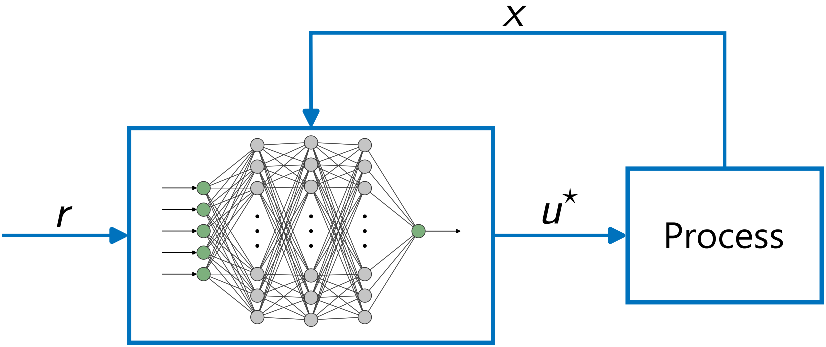




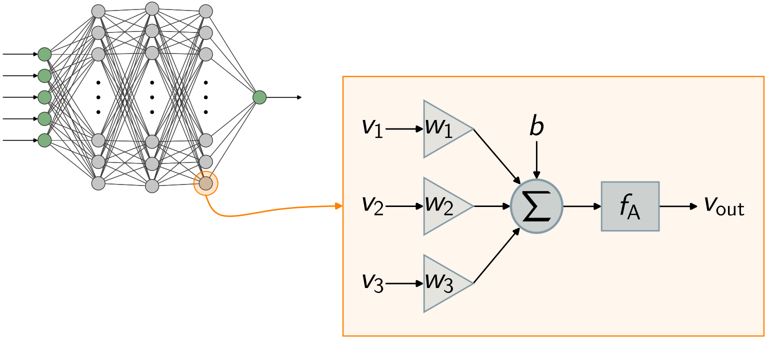
Closed-loop Arrangement with Neural Network



Closed-loop Arrangement with Neural Network



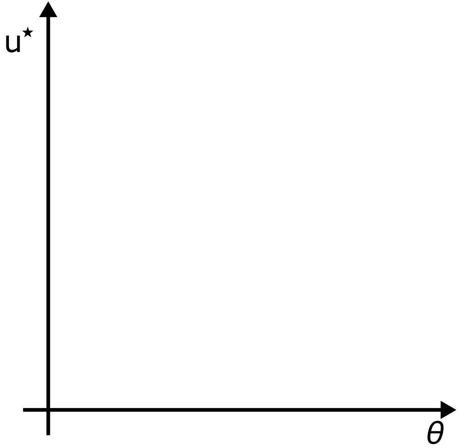
Single Neuron



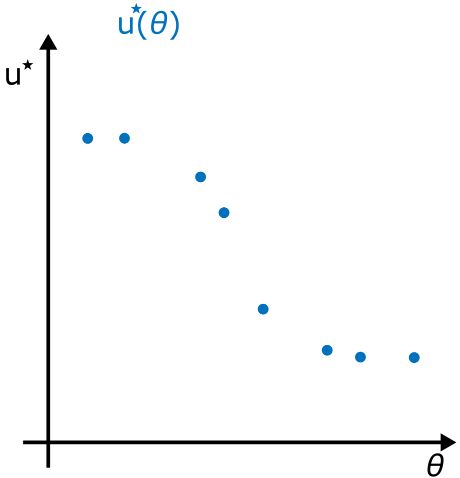
Neural Networks as Controllers

Is it a feasible approach? Can we do that?

