FROM ANTS TO A(GE)NTS

The Wonderfully Weird World of Multi-Agent Swarms

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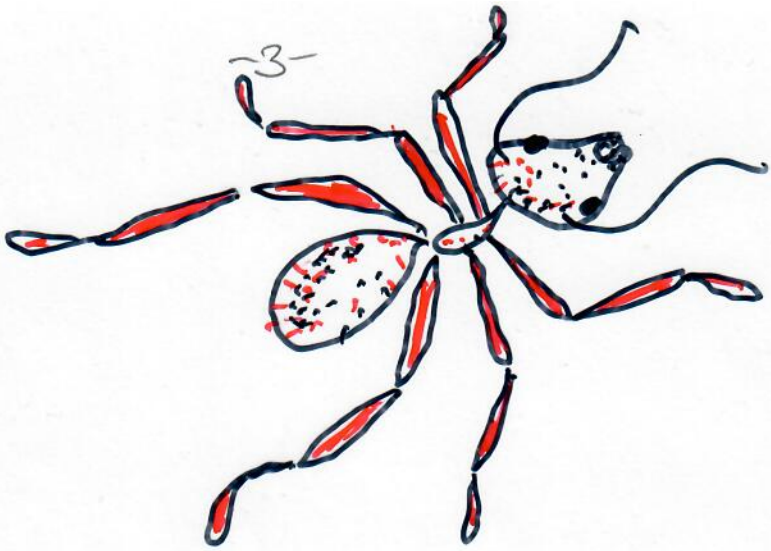
"GO TO THE ANT, THOU SLUGGARD
CONSIDER HER WAYS AND BE WISE
WHICH HAVING NO GUIDE OVERSEER
OR RULER - PROVIDETH HER MEAT
IN THE SUMMER AND GATHERETH
HER FOOD IN THE HARVEST..."

PROVERBS 6/6



ANTS

TRIVIA: 12000 named species,

0.7 - 52 milimeter sizes,

3/4 live in Jungles, 1/4 rest of the world (except Antarctica),

eat everything,

biomass (≅ 20% of all animals higher than vertebrates!),

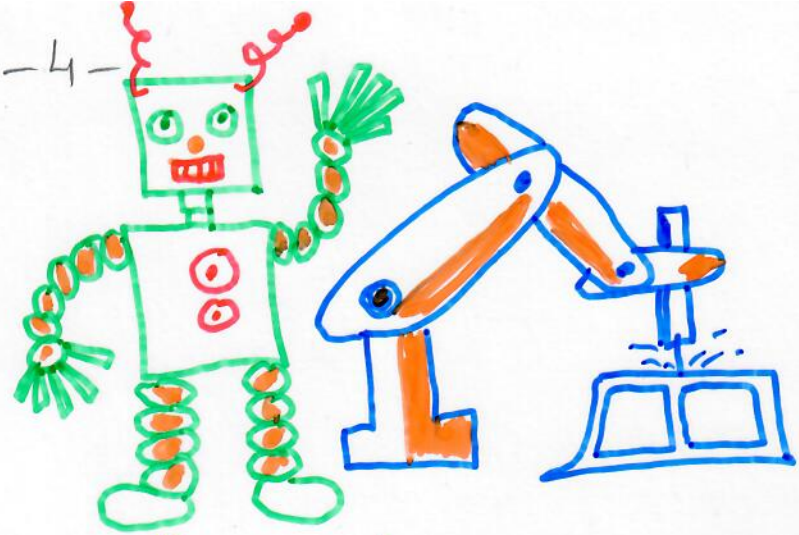
raise livestock ("aphids"),

grow fungi (leafcutter ants),

make war using "suicide bombers" "trojan horses",

take slaves, raid other species & other animal nests

- LIVE IN "RUTHLESSLY EFFICIENT COLONIES" & operate LIKE A SUPERORGANISM
- coordination & communication via PHEROMONES



