Collective Robotics

Part 1: Introduction

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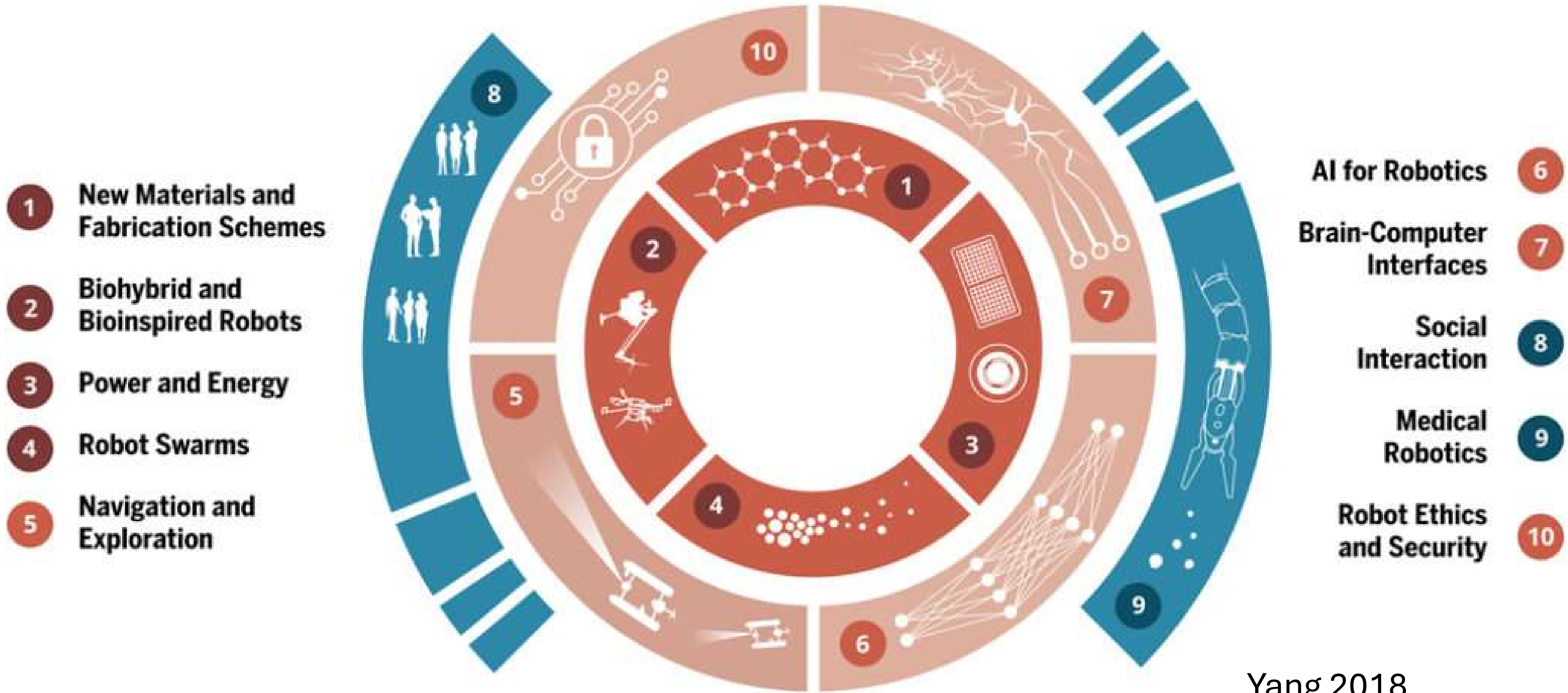
Lecture & tutorial

Collective Robotics

(Autonomous systems, computer science, etc. / master studies)

- Lectures: Tuesday 13:30 – 15:00
- room: C120
- Tutorials: every 2 weeks, after the lecture
- first tutorial/lab on April 22
- room: C120
- slides, announcements: https://lea.hochschule-bonn-rhein-sieg.de/
- oral exam
- (exam days will be announced)

10 Biggest Challenges in Robotics



Yang 2018

The 10 biggest challenges in robotics that may have breakthroughs in 5-10 years. (Credit: Science Robotics)

Outline

1. Introduction to collective robotics
2. Short journey through nearly everything
3. Scenarios of collective robotics
4. Modeling collective systems
5. Local sampling
6. Collective decision-making
7. Case study – adaptive aggregation
8. Bio-hybrid systems

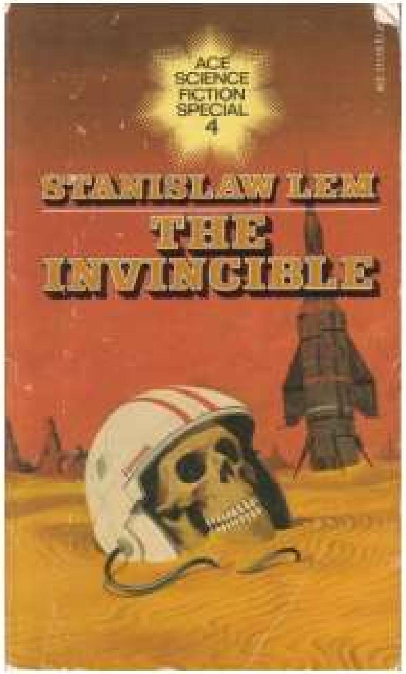
optional: recap robotics & behavior-based robotics

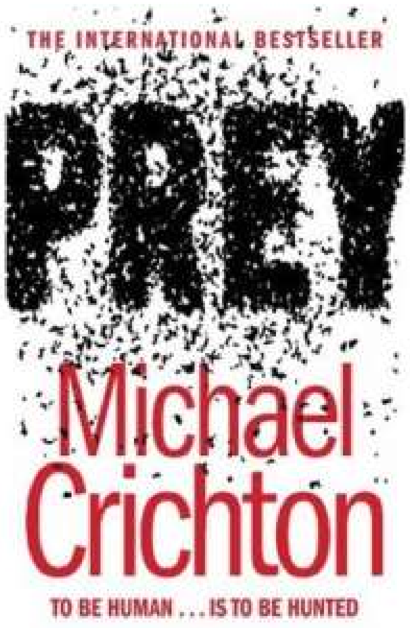
Bibliography

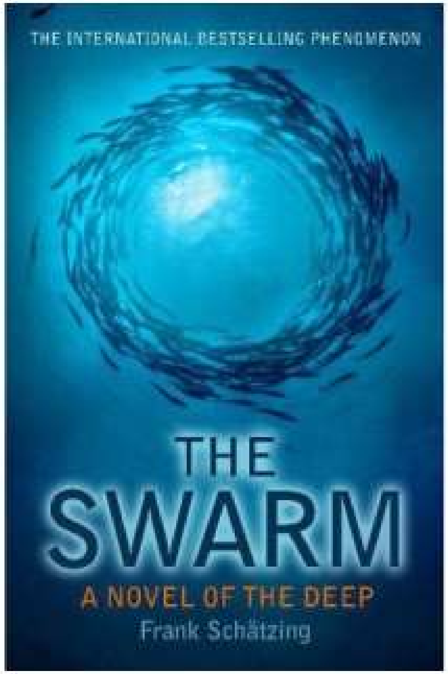
- Floreano, Dario, and Claudio Mattiussi. *Bio-inspired artificial intelligence: theories, methods, and technologies*. MIT press, 2008.

