Self-Organizing Smart Microgrids

Priv.-Doz. Dr. Wilfried Elmenreich | 2012-07-09

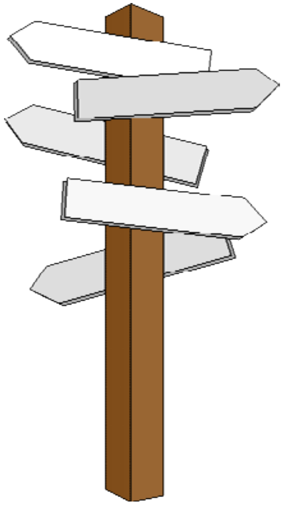
ALPEN-ADRIA UNIVERSITÄT KLAGENFURT

FAKULTÄT FÜR TECHNISCHE WISSENSCHAFTEN

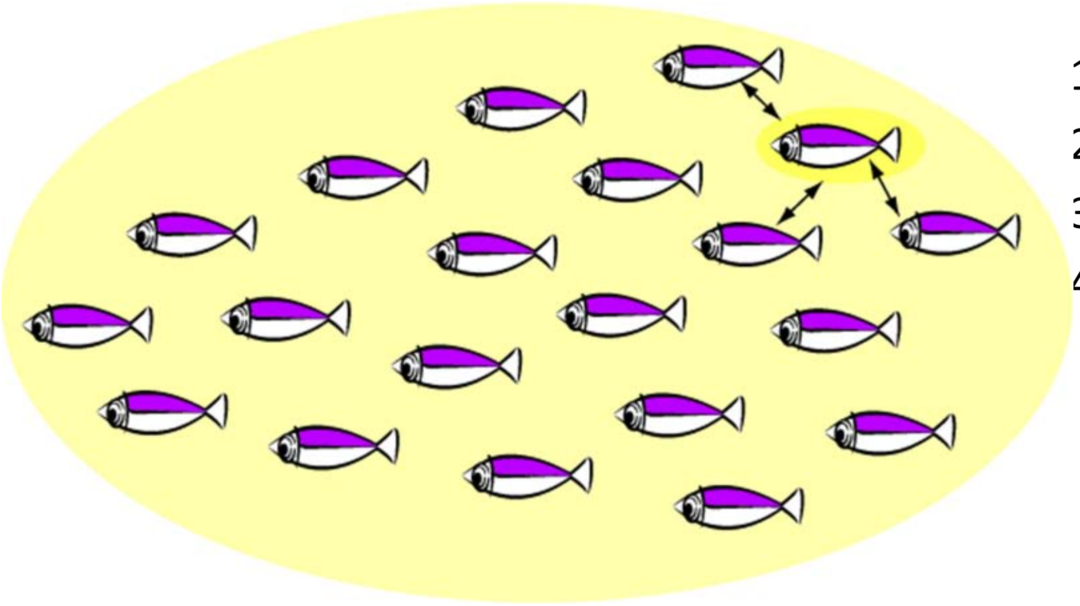
Networked and Embedded Systems

Overview

- Self-organizing systems
- Engineering self-organizing systems
- Smart microgrids
- The smart microgrid lab
- Goals for this workshop



A School of Fish as SO example

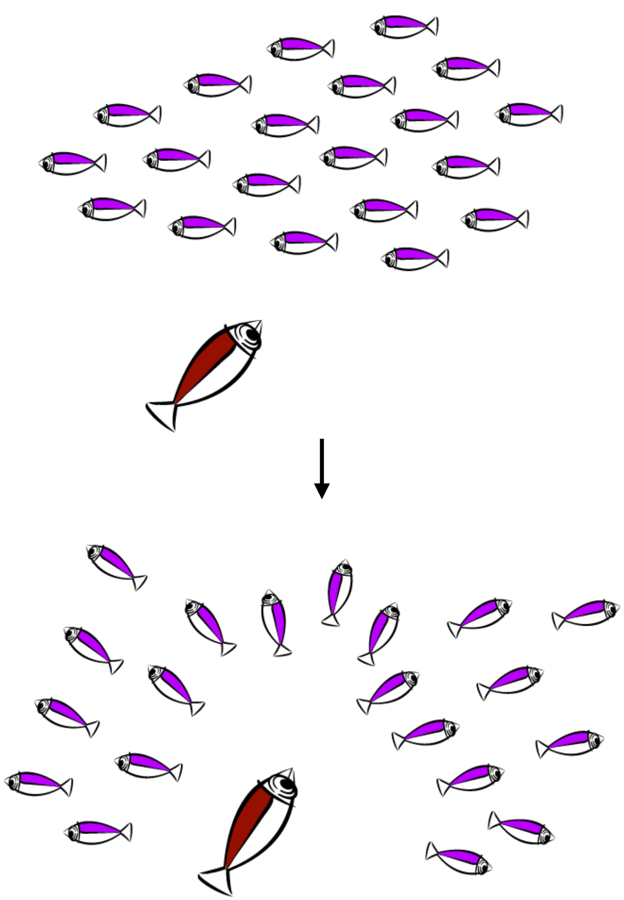


- Several swarm fish with simple behavior ("local rules")
  1) Swim where other fish are
  2) Avoid coming too close
  3) Being attracted by food
  4) Flee from predators

