Quantitative Emergence

Metrics, Observation and Control Tools for Complex Organic Ensembles

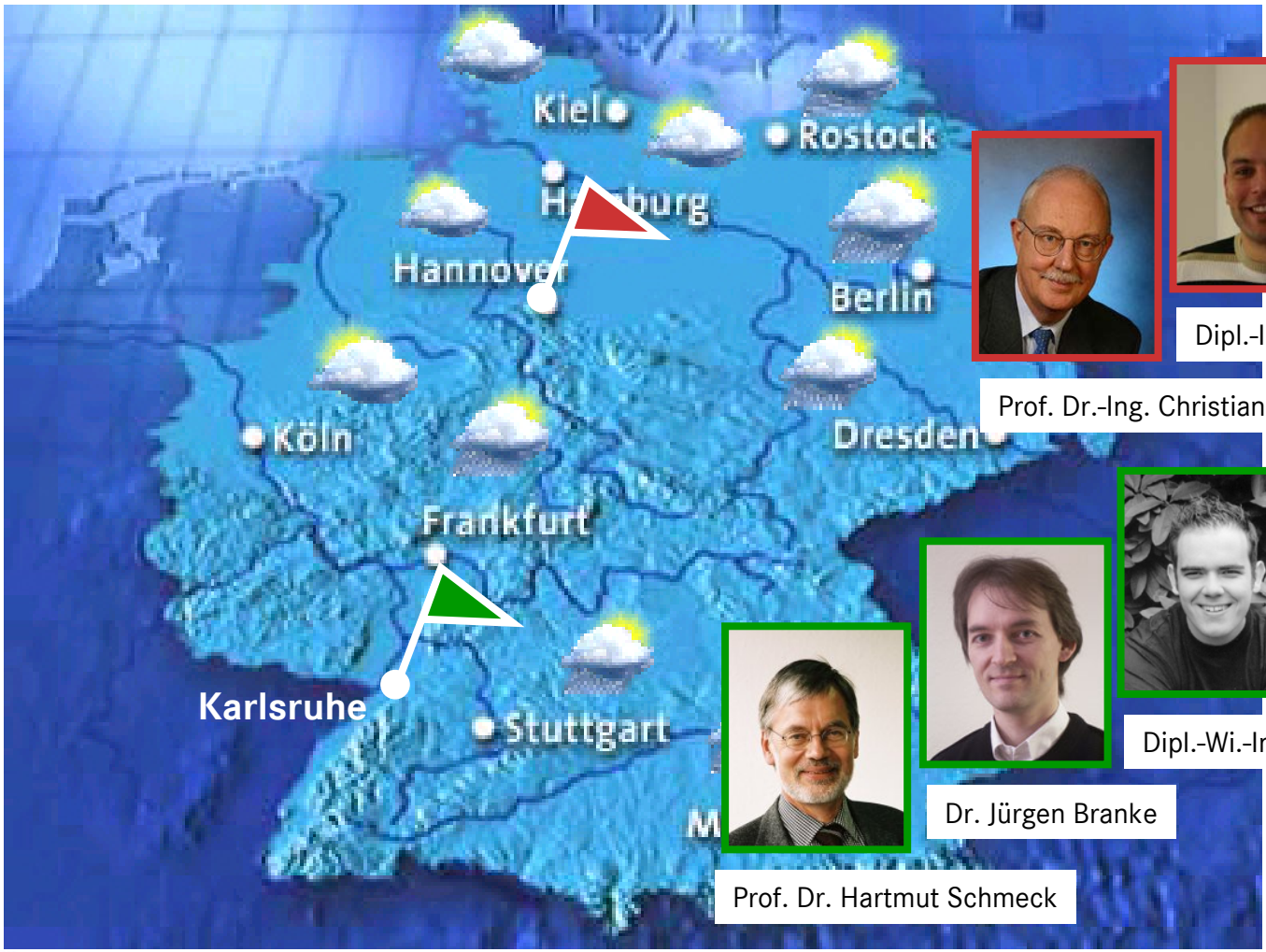
Jürgen Branke, **Urban Richter**, Hartmut Schmeck
University of Karlsruhe (TH), Institute AIFB

