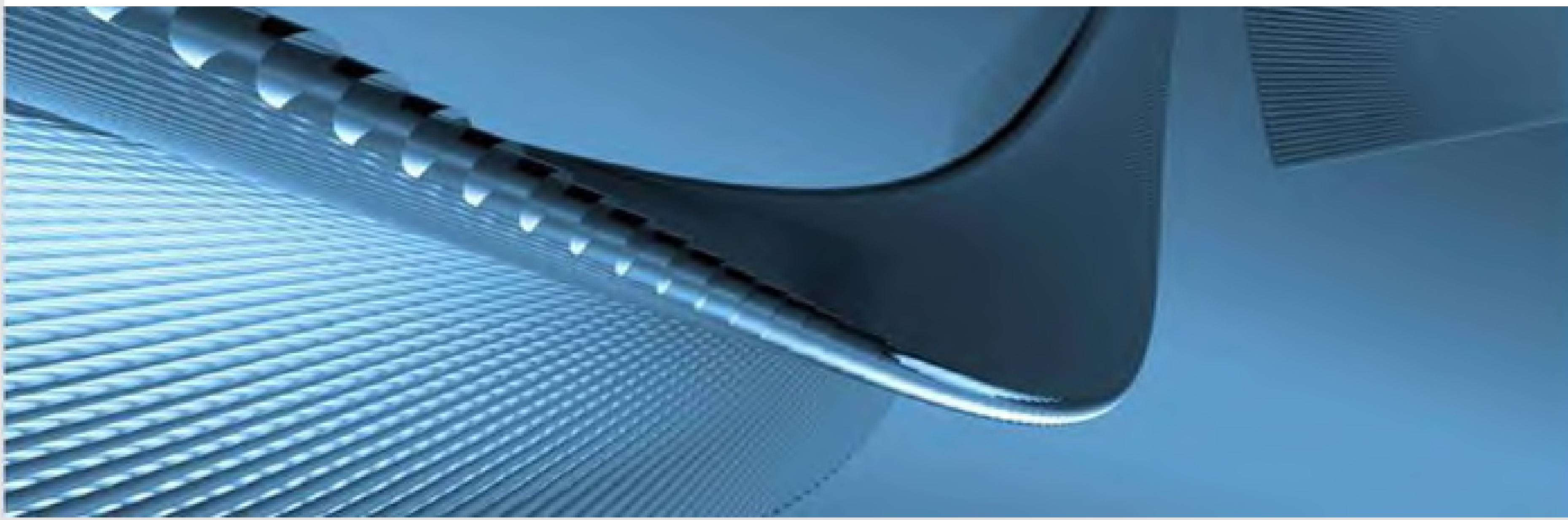
Organic Computing – a Generic Approach to Controlled Self-organization in Adaptive Systems

Prof. Dr. Hartmut Schmeck, Institut AIFB, KIT

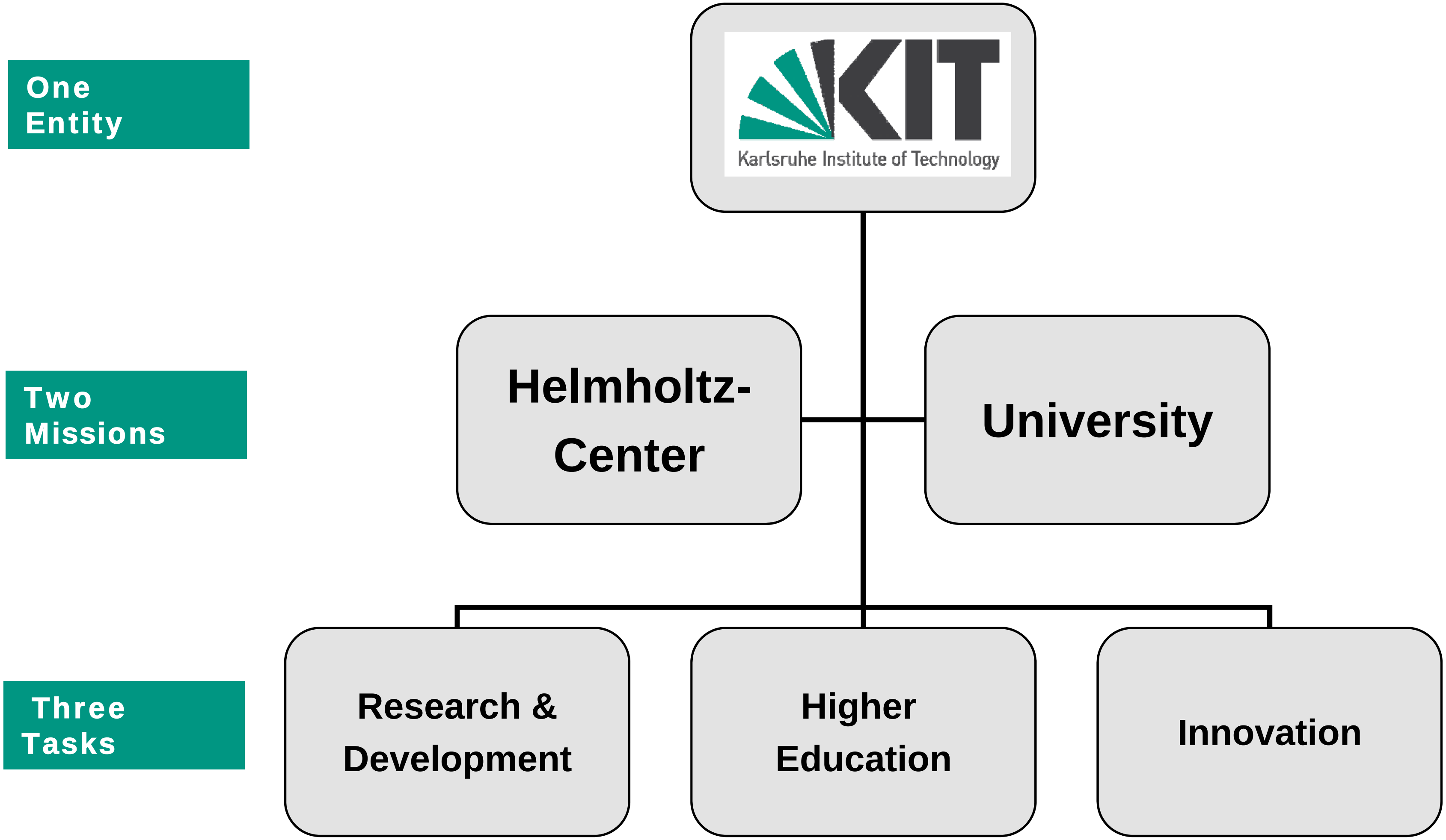
Overview

- Brief introduction of KIT
- What is Organic Computing?
  - Motivation
  - Vision
- Generic Observer/Controller-Architecture
- Application of OC principles
  - Traffic control
  - Smart energy
- Conclusion

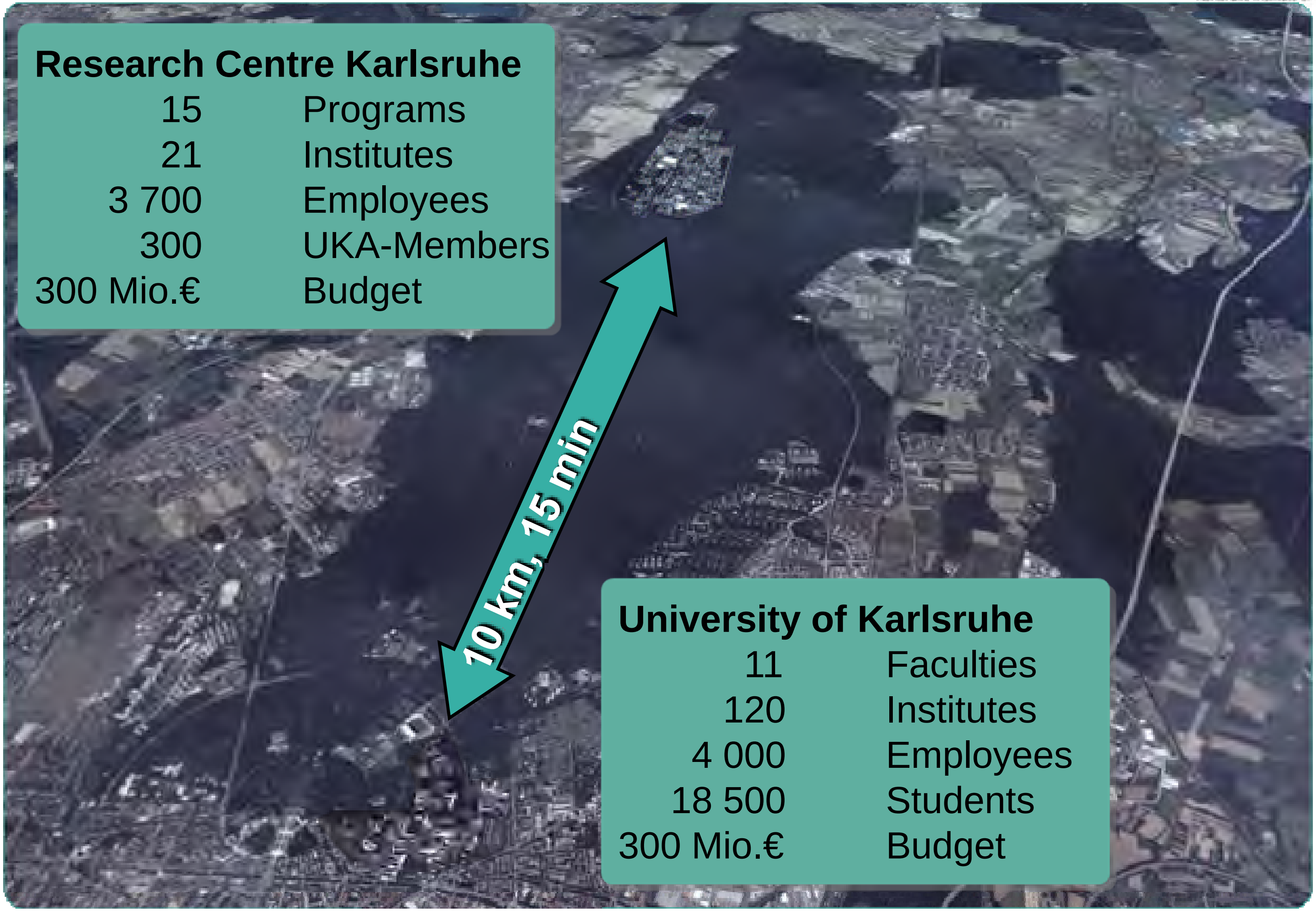
Karlsruhe Institute of Technology KIT –
A merger for excellence in science



KIT – One Entity, Two Missions, Three Tasks



Ideal Preconditions at Karlsruhe



Research Centre Karlsruhe

15	Programs
21	Institutes
3 700	Employees
300	UKA-Members
300 Mio.€	Budget

University of Karlsruhe

11	Faculties
120	Institutes
4 000	Employees
18 500	Students
300 Mio.€	Budget

Research at KIT:
30 Competence Fields in 6 Competence Areas

KIT Karlsruhe Institute of Technology

Matter and Materials (6)

- Elementary Particle and Astroparticle Physics
- Condensed Matter
- Nanoscience
- Microtechnology
- Optics and Photonics
- Applied and New Materials

Earth and Environment (4)

- Atmosphere and Climate
- Geosphere and Risk Management
- Hydrosphere and Environmental Engineering
- Constructed Facilities and Urban Infrastructure

Applied Life Sciences (4)

- Biotechnology
- Toxicology and Food Science
- Health and Medical Engineering
- Cellular and Structural Biology

Technology, Culture and Society (3)

- Cultural Heritage and Dynamics of Change
- Business Organization and Innovation
- Interaction of Science and Technology with Society

Information, Communication, and Organisation (6)

- Algorithm, Software and System Engineering
- Cognition and Information Engineering
- Communication Technology
- High-Performance and Grid Computing
- Mathematical Models
- Organisation and Service Engineering

Systems and Processes (7)

- Fluid and Particle Dynamics
- Chemical and Thermal Process Engineering
- Fuel and Combustion
- Systems and Embedded Systems
- Power Plant Technology
- Product Life Cycle
- Mobile Systems and Mobility Engineering

Research at KIT: Centers and Focuses

KIT-Centers

- Energy
- NanoMicro
- Elementary and Astroparticle Physics
- Climate and Environment

KIT-Focuses

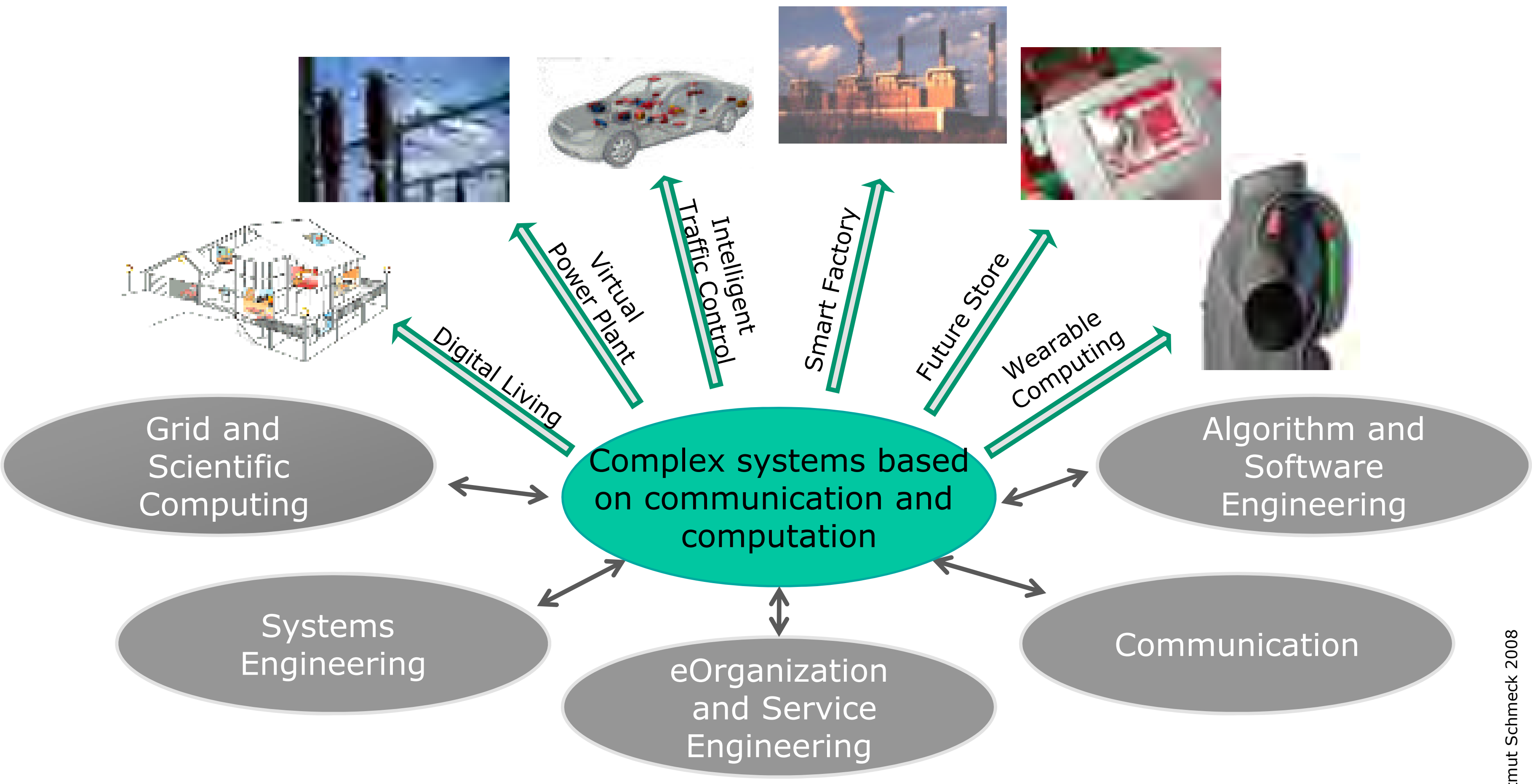
- COMMputation
- Optics and Photonics
- Mobility
- Man & Technology

KIT-Focus COMMputation

- Relevance of **Communication** and **Computation**:
  - Increasing presence of intelligent embedded systems
  - numerous intelligent objects (“devices”) capable
    - to communicate among each other and with humans
    - to be aware of their environment
    - to adapt to dynamically changing requirements
  - Typical objects: computers, mobile phones, cars, air planes, appliances, ….)
- **Emphasis on concepts, architectures, methods, tools,** and **selected applications** of
  - Information processing,
  - Communication,
  - Organisation and services,

to guarantee **trustworthy**, **robust** and **efficient behaviour** of complex, adaptive systems.