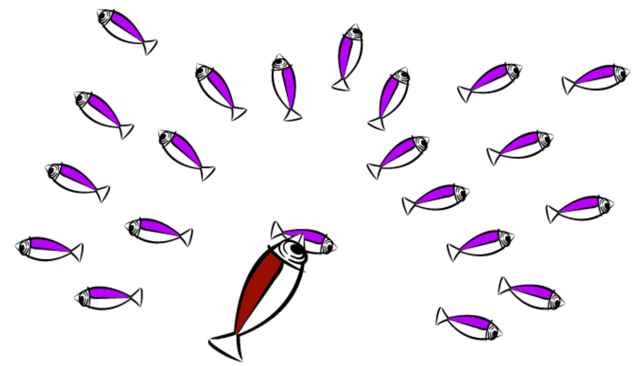
(Example from Prehofer/Bettstetter)

Properties of a Fish Swarm

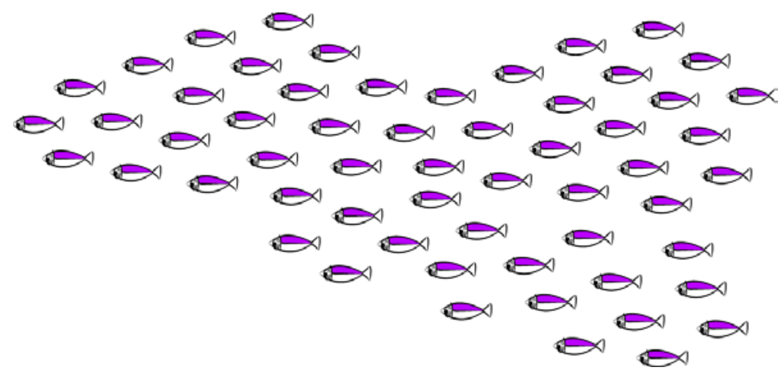
Adaptability



Robustness



Scalability



aus C. Bettstetter, „Lakeside Labs“

Fish School Example Analysis

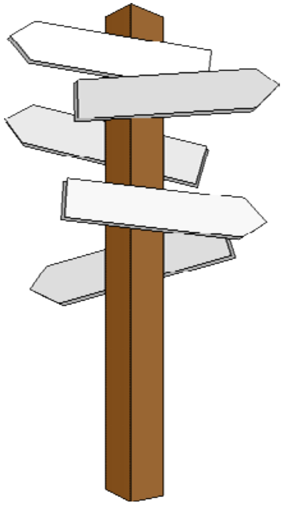
- **Individuals ("Fish")**
- Local observations
- Interaction with other fish
- No centralized control
- Simple behavior

Emergence

- **Overall system ("Fish school")**
- Complex behavior
- Robust, adaptive and scalable

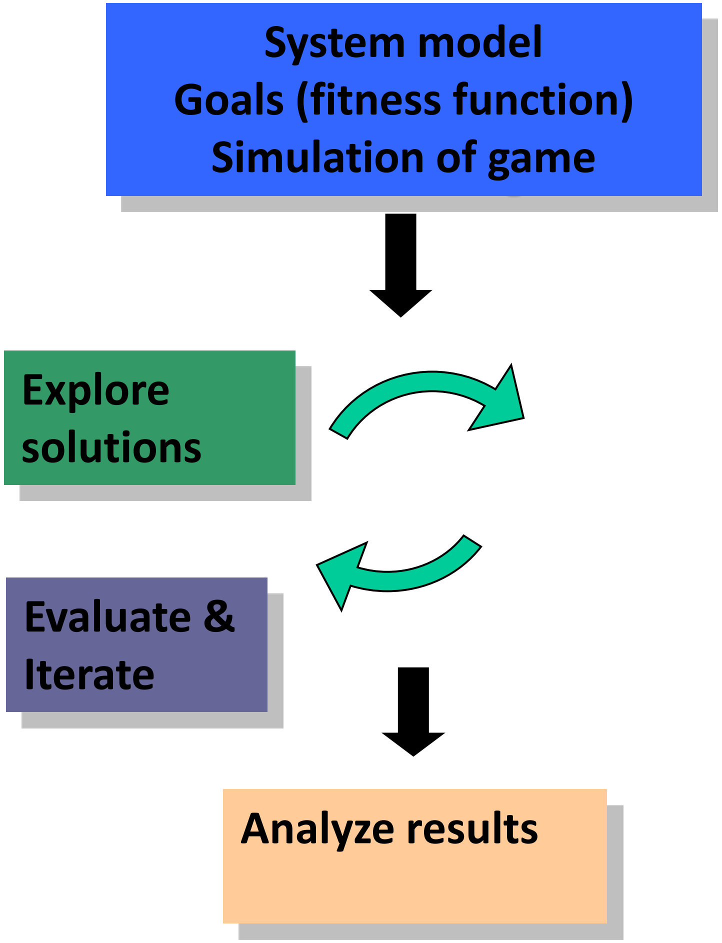
Overview

- Self-organizing systems
- Engineering self-organizing systems
- Smart microgrids
- The smart microgrid lab
- Goals for this workshop