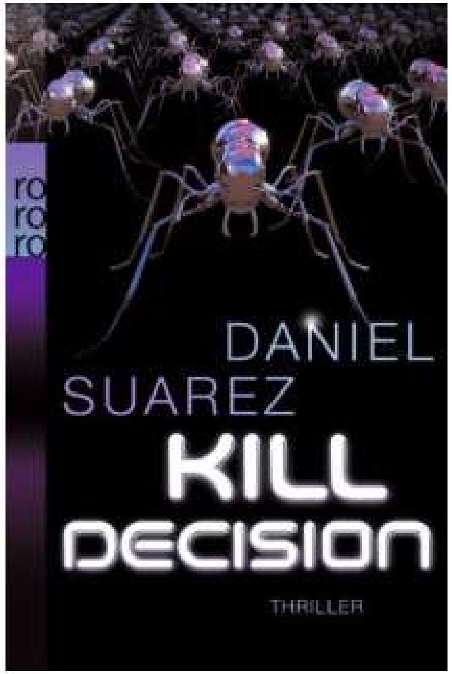
- Hamann, Heiko. *Swarm robotics: A formal approach*. Vol. 221. Cham: Springer, 2018.

(inofficial bibliography)









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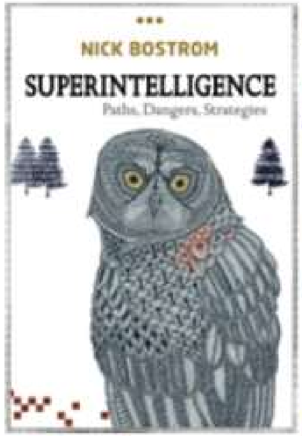


Superintelligence: Paths, Dangers, Strategies
This is the new book.

[Oxford University Press, 2014]

Stephen Hawking warns of the dangers of 'intelligent' robots

Rob Waugh for Metro.co.uk Tuesday 13 Jan 2015 11:35 am

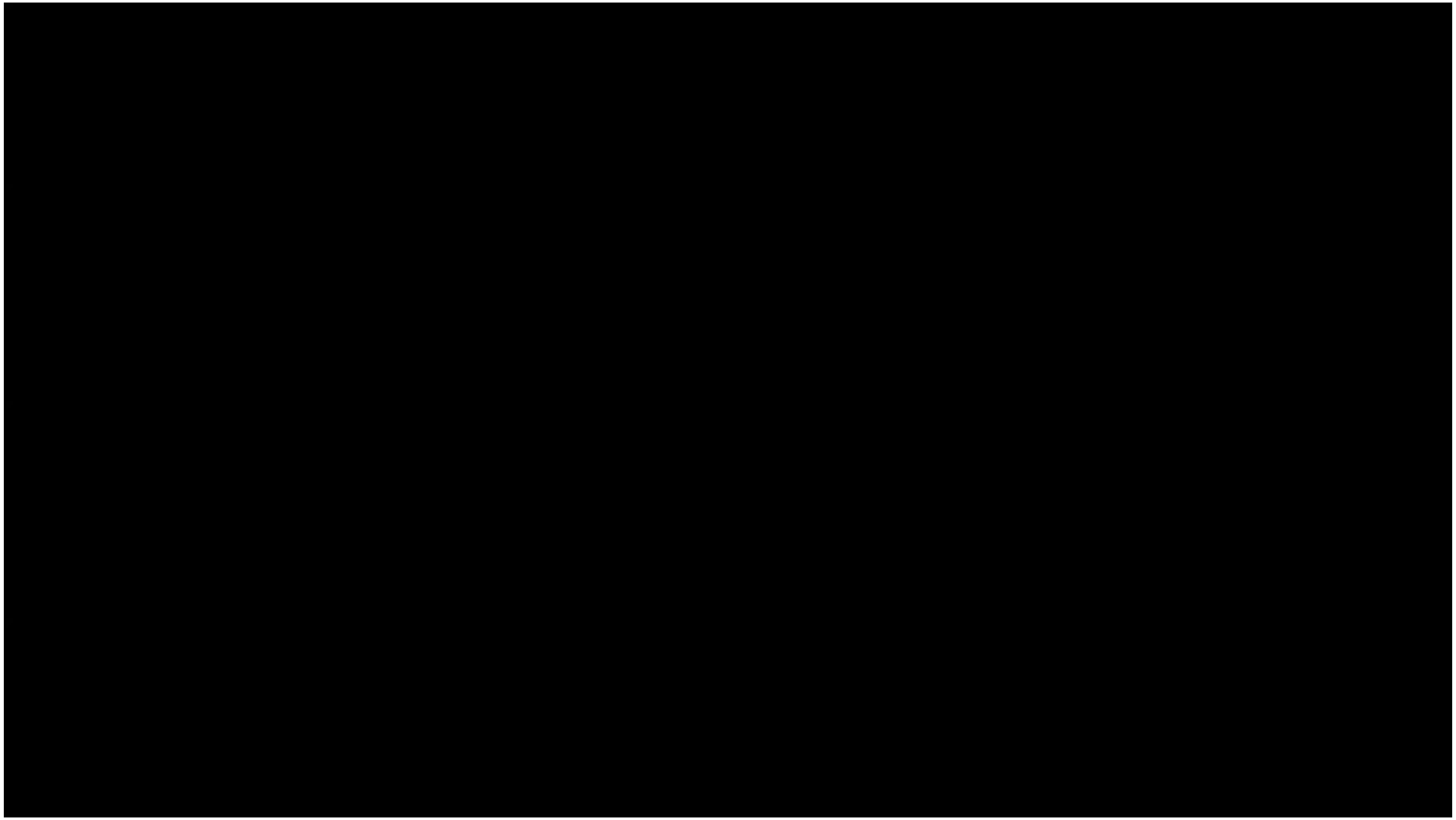
Stephen Hawking is among 150 scientists who have written an open letter warning of the dangers of artificial intelligence – and calling for limits in its use, especially in hi-tech robotic weapons systems.

Hawking has previously warned that the development of 'true' artificial intelligence could be the beginning of a process that ends with the annihilation of all life on Earth.

"Nick Bostrom makes a persuasive case that the future impact of AI is perhaps the most important issue the human race has ever faced. Instead of passively drifting, we need to steer a course. Superintelligence charts the submerged rocks of the future with unprecedented detail. It marks the beginning of a new era."