KIT-Focus COMMputation
Topical Structure and Exemplary Applications



www.commputation.kit.edu

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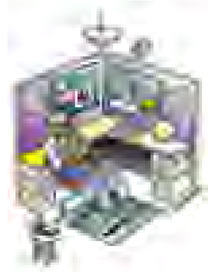
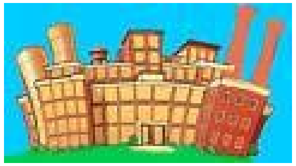
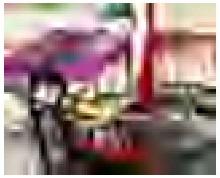
What Organic Computing is *not about*

So, what is it about?




- Collections of **intelligent (embedded) systems**
(scenarios like **smart house, car, office, factory, shop, healthcare**,…
…**ubiquitous, pervasive computing**).
- Potentially **unlimited networks** (large number, mobility)
- **Spontaneous local interaction,** leading to unexpected global behaviour
(**emergent phenomena** as a result of **self-organization**)
- **Robust services** in dynamically changing environments
(e.g. mobile communication).
- **Flexible behaviour** as a reaction to varying external constraints
(e.g. traffic light control)
- **Design, management and acceptance problems** wrt increasingly **complex systems**
→ **Controllability? Trustworthiness?**

⇒ **We have to come up with good ideas for**
  - **designing, managing, and controlling unlimited, dynamical networks of intelligent devices,**
  - **utilising the available technology for the utmost benefit to humans.**

Origin of Organic Computing

Workshops of the GI-/ITG-Sections on Computer Engineering in 2002

- Information technology is moving towards the ubiquitous networked computer.
- Complex ubiquitous systems need new concepts for organization and user interfaces to remain manageable and controllable.
- Future computer systems have to be designed with respect to human needs.
- Future computer systems have to be trustworthy.
- Future computer systems have to be robust, adaptive, and flexible.
- **Systems having these properties will be life-like.**
  We call them *Organic Computer Systems*.
- **Based on range of other initiatives: ubiquitous, autonomic, …**

GI/ITG Position paper 2003:

Vision for System Architecture > 2010

- **Organic Computer Systems**
  - will possess lifelike properties.
  - will consist of autonomous and cooperating sub systems and will work, as much as possible, in a self-organized way.
  - will adapt to human needs,
  - will be robust, adaptive, and flexible,
  - will be controlled by objectives (“goal-driven”),
  - will be trustworthy.

- **Self-organization** allows for adaptive and context aware behaviour:
  - self-configuring
  - self-optimizing
  - self-healing
  - self-protecting
  - self-explaining
  - self-managing
  - …

Meta-data?

Model-predictive?

Controlled-self-organized?

Model-based?

Organic Computing

You-name-it…

Feedback control?

Policies?

It is not the question,
whether adaptive and self-organising systems will emerge,
but ***how*** they will be designed and controlled.

Self-managing?

Autonomic?

Feedforward control?

Self-adaptive?

Self-organized?

Emergent control?

German Framework for Research on OC :

DFG priority program 1183 „Organic Computing“ (2005 – 2011)
3 phases of two years each, currently 19 projects, ~2 Mio € per year

www.organic-computing.de/SPP

Nature	(1) OC-Principles	(2) OC-Technology	(3) Technical Applications
	Emergence Self-x	OC-toolbox	
→	→	↔	
Dissip. Struct. Ants Swarms Brain ….	Autonomy Self-x. Emergence Awareness Cooperation Competition …	Basic technologies Observer/Controller Guarding Helper Threads Embedded Learning Complete system arch. …	Car Office Telecom Factory Home Health&Care …

Phase II: 19 Projects

- **Learning to Look at Humans** (Würtz, Uni Bochum)
- **Model-Driven Development of Self-Organizing Control Applications** (Heiß, Mühl, TU Berlin, Weis Uni Duisburg)
- **Organic Fault-Tolerant Control Architecture for Robotic Applications** (Maehle, Brockmann, Uni Lübeck, Großpietsch FhG, St. Augustin)
- **Smart Teams: Local, Distributed Strategies for Self-Organizing Robotic Exploration Teams** (Meyer auf der Heide, Schindelhauer, Uni Paderborn)
- **Formal Modeling, Safety Analysis, and Verification of Organic Computing Applications – SAVE ORCA** (Reif, Uni Augsburg)
- **Embedded Performance Analysis for Organic Computing** (Ernst, TU Braunschweig)
- **OCCS - Observation and Control of Collaborative Systems** (Branke, Schmeck, KIT; Hähner. Müller-Schloer Uni Hannover)
- **OTC² - Organic Traffic Control Collaborative** (Hähner, Müller-Schloer, Uni Hannover, Branke, Schmeck Uni Karlsruhe)
- **AUTONOMOS: A distributed and self-regulating approach for organizing a large system of mobile objects** (Fekete, TU Braunschweig, Fischer, Uni Lübeck)
- **Organisation and Control of Self-Organising Systems in Technical Compounds** (Middendorf, Uni Leipzig)
- **Architecture and Design Methodology for Autonomic System on Chip** (Rosenstiel, Uni Tübingen, Herkersdorf, TU München)
- **Multi-Opjective Intrinsic Evolution of Embedded Systems (MOVES)** (Platzner, Uni Paderborn)
- **OCμ - Organic Computing Middleware for Ubiquitous Environment** (Ungerer, Uni Augsburg)
- **The bio-chemical information processing metaphor as a programming paradigm for organic computing** (Dittrich, Uni Jena)
- **Energy Aware Self Organized Communication in Complex Networks** (Timmermann, Uni Rostock)
- **Generic emergent computing in chip architectures** (Fey, Uni Jena)
- **On-line Fusion of Functional Knowledge within Distributed Sensor Networks** (Sick, Uni Passau)
- **A Modular Approach for Evolving Societies of Learning Autonomous Systems** (Rammig. Kleinjohann, Uni Paderborn))
- **Digital On-Demand Computing Organism for Real-Time Systems** (Becker, Brinkschulte, Henkel, Karl, Uni Karlsruhe)

The Principle of Self-organization

- Under appropriate environmental conditions the interaction of simple agents may lead to highly complex, adaptive Systems.
- No need for central control
- Examples:
  - Termite/Ant colonies
  - Swarms of bees
  - Economy
  - Traffic
  - Internet

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Idea: controlling complexity by
self-organization

But: Who is controlling self-organization?

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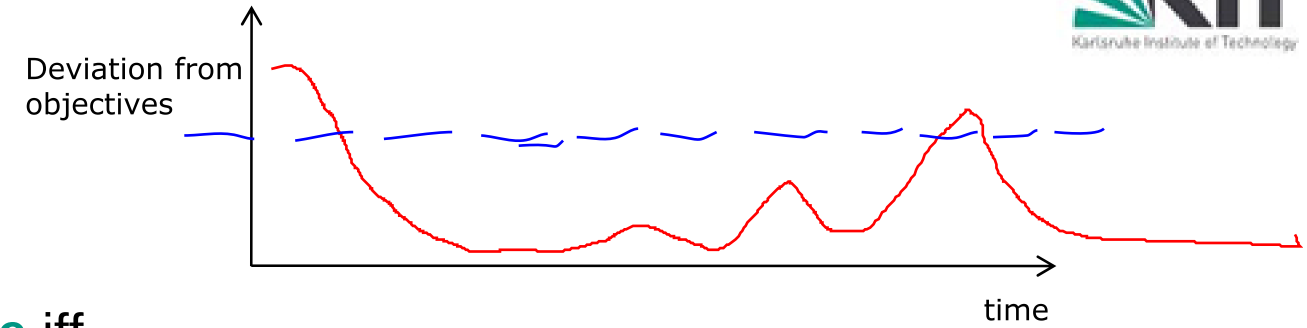
A few terms …



- System is **adaptive** iff
  system can adapt to changing operating conditions and disturbances (“**robustness**”) or to changing objectives (“**flexibility**”).

- **Self-organization**:
  Ability to operate acceptably with respect to certain objectives in a dynamically changing environment without the need for external control and with decentral control.

- **Controlled self-organization**:
  providing a range of operating modi varying with respect to the degree of external control, i.e. allowing for self-organisation but retaining the option for external interference.

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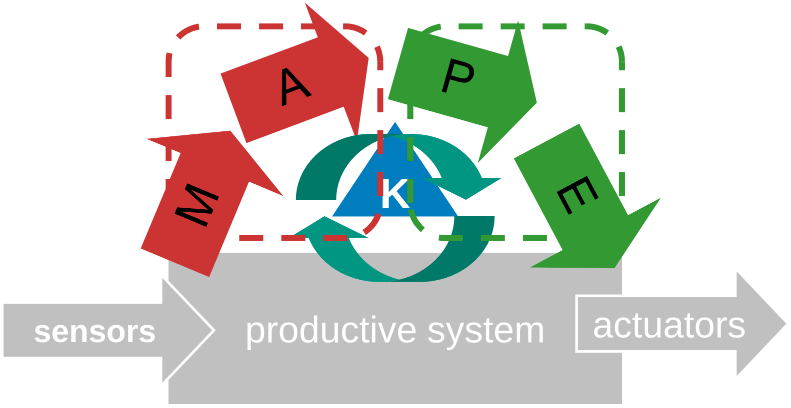
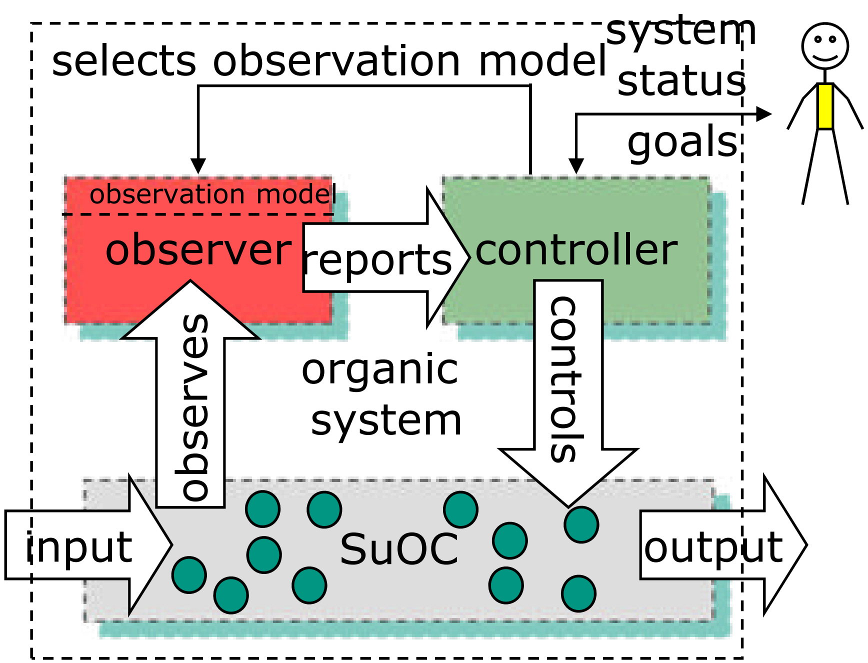
(Generic) Concepts for Control of SO-Systems

- IBM's **MAPE cycle** for autonomic computing
  - Monitor
  - Analyze
  - Plan
  - Execute
  - Knowledge

  (called "autonomic element")



- System under observation and control (SuOC)
  - A set of interacting elements/agents.
  - Does not depend on the existence of observer/controller.
- Distributed and/or central **observer/controller-architecture**
  - Driven by external goals
- Multilevel organization



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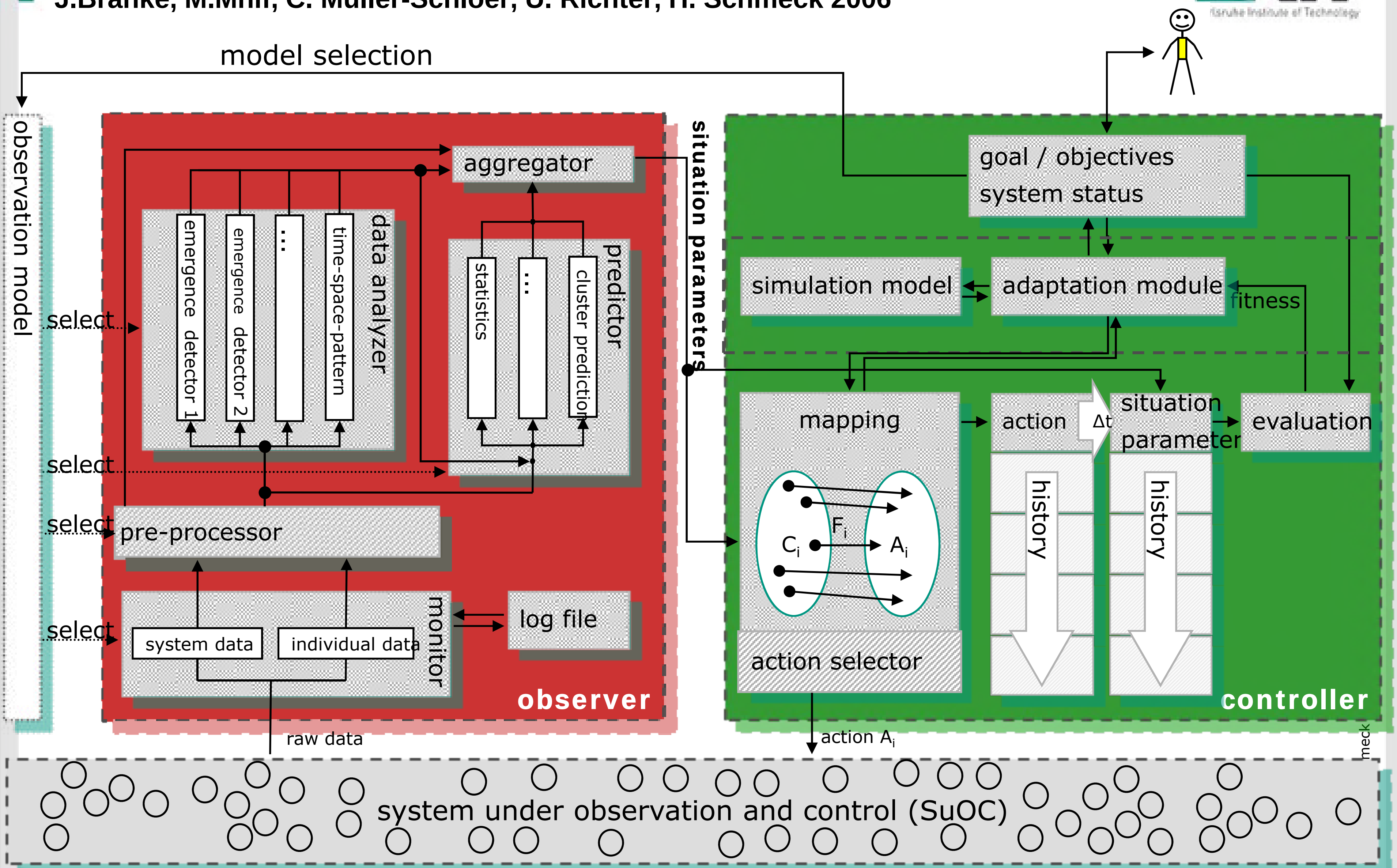
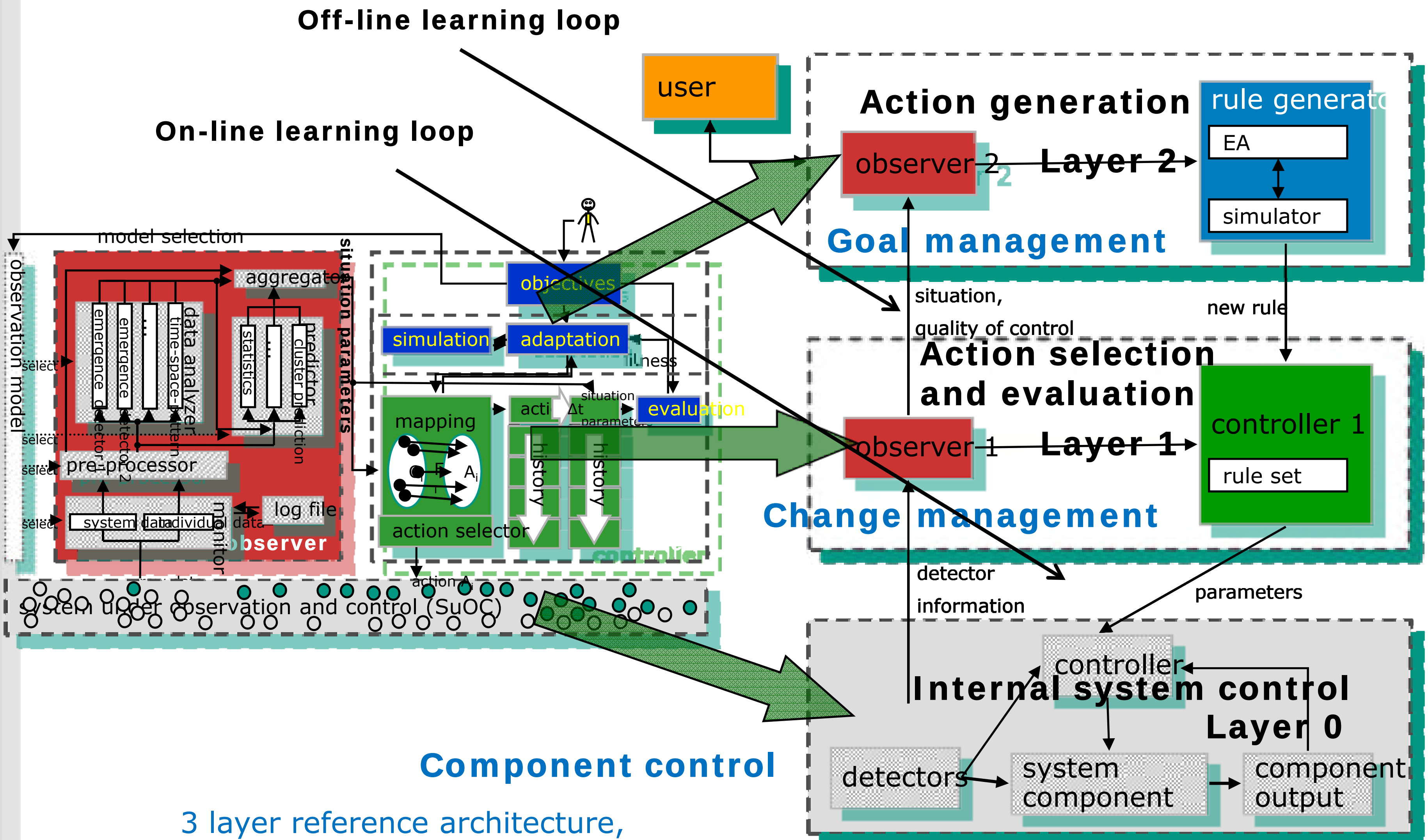
Generic O/C-Architecture

