



# ORGANIC: Self-organized recurrent neural learning for language processing

Annual Public Report (Year 1 – November 2010)

## Key Facts

### Mission

Establish neurodynamical architectures as viable alternative to statistical methods for speech and handwriting recognition

### Website

<http://reservoir-computing.org/>

### Duration

April 1, 2009 – March 31, 2012

### Budget

3.52 MEuro (2.7 MEuro EU funding)

### Staffing

6 principal investigators  
30 researchers (PhD/Postdoc;  
17 fully funded by project)  
1 administrative assistant

### Project Type

EU FP-7, ICT Challenge 2: Cognitive Systems, Interaction, Robots Collaborative Project (STREP)  
Grant agreement No: IST- 231267

### Coordinator

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## Project Outline

Current speech recognition technology is based on mathematical-statistical models of language. Although these models have become extremely refined over the last decades, progress in automated speech recognition has become very slow. Human-level speech recognition seems unreachable. The ORGANIC project ventures on an altogether different route toward automated speech recognition: not starting from statistical models of language, but from models of biological neural information processing – from *neurodynamical* models.

ORGANIC will combine a large variety of neurodynamical mechanisms – of signal filtering, learning, short- and long-term memory, dynamical pattern recognition – into a complex neurodynamical "Engine" for speech recognition. A major scientific challenge of ORGANIC lies in the very complexity of the targeted architectures. In order to master the resulting nonlinear dynamical complexity, a special emphasis is put on mechanisms of adaptation, self-stabilization and self-organization. The overall approach is guided by the paradigm of *Reservoir Computing*, a biologically inspired perspective on how arbitrary computations can be learnt and performed in complex artificial neural networks.

R&D activities in ORGANIC will result in

- a much deeper theoretical understanding of how very complex computations, especially those related to language processing, can be robustly and adaptively performed in neurodynamical systems,
- a publicly available *Engine* of programming tools which conforms to recent interface standards for parallel neural system simulations,
- prototype implementations of large-vocabulary speech recognizers and handwriting recognition solutions.

**Partner institutions / group leaders:** Jacobs University Bremen / Herbert Jaeger (JAC); Technische Universität Graz / Wolfgang Maass (TUG); INSERM Lyon / Peter F. Dominey (INSERM); Universiteit Gent / Benjamin Schrauwen (Reservoir Lab) and Jean-Pierre Martens (Speech technology group) (UGT); Planet intelligent systems GmbH Raben-Steinfeld / Welf Wustlich (PLA)



## Scientific Objectives

**Basic blueprints:** Design and proof-of-principle tests of fundamental architecture layouts for hierarchical neural system that can learn multi-scale sequence tasks.

**Reservoir adaptation:** Investigate mechanisms of unsupervised adaptation of reservoirs.

**Spiking vs. non-spiking neurons, role of noise:** Clarify the functional implications for spiking vs. non-spiking neurons and the role of noise.

**Single-shot model extension, lifelong learning capability:** Develop learning mechanisms which allow a learning system to become extended in "single-shot" learning episodes to enable lifelong learning capabilities.

**Working memory and grammatical processing:** Extend the basic paradigm by a neural index-addressable working memory.

**Interactive systems:** Extend the adaptive capabilities of human-robot cooperative interaction systems by on-line and lifelong learning capabilities.

**Integration of dynamical mechanisms:** Integrate biologically mechanisms of learning, optimization, adaptation and stabilization into coherent architectures.

## Community Service and Dissemination Objectives

**High performing, well formalized core engine:** Collaborative development of a well formalized and high performing core Engine, which will be made publicly accessible.

**Comply to FP6 unification initiatives:** Ensure that the Engine integrates with the standards set in the FACETS FP6 IP, and integrate with other existing code.

**Benchmark repository:** Create a database with temporal, multi-scale benchmark data sets which can be used as an international touchstone for comparing algorithms.

## Work Progress and Results

### Summary

A special advantageous condition of ORGANIC is that most of the partners were engaged in collaborations long before the project start. This allowed a quick and productive start, and the project is ahead of schedule in a number of tasks. The good collaboration tradition became manifest in an ORGANIC internal workshop in Fall 2009, which brought together all Organic researchers and allowed the young and new-coming collaborators to become networked. This workshop was realized beyond the contractual commitments of the project. The website, which was launched almost immediately after project start, is functioning as a public portal to the reservoir computing community beyond the lifetime of ORGANIC. It now has 86 registered users, 159 subscribers to the mailing list, a swiftly growing reservoir computing publications list with now 150+ entries, pointers to 7 public RC toolboxes, and a rich collaborative infrastructure on the ORGANIC internal pages. The Engine V1.0 was publicly launched in April 2010, 6 months ahead of schedule. Its version 1.1 has been enriched with a tutorial and numerous documented, runnable demo examples and has been advertised in the neural computation community under the new name OGER (*Organic Engine for Reservoir Computing*). The project so far spawned 13 accepted/appeared journal articles and 12 accepted/appeared conference papers, among them 5 in the premier journals *Neural Computation* and the *Journal of Neuroscience*, and 4 at the premier conference *NIPS*.