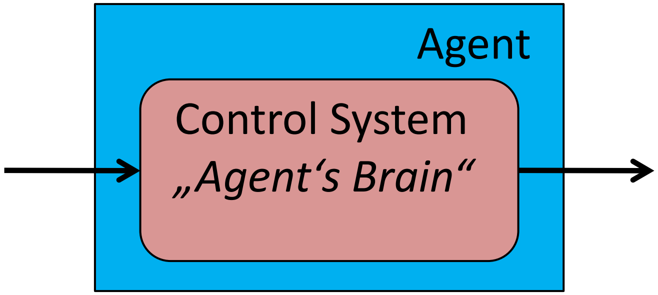
Evolving a self-Organizing System

- Simulation of target system as playground
- Evolvable model of local behavior (e.g., fuzzy rules, ANN)
- Define goal via fitness function (e.g., maximize throughput in a network)
- Run evolutionary algorithm to derive local rules that fulfill the given goal



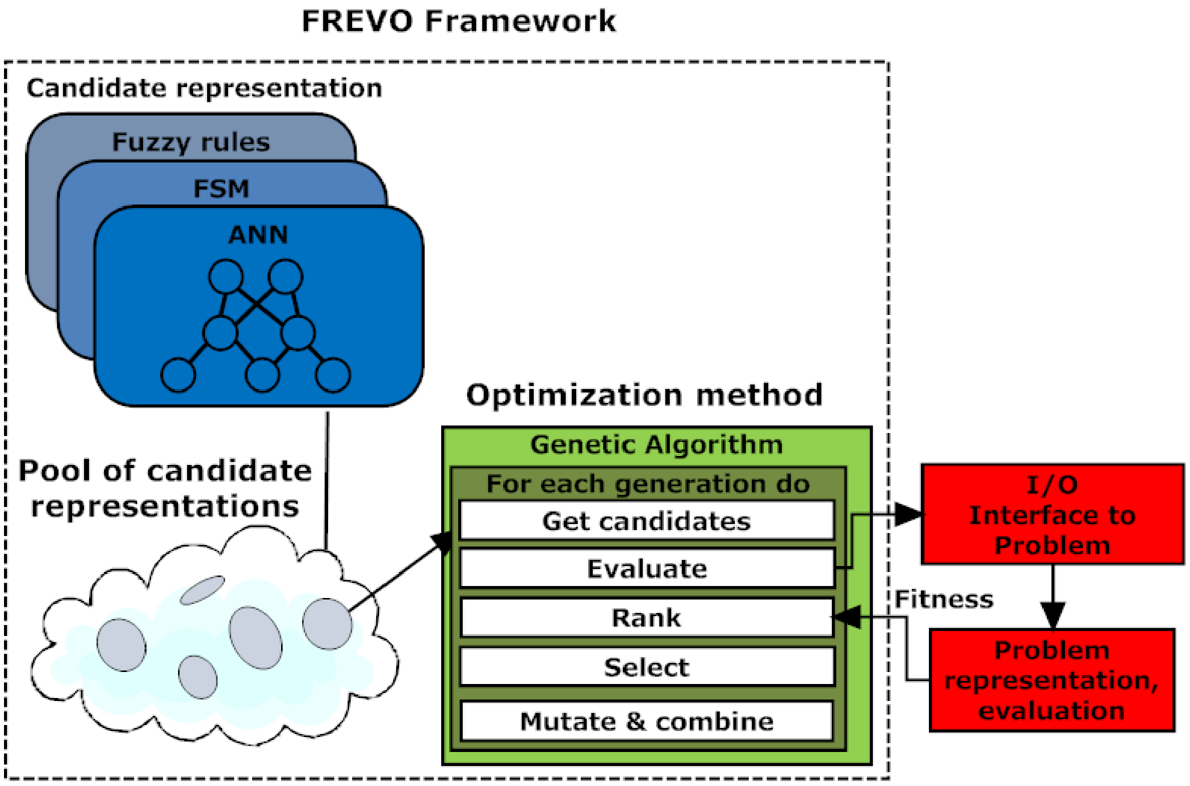
Agent behavior to be evolved

- Controls the agents of the SOS
- Processes inputs (from sensors) and produces output (to actuators)
- Must be evolvable
  - Mutation
  - Recombination
- Currently we can evolve
  - Multi-layer artificial neural networks
  - Fully meshed recursive neural networks
  - Finite state machines (Mealy model)



Framework for Evolutionary Design

- FREVO (Framework for Evolutionary Design)
- Modular Java tool allowing fast simulation and evolution
- FREVO defines flexible components for
  - Controller representation
  - Problem specification
  - Optimizer



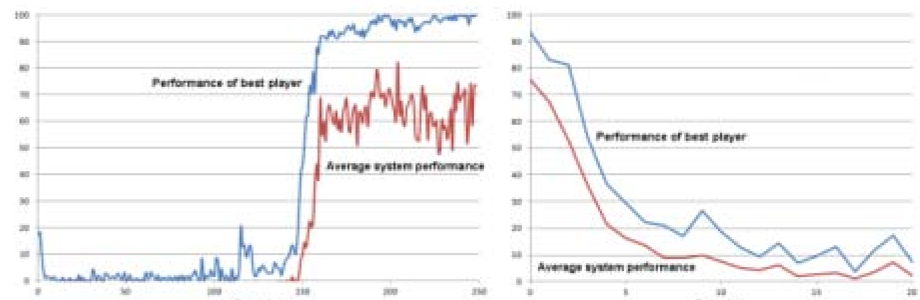
Giving FREVO a Problem

- Basically, we need a simulation of the problem
- Interface for input/output connections to the agents
  - E.g. for the public goods game:
  - Your input last round
  - Your revenue
- Feedback from a simulation run -> fitness value
- FREVO source code and simple tutorial for a new problem at http://www.frevotool.tk