J.Branke, M.Mnif, C. Müller-Schloer, U. Richter, H. Schmeck 2006



Different view on O/C-architecture



Component control

3 layer reference architecture,
Jeff Magee, (DagSEfSAS 2008)

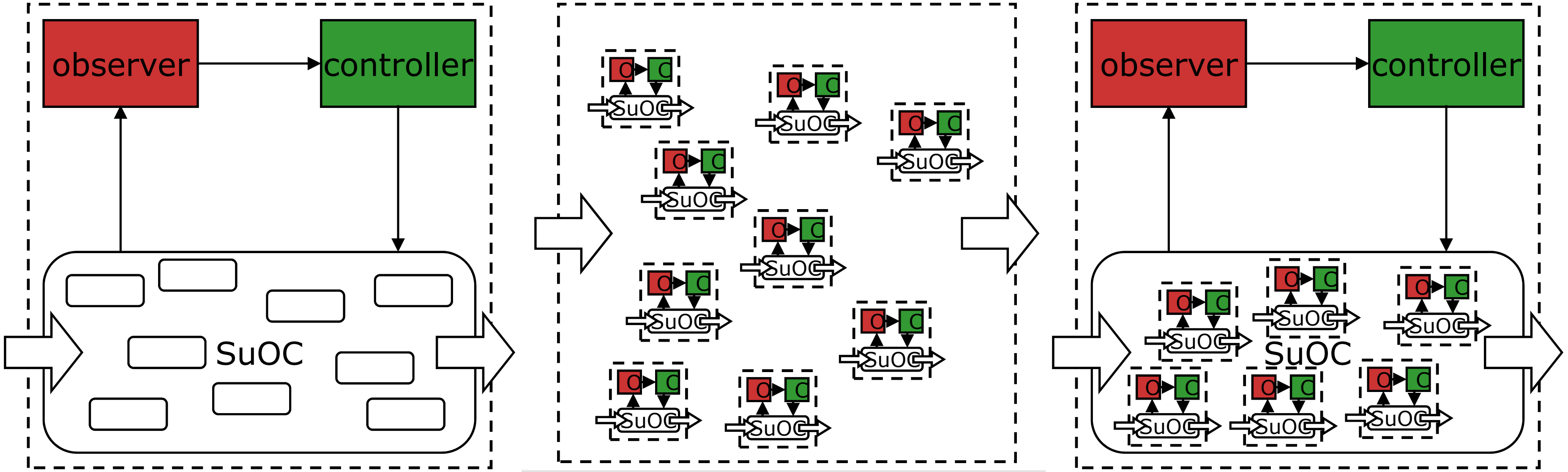
Realisation of OC systems

1. **Central**: One observer/controller for the whole system.
2. **Distributed**: An observer/controller on each system component.
3. **Multi-level**: An observer/controller on each system element as well as one for the whole system.

- adaptive
- top-down

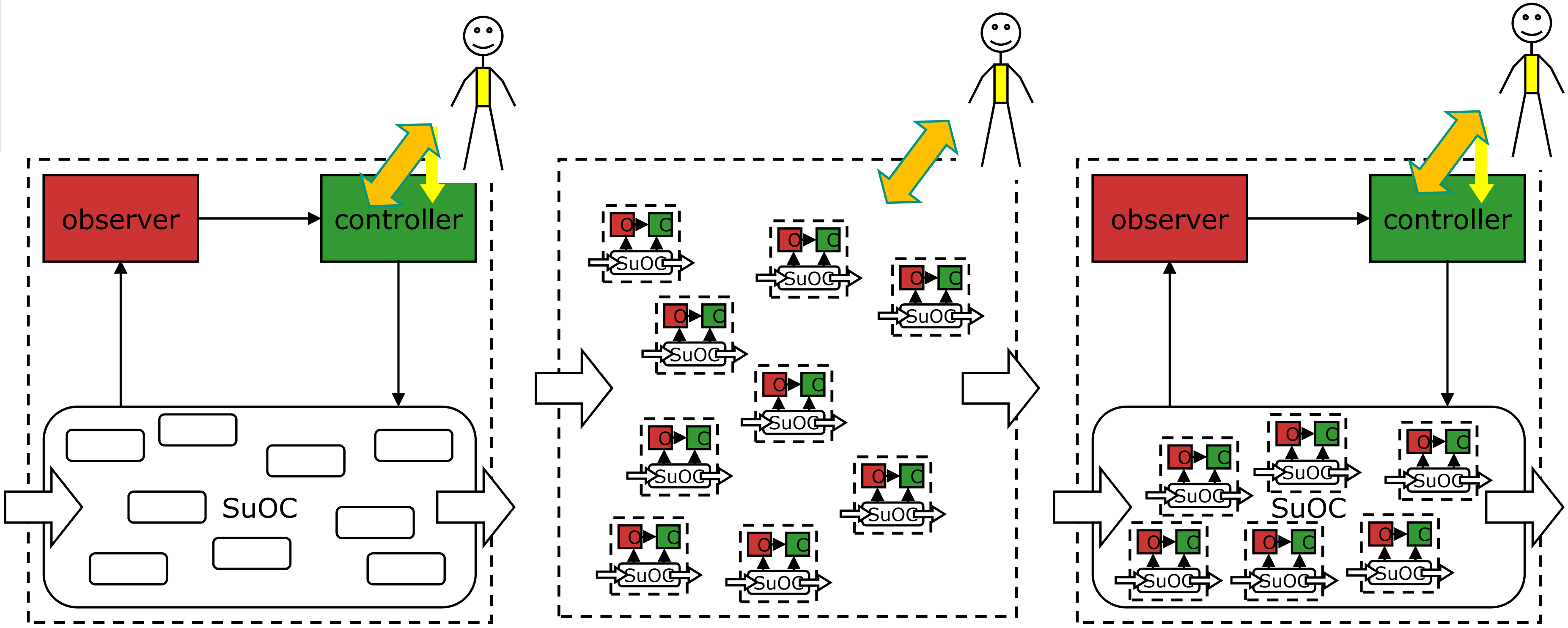
- self-organising
- bottom-up
- emergent control

- controlled self-organising
- bottom-up / top-down



Types of control actions

1. **Control the environment** (e.g. speed limit in traffic)
2. **Control the communication** (messages, addresses, neighborhoods,…)
3. **Control the local behavior of components** (reconfigure HW, update software, modify skills, set new local objectives,..)



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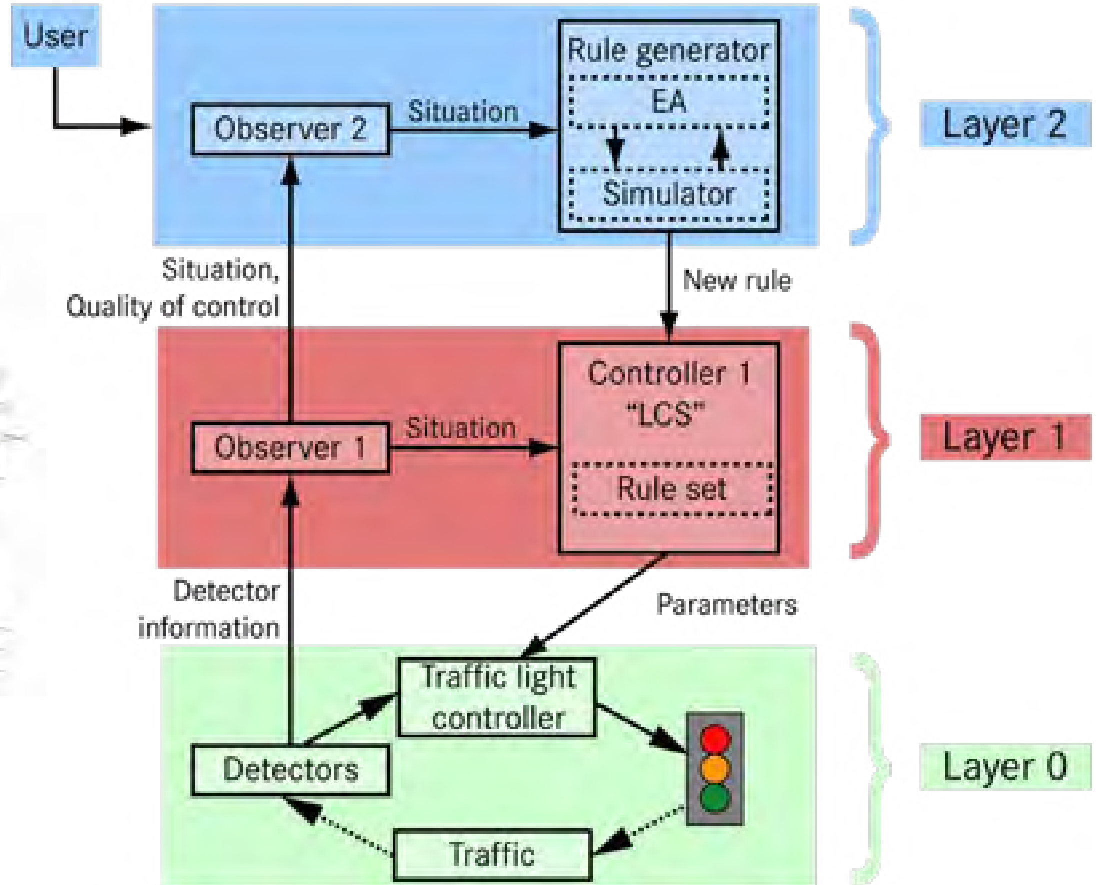
Application of OC Principles to Traffic Control

- Project **Organic Traffic Control** within the SPP Organic Computing
- **Goal**: Realization of a realistic organic system in a technical scenario

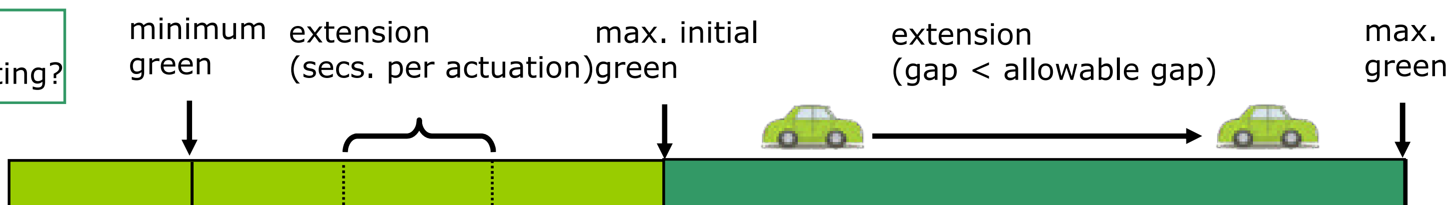
Decentralized Traffic Control

- Investigation of learning and adaptive traffic light control …
(Phase 1 of the SPP, 2005-2007)
- … and of their cooperative behavior in a street network
(Phases 2 and 3, 2007-2011)

Example Application: Organic Traffic Control



Recall:
car waiting?



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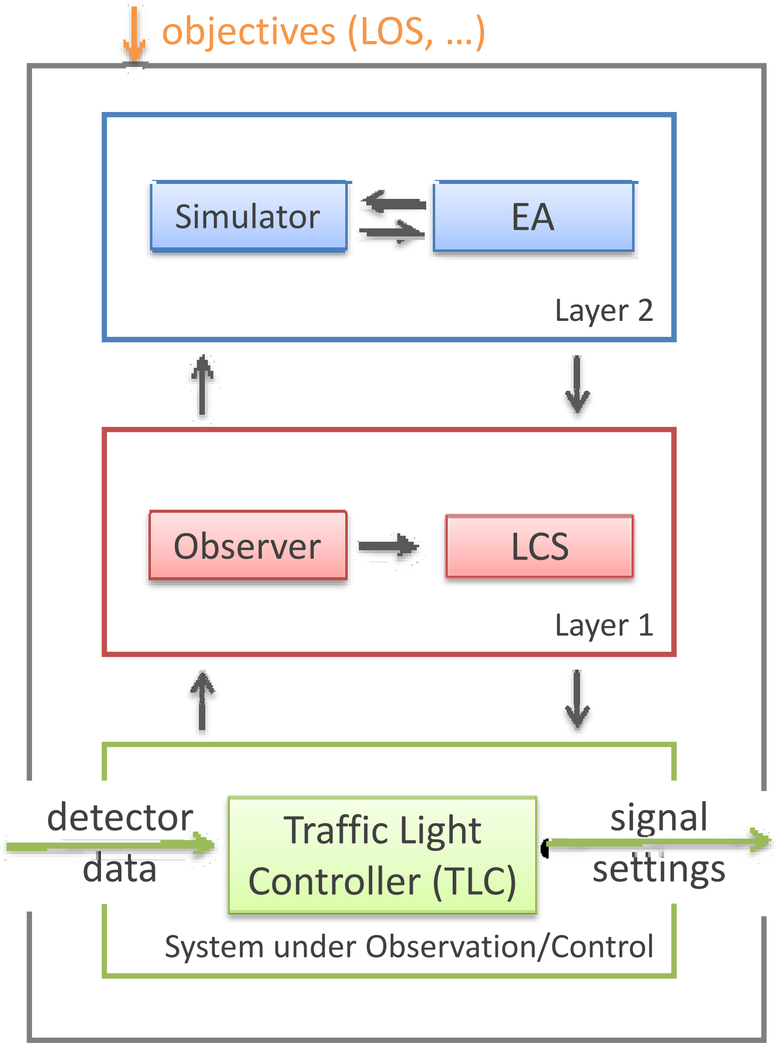
Architecture



User

Definition of system objectives

Layer 2

Off-line parameter optimisation
- Evolutionary Algorithm (EA) evolves TLC parameters
- Simulation-based evaluation

Layer 1

On-line parameter selection
- Observer monitors traffic
- Learning Classifier System (LCS) selects TLC parameters and learns rule quality

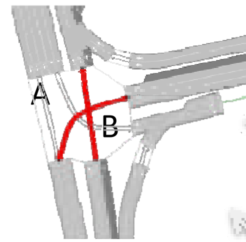
SuOC

Control of traffic signals
- Industry-standard TLC
  - Fixed-time
  - Traffic-responsive
  - Parameters determine performance

Layer 1: On-line parameter selection

Observer

Turning	A	B	...
veh/h	500	750	...