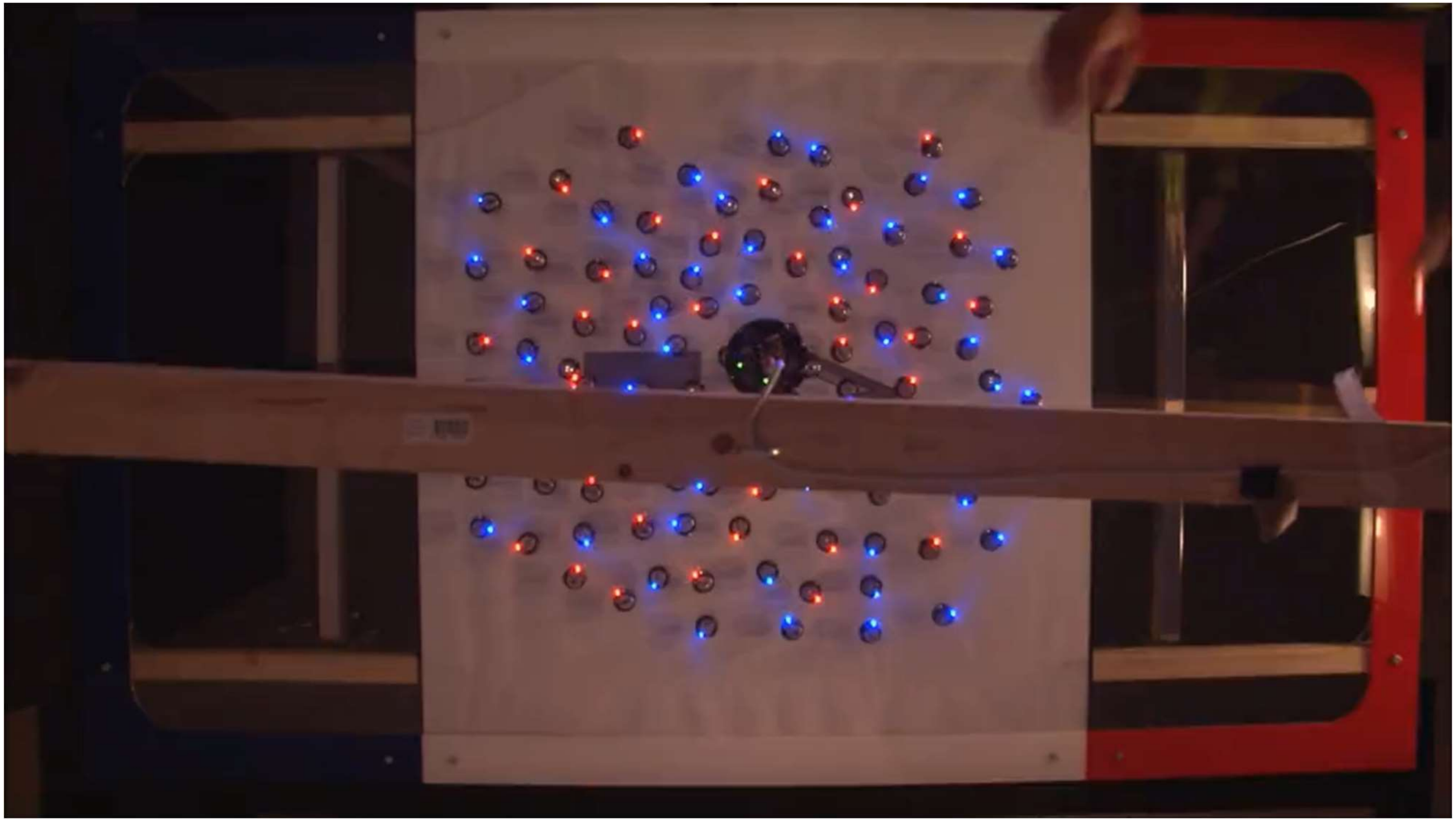
(Stuart Russell, Professor of Computer Science, University of California, Berkley)

