

# Social insect constructions: functional insights from modern imaging techniques



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**ANR**

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CENTRE NATIONAL  
DE LA RECHERCHE  
SCIENTIFIQUE

# The **building abilities** of social insects

- Social insects build elaborate nests that can be extremely complex and whose size is several thousands times the size of a single individual



**Wasp nest (*Epipona tatua*)**



**Honeybee nest (*Apis mellifera*)**

# Large-scale nests



*Pogonomyrmex badius*

# Large-scale nests

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*Nasutitermes triodiae*

# X-ray tomography

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Tomographic scans are a powerful tool for the characterisation of complex 3-D structures.



- **non-destructive** (allowing to follow the growth of the structure).
- **quantitative** (size and position of individual elements can be recorded with high accuracy).
- **provide data in a digital format**, that can be automatically processed.

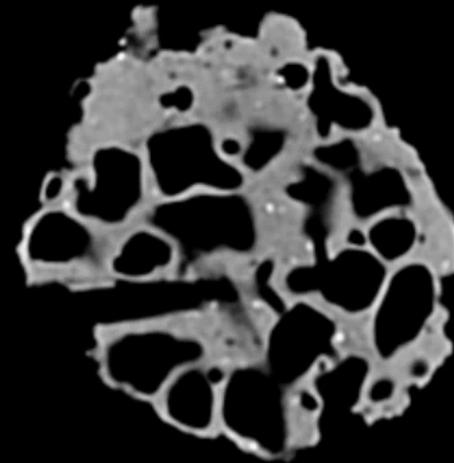
# X-ray tomography

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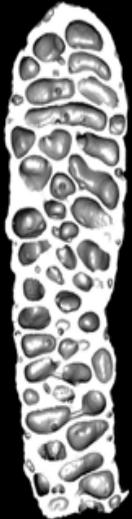
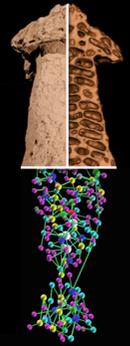
À l'aide de la tomographie aux rayons X nous avons pu visualiser la structure interne de plus de 60 nids de termites de différents espèces.



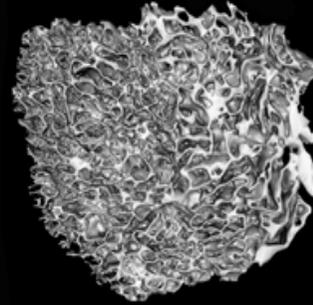
*Cubitermes sp.*



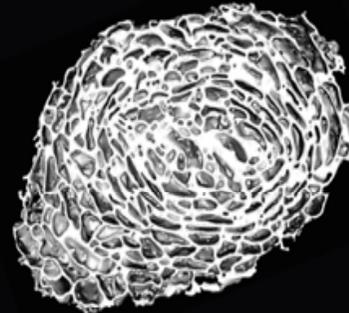
# A large variety of structures



*Thoracotermes* spp.



*Nasutitermes* spp.



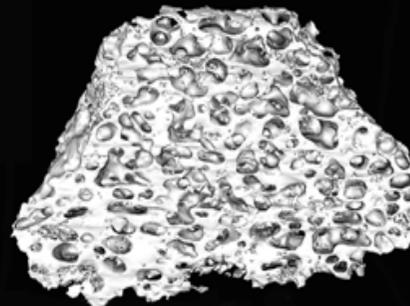
*Microcerotermes* spp.



*Apicotermes lamani*

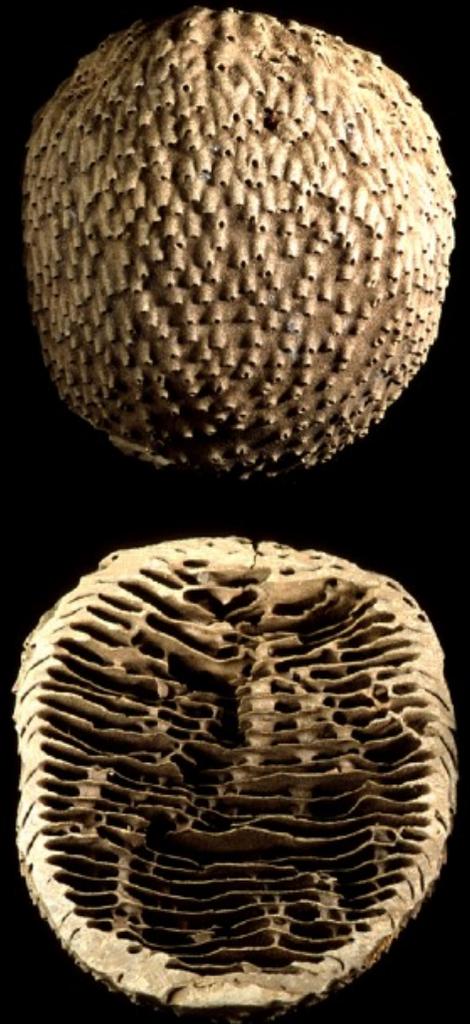


*Cubitermes* spp.



*Lasius niger*

# Visualization of structures



*Apicotermes* sp.

Movie realized by Guy Theraulaz and Fabien Picarougne

# Termitinae nests

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*Thoracotermes macrotorax*



*Cubitermes* sp.



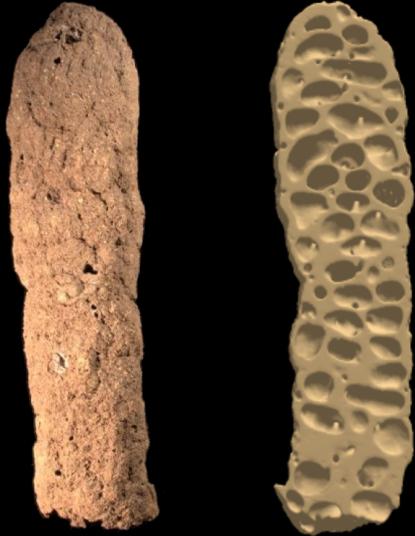
*Procubitermes sjoestedti*



*Noditermes curvatus*

# Visualization is not sufficient

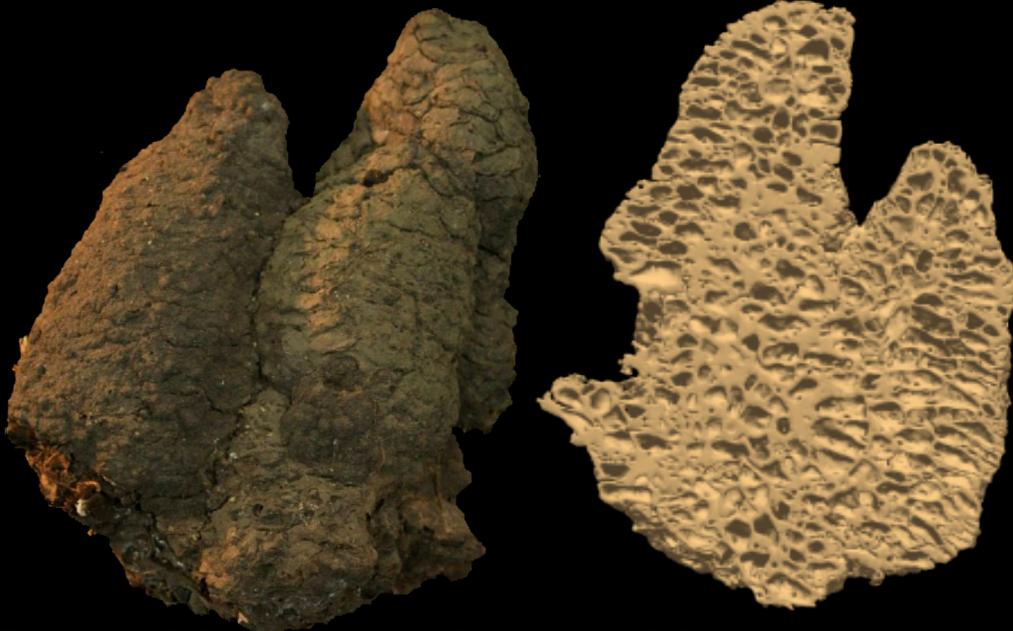
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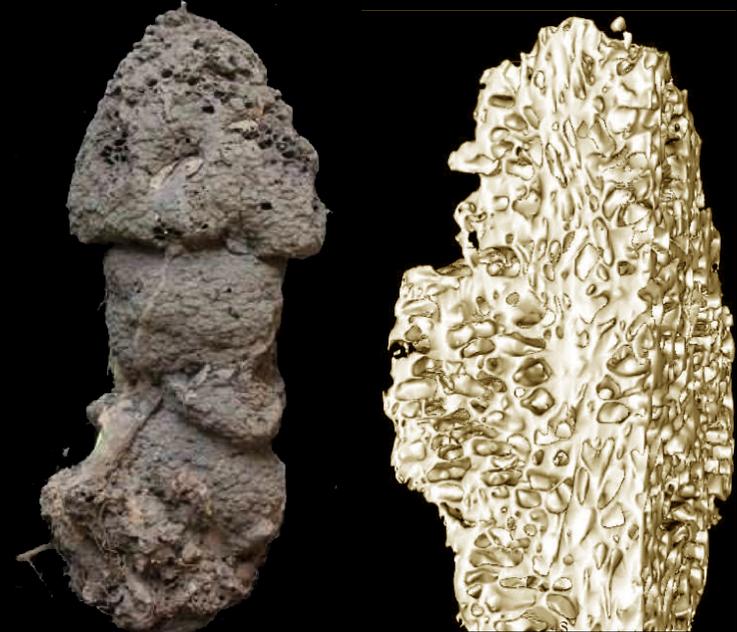
*Thoracotermes macrotorax*



*Cubitermes* sp.



*Procubitermes sjoestedti*



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# Simplifying termite nests

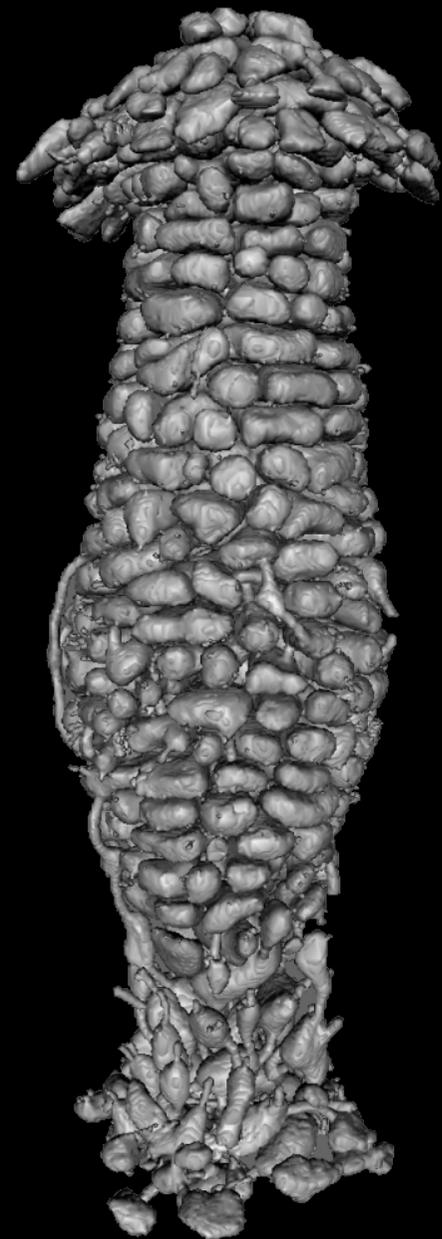
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*Cubitermes* sp.

