Implications of patterned interactions in complex systems for the structure of decision making organization

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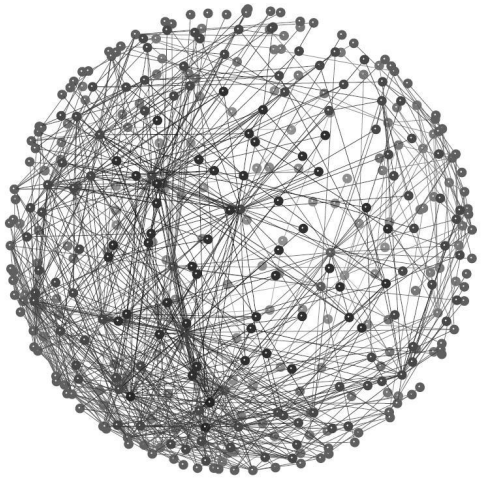
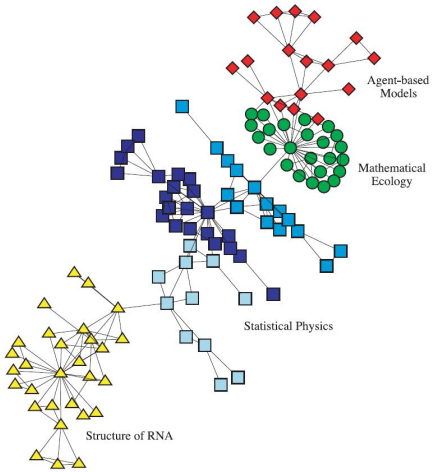
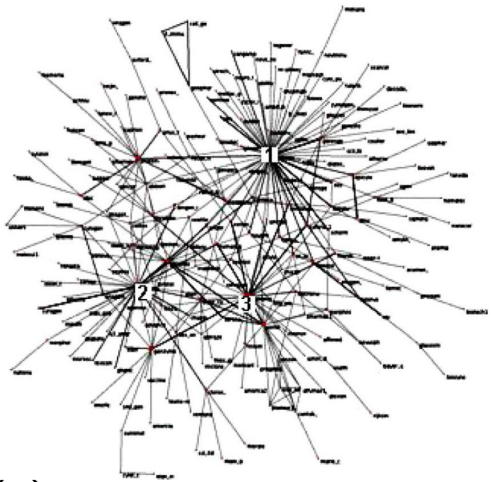
Motivation: Interactions pattern in organizational, social and technological sytems



(a) Organizational systems: Product development information flow [1]