Swarm Intelligence



1000 swarm robots

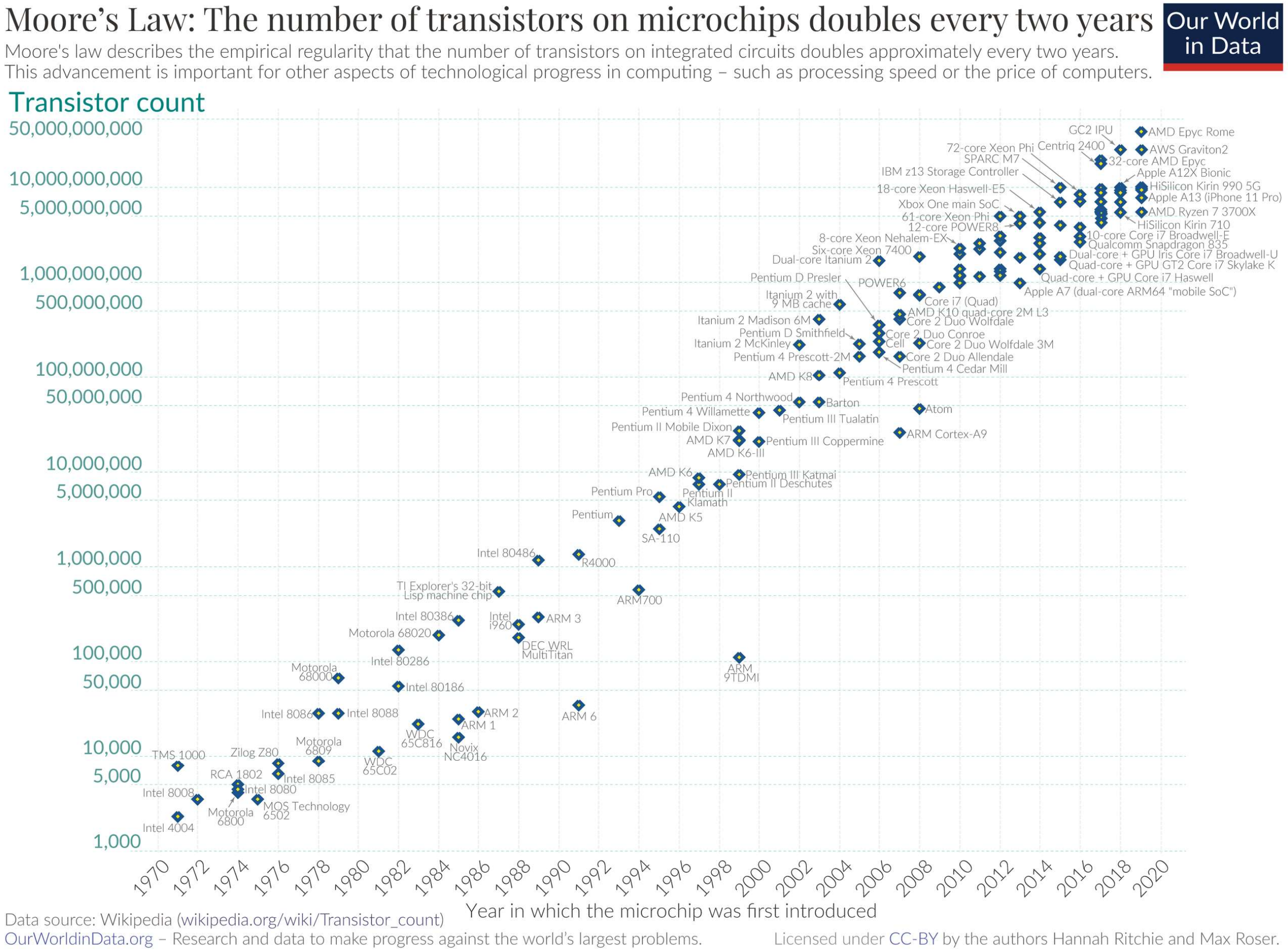
100 swarm robots



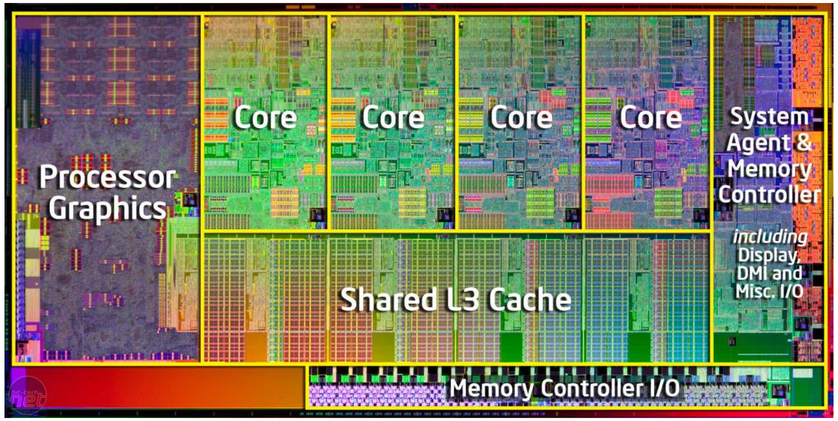
What do you think? (3X5 minutes discussions)

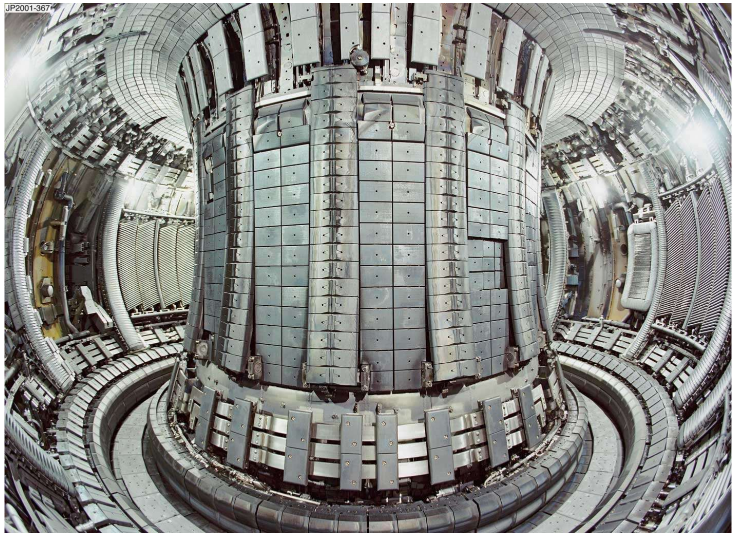
1. Why do we need to investigate collective robotics?
2. How would you define collective robotics?
   What are its key features?
3. What advantages can you envision in using collective robotics?
   How does it differ from other fields of robotics?

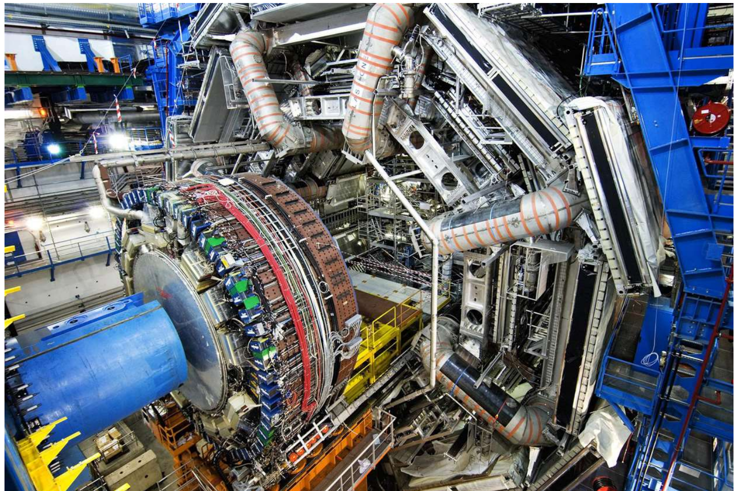
Ever increasing complexity



Ever increasing complexity







Agent complexity & complexity of behavior

~ 2.5 × 105 neurons

(not simple, but simpler!)

~ 8.6 × 1010 neurons

(beware of fallacy*: transistor , neuron)

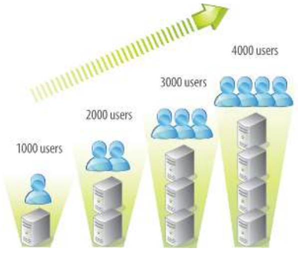
*(cf. senseless extrapolations, Manfred Eigen vs Ray Kurzweil)

Social insects as architects

Complexity and the art of simplicity

How to create complex & reliable systems based on simple & unreliable components?

Main ideas of swarm robotics



➢scalability

maximal scalability requirement

⇒ unlimited swarm size

➢keep it simple!

simple individual behaviors of robots

but complex swarm behavior

➢key technology

self-organization

⇒ exploiting feedback processes and fluctuations

Collective behaviors across species

LOCUSTS

Behavior: Cannibalism When enough locusts squeeze together, bites from behind send individuals fleeing to safety. Eventually they organize into conga-line-like clusters to avoid being eaten. They also emit pheromones to attract even more locusts, resulting in a swarm.

STARLINGS

Behavior: Do what the neighbors do These birds coordinate their speed and direction with just a half dozen of their closest murmuration-mates, regardless of how packed the flock gets. Those interactions are enough to steer the entire group in the same direction.

HONEYBEES

Behavior: Head-butting When honeybees return from searching for a new nest, they waggle in a dance that identifies the location. But if multiple sites exist, a bee can advocate for its choice by ramming its head into other waggling bees. A bee that gets butted enough times stops dancing, ultimately leaving the hive with one option.