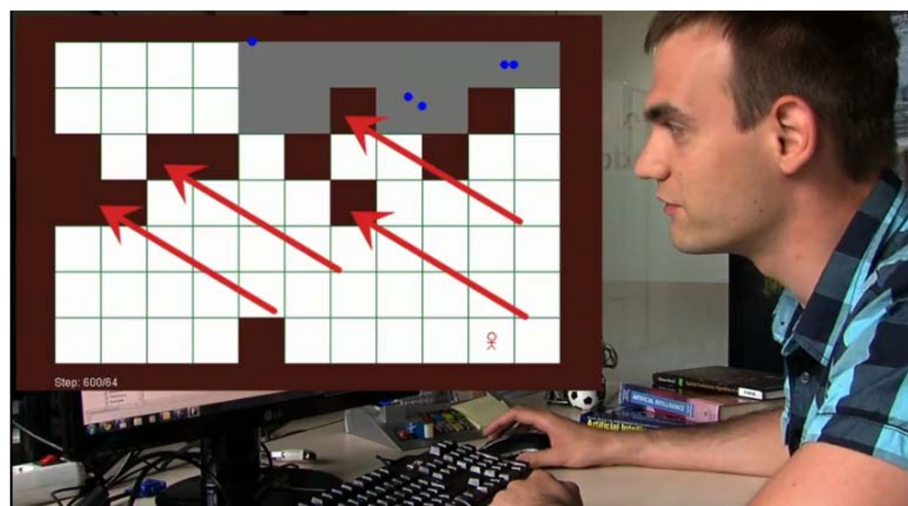
Example Applications of FREVO

- Evolution of cooperative behavior in simulated robot soccer

- Study on evolution of cooperative behavior

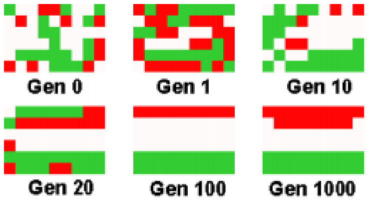


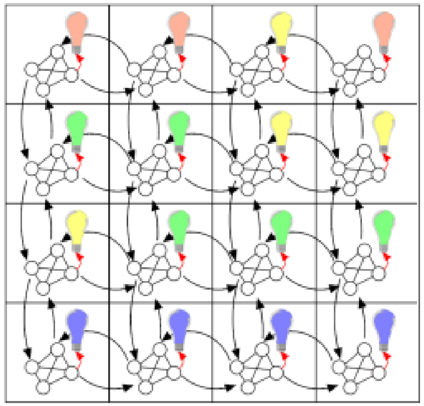
- Algorithm for coordinating microcopters in a search mission



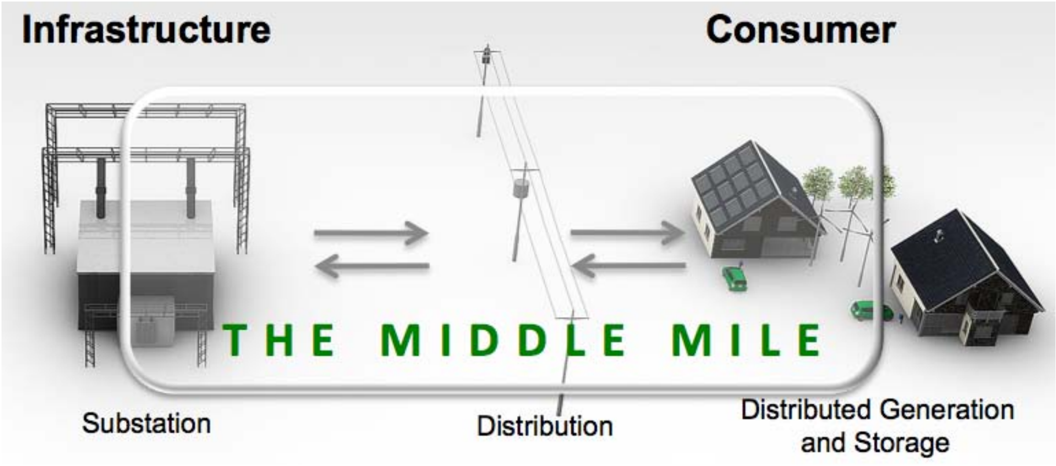
Example Applications of FREVO (cnt.)

- Case study on self-organizing cellular automata patterns



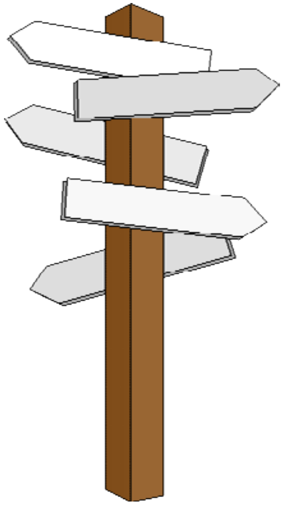


- Estimating consumer behavior in a real-time energy market



Overview

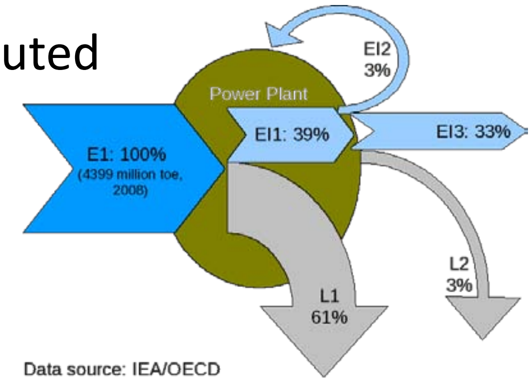
- Self-organizing systems
- Engineering self-organizing systems
- Smart microgrids
- The smart microgrid lab
- Goals for this workshop