Observer
avg. delay = 24

Prediction update

TLC04

Rule base *Condition*	*Action*	*Pred.*
[420,530] [700,800][...]	: TLC05	26
[420,510] [740,910][...]	: TLC04	18
[100,250] [350,430][...]	: TLC07	23
[290,510] [700,980][...]	: TLC04	22

Action set [AS]

[420,510] [740,910][...]	: TLC04	18
[290,510] [700,980][...]	: TLC04	22

Match set [MS]

[420,530] [700,800][...]	: TLC05	26
[420,510] [740,910][...]	: TLC04	18
[290,510] [700,980][...]	: TLC04	22

Prediction array

TLC04	TLC05
20	26

LCS

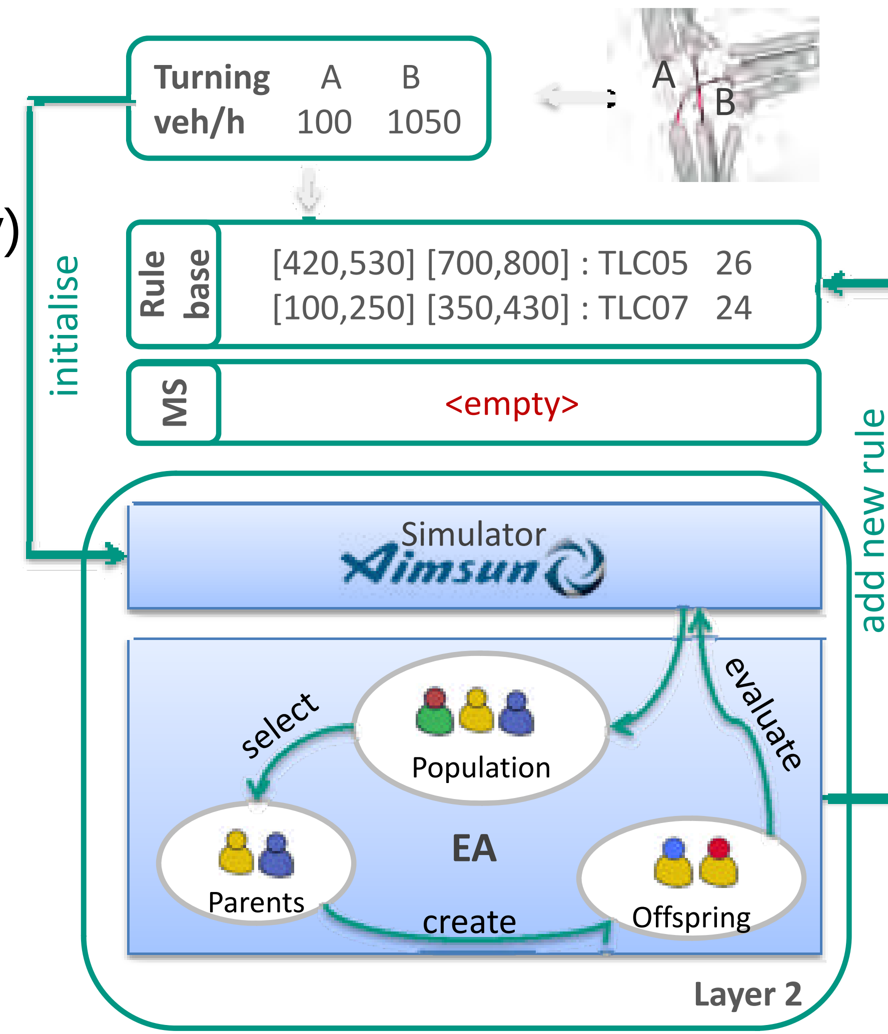
Layer 2: Off-line parameter optimisation

Rule creation in “classical” LCS

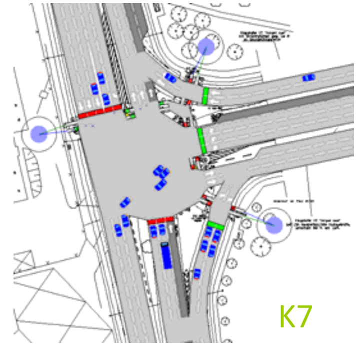
- Covering
  (Create matching rules randomly)
- Random crossover / mutation of existing rules
- Environment used for evaluation

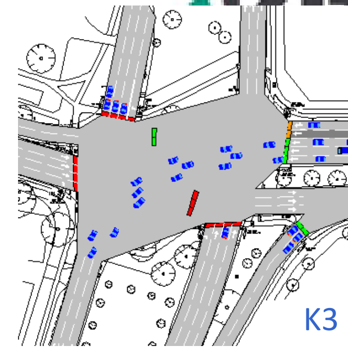
… in OTC

- EA optimises TLC parameters for observed situation
- Simulation-based evaluation

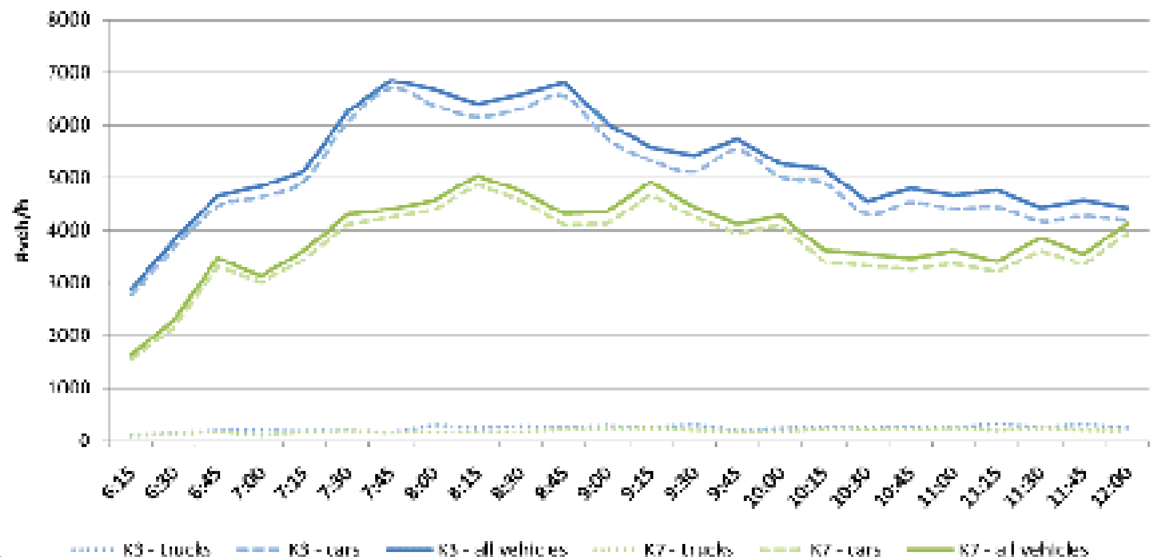


Test scenario





- Intersections located at Hamburg, Germany
- Traffic demands: From traffic census

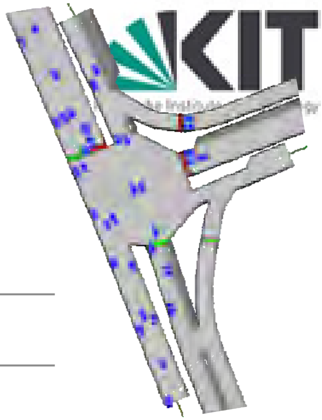


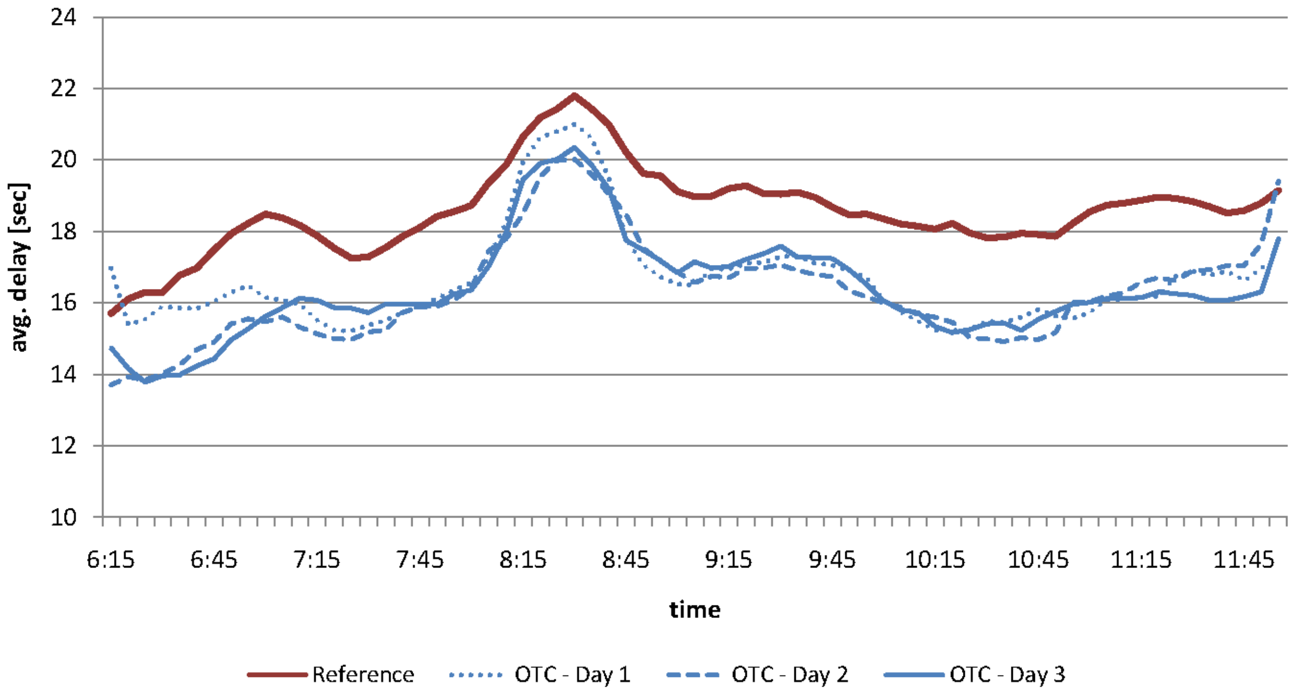
- Reference: Fixed-time controller provided by traffic engineer
- Criterion: Avg. delay time

$$\frac{\sum_{t\in T} f_t \cdot d_t}{\sum_{t\in T} f_t}$$

T set of intersection's turnings
f_t flow for turning t
d_t avg. delay for turning t

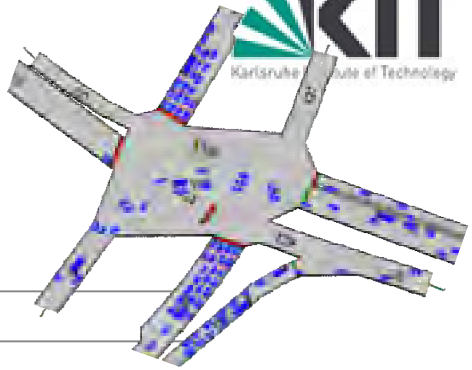
Results (K7)

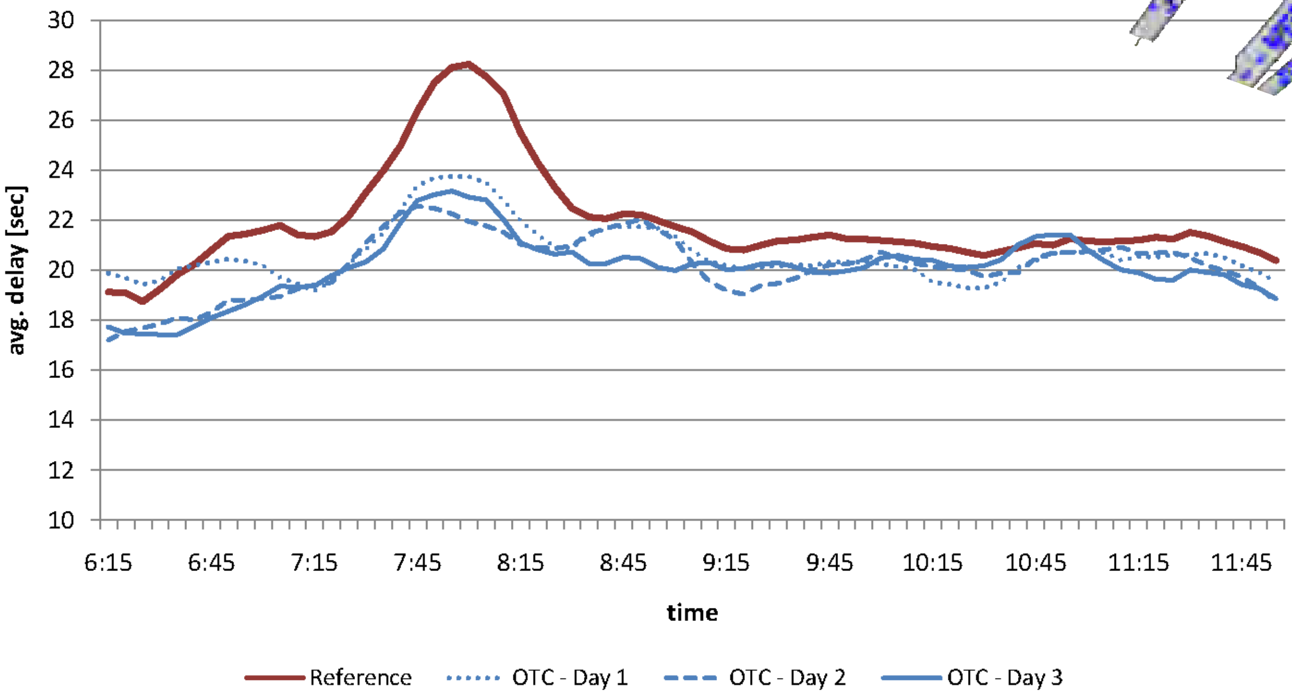




	Day 1	Day 2	Day 3
Improvement by organic approach	10%	12%	12%

Results (K3)





	Day 1	Day 2	Day 3
Improvement by organic approach	6%	8%	8%

Organic traffic control in street networks

Goal Optimize network performance

→ Minimize waiting time / #halts / …

Challenges

- Traffic dynamics in a street network

Example street network at Hamburg
[Data from traffic census]

- (Decentralised) Coordination of the network nodes

Project: Organic Traffic Control Collaborative

Goals

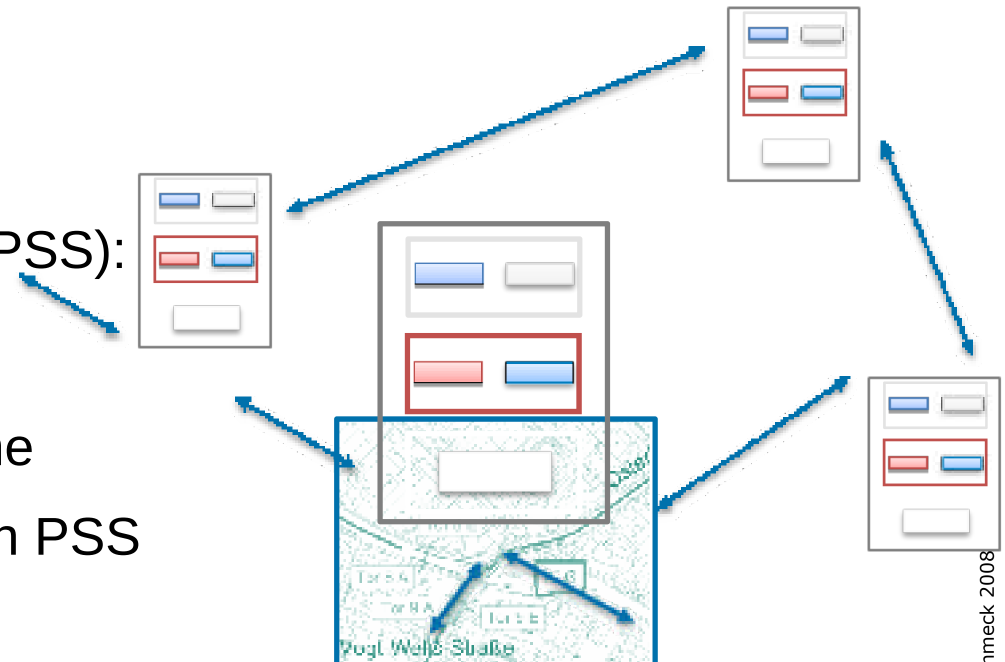
- Investigate possibilities for collaboration
- Study different architectural variants

Current focus

- *Traffic-responsive* creation of Progressive Signal Systems (PSS):

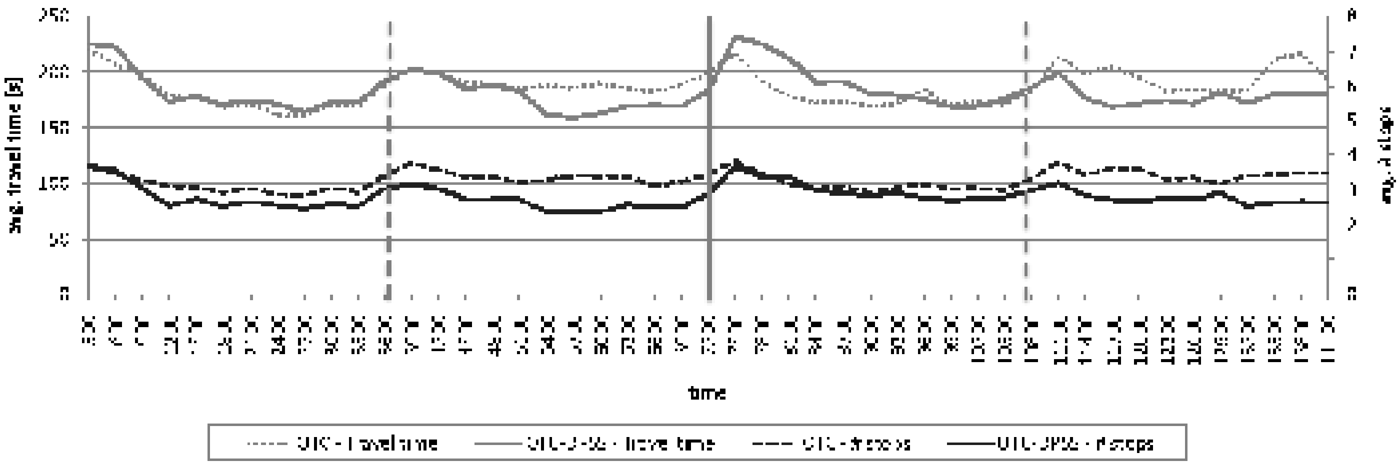
1. Determine partners for PSS
2. Determine a common cycle time
3. Determine offsets and establish PSS

