Challenges in P2P Data Management: Clustering

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Data management in Peer-to-Peer (P2P) systems

- This is a challenging issue due to the scale of network and extremely high dynamics
- There are many research issues regarding data management in P2P systems detected as [1]:
  - Indexing
  - Data integration
  - Query processing
  - Data replication
  - Clustering
  - Incentive mechanisms
  - etc.

About Clustering

- A method of unsupervised learning → no training step required
- Grouping collection of observations in smaller subsets

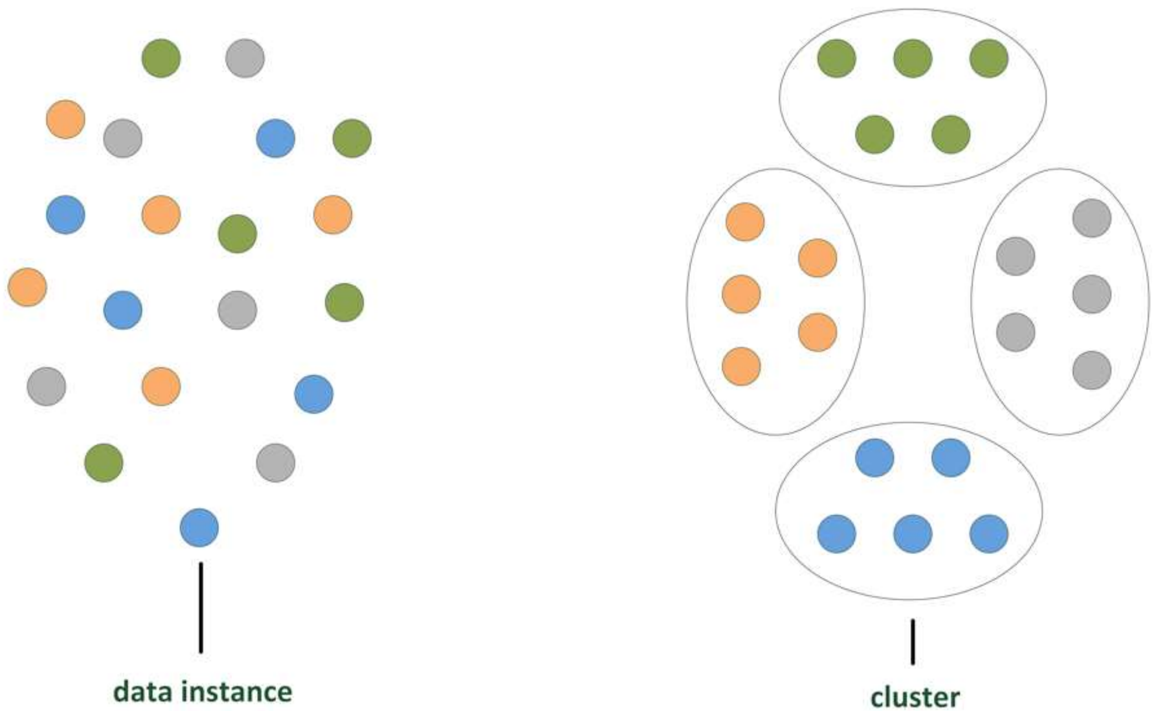


Fig. 1: (a) observations (b) clustered observations [2]

Clustering in P2P (1)

- P2P systems have capability of self-organization and fault-tolerance → a demand for an adaptive network topology due to churn [1].
- Peers in a P2P system are autonomous [10]
  - Therefore, characteristics of P2P systems make clustering a challenging task.
  - Autonomy is violated by data clustering.
- Very dynamic nature of P2P environments [1,6,7]
  - Another concern for the application of clustering.
  - Clusters needs to dynamically adapt to the frequent changes in peer populations and their data.

