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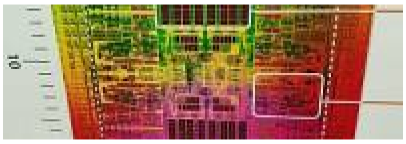
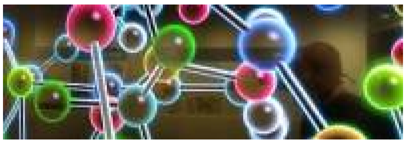
Research

Inverse Problems and Data Assimilation

Some notes on current research activities: [research_notes]

Algorithms and Analysis for Inverse Problems

Our research is concerned with inverse problems and data assimilation in three areas:

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numerical weather prediction (NWP),
cognitive neuroscience / neural field theory (NFT),
inverse scattering problems / remote sensing.
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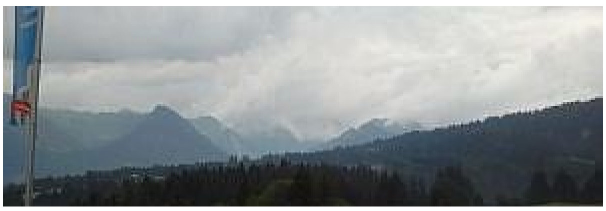
These are extremely exciting areas scientifically and very important for society, for example for the airspace industry by turbulence predictions, in medicine by medical imaging and for micro-electronics by inverse problems.

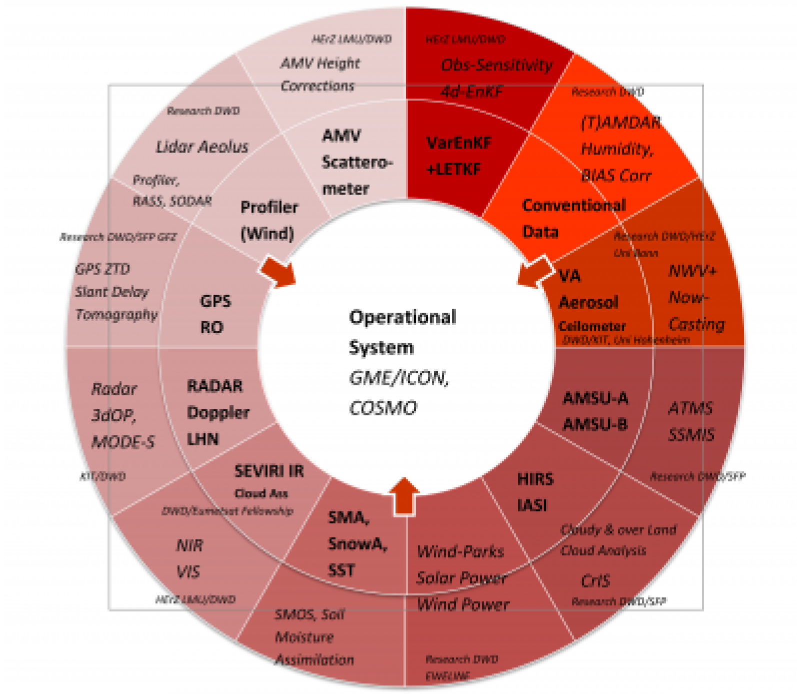
Personally, my main focus is the development and analysis of efficient algorithms, the development of concepts and more general mathematical analysis and its interplay with key applications.

At Reading, UK we have an intensive interdisciplinary collaboration with Meteorology in atmospheric applications and with the Centre for Integrative Neuroscience and Neurodynamics (CINN), with several PhD students and PostDocs. Reading has strongly invested into this area since 2012, with several new lecturers and professors in the field.

At DWD in Offenbach, Ger, our data assimilation unit FE12 consists of 19 senior researchers and about 20 positions by externally funded projects (e.g. an Eumetsat fellowship or funds by the German transport ministery) plus several PhD students. It is part of a larger section FE1 for numerical weather prediction. Within the newly established Heinz Ertel Center for Atmospheric Research (HERZ) there are 6 positions (FTE) funded by the German government to work in intense collaboration with our group since 2011.




Data Assimilation for Numerical Weather Prediction

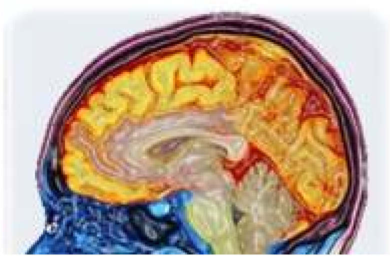


The main goal of data assimilation algorithms is to determine the state of some system from measurement data. For numerical weather forecast as it is used every day by millions of people, we use a broad range of measurements (see NWP measurements ground stations, weather baloons, ships, commercial airplanes, radar, satellite radiances and GPS signals) in mathematical algorithms which are run on our supercomputers in Offenbach, Germany, 24/7. The state of the weather at time t0 is the basis for forecasts, which are calculated by running an ensemble of simulations forward in time. Our research and services are used by numerous institutions and businesses.

