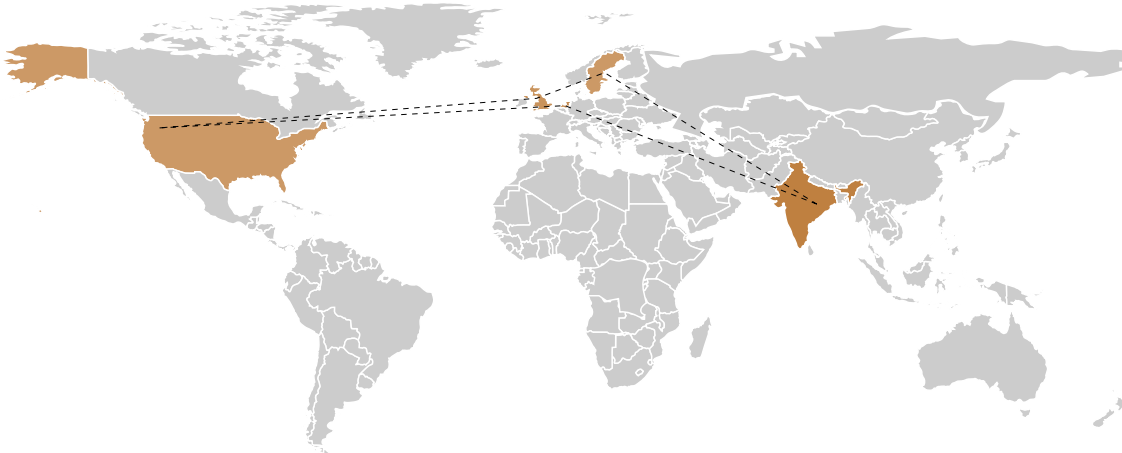
Ode to $+/-$ signs in feedback control

my journey through the realm of control systems

Amritam Das

My journey (geographically)



My journey (academically)

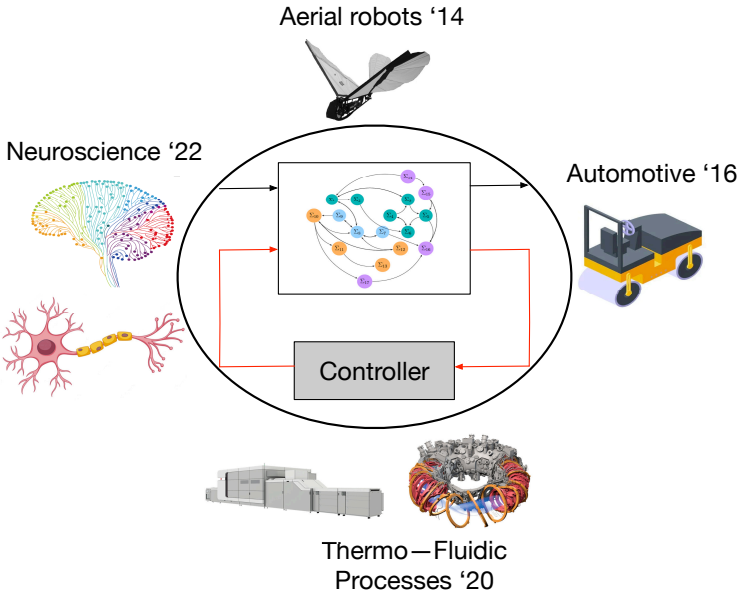
Aerial robots ‘14

Neuroscience ‘22

Automotive ‘16

Thermo—Fluidic Processes ‘20

My journey (academically)



Recurring theme:

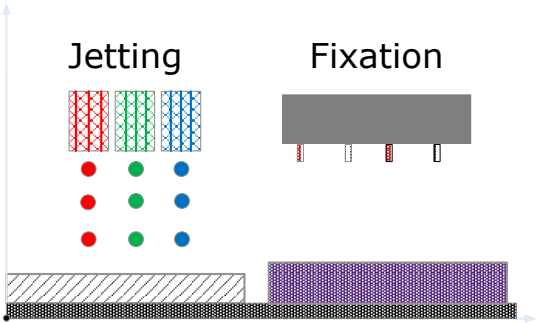
- Interconnection of components (position-dependent)
- Occurrence of natural or synthetic feedback