## Scientific Progress: Detail

Research in ORGANIC develops in many ramifications, reflecting the complexity of the scientific objectives. Here only a summary of highlights can be attempted.

- UGT has developed a new approach to employ **slow feature analysis (SFA) for training hierarchical reservoir systems** in an unsupervised way. This led to learning results that are analog to the emergence of place cells in the rat hippocampus, a widely studied learning and representation phenomenon in biological systems.
- UGT has developed a strategy for creating **hierarchical reservoirs for speech recognition**. For phoneme recognition and single-word (isolated digits) recognition, the reservoir based system has reached the performance level of state of the art HMM-based systems. The phoneme recognition work was rewarded by becoming accepted as a NIPS oral presentation (only 20 of the 1219 submissions were accepted for an oral presentation).
- INSERM has implemented a **brain-based model of language processing** that uses reservoir-like recurrent networks to decode the syntactic structure of sentences. The model has demonstrated sequence categorization capabilities similar to those observed in the primate, namely, the ability to categorize sequences that have common underlying structure.
- TUG is developing **new methods for emulating HMMs** and other tools from the area of probabilistic inference in networks of spiking neurons, This approach promises to enrich reservoir computing through the integration of methods from probabilistic inference.
- PLA prepares fielding of a **reservoir-based handwritten word recognizer** as a module in their parcel sorting systems (scheduled for February 2010). At the world's largest postal trade show "POST-EXPO 2010" (Copenhagen Oct. 6 – 10, 2010) PLA has showcased a demonstrator (Figure 1) which was able to read handwritten addresses on letter mail with very positive responses especially from the US market.

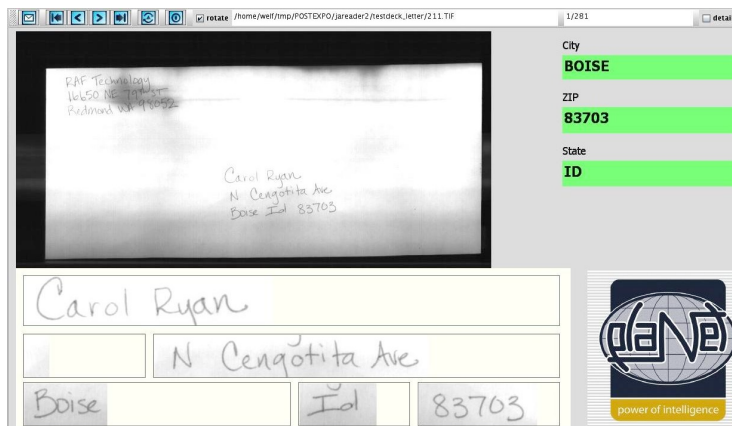


Figure 1. A screenshot from the reservoir-based city name recognizer from a demonstration at the POST-EXPO 2010.

- JAC has developed a method for controlling slow observables of a reservoir. This is a basis for **autonomous online self-regulation of reservoir dynamics**. First successful demo on synthetic data, where this method was used to making the responses of a reservoir insensitive to slow variations in the input data (e.g., drifts in scale, shift, or typical frequency).
- TUG showed that a simple reward-modulated version of Hebbian learning can **explain the experimentally observed reorganization of neural codes in the cortex** for optimizing performance in some closed-loop task (leading to a plenary talk at NIPS (acceptance rate < 3%), and an article in the J. Neuroscience (impact factor 8.5)).

- UGT has carried out a **mathematical analysis of transient memory capacity in reservoirs**. This work by far transcends the "classical" results in this field and covers the more realistic and practically relevant impact of state noise on memory capacity.
- INSERM has developed and tested a **3-layered reservoir based on the laminar structure of primate cortex**, and investigated how sequence-discriminating information is retained in it. The objective of this work is to develop a neurophysiologically realistic model of the three layer structure of cortex in order to study the efficiency of cortico-cortical interactions in cognitive tasks, and to compare this with electrophysiological data recorded from the behaving primate.
- INSERM has completed an **fMRI study of the role of cortex and basal ganglia in learning temporal structure of sensorimotor sequences**. The role of this neural system in the processing of temporal structure in sequences is still an open issue, to which this study provides new insight. The data are suitable for analysis in the context of the three-layer reservoir model as mentioned in the previous point.
- JAC has developed a **reservoir-based model of working memory**. In this model, a single reservoir serves the dual task of processing input information and storing relevant events in memory in a dynamically stable way. The architecture was demonstrated on a noisy printed character recognition task, where the objective is to memorize grammatical nesting levels indicated by bracket symbols which appear in the graphical input stream immersed in about 80 distracting symbols (Figure 2), and to demonstrate that the memorization of the current bracketing level enables to exploit grammatical structure for a prediction task.



