Smart Teams

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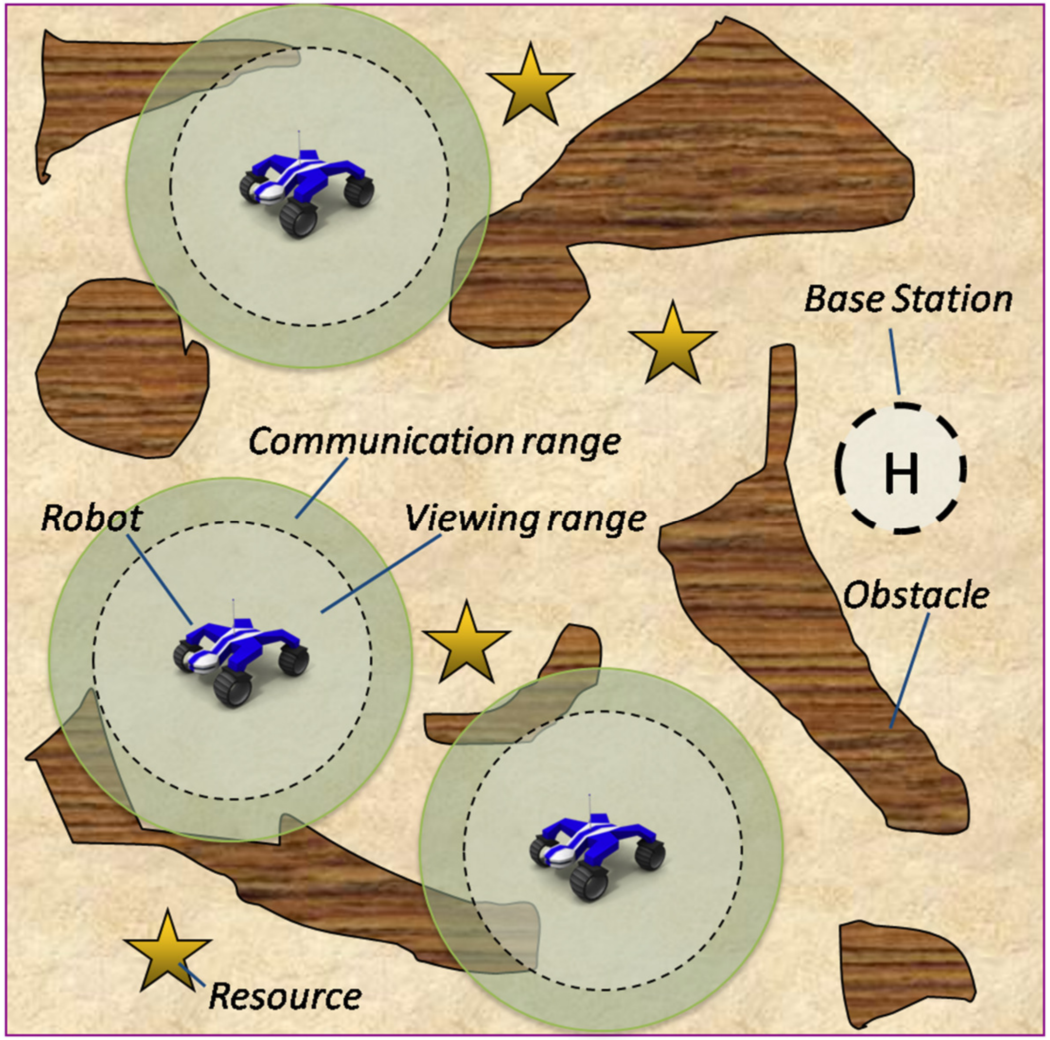
  - Christian Schindelhauer
- University of Paderborn
  - **Barbara Kempkes**
  - Friedhelm Meyer auf der Heide

13th Organic Computing Colloquium

What is a Smart Team?



