EPOS: Energy Plan Overlay Summation

Using intelligent agents for self-adaptation and self-optimization of energy consumption in power networks

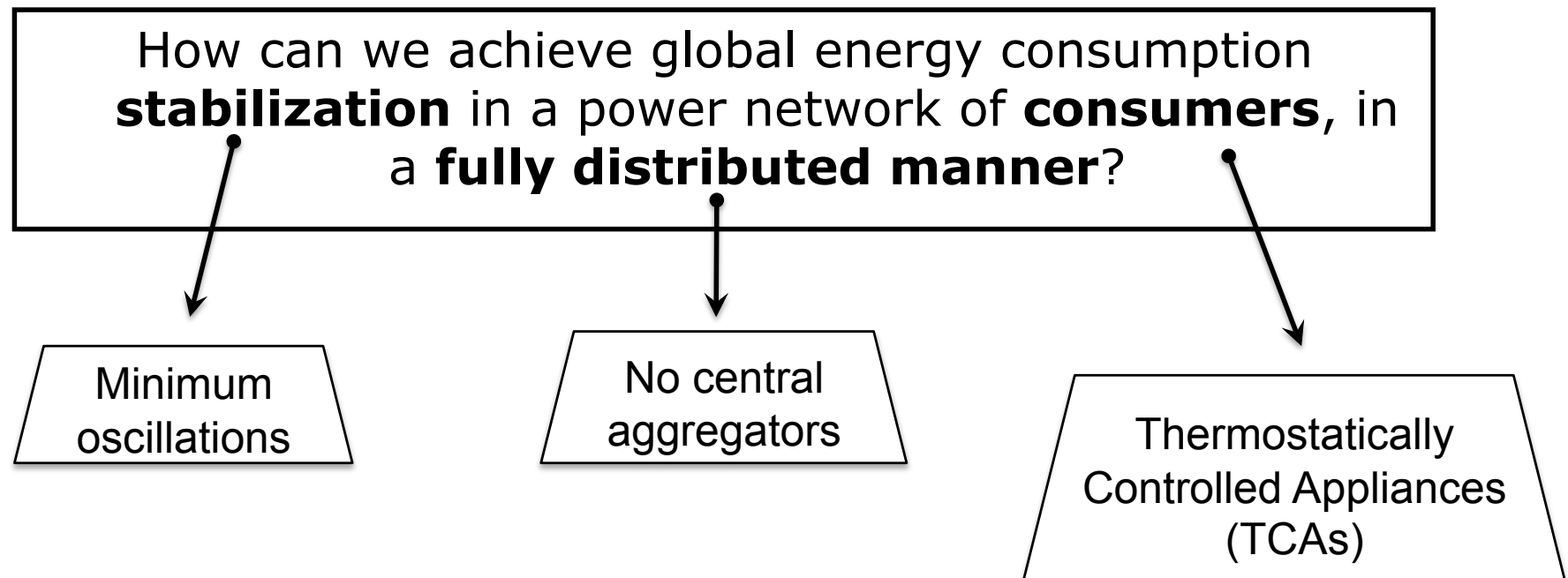