GOLDEN SHINERS

Behavior: Seek darkness Presumably for protection, shiners search out dark waters. But they can't actually perceive changes in light levels that might guide their way. Instead, they follow one simple directive: When light disappears, slow down. As a result, the fish in a school pile up in dark pools and stay put.

ANTS

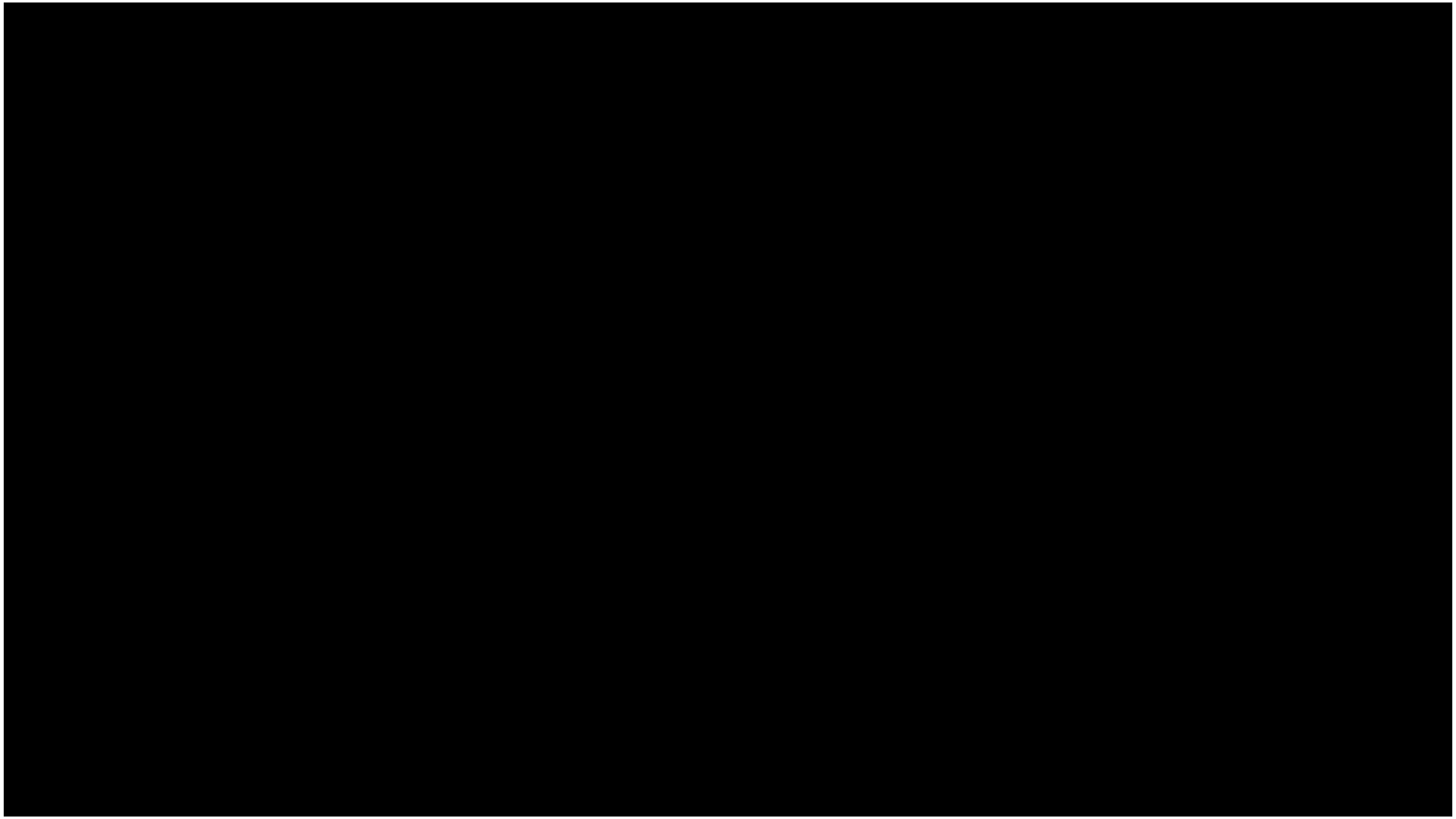
Behavior: Work in rhythm When ants of a certain species get crowded enough to bump into each other, coordinated waves of activity pulse through every 20 minutes.

HUMANS

Behavior: Be a follower Absent normal communication, humans can be as impressionable as a flock of sheep. If one member of a walking group is instructed to move toward a target, though other members may not know the target—or even that there is a target—the whole group will eventually be shepherded in its direction.

Starlings

Fish



Locusts

Sheep

What is a swarm?

Biology defines a swarm via swarming behavior

swarm behavior is aggregation,
often combined with collective motion

examples which have their own word for the behavior:

- birds (e.g., starlings) – flocking
- fish (e.g., herring) – shoaling/schooling
- quadrupeds (e.g., buffaloes) – herding

other examples:
social insects: ants, termites, honeybees, wasps,
cockroaches, locusts

How big is a swarm?

1, 2, many?

swarm size (number of units) (Beni, 2005)
not as large as to be dealt with statistical averages
not as small as to be dealt with as a few-body problem
$\Rightarrow$ order of 10^2 to $\ll 10^{23}$ (i.e., not in “Avogadro-large” numbers)

footnote:
Avogadro constant, 6.02×10^{23} 1/mol
Mole: amount of substance containing as many elementary entities as in 12 grams of pure carbon-12

Question: why not more than Avogadro number?

Avogadro’s number is huge — it's the number of atoms or molecules in a mole of a substance. Having that many *physical* robots is simply not feasible.

If you want to control 10^{23} agents, you're essentially entering the realm of molecular robotics or synthetic biology, not traditional swarm robotics.

Swarm robotics typically involves 10s to 1000s of robots (maybe up to millions in theory), but Avogadro-scale swarms are purely theoretical, and beyond the bounds of physics, engineering, and current computation.

What is swarm robotics?

- swarm robotics (Dorigo and S¸ahin, 2004)

  Swarm robotics is the study of how a large number of relatively simple physically embodied agents can be designed such that a desired collective behavior emerges from the local interactions among agents and between the agents and the environment.

- properties of a robot swarm (Beni, 2005)
  1. decentralized control
  2. lack of synchronicity,
  3. simple (quasi) identical members / quasi-homogeneous
  4. mass produced

What is swarm robotics?