Clustering in P2P (2)

- Further concern is the lack of global knowledge of data and peer interests
  - A serious difficulty in forming clusters in P2P systems.
- We can differentiate two types of clustering in P2P:
  - **Data clustering**
  - **Peer clustering**

Data Clustering

- Data items with common attributes or properties can be grouped together → *data clusters.*
- The main goal of clustering:
  - To reduce the communication cost in query processing.
  - Related data are placed in nearby locations.
- In *structured* P2P systems, it is possible to store similar data at the same or neighboring peers by using an order-preserving hash function [3].
- What to do in *unstructured* P2P systems?

Load Clustering (1)

- Load clustering deals with the clustering of work loads in a computer system.
- We derived it from data clustering [4]:
  - data clustering
    - group and stores similar data
    - rather static
  - load clustering
    - not only attributes of data, but also consideration of the payload
    - group, temporarily store and process similar requests and reply
    - highly dynamic
- Benefits for applications (e.g., better performance)

Load Clustering (2)

- It makes further optimizations of the load distribution based on the content of the load items [4]:
  - A single load item → a task that consists of several attributes (e.g. a certain priority), has a payload, a dynamic life cycle and is handled by a computer or processor.
- The **goal**:
  - Cluster loads not only on the basis of simple attributes, but also take into consideration the payload as well as the dynamic.
  - Increase performance by allowing a worker in a computer system to process not only a single load at once but a cluster of loads which are similar.

Load Clustering (3)

- Load clustering systems are complex systems
  - They should be self-organizing and adaptive, and capable to flexibly adapt to dynamically changing loads and resources.
- There are many load clustering scenarios
  - Different algorithms and configurations are needed to satisfy different kinds of load clustering scenarios.
- **Self-Initiative Load Clustering Agents** (SILCA) [4] a load clustering framework that provides the possibility for plugging and benchmarking different clustering algorithms
  - It is based on autonomous agents with decentralized control and a blackboard based communication mechanism.

SILCA

- Design of a general software architecture framework [2,4]
  - component-based → “plug”-able algorithms and policies
  - pattern-oriented → composition towards different solutions
  - agent-based → adaptive
  - space-based middleware → decoupling, autonomy, agility
- Evaluation through benchmarking
  - comparing different
    - algorithms and combinations
    - network topologies
    - parameter settings

SILCA

- A composable and agile software architecture pattern for load clustering
- Problem independent and allows for plugging different clustering algorithms
- Basic SILCA consists of several sub-patterns, implemented in a space-based architectural style,
  - decoupling of the agents
  - autonomic behavior of agents
- This allows finding the best algorithm for each specific problem.