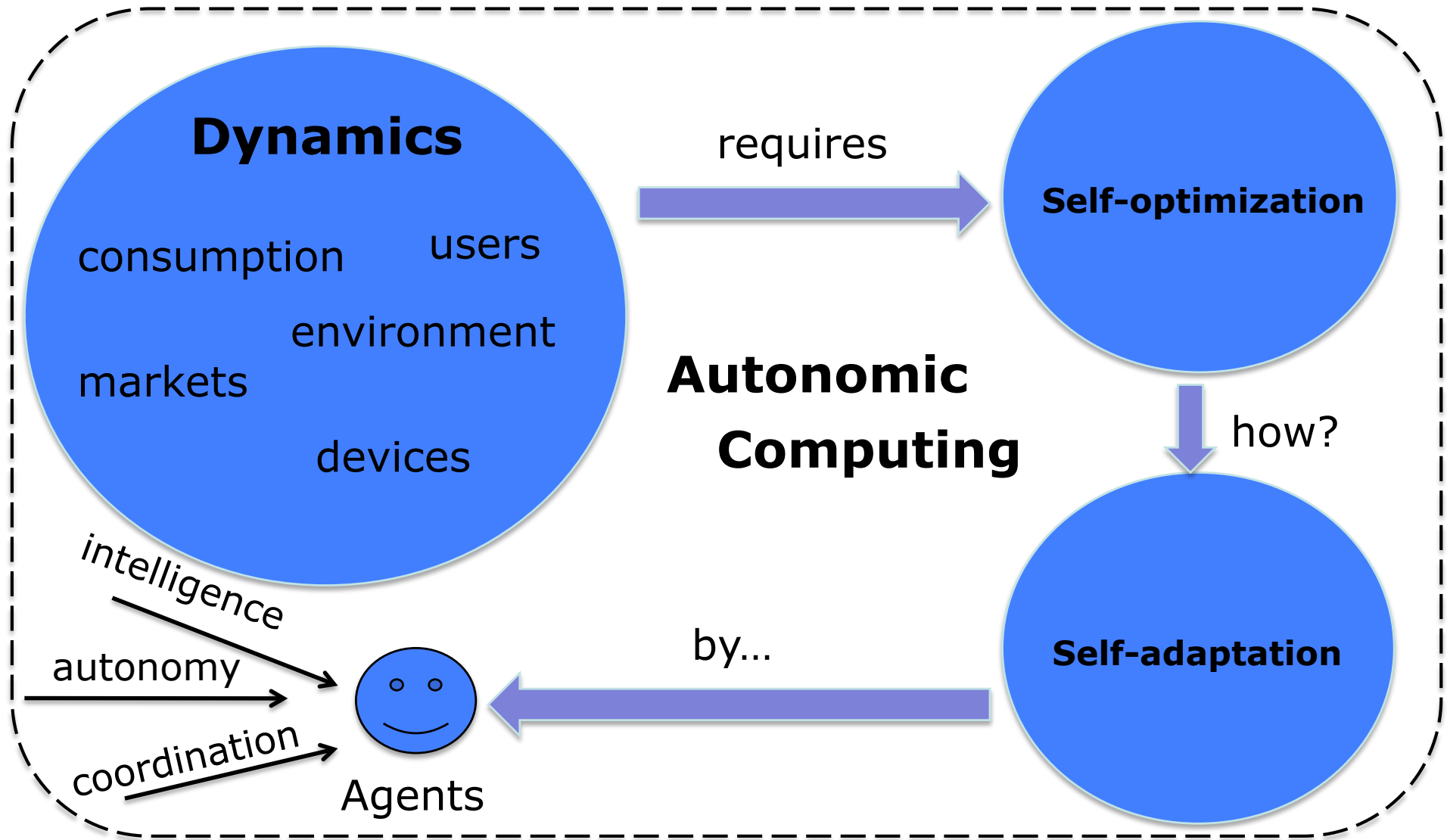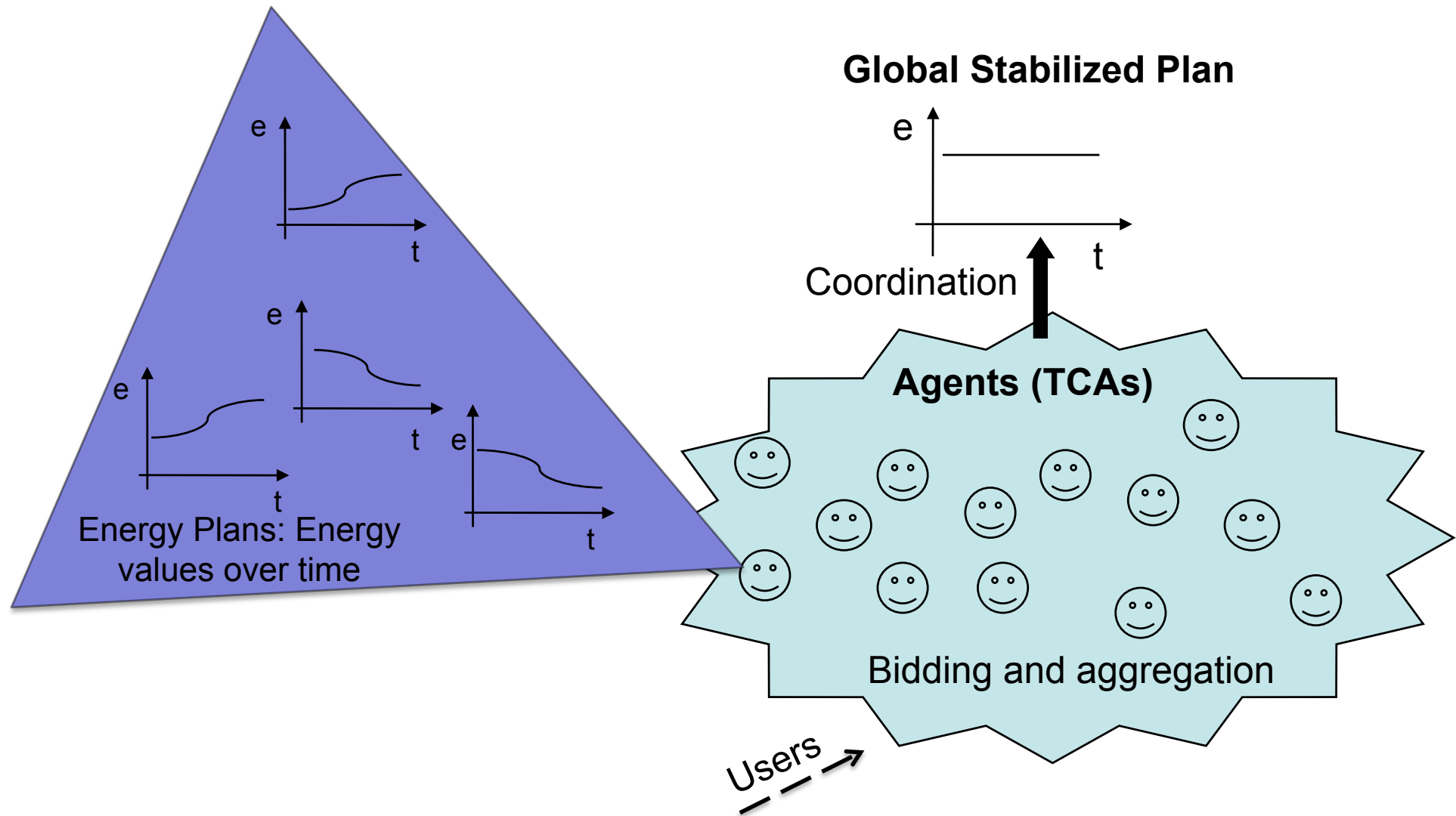**Evangelos Pournaras**
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International Conference on Autonomic Computing