Ensemble filters are very popular tools for data assimilation in large-scale applications. In several projects we develop the analysis for different convergence concepts, in particular for nonlinear systems and ill-posed observation operators. In particular, a **rigorous convergence analysis** for local ensemble transform filters (EnKF) and hybrid variational-ensemble filter (VarEnKF) approaches is a basis for further algorithmic progress.

The use of remote sensing techniques within numerical weather prediction (NWP) systems leads to a large number of important research problems, ranging from the interplay of tomography with dynamical systems data assimilation methods to the development of adequate strategies for integrating new observation techniques like LIDAR measurements of turbulence into NWP schemes.

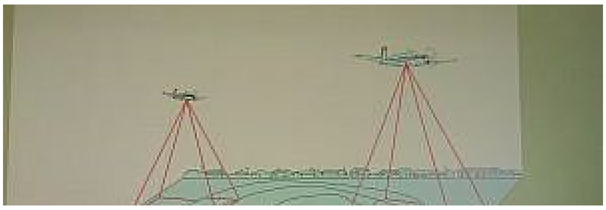
Cognitive Neuroscience



Cognitive Neuroscience is a broad area trying to understand cognition - cognitive structures in our brain. What happens in our brain when we see, hear, think and act? How can we model it and understand what we do easily in every minute of our life? My interest here is to develop **field theories of cognition**, linking mental processes with neural structures as they are the basis of our brain activities.

In September 2010 at Reading we organized the first **International Conference on Neural Field Theory** at Reading, with a high-level collection of internationally reknowned experts (conference webpage). A second conference on the topic took place in Febuary 2012 at Reading. The research group at Reading (Beim Graben, Saddy, Grindrod, Nasuto and Potthast) received several awards by EPSRC over the past years, including a high-profile “bridging the gaps award” (0.5M). A whole collection of papers develops inverse problems for neural field equations, compare publication list. **Dynamic cognitive modelling** is a top-down approach to develop and study mental structures by representations in a function space. Dynamics of mental processes is represented and generated by neural field dynamics.

Inverse Problems and Remote Sensing



Inverse problems for waves works on the reconstruction of shapes and material properties from measurements of scattered wave fields. Ultrasound imaging uses acoustic waves, radar employs electromagnetic fields, for example microwaves. Tomography is usually concerned with the reconstruction of material distributions from the integrated delay or decay of some signal which passes straight through some medium. But more and more nonlinear effects are investigated to obtain better reconstructions. Over the past years we have suggested and analysed several powerful new algorithms in these areas.

Recent research results include:

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 + the orthogonality sampling scheme (Potthast in Inverse Problems 2010)
 + results on source splitting via the point source method (Potthast, Fazi,
Nelson: Inverse Problems 2010)
 + a new time-domain probe method (Burkard and Potthast: Inverse Problems
and Imaging 2009)
 + new results on inverse problems in neural field theory (Potthast and Beim
Graben 2009)
 + further development of the singular sources methods for inverse problems
  (Ben Hassen, Erhard, Potthast: IMA J. Appl. Math 2010)
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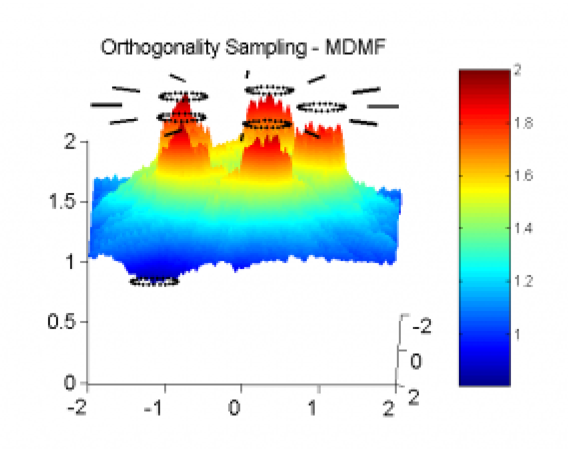

The **point source method** is a scheme for reconstructing wave fields from remote measurements (P. 1996, 1998). The key idea here is to use Green's formula and approximate the fundamental solution (point source) by a superpositioni of fields arising from remote sources, which can be used to derive a reconstruction formula.

The key idea of probe methods like the **singular sources method** (P. 2001) is to use a virtual singular source as a probe and move it towards an unknown object. The response field in the source point can be calculated from remote measurements. The size of the response can be used to reconstruct the location and shape of an unknown object.

The **time-domain probe method** sends a time-dependent pulse and reconstructs the full time-dependent scattered field. The generation of the scattered field when a pulse hits the object can be used to find the location and shape of scattering surfaces.

Orthogonality sampling (P. 2010), also called Direct Sampling, is the simple idea to superpose plane waves according to the measured far field amplitude for scattering of a time-harmonic field. This leads a stable technique which can be used to detect the location, shape and further properties of objects.