CIRCUITS AND SYSTEMS

MSc Thesis Project Information 2019

TU Delft

Delft University of Technology

Faculty EEMCS

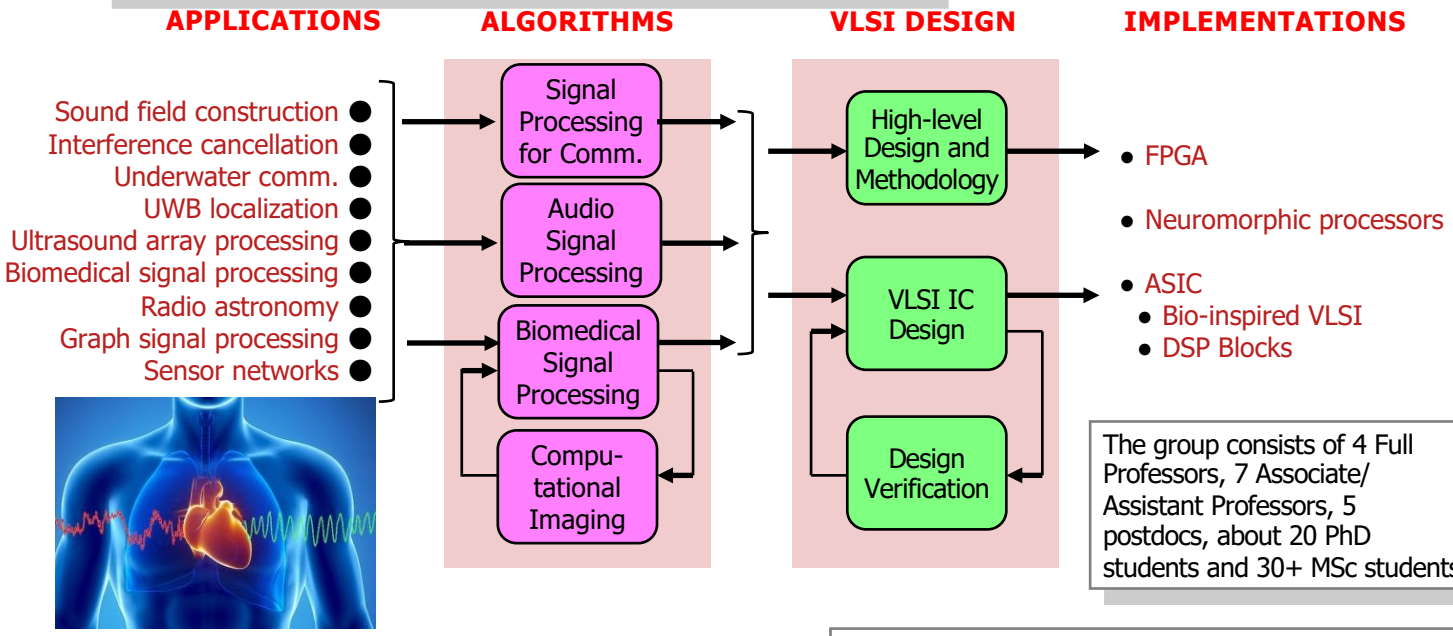
cas.tudelft.nl

The CAS group

CAS covers the theory and applications of circuits and systems, signal processing, and VLSI circuit/system design and methodology

One track of activities centers around ***acoustical signal processing, signal processing for communication and array signal processing***, with applications in hearing aids, localization of sound sources, receiver algorithms for wireless communication, array signal processing (utilizing multiple antennas) for radar and radio astronomy, and ***biomedical signal processing. Computational imaging*** can be viewed as a specialization of array processing: how to make an image out of samples taken with many antennas.

Ultra-wideband communication and positioning, cognitive radio, radio astronomy and computational image formation, RFID, signal processing for sensor arrays, e.g. sensor node localization, massive MIMO, are some communication signal processing topics …



The group consists of 4 Full Professors, 7 Associate/ Assistant Professors, 5 postdocs, about 20 PhD students and 30+ MSc students.

Electronic systems and VLSI design is another track of the group. We facilitate a performance conscience methodology to realize digital and mixed electronic systems (e.g. SoC's, multi-core, dataflow DSP) starting from high level algorithm descriptions. Further, we use this methodology to realize typical complex computing blocks, for example security and safety hardware, multi-core processors, network interconnect, neuromorphic compute blocks, high-speed communication interfaces or similar complex compute blocks.