vrije Universiteit *amsterdam*

nlnet FOUNDATION

IIDS Intelligent Interactive Distributed Systems

Agents for Autonomic Computing, June 2008

Problem and Goal

How can we achieve global energy consumption **stabilization** in a power network of **consumers**, in a **fully distributed manner**?

Minimum oscillations

No central aggregators

Thermostatically Controlled Appliances (TCAs)

The Problem in Autonomic Computing

Dynamics

consumption   users

environment

markets

devices

requires → **Self-optimization**

Autonomic Computing

how? ↓

Self-adaptation

intelligence

autonomy

coordination

Agents

by…

Problem Environment

Global Stabilized Plan

Coordination

Agents (TCAs)

Energy Plans: Energy values over time

Bidding and aggregation

Users

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EPOS Concept

Self-optimization *of energy utilization through the* **self-adaptation** *in the selection of energy plans*

Autonomic Computing

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Agents & Autonomic Computing

Autonomic Computing

Hierarchical structure

Self-Optimization

EPOS Plan Coordination

Self-Adaptation

TCA

Intelligence

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EPOS Outline

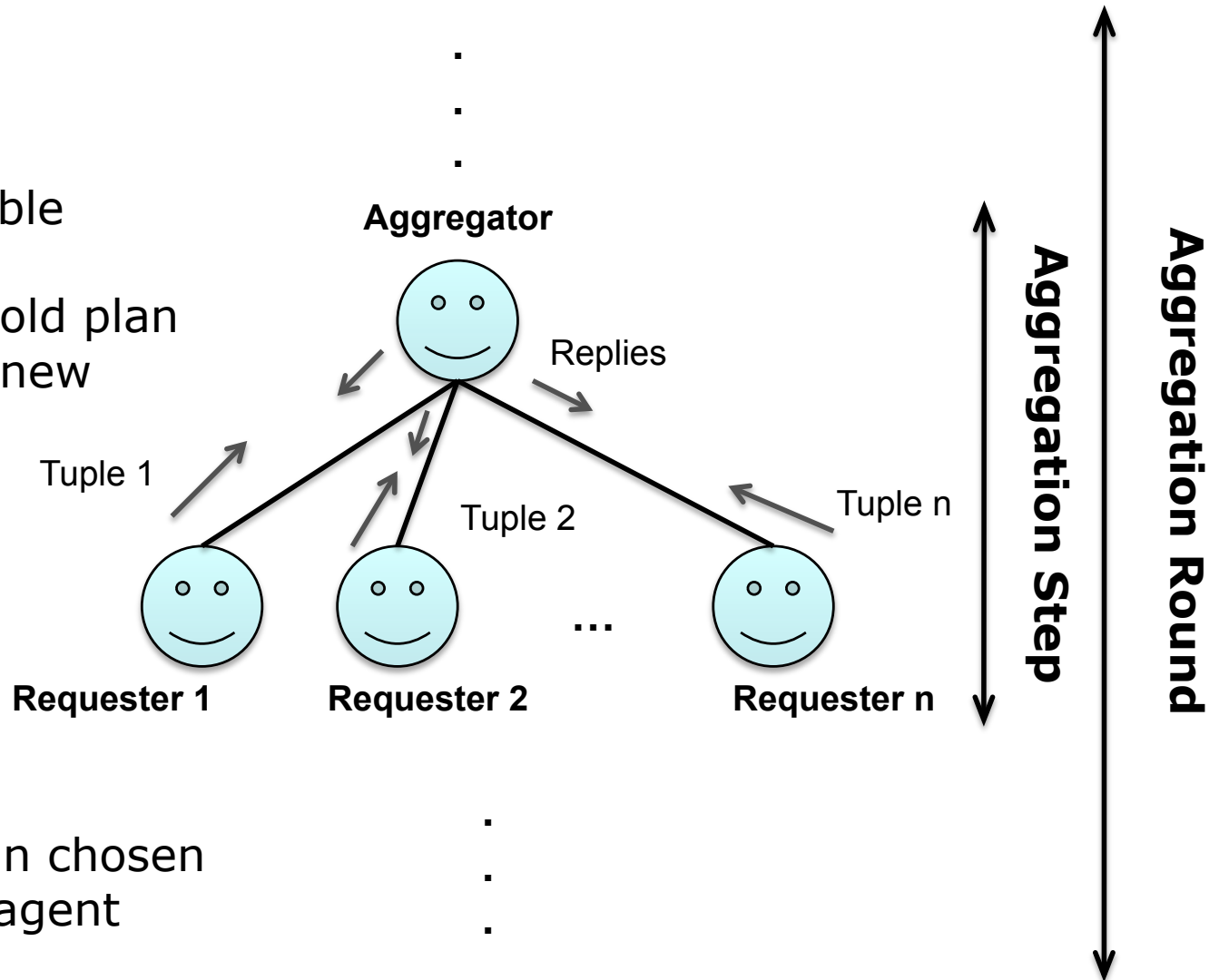| Points	Choice
Goal	Global stabilization in energy consumption
Environment	TCA agents that generate energy plans
Infrastructure	Tree structure
Operation	Decentralized energy plan aggregation