*Das et al (’14), *https://www.youtube.com/watch?v=dQrIFIgPilk&t=39s*
*Das et al (’16), *Optimal trajectory tracking control for automated guided vehicles*
*Das (’20), *A digital twin for controlling thermo-fluidic processes*
*Das et al (’22), *Oscillations in mixed-feedback systems*

Example: my PhD research

Example: my PhD research

Interaction of solids and fluids



Example: my PhD research

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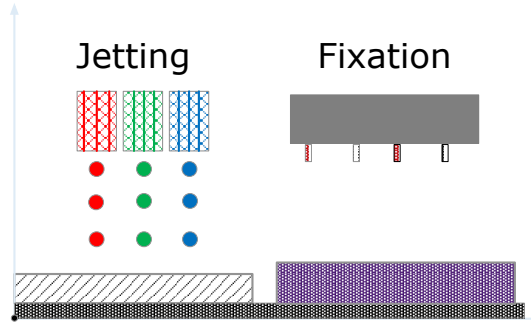


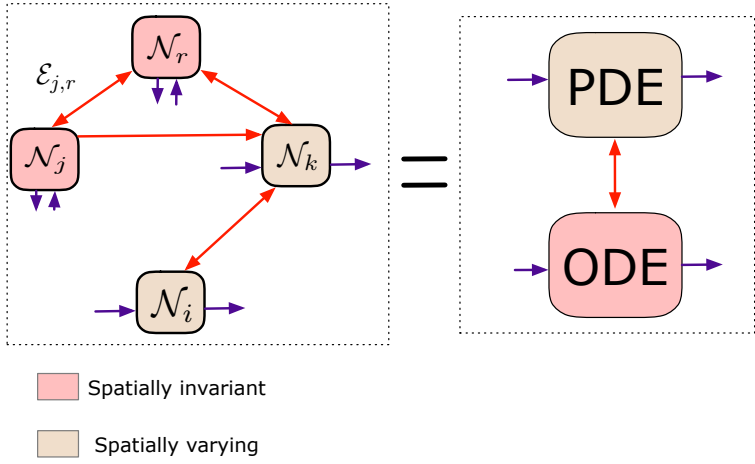
Print-quality → thermo-fluidic processes

1. Liquid temperature
2. Moisture and temperature of paper

Theme of Research

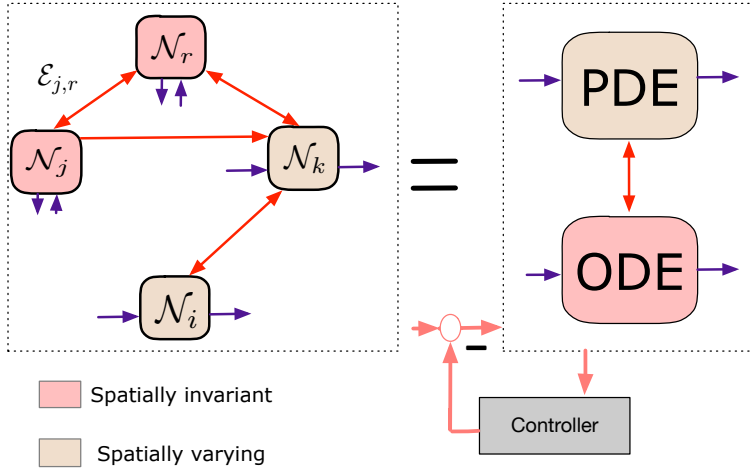
Develop *A Digital Twin for Controlling Thermo-Fluidic Processes* (PhD thesis '20)

Theme of my PhD research



- **Multi-physics models** in linear state-space form
- Synthesizing **(-ve) feedback loop** in 3-ways
- Computational tools from **convex optimization**

