SPONSORED BY THE
Federal Ministry
of Education
and Research

Freie Universität Berlin

Self-Organization in Distributed Semantic Storage System

Anne Augustin, Sebastian Koske, Marko Harasic, Hannes Mühleisen, Philipp Obermeier, Kia Teymourian, Robert Tolksdorf

{frirstname.lastname}@inf.fu-berlin.de

Presenter: Kia Teymourian

Freie Universität Berlin

Department of Mathematics and Computer Science

Networked Information Systems

http://digipolis.ag-nbi.de

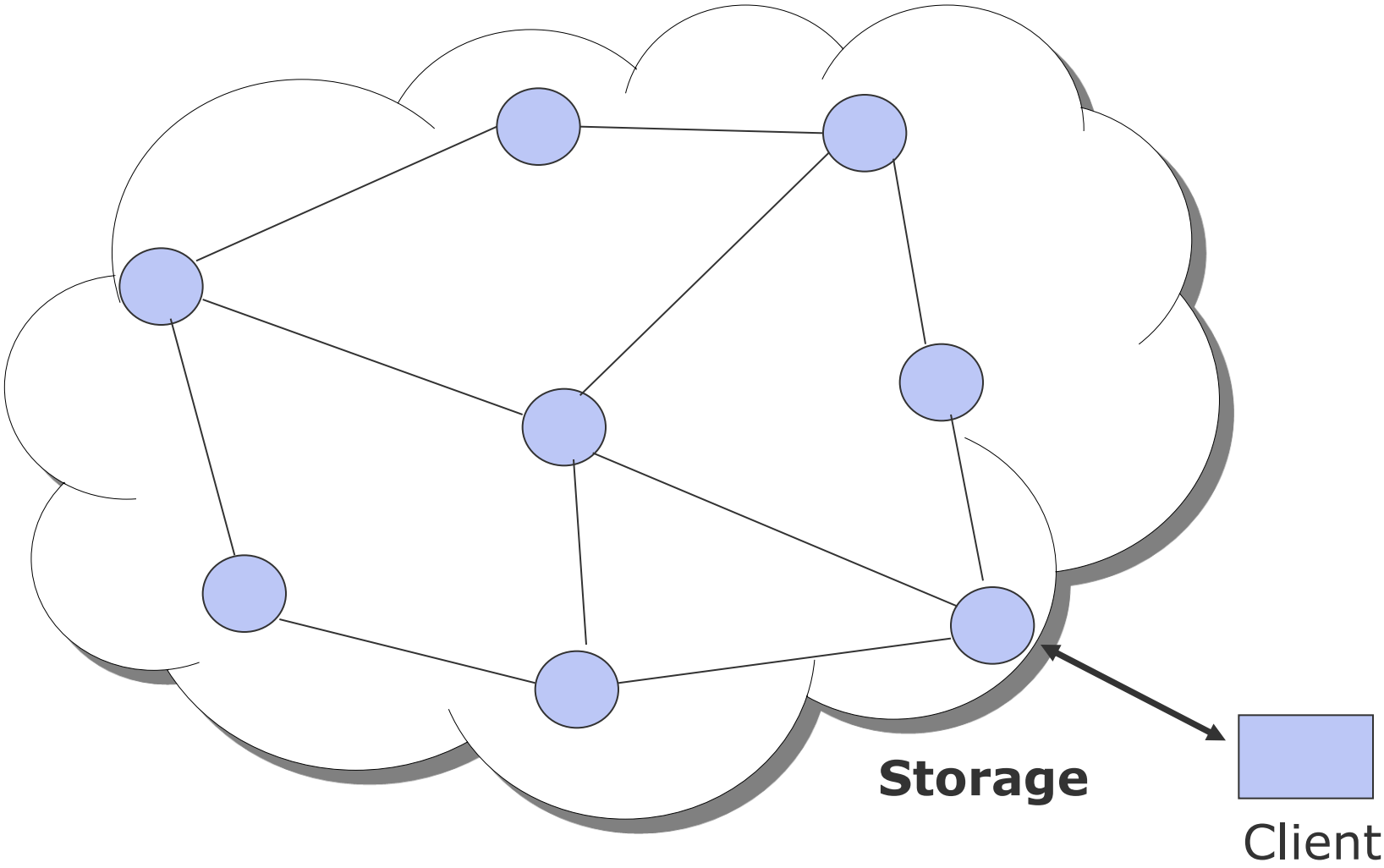
Motivation

- Semantic Storage Service
  - General Requirements
    - ***High Scalability,***
    - **Reliability,**
    - **Resilience,**
    - **Inexpensiveness ,**
    - **Simplicity,**
    - **Security,**
    - **etc ...**
  - Semantic requirements
    - **Reasoning**
    - **Optimized Metadata Storage**

SPONSORED BY THE
Federal Ministry
of Education
and Research

Storage Service

Freie Universität Berlin



State of the Art

	Store	*Description*		*#Triples*
centralized	Virtuoso	No reasoning, proprietary		1.0 B [9]
	AllegroGraph	RDFS supported, proprietary		1.1 B [16]
	Jena TDB	No reasoning, open source		1.7 B [31]
	OWLIM	RDFS / OWL-Lite supported, proprietary		12 B [26]
		Overlay Network	*Routing Cost*	
distributed	Edutella	Flooding	$O(N)$	-
	S-RDF	Restricted Flooding	$O(N)$	-
	RDFPeers	CHORD DHT	$O(log(N))$	-
	YARS2	unspecified DHT	$O(N)$	6.8 B [14]
	GridVine	P-Grid	$O(log(N))$	-

- Existing Distributed Storage Systems have some difficulties to scale out
- Billion triple challenge
  - DBpedia consists about 0.5 billion RDF triples
  - In future, billions , trillions, quadrillions, etc ...