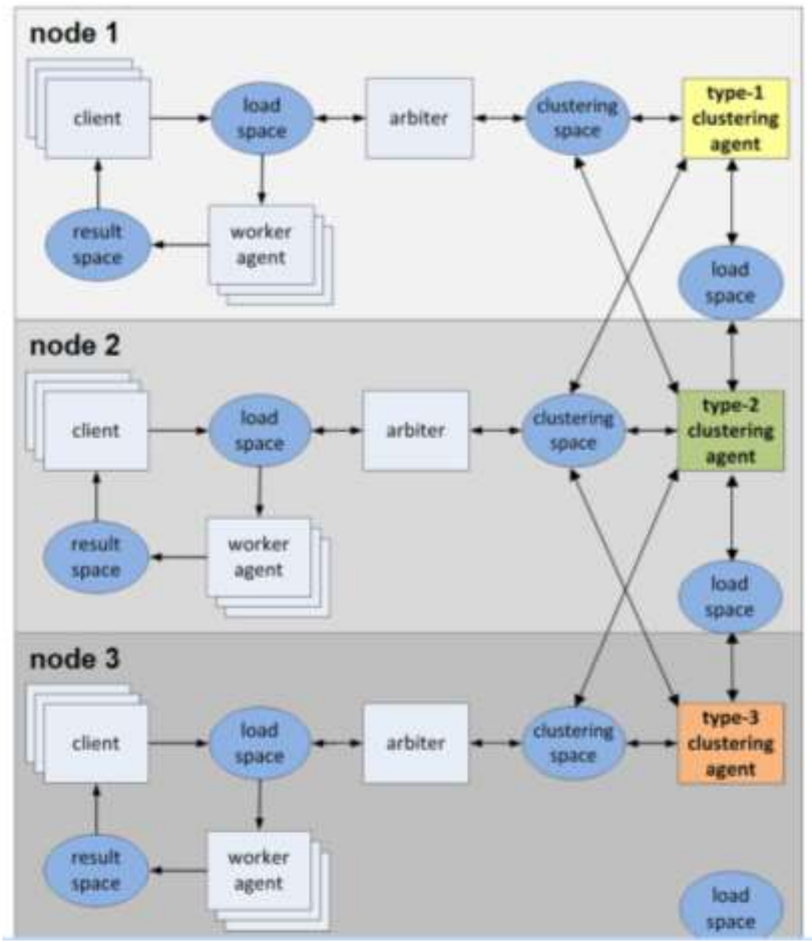


Fig 2. SILCA pattern composition [4]

Algorithms applied

- Hierarchical,
  K-Means,
  Fuzzy C-Means,
  Genetic K-Means,
  Ant K-means

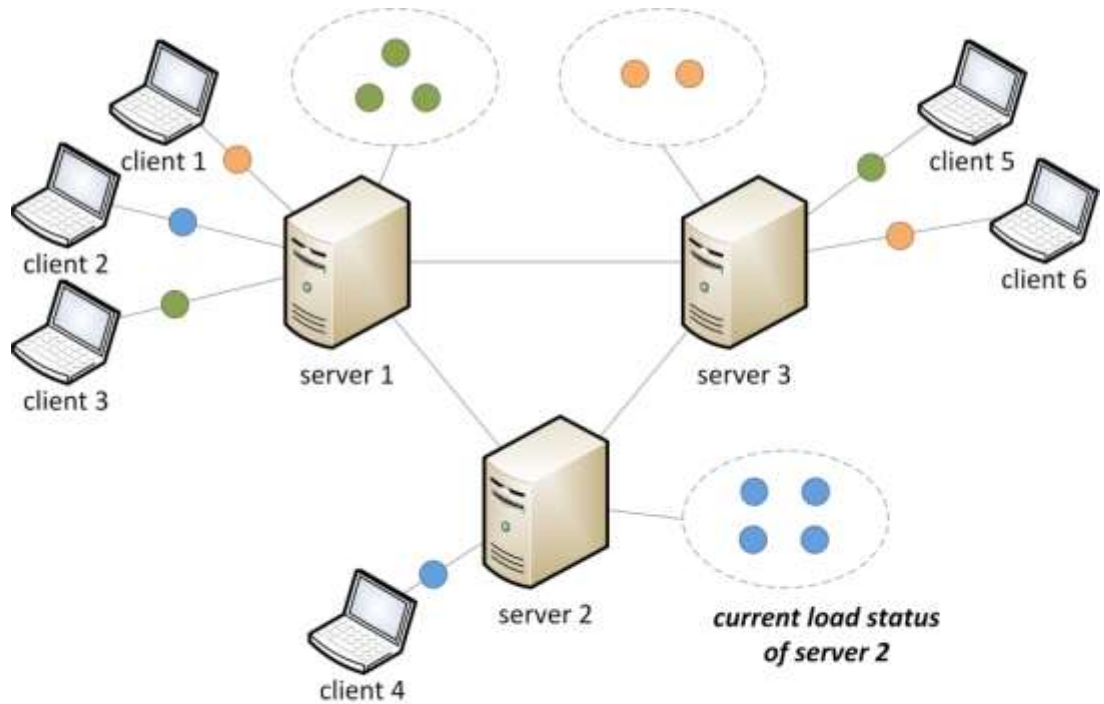


Fig. 3: Load Clustering [2]