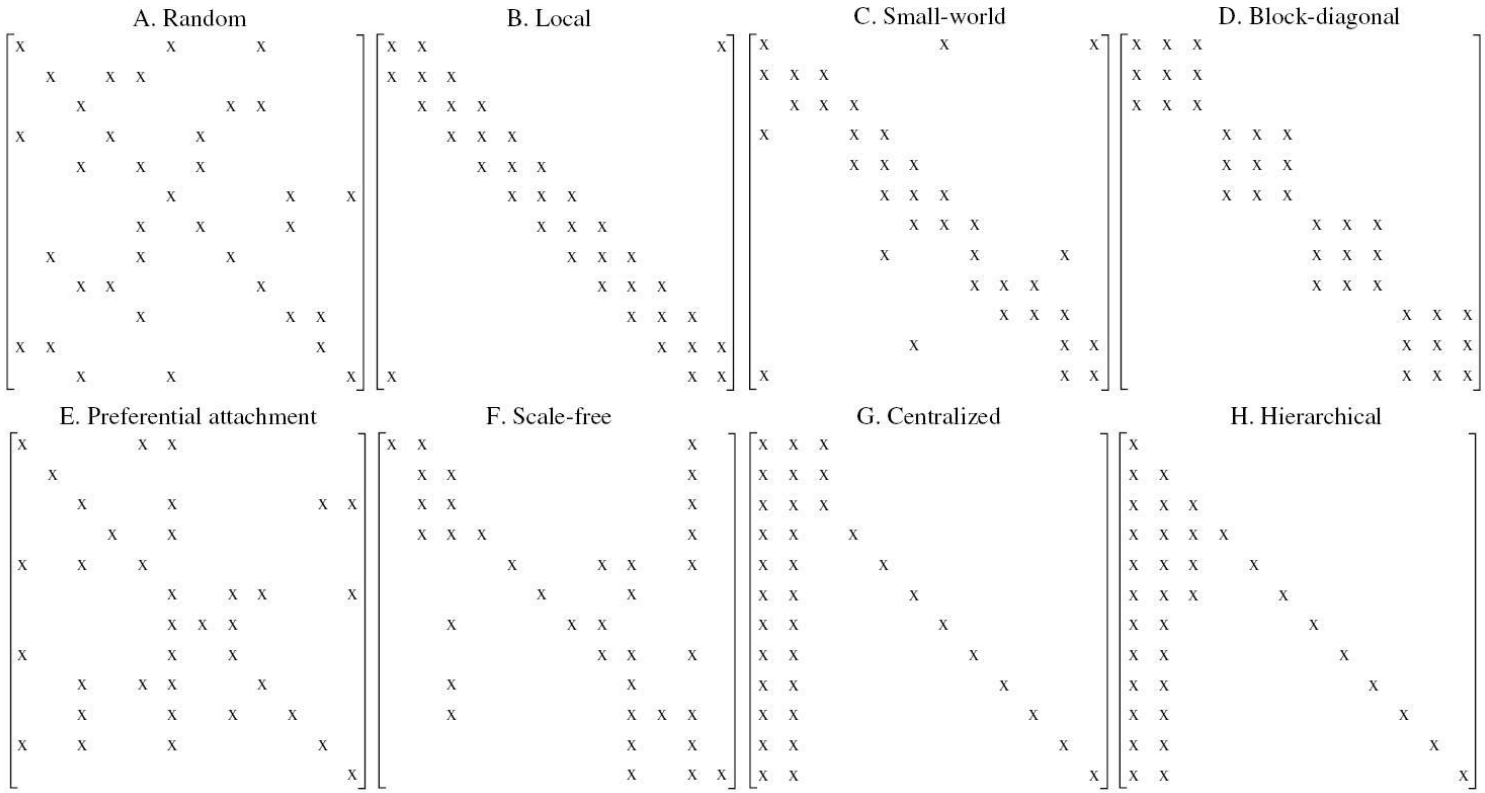


(b) Social systems: Co-authorship network [5]

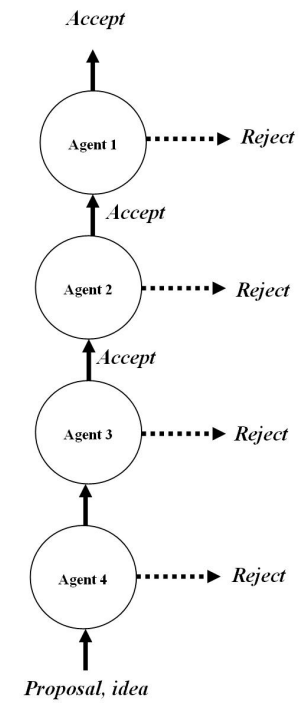


(c) Technological: Alliances in biotechnology industry [2]

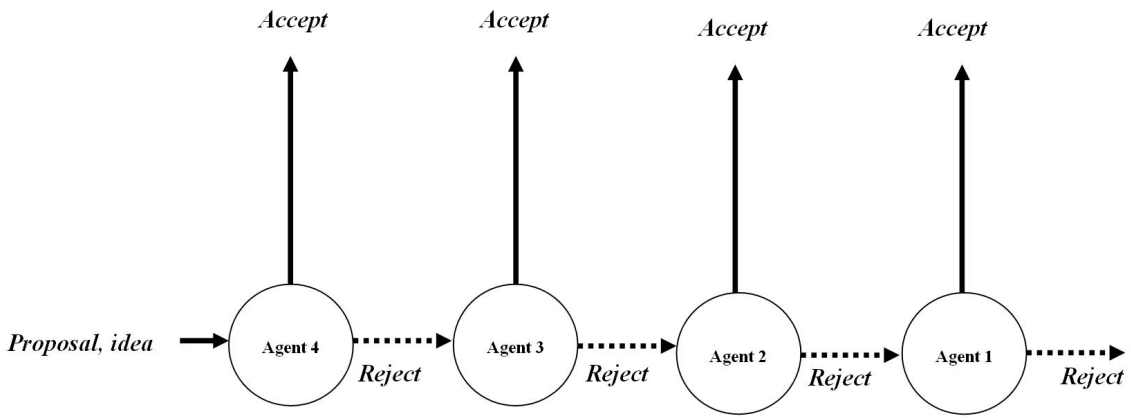
Motivation- cont: Patterns of interactions sytems [6]