The Self-Organized Semantic Storage Service (S4)

SPONSORED BY THE
Federal Ministry of Education and Research

Swarm Intelligent

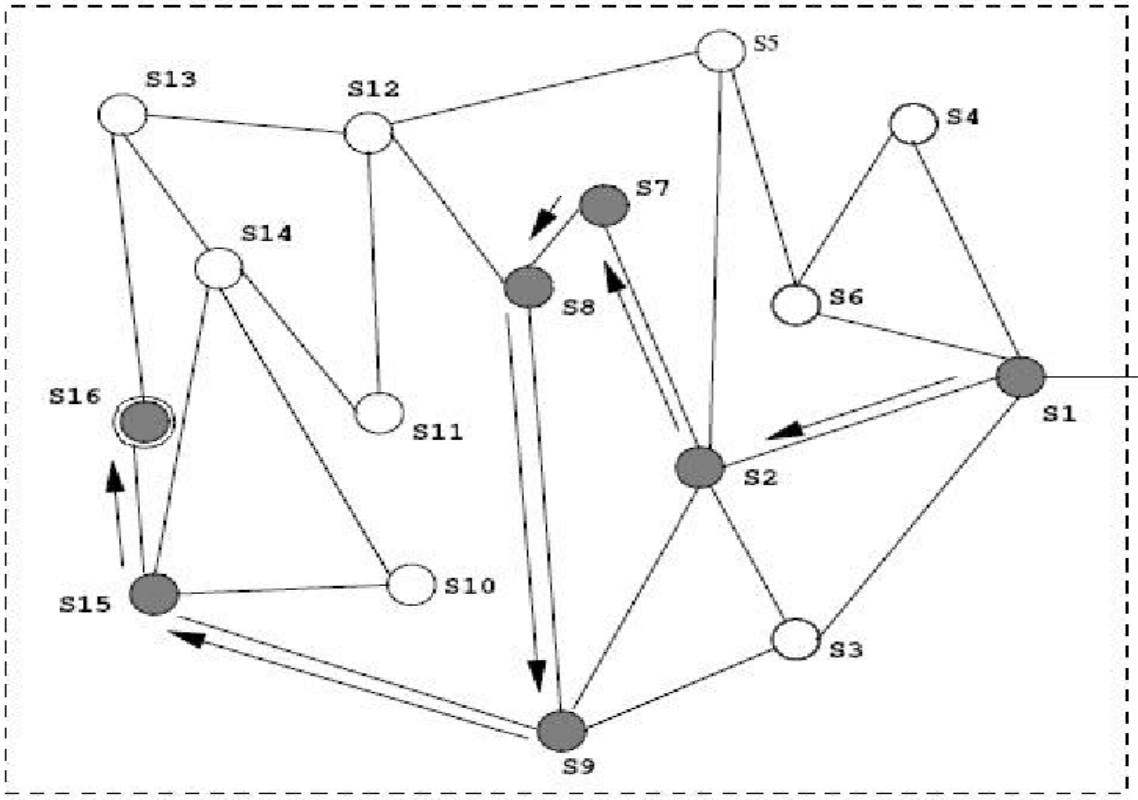
Freie Universität Berlin

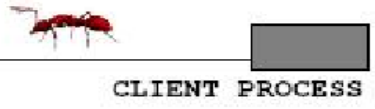
Swarms:

- -Simplicity
- -Dynamism
- -Locality

Idea

- Operations are represented by ants
- Nodes can be ant colonies, ant hills
- Ants carry data chunks/queries