Theme of my PhD research



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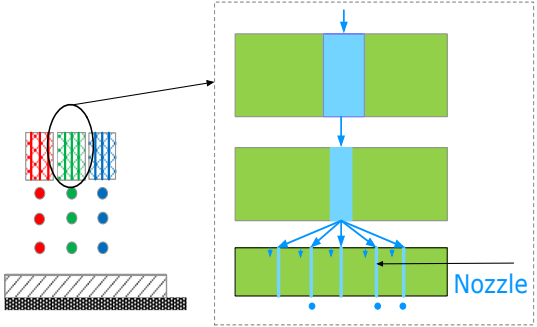
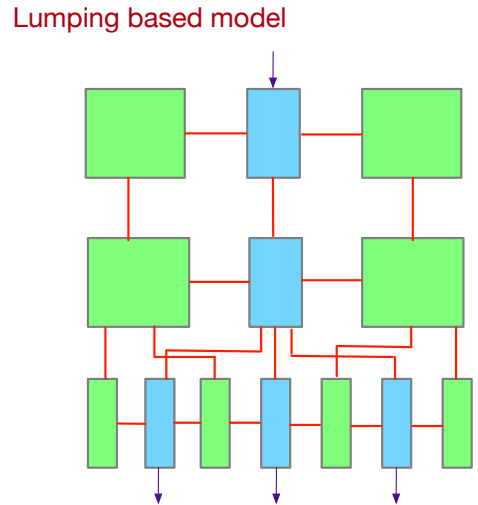
Application: how feedback controls temperature of jetting liquid in printers





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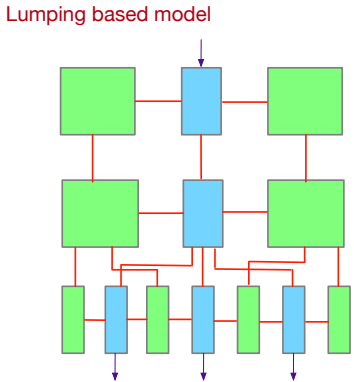
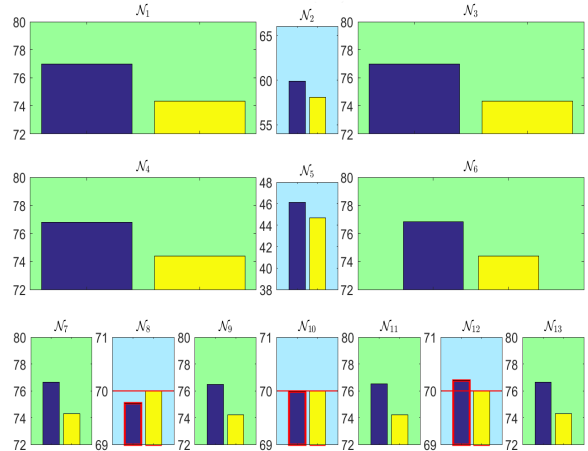
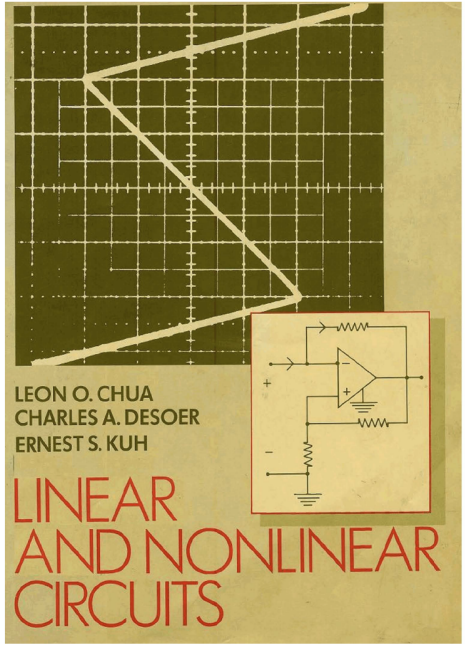




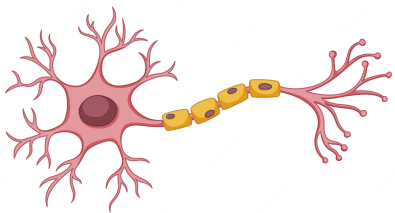
Without adding new sensors or actuators, by using negative feedback controller, fluctuation in liquid temperature among nozzles is kept below $\pm 0.3^{\circ}C$