Motivation- cont: Decision-making organizations' structure [7]



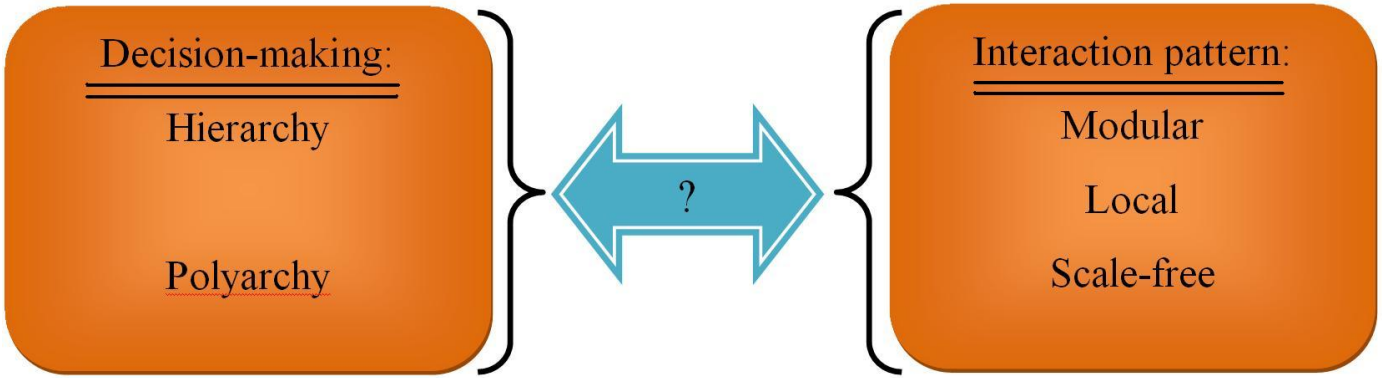
(e) Hierarchy



(f) Polyarchy

Figure: *Hierarchy reduces possibility of accepting an inferior decision (Type II error) , polyarchy reduces possibility of rejecting a superior (Type I error).*

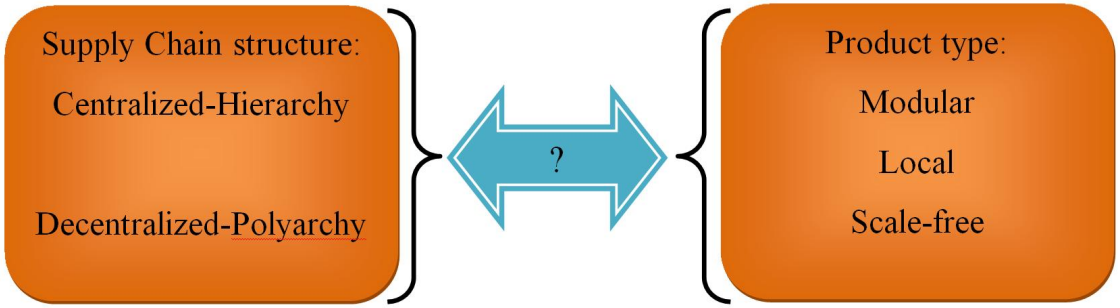
Problem definition



Research questions:

- Does any of the organizational decision making structures, hierarchy or polyarchy, have a superior performance than the other one when deployed for a particular interaction pattern?
- Are there interaction patterns for which deployment of an organizational decision making structure (hierarchy or polyarchy), results in higher performance than the other interaction patterns?