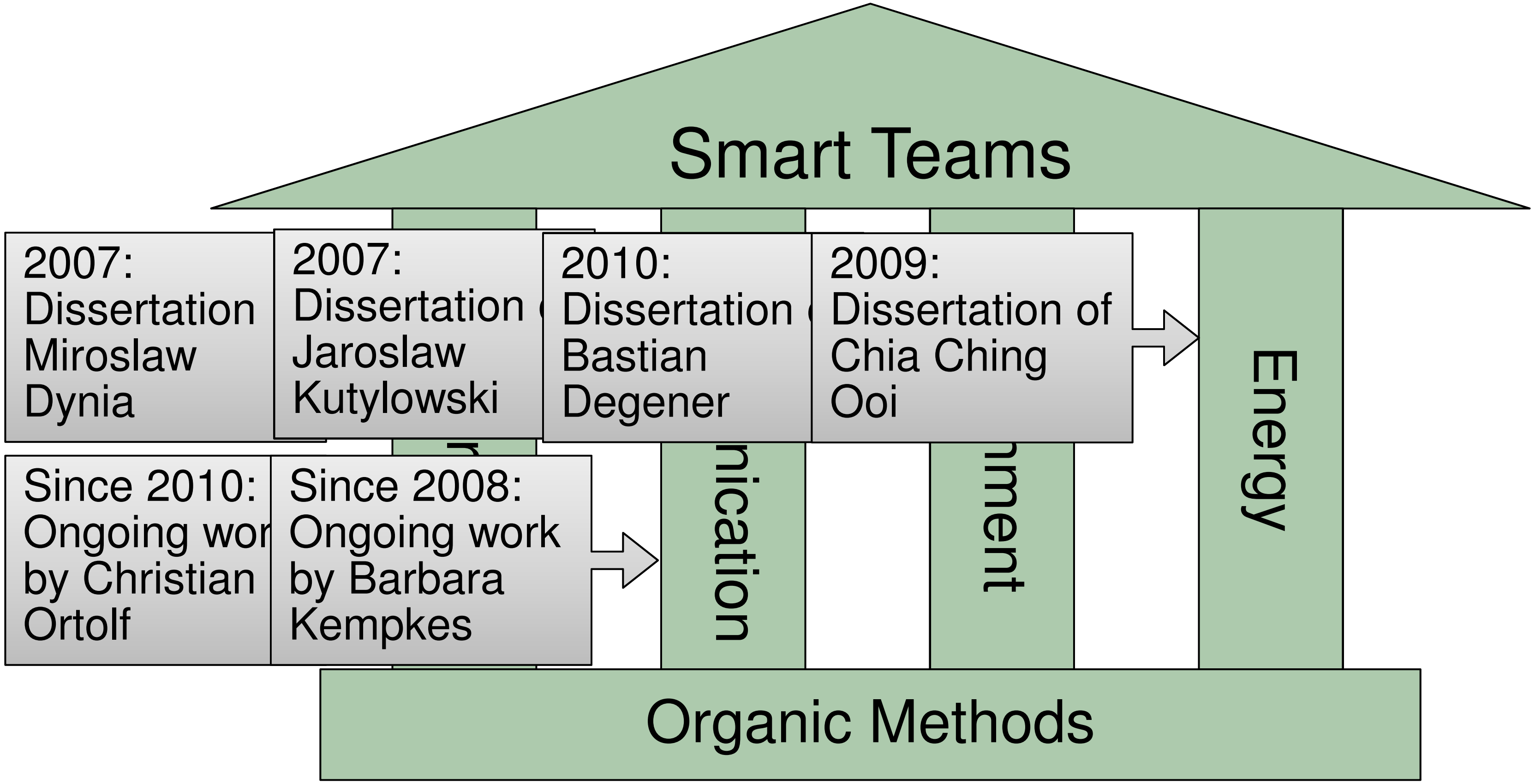
- A set of robots in an unknown terrain
  - E.g. a planet or an ocean
- No remote control: The robots have to organize themselves
- The robots are widely distributed
- Each robot can only contact few robots nearby

The Challenge

There is no global control guiding the Smart Team, so we need simple local rules for the robots that lead to globally good behavior

- Design of local algorithms
- Theoretical analysis: Worst-case analysis, competitive analysis of local distributed online algorithms
- Experimental analysis using simulators

Smart Teams


Smart Teams
2007: Dissertation Miroslaw Dynia
2007: Dissertation Jaroslaw Kutylowski
2010: Dissertation Bastian Degener
2009: Dissertation of Chia Ching Ooi
Since 2010: Ongoing wor by Christian Ortolf
Since 2008: Ongoing work by Barbara Kempkes
nication
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Energy
Organic Methods

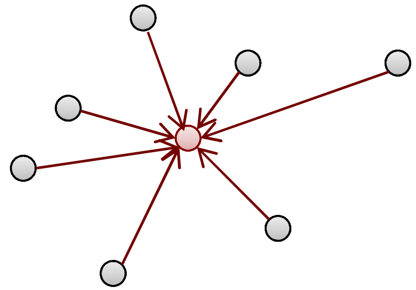
Communication: Overview

- Goal: Set up and maintain short communication infrastructure within the robot team
- Each robot has restricted communication range
  → Relay robots to forward communication
- Challenge: Relays have restricted capabilities and information
  - Restricted viewing range
  - Restricted communication
- Main restriction: Locality. Requires to replace central control by distributed self-organization of the relays.

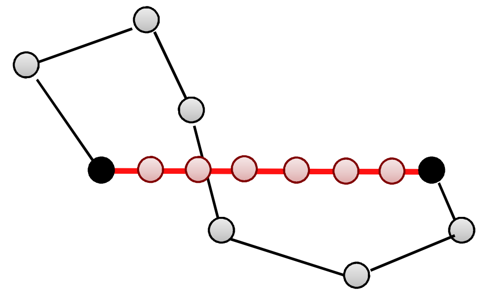
Smart Teams and Robot Formation Problems

Given: n robots distributed in the Euclidean plane

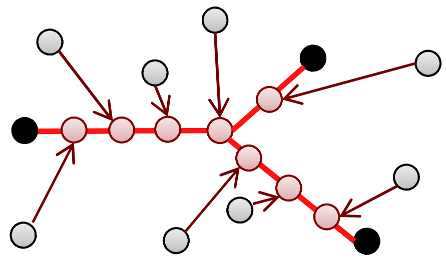
- Gathering problem:
  Gather all robots in a not predetermined point



- Relay chain problem:
  Minimize the length of a chain of relays between two stations