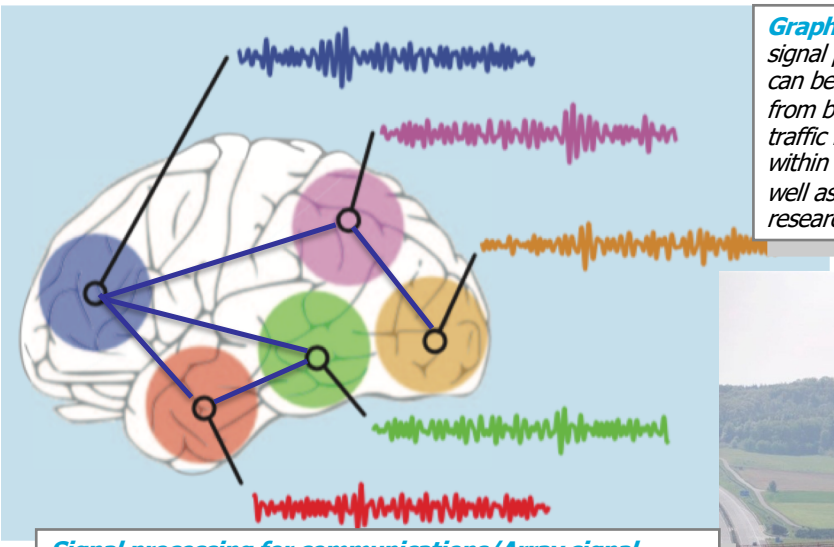
We have strong networks of co-operation with various companies, in the Netherlands, Europe and overseas. Such companies include Philips, NXP, Magma, Infineon, Magwel, Controlec, Thales, TNO, ASTRON, Holst Centre, Huawei, Oticon. We collaborate with several University Medical Centers (Rotterdam, Leiden, Utrecht, Amsterdam).

We also participate in multiple European and national research projects where we have research co-operations with other universities.

We have a strong international orientation – considering cooperations as well as group members

Signal Processing for Communication

CAS offers a mix of research topics from highly mathematical and theoretical to practical hands-on work in the lab. Notwithstanding their diverse nature, they are highly interrelated and work towards some common goals of researching new things and demonstrating their effectiveness in practice. That is, in the CAS group, we enjoy doing new things that are both scientifically and practically relevant. And by actually working towards real implementations of our ideas, we stay connected to practice and learn a lot about what are interesting problems to solve. On the following pages you can read about our current research tracks.



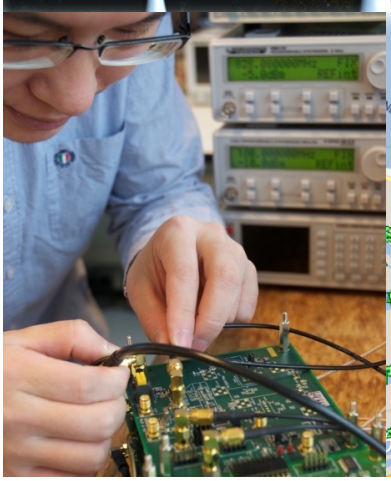
Graph signal processing (GSP) *extends the field of classical signal processing to signals that have an irregular domain that can be characterized by means of a graph. Examples are signals from brain networks (fMRI, fUS, EEG, etc.), social networks and traffic networks. Our group has pioneered some key concepts within this field. We are currently developing new GSP theory as well as applying GSP to real data improving state-of-the-art research results.*

Signal processing for communications/Array signal processing refers to the parallel processing of signals from multiple antennas. This allows separating multiple signals, and can be used to increase the capacity or the robustness of mobile systems. We mainly work on advanced receiver algorithms and localization using multiple antennas and multiple nodes, and develop algorithms for "compressive sampling" (below Nyquist rate) and distributed processing.

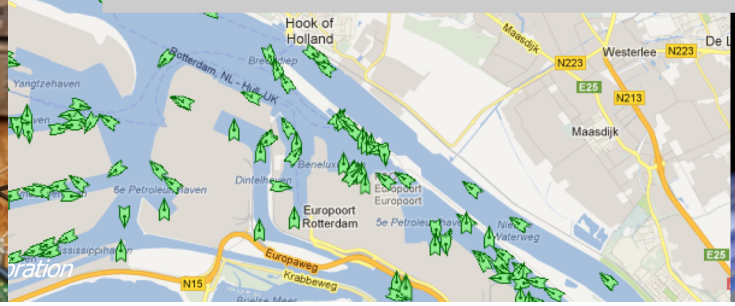
The SuperGPS projects aims to achieve reliable cm-level accuracy of cars using accurate timing estimation of UWB signals to enable autonomous driving applications

