FRONTS

Research Project: Foundations of Adaptive Networked Societies of Tiny Artefacts

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Project Main Concept

In the near future . . .

New types of systems will appear, designed or emerged, of massive scale, expansive and permeating their environment, of very heterogeneous nature, and operating in a constantly changing networked environment.

- Will have the form of large societies of networked artifacts
  1. Small size.
  2. Limited capabilities (sensing, processing, communication).
  3. Limited energy.
- By cooperation, they will accomplish tasks that are difficult or beyond the capabilities of todays conventional centralized systems.

Need for Adaptation

The ability of networked societies of small artefacts to adapt is composed of two almost orthogonal dimensions:

- The ability for internal continual self-organizational of the network.
  - Components should adapt to the needs and to changes in the environment and in the operating conditions.
  - Network must be always able to adapt (i.e. be ready).
  - Adaptation influences the performance of the network as the individual entities are adapting.
- The ability to adapt to environmental changes in a dynamic way.
  - Components need to adapt in cases of (external) alerts.
  - Prioritize the environmental changes (characterization of changes as major/critical where adaptation is needed, provide some thresholds).

Project Main Objective

The aim of this project is to establish the foundations of adaptive networked societies of small or tiny heterogeneous artefacts.

- Develop an understanding of such societies.
- Establish their fundamental properties, laws and their inherent trade-offs.

We will approach our goal by providing

- Constructive (algorithmic) distributed adaptation techniques.
- Laws on the effect of adaptation on the system performance, cost of distributed coordination of adaptation, incurred overhead (in terms of communication, energy) and possible trade-offs.
- Investigate limits of adaptation (how much to adapt, how long to adapt) and cases where adaptation is impossible.

Joint Theoretic/Experimental Approach

We intend to apply our models, methods, and results to the scrutiny of large-scale simulations and experiments

- Test our theoretical insights in practical scenarios.
- We expect to obtain valuable feedback.

The foundational results and the feedback from simulations and experiments

- Form a unifying framework for adaptive networks of artefacts.
- Enable us to come up with a coherent working set of design rules for such systems.

Scope & Use Scenarios

- The scope of the project is mainly of a generic level.
- Very wide range of possible scenarios.
  - Systems made of medium to large numbers of tiny heterogeneous and communicating artifacts.
  - Monitoring of earthquake regions, forests for fire protection, fluids, robot swarm organization in unknown terrains, nodes in traffic ...
- We focus on two possible use scenarios:
  1. RFID artefacts for monitoring systems for industry.
  2. Wireless sensor devices for monitoring traffic.
- These scenarios still include a wide range of different technical situations.

The importance of our objectives

- Establishing a science of adaptive organization of large nets of small or tiny artefacts will allow researchers to use our models, laws and fundamental properties in order to further investigate the operation of such systems in particular cases, specific to real application scenarios.
- System designers and solution developers will be able to apply the fundamental principles during the design process in order to investigate the performance of the systems under development and better understand the inherent trade-offs of the resulting network.

The importance of our objectives (contd.)

- We will provide mechanisms that can be used directly to ensure the adaptiveness, self-stabilization and self-organization design criteria or they can be integrated as part of larger systems in order to deal with specific problems.
- We forsee a future contribution to embedded systems design.
- System developers of Future Open Systems (e.g., robotic systems) will be able to better understand the ability of systems to achieve particular goals, given the actual conditions of the environment.

S/T methodology

Our work is structured into the following 6 work packages (WPs):

- WP1: "Principles of Adaptively Organized Societies of Artefacts"
- WP2: "Designing the Adaptable Network Infrastructure"
- WP3: "Adapting to the Dynamic Environment"
- WP4: "Experiments and Testing"
- WP5: "Management, Review and Self-Assessment"
- WP6: "Dissemination, Collaboration and Exploitation"

The work packages are structured further in tasks that focus on particular aspects regarding the scientific and technological methodology and expected results.

S/T Objectives (1)

The ability for internal continual self-organizational of the network:

- We will characterize the network awareness of components and adaptability to the needs and to changes in the environment and in the operating conditions.
- We will investigate the necessary technical requirements for the network to be always able to adapt (i.e. be ready).
- We will examine how fast it responds (in real time) to track variations in the operation of the network.
- We will investigate the influence on the performance of the network as the individual entities are adapting (how long does it take to reach a "steady state").

S/T Objectives (2)

The ability to adapt to environmental changes in a dynamic way:

- We will investigate the ability to adapt in cases of alerts.
- We will provide rules to prioritize the environmental changes (characterization of changes as major/critical where adaptation is needed, provide some thresholds).