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Information Exchanged

Requesting Agent

1. Agent's list of possible plans for this round
2. Branch-cumulative old plan
3. Branch-cumulative new plan

Aggregator Agent

1. Replies with the plan chosen for each requester agent

Aggregator

Replies

Tuple 1

Tuple 2

Tuple n

...

Requester 1

Requester 2

Requester n

Aggregation Step

Aggregation Round

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Aggregator

➢ Matchmaking and selection of the best plans for each requester

➢ How?

1. Plan pre-processing and convergence
2. Adaptive Global Aggregation Plan Operation (AGAPO)
3. Stabilization calculation

1. Plan Pre-Processing & Convergence

- Candidate plans
  - Calculation of all unique plan combinations for this aggregation round

- Leaves-to-branch-to-tree convergence:
  - Cumulative plan summation from leaves to branches and finally to the root
  - Convergence to the new global stabilized plan

2. AGAPO Operator

- ➢ AGAPO->Adaptive Global Aggregation Plan Operator
- ➢ Core of self-adaptivity
- ➢ Local-to-global stabilization
  - ▪ Adapts the candidate plans to an evolved new global plan

Old Knowledge

↑

Global AGAPO Plan = (Old Global Plan) − (Old Branch Cumulative Plan)

+ (New Branch Cumulative Plan) + (Candidate Plan)
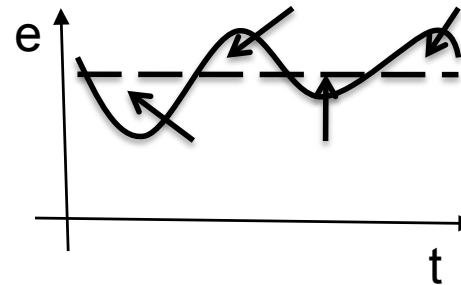
↓

New Knowledge

3. Matchmaking & Plan Selection

➢ Comparison of AGAPO plans
➢ Stabilization – 2 methods for calculation:
  ▪ Standard deviation

$$sd = \sqrt{\frac{1}{|s_{\text{agapo}}| - 1} \sum_{t \in s_{\text{agapo}}} (s_{\text{agapo}}[t] - \bar{s}_{\text{agapo}})^2}$$

  ▪ Area-based

$$a = \sum_{t \in s_{\text{agapo}}} |\bar{s}_{\text{agapo}} - s_{\text{agapo}}[t]|$$

➢ The minimum AGAPO plan value is the selected one
➢ Extraction of candidate plan -> Extraction of selected plans
➢ Aggregators respond to requesters the selected plans