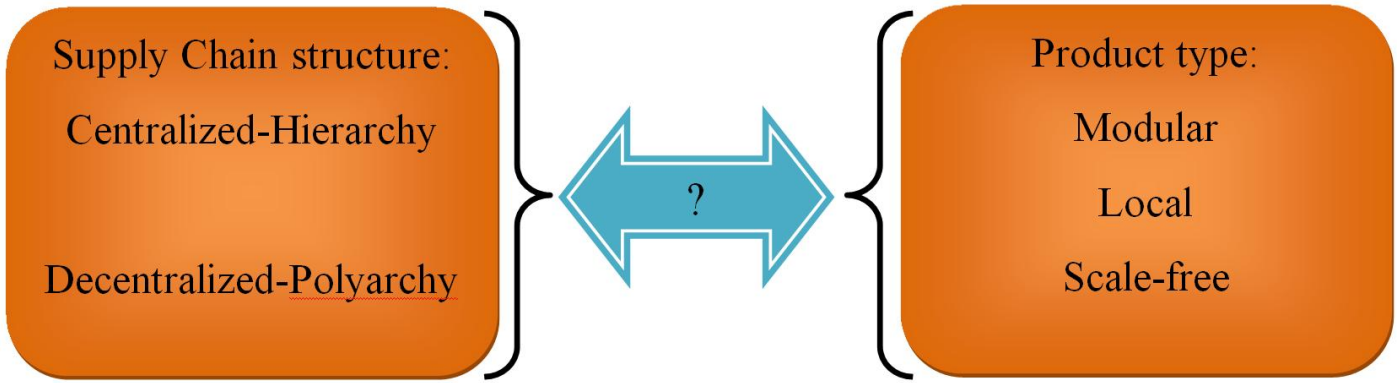
Problem definition- cont- Implications of products for Supply Chain



Research questions:

- A centralized Supply Chain (SC) uses a hierarchical decision making structure in which there is a high level of control on SC firms. A decentralized SC applies a polyarchy decision making structure in which there is a high level of authority.
- A product type is a set of product with a particular interaction pattern (i.e. modular product).

Problem definition- cont- Implications of products for Supply Chain



Research questions:

- Does any of the supply chain structures (centralized or decentralized) have a superior performance than the other one when deployed for a particular product type?
- Are there product types for which deployment of a supply chain structure (centralized or decentralized), results in higher performance than the other product types?

Research methodology

NK fitness landscape model [3]:

- An agent is responsible for design of a system with N elements each of which can have two binary states.
- Contribution of each element of system depends on (has interactions with) the state of K other elements of that agent.
- There are a number of possible states for agent (for $N = 6$ binary elements, $2^6 = 64$ states).
- Agent at each state has a fitness value (average of the contribution of each element).
- Agent searches to find the best state with the highest fitness.

Research methodology- cont.

(1) Generate the interactions among the elements of agents:

- To specify which elements influence contribution of an element to the fitness of the agent.
- Interaction matrix of system with six elements ($N = 6, K = 4$):

	Agent	A					
Agent	Elements	1	2	3	4	5	6
A	1	√	√	√		√	√
	2	√	√		√	√	√
	3	√	√	√	√		√
	4	√		√	√	√	√
	5	√	√		√	√	√
	6	√		√	√	√	√

Research methodology- cont.

(2) Generate the fitness landscape:

- The contributions are generated from an uniform distribution [0,1].
- Fitness landscape: Not sensitive to the type of distribution [8].
- Contributions of the elements of agent A from uniform distribution [0,1] for $N = 6, K = 4$ is shown in below table.
- The fitness of agent A at state $s = 110001$ is:
  $f_A[s_A = (110001)] = \frac{0.31+0.82+0.39+0.22+0.17+0.75}{6} = 0.44$

Focal element	**Agent**	State of decisions	**Contribution**
		s_A	*randomlygenerated*
1	A	**1**10*01	0.31
1	A	**0**10*01	0.43
2	A	1**1***001	0.82
2	A	1**0***001	0.11
3	A	11**1**0*1	0.65
3	A	11**0**0*1	0.39
4	A	1*0**1**01	0.68
4	A	1*0**0**01	0.22
5	A	11*0**1**1	0.91
5	A	11*0**0**1	0.17
6	A	1*000**1**	0.75
6	A	1*000**0**	0.41

Research methodology- cont.