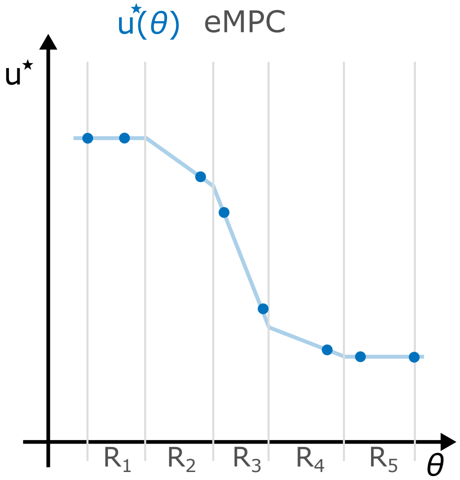
Explicit Controllers



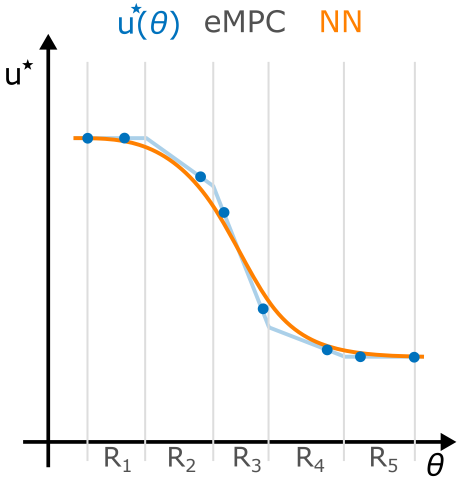
Explicit Controllers



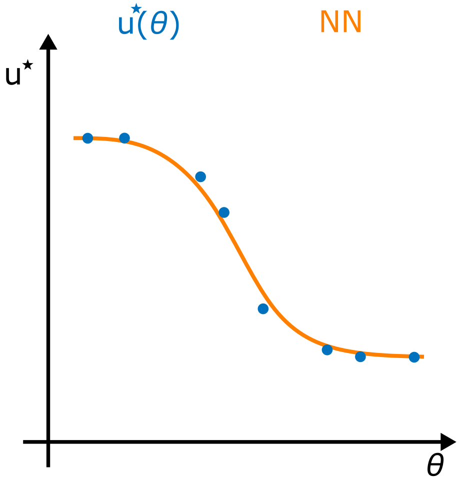
Explicit Controllers



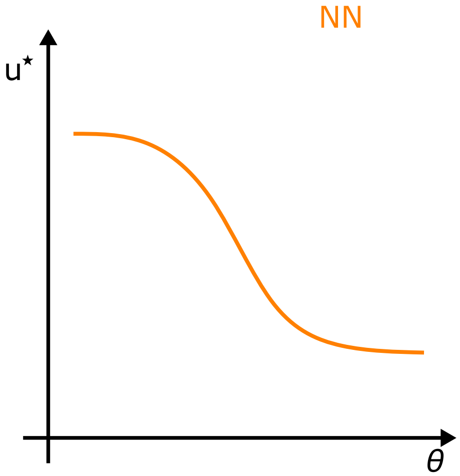
Explicit Controllers



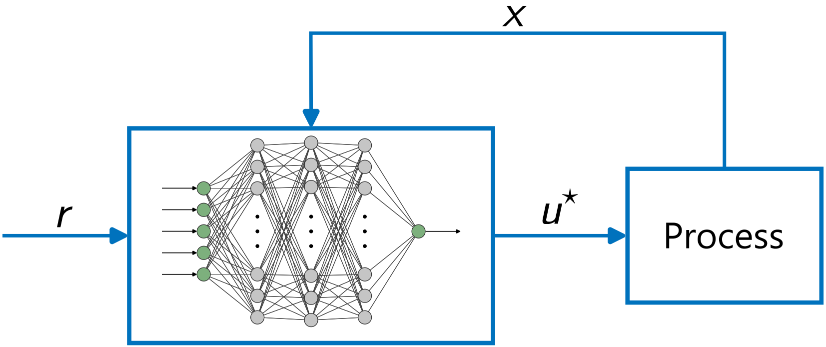
Explicit Controllers



Explicit Controllers



Closed-loop Arrangement with Neural Network

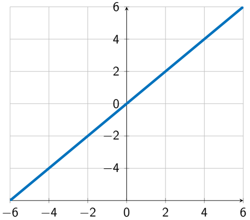


Activation Functions

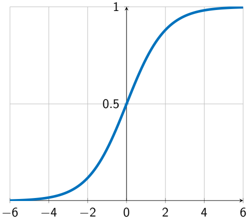
Type	Expression
Linear function	$f_{\mathsf{A}}(\gamma) = \gamma$
Sigmoid function	$f_{\mathsf{A}}(\gamma) = \dfrac{1}{1 + \mathrm{e}^{-\gamma}}$
Hyperbolic Tangent	$f_{\mathsf{A}}(\gamma) = \dfrac{e^{2\gamma - 1}}{e^{2\gamma + 1}}$
Rectified Linear Unit	$f_{\mathsf{A}}(\gamma) = \max(0, \gamma)$