Minimalist approach (primarily concerning the hardware)
seems not to be a consensus in the community anymore:

- scalable swarm robotics: not minimalist and not directly nature-inspired
- practical minimalist swarm robotics: not directly nature-inspired
- nature-inspired minimalist swarm robotics

Synonyms and related fields:

- minimalist robotics
- robot colonies
- distributed robotics
- large-scale minimalist multi-robot systems
- collective robotics

(Sharkey, 2007)

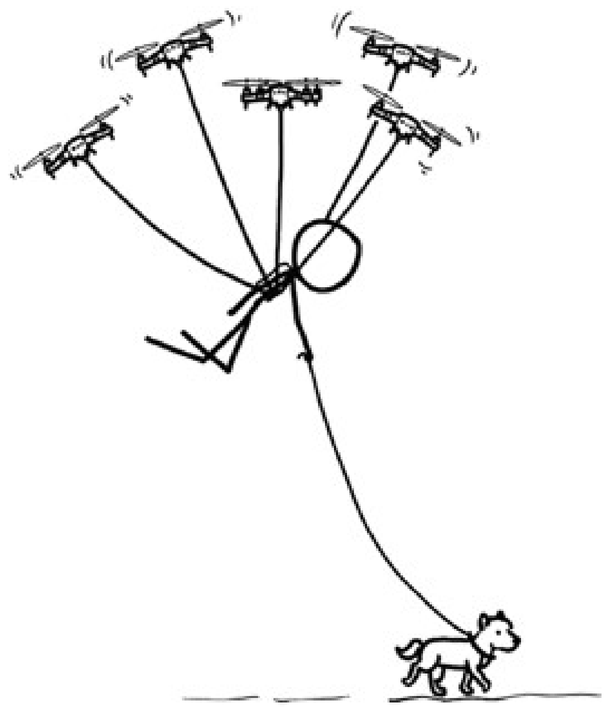
Why swarm robotics?

3 main advantages:

Robustness: redundant system, no single-point-of-failure, loss of certain percentages of the swarm possible without big effects on effectivity

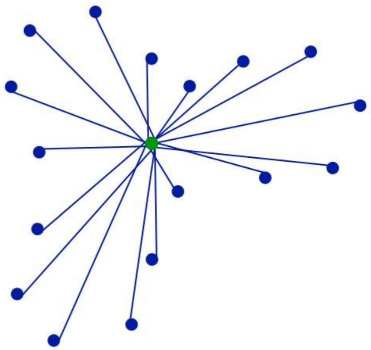
Flexibility: identical members, no specialization in hardware

Scalability: same algorithm is applied for different swarm sizes, efficiency per robot does not decrease considerably with increasing swarm size