(3) Agent searches on the generated landscape function:

- At each time, the agent flips the state of one (or some) of its elements toward a higher fitness (perfect search).
- Agent A at state $s_t = 110001$ flips its state to $s_{new} = 111001$.
  1. If the fitness of agent A at $s_{new} = 111001 > 0.44$, then agent A changes its state to $s_{t+1} = 111001$.
  2. If the fitness of agent A at $s_{new} = 111001 \leq 0.44$, then agent A retains its state to $s_{t+1} = 110001$.

Research methodology- cont.

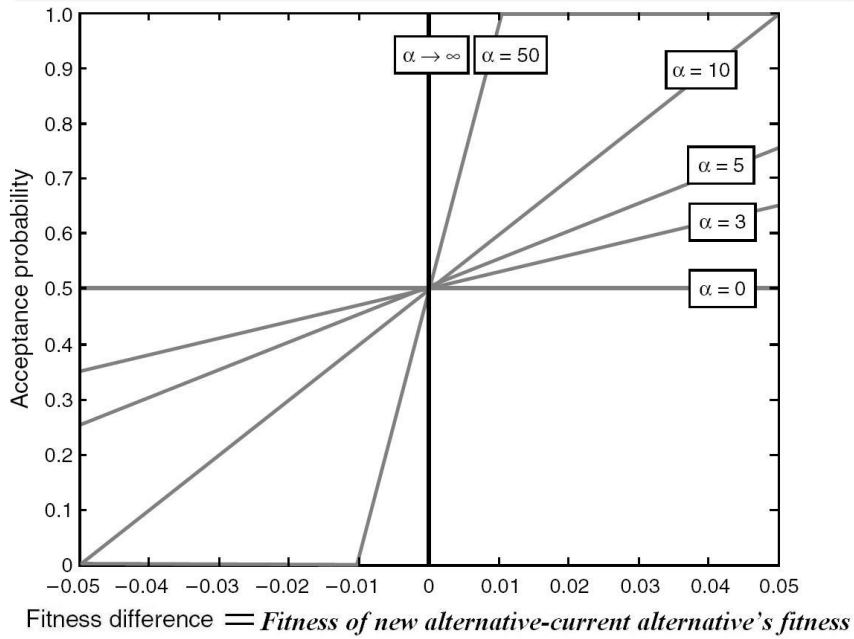
(3) Agent imperfectly searches on the generated landscape function:

- At each time, the agent flips the state of one (or some) of its elements toward a higher fitness (imperfect search).
- Agent A at state $s_t = 110001$ flips its state to $s_{new} = 111001$.
  1. If the fitness of agent A at $s_{new} = 111001 > 0.44$, then agent A may retain its state to $s_{t+1} = 110001$ (Type I error-rejecting a superior solution).
  2. If the fitness of agent A at $s_{new} = 111001 \leq 0.44$, then agent A may change its state to $s_{t+1} = 111001$ (Type II-accepting an inferior).

Addressing research questions by NK landscape.

Decision-making structure (3):

- Imperfect local search on generated landscape.
- Screening function of a decision-maker $f(x) = \alpha x + \beta$ [4].



Interactions pattern (1):

