Division of Systems and Control

Presentation 2021

Deep Neural Network

\[ p(y \mid x; \theta) \]
Today’s program

1. Division of Systems and Control – a brief overview (Stefan)
2. Undergraduate courses (Hans)
3. Research in Automatic Control (Alexander)
4. Research in Artificial Intelligence (Thomas)
5. PhD courses and outreach (David)
Mathematics, statistics, natural sciences

Basic Research

Machine Learning/AI and Control: modelling, analysis, design

Applied Research

Control systems technology

Machine Learning/AI: Ex. medicine, automotive, telecom, physics, ...

Product development
Characteristics

▪ Internationally recognized research in **System identification, Signal processing, and Machine Learning**
▪ Common theoretical ground – **Dynamical systems**
▪ **Application driven research** – Motivates and stimulates theoretical development
▪ Main application areas include: Biomedical Systems, Automotive Industry, Environmental systems, Telecommunications, Safety and Security in Control Systems
▪ Our PhDs/post-docs find good future careers both in industry (e.g., ABB, Ericsson, Klarna, Uber, Öhlins Racing, ÅF, Prevas) and at universities (e.g., Columbia, Linköping, Chalmers)
Personnel

- **Professors**
  - Bengt Carlsson
  - Alexander Medvedev
  - Thomas Schön
  - David Sumpter

- **Professor Emeritus**
  - Torsten Söderström
  - Petre Stoica

- **Visiting researcher Torbjörn Wigren (Ericsson)**

- ~7 Teachers and Researchers

- 23+ PhD-students (incl guests and IndD)
Courses and teaching at SysCon

- **Volume**
  - 126 HÅS/FTE ⇔ 9% of IT budget (excl. master theses)

- **Our students**
  - ~20% from master programs
  - ~80% from engineering programs:
    - mainly from F, STS, W, ES, E, IT

- **Our courses** (*in total 15-17 courses*)
  - **G/Bach level**: 5 courses, ~46 HÅS/FTE
  - **A/Master level**: 10 (12) courses, ~80 HÅS/FTE
  - **Subjects**:
    - *Automatic Control*: 6 courses, 9 instances, 50 HÅS/FTE
    - *Machine Learning*: 3 courses (5 incl. 7.5hp versions), 4 instances, 42 HÅS/FTE
    - *Modelling (and others)*: 6 courses, 6 instances, 34 HÅS/FTE
Courses and teaching at SysCon

**Volume**
- 15-17 courses
- 5 new courses in three years
- 126 HÅS/FTE $\Leftrightarrow$ 9% of IT budget (excl. master theses)

**Our students**
- $\sim$20% from master programs
- $\sim$80% from engineering programs:
  - *mainly from F, STS, W, ES, E, IT*

**Level**
- **G / Bachelor level:** 5 courses, $\sim$46 HÅS/FTE
- **A / Master level:** 10 (12) courses, $\sim$80 HÅS/FTE
Courses and teaching at SysCon

Subjects (very roughly)

Automatic Control:
○ 6 courses, 9 instances, 50 HÅS/FTE

Machine Learning:
○ 3 courses (+2 incl. 7.5hp versions), 4 instances, 42 HÅS/FTE

Modelling (and others):
○ 6 courses, 6 instances, 34 HÅS/FTE
Research programs

1. Automatic Control (Alexander)

2. Artificial Intelligence (Thomas)
Automatic control – a technology for efficient process operation
Automatic Control

- **Method development**
  - Nonlinear system identification
  - Impulsive feedback systems

- **Control technology**
  - Biomedical systems
    - Medical signal processing
    - Closed-loop and individualized therapies
    - Endogenous biological feedback
  - Biomechanics
  - Environmental systems
    - Modelling and control of wastewater treatment plants
  - Telecommunications
    - Networked data flow control
Project: Modeling of smooth nonlinear infinite-dimensional systems by Volterra series:

\[ y(t) = y_0 + \int k_1(\theta_1)u(t - \theta_1)\,d\theta_1 \]
\[ + \int\int k_2(\theta_1, \theta_2)u(t - \theta_1)u(t - \theta_2)\,d\theta_1\,d\theta_2 + \ldots \]