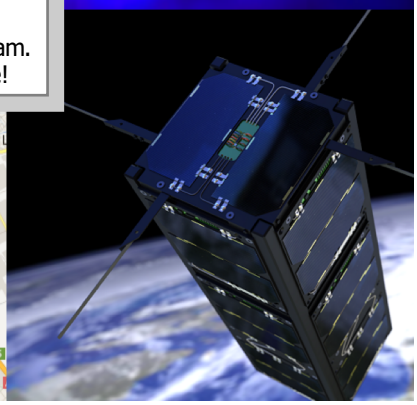
Radio astronomy We do not just consider mobile communications, but also work on computational aspects of radio astronomy image formation, to enable future telescope arrays such as SKA (Square Kilometer Array)

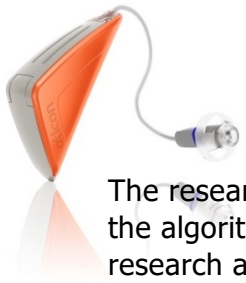
Time synchronization of clocks is key to many applications



Separation of overlapping ship transponder signals (AIS system), used for tracking ships. An experimental 4-antenna system allows to separate 4 overlapping signals at a time, allowing to resolve many more ships in the harbor of Rotterdam. One of our separation algorithms was actually sent into space!







Audio and Speech Signal Processing

The research in the audio and speech signal processing group is focused on the development of the algorithmic and theoretical foundations of signal and information processing. The main research areas currently covered are multimedia data compression (speech, audio, video), single- and multi-channel speech enhancement, signal processing for large-scale sensor networks (localization, distributed signal processing), signal processing for hearing aids, and acoustical signal processing. The audio and speech processing group has tight connections with industry (sponsored research), e.g., Google, Bosch, Bang & Olufsen, Oticon A/S, Philips, etc.

Speech reinforcement In large public environments, such as train stations, airports or shopping malls, public address systems broadcast spoken messages to the audience for security purposes (evacuation) or for conveying useful information. In such an announcement scenario, understanding of speech is compromised due to noise in the vicinity of the listeners, reverberation of the acoustic environment or crosstalk between announcement regions (e.g., two platforms of a train station). In this scenario, we wish to pre-process the speech signal at the public address system such that when it is played back in the environment, intelligibility is improved.

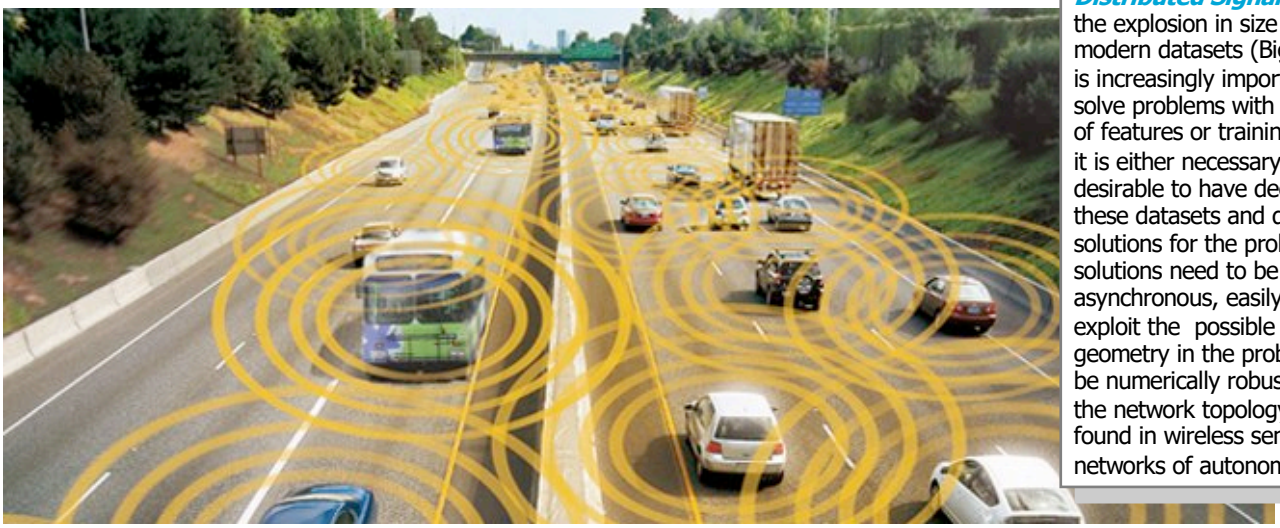
Signal Processing for Hearing Aids Hearing impairment has become a serious problem for a large and increasing portion of the population. Often reported problems for hearing-impaired people are the inability to understand speech in acoustic challenging situations, and, the inability to correctly localize sound sources. Together with Oticon A/S, we develop algorithms to improve the speech intelligibility while preserving the ability to correctly localise the acoustic sources. In addition to algorithm development, we also develop models that can predict human speech intelligibility of processed noisy reverberant speech signals.