EPOS Algorithm – Step 0
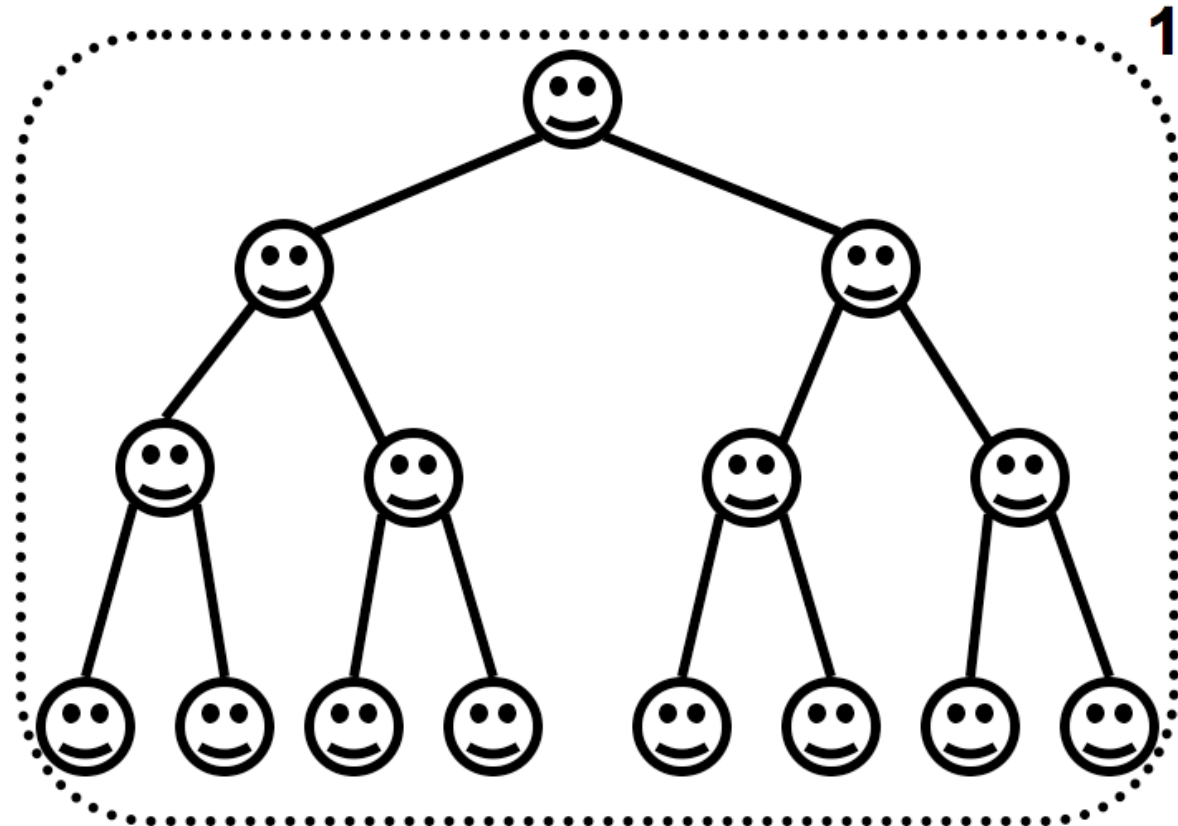

Legend:
- TCA Agents
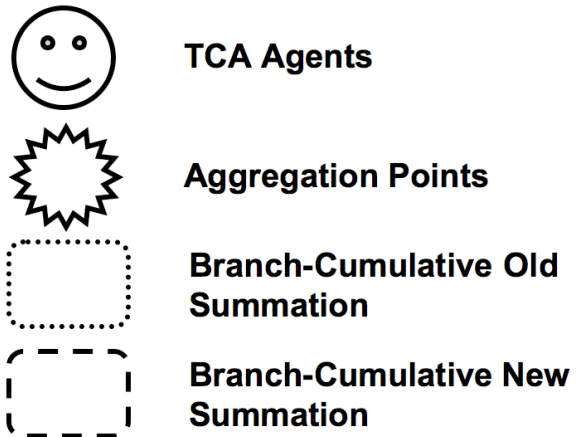- Aggregation Points
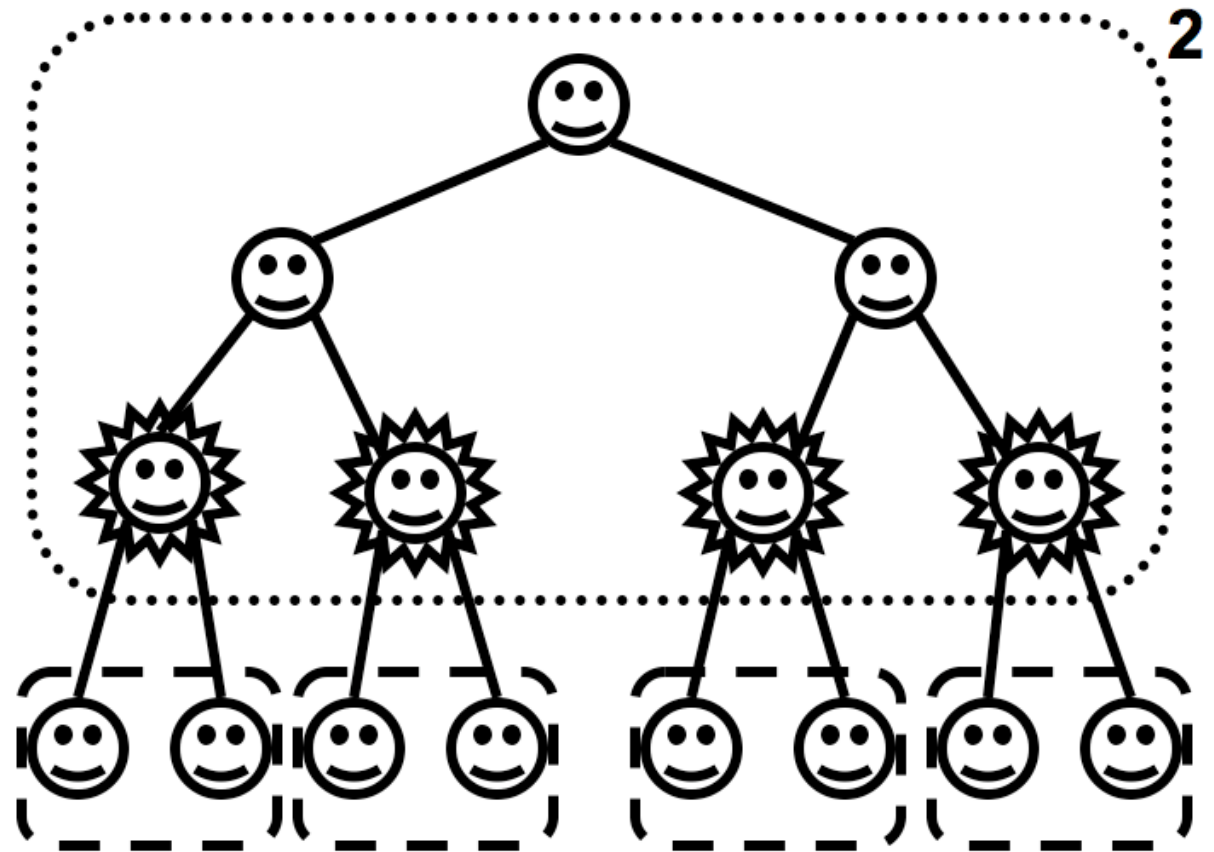- Branch-Cumulative Old Summation
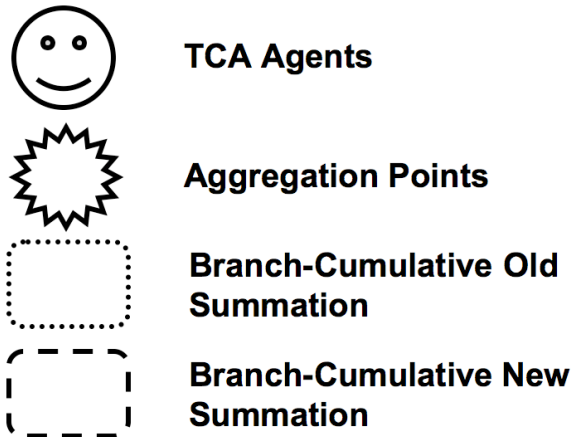- Branch-Cumulative New Summation