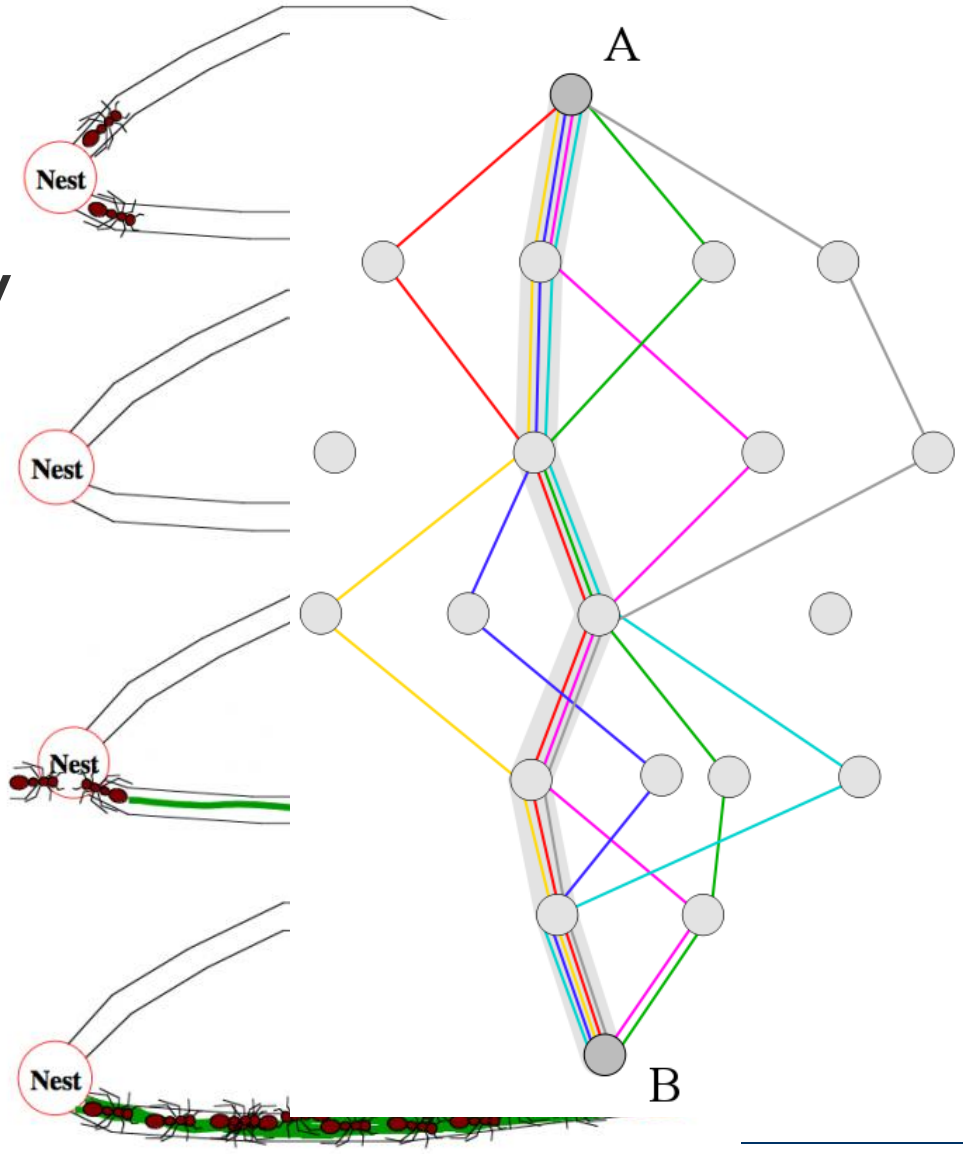




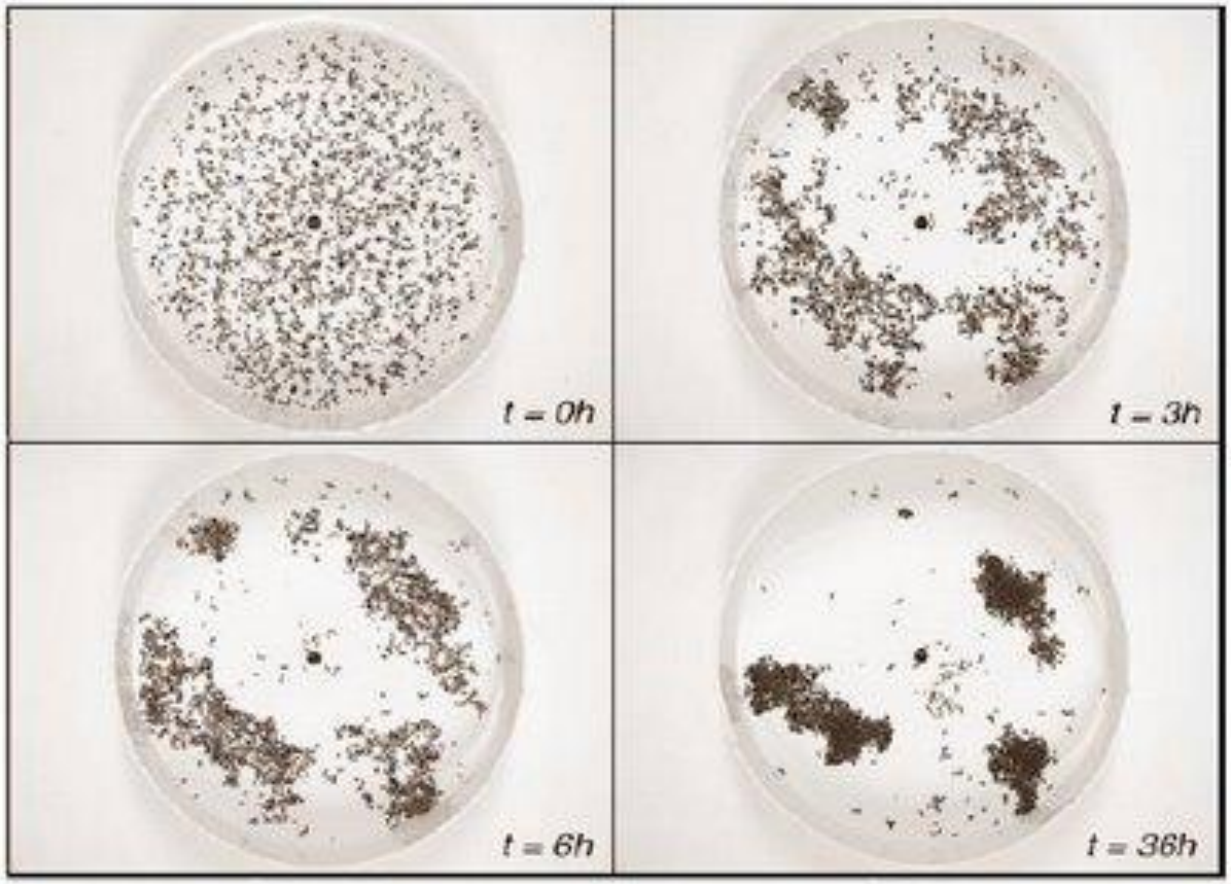
Data are considered as brood or food

1. Ant Foraging

Ants are collectively able to find the shortest path between a food source and the nest.



2. Ant Brood Sorting



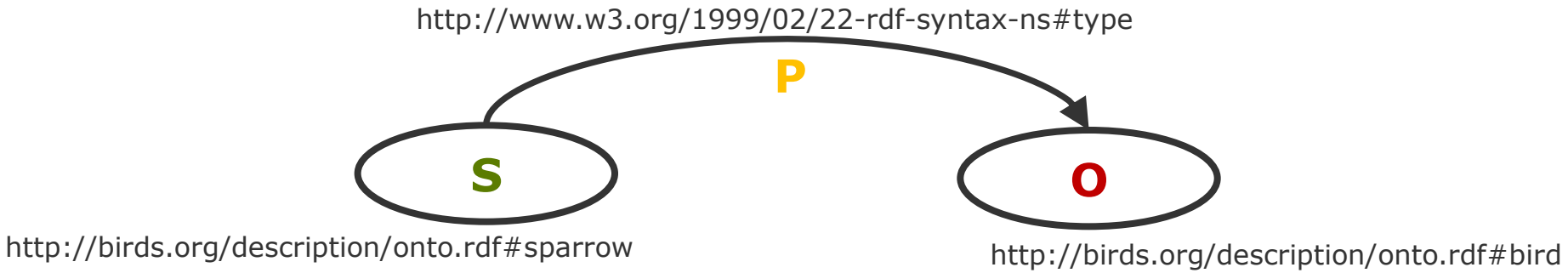
Lumer, E. D. and Faieta, B. 1994. Diversity and adaptation in populations of clustering ants. In *From Animals To Animats 3*, pp. 501-508.

Algorithms

Semantic Data - RDF

- RDF (Resource Description Framework)
  - Language to represent knowledge in a formal way
  - RDF-statements (RDF-triples) are primitive wich build a directed Graph

- RDF-triple <**S**ubject, **P**redicate, **O**bject>
  - Resource (**S**ubject) has a property (**P**redicate) with a value (**O**bject)
  - S and P have to be URIs; O can be an URI or a literal (e.g. integer)



- Basic Triple Pattern e.g. <?, ?, **O**>
  - Primitive for lookup operations
  - Finds all triples with same value in the field (e.g. all triples with **O** as object)

Write Triples

- Create three ants, one for each triple (S,P,O)
- Each ant carrying the triple and the corresponding field as ant-template

<S, P, O> ➔

S ➔
P ➔
O ➔

- These ants search the cluster by following the pheromone which matches the triple
- After storing the triple, the ant returns home and amplifies the pheromone on its way.