- *Decentralised* operation



Experimental results
Arterial road

Network-wide results

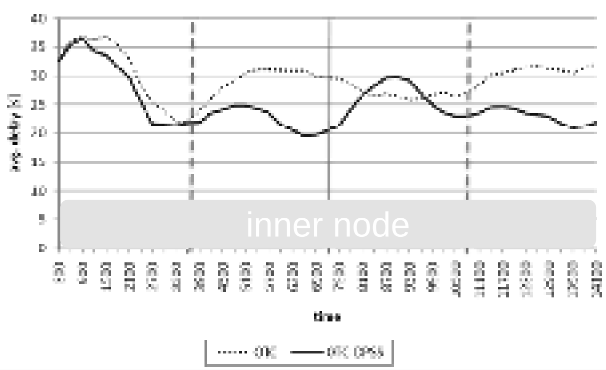


Number of stops
15% reduction

Travel times
Slightly reduced

Local delays

K 350



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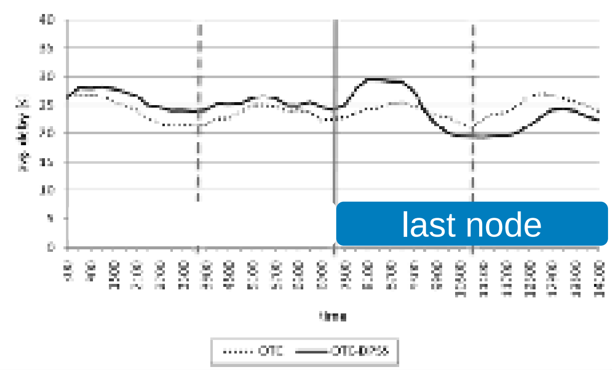
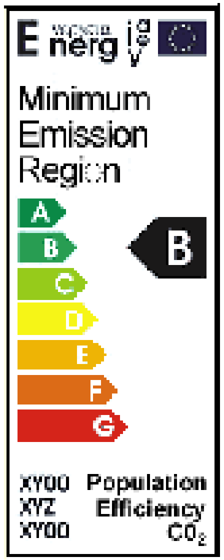
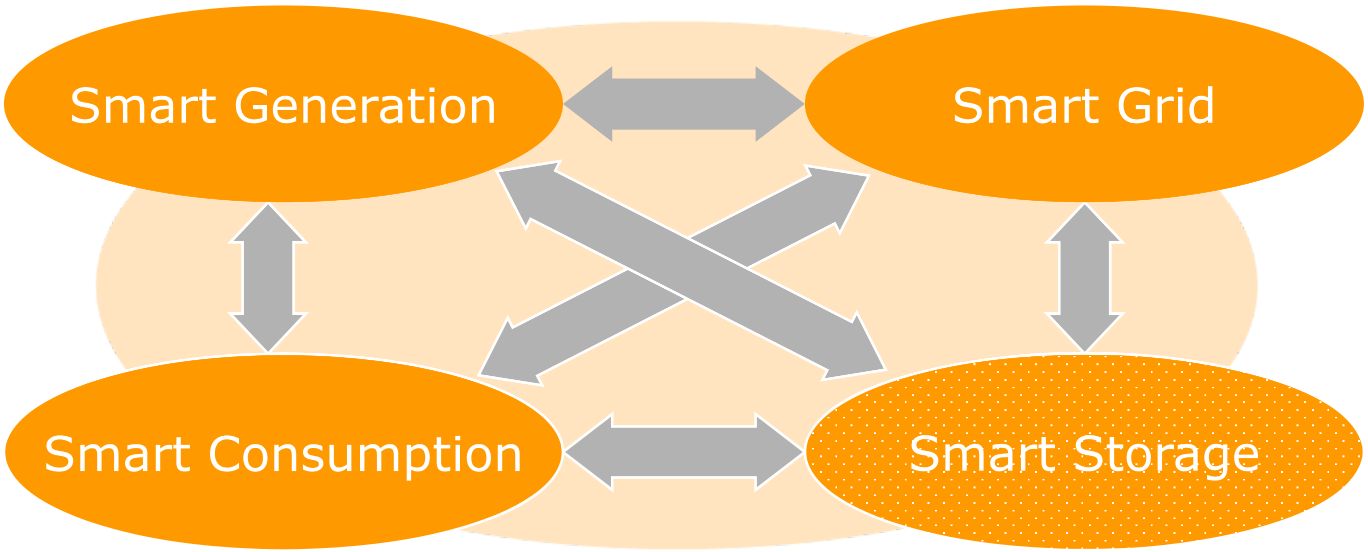


Application scenario: Energy system

- Project MEREGIO within the German **e-energy** program (federal R&D program)
- Focus of **e-energy**:
  using market mechanisms and ICT in all parts of the energy value chain in order to improve the efficiency of the energy system (60 Mio.€, 4 years, 6 "model regions")
- MEREGIO: ("Moving towards Minimum Emission Regions")
  - Cooperation of EnBW, IBM, SAP, ABB, SystemPlan, KIT (management sc., energy economics, informatics, law)
  - Model region: 1000 participants, enhanced by virtual participants
  - Development of "MEREGIO certificate" on CO_2-efficiency
- MEREGIOmobile / ecar@home: integrating mobile storage systems (e-vehicles, plug-in hybrids) into the energy system



E-Energy:
Linking all Components of a Smart Power System



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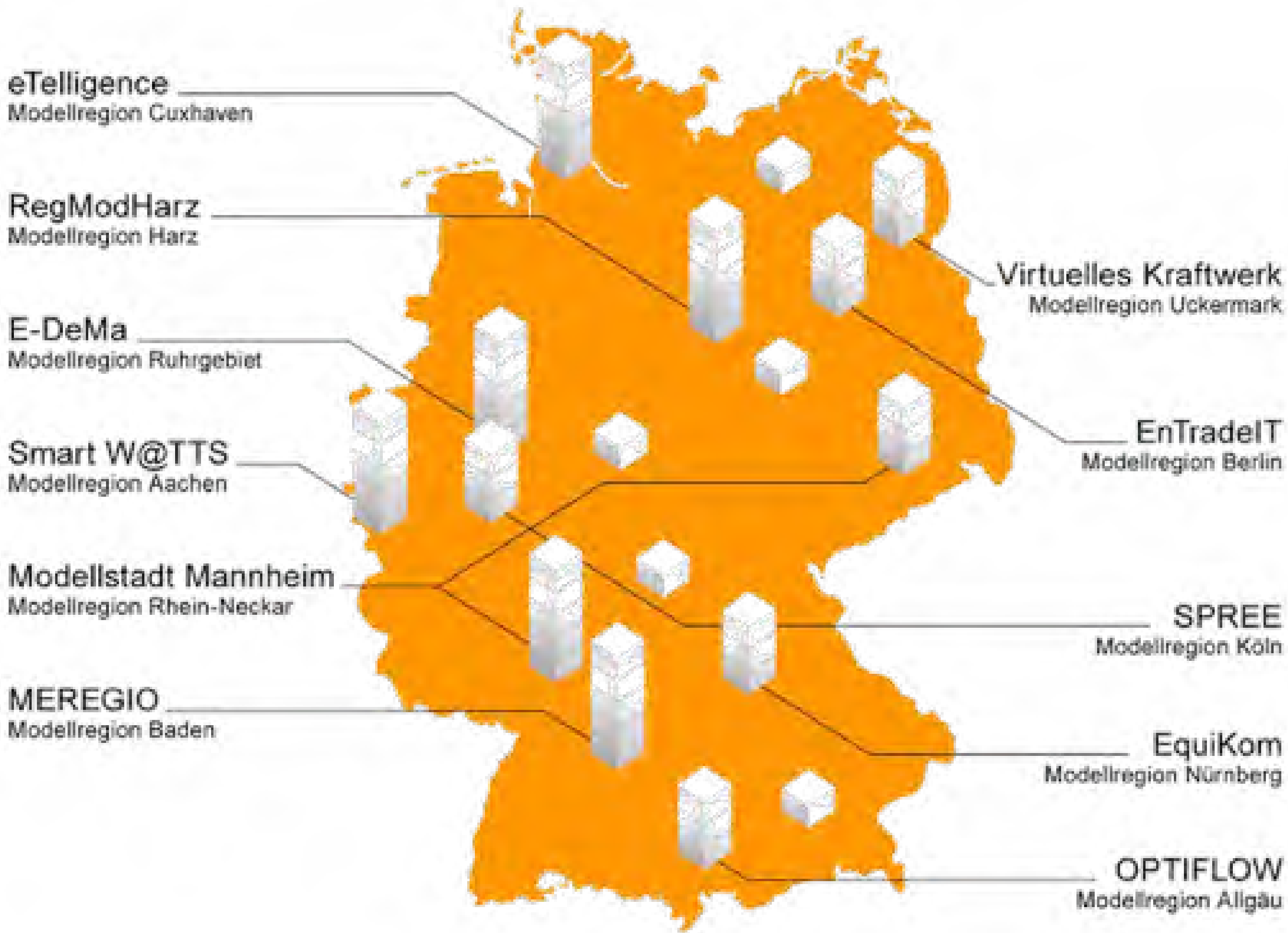
E-Energy Pilot Regions



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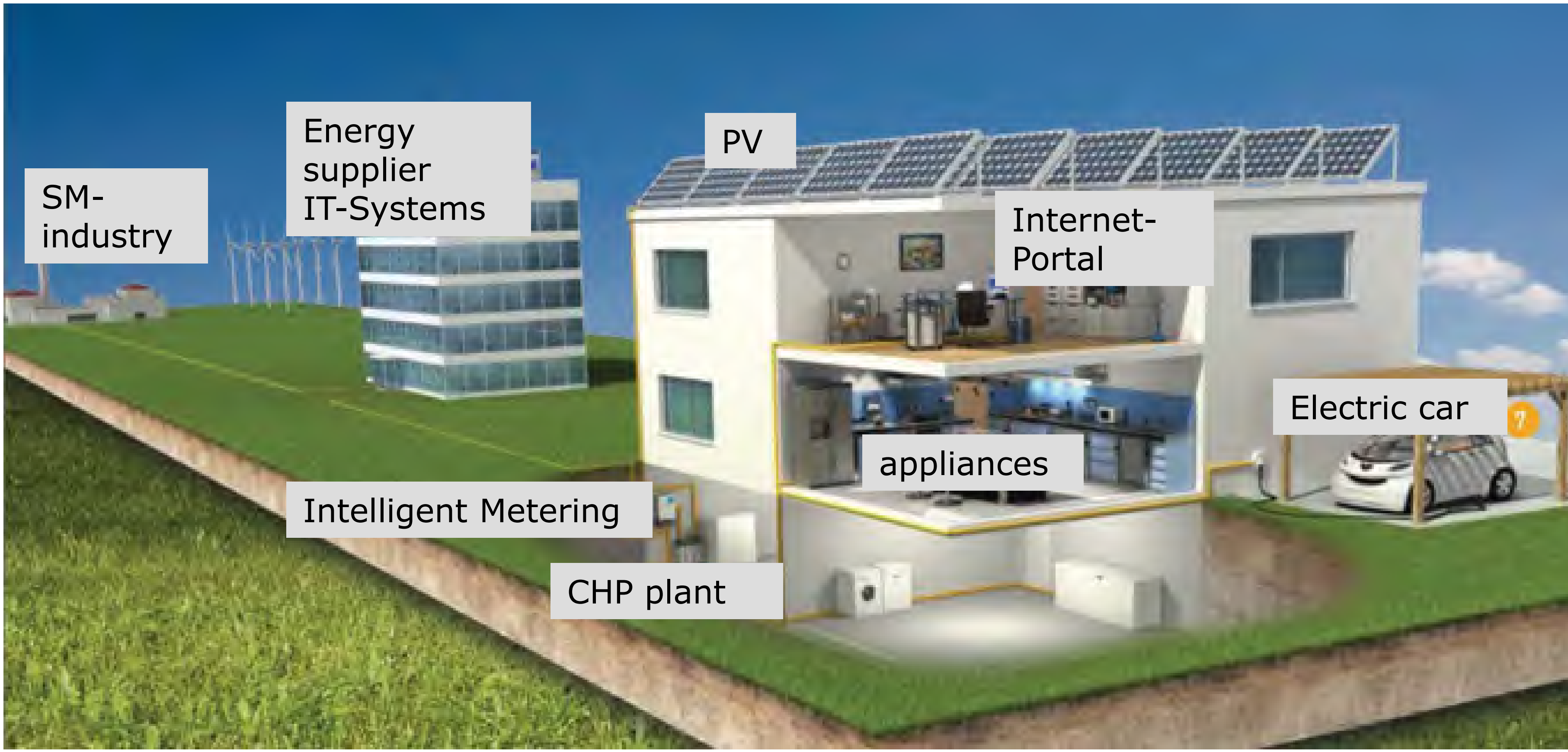
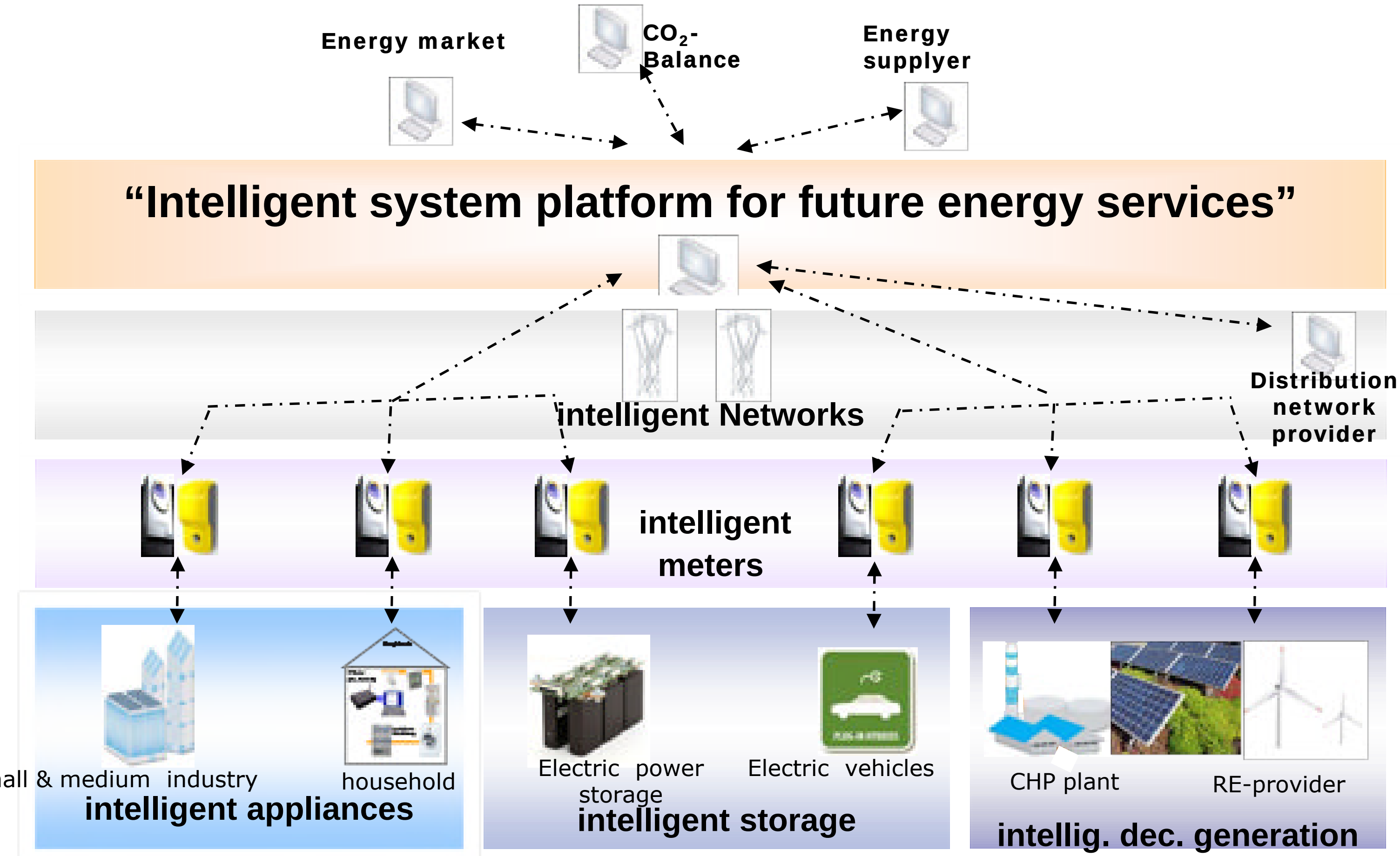
MEREGIO: Improving energy efficiency by intelligent use of ICT and market mechanisms