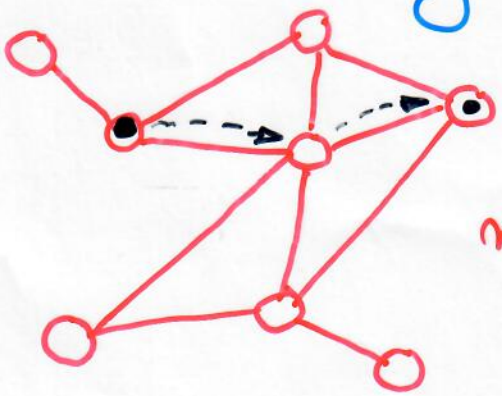
ROBOTS

TRIVIA

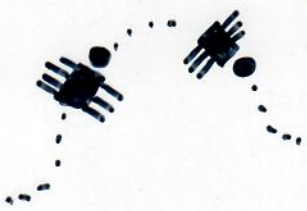
- man made machines
- name means "worker" (robota)

  introduced by Karel Čapek play RUR (Rossum's Universal Robots) (1921)
- popularized by Asimov
- not too many "species"
- consume electrical energy and/or hydraulic power
- "few" sensing capabilities

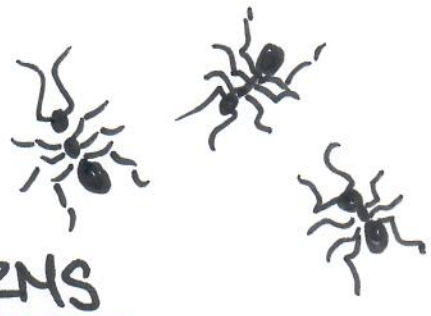
More recently BOTS: "virtual artificial agents"



nanoROBOTS: "chemical-biological agents"



RESEARCH ON MULTI-A(GE)NT SWARMS



CONSIDERS SYSTEMS OF INTERACTING SIMPLE ROBOTS/BOTS/MOBILE AGENTS

WHERE

- AGENTS HAVE LIMITED CAPABILITIES
  (identical, anonymous, oblivious - i.e. limited memory - myopic - i.e. simple local sensing, mute - i.e. no direct communication, using pheromone signals or traces in the environment)
- INTERACT ACCORDING TO FIXED RULES OF SENSING BASED MOTION

AND AIMS TO EXPLORE THE CAPABILITIES AND FUNDAMENTAL LIMITATIONS OF SUCH SYSTEMS

ANT ROBOTICS

THE ROBOT ~ A(GE)NT

- can sense (a "see") others / objects in a small neighborhood
- can smell pheromones left in the environment (in its neighborhood)
- can move to a new location with a given speed

THE ENVIRONMENT

- a region in the plane or on a surface
- an array of "rooms" ~ locations arranged on a grid
- a connected network of computers
  THE INTERNET (a GRAPH)

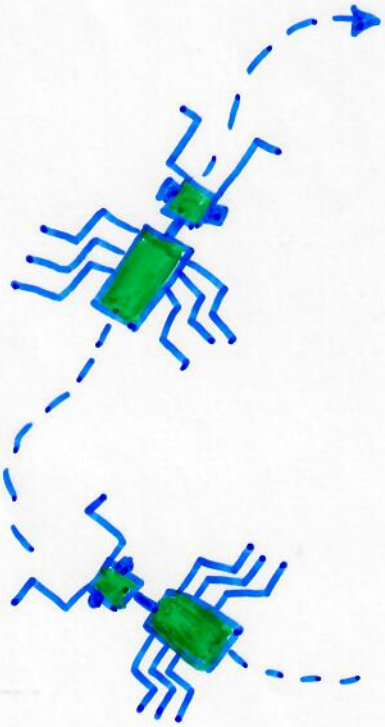
ANT/SWARM ROBOTICS

INSPIRATION : • THE INSECT/ANIMAL SOCIETIES
• ANT COLONIES

PRINCIPLES : SIMPLE AGENTS
with limited capabilities
- sensing
- communication
- action

EMERGENCE OF TASK EXECUTION
by local interactions between the agents

USE OF ENVIRONMENT AS A SHARED MEMORY RESOURCE
by using "pheromone" based interactions



