Predicting Co-Evolutionary Adaption of MAS-Organisations

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MAS-Organisations

Agents

- local autonomy
- intelligence: goal-orientation, learning
- social awareness: cooperation, competition

Organisations

- global coherence
- organisational learning, data mining
- teams

Problems with Agents

- bounded rationality: sub-optimal solutions
- price of anarchy
- scaling problem for large agent populations

Organisations as Solutions

- social structures: roles, protocols, norms
- reduction of complexity: interaction networks, e.g. hierarchies

Co-Evolutionary Adaptation Process = Sonar-MAPE-Loop

- Adaptation Pattern: Monitor-Analyse-Plan-Execute (MAPE)
- For Org-MAS we have a cyclic dependency between the structure (organisation and workflow nets) and the member agents: *the micro-macro link*.
- Use of Nets-as-Tokens to specify the SONAR-MAPE-Loop.

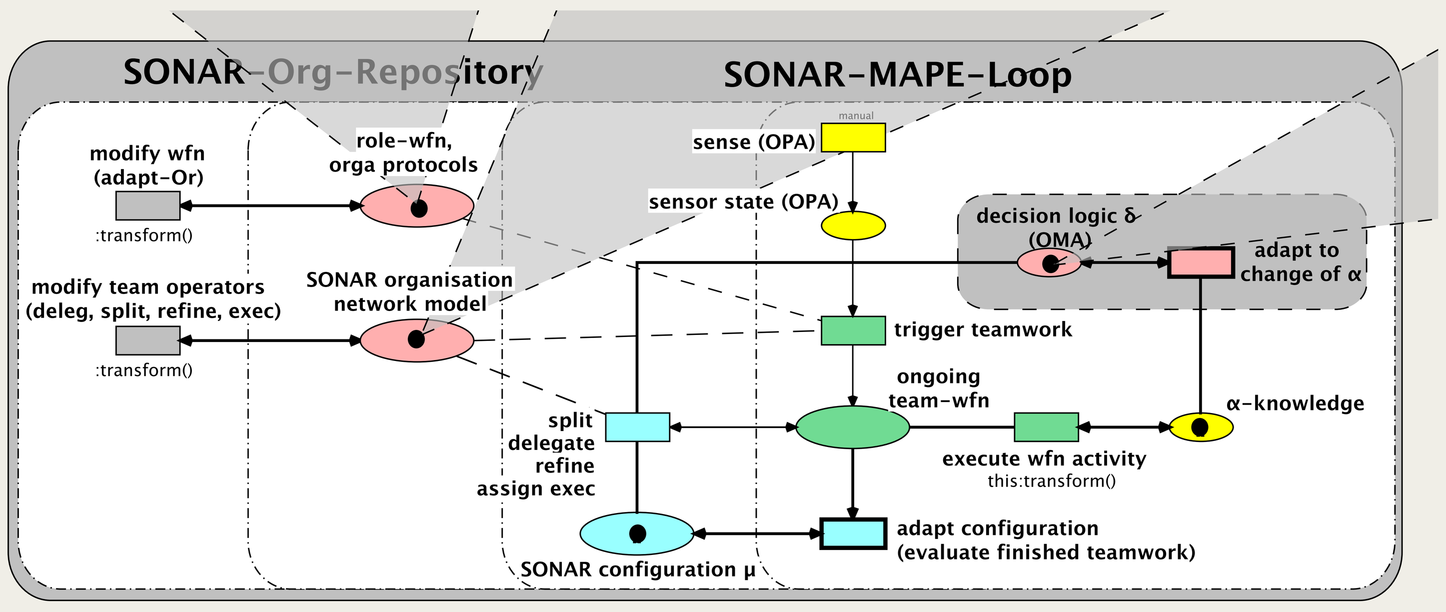

Figure 1. The SONAR-MAPE-Loop with Nets-as-Tokens [Köhler-Bußmeier and Sudeikat 2024]