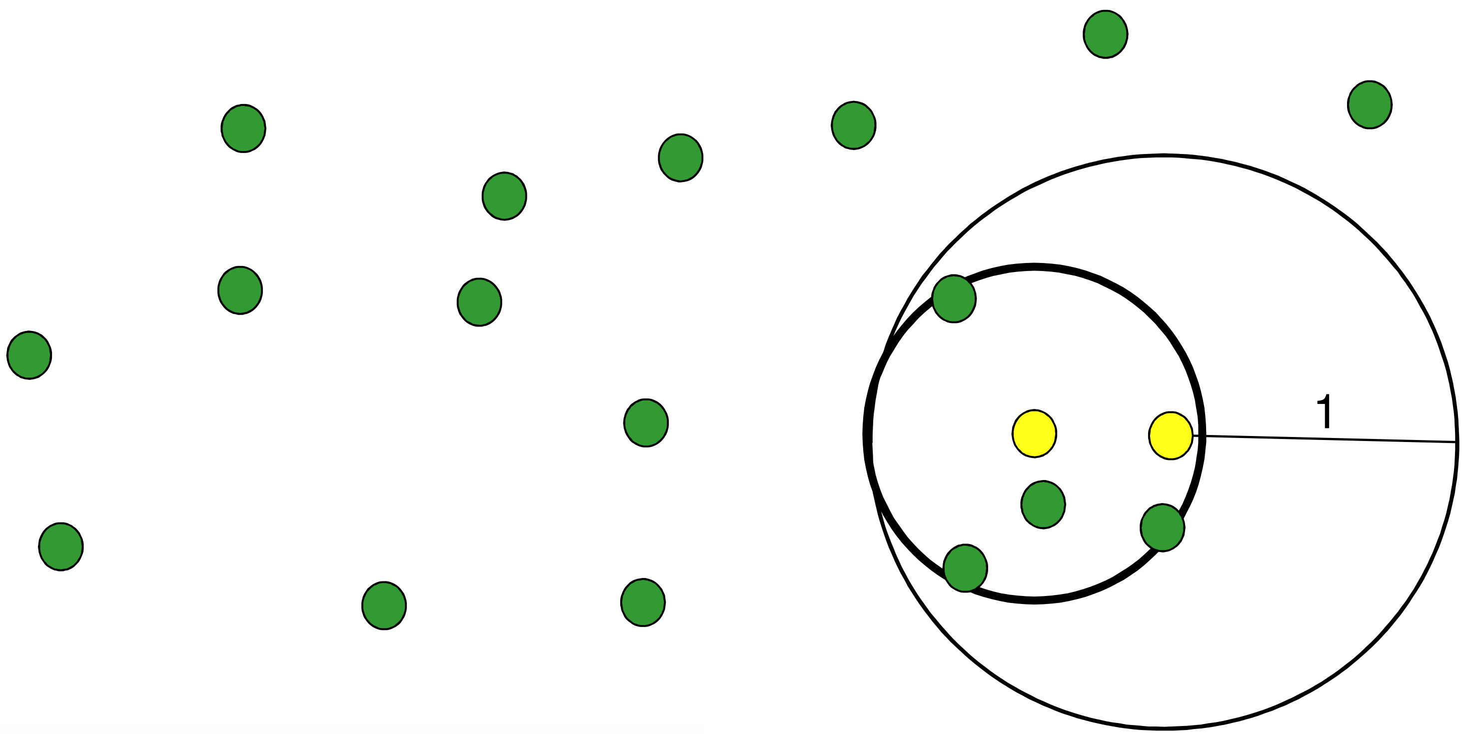
- Communication network problem:
  Minimize the length of a communication network between several stations



The gathering problem

A simple local rule: Go-To-The-Center

- In a step, a robot walks to the center of its neighbors, i.e. to the center of their smallest enclosing ball



The gathering problem

A simple local rule: Go-To-The-Center

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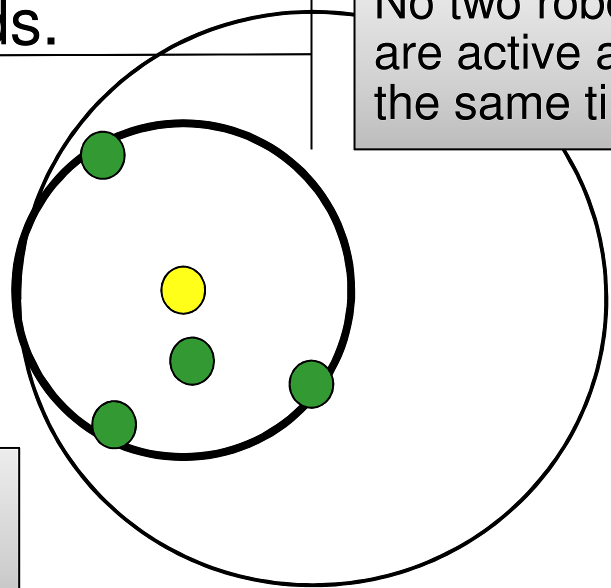
Go-To-The-Center performs gathering in finitely many asynchronous rounds.