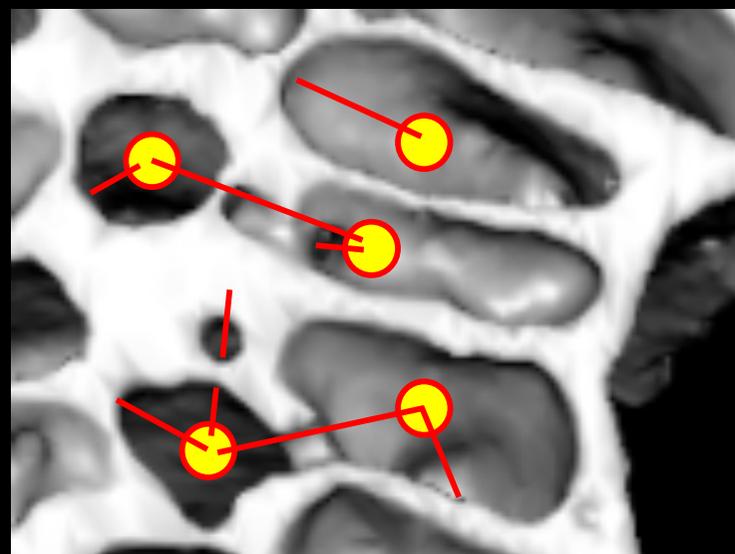
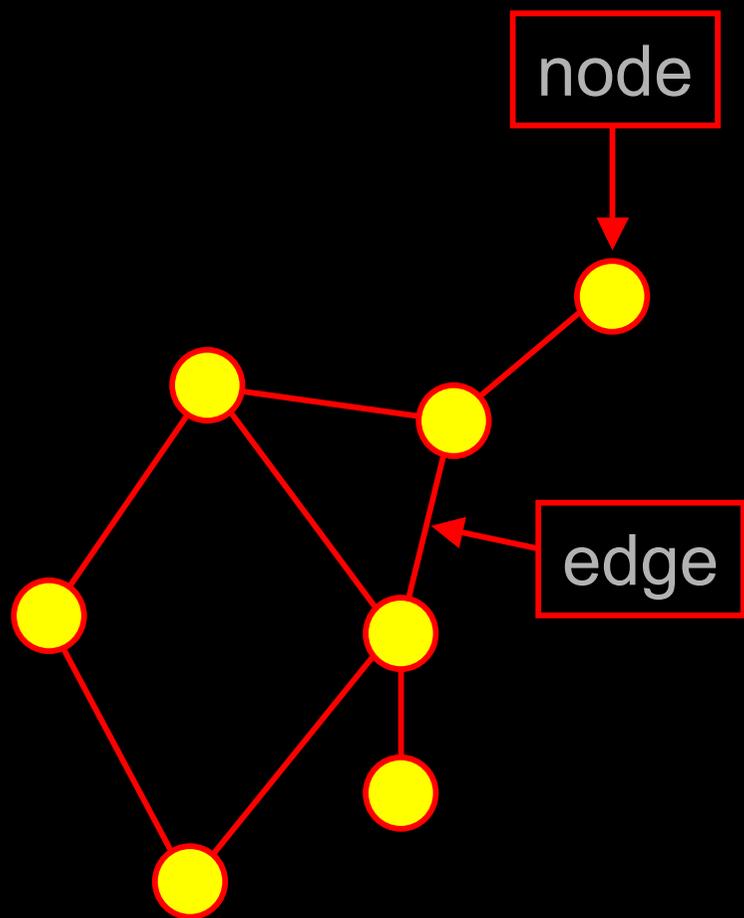
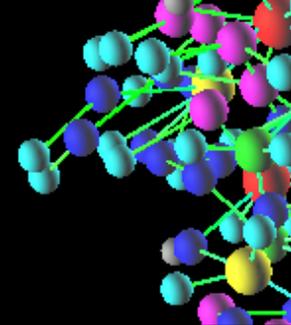
# Simplifying termite nests

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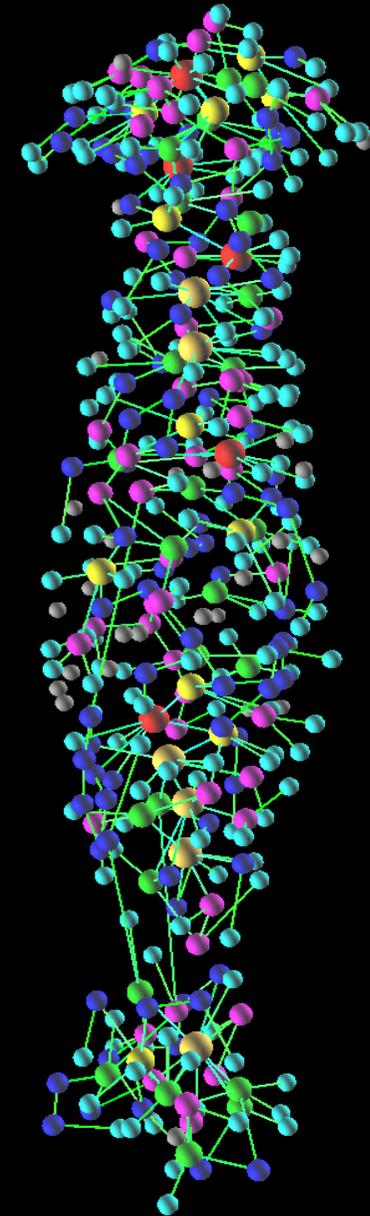
***Cubitermes* sp.**

# Social insects nests as communication networks



# Social insects nests as communication networks

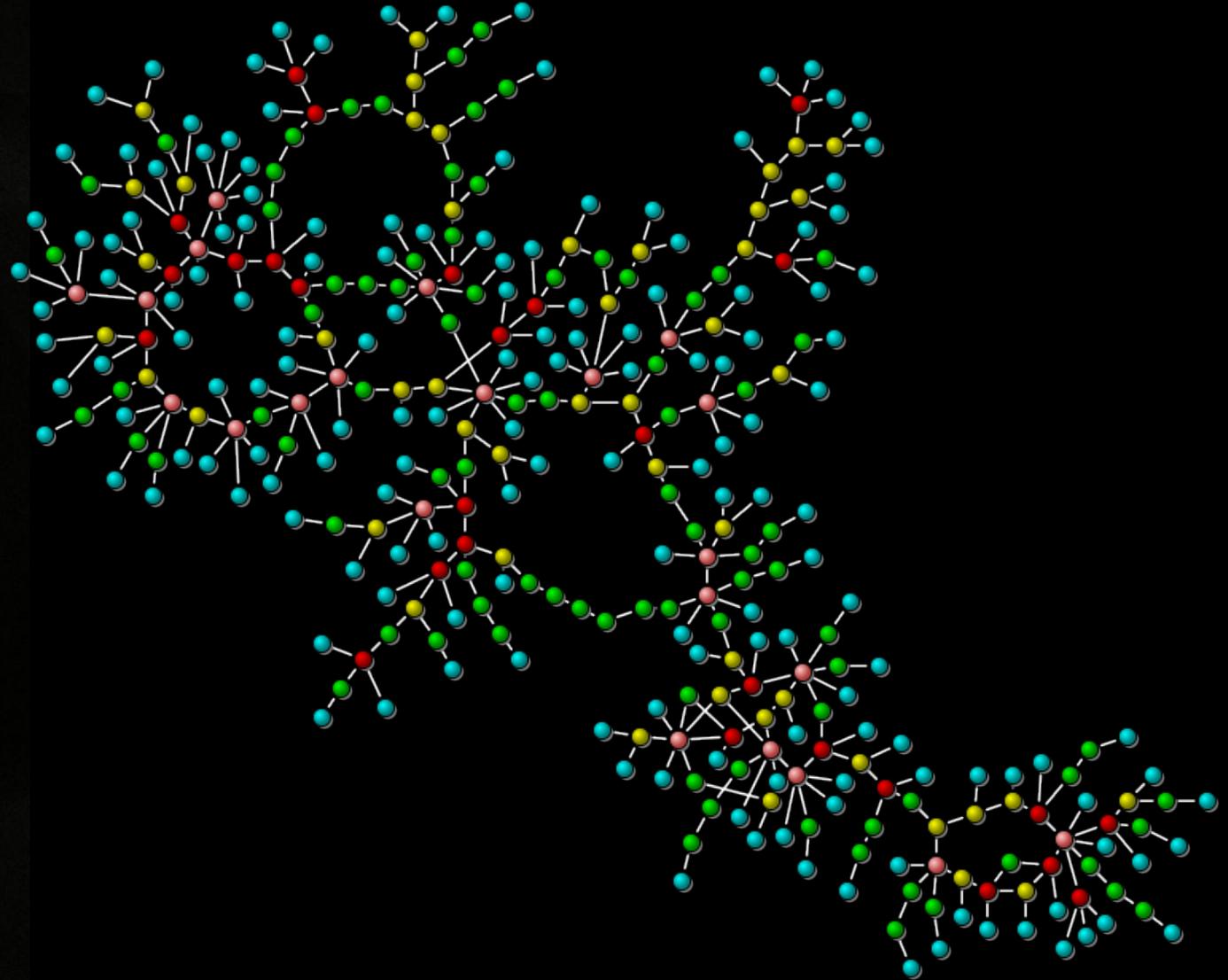
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*Cubitermes* sp.

# Social insects nests as communication networks

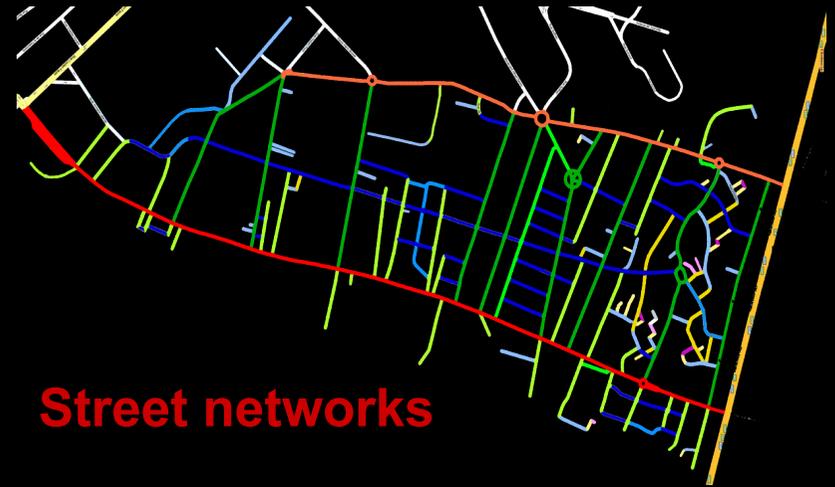
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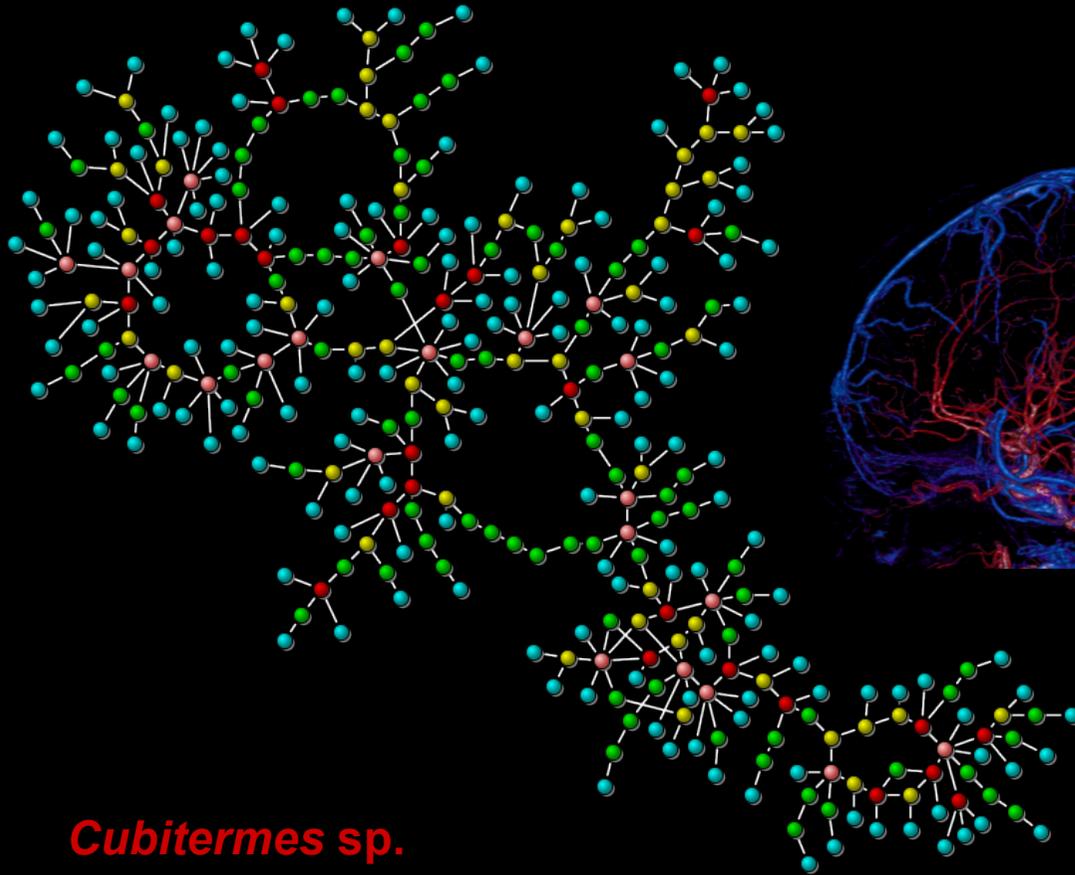
*Cubitermes* sp.

# Social insects nests are communication networks

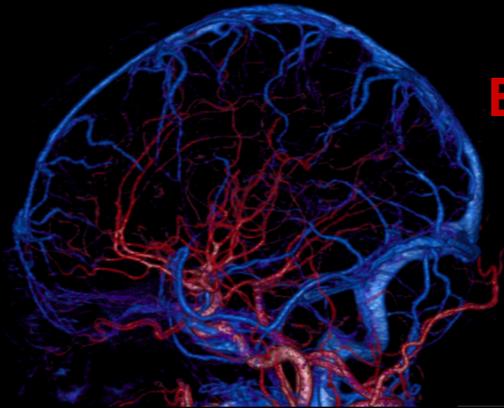
The representation of termite galleries as networks, gives access to a variety of tools developed in the field of graph theory to describe different types of interaction networks.