Comparison

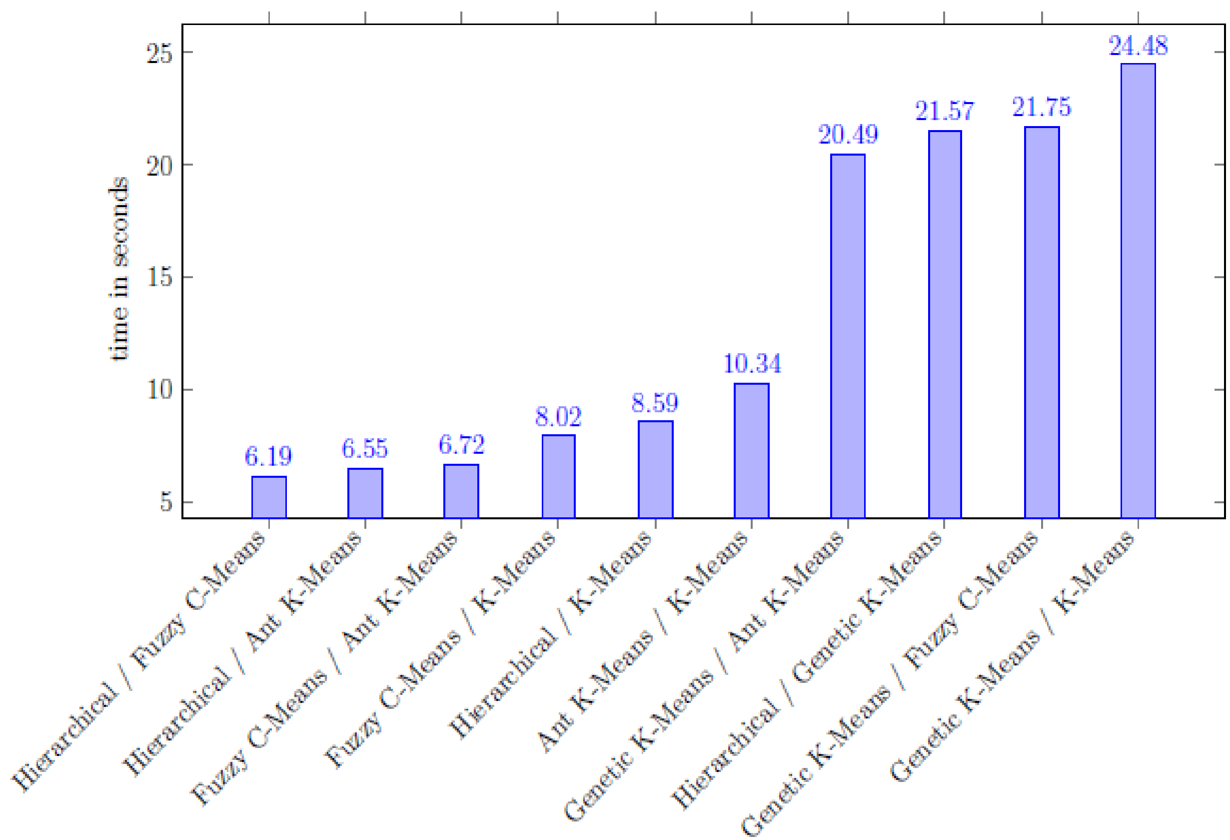


Fig. 4: Comparison of algorithms combinations in SILCA [4]

Results

- The combination of the Hierarchical algorithm with any other, except the Genetic K-Means algorithm, leads to a good execution time.
- For small networks , the unintelligent Hierarchical Clustering showed the best results.
- For large and more complex networks, an intelligent approach will help.

use-case	**metric**	**the most successful algorithm(s)**
Load Clustering	absolute time	Hierarchical /Fuzzy C-Means (amount of load = 20, chain topology)

Peer Clustering (1)

- Usualy, peers are placed randomly or based on their geographical position in a P2P network →
  a performance bottleneck →
  extremely poor performance
- This problem can be solved by using peer clustering.
- Peer Clustering aims to group peers, which have certain characteristics in common, together as neighbors.
- Peer Clustering is a highly dynamic procedure as peers are leaving and entering the network dynamically.

Peer Clustering (2)

- As a consequence, query performance can be significantly improved compared to a random network topology [5]:
  - Requests are routed more efficiently and only to nodes which are likely to fit the request.
  - If it is possible to find a cluster that contains a node, which should fit the request, query flooding through the whole network is not necessary.
  - Consequently, the workload on nodes, which are probably not fitting the request, can be reduced.