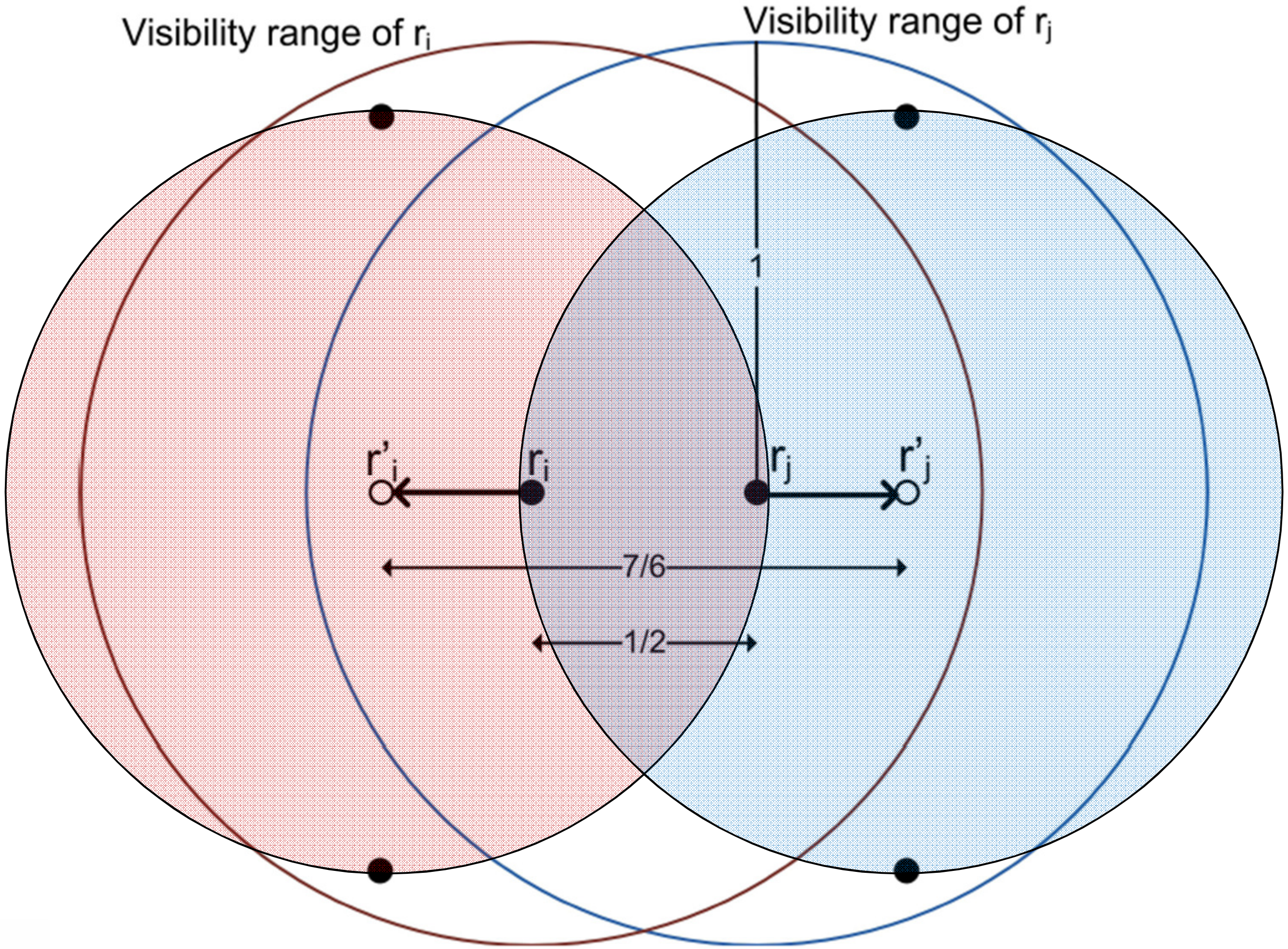
No two robots are active at the same time



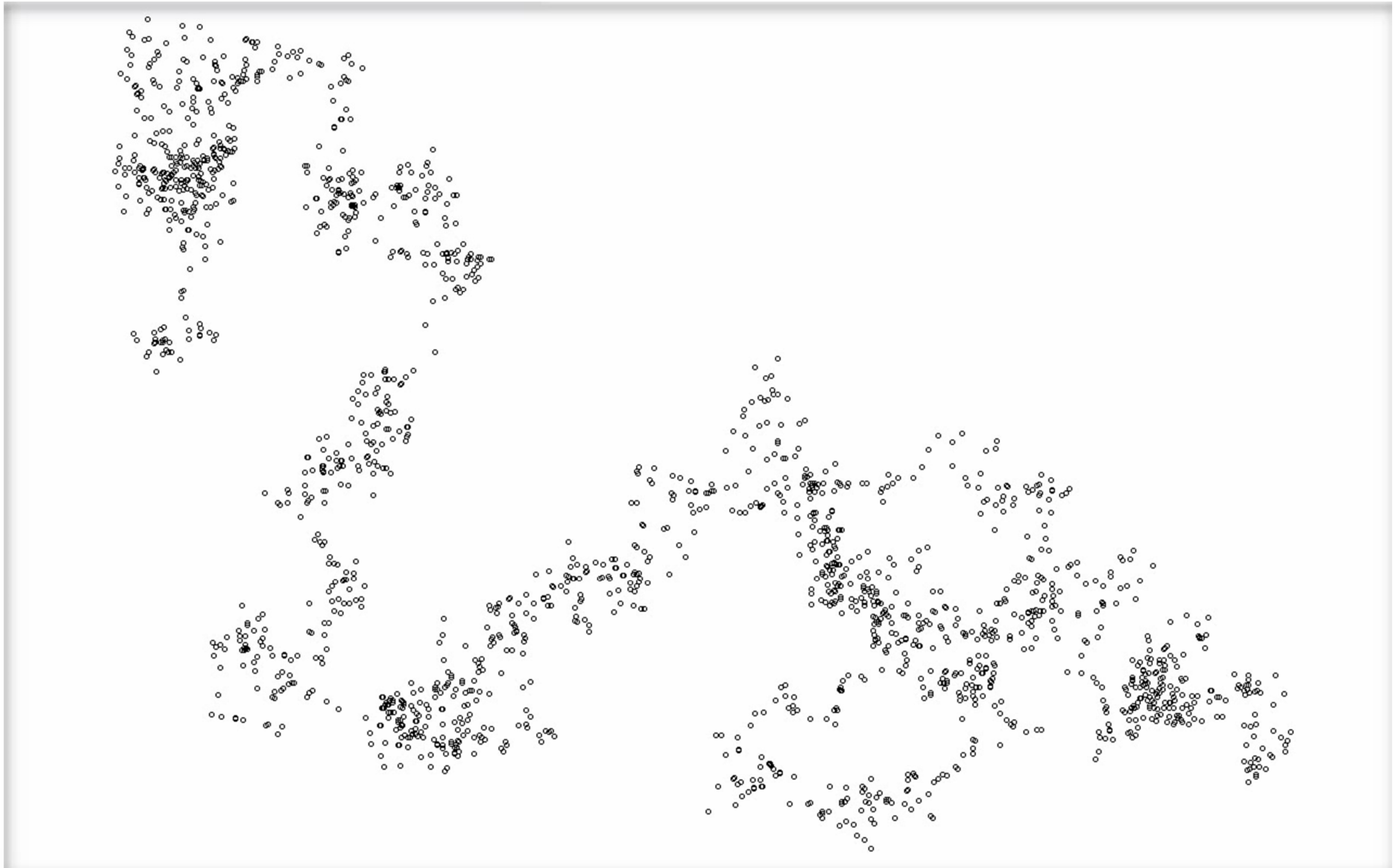
It does not even guarantee connectivity in the synchronous model.