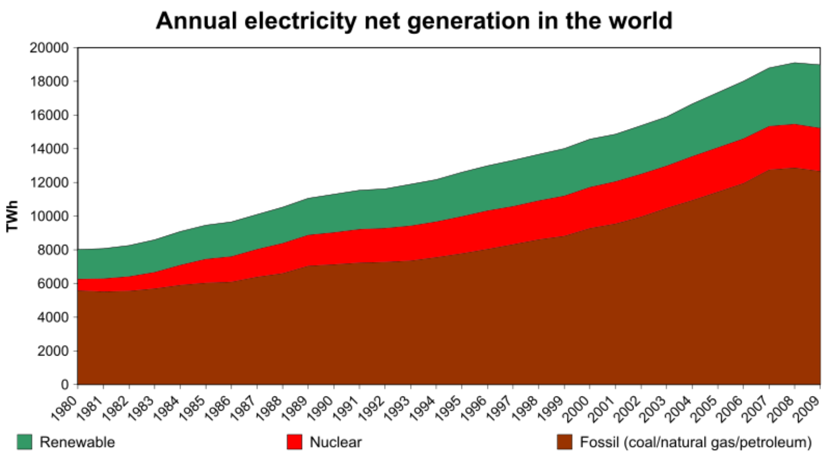


Why microgrids?

- Economies of scale are failing for central plants
  - Alternative energy generation is inherently distributed
  - Significant transmission losses
- Single grid = single point of failure
  - Reliability against random faults
  - Security against targeted attacks
- Expected reduced cost for maintenance of grid infrastructure

- Now we have the technology to overcome these problems!

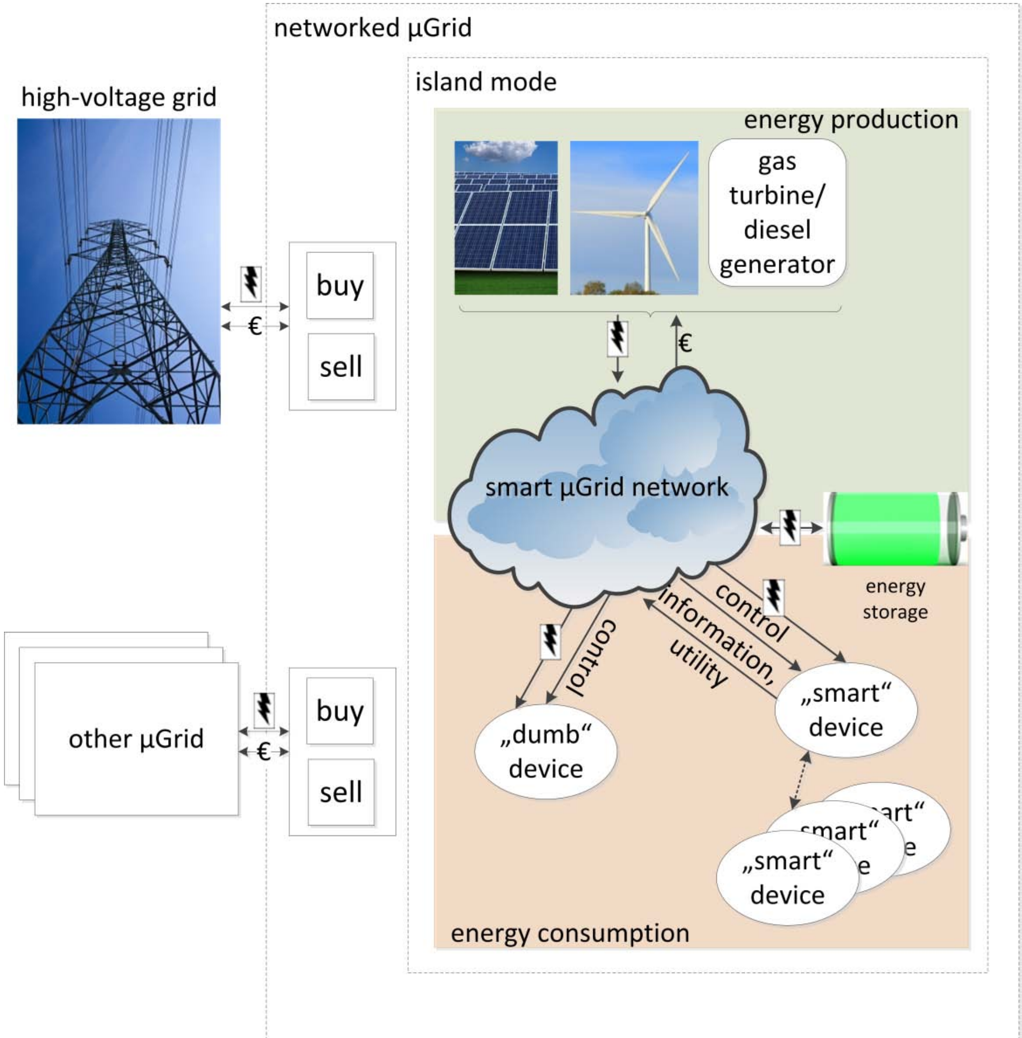




Source: Wikipedia

Components of a Smart Microgrid

- Power generation
- Energy storage
- Energy consumers
  - Smart appliances
  - „Dumb devices“
- Interface to other grids
  - Market agent
  - Transmission
- User control interface