$$\gamma = \sum_{i=1}^{n_{\mathrm{v}}} w_i \cdot v_i + b$$

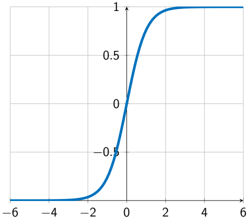
Activation Functions



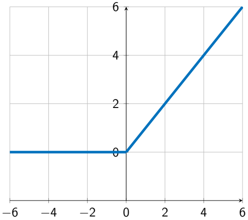
(a) Linear function



(b) Sigmoid function

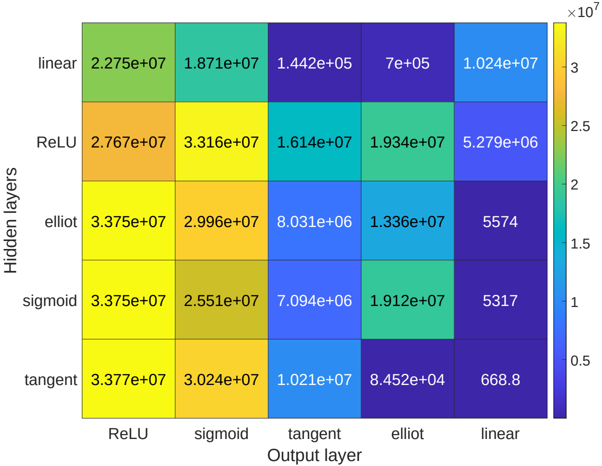


(c) Hyperbolic tangent function



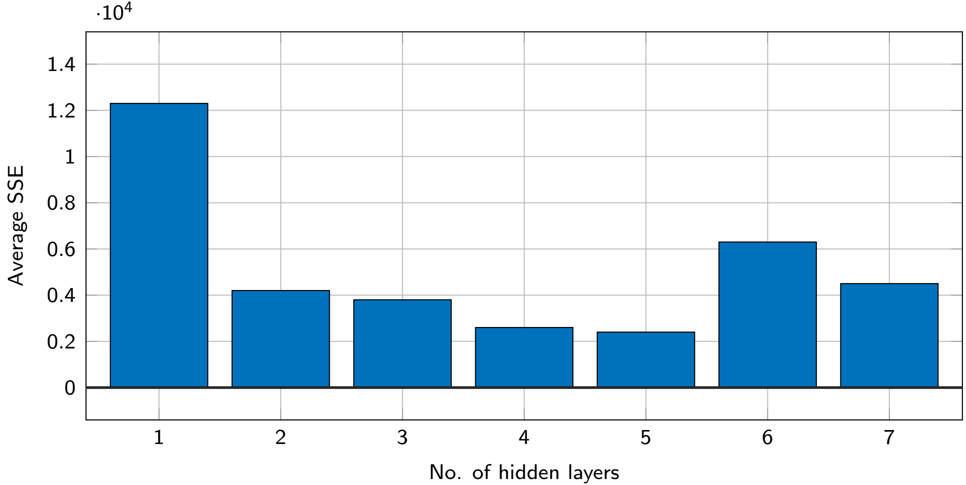
(d) ReLU function

Choice of the Structure of NN-based Controller #1



K. Kiš – M. Klaučo – A. Mészáros: *Neural Network Controllers in Chemical Technologies*. In 2020 IEEE 15th International Conference of System of Systems Engineering, IEEE, pp. 397–402, 2020.

Choice of the Structure of NN-based Controller #1



K. Kiš – M. Klaučo – A. Mészáros: *Neural Network Controllers in Chemical Technologies*. In 2020 IEEE 15th International Conference of System of Systems Engineering, IEEE, pp. 397–402, 2020.

Training of the Neural Network – NLP

$$\min_{w_i, bi} \sum_{j=1}^{M} |u_{\mathrm{NN},j} - u_j^\star|$$
$$\text{s.t.} \quad u_{\mathrm{NN},j} = F(\theta_j), \quad \forall j \in \mathbb{N}_1^M$$

where

$$F(\theta) = f_{\mathrm{A},1}\Big(f_{\mathrm{A},2}(\ldots), \ldots\Big)$$

objective function alternatives

$$\ell(\theta, u^\star) = \frac{1}{n}\left(u_{\mathrm{NN},j} - u_j^\star\right)^2$$

solved usually by Stochastic Gradient Descent Method

Main Goals

- Concept of neural networks
- Role of neural networks as controllers
- Data generation and NN training in MATLAB
- Deployment of NN-based control laws in MATLAB

Further Reading

- K. Kiš - P. Bakaráč - M. Klaučo: Nearly Optimal Tunable MPC Strategies on Embedded Platforms. In 18th IFAC Workshop on Control Applications of Optimization, IFAC-PapersOnline, pp. 326-331, 2022, LINK
- Y. Lohr - M. Klaučo - M. Fikar - M. Mönnigmann: Machine Learning Assisted Solutions of Mixed Integer MPC on Embedded Platforms. IFAC World Congress 2020, LINK
- Sergio Lucia - Benjamin Karg: A deep learning-based approach to robust nonlinear model predictive control, 6th IFAC Conference on Nonlinear Model Predictive Control NMPC 2018, LINK

Software to Install

- Matlab
- tbxManager https://www.tbxmanager.com/
- YALMIP `tbxmanager install yalmip`
- (optional) MPT3 `tbxmanager install mpt mptdoc cddmex fourier glpkmex hysdel lcp yalmip sedumi espresso`
- Statistics and Machine Learning Toolbox, Deep Learning Toolbox, Control Toolbox, Optimization Toolbox

Enjoy, learn, and keep in touch

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