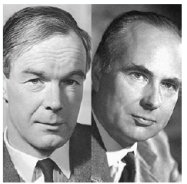
My academic journey post PhD



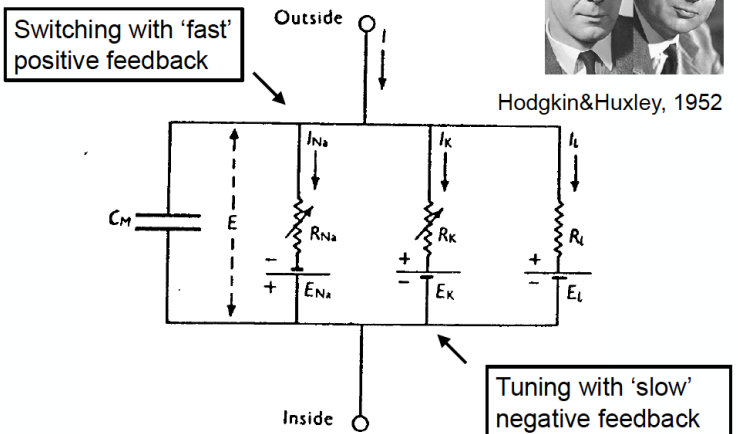
The fundamental device
for switches and oscillations
in the pre-digital age

Natural occurrences of +ve and −ve feedback





Hodgkin&Huxley, 1952



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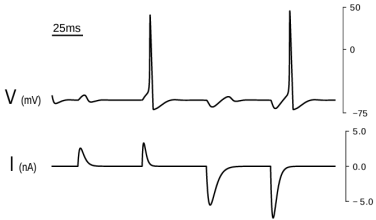

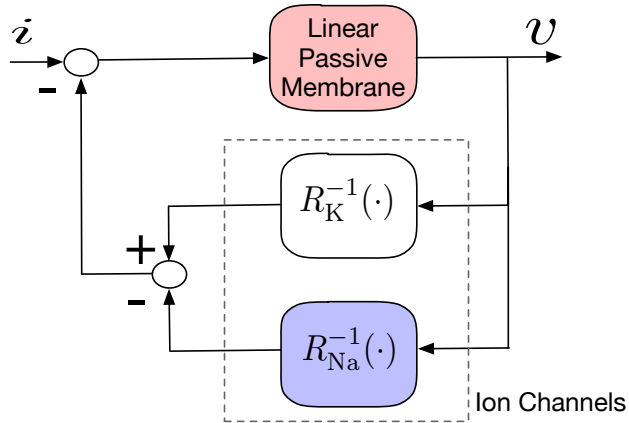

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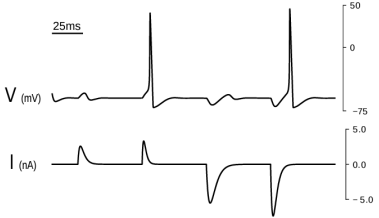
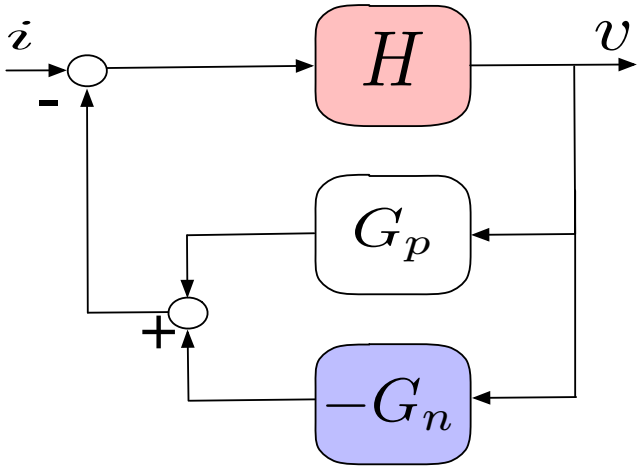
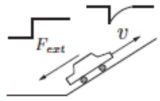
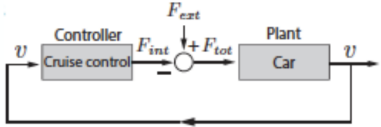
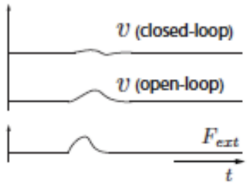




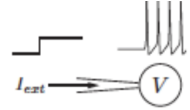
My academic journey post PhD: from classical feedback to mixed-feedback