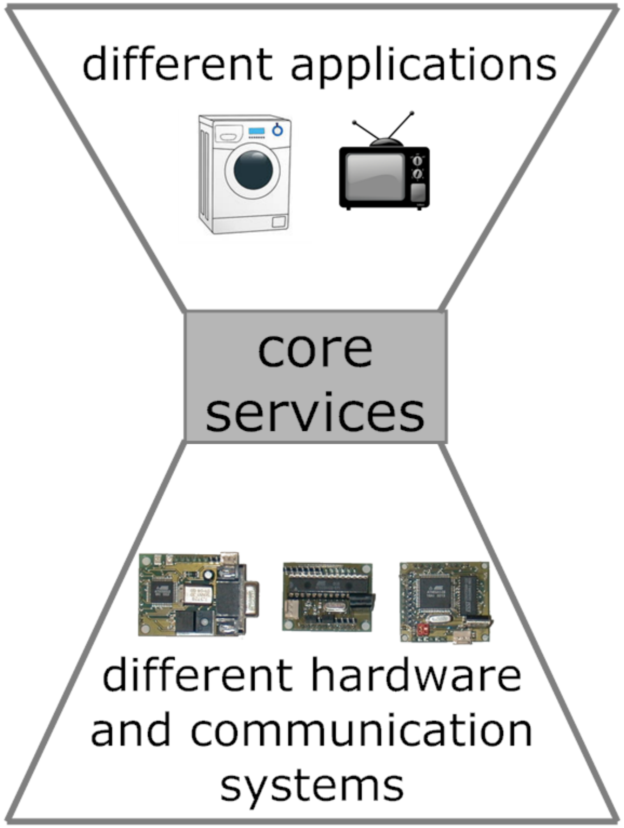
A. Sobe, W. Elmenreich: "Smart Microgrids: Overview and Outlook"; ITG INFORMATIK 2012, Workshop on Smart Grids, September, 2012.

Smart Appliances

- A smart appliance consists of
  - a communication interface
  - a local processing and decision unit
  - the appliance's actual function
- Smart plug concept
  - plug with measurement, control and communication features
    (+) Unified communication interface
    (-) Missing knowledge about device condition
- Embedded intelligent control
  - measurement, control and communication integrated with device
    (+) Device parameters (e.g., fridge temperature) can be considered for control decisions
    (-) Different implementations of data structures and access

Waistline Architecture

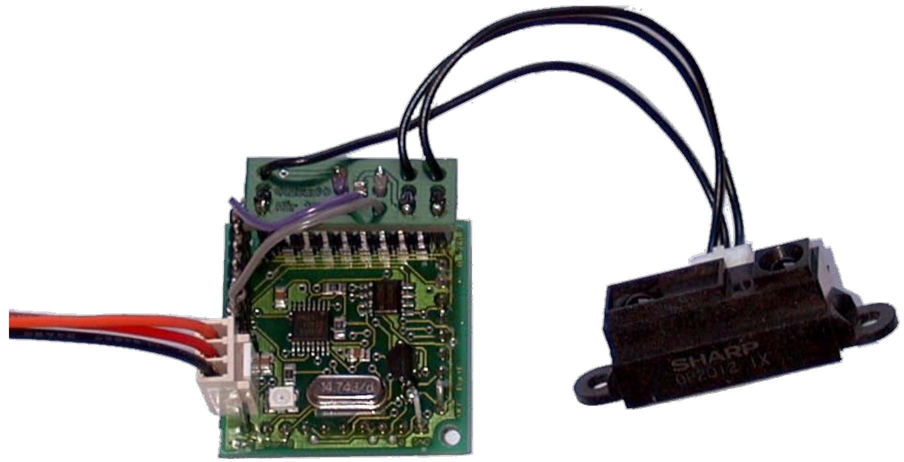
- Proposed solution: Waistline architecture supporting different systems
- Interoperability via core services
- Use concept of self-describing nodes from smart transducers



W. Elmenreich, D. Egarter: " Design Guidelines for Smart Appliances "; Proceedings of the 10th International Workshop on Intelligent Solutions in Embedded Systems (WISES'12), 2012.