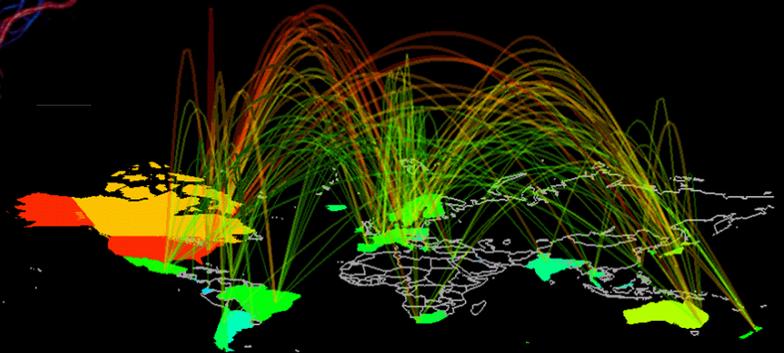
Street networks



*Cubitermes* sp.



Blood vessels



The internet

# From local to global properties

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**Local**

**Intermediate**

**Global**



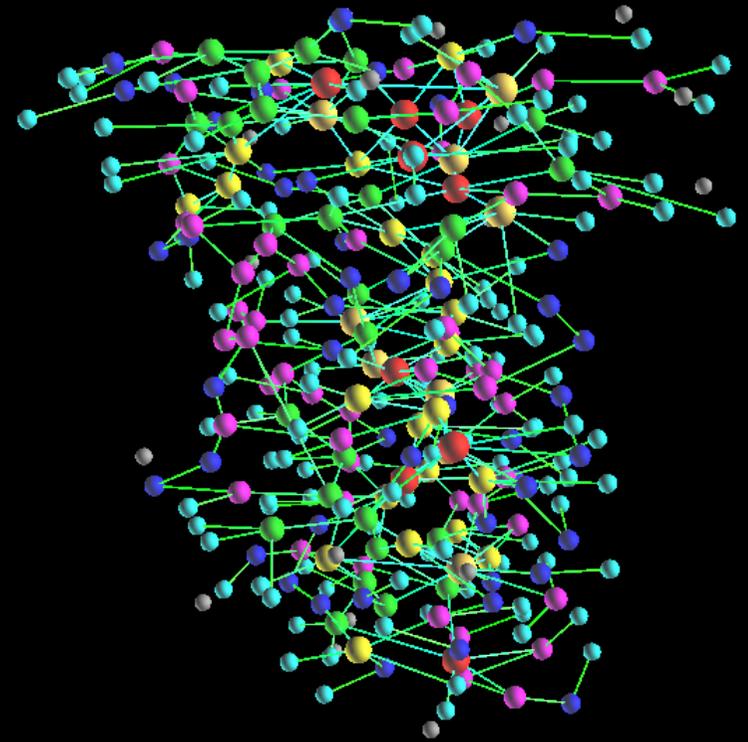
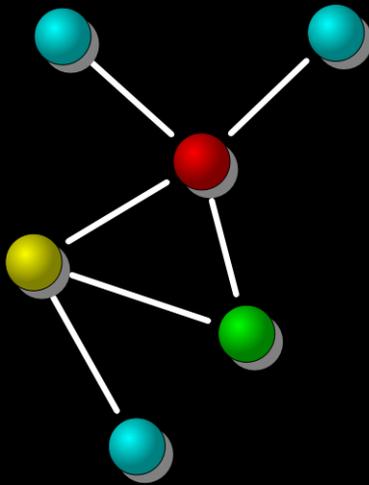
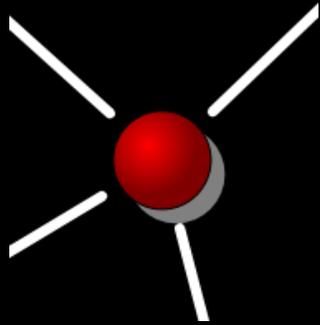
# From local to global properties

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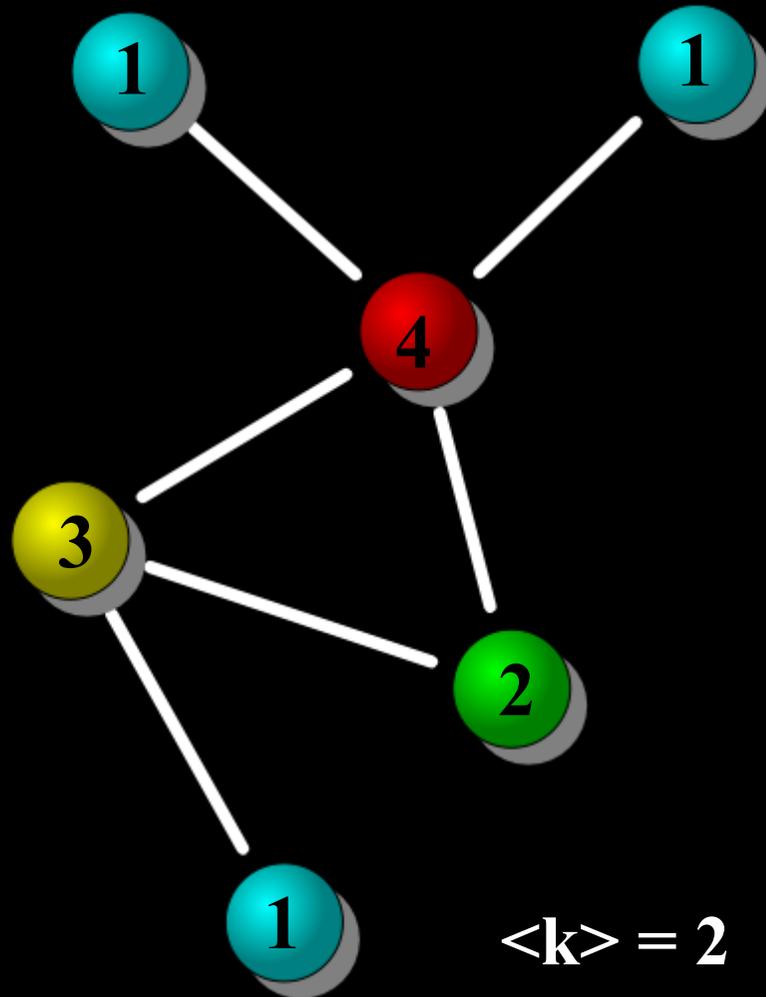
**Local**

**Intermediate**

**Global**



# Node degree



The degree of a node is the number of nodes it is connected to.

The average degree of a network is:

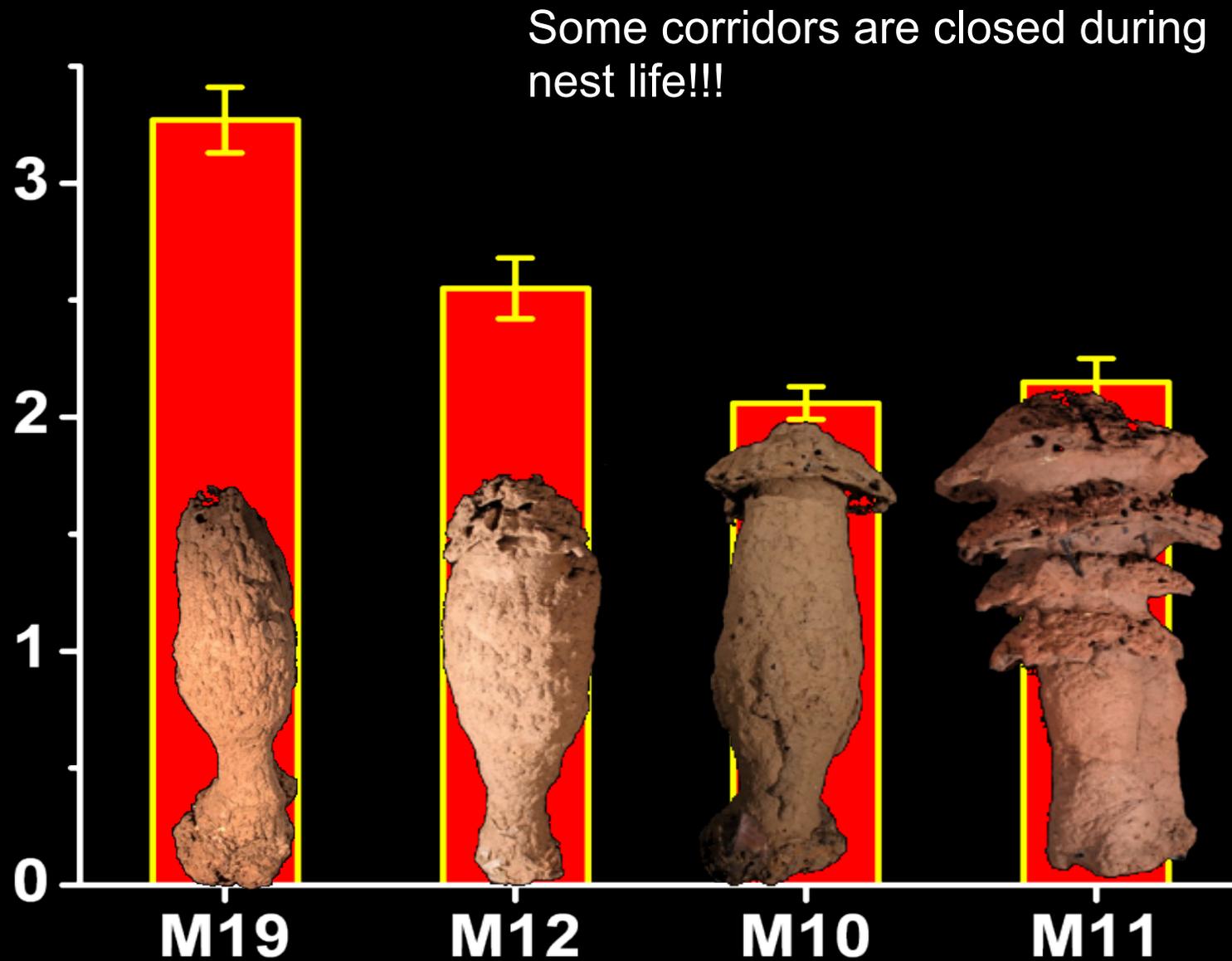
$$\langle k \rangle = \frac{1}{N} \sum_i k_i$$

# Nest age and size

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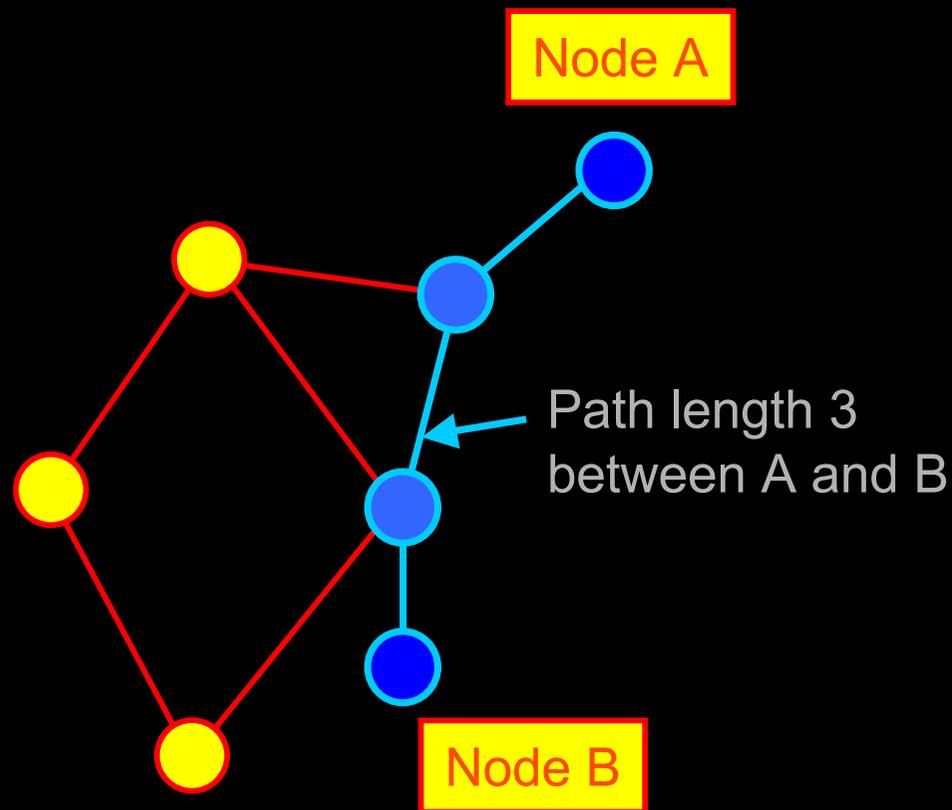


# Average node degree



# Average path length ( $L$ )

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The average path length of a graph is the mean length of the shortest path between any couple of nodes.