For systems deployed to achieve particular goals, this adaptability should also address the needs, constraints, and commands of its users.

S/T Challenges (1)

The internal self-organization requires to address at least two problems:

- How to continually adapt the communication infrastructure ?
- How to achieve "self-stability", which allows effective recovery from transient unexpected faults ?

The second problem is of central importance because self-stabilization is a necessary property of the systems under examination.

S/T Challenges (2)

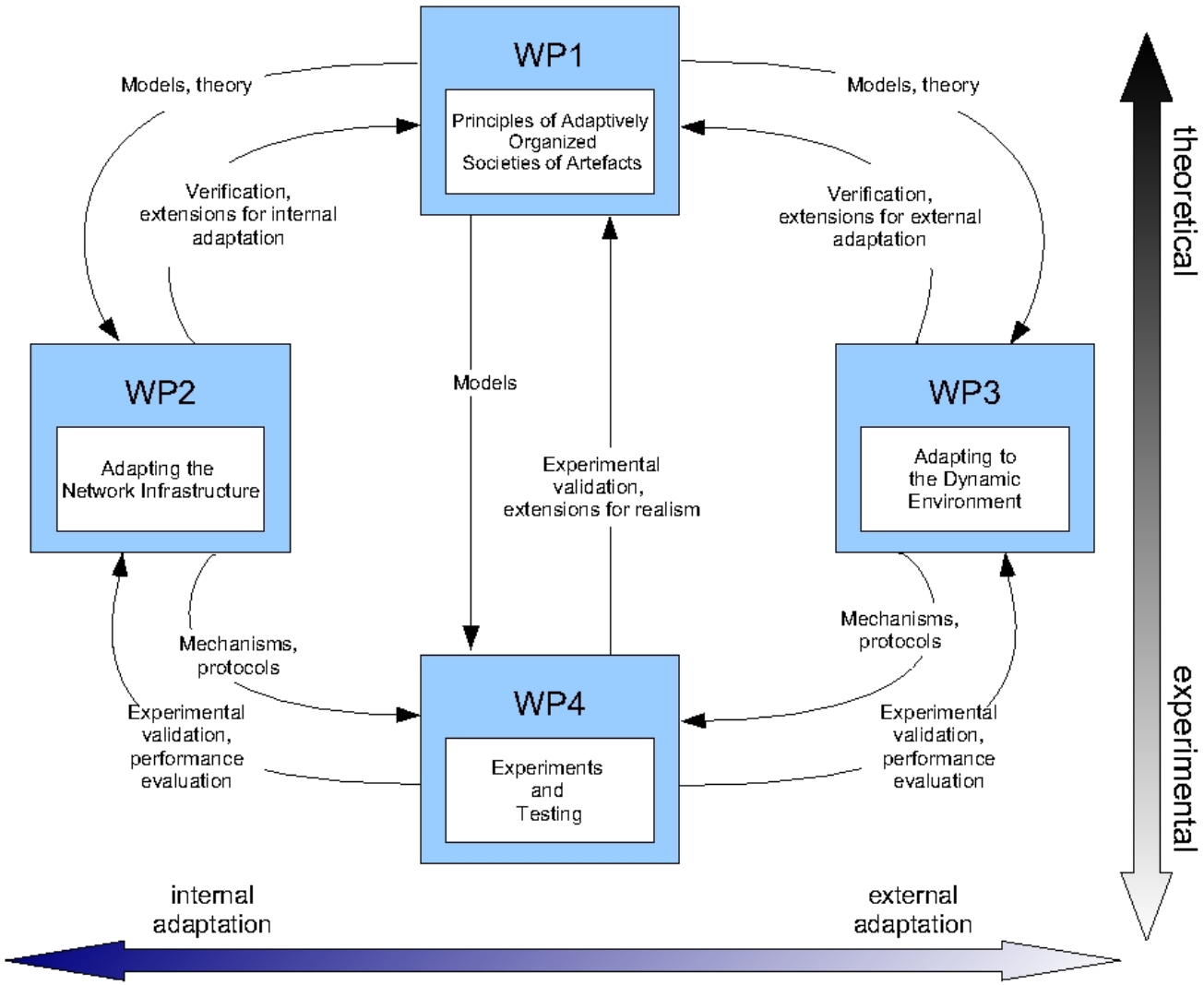
The adaptation to the environment and to the needs of users requires to address the following problems:

- How to achieve distributed cooperation ?
- How the system "tribes" discover and track resources ?
- How the net reacts to imposed, uncontrolled dynamicity (such as externally imposed movements of the artefacts because, e.g., they follow ocean currents or are attached to humans) ?
- How trust develops or emerges in the whole net or its parts?