Smart Transducers Concept

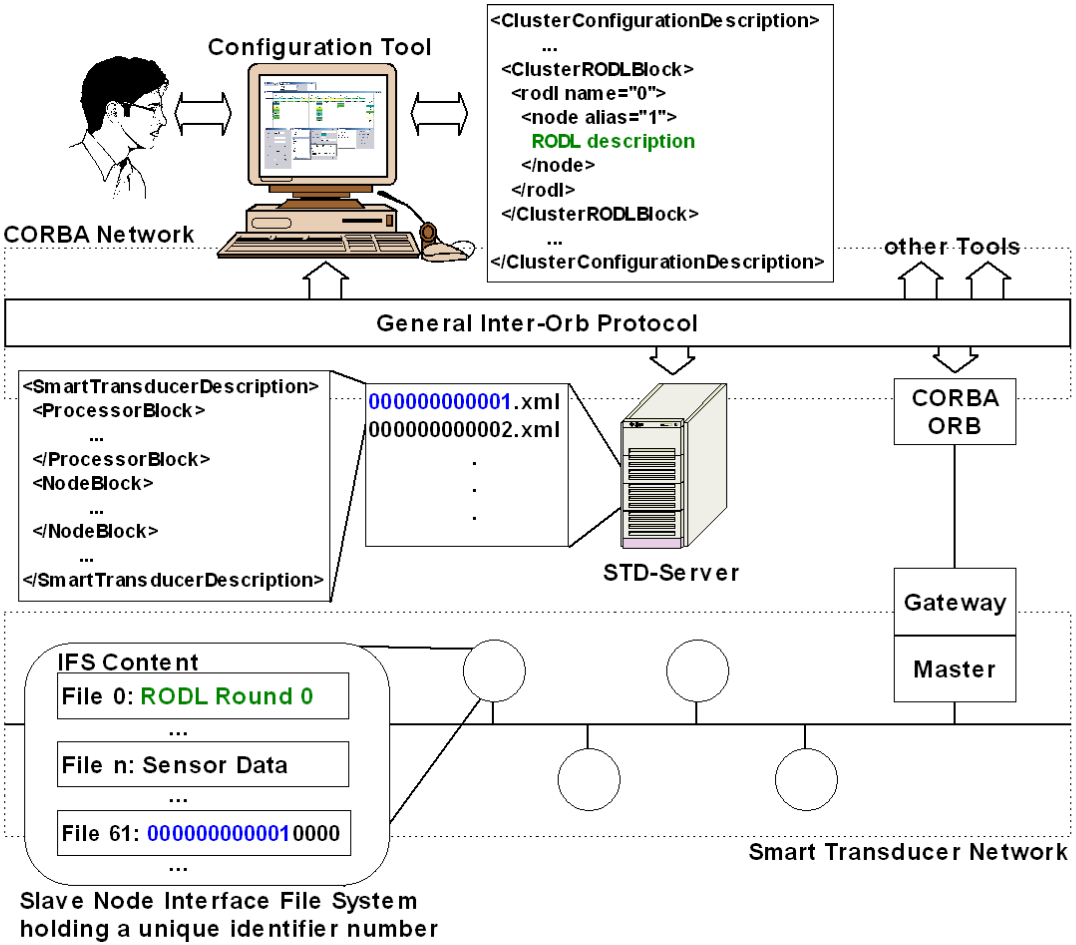
- Integration of
  - Sensor/actuator
  - Microcontroller (ADC and local signal conditioning)
  - Standardized network interface



- Advantages of smart transducer technology
  - No noise pickup over long analog transmission lines
  - Support for configuration and set-up
  - Parallel processing/measurements
  - Enhanced diagnosis via combination of local observations and global phenomena

W. Elmenreich: "Time-Triggered Smart Transducer Networks"; IEEE Transactions on Industrial Informatics, 2 (2006), 3; 192 - 199.

Configuration and Maintenance Architecture



- Configuration interface allows to read unique identifier
- Repository holds machine-readable device descriptions
- Tools support the user in creating a configuration
- Configuration interface allows to upload configuration to nodes

Elmenreich, Pitzek, Schlager: "Modeling Distributed Embedded Applications on an Interface File System“ Proc. IEEE ISORC (2004), 175 - 182.

Need for Self-Organizing Smart Devices

- Problem: configuration of large networks via central authority is error-prone and cumbersome
- Understand devices as independent agents
- Self-organizing process reduces effort and number of possible (meaningful) configurations

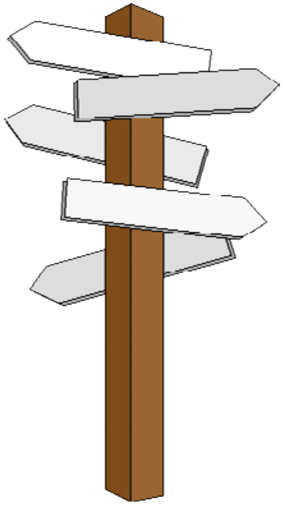
- Implementation of smart appliances will be part of InterReg MONERGY
  - Project start Q4 2012
  - Partners are Lakeside Labs (Klagenfurt) and WitiKee company (Udine)

Source: Wikipedia

Pitzek, Elmenreich: "Plug-and-play: Bridging the semantic gap between application and transducers". Proc. IEEE Int. Conf. Emerging Technologies and Factory Automation, 2005.