Peer Clustering (3)

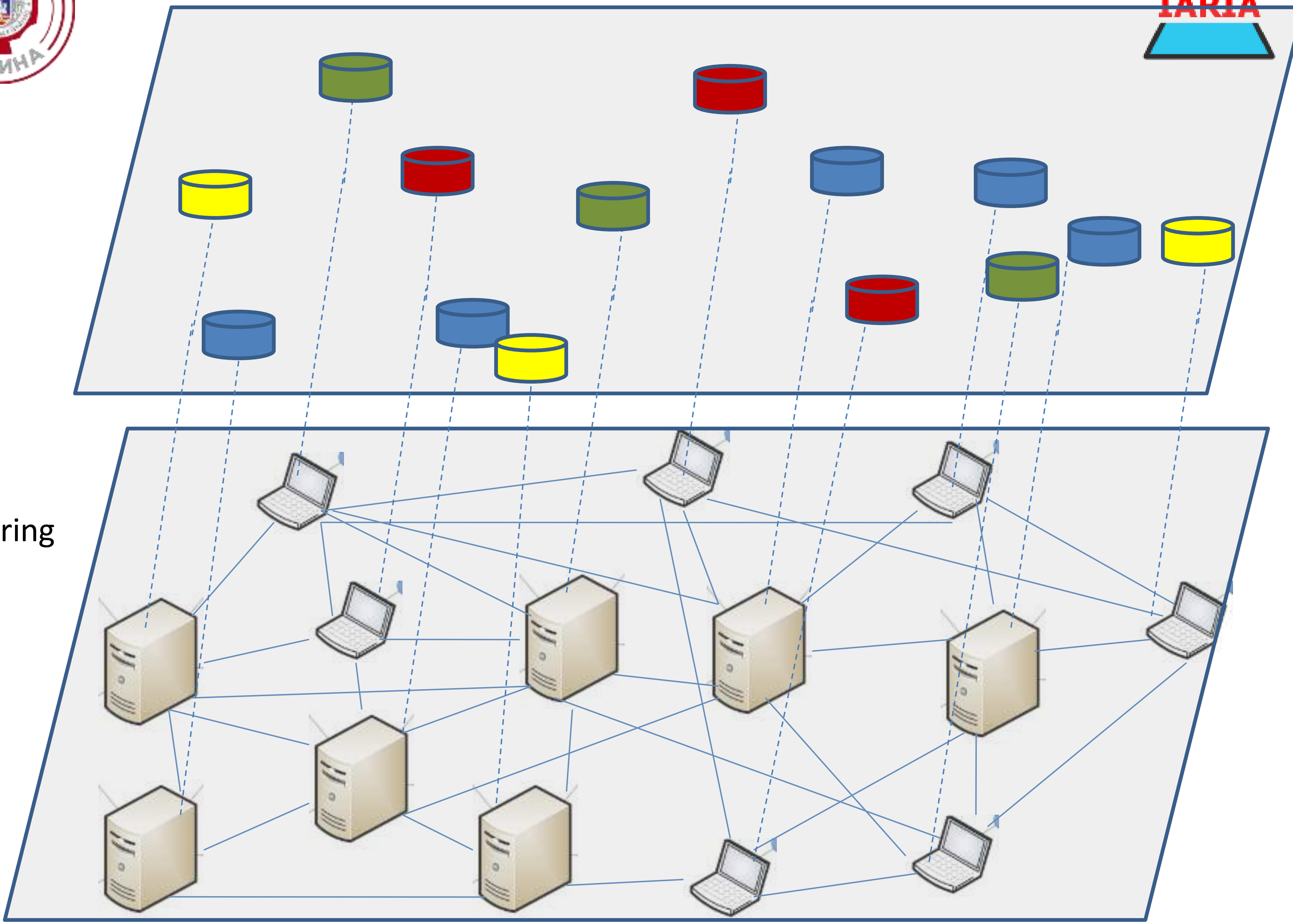


Fig. 5: Peer Clustering

SIPCA

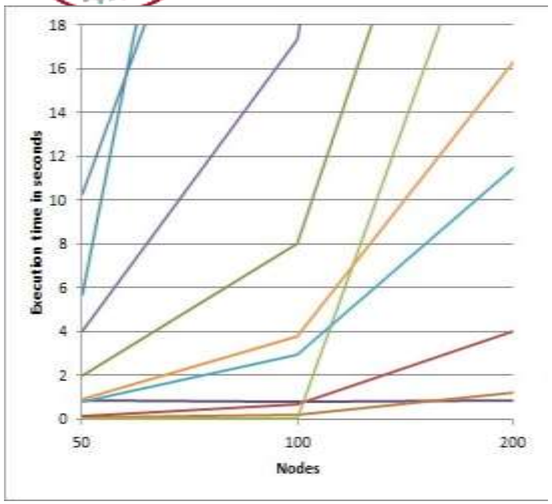
- **Self-Initiative Peer Clustering Agents** (SIPCA) [5] - a peer clustering framework for unstructured P2P networks.
- It allows plugging of different peer clustering algorithms with their easy exchangeability and enable systematic benchmarking and comparison of these algorithms.
- It is problem independent → it should be used to find the best suiting algorithm for a specific problem.

Algorithms applied

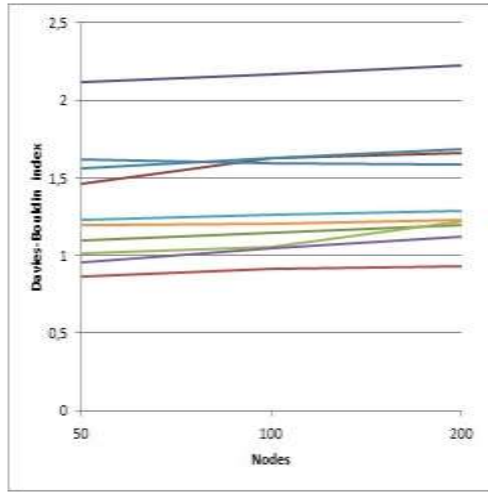
- The following conventional and swarm-based algorithms are competitively benchmarked, evaluated and compared [5]:
  - Slime Mold and Slime Mold K-Means, Artificial Bee Colony, Artificial Bee Colony combined with K-Means, Ant-based Clustering, Ant K-Means, Fuzzy C-Means, Genetic K-Means, Hierarchical Clustering, K-Means and Particle Swarm Optimization.
- The metrics used for the evaluation are [5]:
  - Execution time, the Davies-Bouldin index (DBI), the Dunn index (DI), the silhouette coefficient (SC) and Averaged Dissimilarity coefficient (ADC).