Sensor localization Sensor networks facilitate the use of spatial signal processing such as multi-microphone speech enhancement where multiple microphones can be used to improve both speech quality and speech intelligibility in noisy environments. We focus on the situation where we have separate transmitting and receiving sensors, such as a microphone network that has to be calibrated using external acoustical events, and develop methods to automatically localize the sensors.

Acoustical Signal processing Human technologies are close to achieve the next milestone in communication experiences of giving the illusion of being at a remote place with great fidelity. In order to create the illusion of presence and the ability to roam free through the place, an accurate acquisition and control of the sound fields is necessary. In this context we work on developing low-complexity methods for modeling room impulse responses.

HUAWEI

Distributed Signal Processing

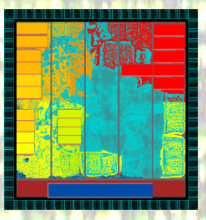


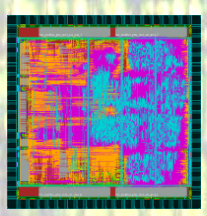
Distributed Signal processing Due to the explosion in size and complexity of modern datasets (Big Data), it is increasingly important to be able to solve problems with a very large number of features or training examples. Hence, it is either necessary or at least highly desirable to have decentralised storage of these datasets and distributed solutions for the problems. These solutions need to be parallelisable, asynchronous, easily scalable, be able to exploit the possible (large) sparse geometry in the problem and need to be numerically robust against changes in the network topology. Applications can be found in wireless sensor networks or networks of autonomous driving vehicles.

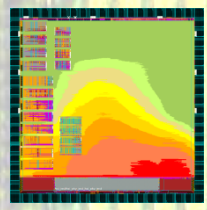
Electronic Systems and VLSI Design

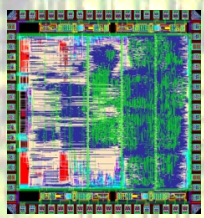
Research topics of our group offer you plenty of opportunity for interesting thesis work; ranging from creating or implementing a System-on-Chip or FPGA design via finding new ways of solving some VLSI modeling problems related to safety, security, healthcare and automotive applications, that will be immediately useful. Get involved in the world of block-chain and IoT!

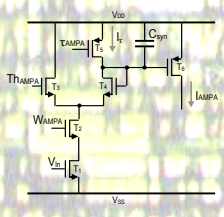
- Low-power & high-speed SOC designs and methods
- High performance compute blocks, safety&security methods, high-speed interconnect engines
- Neuro-inspired or neuromorphic circuits and algorithms (AI platforms & ML)
- On-chip learning and intelligent sensor fusion/cognitive acceleration
- High-speed and secure on-chip and off-chip communication
- Design languages, e.g. high-level simulation models (C, SystemC, Phyton)
- Determining performance boundaries and automatic loop optimization of High-Level Systems (EDA tools)
- High-speed and secure NoC adaptive routing strategies
- FPGA prototype boards
- Semi-custom VLSI design (standard cell)



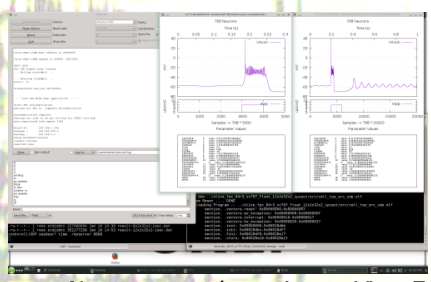








Synapse circuit



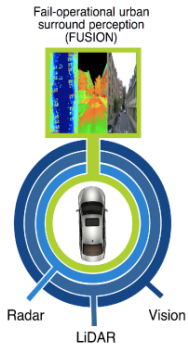
Neuron network running on Virtex7

Early detection of PD activity can provide warnings about pending insulation/device failures

Multi-FPGA development board

Neuromorphic processors and bio-inspired VLSI design We conduct highly interdisciplinary involving the fields of digital/mixed-signal VLSI design, computational neuroscience, reconfigurable system-on-chip, and non-linear dynamics. Our current work focuses on the two areas of (i) low-power neuro-inspired or neuromorphic circuits and algorithms, and (ii) low-power circuits and systems for neural interfacing.