Moez Mnif, Christian Müller-Schloer
University of Hannover, Institute SRA

Outline

1. Team
2. Motivation
3. OC-Architecture
4. Goals
5. Test scenarios
6. Summary/Outlook

1. Team/Members



Dipl.-Ing. Moez Mnif

Prof. Dr.-Ing. Christian Müller-Schloer

Dipl.-Wi.-Ing. Urban Richter

Dr. Jürgen Branke

Prof. Dr. Hartmut Schmeck

2. Motivation

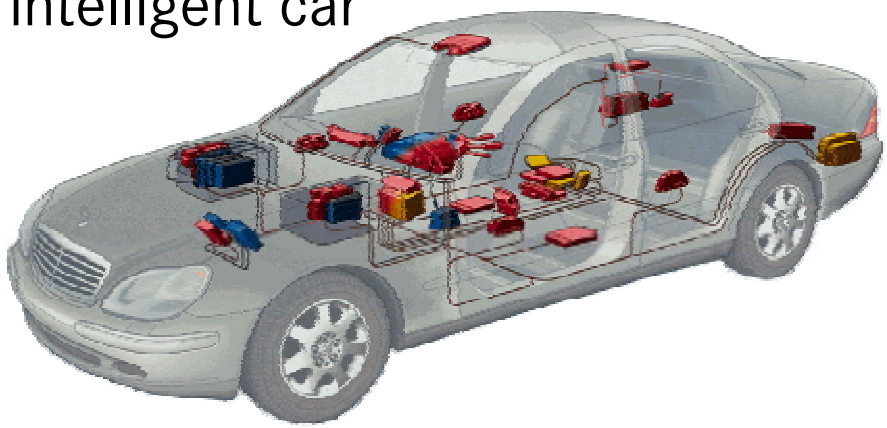
Technical systems

- Increasing complexity
- Life-like characteristics (learning, adaptation,...)
- Maintain themselves
- Survive attacks and breakdowns
- Self-x-properties

- Move from a centralised system to a decentralised one
- Large number of interacting sub-systems
- Self-organization

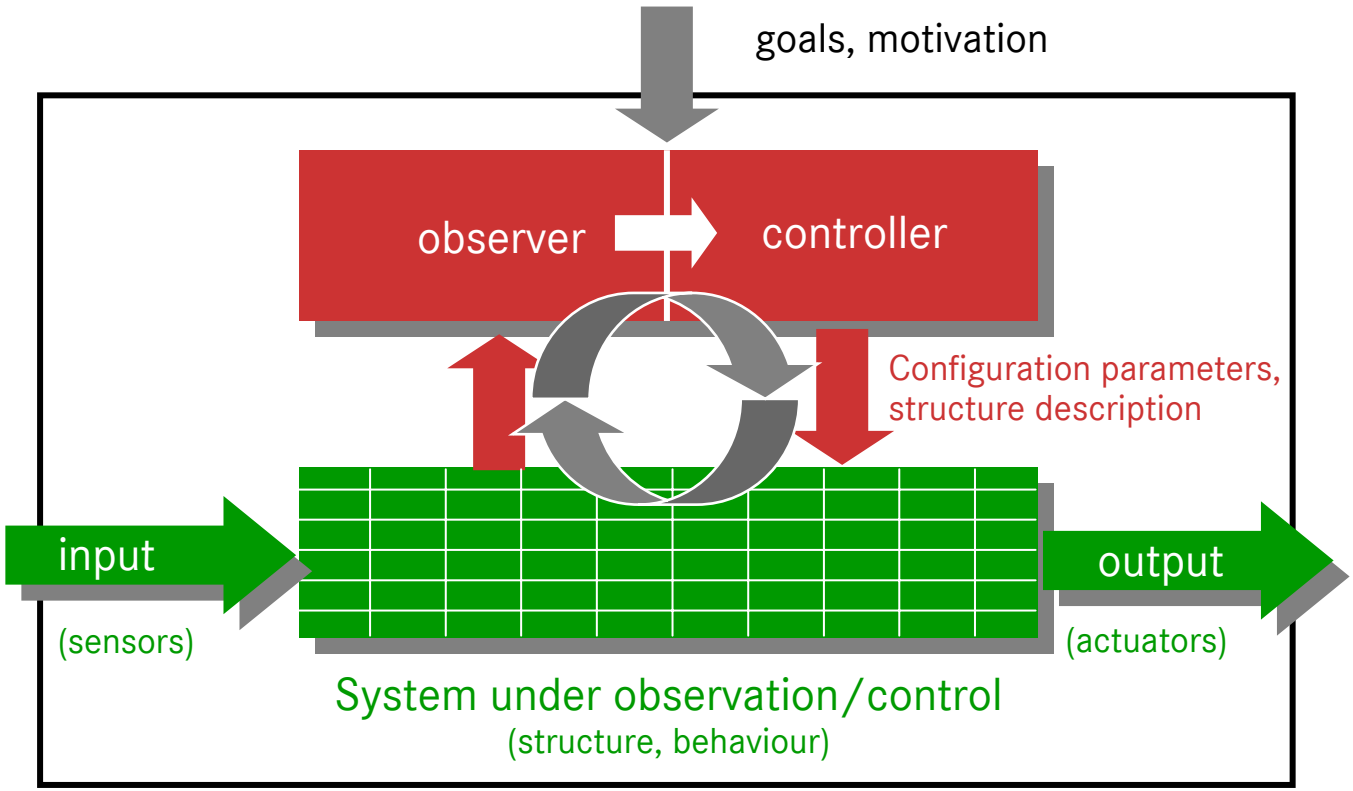
2. Motivation (2)