- Reliability through Redundancy
- Scalability through Identical Agents

THE TASK / THE JOB TO BE DONE

- find a good path from START to END POINT (with/without obstacles)
  → NAVIGATION
- cover an area, i.e. visit all the region of interest (to search for something / to clear the region etc.)
  → COVERING
- to visit repeatedly all places in a region for surveillance, intruder detection etc.
  → PATROLLING
- to bring the agents together or to deploy them in a formation that is desired over the region of interest
  → GATHERING & SPREADING

My entry to the topic

"One question that I wondered about was Why the ant trails look so straight and nice. The ants look as if they know what they are doing, as if they have a good sense of geometry. Yet the experiments that I did to try to demonstrate their sense of geometry didn't work"

R. P. Feynman
Surely You're Joking, Mr Feynman
WW Norton Co, Inc, 1985

Feynman's Question led to a 1991/93 paper and this paper led to the TECHNION

ANT-TEAM at the MARS Lab

- Dr Israe Wagner (IBM Research) (PhD)
- Prof Michael Lindenbaum (Technion CS)
- Dr Vladimir Yanovski (U Toronto) (MSc)
- Dr Noam Gordon (CamTek) (PhD)
- Dr Yaniv Altshuler (MIT-Medialab) (PhD)
- Dr Eli Osherovich (Amazon) (MSc)
- Dr Yotam Ebor (Final) (PhD)
- Mr. Levi-Itshak Bellaiche (MobilEye) (MSc)
- Mr David Dovrat (Technion) (MSc) → (PhD...)
- Mr Erez Brickner (HiTech) (MSc)
- Dr Rotem Manor (HiTeck) (PhD)
- Mr Ariel Barel (PhD.....)
- Ms Ilana Segall (PhD.....)
- Mr Michael Amir (MSc) → (PhD....)
- Mr Dmitry Rabinovich (MSc) → (PhD...)
- Mr Roee Francos (MSc....)
- Mr Gidi Elazar (?)

To ILLUSTRATE OUR WORK ON

MULTI-AGENT SWARMS

I SHALL PRESENT SOME EXAMPLES

AND DEMOS

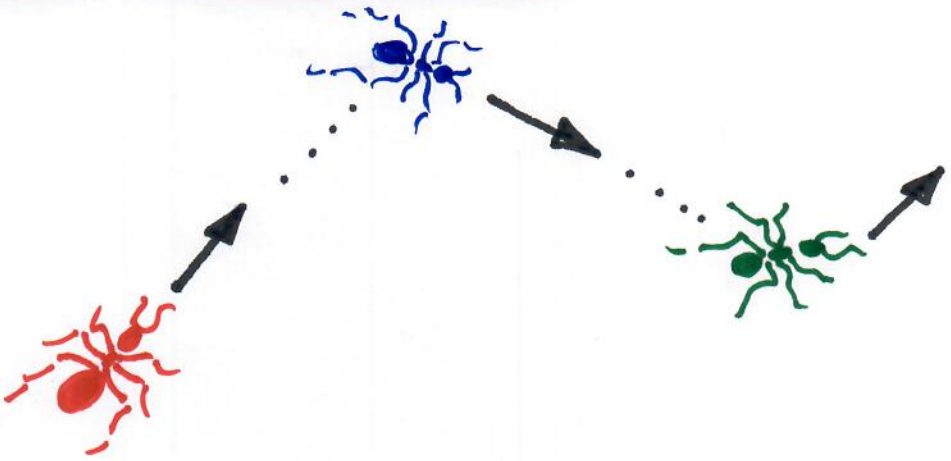
1) "HAPPY PURSUITS"
or Why the Ant-Trails look So Straight & Nice

2) "COME TOGETHER"
or Gathering / Geometric Consensus

3) "COOPERATIVE CLEANING"
or How to Extinguish Stationary & Expanding Fires

4) "FAIR PATROLLING"
or Pheromone Based Collective Patrolling

"HAPPY PURSUITS"