➢ Pre-existing knowledge (old plans)

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EPOS Algorithm – Step 1

TCA Agents

Aggregation Points

Branch-Cumulative Old Summation
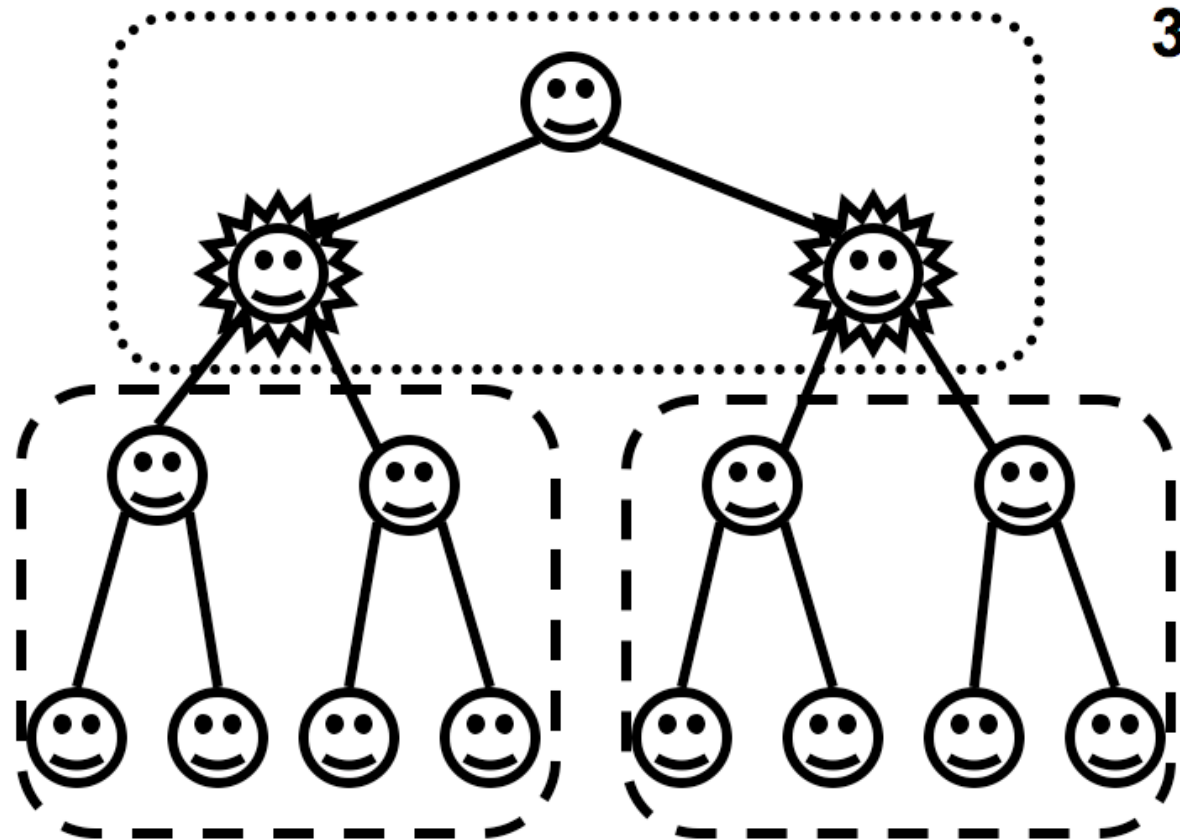
Branch-Cumulative New Summation

➢ 4 branches-aggregation points
➢ Low branches height
➢ Old knowledge influence decreases

2

EPOS Algorithm - Step 2

TCA Agents

Aggregation Points

Branch-Cumulative Old Summation

Branch-Cumulative New Summation

3

- ➢ 2 branches-aggregation points
- ➢ Increased branches height
- ➢ Influence of old knowledge decreases more