All robots act at the same time

Unit disk graph becomes disconnected



Example for Gathering: 1848 nodes, 24 rounds, activation in random order



Gathering with provable time bounds in the asynchronous setting

Degener, Kempkes, MadH (SPAA 2010)

Gathering can be done by a local algorithm in $O(n^2)$ rounds, if the activation of robots is asynchronous and the order of activation at random.

The algorithm is a complicated extension of Go-To-The Center.

A synchronous variant of Go-To-The Center

introduced by Ando, Suzuki, Yamashita (Intelligent Control 1995)

Robots move towards the center of the smallest enclosing ball around their neighbors,

maintain connectivity by “stopping sufficiently early”

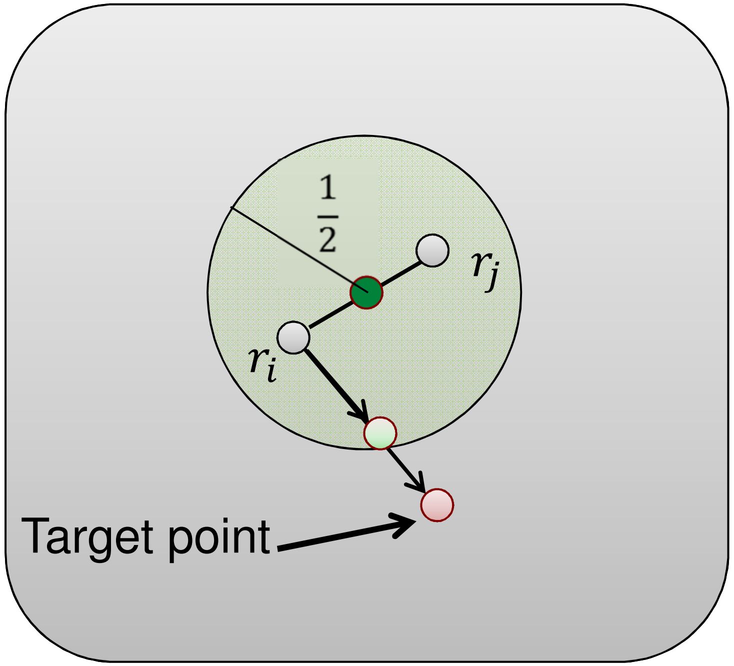
Result:

Gathering achieved in finitely many synchronous rounds.