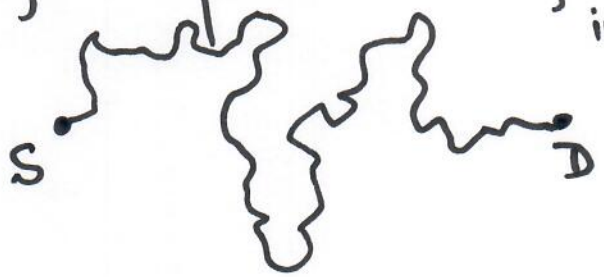


- The local interaction rule:
  Chain Pursuit.

$$\frac{d}{dt} p_{n+1}(t) = \left(p_n(t) - p_{n+1}(t)\right) \Big/ \|p_n(t) - p_{n+1}(t)\|$$

(unit speed pursuit of the agent "ahead")

- The first "foraging agent finds a wiggly route from anthill to food $p_0(t)$; others follow at Δt intervals.



- THEOREM:
  The paths of consecutive Ants converge to the straight line (geodesic) from S to D.

The proof of this result:

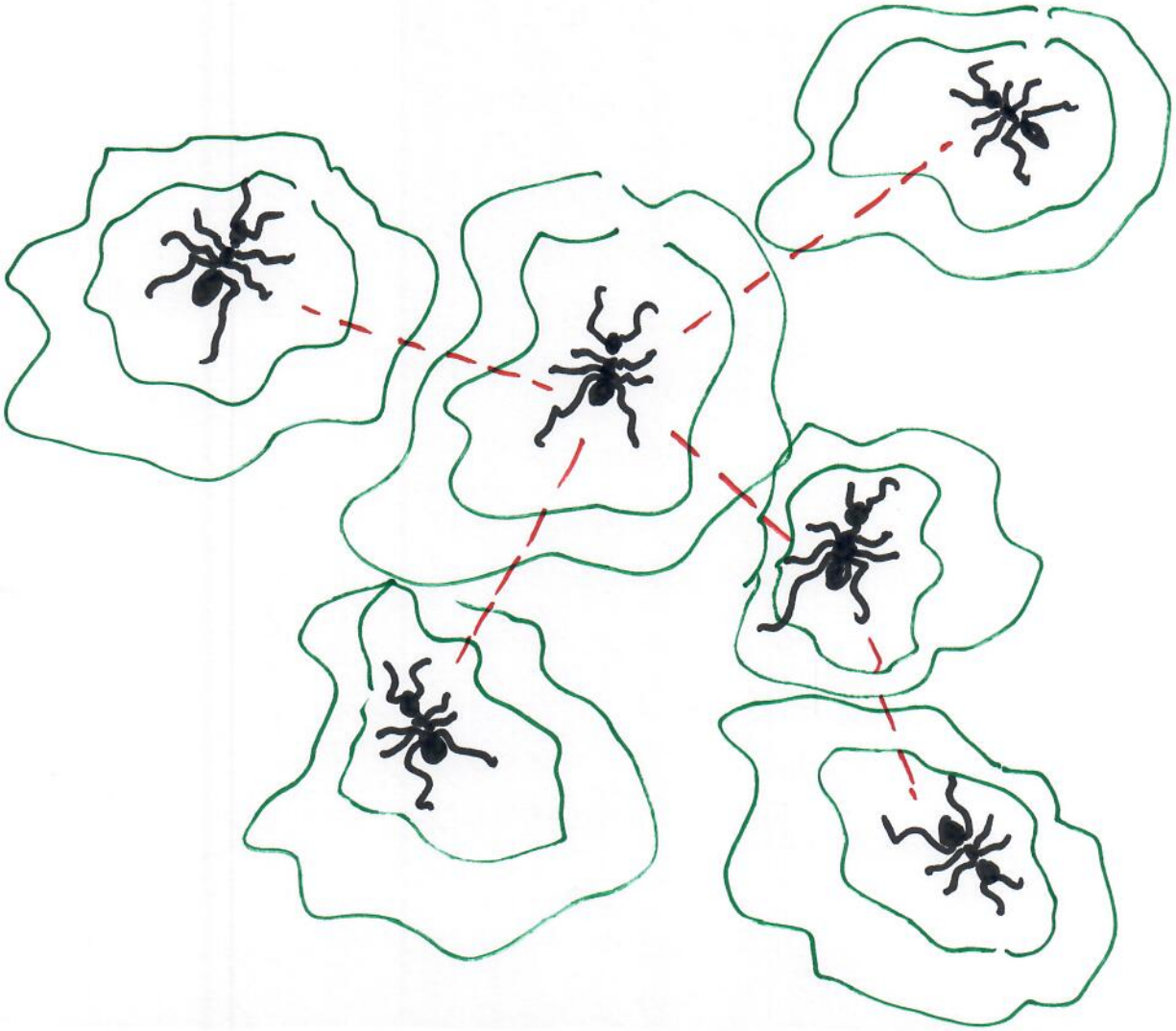
based on considering the length of paths $\{L_n$ - distance from S to D$\}$ and showing that L_n - dist(S,D) is a positive, decreasing function, converging to 0, yielding a sequence of ants moving "straight from S to D".