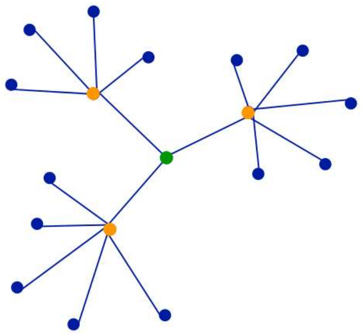


Coordination schemes

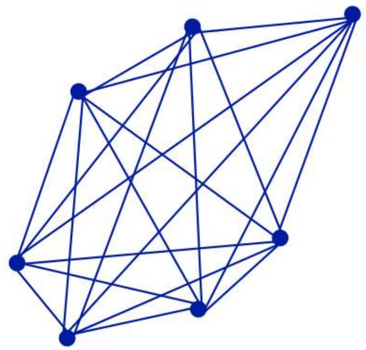
centralized



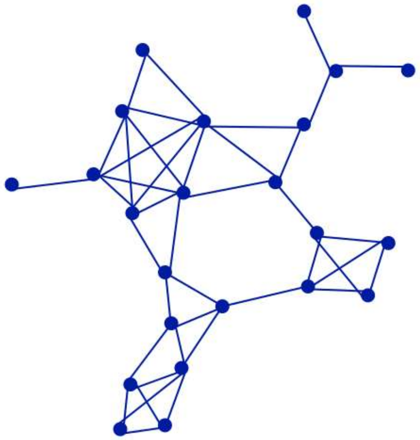
hierarchical



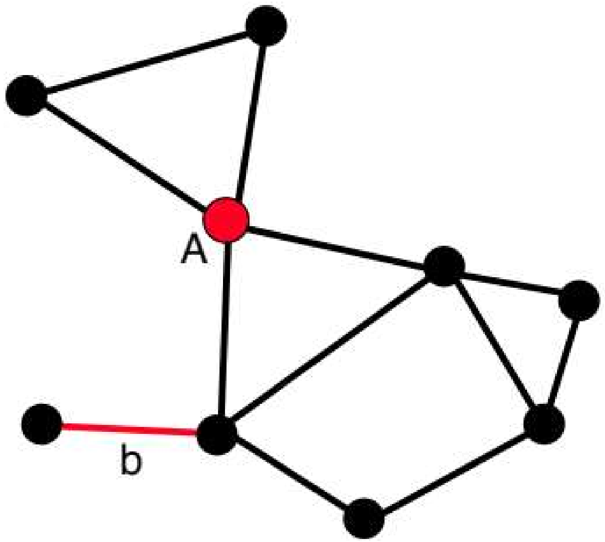
coordination



emergent / distributed



Robustness

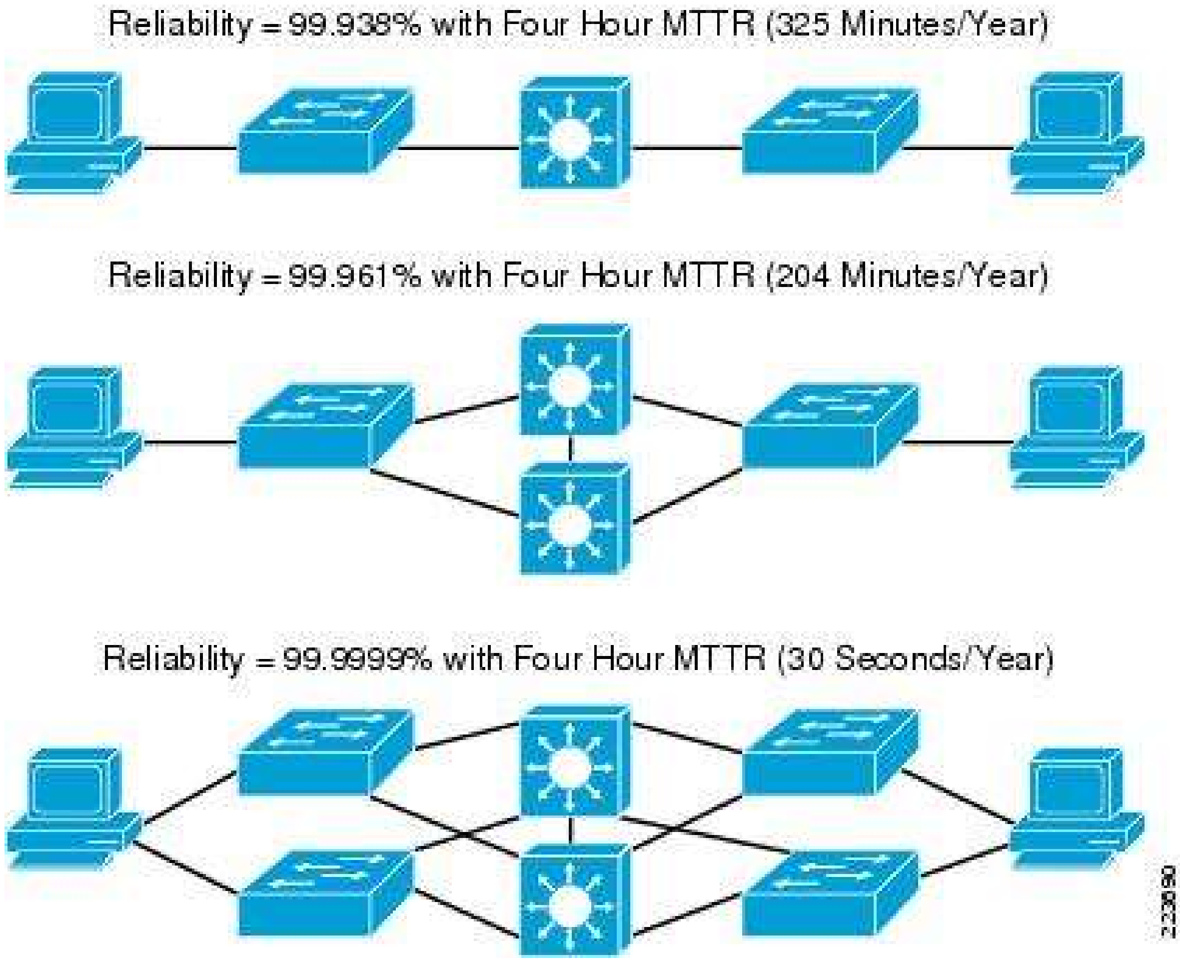


avoid single-point-of-failure:
If node A or edge b is lost
the graph is separated into
two connected components

in robot groups: avoid concentration of responsibilities or information within a single robot, every robot needs to be substitutable any time without too much overhead

⇒ no central control, no central data storage, no specialization

Robustness: Design guide line

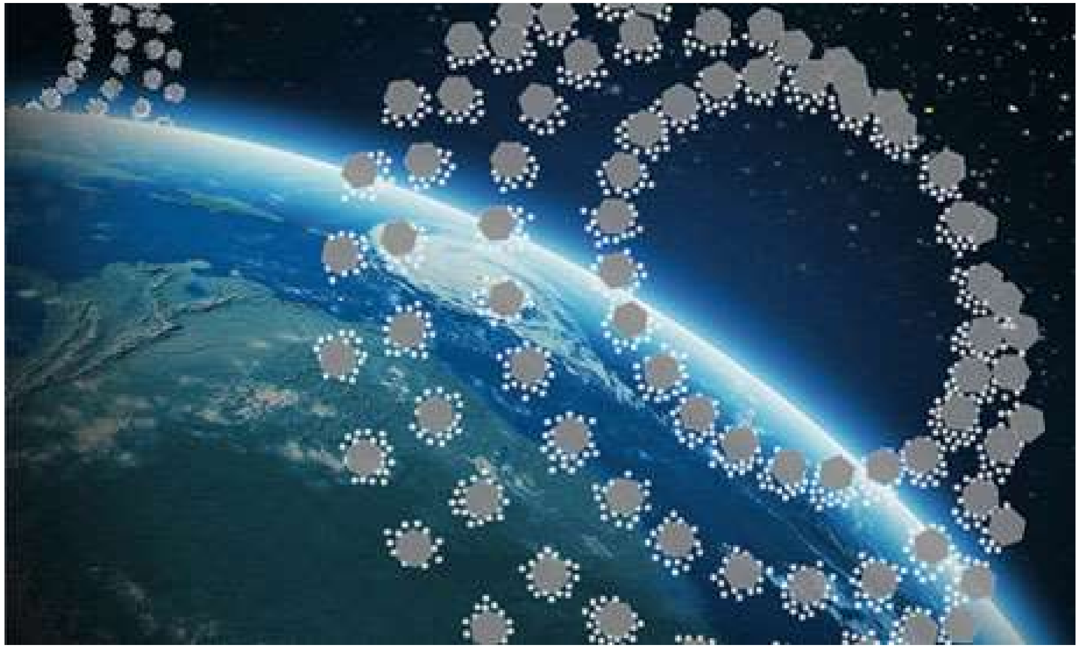


avoid single-point-of-failure:

by redundancy

and/or by **flexibility**
(each robot is able to switch to any other task)