Write Algorithm


```
initialize age to a given integer value > 0

while age > 0 do
  if (drop probability currently high) then
    Drop triple, drop the scent of cluster-resource and
     in weaker quantity on the neighbor nodes and die
  else
    move to neighborhood node based on cluster-resource
    age = age - 1
  end if
end while
```

Drop triple, drop the scent of cluster-resource and
in weaker quantity on the neighbor nodes and die

Read Algorithm

- Create an ant carrying the fixed part of the Basic Triple Pattern as ant-template

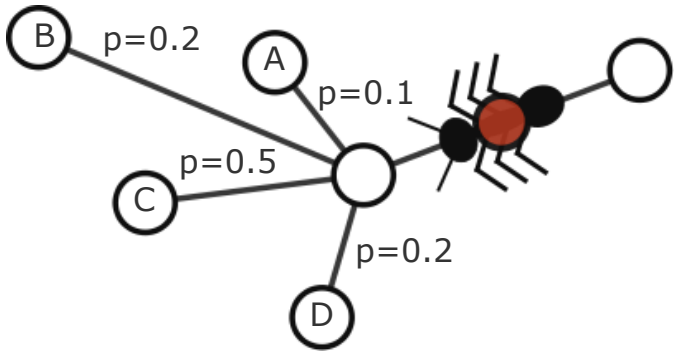
<?, ?, **o**> ➔ **o** ➔ 

- The ant follows the pheromone which matches the template and searches in the appropriate layer

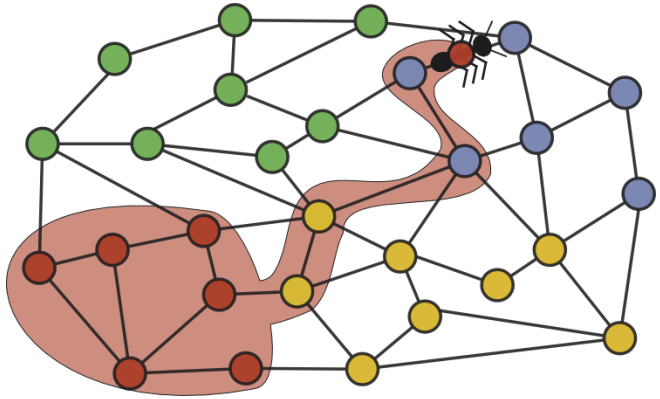
- When it finds a result, returns home carrying the result and amplifies the pheromone

Algorithms
Foraging

- Ants choose their next node
  - Only with local knowledge
  - At random
  - With the propability of each edge depending on the pheromone strength matching the carried template



- Ants leave pheromones on their way back, which evaporate over the time



Shortest paths to clusters emerge

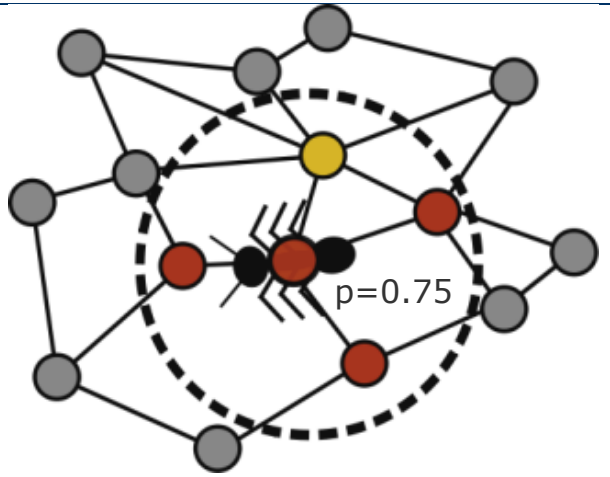
Read Algorithm

initialize *age* to a given integer value > 0

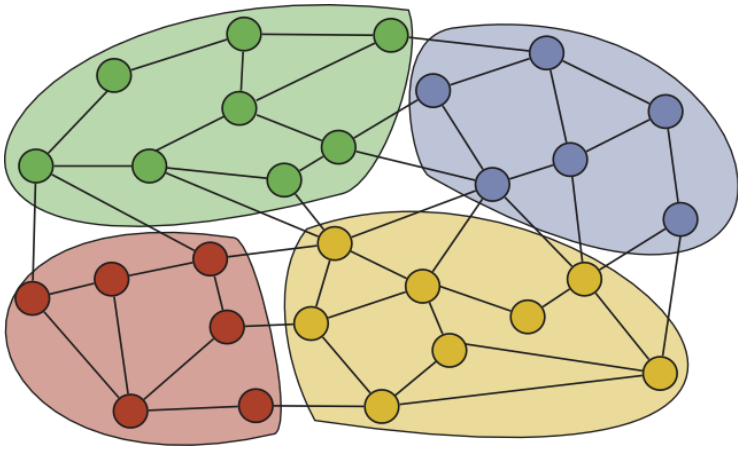
```
while age > 0 do
  add the current node to memory
  if (match found on current node) then
    make a copy and use memory to return to the origin. Leave scent of
     cluster-resource on each node on the way back with each hop in a
     weaker quantity.
    return the copy as result and die.
  else
    Move to neighborhood node based on cluster-resource
        age = age - 1
  end if
end while
die
```

Algorithms
Data Clusters, Brood Sorting

- Data is stored on a node
  - only with local knowledge
  - with a probability depending on the similarity of the data to the neighborhood
  - only if the similarity to the current node is over a threshold value



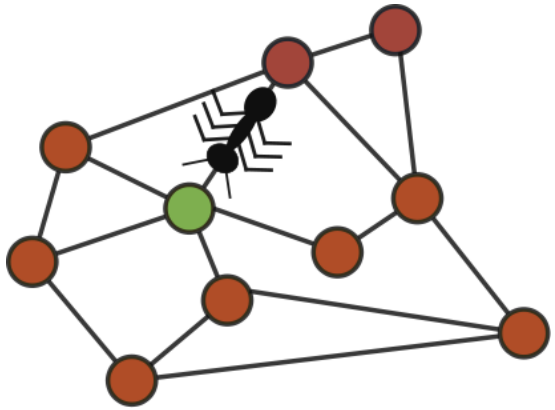
Creates clusters of similar data



- Clusters have to be maintained by moving misplaced data to its cluster

Algorithms
Brood Sorting (Cleaning)

- Misplaced data („corpses“)
- Special ants without template roam the network randomly and clean it from corpses



- If a corpse is found, it will be moved by a spawned *write-ant* carrying the corpse

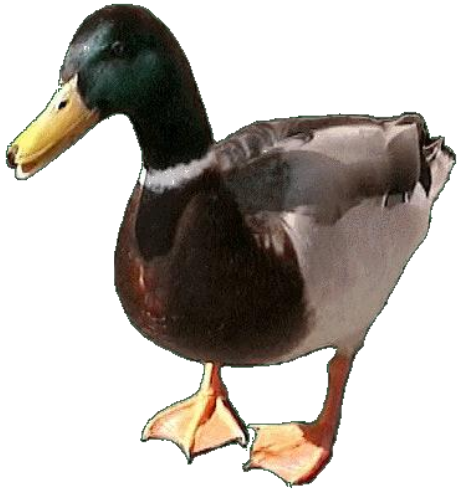
Leads to more homogeneous clusters und increases recall