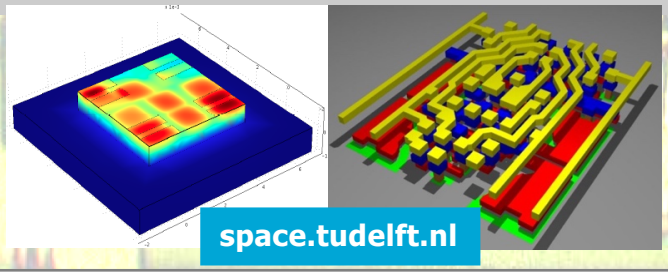
High-level VLSI system design and automation aims to develop complex compute intensive IP blocks for DSP applications and automated tools for the mapping from algorithms to hardware architectures, and software running on these architectures.



Programmable Systems for Intelligence in Automobiles

Physical modeling and verification of VLSI circuits centers around the development of a large software package called SPACE, a layout-to-circuit extractor for VLSI which models the parasitic effects on the chip. It is commercially available with the Tanner IC Design tools, and is used as a point-tool by several large companies (Philips, Intel), and many institutes. Topics are the correct extraction of large RF ICs, including all essential EM effects and interaction with the substrate. Currently, modeling for manufacturing variability is an important R&D topic.

One of the major challenges to successfully realizing highly ***automated driving*** is the step from SAE Level-2 (Partial automation) to SAE Levels-3 (Conditional automation) and above.



Design of programmable compute hardware to enable automatic driving functions, across two application targets: data fusion for robust perception; and acceleration of AI frameworks for decision making.
We study the applicability of neuromorphic computing architectures and programmable hardware fabrics, targeted at robust perception & dependable embedded control at reduced cost and power-consumption.
This leads to an architectural exploration of a hardware compute solution for multi-sensor data fusion.

Variability, aging and reliability of integrated circuits
As feature sizes on chips decrease, the precision with which we can fabricate them deteriorates. This leads to transistors and interconnect with variable, unpredictable properties. Also, these properties change over time due to various environmental and aging effects. How to analyze the variable behavior, and how to still build reliable circuits with a long lifetime under these conditions is actively researched in various projects. Your help is more than welcome!

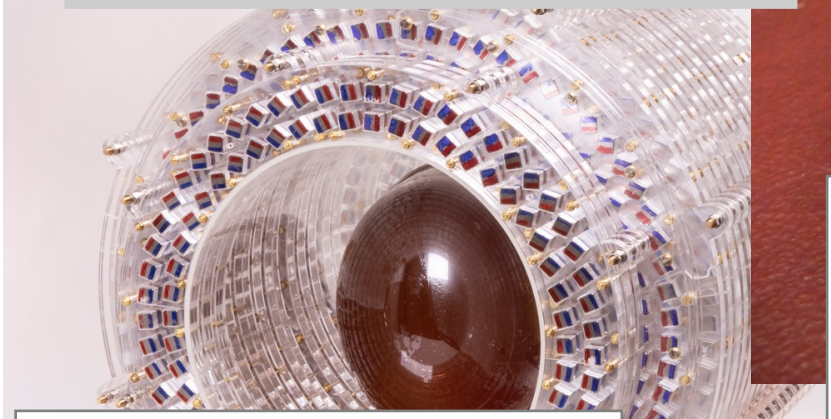
Smaller feature sizes and more ambitious design styles (such as mixed-signal and RF CMOS IC's) mandate improved understanding, modeling and verification of various (parasitic) physical/electrical phenomena that exceeds by far the current state-of-the-art. In the SPACE project you will work to bridge this knowledge gap by developing and implementing new modeling methods and algorithms. Your work can be immediately useful to all users of the software.

Computational imaging

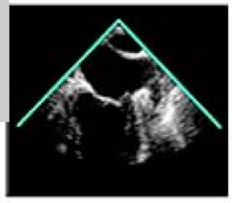
Remote image formation Suppose you want to look inside some object without opening it up, digging it up, cutting it open, or breaking it into pieces. How are you going to do this? Or suppose you want to study celestial objects. You cannot go to a distant star or pulsar and have a look around. What you can do is measure waves that scatter from objects or emanate from certain (celestial) regions of interest. Based on the measured signals you can now try to make an image of the object or region you are interested in.
This imaging process goes by different names in different disciplines. It is called *nondestructive testing and evaluation* in manufacturing and materials science, *remote sensing* in the earth sciences, *radio astronomy imaging* in astronomy, and in medicine there are many noninvasive imaging techniques such as *computerized tomography* (CT) and *magnetic resonance imaging* (MRI).