Robustness: Example

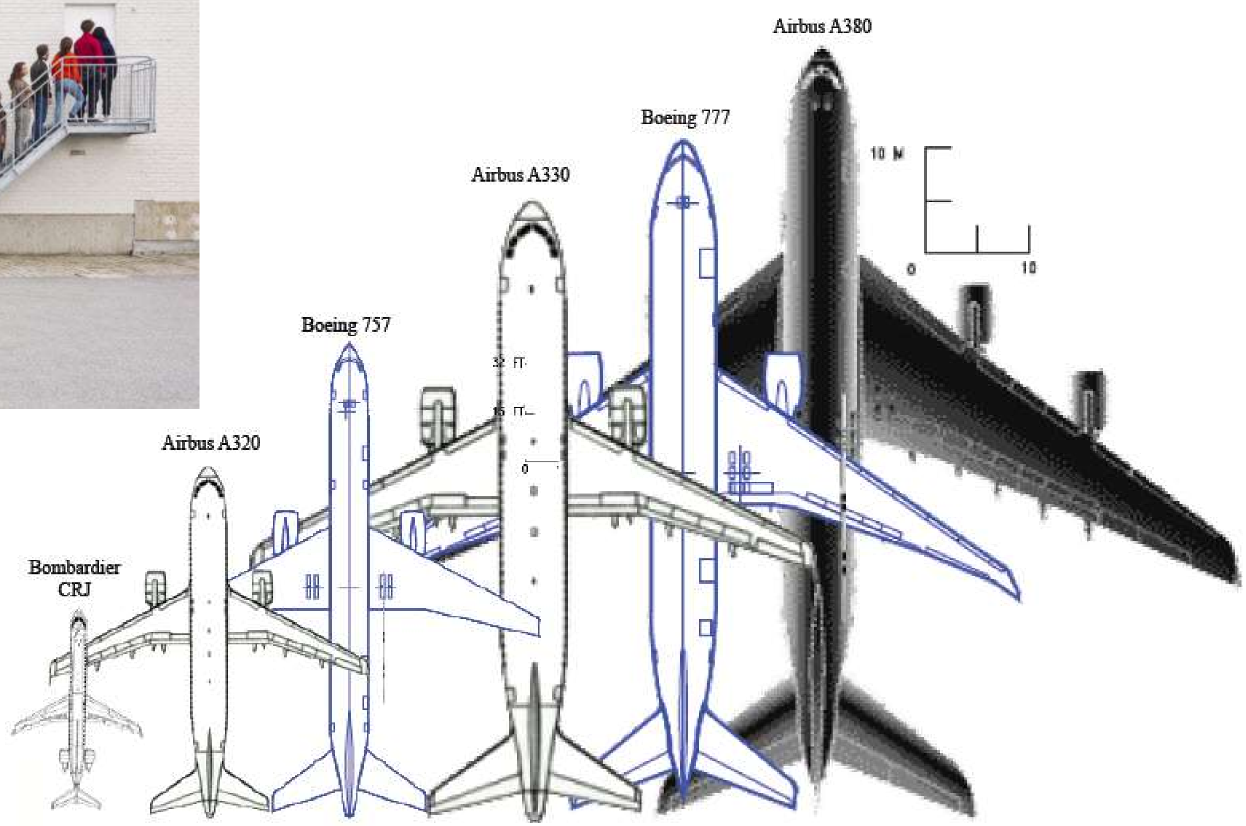


Instead of sending up 1 space probe for 3 billion Euros

send up 100 small space probes for 30 million each

Scalability

How does system performance scale with increasing work load?

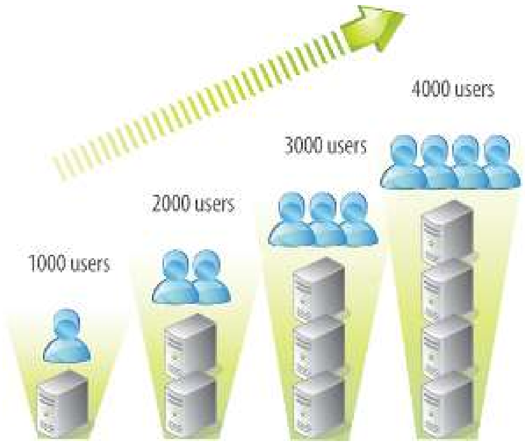


How does a design concept scale with increasing size?

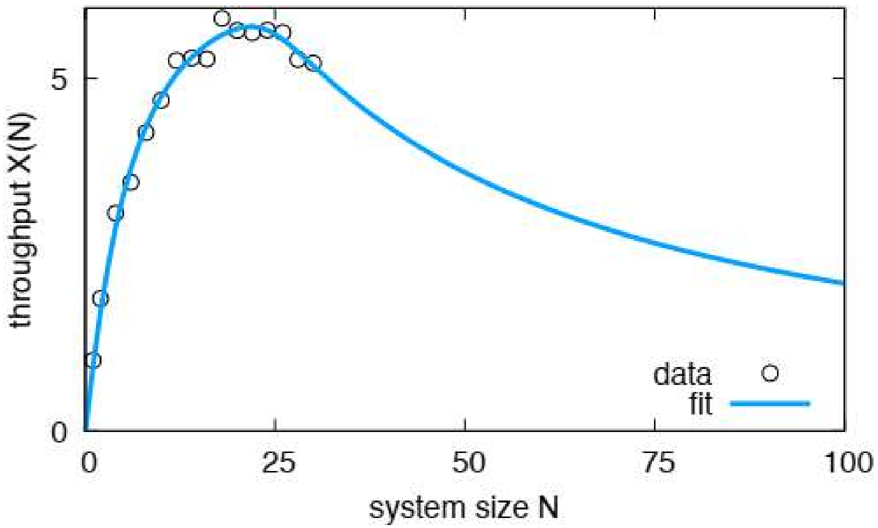
Scalability in computer systems

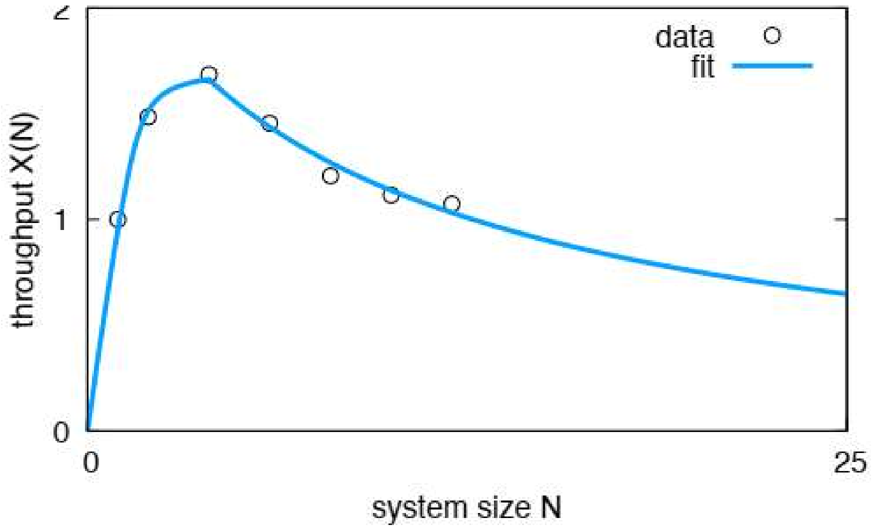
Increasing number of users is answered with increasing number of servers.

Does it scale (1 server for 1000 users, for any number of users)?



Scalability in computer systems



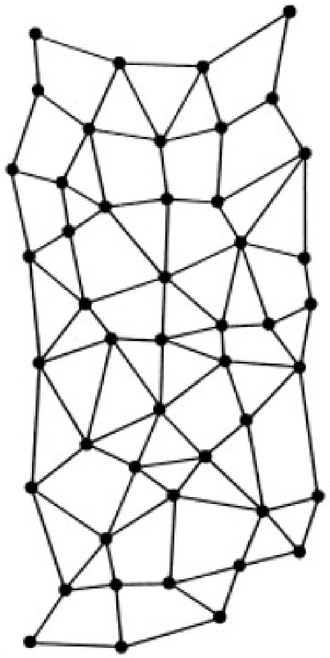


left: SQL server benchmark (Gunther, 2007), transactions per second over number of virtual users

right: NAS Parallel Benchmark (Jin et al., 1999), computational fluid dynamics (Navier-Stokes eq.), numerical solver for scalar pentadiagonal bands of linear equations, speedup over number of cores

→ arbitrary scalability not feasible (bottlenecks, overheads etc.)

Scalability: Design guide line



DISTRIBUTED

- only local interactions,
- only storage of local data,
- no broadcasting,
- no traveling on swarm-scale
- (circling swarm, crossing swarm)
- swarm size might increase
- but swarm density should be limited

What is not swarm robotics?

multi-agent systems / multi-robot system (e.g., RoboCup)

- distribution of / access to global information
- all2all communication (broadcasts)
- sophisticated communication protocols
- explicit assignment of roles
- negotiations between agents
- generally not scalable