Similarity Measurement

Similarity

- All creatures are equal…

… but some are more equal than others

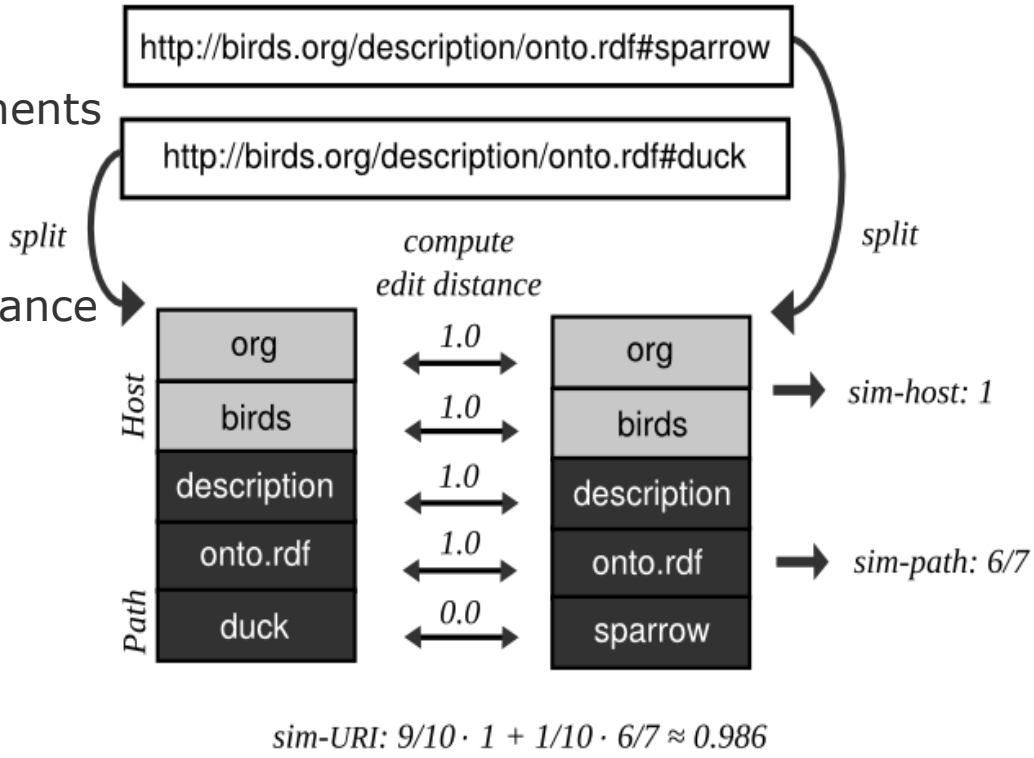


http://birds.org/description/onto.rdf#sparrow

http://birds.org/description/onto.rdf#duck

Similarity Measures
URI Similarity

- Idea: **Similar Things might have similar URIs**
- Algorithm :
  1. Split path and domain components of the URIs
  2. Compare parts of both URIs pairwise with Levenshtein distance
  3. Sum up the weighted results
  4. Similarity between the URIs is the sum

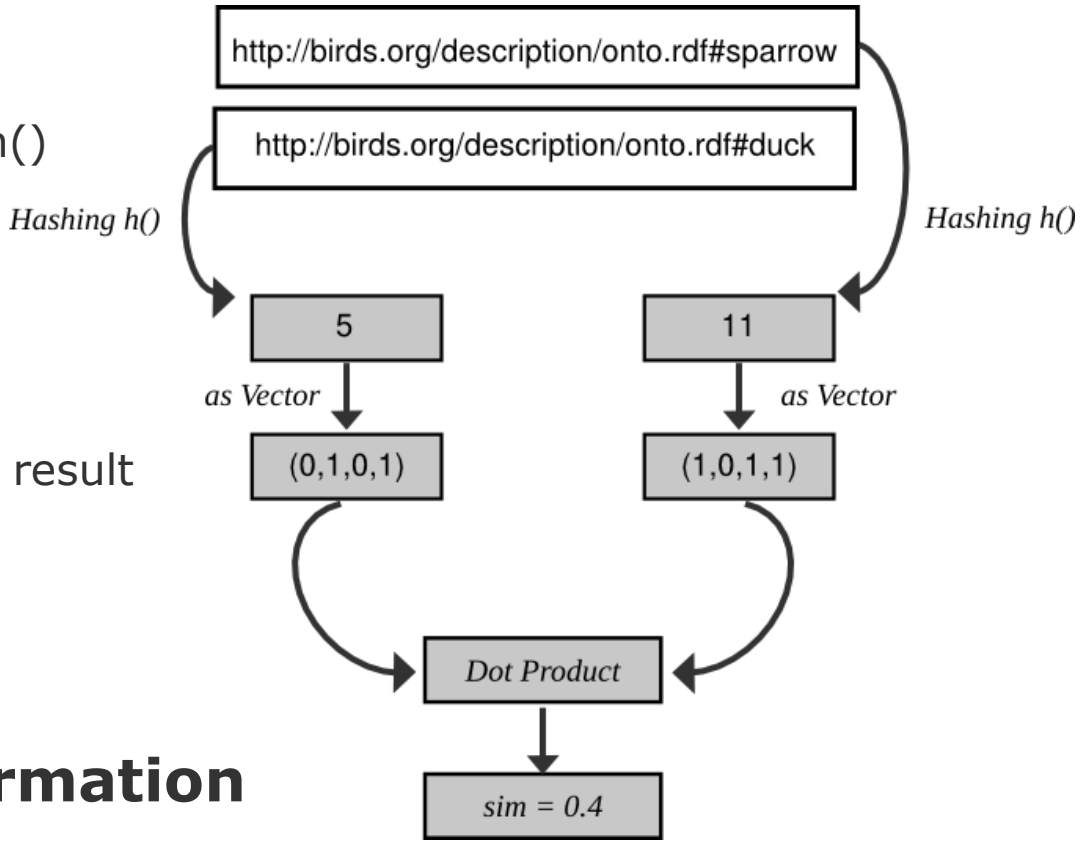


- No Ontological Semantic
- Clusters based on namespace scheme

Similarity Measures
Fingerprint Similarity

- Idea: String Hashing

- Algorithm :
  1. Hash the URI Strings with h()
  2. Interpret the values as bitvectors
  3. Compare the vectors with the dot-product
  4. Similarity is the normalized result



