

# MSc Project cocktail: Advanced data analysis through embedded intelligence

## Why would you choose such a master thesis project?

It is a novel and an exciting research field with enormous practical relevance. The standard process of data analysis involves two steps that are performed in a sequence, starting with a data collection step followed by an analysis step that is performed by using a central artificial intelligence unit that “sees” all the information and makes a decision. For example, pictures sent from cameras are analyzed centrally to make a decision whether the current speed limit should be changed or not. An interesting question is whether a part of the analysis effort done by the central analyzer can be performed at the same place where the information is collected. Can the analysis part be moved deeply into the sensor? by e.g. constructing an intelligent sensing substrate. This possibility is explored within the H2020 project RECORD-IT, coordinated by Chalmers.

## What are the benefits?

The master thesis projects provide an ample opportunity for young people to train in a novel, exciting, and emerging area that can be described with keywords such as “embedded computation”, “internet of things”, “functional diversification”, “energy efficient computation”, or “unconventional computation”. Academia, small, and large businesses are aggressively reacting to such possibilities.

## Scientific goals

The master thesis projects listed below aim to answer the following questions, but with some specific focus added:

- How do we design dynamical systems that are useful for data collection and analysis?
- What are the limits of embedded computation with generic dynamical systems?
- How do we compare computing capacities of different dynamical systems?

## Organizational

The project descriptions provided below a very broad outline of the specialization possibilities. Every project has two parts: the initial reading period, followed by an implementation of the ideas found in literature, or newly generated ideas obtained by reading the literature. All work is theoretical. No experiments are envisioned (unless they can be simulated on a computer).

## Generic prerequisites for all projects

- some affection towards abstract thinking
- ODE systems: ability to numerically integrate a system of equations using e.g. Euler method or implicit Euler method
- elementary understanding of the “dynamical system” concept
- rough understanding of workings of neural networks
- generic understanding of pattern recognition

## Useful knowledge from your master program courses

- generic machine learning concepts
- pattern recognition
- supervised versus unsupervised learning
- neural networks basics

## Projects

**It is strongly advised that you get in touch with the contact provided below for further specific steps. The generic project descriptions provided below only serve as a start of the discussion to tailor the project for each candidate.**

The central theme in all project suggestions is reservoir computing. This is an exciting new technique in the field of machine learning. It can be approached from variety of angles; theory and applications in all colors and flavors; this is really a broad topic. As a model of computation, reservoir computing is useful for understanding/implanting embedded computation. Reservoir computing has emerged as an exciting novel paradigm for describing information processing with generic dynamical systems.

Each project suggestion describes a problem related to an implementation of reservoir computing on a particular sensing substrate. We focus on a class of such substrates, a network of environment sensitive elements. Each networks is constructed by linking environment sensitive elements into a big dynamical system. The projects target different element types, and types of networks. Should a student wish to investigate another sensing substrate, or architecture, it can be discussed. As a case study, we focus on pattern recognition problems that are typical for time-series data analysis.

Useful dictionary:

- dynamical system: can be described by a state  $x$  at time  $t$ ,  $x(t)$ , and the state changes according to some predefined (dynamical) law:  $x(t+1)=f(x(t),q(t))$  where  $q(t)$  is the variable that represents the influence of the environment on the state of the system.
- network: a system made of elements connected together
- element: the operational part of the network, should be sensitive to the environment
- links: connect the elements into a network, these links can be concrete (engineered) or abstract
- element model: a dynamical model that describes how a single element behaves, we used a small ODE system to describe such an element

### **Project 1: Environment sensitive memristor networks for advanced sensing applications**

*Problem:* Investigate sensing capacity of environment sensitive memristor networks.

*Method:* Numerical work mostly, but some sort of measure for estimating the sensing performance needs to be developed, which requires an ability to do abstract thinking. The idea is very simple: Use the simplest possible memristor model, build networks of these, simulate such networks on a computer, and sort all performances, inspect and analyze for trends.

### **Project 2: Environment sensitive transistor networks for advanced sensing applications.**

*Problem:* Investigate the sensing capacity of the system.

*Method:* Same as for Project 1. The only difference is that we focus on the elements that are transistors. To that end, the simplest possible transistor model will be used (e.g. the ideal transistor

model found in the textbooks). Optionally, based on an interest, one can use the more exotic models developed internally at MC2 within the RECORD-IT project.

### **Project 3: Environment sensitive amorphous materials for advanced sensing applications.**

*Problem:* Projects 1 and 2 focus on engineered structures. Can one do the same with random structures? Do we gain or lose in the sensing capacity?

*Prerequisites:* In addition to the generic ones listed above, some understanding of probabilistic concepts is a huge advantage. If probability theory is not your strong side, it is ok to aim for this project nevertheless, one learns as one does, but you should at least enjoy probabilistic thinking.

*Method:* As for Projects 1-3. However, here we consider random network structures. Here the goal is to assume much simpler elements, but their number should be very large.

*Note:* No previous knowledge is required about the physical and chemical properties of amorphous materials. All concepts will be explained by the supervisor. The simplest possible element model will be used. Such a model will include the usual equivalent electrical circuit linear element models such as resistances, capacitances, etc.

### **Project 4: Measuring computing capacities of vastly different systems**

*Problem:* For Projects 1 to 3, a very crude measure of the sensing capacity will be used. The goal of this project is to design better measures of the computing/sensing capacity. This is a very open problem, only for true thinkers, who are not afraid of unknown and enjoy abstract thinking.

*Method:* Start from the recently published algorithmic template, and implement it for a specific problem. For example, have you ever wondered: how intelligent is a neural network? If yes, then this could be your system of interest.

## Contact information

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## Recommended reading

**Dambre, J., et al., Information Processing Capacity of Dynamical Systems. Scientific Reports, 2012. 2: p. 514. (<http://www.nature.com/articles/srep00514.pdf>)**

Pedagogical introduction to a brute force estimation of the computing capacity. One simply counts the number of functions a system can compute. This publication reflects to some extent the technical side of the suggested projects.

**Konkoli, Z., On developing theory of reservoir computing for sensing applications: the state weaving environment echo tracker (SWEET) algorithm. International Journal of Parallel, Emergent and Distributed Systems, 2016: p. 1-23. (<https://doi.org/10.1080/17445760.2016.1241880>)**

Generic theory of using reservoir computing for sensing applications.

**Athanasiou, V. and Z. Konkoli, On using reservoir computing for sensing applications: exploring environment-sensitive memristor networks. International Journal of Parallel, Emergent and Distributed Systems, 2017: p. 1-20. (<https://doi.org/10.1080/17445760.2017.1287264>)**

Application of reservoir computing to memristor networks. The memristor network is an example of a neuromorphic structure where nonlinear elements interact and influence each other. The key point: it does not have to be a neuron. There are many ways of realizing neuromorphic computation.