MRI Scan At the CAS group, you can contribute to the development of efficient EM wave field optimization techniques to significantly improve image quality in high-field MRI.

Sparse sensing for ultrasound Traditionally, 3D ultrasound is achieved using a 2D sliced crystal, consisting of 10,000 transducing elements. Reading out so many elements is nearly impossible. With Erasmus MC, we developed an alternative: a single transducer, and a plastic cap that scatters the acoustic waves such that a unique signal is sent into each direction. This unique approach was published in Science Advances and made international headlines end of 2017!

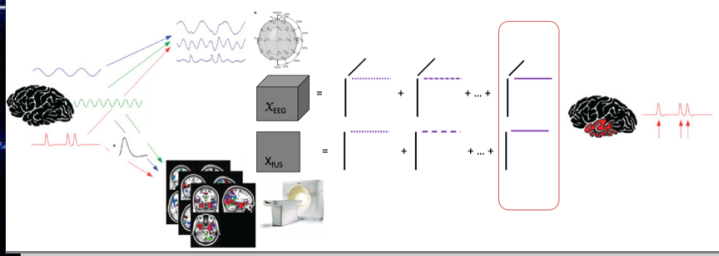


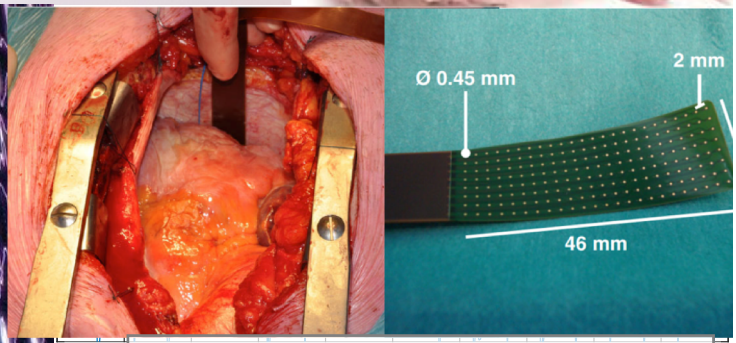
Reinventing MRI In collaboration with Leiden, Amsterdam and Utrecht University hospitals, we run several projects on MRI. Our work focuses on EM modeling and imaging and inversion techniques for improved functionality and reduced hardware costs. E.g., accurate reconstruction of the actual conductance of the body, needed for hyperthermal therapy.

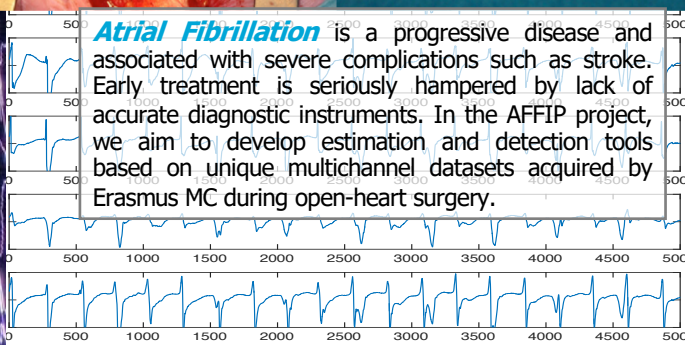


Biomedical Signal Processing

Estimation and detection Biomedical signal processing starts with signal modeling: what is a simple, yet sufficiently accurate, model for a certain biomedical signal? With this model, we can estimate unknown parameters and e.g. detect the onset or origin of an event (anomaly). Ideally, the model is 'learned' automatically from processing a large database of signals. We work with multichannel, multimodal time series such as EEG, functional MRI or ultrasound (fUS). The data inherently live in a higher dimensional (tensor) space and the pattern of interest is often hidden in the noisy mixture of physiological activity and artifacts.







Atrial Fibrillation is a progressive disease and associated with severe complications such as stroke. Early treatment is seriously hampered by lack of accurate diagnostic instruments. In the AFFIP project, we aim to develop estimation and detection tools based on unique multichannel datasets acquired by Erasmus MC during open-heart surgery.