- When collections of intelligent, autonomous devices cooperate in a self organized way, unexpected things may happen: (positive/negative) Emergence
- Example for emergence: smart intelligent car
  - Large number of controllers
    - To keep the vehicle on road
    - To control the engine
    - To assist the driver
    - ...
  - Unexpected behaviour with respect to the environment



- ▶ Who can manage the complexity of such a network?
- ▶ Regulatory feedback mechanism

3. OC-Architecture



4. Goals

1. Development and investigation of metrics for the observation and analysis of emergence in self-organizing systems (H)
2. Development and investigation of mechanisms to influence and control the effects of emergence in self-organizing systems (K)
3. Realisation of tools and validation of the tools in various test scenarios

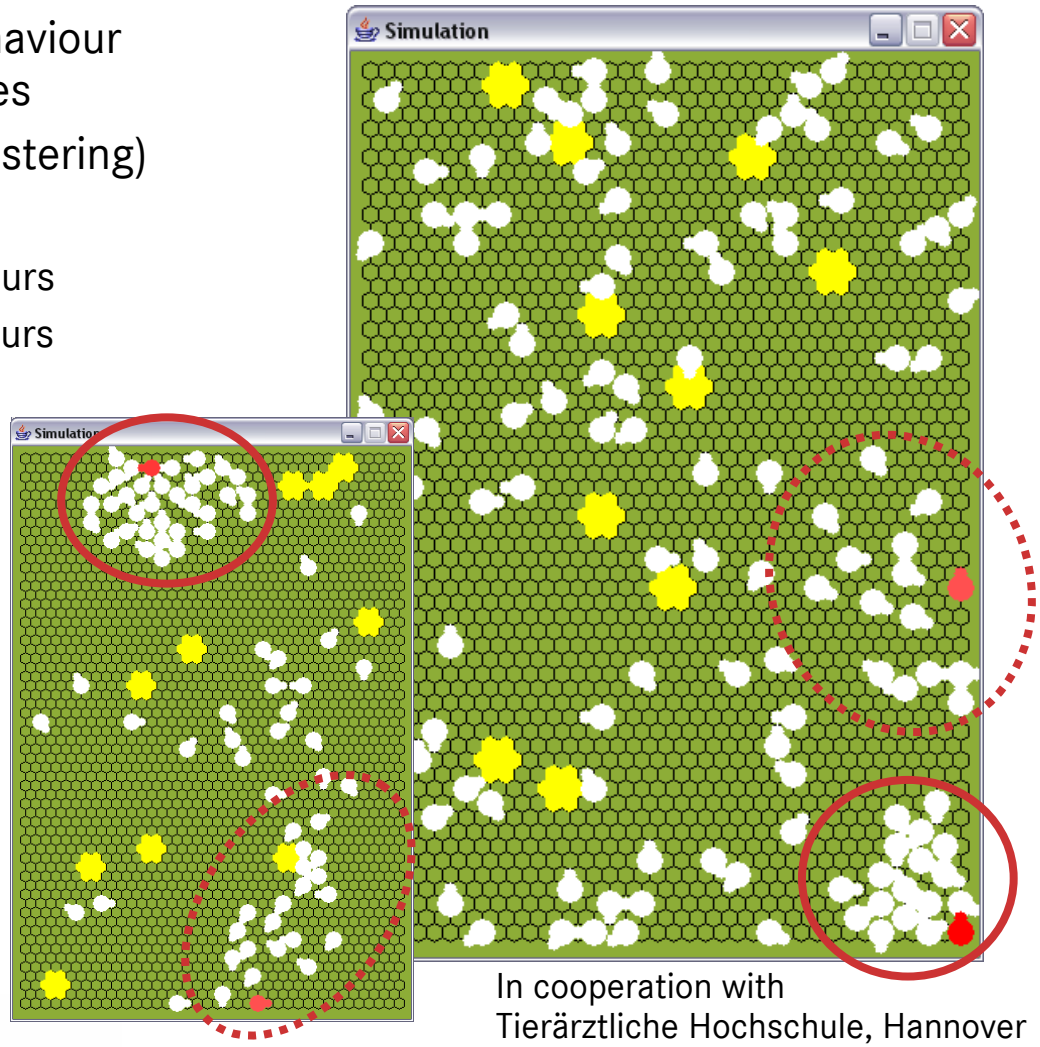
- Observer/Controller-Architecture
- Toolbox with basic mechanisms to observe, analyze, and control emergent behaviour