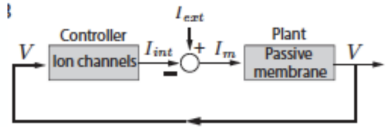


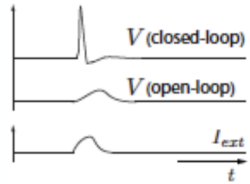




reduces sensitivity



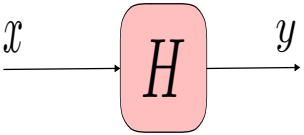




shapes ultra-sensitivity

Thematic viewpoint: incremental I/O analysis

- Let us look at one element:



- The supplied energy (in incremental sense)
  $\Delta V := \left\langle x_1 - x_2, y_1 - y_2 \right\rangle$
- H is **incrementally passive** if $\Delta V \geq 0$

Thematic viewpoint: incremental I/O analysis

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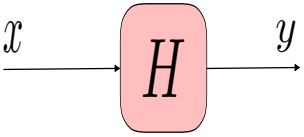

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In the language of operator theory

For causal operators, incremental passivity is synonymous to *Monotonicity* on signal space
(A positive change in the input should cause a positive change in the output)

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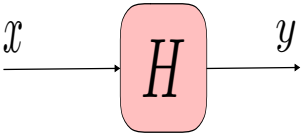

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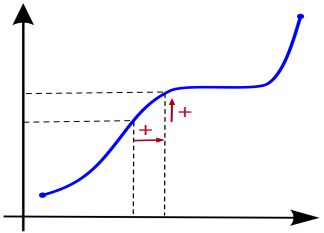

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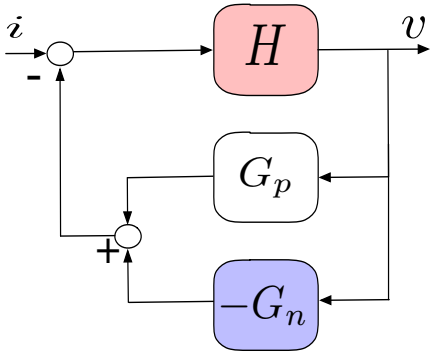
*Minty(1960), "Monotone networks"
*Camlibel and Schumacher (2016), "Linear passive systems and maximal monotone mappings"

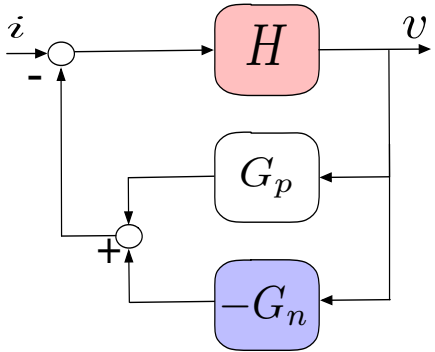
Mix-signed feedback interconnection of monotone operators
= Difference of monotone operators



$$0 = H^{-1}(v) + G_p(v) - i\underbrace{-G_n(v)}$$

H, G_p, G_n are monotone

Mix-signed feedback interconnection of monotone operators = Difference of monotone operators



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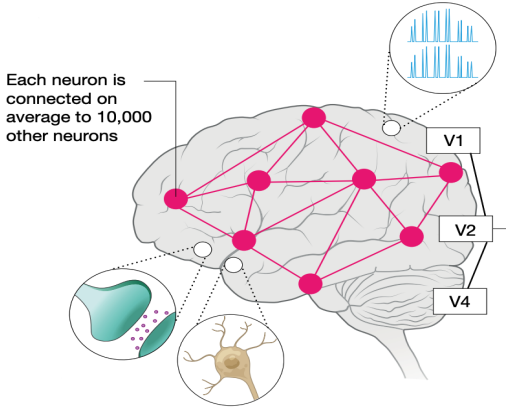
Takeaway: Connecting monotonicity and theory of optimization

- Computing output requires minimizing the difference of convex function: leads to a locally convergent algorithm
- Scalable to larger networks by port-interconnection mixed-feedback systems in series, parallel, and -ve feedback
- Operator-splitting algorithm allows for solving a large network of mixed-feedback systems

*Das, Chaffey, and Sepulchre ('22): *Oscillations in Mixed-Feedback System*

Part of my research plan for future: motivation

How control occurs in brain: understanding patterns that emerge from a cluster of neuron