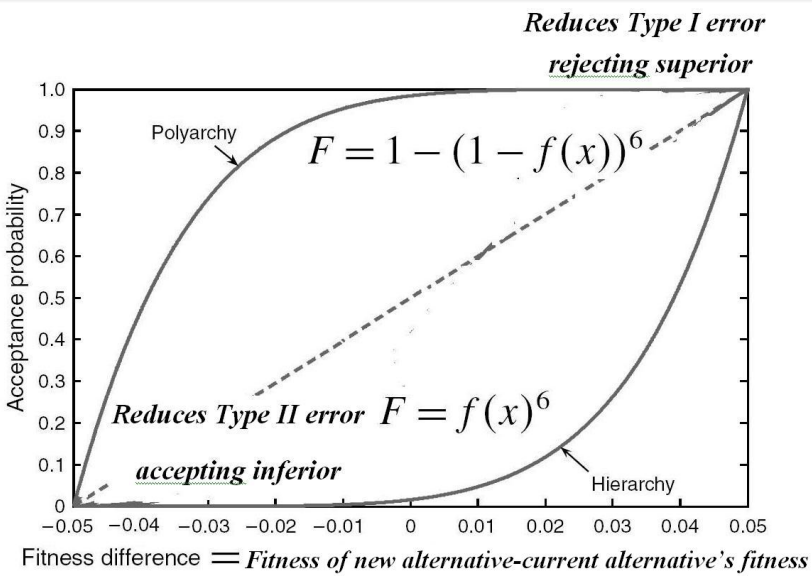
- A particular interaction pattern is used to the first step of NK landscape.
- Modular with $N = 6$ and $K = 2$:

	Agent	A					
Agent	Elements	1	2	3	4	5	6
A	1	√	√	√			
	2	√	√	√			
	3			√	√	√	
	4			√	√	√	
	5				√	√	√
	6				√	√	√

Addressing research questions by NK landscape-cont.

Decision-making (DM) structure (3):

- Imperfect local search at organizational level.
- Organizational screening function of $n = 6$ and $\alpha = 10, \beta = 0$[4]:



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A	1	√	√	√			
	2	√	√	√			
	3			√	√	√	
	4			√	√	√	
	5				√	√	√
	6				√	√	√

Experiments and results

Simulation goal

- Simulate hierarchy/polyarchy structure on NK landscape instances with different interaction pattern and analyze their performances.

Parameters and experiments

- Number of elements, N=12, K=[1,6].
- Number of runs/landscape instances: 35
- Simulation time in each run: 800 (search space, $2^{12} = 4096$).
- Pattern: Random, local, central, and small-world.
- $n = 6$ decision-makers.
- $\alpha = [-0.2, 0, 0.2]$ and $\beta = [-0.05, 0, 0.05]$.

Experiments and results- cont.

Statistical analysis of results ($\alpha = 0.1$)

Inputs				Results	Conclusion
Pattern	α	β	K	P-value	DM with higher performance
Random	-0.2	-0.05	1	0.225	-
Random	-0.2	-0.05	6	0.018	Hierarchy
Random	0	-0.05	1	0.003	Hierarchy
Random	0	-0.05	6	0.062	Hierarchy
Random	0.2	-0.05	1	0.798	-
Random	0.2	-0.05	6	0.005	Hierarchy
Local	-0.2	-0.05	1	0.009	Hierarchy
Local	-0.2	-0.05	6	0.021	Hierarchy
Local	0	-0.05	1	0.024	Hierarchy
Local	0	-0.05	6	0.093	Hierarchy
Local	0.2	-0.05	1	0.073	Hierarchy
Local	0.2	-0.05	6	0.050	Hierarchy
Central	-0.2	-0.05	1	0.005	Hierarchy
Central	-0.2	-0.05	6	0.039	Hierarchy
Central	0	-0.05	1	0.001	Hierarchy
Central	0	-0.05	6	0.057	Hierarchy
Central	0.2	-0.05	1	0.048	Hierarchy
Central	0.2	-0.05	6	0.002	Hierarchy

Experiments and results- cont.

Statistical analysis of results - ($\alpha = 0.1$)