Smart ICT-based integration of decentral generation and usage of electric energy (incuding flexible mobile buffer storage for electricity)

MEREGIO system view

- **Intelligent system platform**
- Central element for integration in the model region.
- Ideal example of hierarchical monitoring and control



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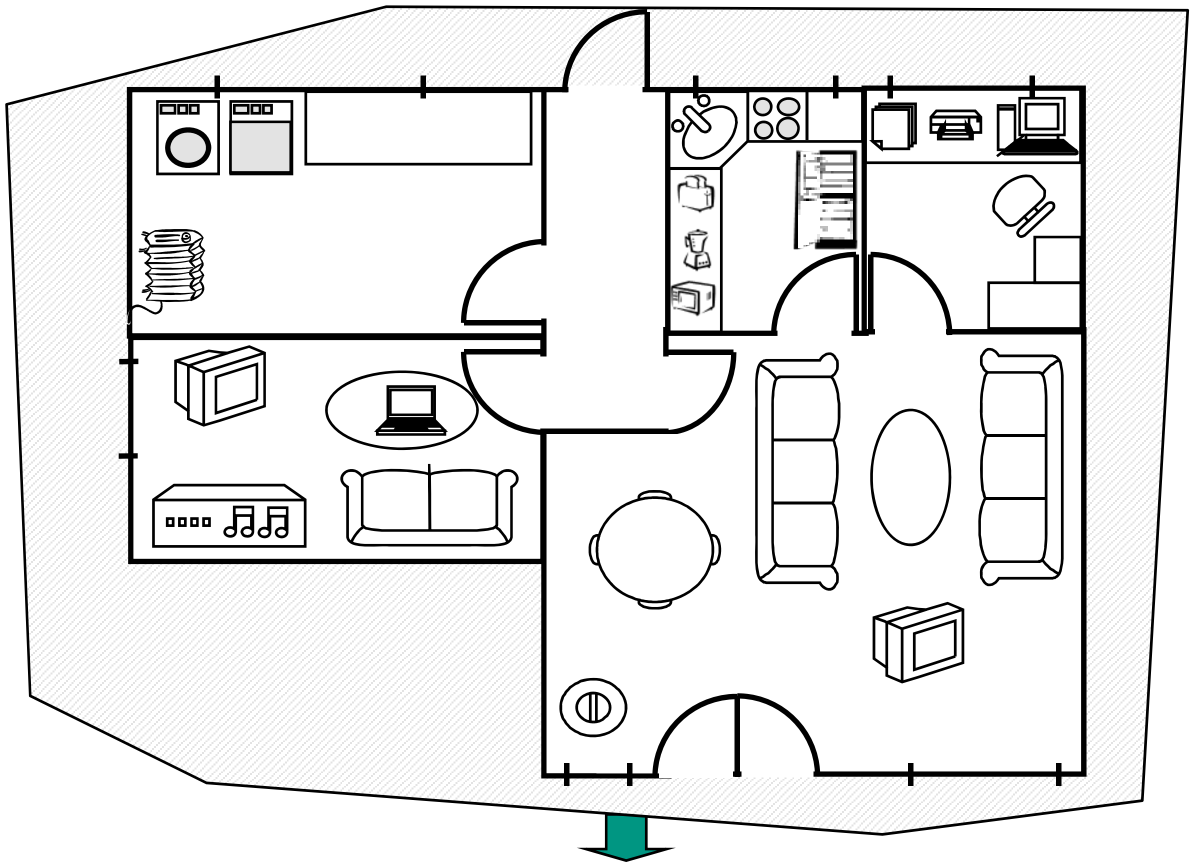
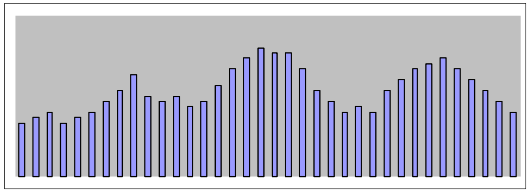
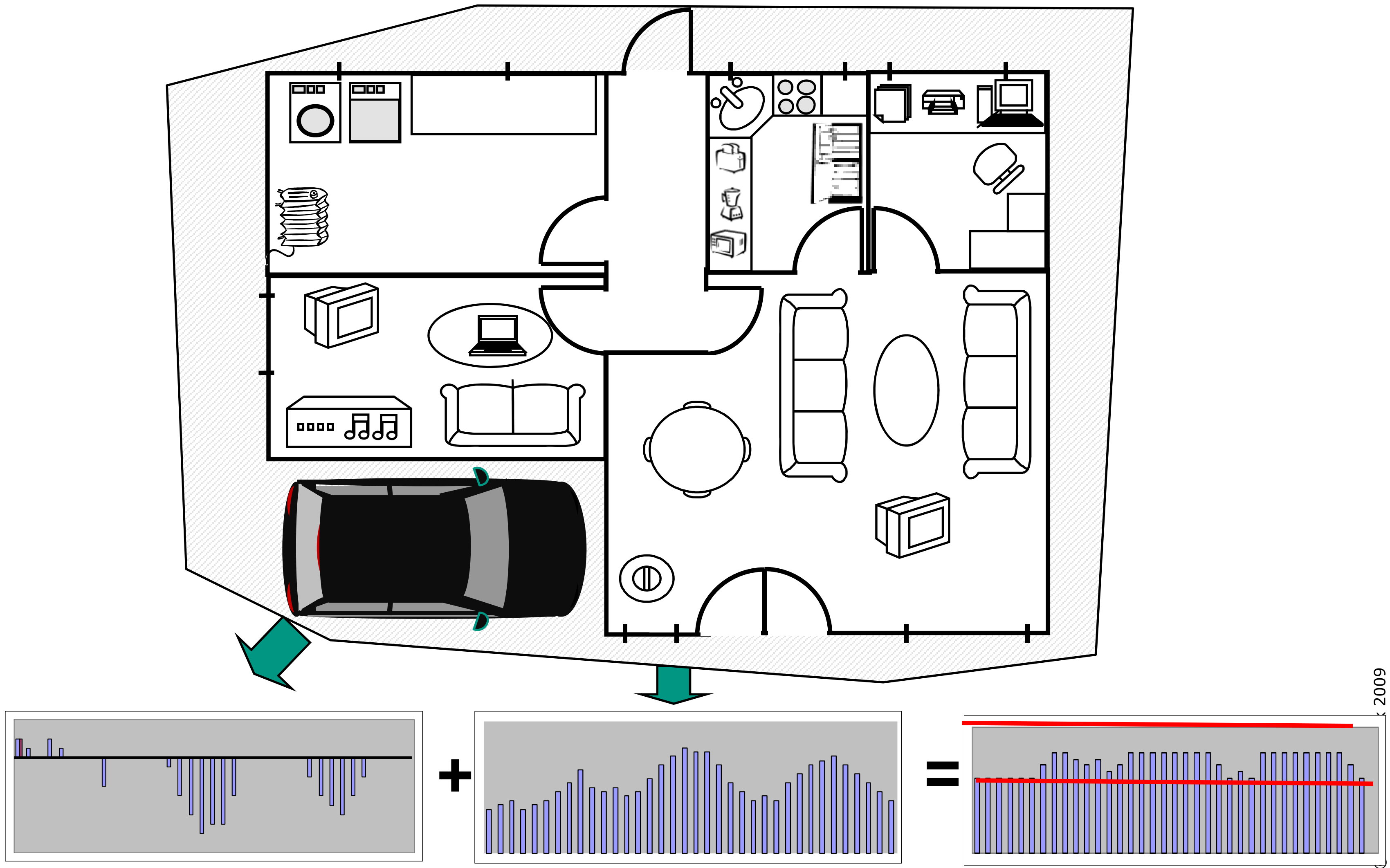
Scenario for ecar@home
demand profile without electric buffer storage elements





Scenario for ecar@home

demand profile using mobile batteries



Decentralised load management *(A. Kamper)* → smart energy

Scenario

- Large number of home appliances (fridge, freezer, air cond., ...)
- Increasing number of CHP plants and buffer storage
- Broadband internet (with router) in most households

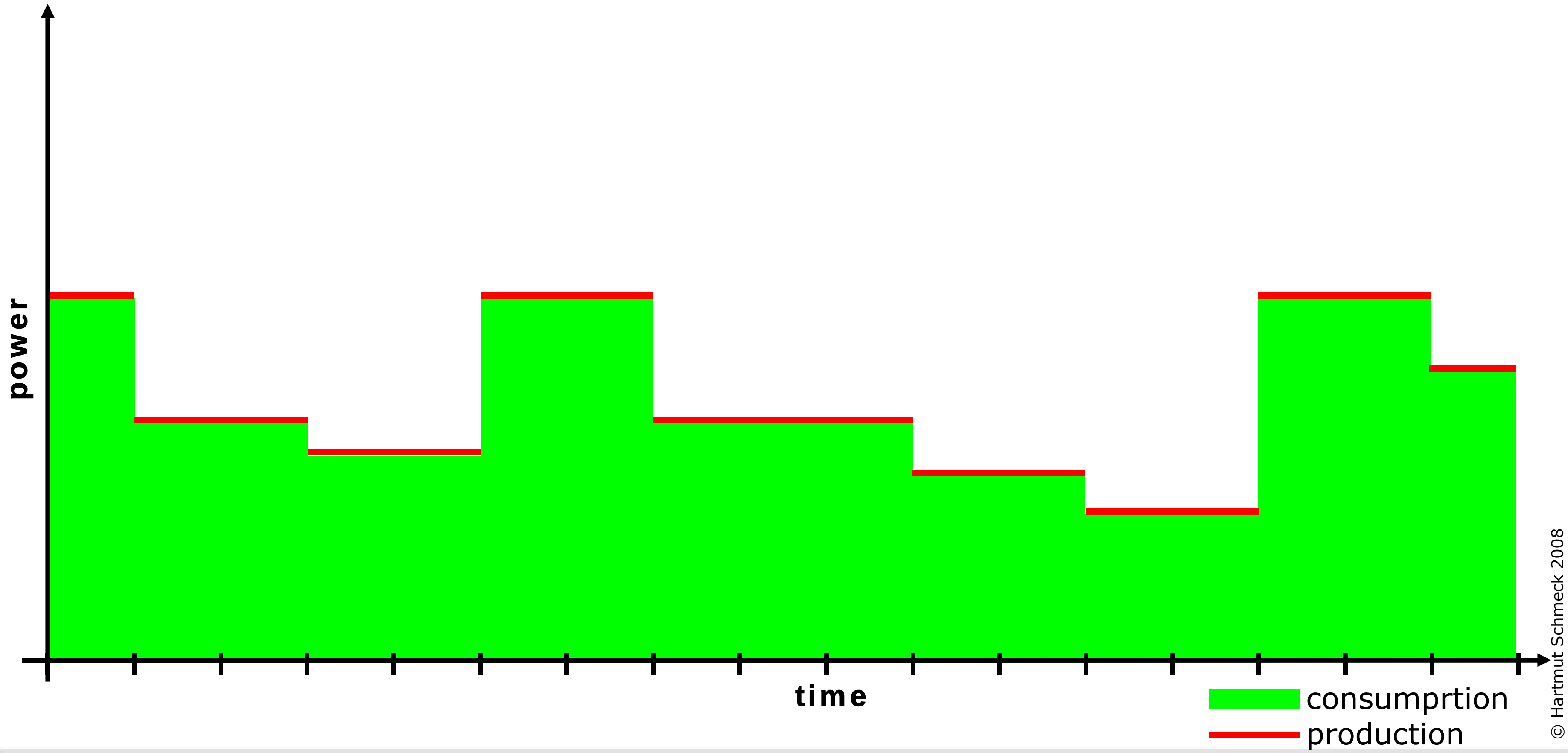
Environment

- No balancing power
- Coordination through Internet router or small control units
- Privacy
- Restrictions of devices must be met
- Overall production and consumption are fixed

→ Short term schedule changes
→ Automated control
→ Used by balancing groups

Decentralised load management

- Production and consumption in balance
- No correction necessary



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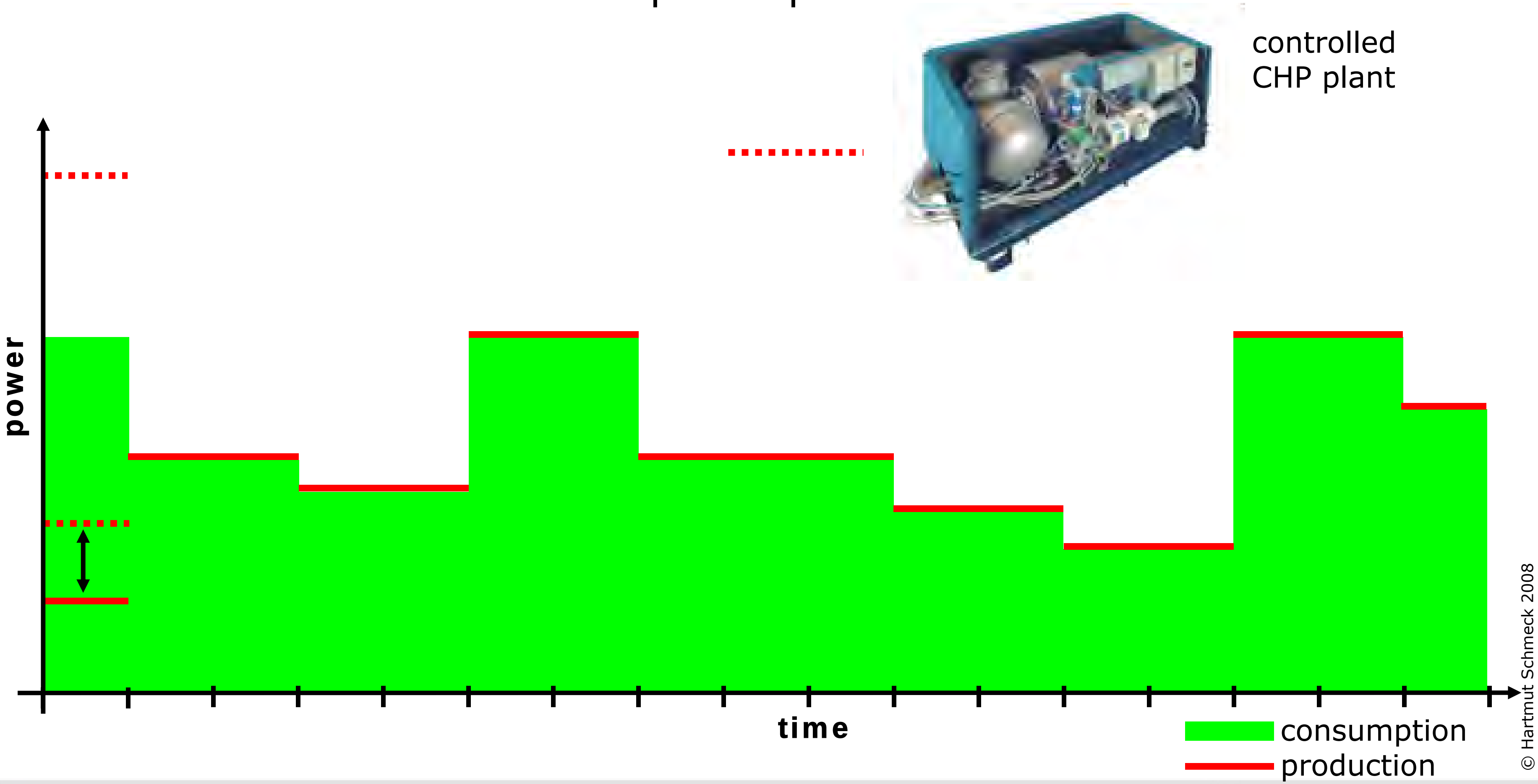
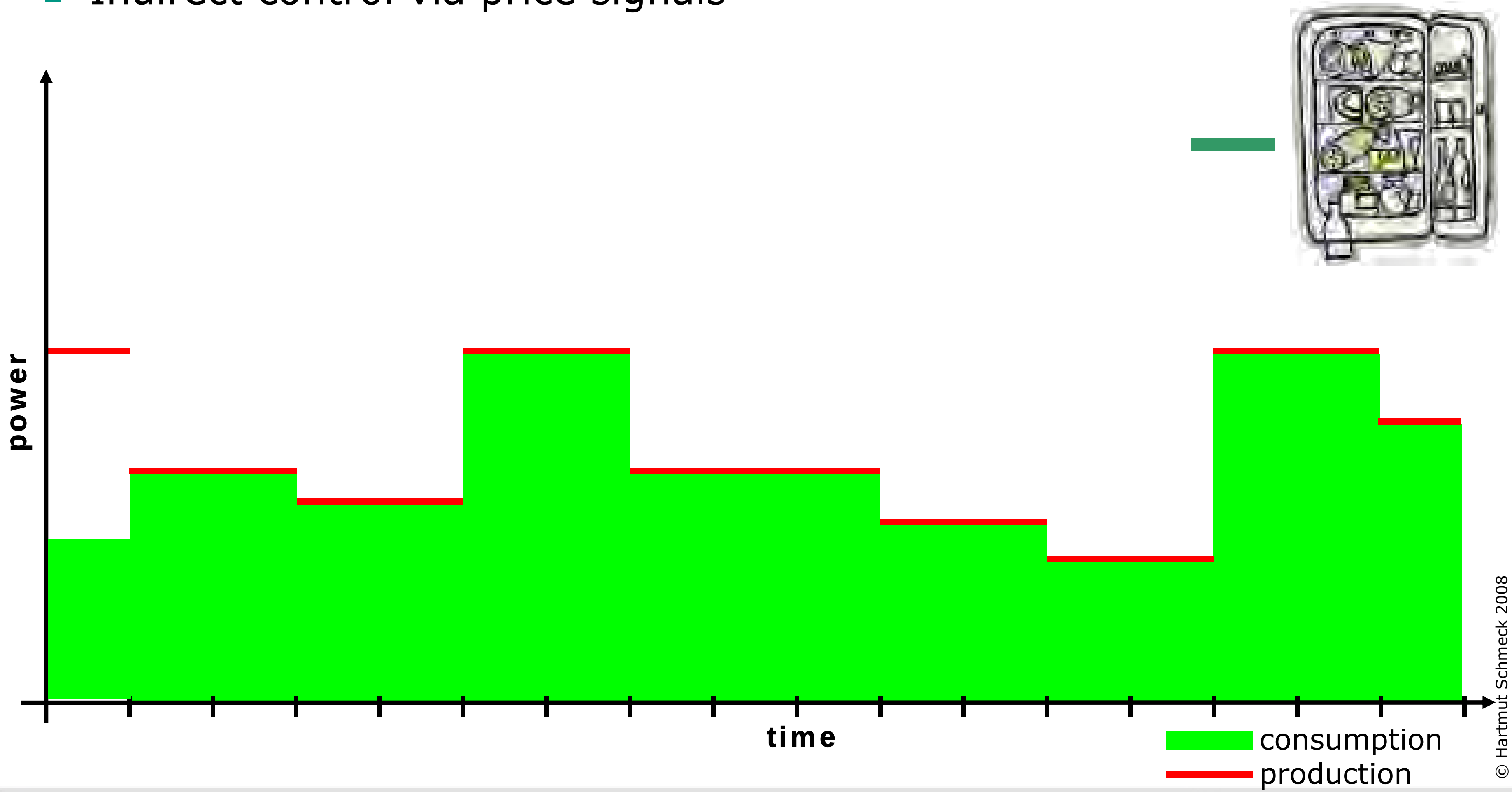
Decentralised load management using central CHP plant