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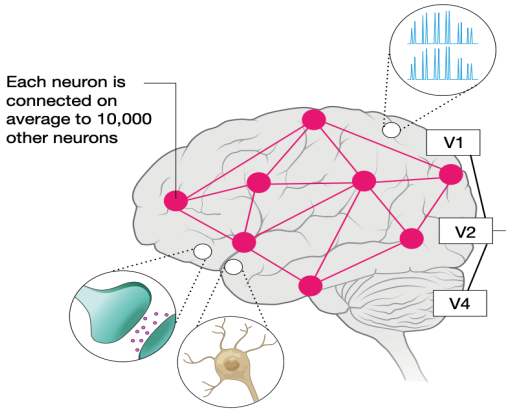

Neuronal Signaling

- Patterns varies spatio-temporally
- Rhythmic, spiking, and bursting
- Ultra-sensitive
- **Excitable**

Part of my research plan for future: theme

Develop a computational tool to analyze and synthesize mixed-feedback architecture for robust modulation of spatio-temporal neuronal patterns

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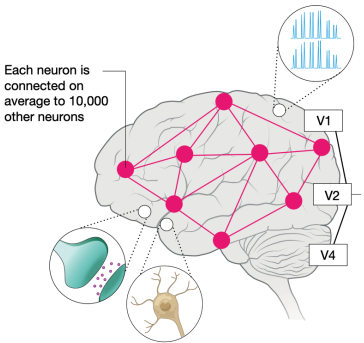

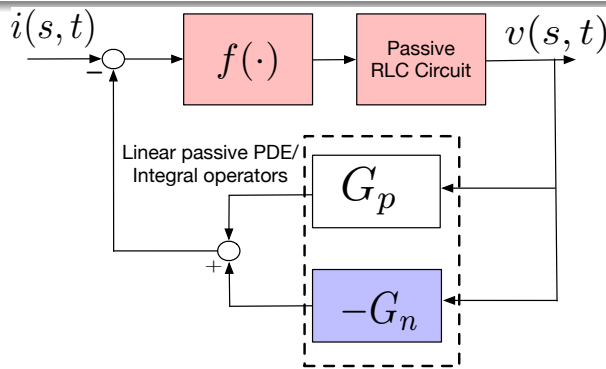

$f(\cdot) :=$ 

*Schiff ('21): *Neural Control Engineering*

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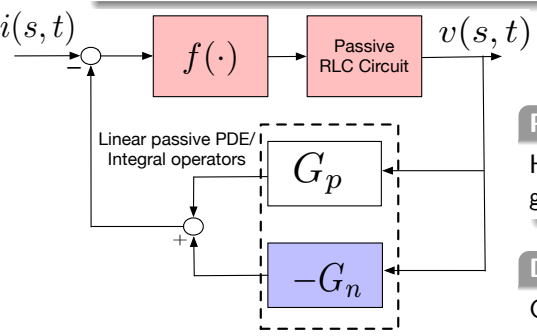


Physics-driven approach

How to synthesize G_p, G_n such that a specific pattern can be generated?

Data-intensive approach

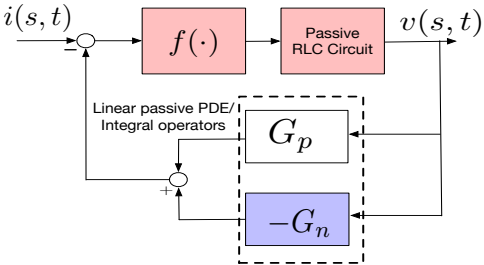
Given input output data, how to learn the mixed-feedback architecture of a neural field?

*Schiff ('21): *Neural Control Engineering*

*Sepulchre ('22): *Spiking Control Systems*

Part of my research plan for future: proposal for VENI'23

Synthesizing G_p, G_n



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Part of my research plan for future: proposal for VENI'23

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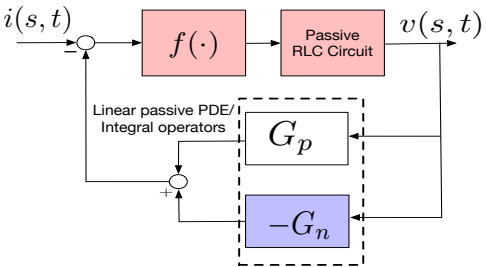