Some Modern Techniques (1)

- Markov Chains & Random Walks
  Multiple / Hybrid / Composite chains / Weighted RW
- Game Theory
  Robust Markets / Self-Convergence to Equilibria / Nashification sequences
- "Distributed Online Algorithms"
- Population Models
- Security & Trust
  Adaptive key-length / Locally stop-start a cryptographic protocol
- Local-Global Knowledge
  Limitations / Trade-offs

Relation and interdependencies of the work packages



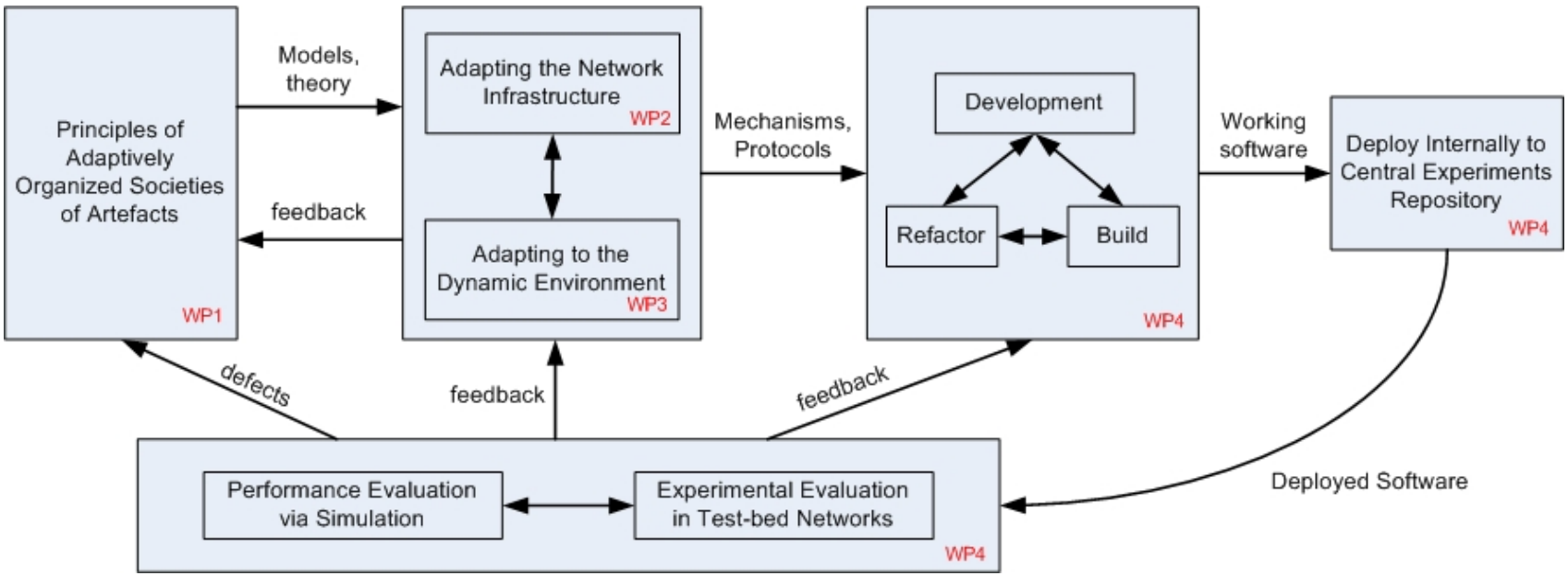
Overall goal for a unifying scientific framework

The most fundamental question

Is there a single, unifying, abstract model for such adapting, massive nets of tiny artefacts, that can explain their emergent behavior ?

- Our overall objective is to create a unifying framework for adaptive networks.
- We apply an iterative research & developement process that employes three iterations (one per year).
- The aim of these iterations is to integrate the various elements developed in the project.
- Each WP should continuously interact with the other WP for transfer of results.

Unification Iteration



- We must take concrete steps towards answering this question.
- Requires an interdisciplinary approach.

Important Milestones

- The derivation of models for *dynamicity*, *locally restricted computation*, and *cooperation in ad-hoc situations*.
- The organization of our *central experiments repository* and its relation to simulations and experiments at various sites.
- A set of *strategies* that can adapt the communication infrastructure.
- A set of *schemes for distributed cooperation*, aiming specifically at satisfying external requests for discovering and tracking resources, and for reacting to sudden changes of the environment.
- A set of design rules.

Thank You For Your Attention!!