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EPOS Algorithm – Step 3
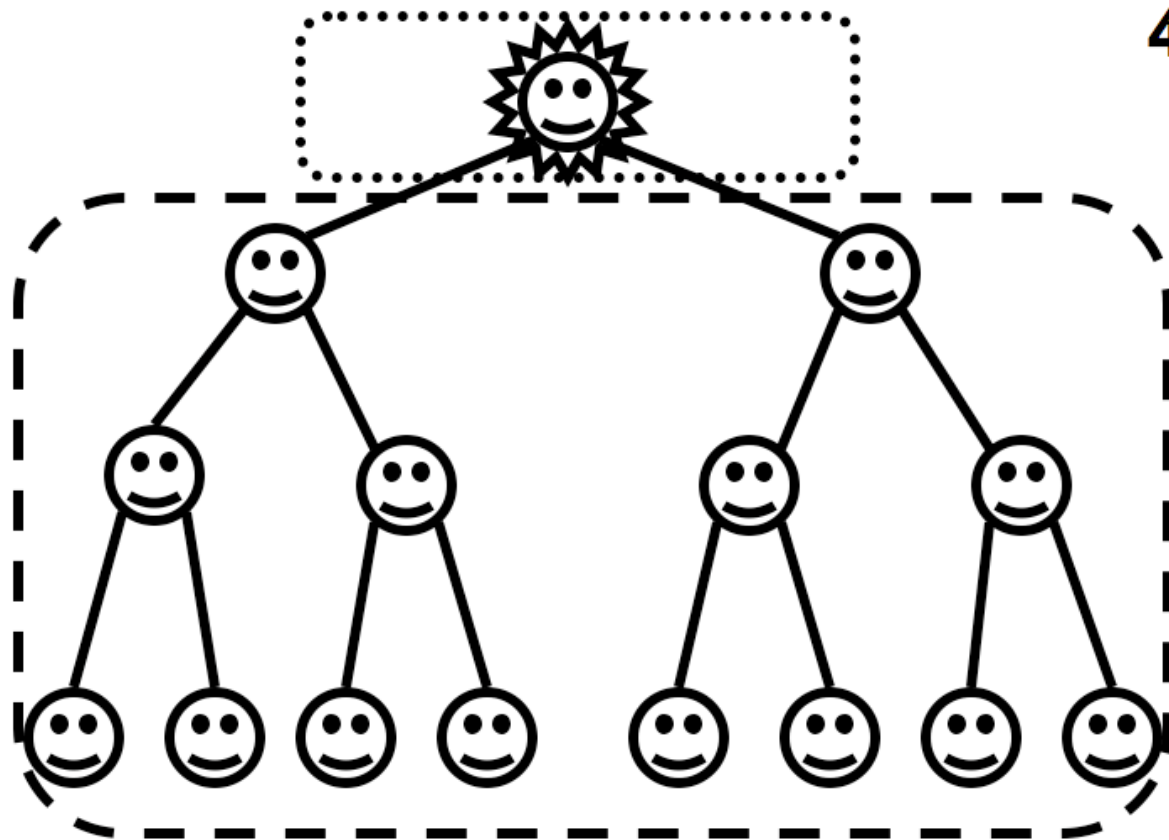
TCA Agents

Aggregation Points

Branch-Cumulative Old Summation

Branch-Cumulative New Summation

4

- ➢ 1 branch-aggregation point
- ➢ High branch height
- ➢ Old knowledge influence decreases even more

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EPOS Algorithm – Step 4
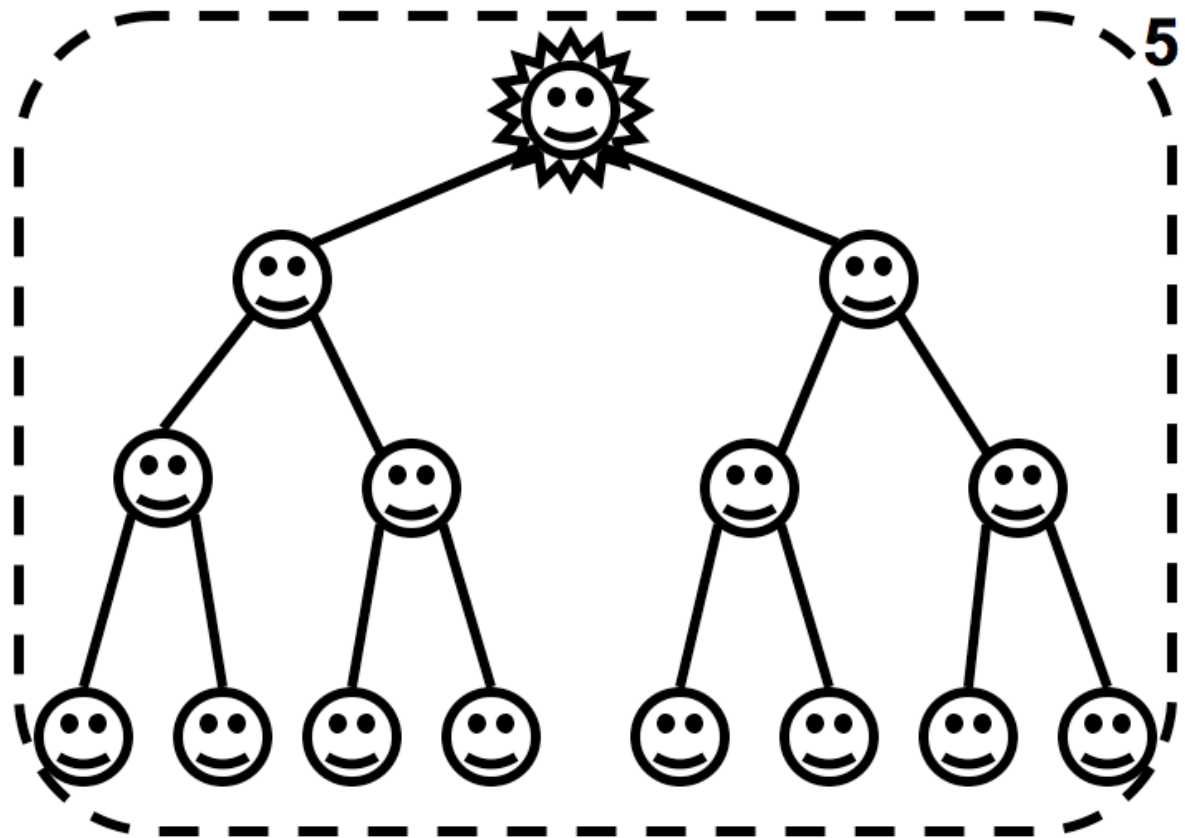