+ Very fast to compute

- Lost of semantic information

Semantic Clustering

- Similarity based on ontological knowledge

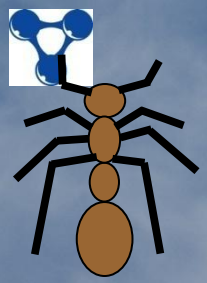
- Requirements and assumptions:
  - Only local decisions
  - No global ontology
  - Similarity measure operating on a fragment of an ontology

Semantic Clustering

- Extended behavior of out ants:
  - Carry triple and local type hierarchy
  - Type concentration on nodes determines responsibility for a certain type
  - Ants learn on their way and merge T-Boxes
  - Drop probability determined by similarity of type carried with type dominant on node

<cat,is-a,animal>
<dog,colored,white>

<bird,is-a,animal>
<cat,is-a,animal>



<cat,colored,grey>
<cat,is-a,type>
<cat,is-a,animal>
<bird,is-a,animal>
<dog,is-a,animal>

<dog,is-a,animal>
<dog,colored,brown>
<bird,colored,yellow>
<cat,is-a,animal>
<cat,colored,grey>

SPONSORED BY THE
Federal Ministry
of Education
and Research

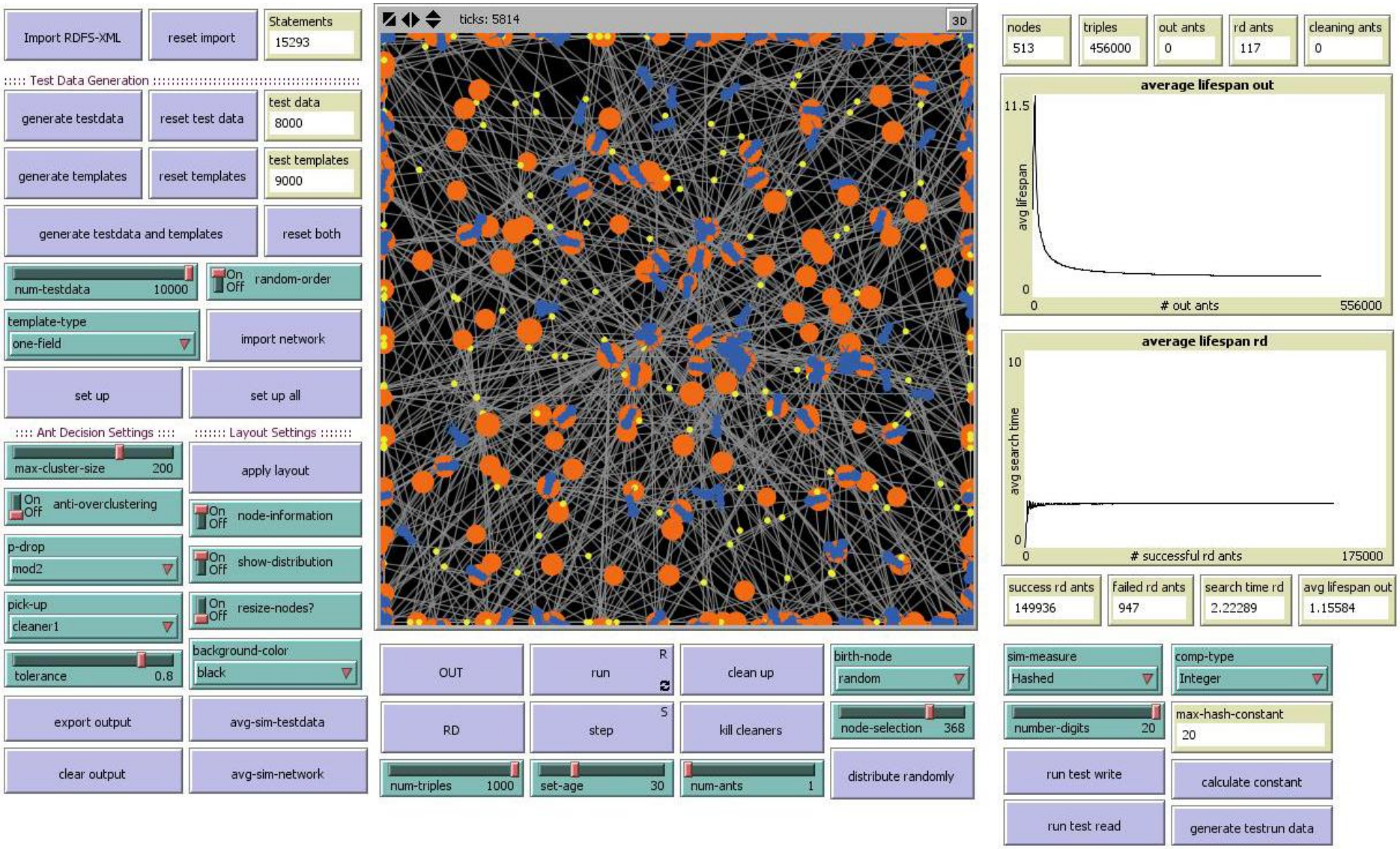
Freie Universität Berlin

Simulation
&
Implementation

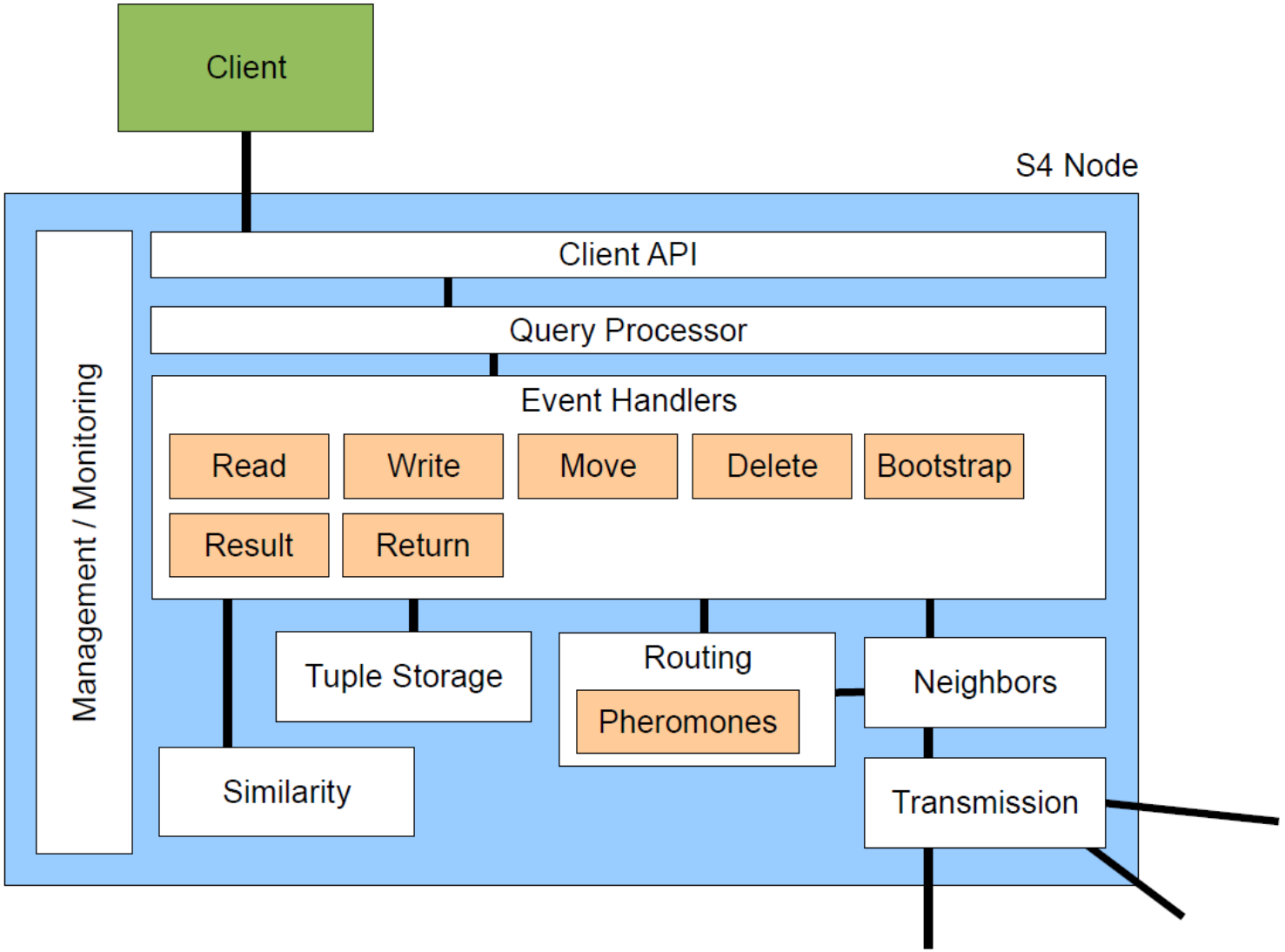
SPONSORED BY THE
Federal Ministry of Education and Research

Simulation

Freie Universität Berlin



Implementation, Architecture



Evaluation

Evaluation
Test environment

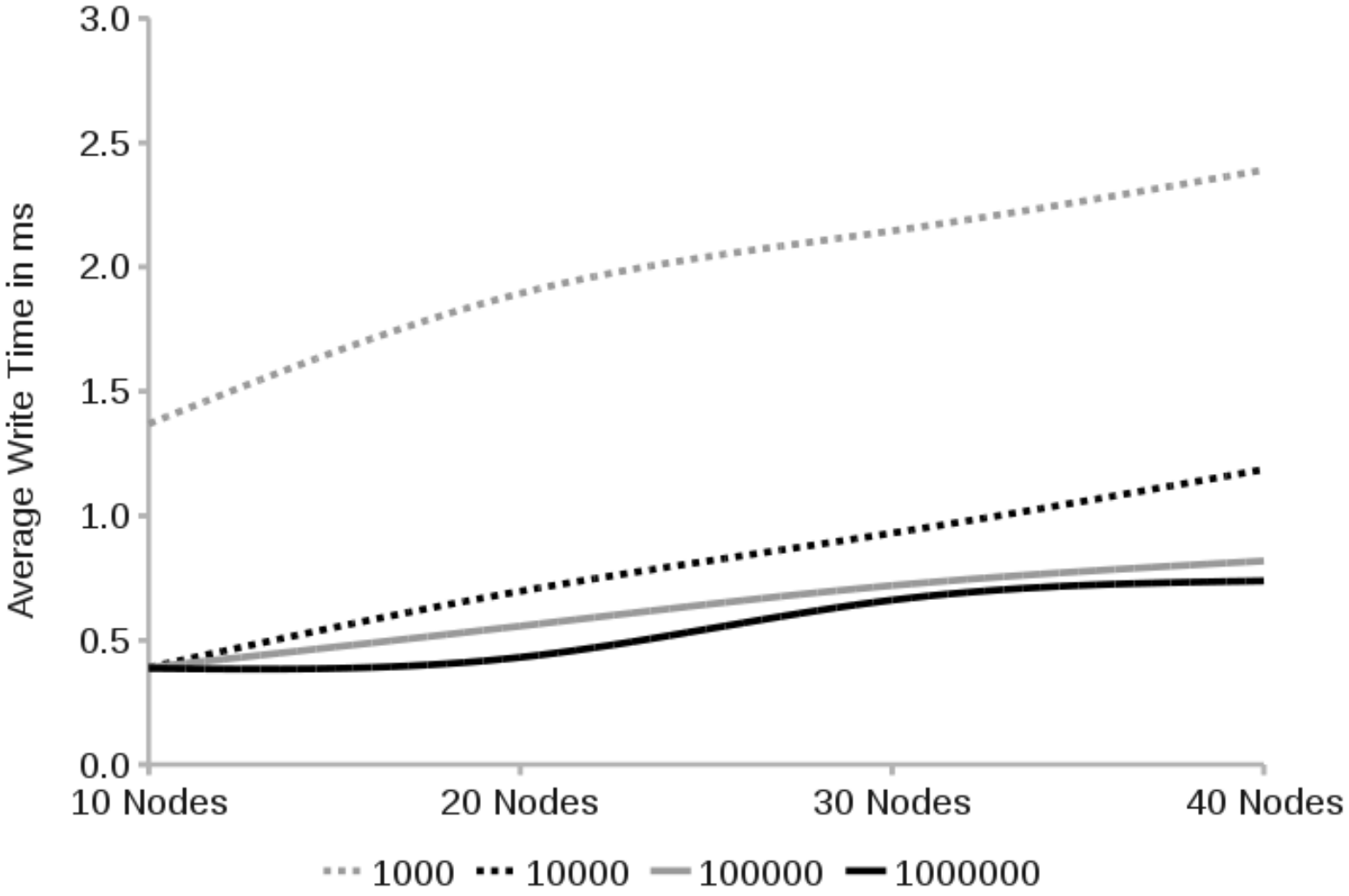
- First Beta Implementation
- 10 computers simulating 10, 20, 30, 40 nodes
  - Nodes form a random graph
  - No connected nodes on the same computer
- Test system