Overview

- Self-organizing systems
- Engineering self-organizing systems
- Smart microgrids
- The smart microgrid lab
- Goals for this workshop



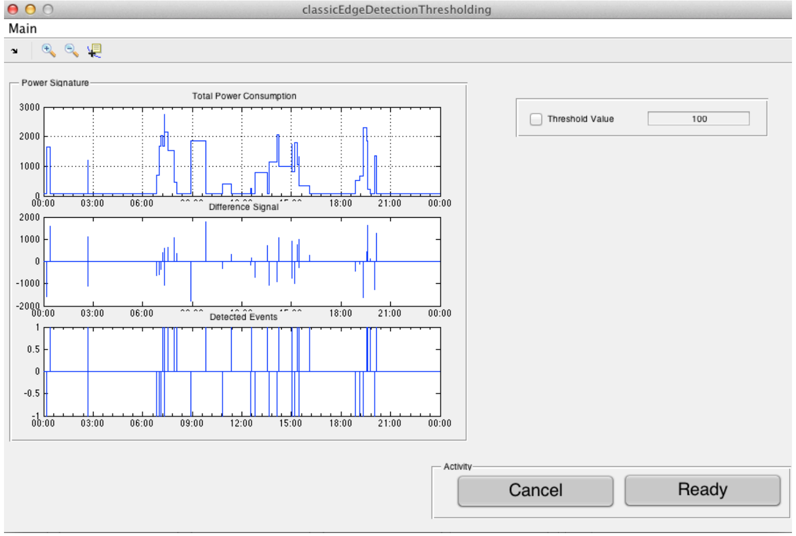
The Smart Microgrid Lab

ALPEN-ADRIA UNIVERSITÄT KLAGENFURT | WIEN GRAZ

- Provide a hands-on lab for measurement in a real microgrid
  - Power generation from photovoltaic panels
  - Island mode/grid mode possible
  - Measurement equipment
  - Reference consumers
  - Energy storage based on batteries
- Train engineers in the field
  - Two PhD students on energy topics, two on complex systems
  - One Postdoc
  - Master and Bachelor students from Information Technology and Computer Science
- Funded by Lakeside Labs/KWF until end of 2014

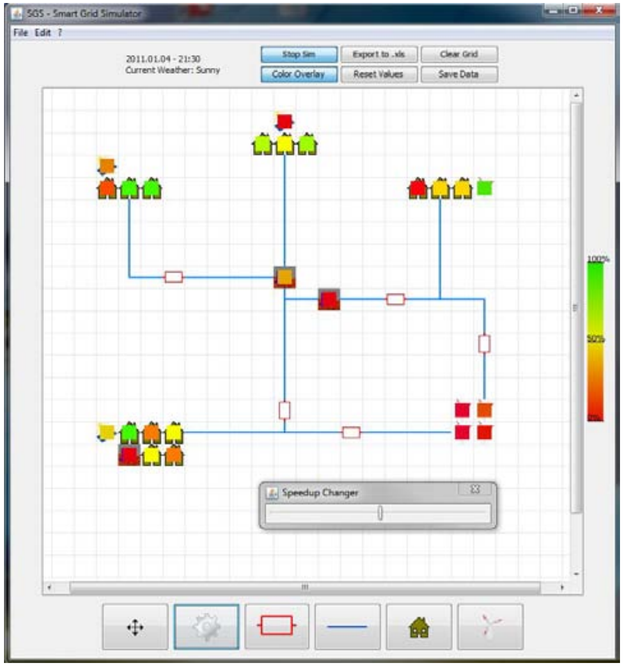
Current Research Topics (1)

- Non-Intrusive Load Monitoring
  - (How) can devices be detected based on their energy signature?
  - Research existing methods
  - Adjust approach to work with smart plug/smart meter systems
  - Add self-organizing aspect to reduce configuration effort
- Research potential
  - Intelligent configuration
  - Bio-inspired detection algorithms
- Application potential
  - Device detection for smart home
  - Profile hiding using small energy buffers



Current Research Topics (2)

- Modeling and simulation of smart microgrids
  - Assumptions based on real measurements
  - Graphical user interface
- Simulation/emulation in real-time mode
  - Interfacing the real lab
- Research potential
  - Hardware-in-the-loop approach
  - energy/information coupling of real lab to simulation
- Application potential
  - Provide validation platform for distributed algorithms that span over multiple smart microgrids



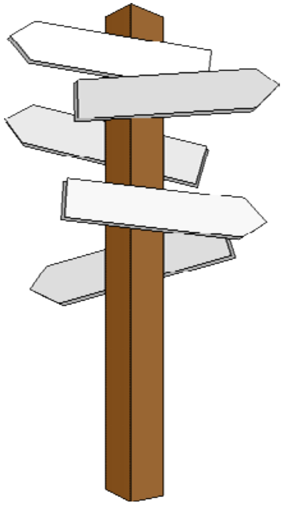
Current Research Topics (3)

- Modeling and testing self-organizing algorithms for smart microgrids
  - Bio-inspired information distribution (hormone model)
  - Pricing/auctions for mediating energy distribution
- Middleware for hormone-based distribution
- Research potential
  - Complex systems, bio-inspired algorithms for smart grid
- Application potential
  - Smart microgrid networks
  - Generic solutions that can be applied in different fields

Source: Wikipedia

Overview

- Self-organizing systems
- Engineering self-organizing systems
- Smart microgrids
- The smart microgrid lab
- **Goals for this workshop**



Our goals for this Workshop

- Find topics for collaboration on
  - Self-organizing smart microgrids
  - Evolutionary design of self-organizing systems
- Possibilities:
  - Exchange of ideas
  - Joint work/publications
  - Students exchange
  - Inviting guest researchers
  - Joint project proposals

- Looking forward to great and fruitful workshop!

Thank you very much for your attention!

- Project SmartGrid: http://smartmicrogrid.blogspot.com/
- Publications: http://www.elmenreich.tk