Application: Quantification of human smooth pursuit in health and disease from eye-tracking data

Result: Smooth pursuit is linear in health and nonlinear in disease
Automatic Control
Individualized therapies

**Project:** Individualization of deep brain stimulation (DBS)

**DBS:** Electrical stimulation of a target in the brain through surgically implanted electrodes

**Funding:** The Swedish Research Council (The EU Joint Program – Neurodegenerative Disease Research)

**Partners:**
- Uppsala University Hospital
- Charité – Universitätsmedizin Berlin
- University of Amsterdam
- University of Luxembourg

**Results:**
- Stimuli design formulated and solved as an optimization problem
- The therapeutical effect of DBS is evaluated in terms of measurable symptoms, e.g. tremor
Project: Model-based data-driven tools for optimization of proactive epidemiological interventions (part of CRUSH Covid)

CRUSH Covid is run at Uppsala University to support the authorities of Uppsala County in pandemic management

Data sources:
- Healthcare
- Covid-19 Symptom App
- Wastewater analysis (in cooperation with Uppsala Vatten)

Funding: Vinnova (Innovation projects that damp the spread and effects of the Covid-19 pandemic)

Results:
- Weekly reports with analysis and prediction of the epidemiological status
- Online public information through CRUSH Covid dashboard
- Data delivered to The Swedish Covid-19 Data Portal
Artificial Intelligence
Research in Artificial Intelligence

1. **Probabilistic modelling**
   a) General: Flexible models, in particular the Gaussian process (GP), deep GPs.
   b) Specific: **Dynamical** phenomena and their surroundings.

2. **Probabilistic numerics** (numerical methods and statistical models are deeply connected)
   a) Stochastic optimization (large-scale non-convex)
   b) Approximate integration/inference
      i) Sequential Monte Carlo
      ii) Variational inference
      iii) Markov chain Monte Carlo
3. **Deep learning (DL)**
   a) Representing uncertainty within deep learning (including Bayesian DL)
   b) Deep GP constructions
   c) Large-scale non-convex optimization algorithms
   d) Mathematical understanding of DL

4. **Probabilistic programming**
   a) Represent probabilistic models using computer programs
   b) Potential to automate modelling!
   c) Developing our own probabilistic programming language (Birch)
Research in Artificial Intelligence

5. **Reinforcement learning/control**
   a) Intersection of reinforcement learning (RL) and robust control (RC)
   b) Given observations find a policy to optimize the expected cost (as in RL), subject to certain robust stability guarantees (as in RC)

6. **Causality** (our newest topic)
   a) Aiming to learn causal relationships (not just associations/correlations)
   b) Naturally leads to the need for combining human knowledge and data.
PhD-level courses

- Deep learning (5+3hp)
- Sequential Monte Carlo methods (5hp)
- Reinforcement learning (5+3hp)
- Statistical inference and learning for data science (9+3hp)
Outreach

Using maths and computer science to do social good
PhD course, autumn term.

During this course the students will conduct their own individual project to use maths, computer science, statistics, machine learning or similar methods to give insight into and/or improve society.

For the hands-on/project part of the course the students will get help with:
1. Formulating a problem.
2. Downloading relevant data.
3. Applying tools from mathematical modelling and machine learning to the problem.
4. Presenting their work in a Youtube video and as a blog.
5. Learn how to balance rigour with time constraints.

Contact: Ida-Maria
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Outreach

Friends of Tracking
10K subscribers

Upcoming live streams

Friends of Tracking Is Back!
Friends of Tracking • 4 waiting • Scheduled for 4/8/21, 8:00 PM
A new season of Friends of Tracking. Hosted by David Sumpter and
season by talking to numbers expert John Muller (https://spacespi

Course: mathematical modelling of football
This series of videos (combination of live videos and prerecorded) take us all the way from loading
in data in to Python, through plotting data, expected goals, evaluating actions, working with tracking

Lecture 1: Mathematical Modelling of Football
Friends of Tracking
7.4K views •

Setting Up to do Data Science
Friends of Tracking
6.1K views • 1 year ago

Loading in and investigating
World Cup data in Python
Friends of Tracking
7.3K views • 1 year ago
Outreach
The final slide...

Thanks!