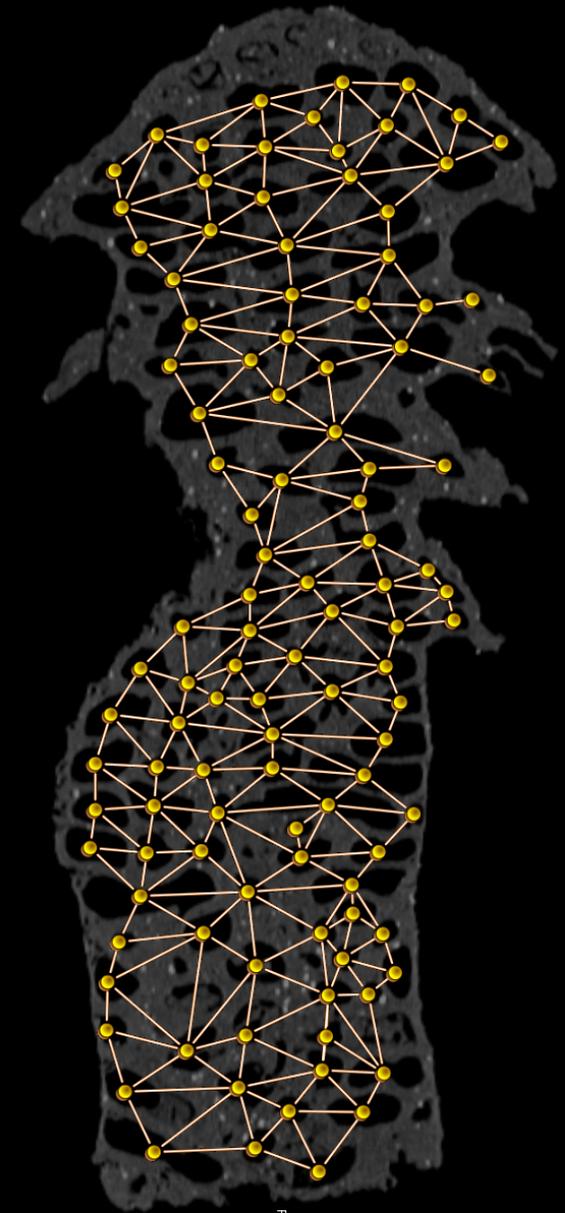
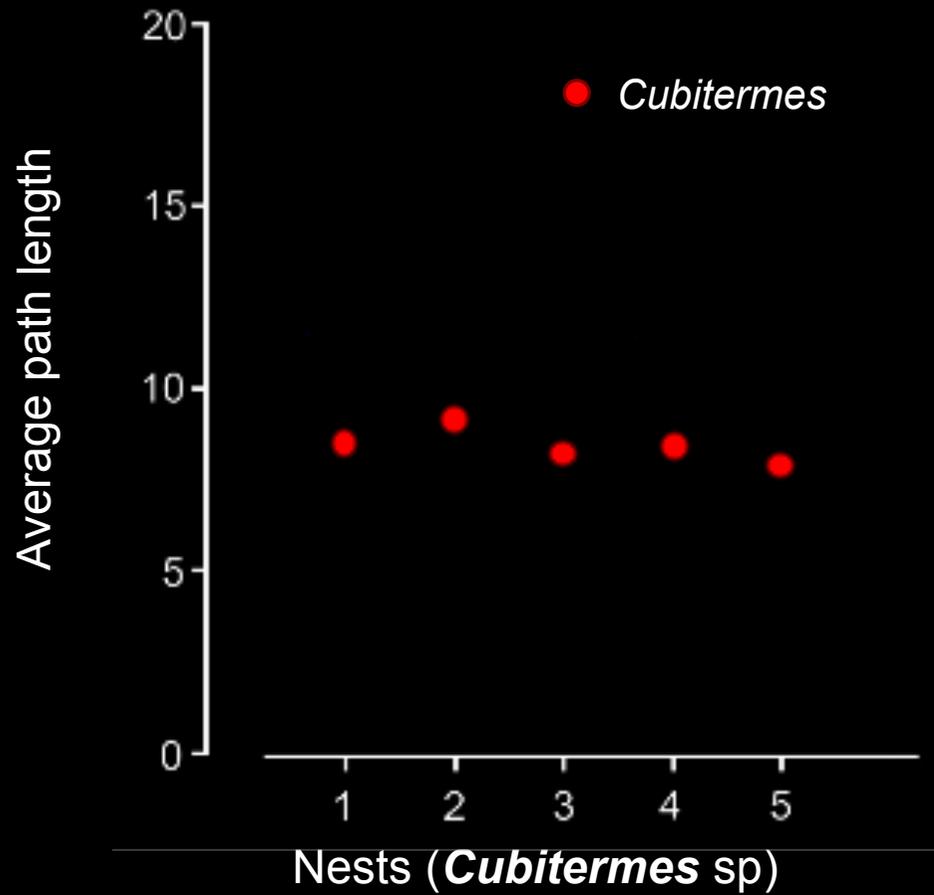
$$L = \frac{1}{N(N-1)} \sum_{i,j} d_{i,j}$$

The shorter is the path length, the more efficient are displacements inside the network

# Average path length ( $L$ )

Global

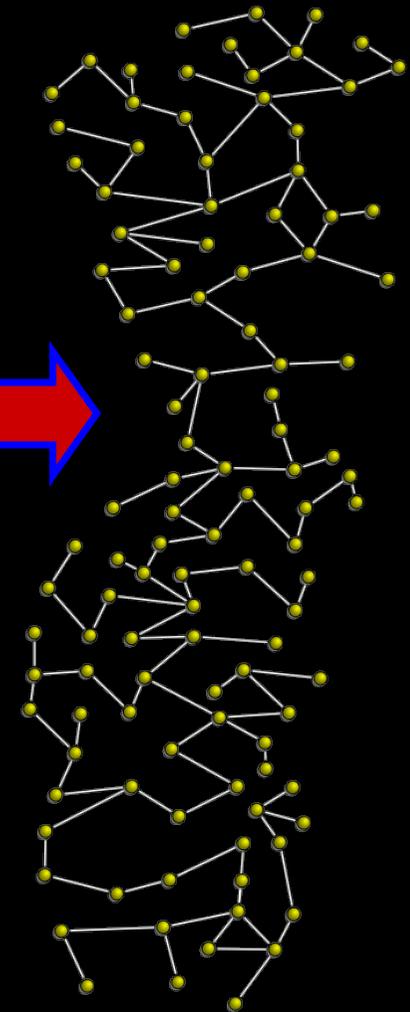
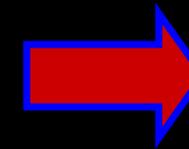
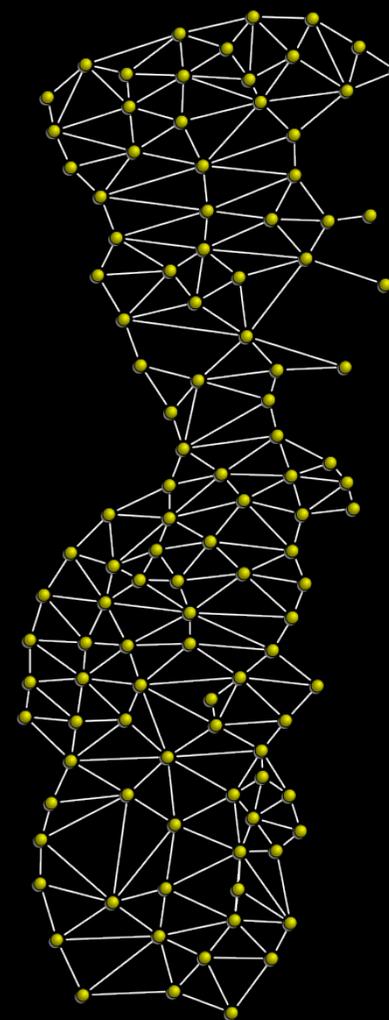
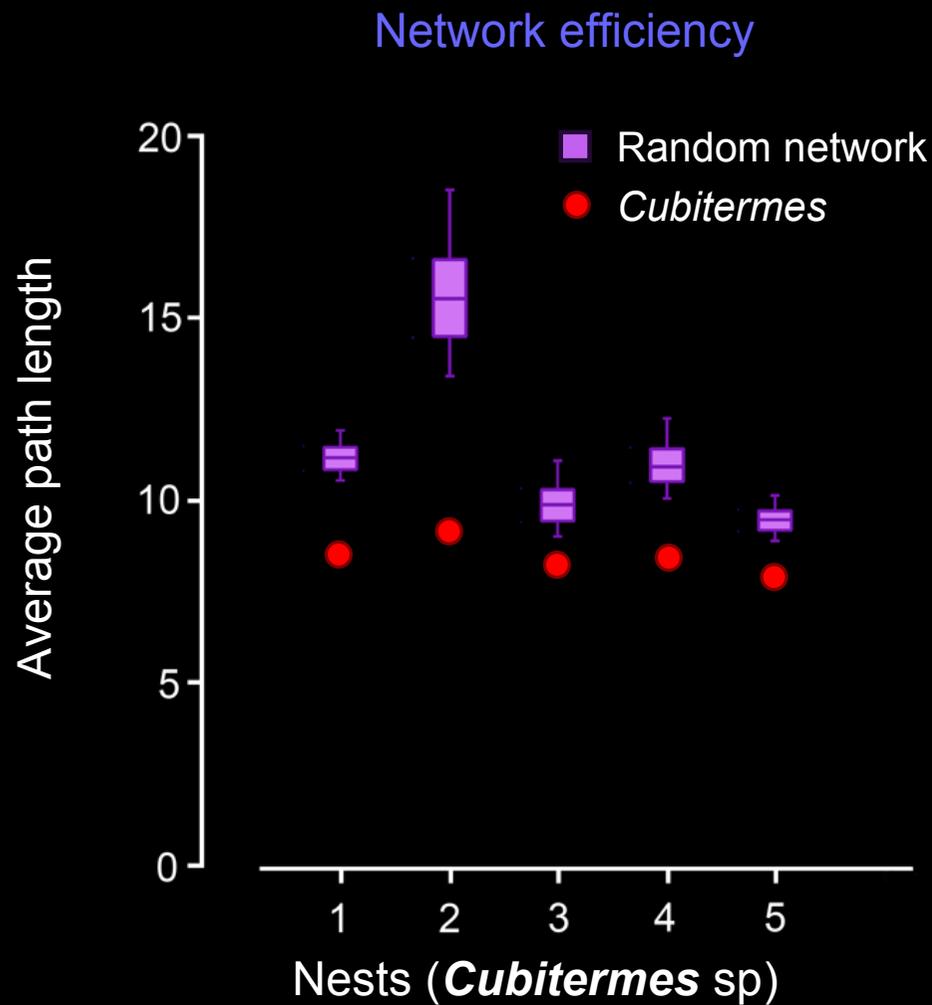
Network efficiency



# Average path length ( $L$ )

Global

Termites optimize a global network property



Maximal allowed graph

Spanner graphs

**Towards** a model?

**Towards a model?**

**Edges are removed during nest life**

**Towards a model?**

**Edges are removed during nest life**

**to obtain efficient final networks**

From **Local** to **Global**

**Towards** a model?

Edges are removed **during nest life**

**to obtain** efficient final networks

**How can termites act locally on the network  
and optimize a global property?**

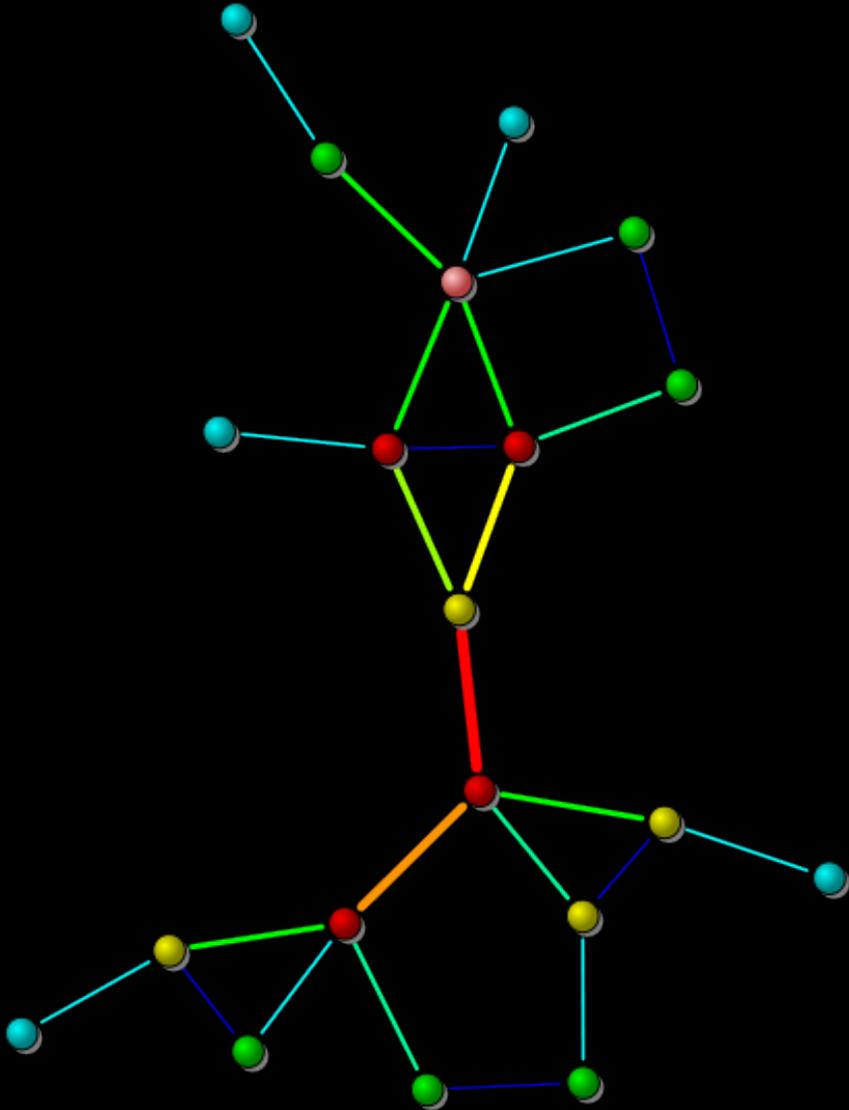
# 1<sup>st</sup> answer: insects can compute in a distributed way a global network parameter