Comparison

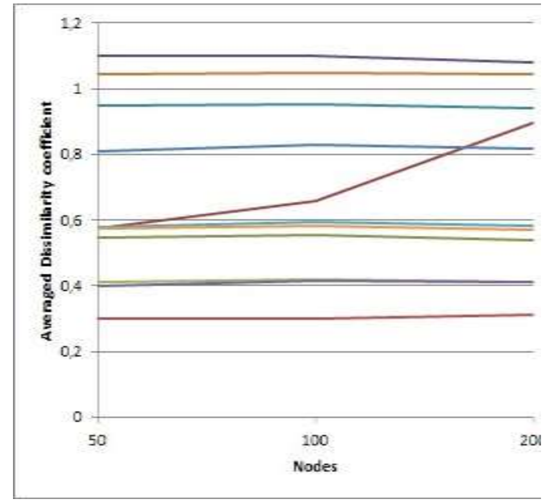
Execution time



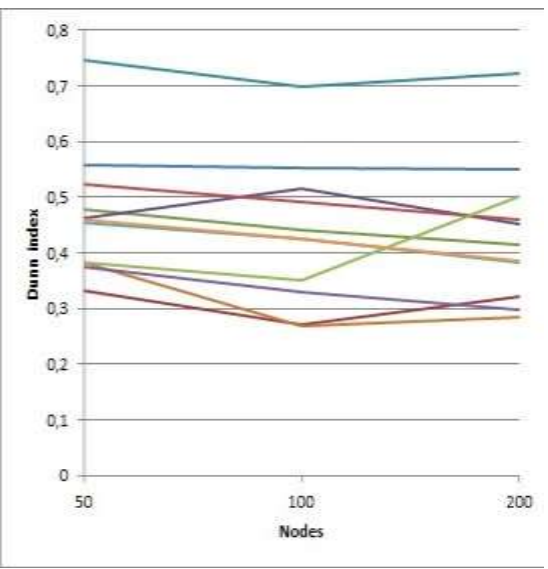
Davies-Bouldin



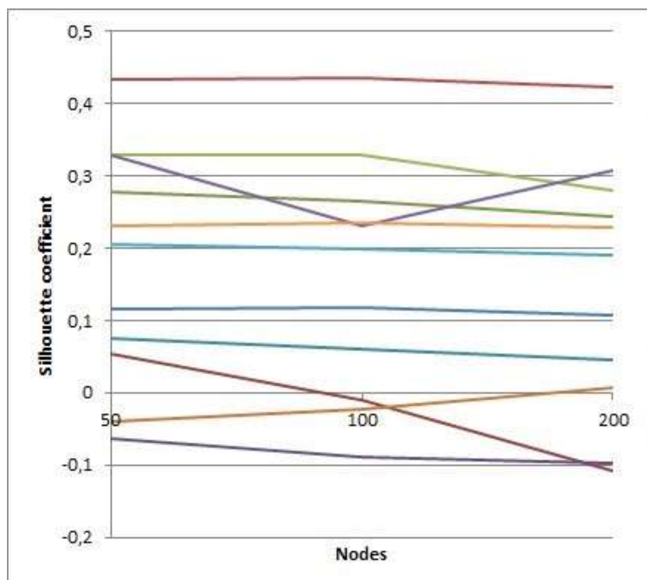
Averaged Dissimilarity coefficient



Dunn index



Silhouette coefficient



Legend

Results

use-case	**metric**	**the most successful algorithm(s)**
Peer Clustering	absolute time	Fuzzy C-Means, Ant-based Clustering, Hierarchical Clustering, Slime Mold and Slime Mold K-Means
	Davies-Bouldin index	Hierarchical Clustering
	Dunn index	Ant K-Means
	Silhouette coefficient	Hierarchical Clustering
	Averaged Dissimilarity coefficient	Hierarchical Clustering

Results

- Slime Mold and Slime Mold K-Means scale very well regarding execution time and effectiveness.
- Those two algorithms never provide unwanted massive variation in clustering effectiveness results.
- Hierarchical Clustering algorithm outperforms all other implemented algorithms.
- A combination of Slime Mold with Hierarchical Clustering → Hierarchical Clustering algorithm thoroughly provides top results in terms of time and effectiveness.

Summary – Challenges (1)

- Huge complexity → one of the main characteristics of nowadays distributed systems.
- Intelligent metaheuristics support optimization and robustness of highly dynamic distributed systems.
- The problem of fair comparison and evaluation of different approaches that use different metaheuristics with a huge number of parameters

Summary – Challenges (2)

- One of the prominent challenges in the P2P data management is the problem of clustering.
- We can differentiate between two similar scenarios: data → load clustering & peer clustering
- Requirements on the evaluation methodology [8,9]:
  - Provisioning of a general framework
  - Composability of the architecture
  - Autonomy and Self-Organizing Properties
  - Support of arbitrary configurations
  - Benchmarking in different environments
  - Possibility of reconstructing the solution

Summary - Perspectives

- A methodology for the evaluation of set of algorithms (conventional, swarm-based, etc.) in distributed systems [8]:
  - a high-level abstraction of the problem's communication in form of composable, agent-based coordination patterns
  - generic and flexible components based on these patterns
  - a framework as a composition of components
    - flexibly exchange of algorithms through "plugging"
  - identification of configuration and evaluation parameters
  - systematic evaluation of different configurations of algorithms, topologies and parameters

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