The Net-Token: The Sonar-Organisation

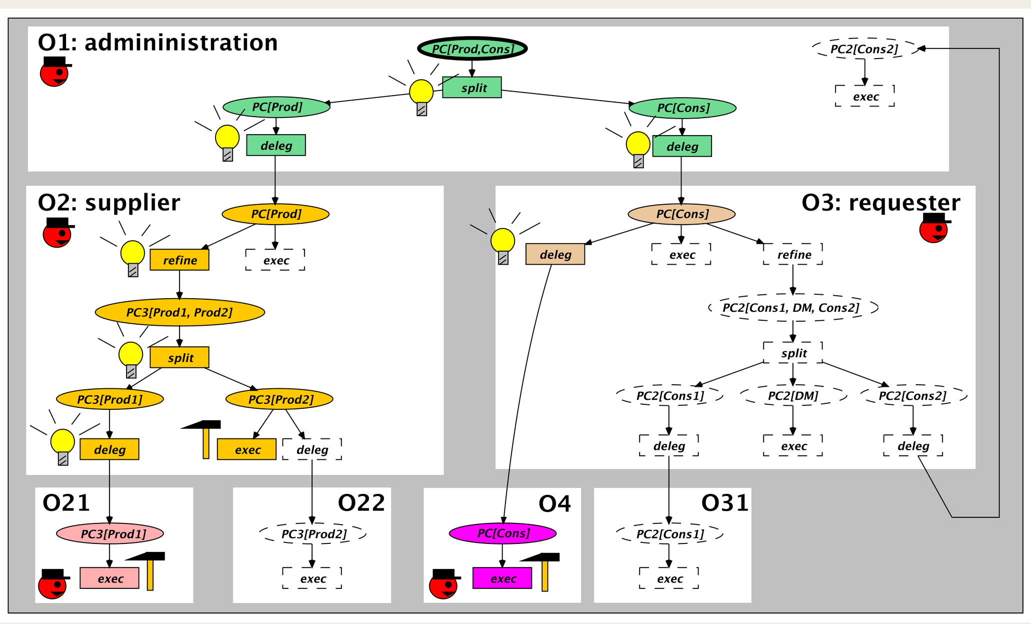

Figure 2. A SONAR-Organisation Model (highlighted: a SONAR-Team)

A Run-Time Model of the MAS-Organisation

- Costs and benefits of an organisational adaption are estimated using a abstracted **run-time model** of our SONAR-MAPE-Loop.
- Two stochastic components:
  - **Environment:** Generation of task is modelled by a stochastic distribution.
  - **Member Agents' decision logic:** In all Workflow Nets the xor-choices are model by a stochastic distribution.
- SONAR specifies constraints in a probabilistic way.
- **Approach:** Superposition of organisational constraints and individual decisions:

$$Prob_{super} \quad := \quad c_{org} \cdot Prob_{org} + (1 - c_{org}) \cdot Prob_{agent} \tag{1}$$

Here, $c_{org} \in [0; 1]$ denotes the organisational impact.

Learning in Org-MAS

- The organisational transparency c_{tra} describes how easily members can adapt its constraints.
- The learning rate η describes how fast agents minimise their loss.

$$Prob(t+1) \quad := \quad (1 - c_{tra}) \cdot \Big(Prob(t) - \eta \cdot loss'(Prob(t))\Big) \quad + \quad c_{tra} \cdot Prob_{org}(t) \tag{2}$$

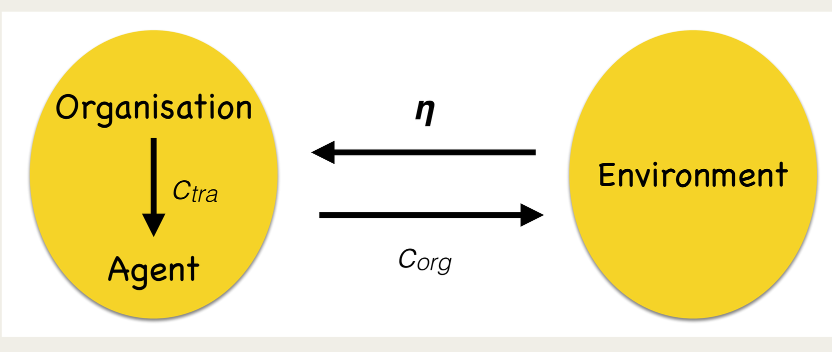

Figure 3. Relationships between the Meta-Parameters

Scenario: Coordinated Production with Environmental State Change

- Production of a or b for two agents.
- The systems rewards an *coordinated* choice around the minima of the loss function.
- We consider an environment toggles between two states.
- Each state describes different preferred probabilities ($\rightarrow$ minima of the loss function)

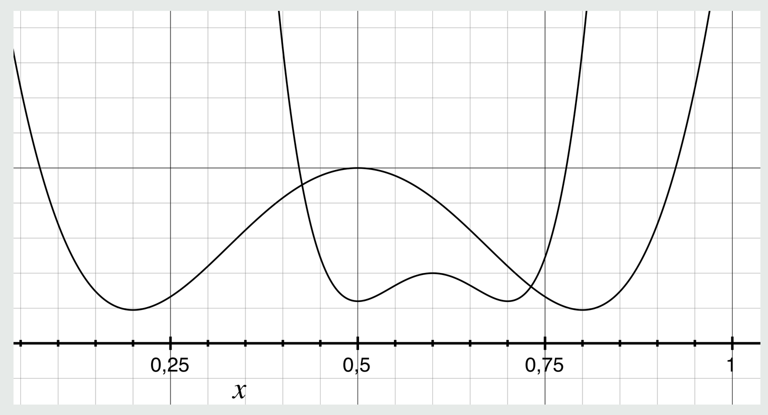

Figure 4. The Loss Functions $loss(Prob)$ for the two Environmental States

Repository: `https://github.com/koehler-bussmeier/digitaltwin/`

Scenario S2: Price of Anarchy

Problem: For the state with clearly separated minima there is a high chance that agents adapt in opposite directions (bad!).
The organisational constraints may mitigate this problem known as the *price of anarchy*:

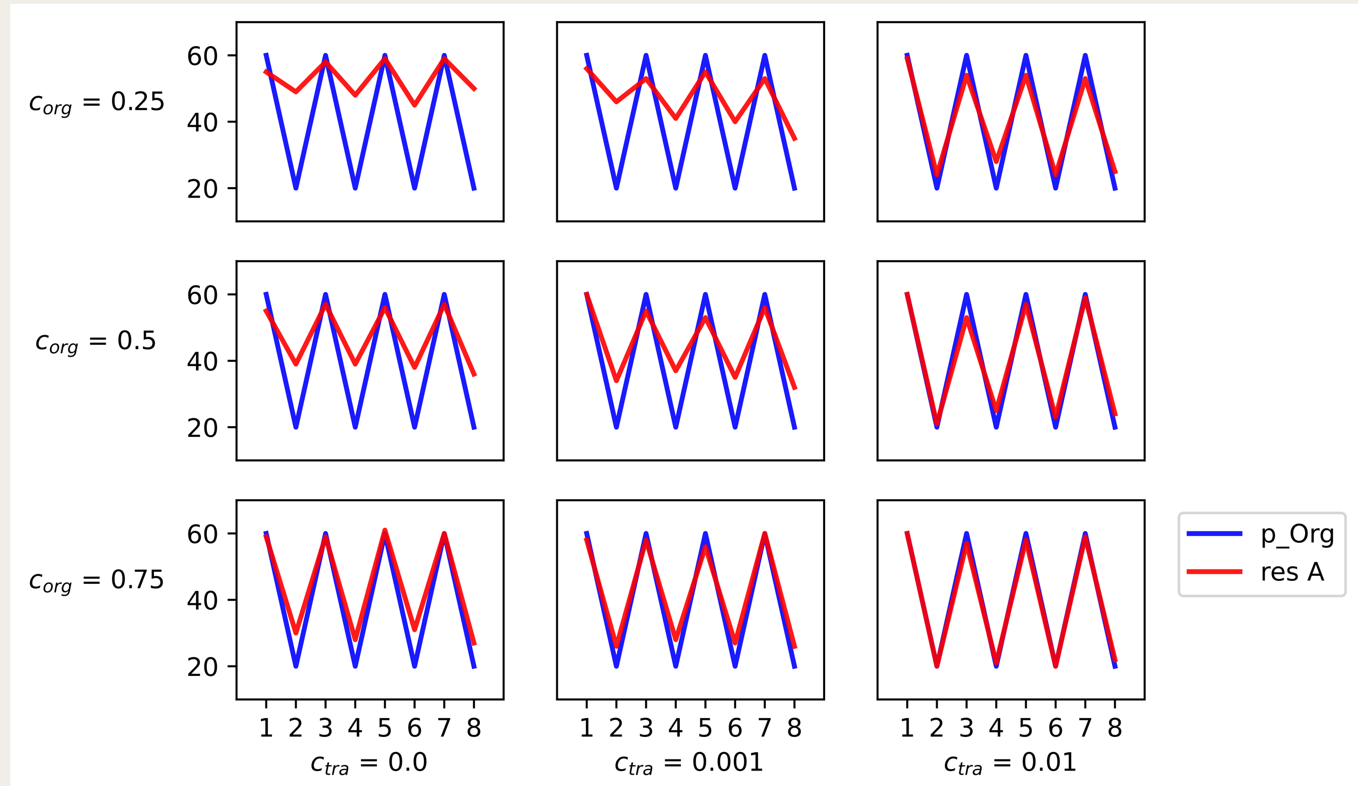

Figure 5. S2: Frequency of resource a over time for $\eta = 0.01$

Scenario S3: Outdated Organisation

But: Organisational constraints may also hinder the learning processes whenever the are outdated.
Here: The organisation constraint (blue) is too low for the even states 2, 4, 6, and 8.