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- A large number of ant and termite species leave pheromones as they move through the environment.
- The concentration of pheromone is higher at places where the insects pass more frequently



# Betweenness centrality

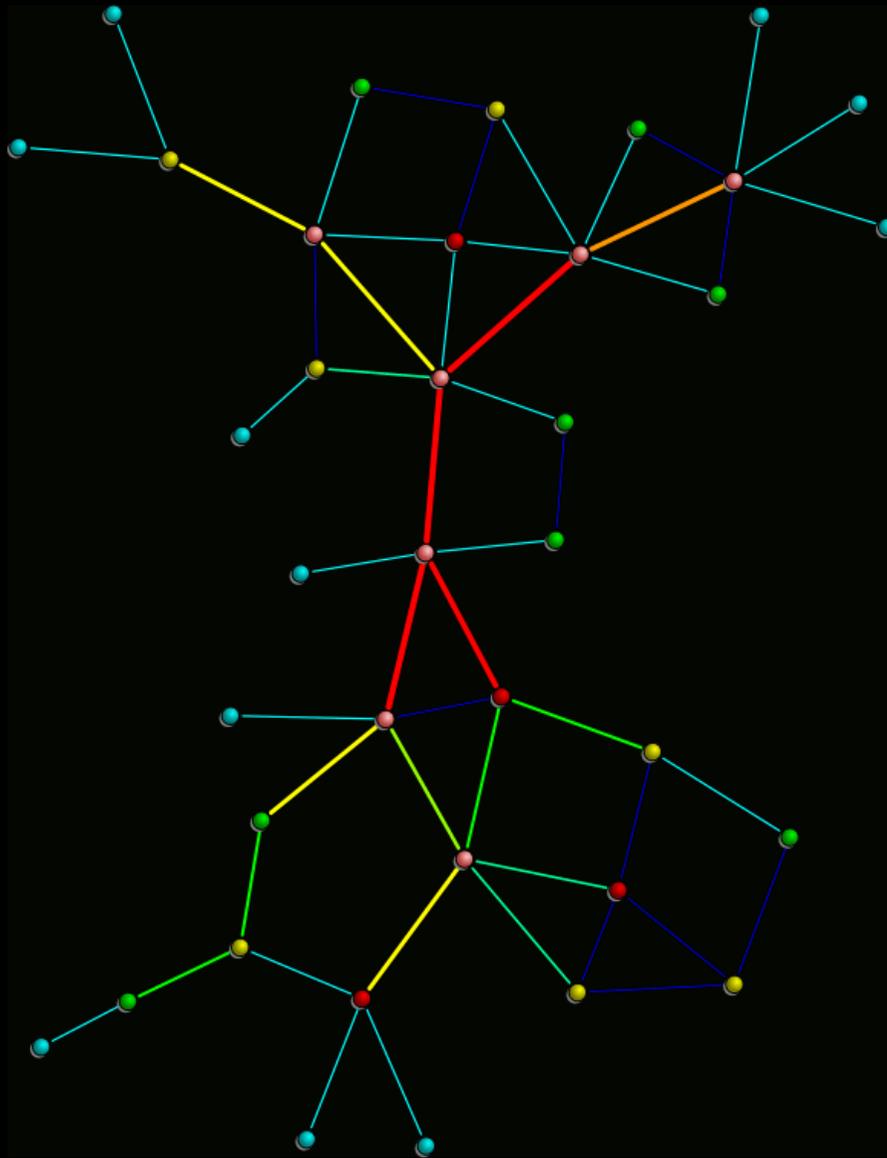


The edge betweenness is a measure of how important is a link (a nest gallery) for the overall network communication

$$C_B(v) = \frac{2}{(V-1)(V-2)} \sum_{s \neq v \neq t} \sigma_{st}(v)$$

# Maximum betweenness spanners

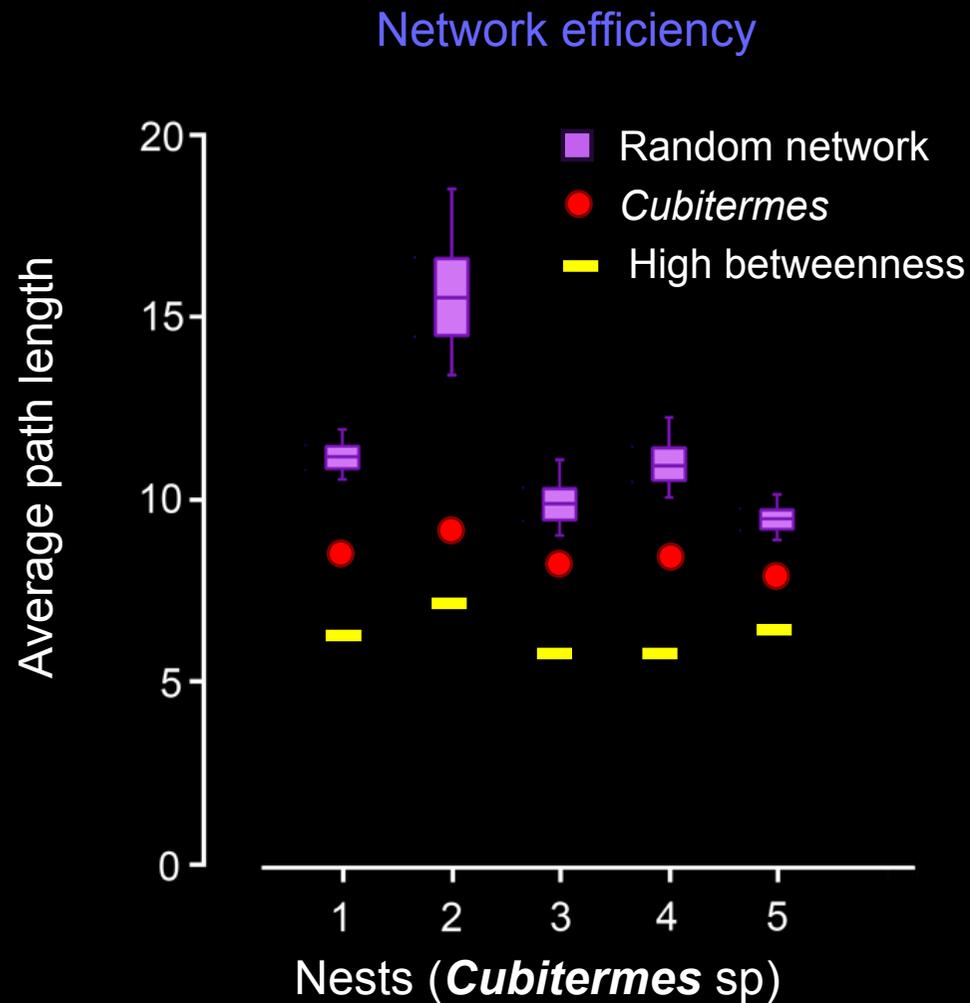
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Removing edges with low betweenness values one obtains highly efficient spanning subgraphs (or trees)

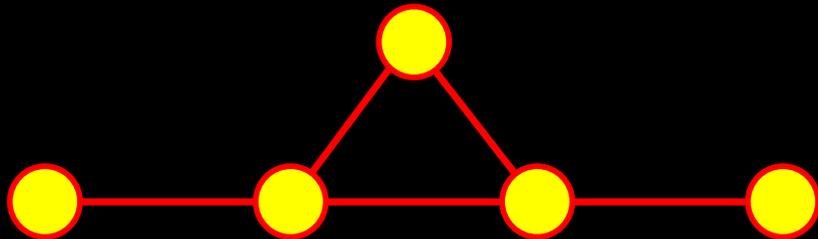
# Efficient networks

- The network of galleries inside a nest is more efficient than its random alternatives with the same number of edges.
- But less efficient than if only all the most central edges were kept



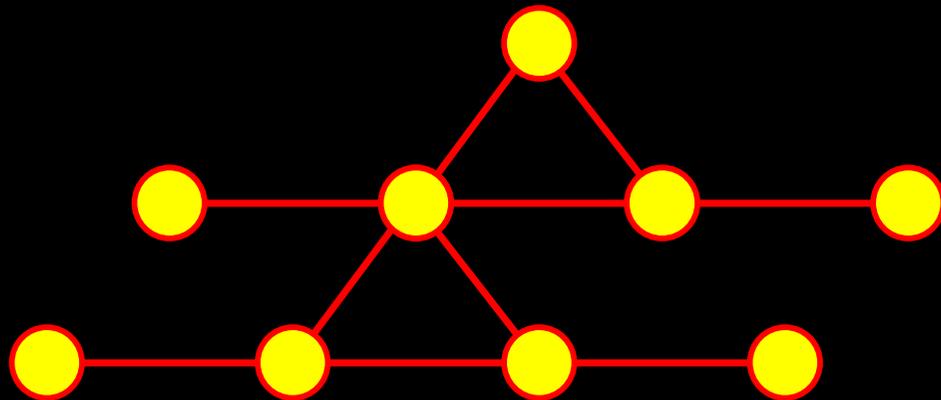
**2<sup>nd</sup> answer: efficient networks result from  
the assemblage of the good building blocks**