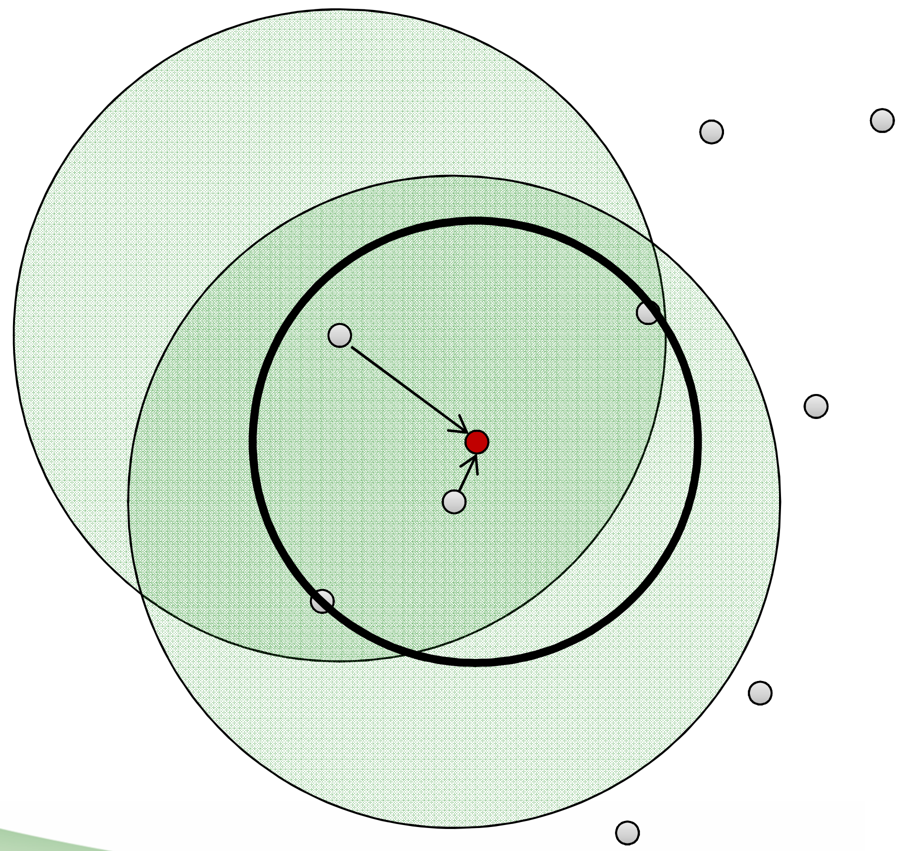
Ando, Suzuki, Yamashita (Intelligent Control 1995)

Time Bound $\Theta(n^2)$

Degener, Kempkes, Langner, MadH, Wattenhofer (SPAA11)



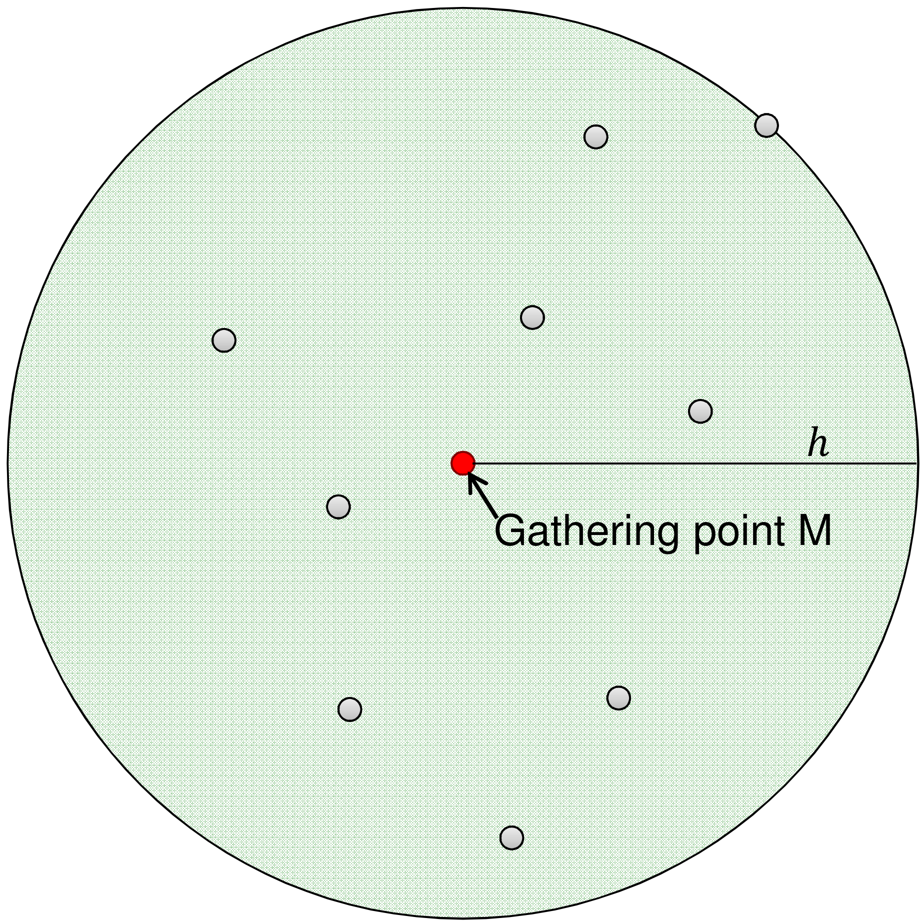
Idea of the analysis



How to measure progress:

1. Two robots merge in a round → n-1 rounds

Idea of the analysis



How to measure progress:

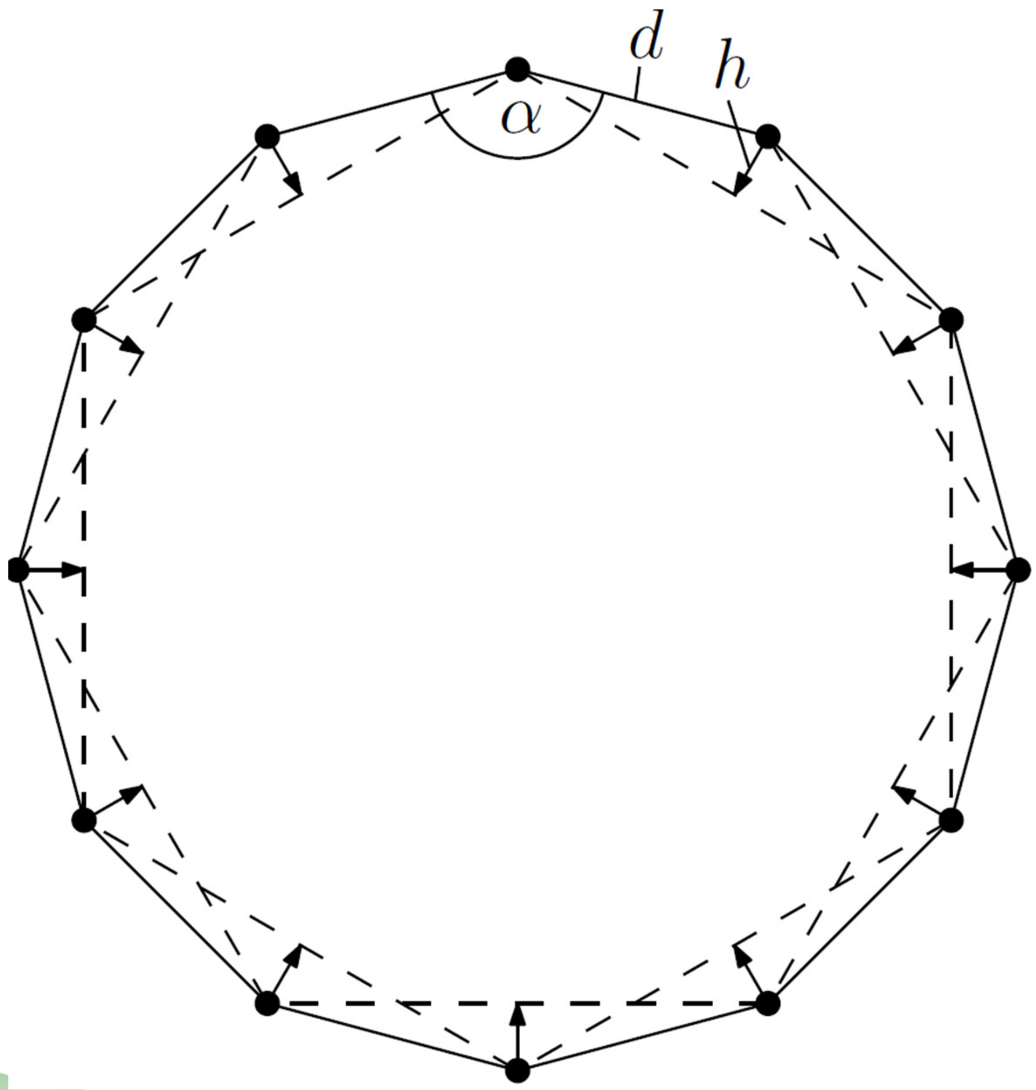
1. Two robots merge in a round → n-1 rounds
2. If no robots merge in two consecutive rounds, the radius h of the configuration decreases by $\Omega(1/h)$.

Result:

$O(H^2+n)$ rounds suffice
(H = initial radius)

As $H \leq n$, $O(n^2)$ round suffice.

Lower Bound $\Omega(n^2)$



Consider n robots on a cycle, distance 1 between neighbours

Are there faster strategies?

Conjectures:

- In the synchronous model : **NO**
- In the worst case asynchronous model: **NO**
- In the random order asynchronous model: NO

- In a model where the activation order may be prescribed (e.g.: “I become active as soon as my neighborhood has a certain property.”)

  MAYBE??

Outlook

- Let the robots learn parameter settings of algorithms which situation (for given classes of initial configurations)
- Use formal methods to prove that runtimes of the learned algorithms are „good“ for given classes of initial configurations
- Swarms: How can certain properties be maintained under dynamics?

Conclusion: Smart Teams in numbers

- 4 PhDs (Miroslaw Dynia, Jaroslaw Kutylowski, Chia Ching Ooi, Bastian Degener)
- 28 papers
- 17 student theses
- 2 project groups (12 + 11 undergraduate students)

Publications of Smart Teams

2011

- Cord-Landwehr, A.; Degener, B.; Fischer, M.; Hüllmann, M.; Kempkes, B. Klaas, A.; Kling, P.; Kurras, S.; Märtens, M.; Meyer auf der Heide, F.; Raupach, C.; Swierkot, K.; Warner, D.; Weddemann, C.; Wonisch, D.: **A new Approach for Analyzing Convergence Algorithms for Mobile Robots.** In: Proceedings of the 38th International Colloquium on Automata, Languages and Programming (ICALP 2011)
- Cord-Landwehr, A.; Degener, B.; Fischer, M.; Hüllmann, M.; Kempkes, B. Klaas, A.; Kling, P.; Kurras, S.; Märtens, M.; Meyer auf der Heide, F.; Raupach, C.; Swierkot, K.; Warner, D.; Weddemann, C.; Wonisch, D.: **Collisionless Gathering of Robots with an Extent.** In: 37th International Conference on Current Trends in Theory and Practice of Computer Science (SOFSEM 2011)
- Degener, Bastian; Kempkes, Barbara; Langner, Tobias; Meyer auf der Heide, Friedhelm; Wattenhofer, Roger: **A tight runtime bound for synchronous gathering of autonomous robots with limited visibility.** In: SPAA 2011
- Brandes, Philipp; Degener, Bastian; Kempkes, Barbara; Meyer auf der Heide, Friedhelm: **Energy-efficient strategies for building short chains of mobile robots locally.** In: SIROCCO 2011
- Degener, Bastian; Kempkes, Barbara; Meyer auf der Heide, Friedhelm: **Organic Computing — A Paradigm Shift for Complex Systems.** , Autonomic Systems, Band 1, Kapitel: Energy-Awareness in Self-organising Robotic Exploration Teams, 2011
- Kling, Peter; Meyer auf der Heide, Friedhelm: **Convergence of Local Communication Chain Strategies via Linear Transformations.** In: SPAA 2011