CPU	Pentium 4 2.4 Ghz
RAM	512 MByte
Network	100 MBit/s Ethernet
Operating System	Debian Linux Kernel 2.6.24
Java	1.5.0.17

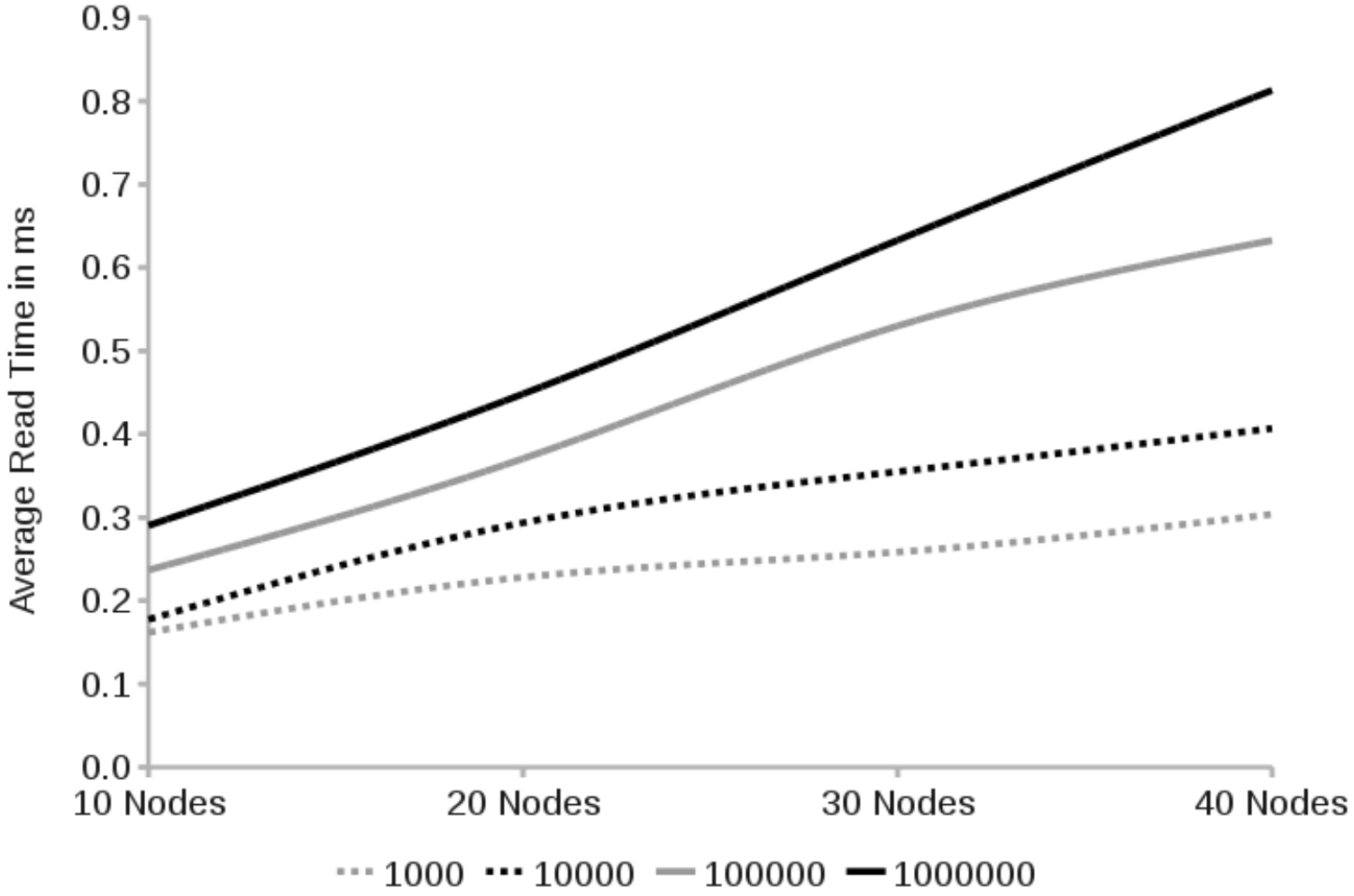
- Test data

Data Source	WordNet Ontology
Write	Sets of 1K, 10K, 100K, 1M triples
Read	10k random operations for each set

Evaluation
Write Operation



Evaluation
Read Operation



Future work

- Semantic Similarity
- Swarm-based Reasoning
- Efficient full SPARQL support
- Use geographical information to cluster even better

Conclusion

- We can use self-organization to cluster similar things, and build scalable storage service
- The evaluation of our initial Alpha implementation shows that such swarm-based storage system can scale out.

Thank You

Questions?

Image Reference

- http://newsitemstoday.today.com/files/2009/04/cat_and_dog_toxic_substances.JPG
- http://1.bp.blogspot.com/_TbfuMu7x3_s/SNrOuYUjxTI/AAAAAAAAAKA/f_s8I8bpyLI/s400/antclusterinicial.jpg
- http://onionesquereality.wordpress.com/2008/01/31/adaptive-routing-taking-cues-from-stigmergy/
- http://www.answers.com/topic/ant-colony-optimization
- http://upload.wikimedia.org/wikipedia/commons/1/17/Aco_shortpath.svg

SPONSORED BY THE
Federal Ministry
of Education
and Research

Freie Universität Berlin

Extra Slides

SPONSORED BY THE
Federal Ministry of Education and Research

URI Similarity

Freie Universität Berlin

- URI Similarity:
- Take pairwise Levenshtein-distance in host and path parts eg:

$$sim_{host} = \sum_{i=1}^{min(k,l)} c_i edit(m_{k-i}, n_{l-i})$$

- Weight components along their hierarchy, eg:

$$c_i = \frac{2^{max(k,l)-i}}{2^{max(k,l)} - 1}$$

- Weight host and path importance, eg. 0.9/0.1

- Cats and dogs are quite similar:

$$1 \cdot 0.9 + (\frac{2}{3} \cdot 1 + \frac{1}{3} \cdot 0) \cdot 0.1 = 0.9\overline{6}$$