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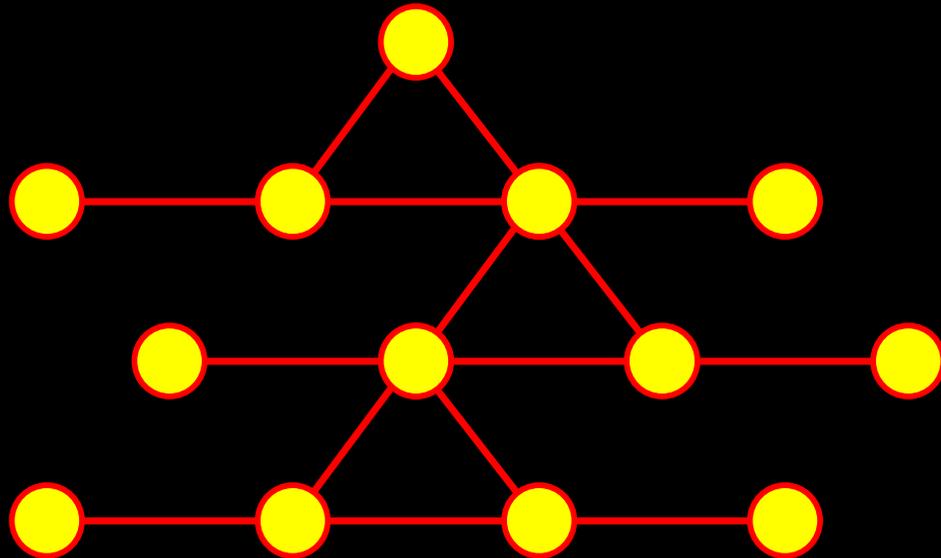
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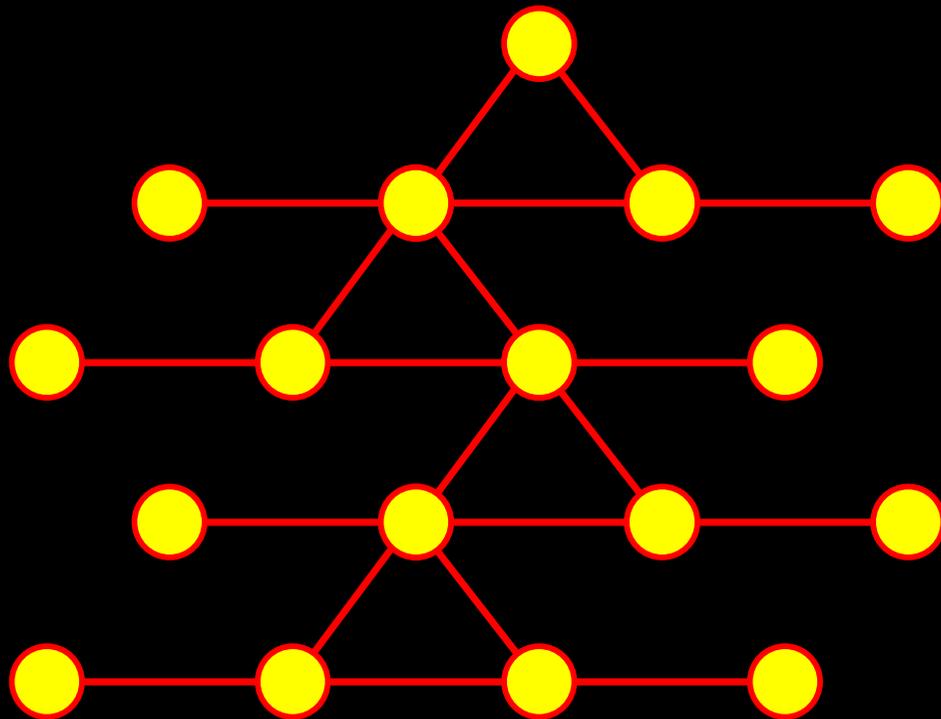
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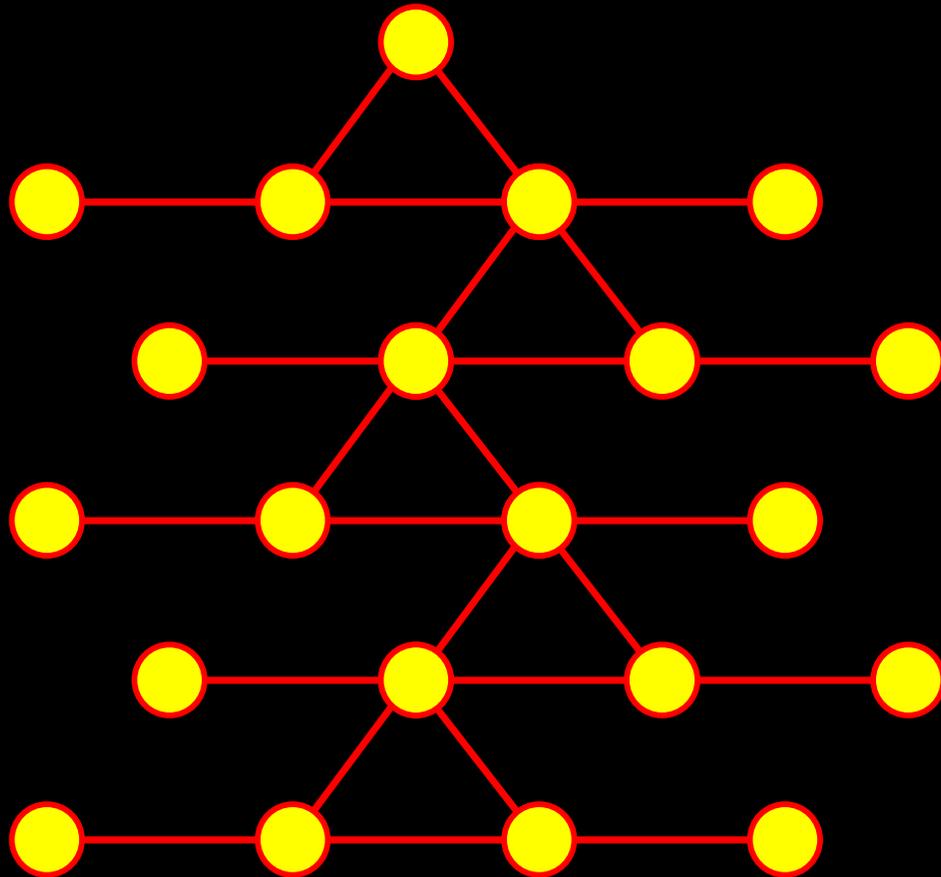
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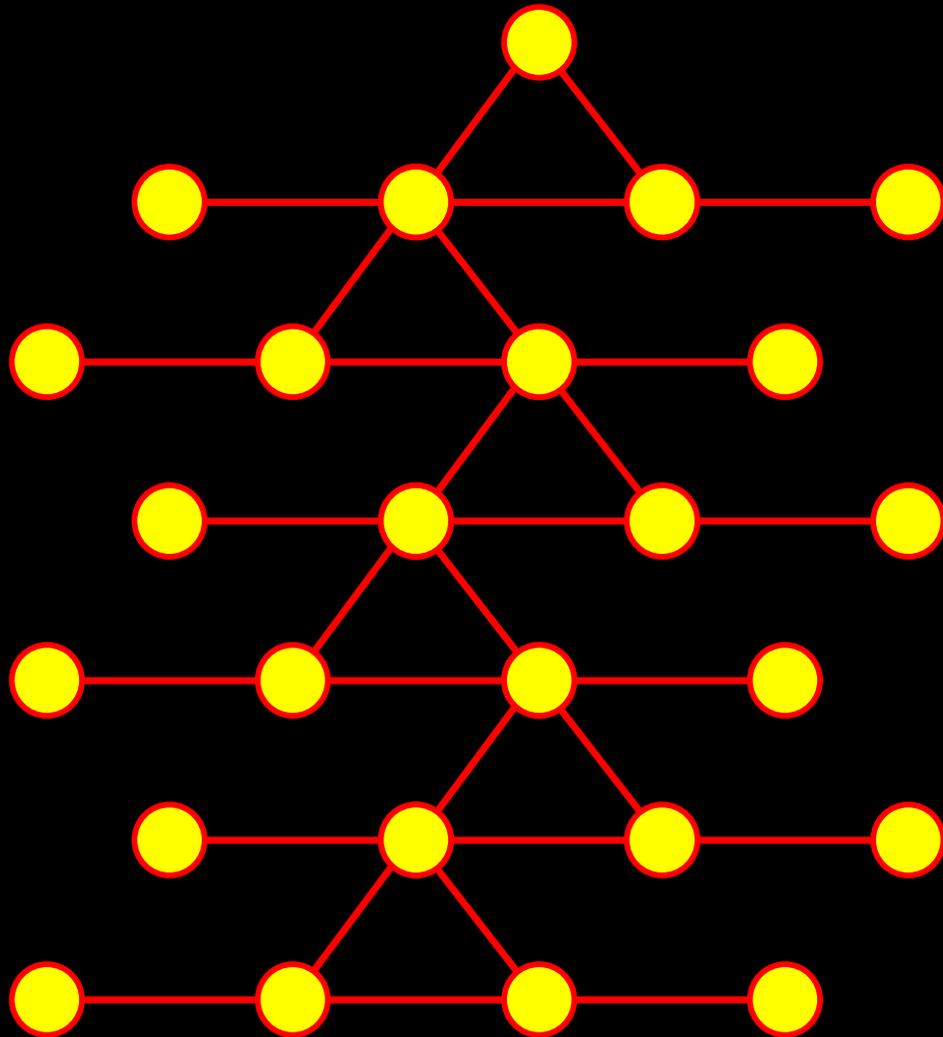
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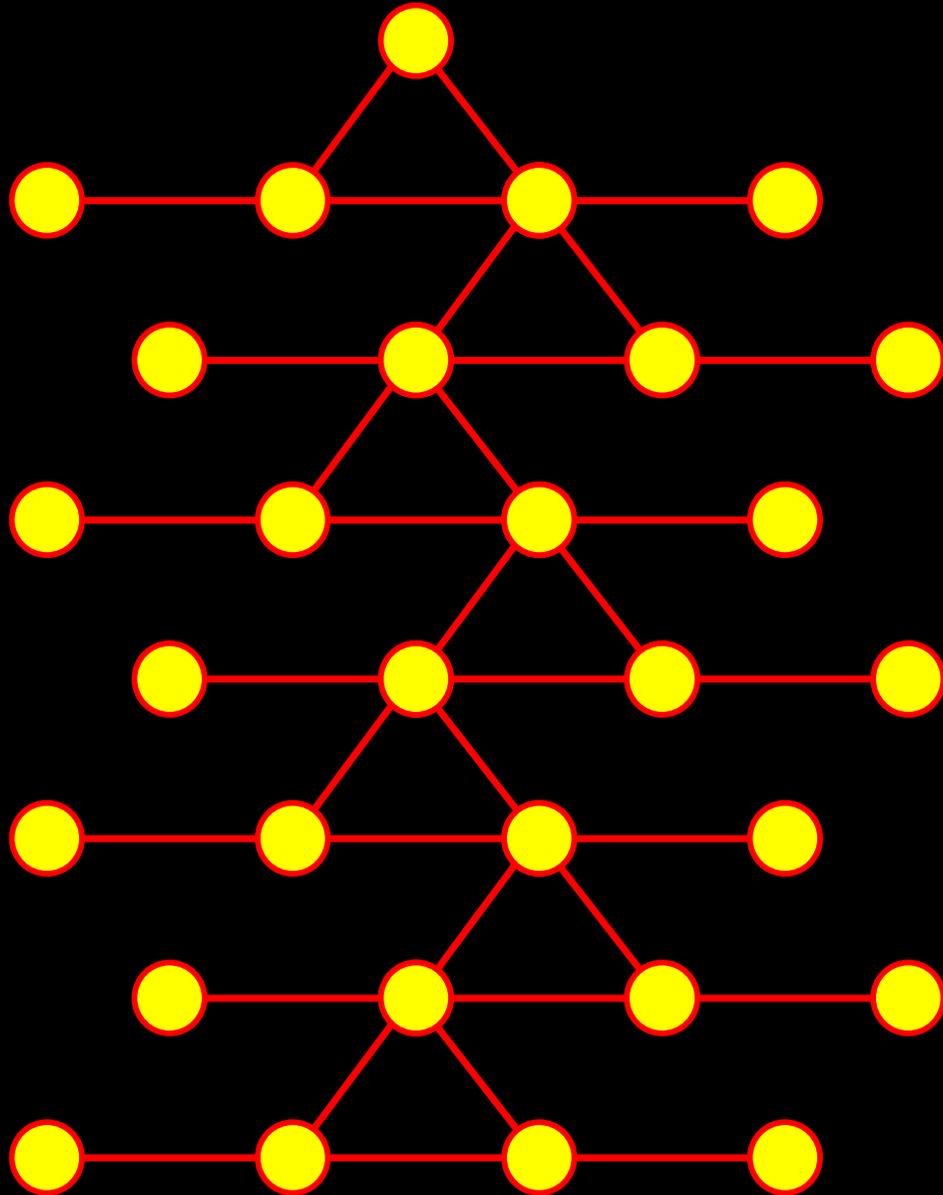
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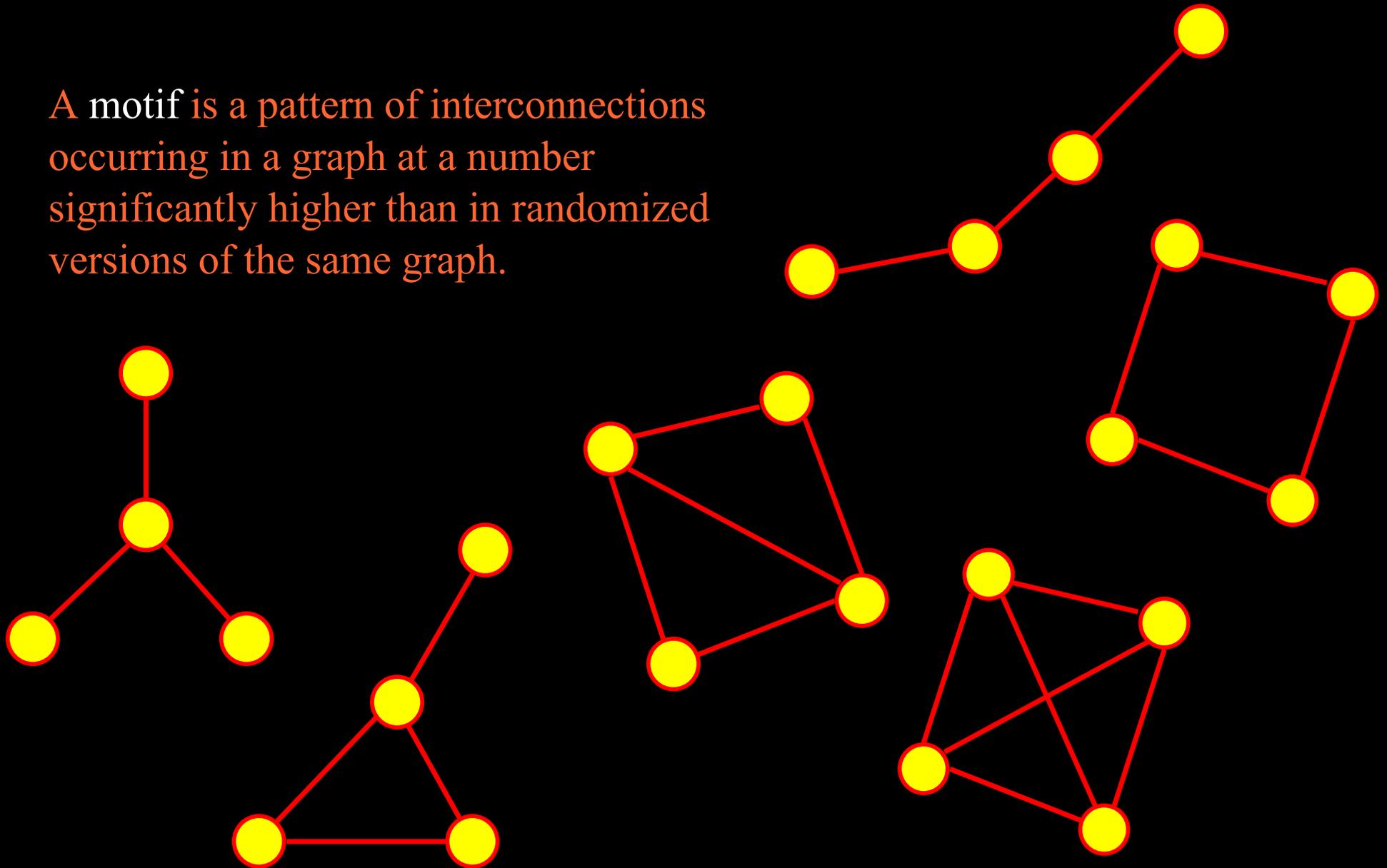
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# Network motifs