- Imbalance in balancing group
- Central combined heat and power plant



Decentralised load management using price signals

- Deficit in balancing group
- Indirect control via price signals



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Decentralised load management using price signals

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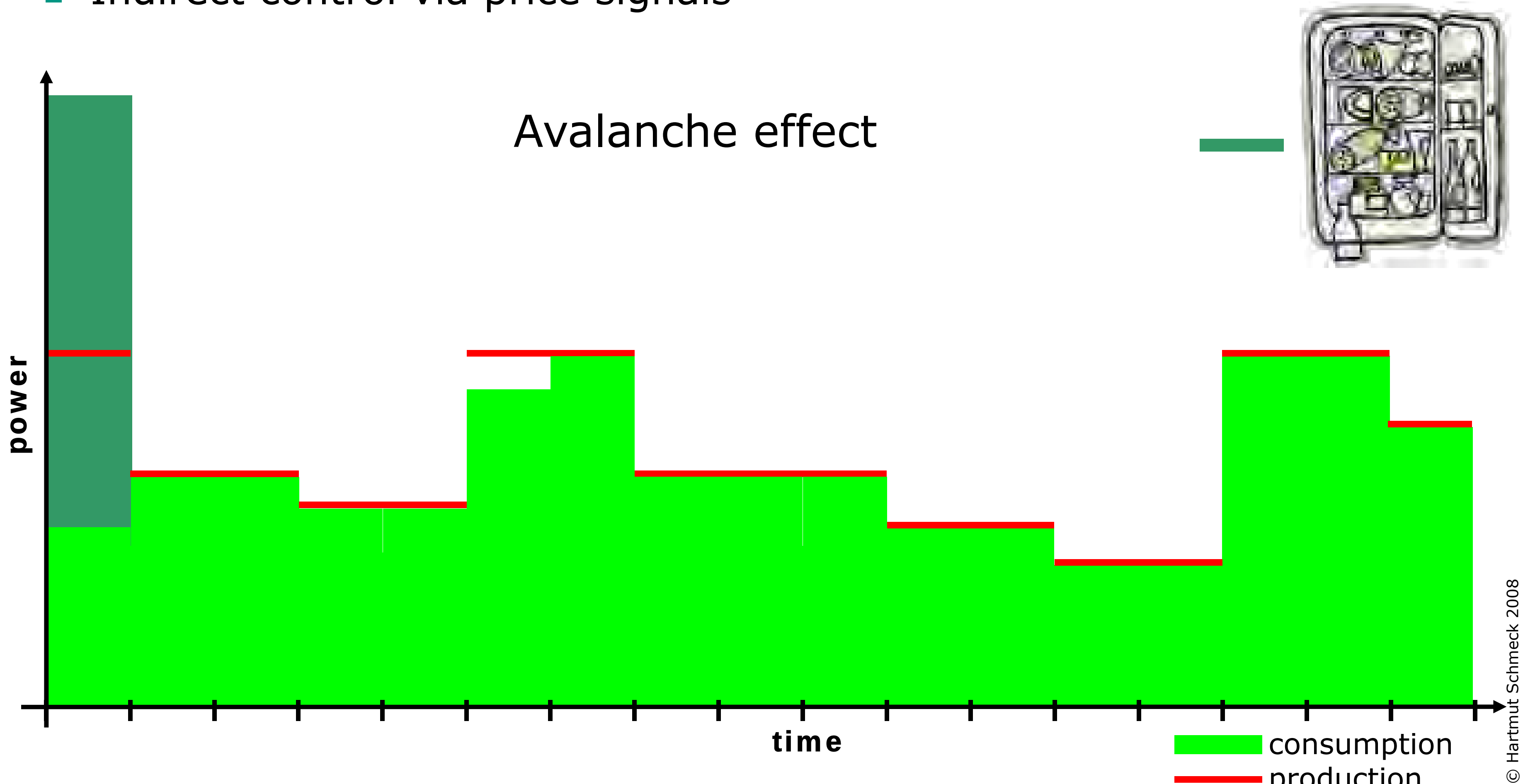

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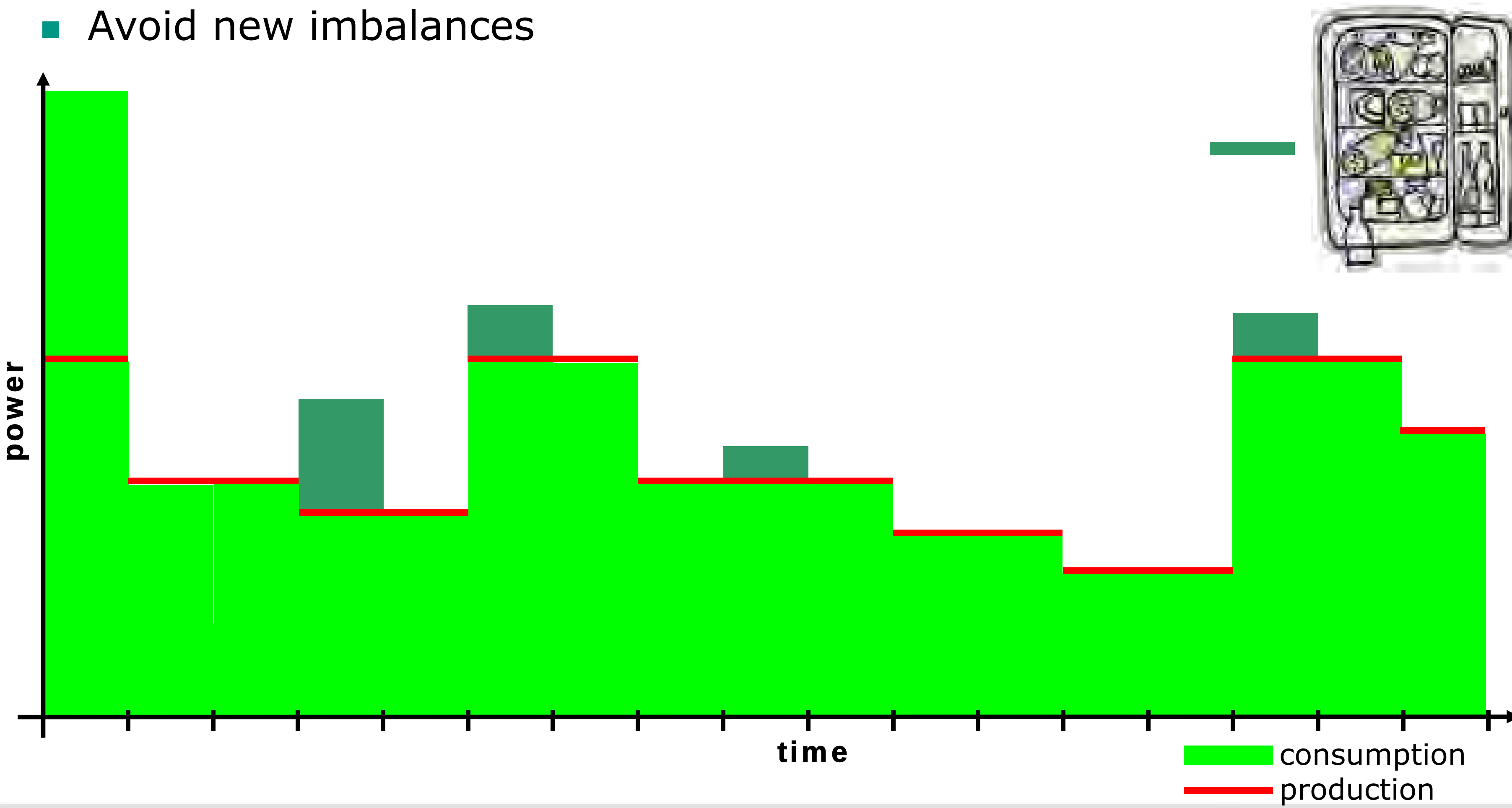
Goal

- Reduction of imbalances
- Respect restrictions
- Avoid new imbalances



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Decentralised load management

Price signals are not suitable

- Accurate control difficult to realise.
- Restrictions of devices lead to new imbalances.
- Price signals must be set in advance but subsequent settlement of balancing power.

➔

- Coordination between devices.
- Consumption and production must be planned together.
- Inevitable imbalances as late as possible.

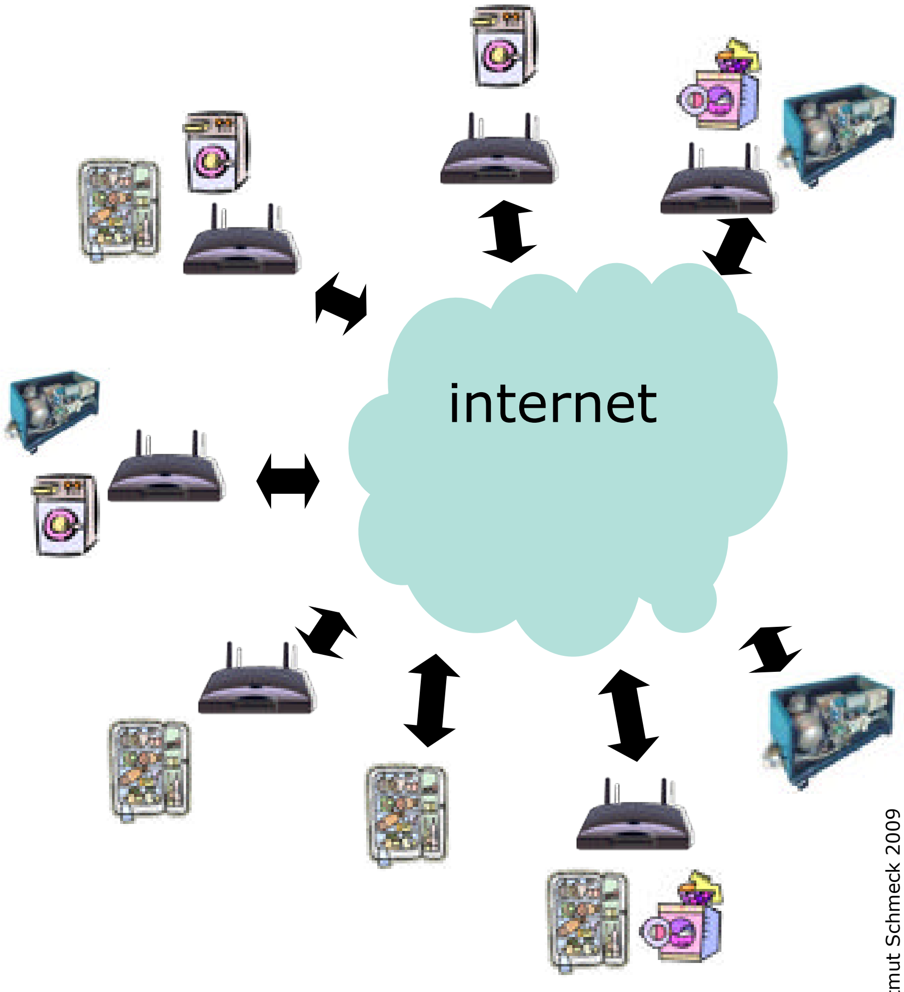
Device pool – peer-to-peer net

Integration of appliances and CHP plant into a decentralised pool

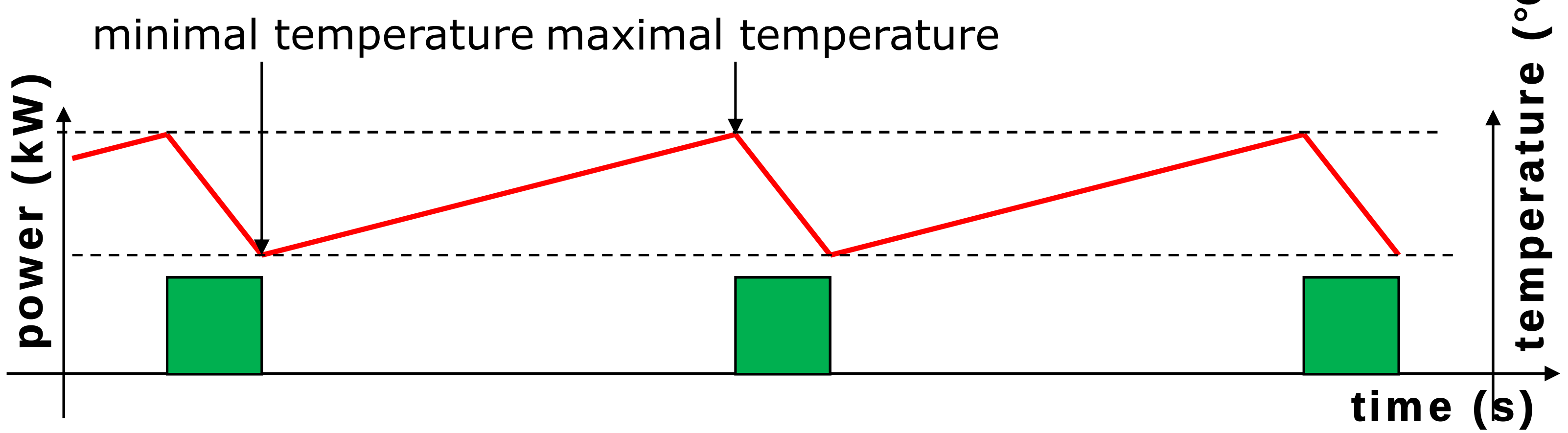
- Direct
- Over internet router
- Virtual neighbourhood