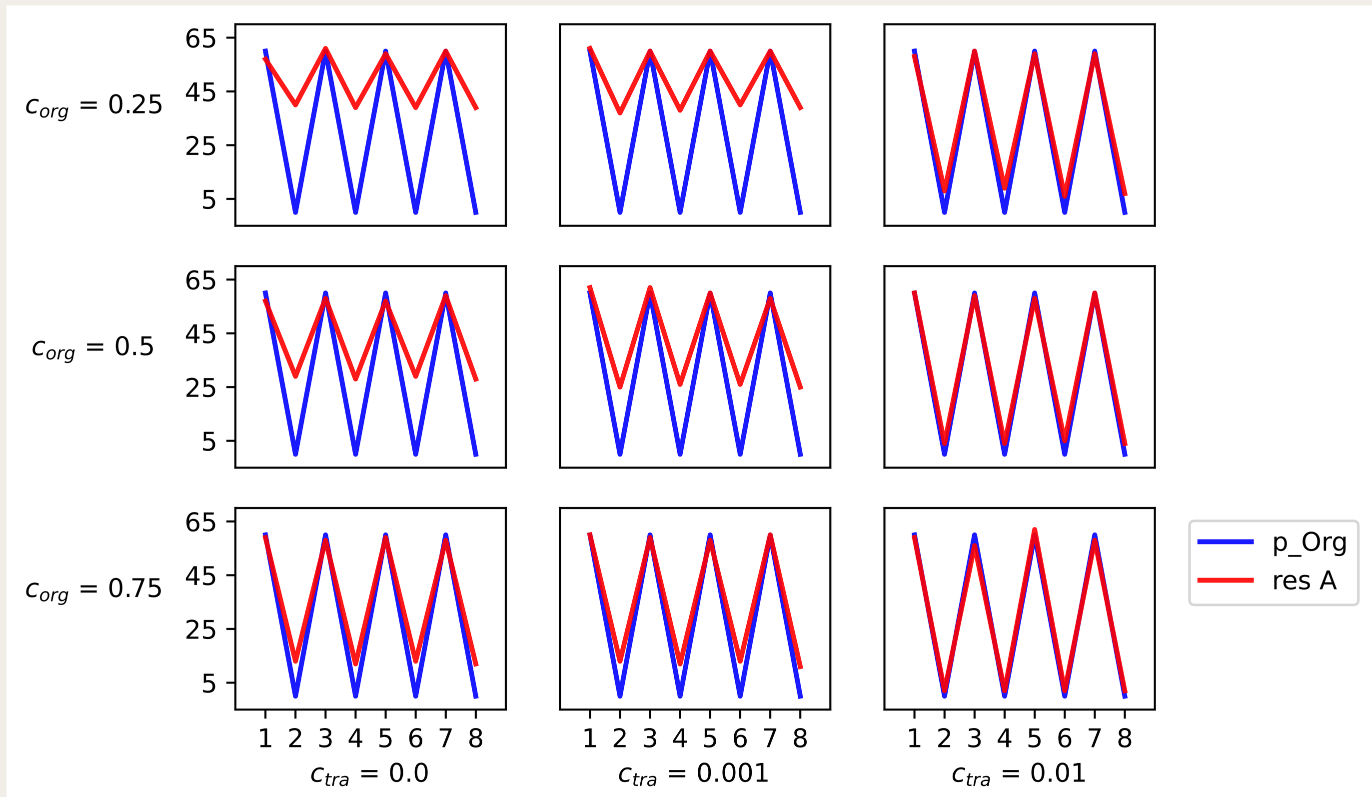

Figure 6. S3: Frequency of resource a over time for for the fixed learning rate $\eta = 0.1$

Sweeping Design-Parameters for an Organisation

c_org \ c_tra	0	0,0001	0,001	0,01	0,1
0,1	3.343,2	3.348,3	3.336,8	147,6	2.185,7
0,2	2.950,7	2.996,1	2.789,5	239,2	2.785,5
0,3	2.427,8	2.281,4	2.416,8	679,9	2.871,6
0,4	1.579,1	1.647,7	1.322,0	1.081,7	4.348,1
0,5	689,1	582,1	539,5	1.601,1	4.540,1
0,6	147,2	202,1	131,1	147,6	5.672,3
0,7	519,9	370,6	472,4	3.872,0	7.206,1
0,8	1.749,7	1.722,4	1.404,4	5.641,2	7.958,9
0,9	5.075,0	5.047,2	5.526,4	7.558,2	9.072,5

Figure 7. Heat-maps of the Loss for all Combinations of $c_{org} = 0.1, 0.2, \ldots 0.9$ and $c_{tra} = 0, 0.0001, 0.001, 0.01, 0.1$ for the learning rate $\eta = 0.1$

References

Köhler-Bußmeier, M. and J. Sudeikat (2024). "Studying the Micro-Macro-Dynamics in MAPE-like Adaption Processes". In: *16th International Symposium on Intelligent Distributed Computing (IDC'23)*.