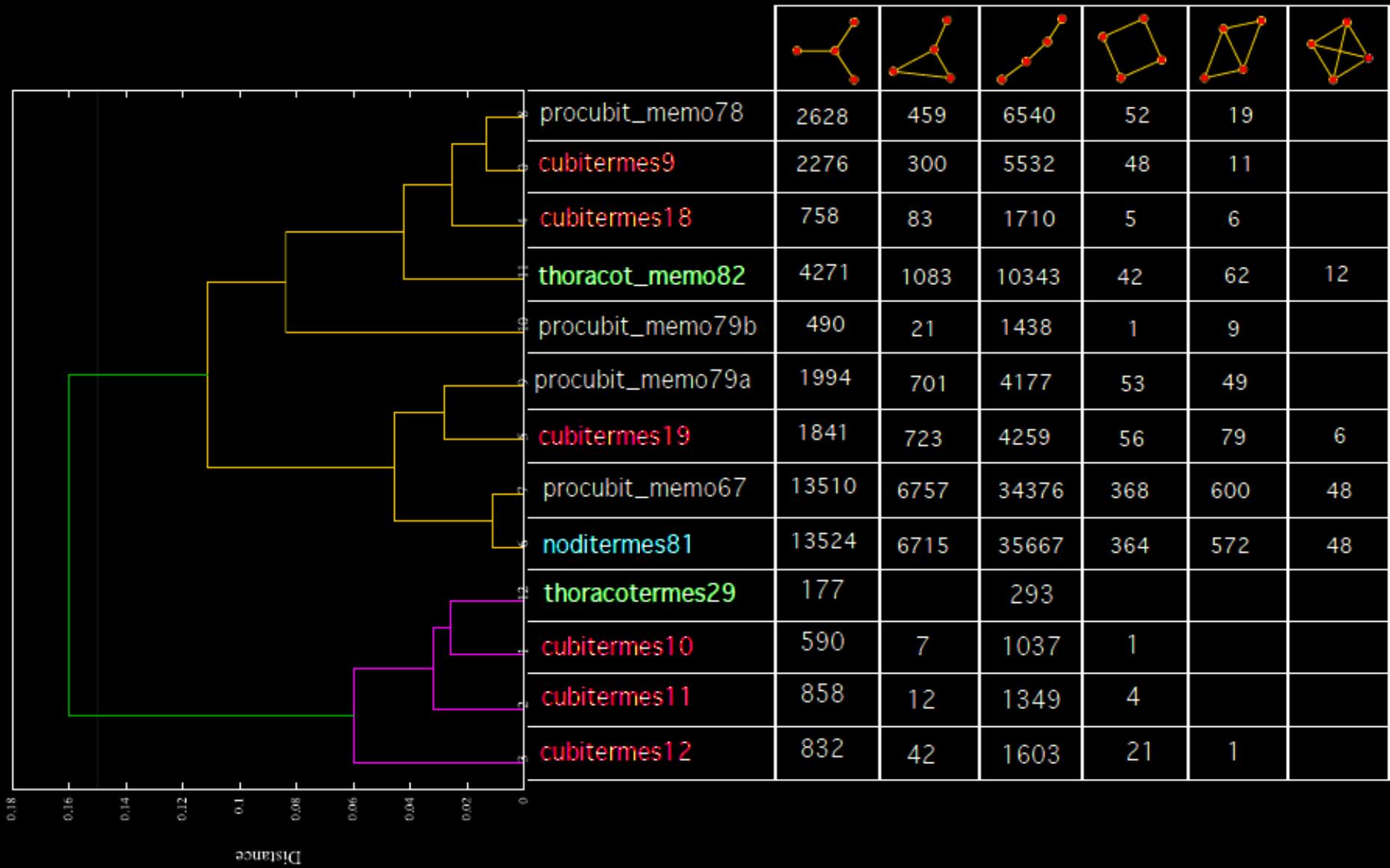
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A **motif** is a pattern of interconnections occurring in a graph at a number significantly higher than in randomized versions of the same graph.

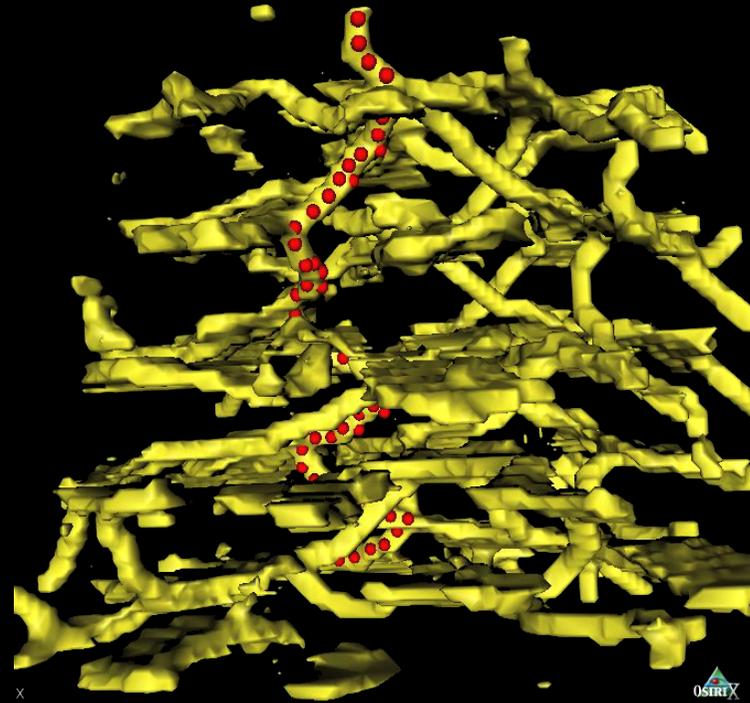
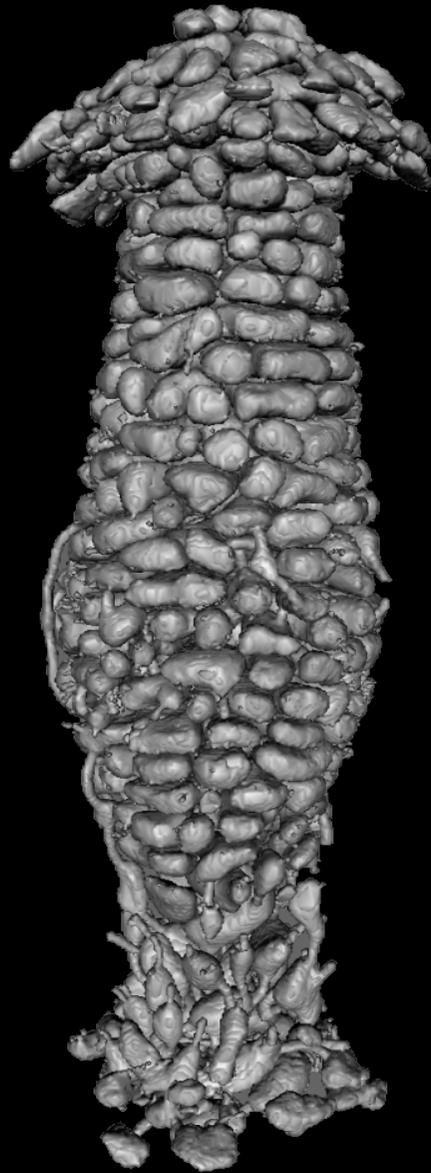


# Network motifs

Intermediate

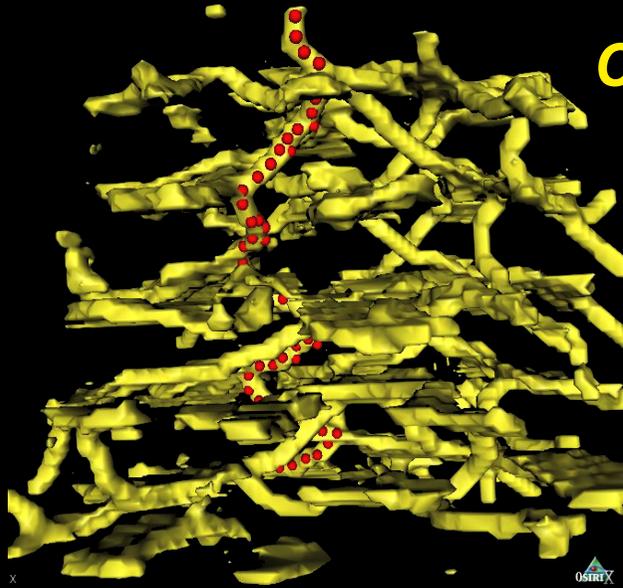


# Motifs in the nests



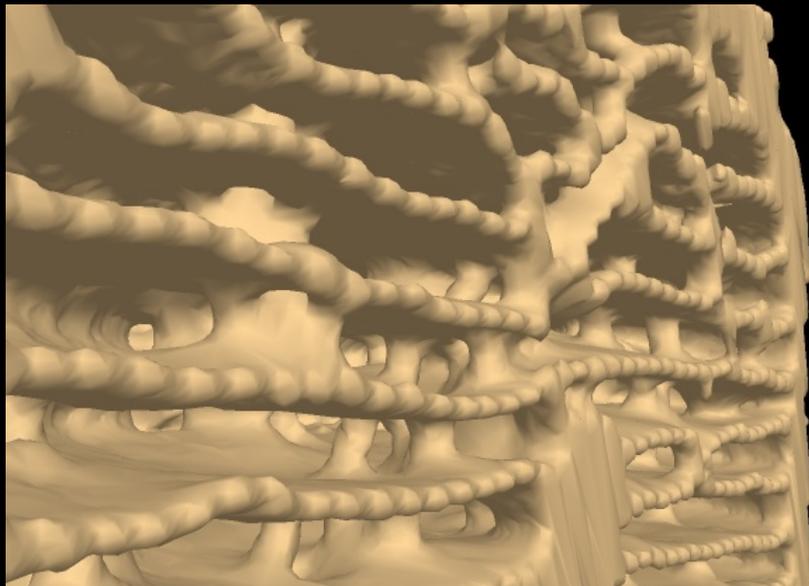
*Cubitermes* sp.

# Ramps



*Cubitermes* sp.