TCA Agents

Aggregation Points

Branch-Cumulative Old Summation

Branch-Cumulative New Summation

➤ Convergence to tree - global plan in the root
➤ Adaptation based fully on the new knowledge

Experimental Environment

- ➢ Binary tree with 7 agents (3 levels)
- ➢ 2 generated plans/agent/aggregation round (normalized in [0,1]
  - ▪ 10 energy values
  - ▪ Random seed/average value
  - ▪ +/- 0,2 deviation
- ➢ 10 aggregation rounds
- ➢ Knowledge of previous round

- ➢ 2 methods examining energy stabilization
  - ▪ **Standard deviation**
  - ▪ Area-based

- ➢ Comparison with random plan selection

Results

➢ 15% improvement
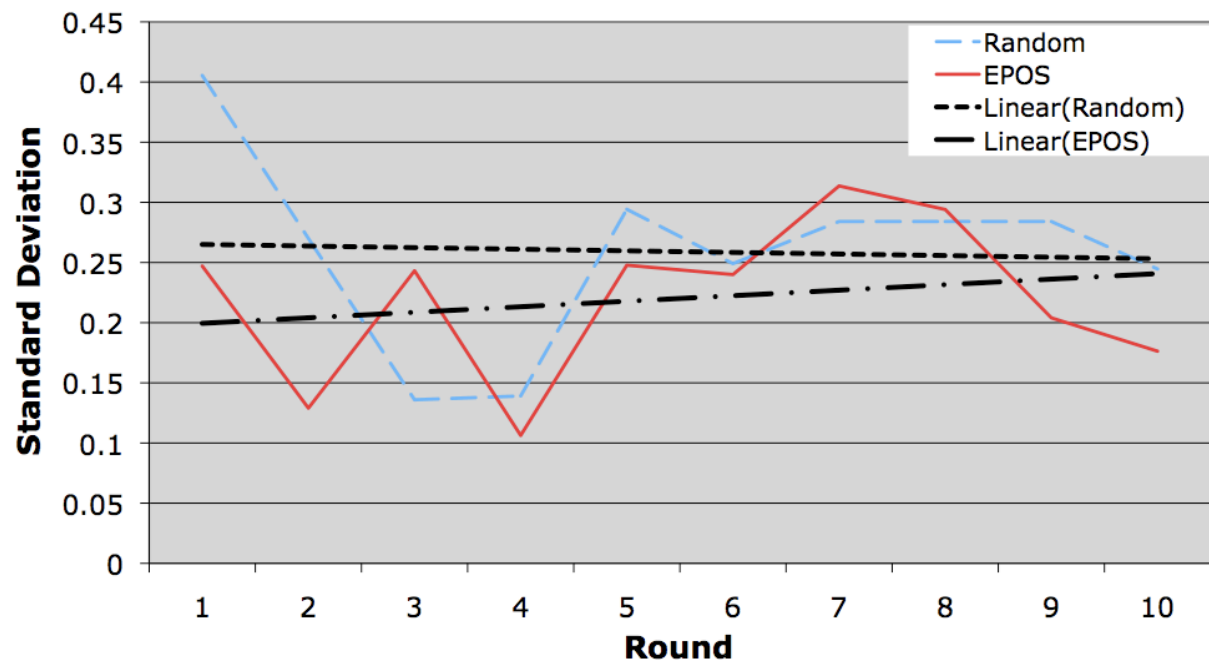
(t=1.20, df=18, p ≥0.13)

Conclusions & future work

- EPOS: Energy Plan Overlay Summation
  - Self-optimization and self-adaptation mechanism in line with the properties of autonomic computing
  - Cumulative plan summations, hierarchy, memory
  - Indications for an effective energy load-balancing mechanism

- Self-organization of tree structure (build & maintenance)
- Exploring the level of knowledge needed for effective adaptation
- Large-scale experiments

- Autonomic computing framework for distributed energy management

Questions?

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