Inputs				Results	Conclusion
Pattern	α	β	K	P-value	DM with higher performance
Small-world (p=0.1)	-0.2	-0.05	1	0.094	Hierarchy
Small-world (p=0.1)	-0.2	-0.05	6	0.001	Hierarchy
Small-world (p=0.1)	0	-0.05	1	0.073	Hierarchy
Small-world (p=0.1)	0	-0.05	6	0.001	Hierarchy
Small-world (p=0.1)	0.2	-0.05	1	0.496	-
Small-world (p=0.1)	0.2	-0.05	6	0.457	-
Small-world (p=0.4)	-0.2	-0.05	1	$3e^{-4}$	Hierarchy
Small-world (p=0.4)	-0.2	-0.05	6	0.002	Hierarchy
Small-world (p=0.4)	0	-0.05	1	0.025	Hierarchy
Small-world (p=0.4)	0	-0.05	6	0.321	-
Small-world (p=0.4)	0.2	-0.05	1	0.612	-
Small-world (p=0.4)	0.2	-0.05	6	0.170	-
Small-world (p=0.9)	-0.2	-0.05	1	0.580	-
Small-world (p=0.9)	-0.2	-0.05	6	0.232	-
Small-world (p=0.9)	0	-0.05	1	0.124	-
Small-world (p=0.9)	0	-0.05	6	0.002	Hierarchy
Small-world (p=0.9)	0.2	-0.05	1	0.342	-
Small-world (p=0.9)	0.2	-0.05	6	0.550	-

Experiments and results- cont.

Statistical analysis of results ($\alpha = 0.1$)

Inputs				Results	Conclusion
Pattern	α	β	K	P-value	DM with higher performance
Random	-0.2	0.05	1	0.049	Polyarchy
Random	-0.2	0.05	6	0.008	Polyarchy
Random	0	0.05	1	0.001	Polyarchy
Random	0	0.05	6	0.045	Polyarchy
Random	0.2	0.05	1	0.001	Polyarchy
Random	0.2	0.05	6	0.038	Polyarchy
Local	-0.2	0.05	1	0.013	Polyarchy
Local	-0.2	0.05	6	0.002	Polyarchy
Local	0	0.05	1	0.021	Polyarchy
Local	0	0.05	6	0.012	Polyarchy
Local	0.2	0.05	1	0.018	Polyarchy
Local	0.2	0.05	6	0.072	Polyarchy
Central	-0.2	0.05	1	0.48	-
Central	-0.2	0.05	6	0.070	Polyarchy
Central	0	0.05	1	0.005	Polyarchy
Central	0	0.05	6	0.081	Polyarchy
Central	0.2	0.05	1	0.031	Polyarchy
Central	0.2	0.05	6	0.032	Polyarchy

Experiments and results- cont.

Statistical analysis of results - ($\alpha = 0.1$)

Inputs				Results	Conclusion
Pattern	α	β	K	P-value	DM with higher performance
Small-world (p=0.1)	-0.2	0.05	1	0.266	-
Small-world (p=0.1)	-0.2	0.05	6	0.033	Polyarchy
Small-world (p=0.1)	0	0.05	1	0	Polyarchy
Small-world (p=0.1)	0	0.05	6	0	Polyarchy
Small-world (p=0.1)	0.2	0.05	1	0.017	Polyarchy
Small-world (p=0.1)	0.2	0.05	6	0.333	-
Small-world (p=0.4)	-0.2	0.05	1	0.254	-
Small-world (p=0.4)	-0.2	0.05	6	$2e^{-6}$	Polyarchy
Small-world (p=0.4)	0	0.05	1	0.055	Polyarchy
Small-world (p=0.4)	0	0.05	6	0.018	Polyarchy
Small-world (p=0.4)	0.2	0.05	1	0.406	-
Small-world (p=0.4)	0.2	0.05	6	0.036	Polyarchy
Small-world (p=0.9)	-0.2	0.05	1	0.043	Polyarchy
Small-world (p=0.9)	-0.2	0.05	6	0.004	Polyarchy
Small-world (p=0.9)	0	0.05	1	0.023	Polyarchy
Small-world (p=0.9)	0	0.05	6	0.45	-
Small-world (p=0.9)	0.2	0.05	1	0.027	Polyarchy
Small-world (p=0.9)	0.2	0.05	6	0.528	-

Discussion and extension.

Discussion on results

- Changes in capability of decision makers (+/- β) changes the better DM structure.
- Different results for small-world pattern than the other patterns.
- Performance of DM structure (hierarchy or polyarchy) depends on interaction pattern as well as individual DM capabilities (+/- β).

Extension

- Incorporating other interaction patterns.
- Analysis of the complete search space for 100 landscape instances [4].
- Investigation of wider range of parameters and hybrid DM structure [4].

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