Figure 2. A sample from the (synthetic) graphical script input which was processed with a reservoir augmented by a working memory mechanism to enable keeping record of the current bracketing level (given by occurrences of the curly braces "{" and "}"). At different bracketing levels, of which there were six, different stochastic grammars were used to generate the script sequence.

- INSERM has extended the **demonstration platform for human-robot cooperation** to allow for a form of **on-line learning of action representations**, based on sequences of primitive visual events including visibility, motion and contact (Figure 3). The platform is based on the iCub robot. These sensory sequences are candidates for RC learning. This work has led to 6 accepted publications in a short time.

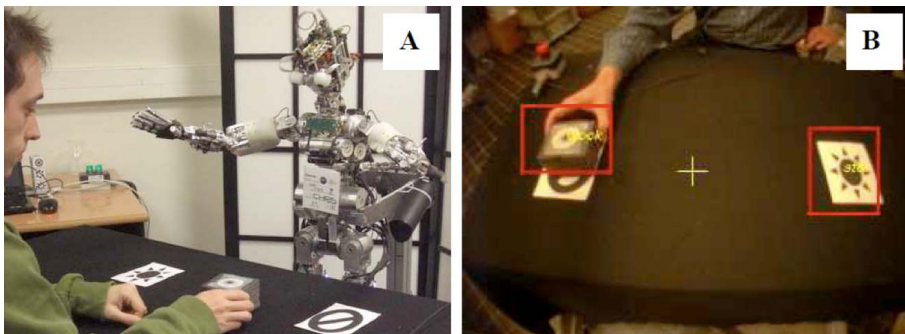


Figure 3. Interacting by language with a robot in a sequential-logic task: learning and generalizing "Cover Arg1 with Arg2". **A.** Robot setup and visual scene. **B.** Robot's view of scene after the block is put on the sign.

- PLA has implemented and tested a **reservoir-based character recognizer**. On the standard NIST single-handwritten-character benchmark, the recognizer achieved immediately a recognition rate of 99.17%, which puts it into the top 10 worldwide (see <http://yann.lecun.com/exdb/mnist/> for a survey of 63 (!) approaches). This is remarkable since no special optimization for hand-printed digits was used.



## Dissemination Activities

- The Engine has been given a catchy acronym (OGER = OrGanic Environment for Reservoir computing) and has been announced on the mailing lists *comp-neuro* and *connectionists*, which have a far outreach in the neural computation and machine learning communities, as well as on our own reservoir computing mailing list. There is now a well-crafted web(sub)site for Oger which provides access to downloads, installation instructions (for Windows, Linux and Mac OS), and importantly, has numerous tutorial examples (<http://organic.elis.ugent.be/oger>).
- A public **repository of benchmark datasets** (<http://organic.elis.ugent.be/organic/benchmarks>) has gone online. One of these benchmark datasets deserves a special mention. The SME consortium partner PLA have made their handwriting training dataset publicly available. This very large dataset (20 GB) of synthetically created samples of handwritten city names was built on the basis of handwriting samples from various regions in the U.S.
- Publicity highlights:
  - A scientific documentary has been produced by the national science museum "Cit  des Sciences" on the cognitive systems that INSERM are developing to control the iCub robot. ORGANIC is acknowledged. The video has been published variously on the Internet, e.g. at [http://www.cite-sciences.fr/francais/ala\\_cite/science\\_actualites/sitesactu/question\\_actu.php?langue=fr&id\\_article=13743](http://www.cite-sciences.fr/francais/ala_cite/science_actualites/sitesactu/question_actu.php?langue=fr&id_article=13743)
  - An interview with the coordinator on Organic was broadcast on the nation-wide German "Deutschlandradio Wissen" on March 16, 2010
  - Eight newspaper articles on reservoir computing have been forthcoming from TUG, see overview at <http://www.igi.tugraz.at/maass/nonexperts.html>
- A highlight of Organic's dissemination activities was the first open workshop on *Cognitive and Neural Models for Automated Processing of Speech and Text* (CONAS 2010, <http://conas.elis.ugent.be>), held at Ghent, Belgium, July 9&10, 2010. This workshop attracted 60+ participants and an illustrious set of keynote speakers from machine learning and cognitive and computational neuroscience. Specifically, these were
  - Yoshua Bengio, U. Montreal (pioneer of complex RNN learning architectures)
  - Alex Graves, TU Munich (designer of current world-best handwriting recognition system; it is based on RNNs)
  - Stefan Kiebel, MPI for Human Cogn. and Brain Sci. (statistical analysis of neural sequence processing)
  - Gordon Pipa, MPI for Brain Research (dynamics and self-organized learning/information processing in spiking RNNs)
  - Tomaso Poggio, MIT (computational theory of cortical processing)
  - Ruslan Salakhutdinov, MIT (pioneer of Deep Belief Networks)
  - Adam Sanborn, Gatsby Unit London (Bayesian modeling of cognitive processing)
  - Peter Tino, U. Birmingham (knowledge representation in RNNs, integration of symbolic and connectionist paradigms)