5. Test scenarios

- Relatively simple (next slides)
- Taken from
  - Biological analogies
  - Straight-forward technical applications
- For Phase II:
  Replace test scenarios with more complex technical scenarios like a traffic light control system:
  - Organic traffic control (OTC, concurrent project)

Test scenario: chicken dynamics simulator (H)

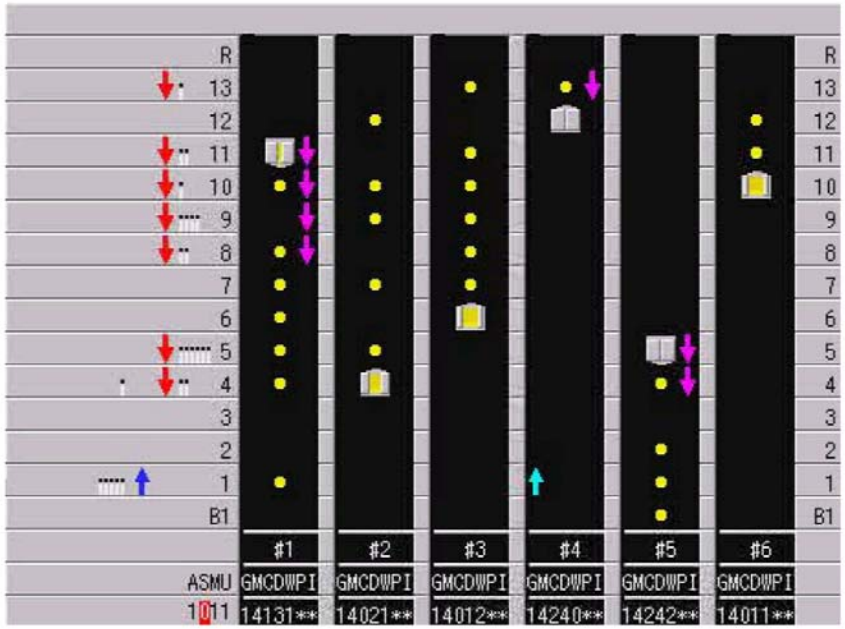
- Explain/control the collective behaviour of densely packed chicken in cages
- Emergent behaviour is spatial (clustering)
- Observation and Control
  - Observation of individual behaviours
  - Aggregation of individual behaviours
  - Influence of individual/ensemble behaviour
- Metrics under investigation e. g.
  - Cluster metrics
  - Vector sums
  - Entropy
- Control mechanisms e. g.
  - Ruby light
  - Noises
  - Screen