Parameterize with Partial Integral (PI) Operators

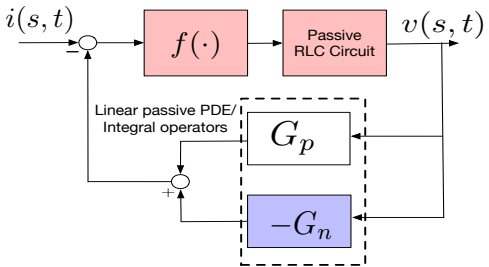
- **What?**

$$P_{\{R_i\}}\mathbf{x}(s) = \int_a^s R_1(s,\theta)\mathbf{x}(\theta)\mathrm{d}\theta + R_0(s)\mathbf{x}(s) + \int_s^b R_2(s,\theta)\mathbf{x}(\theta)\mathrm{d}\theta$$

- **Where?** PI to represent G_p, G_n in a class of neuronal models
- **Why?** Enforcing monotonicity on PI using LMIs and solving them
- **How?** Periodic nature of v is determined by the spectra of a matrix underneath $G_p - G_n$

Part of my research plan for future: proposal for VENI'23

Synthesizing G_p, G_n



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Some relevant fields: Relay-feedback systems, Dominance theory, DC programming

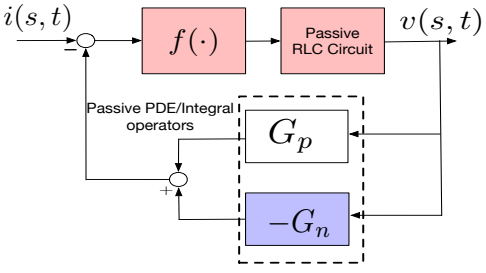
*Shivakumar, Das, Weiland and Peet ('22): *Extension of the Partial Integral Equation Representation to GPDE Input-Output Systems*

*PIETOOLS: *http://control.asu.edu/pietools/*

*Das, Sepulchre, and Johansson (Upcoming): *Mixed-Monotone Analysis of Relay Feedback System*

Part of my research plan for future: a bit more ambitious

Learning from data



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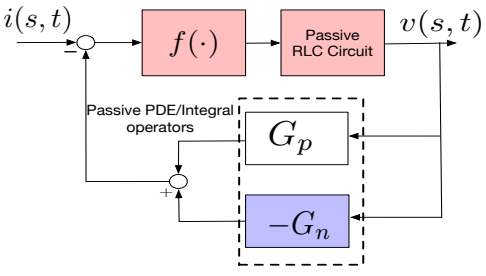


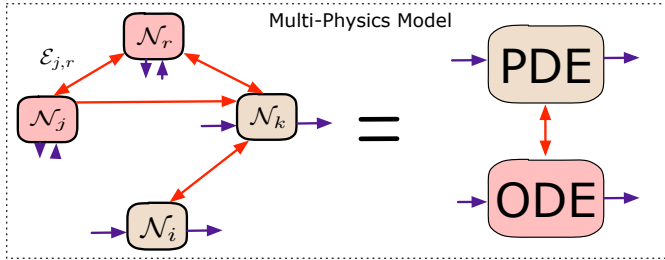
Leveraging machine learning tools

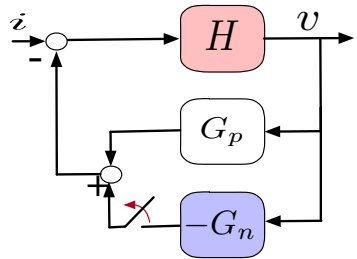
- What would be the model hypothesis for individual path?
- How can we leverage the the mixed-feedback architecture in learning excitable behavior?
- Towards learning G_p, G_n when they are non-linear

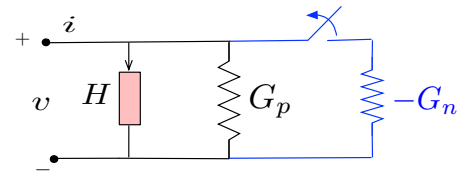
Some relevant fields: Operator learning, monotonic neural network, physics informed learning

*Das, Aguiar and Johansson ('22): *Neural network architecture for learning fows of controlled dynamical systems*

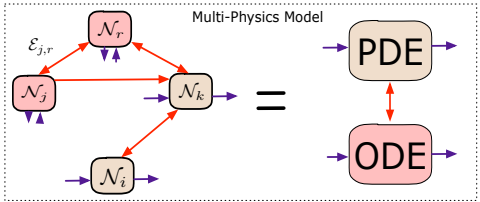
Theme of my future research in a nutshell