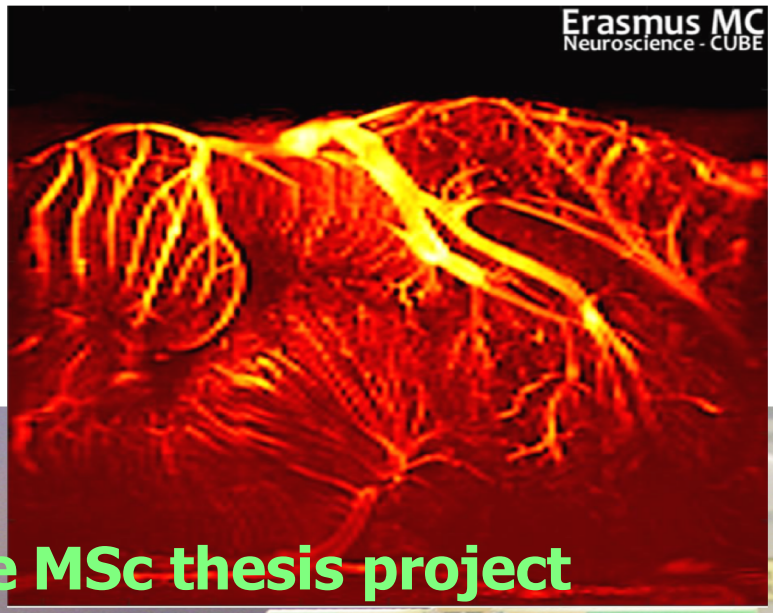
Improving Ultrafast Doppler Imaging using Subspace Tracking

Here is an example of one of the topics that we work on. It is at the fore-front of technology, with a strong link to applications. Written by an MSc student who recently finished his MSc thesis project at the CAS group.

by Bas Generowicz

It was during my first year of the Signals & Systems track that I became very interested in the field of biomedical signal processing - having followed several courses related to the field throughout the year. To start my MSc thesis journey, the CAS group connected me to the Neuroscience department at the Erasmus MC in Rotterdam where I found myself joining a team working on Doppler ultrasound imaging on the brain.

Doppler ultrasound imaging makes use of high frequency sound waves to measure blood flow, and has become an active field of research in recent years mainly due to the massive processing power required for the technique. Together with my thesis supervisor, Geert Leus, we aimed to improve on the current state-of-the-art signal processing techniques applied to Doppler ultrasound. We developed a more efficient and flexible technique to process high frame-rate ultrasound frames in real-time.



This work led to a publication, which I was honored to present and defend at the 2018 IEEE International Ultrasonics Symposium Conference in Kobe, Japan.

The collaboration between the CAS group and the Erasmus MC Neuroscience department enabled the application of theoretical knowledge obtained at the Signals & Systems track to a practical and meaningful field. Working closely with a group of Neuroscientists has proven invaluable for the progress of our project.

After my graduation I had the opportunity to continue with a PhD at the Erasmus MC, which I gladly accepted. Together with the CAS group, we are actively looking to see how we can apply more sophisticated signal processing techniques to the field of Doppler imaging. We are always looking for new brains to join the project, further strengthening the relationship between the CAS group and the Neuroscience department at the Erasmus MC!

The MSc thesis project

Your thesis project starts by contacting one of the professors at our group who can be your future advisor. This typically depends on your research interest and the match with the professor. Typically this is done 1—3 months before the actual start of your project. In a first meeting, we discuss your interests. The first important decision you have to make is if you want to do your graduation work at a company or at the university, in one of our research projects. In the first case, we will help you with finding a suitable place. In the other case, we will help you decide which project you should join. In any case, you'll receive more detailed information, which you can study at home. In subsequent meetings (and with your in-company supervisor if applicable), the actual project is defined, and a plan and time schedule is drafted. The project duration is usually 8-9 months, and is finished by writing a report and giving an oral presentation.

We don't just do theory: completing a design or implementing a tool is also a valid MSc project!

Criteria for a good mark are (1) amount of work, (2) quality/originality of the work, (3) independent working, (4) quality of the report, (5) quality of the presentation.

In many cases, the student also writes a conference paper based on the report. If it gets accepted, the student can attend the conference to present it!

You will have regular meetings with the advisor, usually one of the professors. After 4 months a midterm presentation is scheduled, which records your activities of the first months, and contains a more detailed plan on the remaining 4 months of thesis work.

Students doing their MSc work either go to a company or work in the lab of our group. Combinations are also possible. For students working in our lab, the work is typically connected to one of our research projects.