In cooperation with
Tierärztliche Hochschule, Hannover

Test scenario: elevator simulator (K)

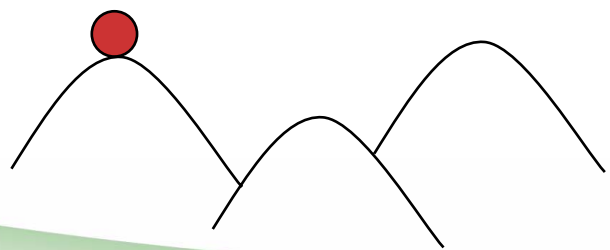
- Several elevators in a building
- All working with a simple rule
- Tend to synchronise (move up and down as a parallel wave)
- Bunching effect (emergence)
  - Sometimes positive
  - Sometimes negative
- Different peaks



Source: Beielstein et al., GECCO, 2003.

Observer

- Structural metrics (deal with order characteristics)
  - Clustering coefficient
  - Entropy (thermodynamics and information theory)
- Behavioural metrics (provide information on the interaction activities)
  - Learning behaviour/convergence
  - Activity, Stability, Complexity
- ▶ Practically applicable to detect and quantify emergence

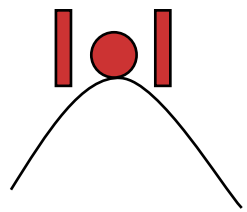


Controller

- To influence the system such that a desired emergent behaviour appears
- To disrupt an undesired emergent behaviour as quickly and efficiently as possible

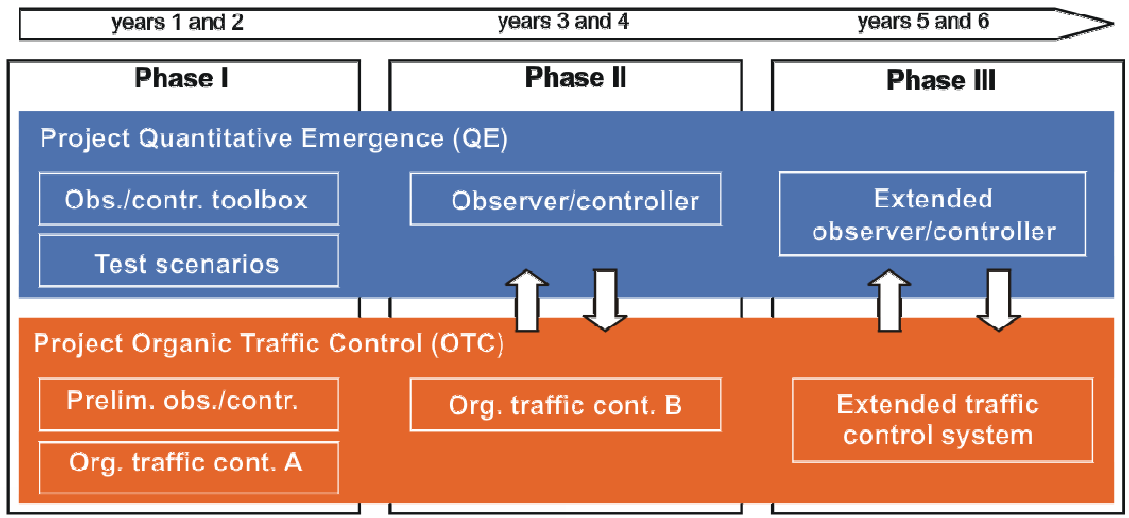
Influencing ...

- local decision rules
- the environment
- the communication network
- ...



6. Summary/Outlook

- Understand the effects of emergent global behaviour in networks of intelligent autonomous units
- Observer/Controller-Architecture
  - Observe self-organizing technical systems
  - Detect, measure, quantify, and control effects of emergence
- Toolbox: Methodology for observing and controlling self-organizing systems



The end

- Thank your for your attention.
- Any questions?
- Contact
  - {cms|mnif} @ sra.uni-hannover.de
  - {schmeck|branke|uri} @ aifb.uni-karlsruhe.de