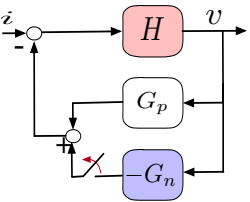


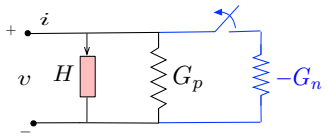




Theme of my future research in a nutshell: outlook







Conventional feedback

- **Theme:** Robust and Nonlinear Control of Multi-Physics Systems
- **Applications (honoring the past):**
  - High-tech systems (Canon, ASML, Philips, TNO, Demcon)
  - Nuclear fusion (DIFFER, ASU)

Mixed-feedback

- **Theme:** Synthesis and learning of spatio-temporal oscillators
- **Applications (bringing the new):**
  - Neuromorphic engineering (UCSD, IMAG/e)

Teaching experience and philosophy

Teaching is a major part of the reason why I want to stay in academia

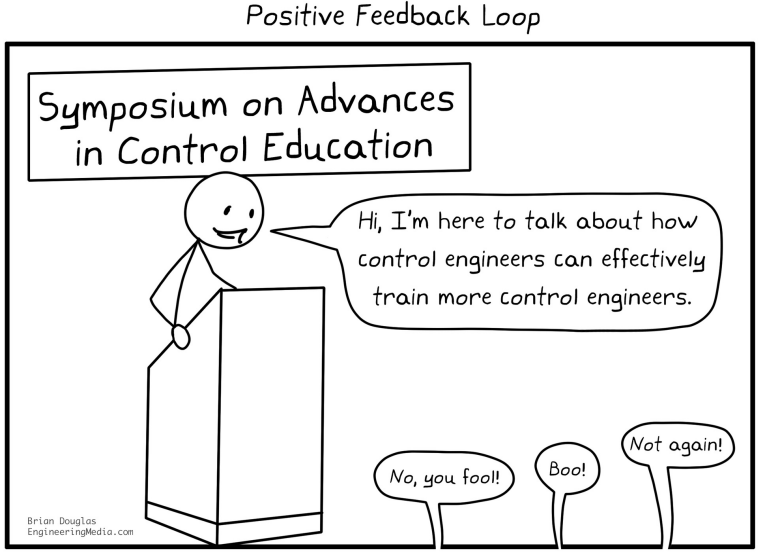
Past teaching experiences (+ 4 Masters students supervision)

1. 5LMA0-Model Reduction(TU/e): Making every year's project 'cooler' than the previous year's
2. 5ESB0-Systems(TU/e): Answering to 'what am I supposed to do with this subject'
3. GF1-Control Systems Porject(Cambridge): Answering to 'this is easy, I want to do more'

Teaching Ambition

1. Student-focused, example driven and project based (*chalk and blackboard are not overrated*)
2. More usage of recitation and flipped-classroom during practice sessions (*e.g. today's lecture*)
3. Love to design my own course (*e.g. nonlinear circuit theory*)
4. **First step: Getting my UTQ certification**

Teaching experience and philosophy: respect the $+/-$ feedback!



To protect against an unstable growth in control engineers, the audience started providing negative feedback.

Networking and Outreach

1. Privileged to serve as a co-author of **IEE CSS Roadmap 2030** (section: Climate Change, only 2 post-docs)
2. Founder and host of **KTH-PIL reading club**
3. Responsible researcher for coordinating EU project with five international collaborators
4. **Upcoming-IFAC WC'23:** 1 Workshop on 'A showcase of LMI-based methods for PDEs' (with M. Peet)
5. **Upcoming-IFAC WC'23:** 1 invited session on 'Physics informed learning for control' (with K. Johansson)

My aspiration

Get inspired by cutting-edge technological developments and enable them with the help of control theory

1. I am self-driven, passionate, and committed to my work
2. My past experience with the academia-industry ecosystem of Eindhoven is an asset
3. I believe scientific and industrial collaboration is key to make an impact in engineering science
4. In future, I am determined to get my own fundings to realise my research plan.

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Thank You!

We hear within us the perpetual call: There is the problem. Seek its solution. — David Hilbert