See here for list of tentative actual thesis topics:
http://cas.tudelft.nl/Education/mscprojects.php

Thesis topic examples

To get an impression of the kind of thesis topics being conducted at the CAS group, see the list of recently finished theses below.

- Multidomain Graph Signal Processing
- Bluetooth Direction Finding
- Acoustic Vector Sensor Based Source Localization
- Phase Domain Ranging for Narrowband ISM Radio Bands
- Calibration and imaging for future radio telescopes
- Room Geometry Estimation from Acoustic Echoes
- Interferer selection for binaural cue preservation in joint binaural linearly constrained minimum variance beamforming
- On speech enhancement in very low SNRs for smart speakers
- Identification of room boundaries for sound field estimation
- Improving Ultrafast Doppler Imaging using Subspace Tracking
- An automated ECG signal quality assessment method with supervised learning algorithm
- Ultrasound Imaging Using a Single Element Transducer
- Analysis and Detection of Neural Synchrony in the Prefrontal Cortex
- Multiway Component Analysis for the Removal of Far Ventricular Signal in Unipolar Epicardial Electrograms
- Automated Detection of Central Apnea in Preterm Infants
- Automatic Initialization for 3D Ultrasound CT Registration During Liver Tumor Ablations
- MRI using CSI-EPT: Towards practical implementation
- Transceive Phase Corrected Contrast Source Inversion-Electrical Properties Tomography
- Design Space Exploration of a Neuromorphic ECG Classification System using a Spiking Self-Organizing Map
- Energy-efficient multipath ring network for heterogeneous clustered neuronal arrays
- Multi-FPGA Interconnection Simulation
- Embedded Real Time Partial Discharge Pulse Feature Extraction
- Design and Characterization of the Time Division Multiplexing concept on a dual clock Imaging DSP
- Digital Neuron Cells for Highly Parallel Cognitive Systems
- A 32 x 32 Spiking Neural Network System On Chip
- Full-Custom Multi-Compartment Synaptic Circuits in Neuromorphic Structures
- Multi-FPGA Interconnection Simulation
- Integrating a Neuron Network application into ZYBO Zynq-7000 development board with AXI-Bus interface
- Hysteresis Compensation in Piezo-Actuator
- Integrating a
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- Implementati
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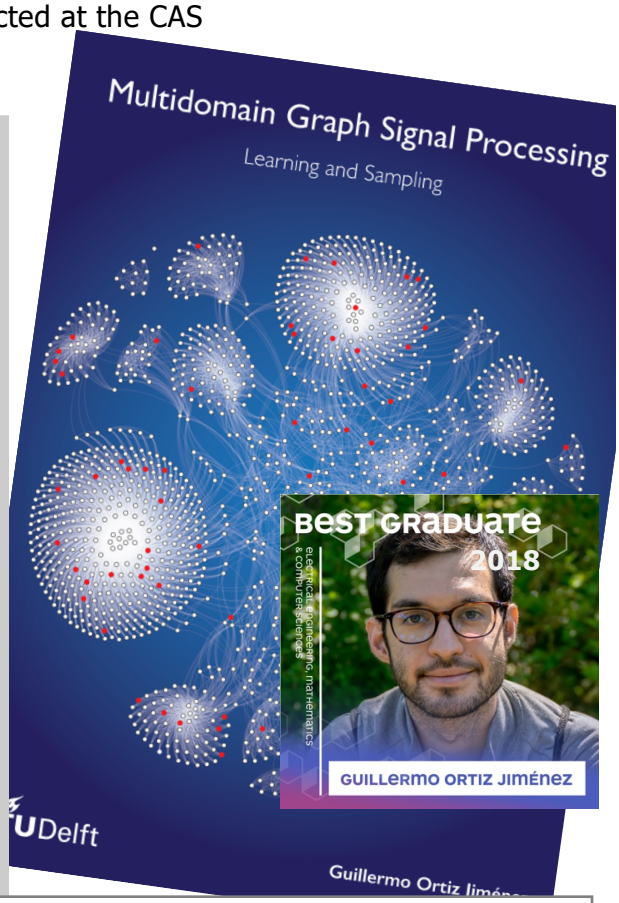

Some of the tools you might (learn to) use:

- Linear algebra, Optimization
- Signal processing
- Circuit theory
- Digital electronics
- Electromagnetism
- Algorithms
- Analysis
- Software engineering
- C, C++, Matlab, Mathematica, Synopsys, Cadence, VHDL, FPGA's, Python, Perl, etcetera.
- and much more...

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