Devices must

- Know own status
- Predict future status
- Know their restrictions



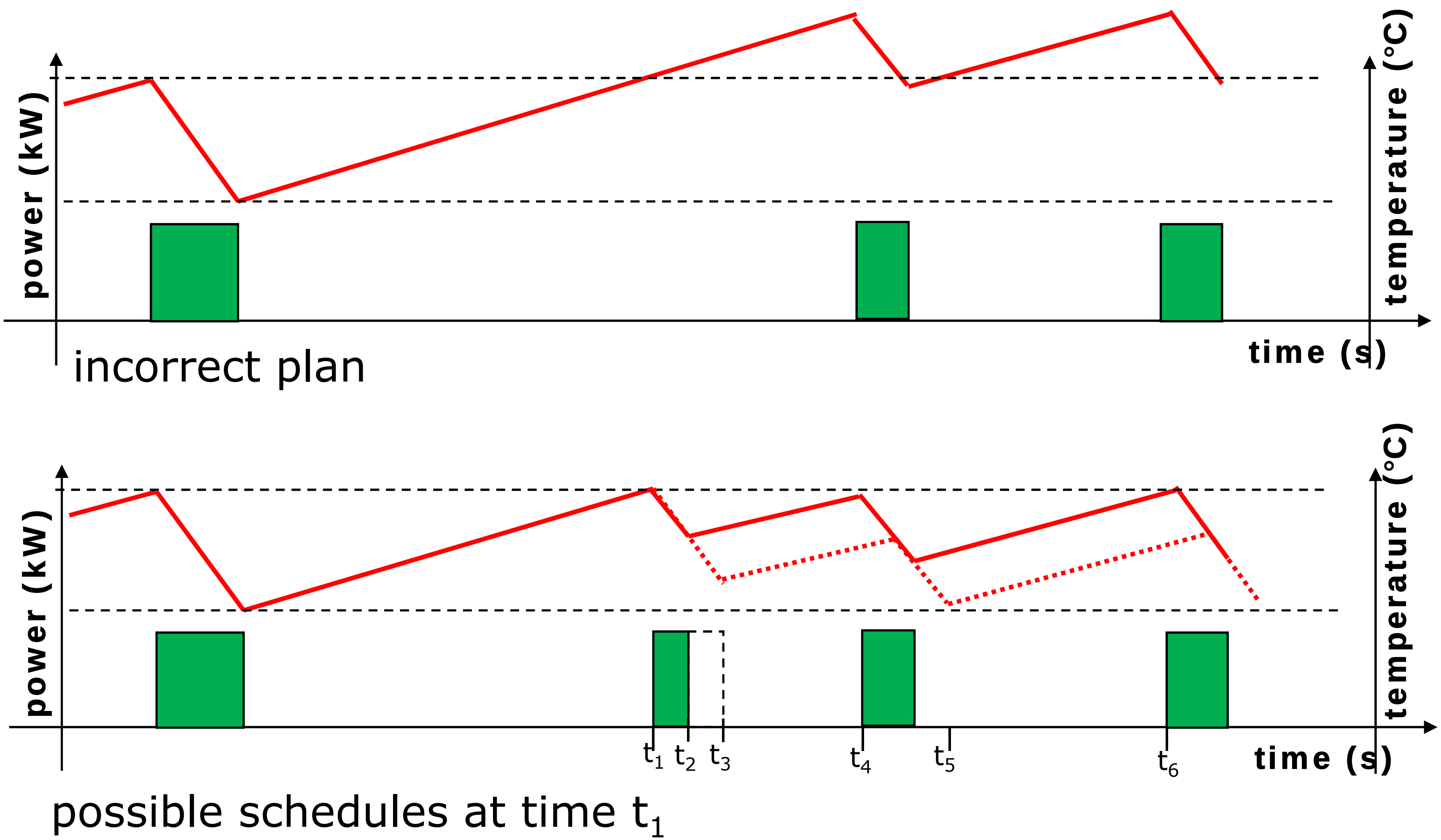
Modelling of appliances (fridge)



Parameters

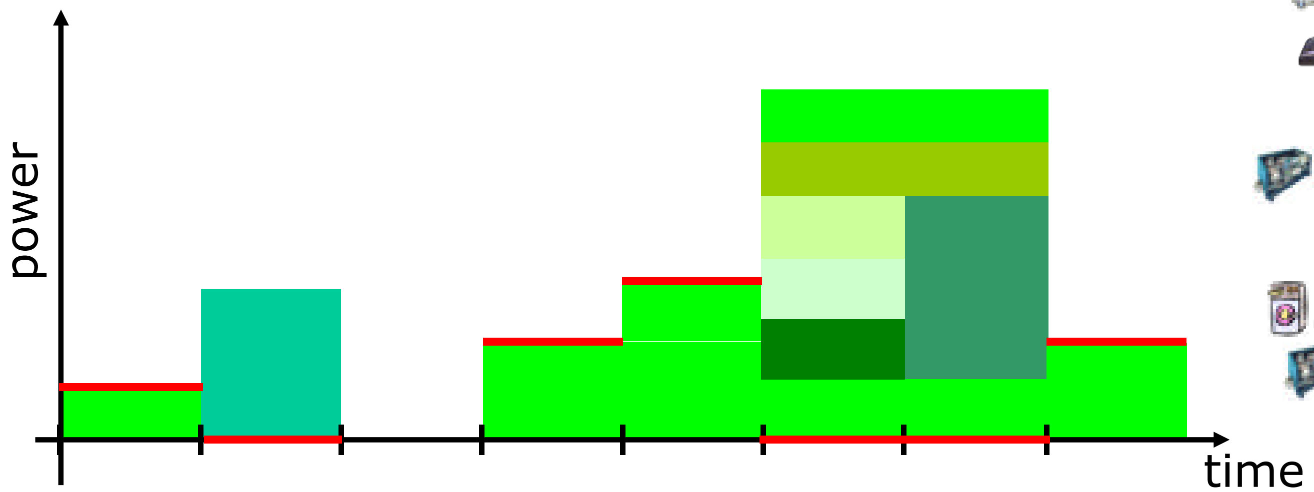
- Current temperature
- Minimal temperature
- Maximal temperature
- Energy consumption turned on
- Energy consumption turned off
- Temperature change turned on
- Temperature change turned off

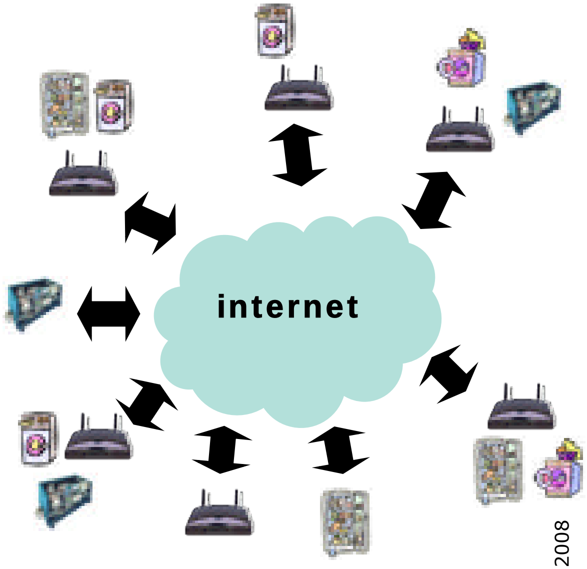
Modelling of appliances



Device pool without restrictions

- Devices should cover their energy usage.
- Devices search for suitable partners.



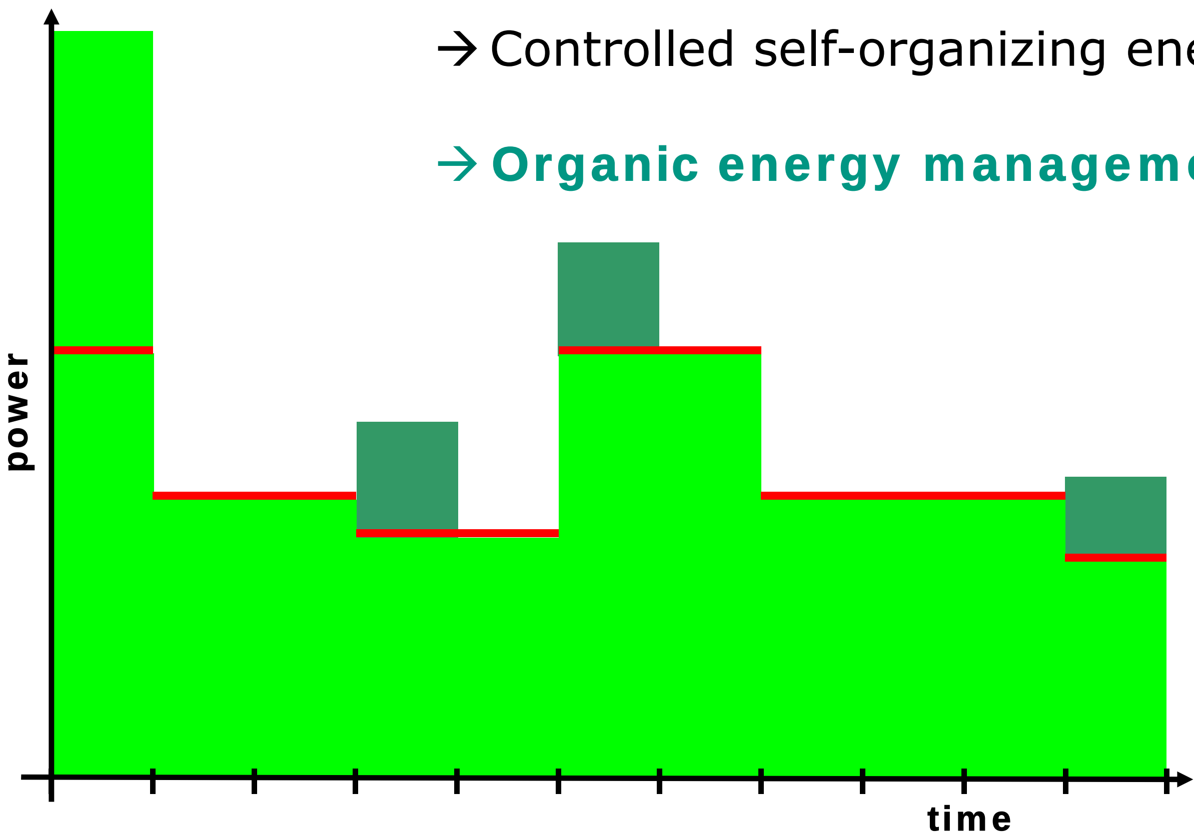


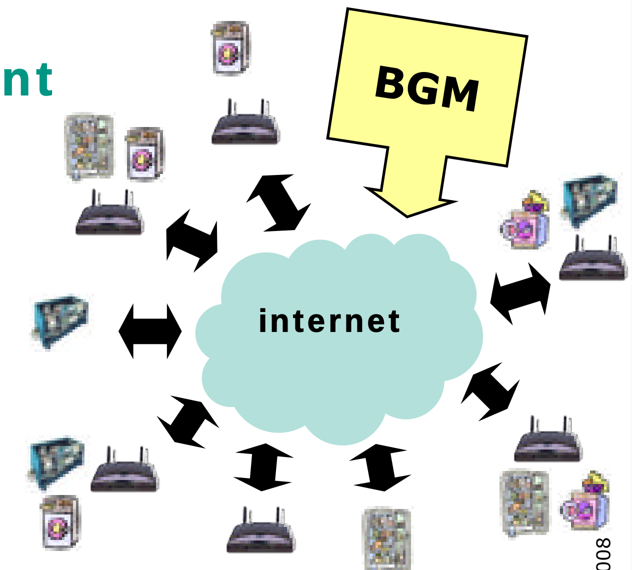
Usage of the device pool

- Shift imbalances to a later point
- Handle device restrictions decentralised

→ Controlled self-organizing energy management

→ **Organic energy management**





consumption
production

Conclusion

- In the future, we definitely will be surrounded by interacting and self-organizing technical systems (and services).
- Organic Computing is a promising approach to the design, management, and control of complex, highly interconnected and adaptive technical systems.
- Traffic and energy systems are ideal application scenarios for Organic Computing.
- Nature-inspired optimization methods and integrated simulation models are well-suited for exploiting potentials for continuous improvement.
- Range of challenges for research remains.

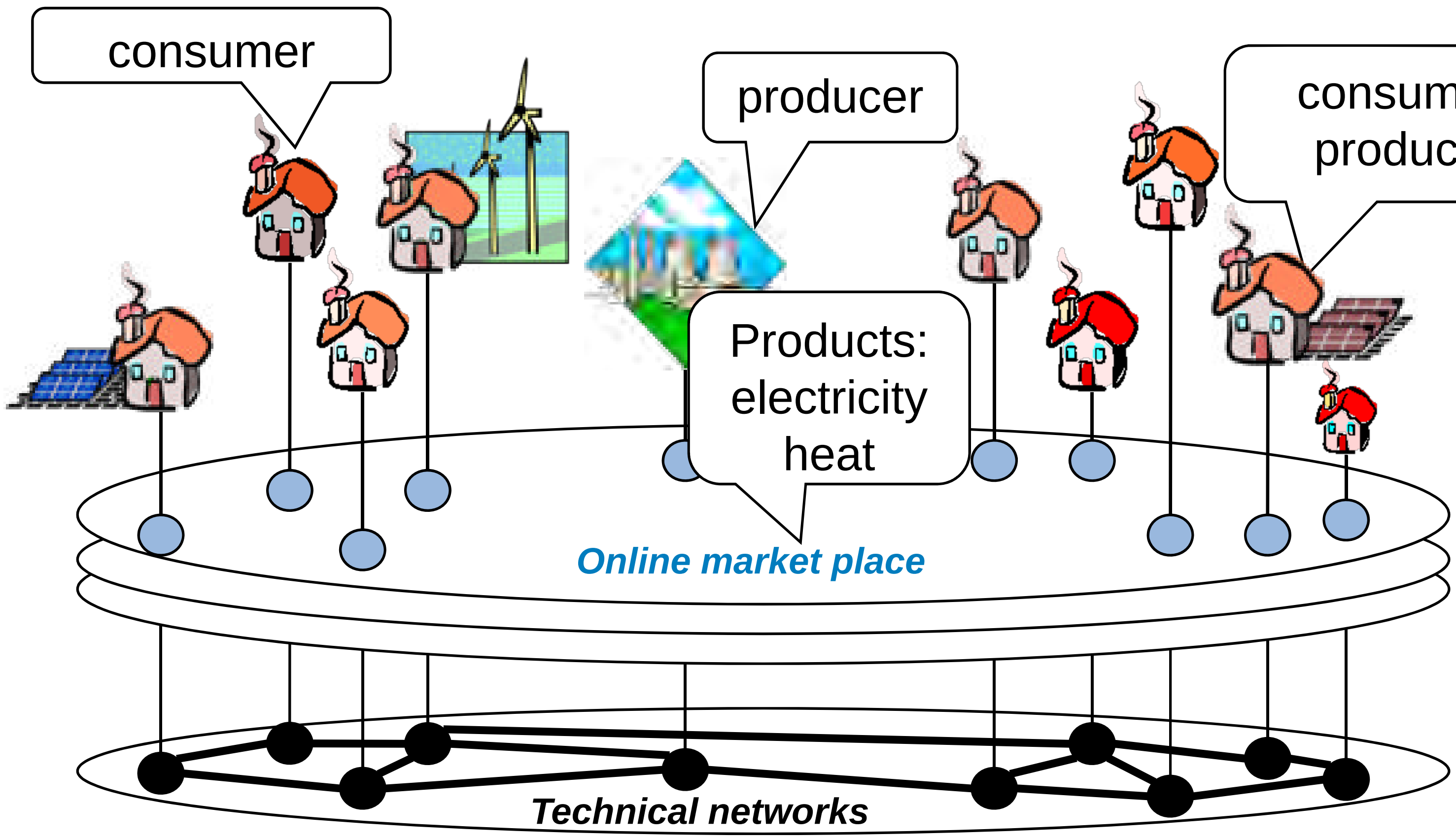
All this has been done together with many others, in particular

Jürgen Branke, Andreas Kamper, Holger Prothmann, Urban Richter (KIT)
Moiz Mnif, Christian Müller-Schloer, Fabian Rochner, Sven Tomforde (Leibniz Universität Hannover)

Thanks for your attention!

Questions?

Distributed Energy Systems - Virtual Power Plants



Projects:

- **SESAM (2003-2007) www.sesam.uni-karlsruhe.de**
- **MEREGIO (eEnergy-Programme, starting 2008)**
- **eMobility – smart integration of mobile batteries into the energy system**

Goal: increased energy efficiency

Characteristics and Challenges of Systems based on COMMputation

- **Dynamic Networks**
  - variable connections
  - mobile nodes
- **Decentralized Management**
  - coordination
  - collaboration
- **Self-organisation**
  - Self-configuring
  - Self-optimising
  - Self-healing
  - Self-protecting
- **High Complexity**
  - heterogeneous nodes
  - complex substructures
- **High frequency of change**
  - Usage and functional requirements
  - Requires adaptivity
- **Trustworthiness**
  - Security and dependability
  - Service level agreements

Projects, participants

- HGF Programme GRID / scientific computing
- 2 Research Training Groups (Graduiertenkollegs),
  - Sensor-Actor-Networks
  - Information Management and Market Engineering
- 3 DFG priority programs (in Informatics), coordinated at Karlsruhe:
  - Algorithm Engineering
  - Basic Software for Ad-hoc Networks
  - Organic Computing
- Karlsruhe Service Research Institute (KSRI) (KIT + IBM)
- One out of six international Cloud Computing Testbeds (SCC)
- Several large EU-, BMBF-, BMWi-Projects
  (e.g. robot swarms, eEnergy, …)
- Currently 26 chairs from FZK and Faculties
  Electrical Engineering, Informatics, Mechanical Engineering, Economics and Business Engineering

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