*Apicotermes*



*Pogonomyrmex badius*

# Conclusions

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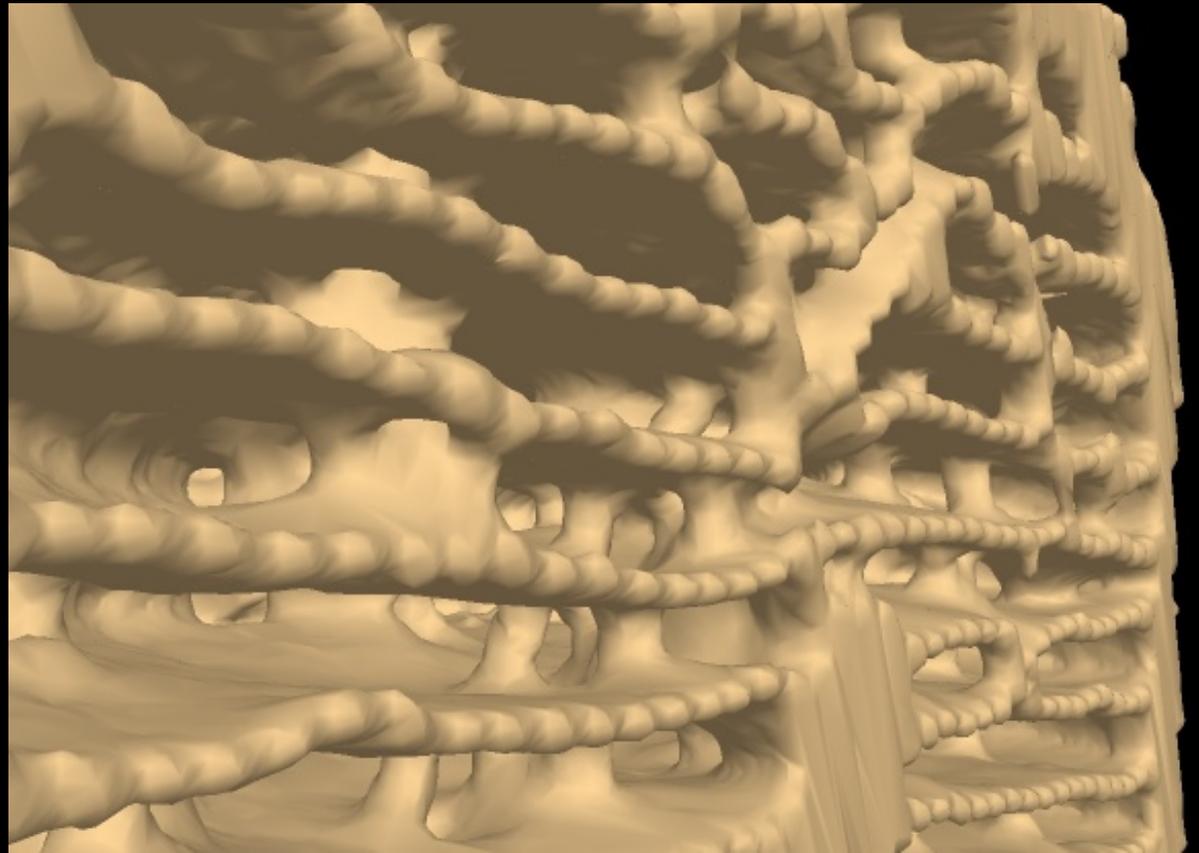
1. Computer Tomography allows to visualize the internal parts of a nest non-destructively



# Conclusions

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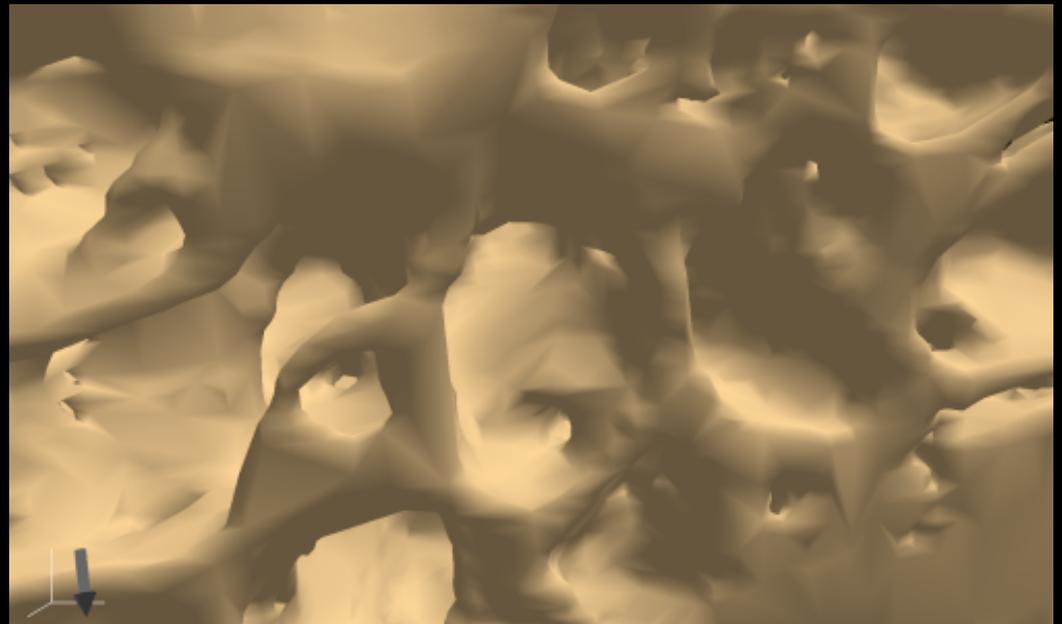
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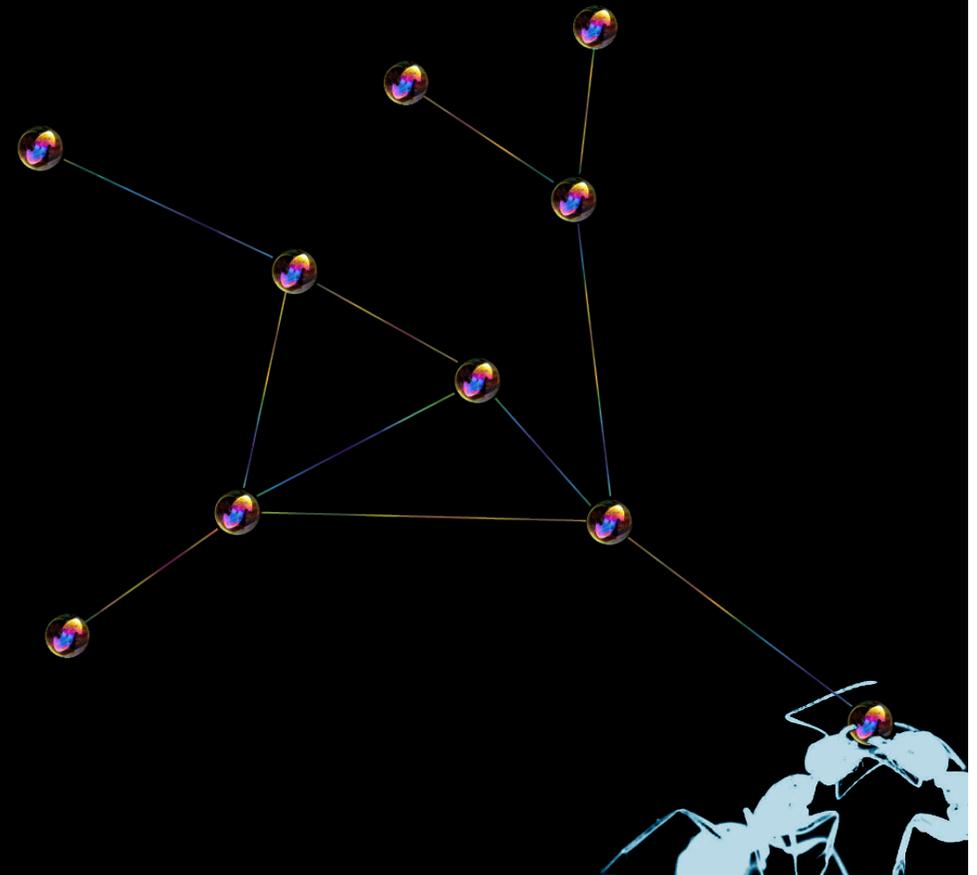
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3. But for other nests we need to extract more “compact” representations of the nest



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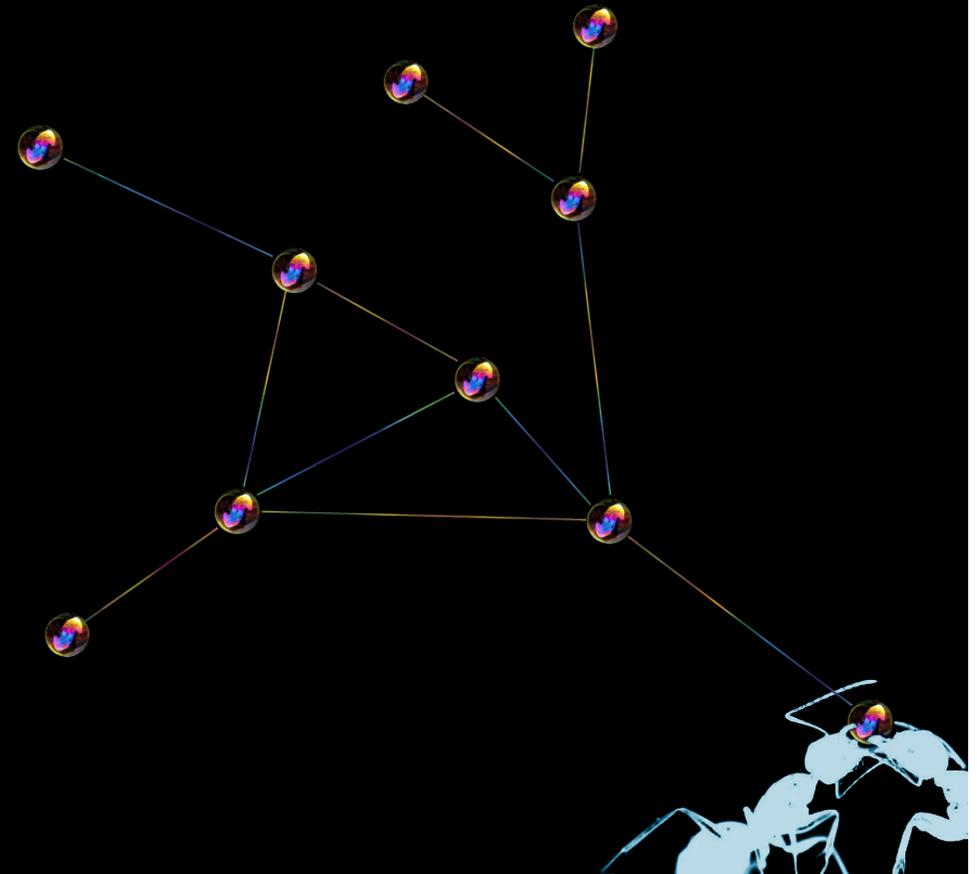
1. Computer Tomography allows to visualize the internal parts of a nest non-destructively
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# Conclusions

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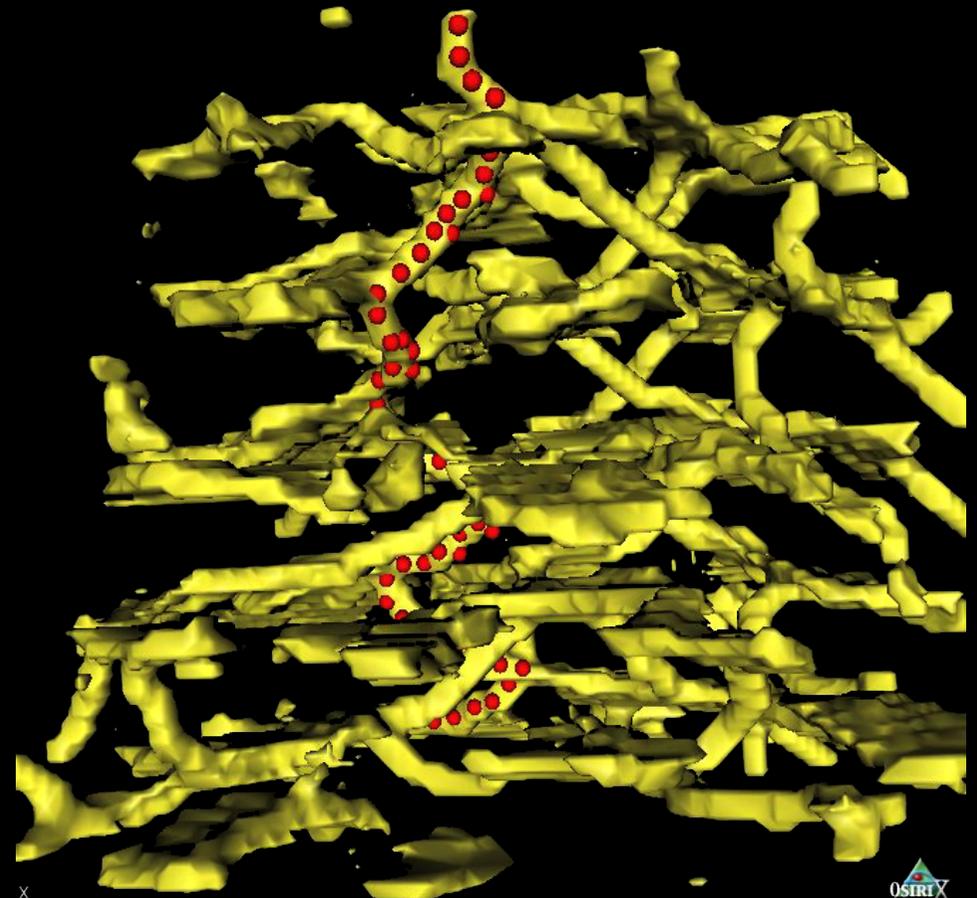
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1. Computer Tomography allows to visualize the internal parts of a nest non-destructively
2. Sometimes visualization is sufficient to give an idea of the internal organization of a structure
3. But for other nests we need to extract more “compact” representations of the nest
4. A promising approach consists in mapping the structures built by an insect colony into graphs.
5. Graphs, however are a poor tool for representing spatial information
6. Which is better represented by models obtained via image processing techniques



# The Mesomorph project



CRCA Toulouse

Christian Jost

Jacques Gautrais

Vincent Fourcassié

Guy Theraulaz

MSC Paris

Stéphane Douady

LINA Nantes

Pascale Kuntz

Fabien Picarougne

ISC Paris

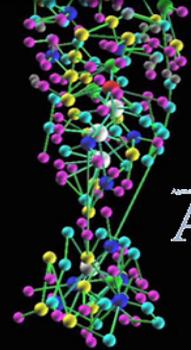
Andrea Perna

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ANR

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