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2010

- Degener, Bastian; Gehweiler, Joachim; Lammersen, Christiane: **Kinetic Facility Location.** In: Algorithmica, 2010
- Degener, Bastian; Kempkes, Barbara; Meyer auf der Heide, Friedhelm: **A local O(n^2) gathering algorithm.** In: SPAA 2010
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- Degener, Bastian; Kempkes, Barbara; Pietrzyk, Peter: **A local, distributed constant-factor approximation algorithm for the dynamic facility location problem.** In: IPDPS 2010
- Ooi, Chia Ching; Schindelhauer, Christian: **Utilising coverage holes and wireless relays for mobile target tracking**. In: IJAHUC 2010

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2009

- Bonorden, Olaf; Degener, Bastian; Kempkes Barbara; Pietrzyk, Peter: **Complexity and Approximation of Geometric Local Assignment Problem.** In: Proceedings of ALGOSENSORS, 2009
- Ooi, Chia Ching; Schindelhauer, Christian: **Minimal Energy Path Planning for Wireless Robots.** In: ACM/Springer Journal of Mobile Networks and Applications (MONET) 2009
- Jaroslaw Kutylowski, Friedhelm Meyer auf der Heide: **Optimal Strategies for Maintaining a Chain of Relays between an Explorer and a Base Camp.** In: Journal of Theoretical Computer Science 2009.
- Ooi, Chia Ching; Schindelhauer, Christian: **Smart Ring: Utilizing Coverage Holes for Mobile Target Tracking**, accepted for publication in International ACM Conference on Management of Emergent Digital EcoSystems (MEDES'09), October, 2009.

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2008

- Degener, Bastian; Gehweiler, Joachim; Lammersen, Christiane: **The Kinetic Facility Location Problem.** In: Proceedings of the 11th Scandinavian Workshop on Algorithm Theory (SWAT), 2008
- Friedhelm Meyer auf der Heide, Barbara Schneider: **Local Strategies for Connecting Stations by Small Robotic Networks.** In: Proc. of 2nd IFIP International Conference on Biologically Inspired Computing (BICC'08)
- Chia Ching Ooi, Christian Schindelhauer: **Detours Save Energy in Mobile Wireless Networks.** In: Proc. of 10th IFIP International Conference on Mobile and Wireless Communications Networks (MWCN'08)
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- Friedhelm Meyer auf der Heide, et. al.: **Smart Teams: Simulating Large Robotic Swarms in Vast Environments.** In: 4th International Symposium on Autonomous Minirobots for Research and Edutainment (AMiRE‘07)
- Chia Ching Ooi, Christian Schindelhauer: **Minimal Energy Path Planning for Wireless Robot.** In: Proc. of International Conference of Robot Communication and Coordination (ROBOCOMM’07)
- Miroslaw Dynia, Jakub Lopuszanski, Christian Schindelhauer : **Why Robots Need Maps.** In: Proc. of the 14th Colloquium on Structural Information and Communication Complexity (SIROCCO’07)
- Miroslaw Dynia, Miroslaw Korzeniowski, Jaroslaw Kutylowski: **Competitive Maintenance of Minimum Spanning Tree in Dynamic Graphs.** In: Proc. of the 33rd International Conference on Current Trends in Theory and Practice of Computer Science (SOFSEM'07)
- Marcin Bienkowski, Jaroslaw Kutylowski: **The k-Resource Problem on Uniform and on Uniformly Decomposable Metric Spaces.** In: Proc. of the 10th Workshop on Data Structures and Algorithms (WADS'07)
- Miroslaw Dynia, Jaroslaw Kutylowski, Friedhelm Meyer auf der Heide, Jonas Schrieb: **Local Strategies for Maintaining a Chain of Relay Stations between an Explorer and a Base Station.** In: Proc. of the 19th ACM Symposium on Parallelism in Algorithms and Architectures (SPAA'07)

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- Miroslaw Dynia, Korzeniowski, Miroslaw, Christian Schindelhauer: **Power-Aware Collective Tree Exploration.** In: Proc. of the Architecture of Computing Systems (ARCS'06)
- Miroslaw Dynia, Andreas Kumlehn, Jaroslaw Kutylowski, Friedhelm Meyer auf der Heide, Christian Schindelhauer: **SmartS Simulator Design.**
- Miroslaw Dynia, Jaroslaw Kutylowski, Christian Schindelhauer, Friedhelm Meyer auf der Heide: **Smart Robot Teams Exploring Sparse Trees.** In: Proc. of the 31st International Symposium of Mathematical Foundations of Computer Science (MFCS'06)
- Miroslaw Dynia, Jaroslaw Kutylowski, Pawel Lorek, Friedhelm Meyer auf der Heide: **Maintaining Communication Between an Explorer and a Base Station.** In: IFIP 19th World Computer Congress, TC10: 1st IFIP International Conference on Biologically Inspired Computing (BICC'06)

Thank you for your attention!

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