(In fact we have exponential decay to zero of the "excursions" of the paths $p_n(t)$ above & below the line from S to D!).

DEMO of ANTS in CHAIN PURSUIT

"COME TOGETHER NOW" (The Beatles, 1969)

AGENTS IN SOME ENVIRONMENT MUST MOVE SO AS TO GATHER AT A MEETING POINT OR CLUSTER TOGETHER. THEY MUST DO THIS BASED ON SIMPLE SENSING-BASED MOTION RULES.



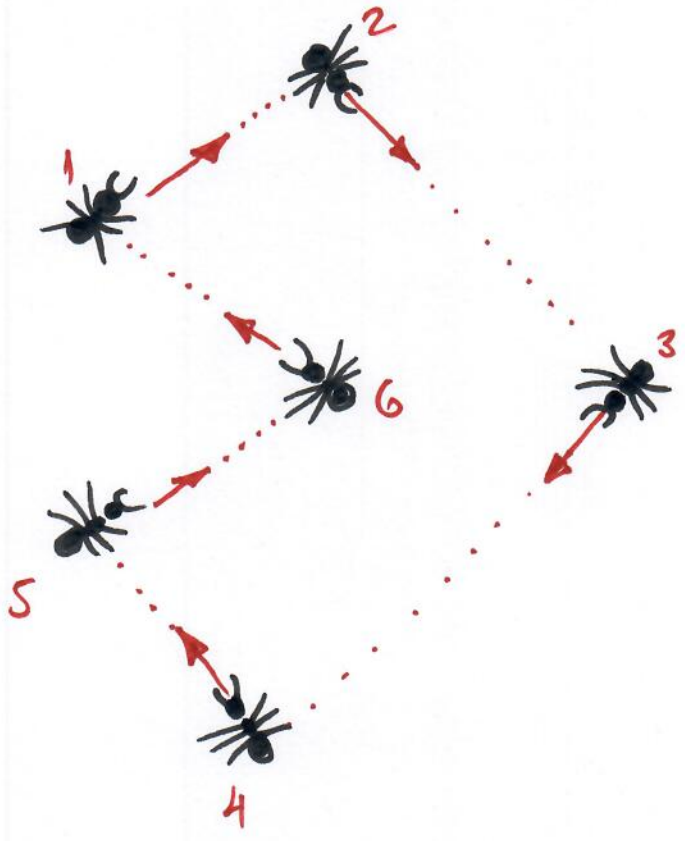
THE TASK IS ALSO CALLED

GEOMETRIC AGREEMENT

with distributed agents.

SOLUTIONS EXIST UNDER VARIOUS ASSUMPTIONS ON AGENT SENSING & MOTION CAPABILITIES.

SOLUTION via CYCLIC PURSUIT



THEOREM : IN CYCLIC PURSUIT AGENTS GATHER TO A COMMON POINT OF ENCOUNTER IN FINITE TIME.

The proof here is based on considering the sum of distances between (cyclically) consecutive agents:

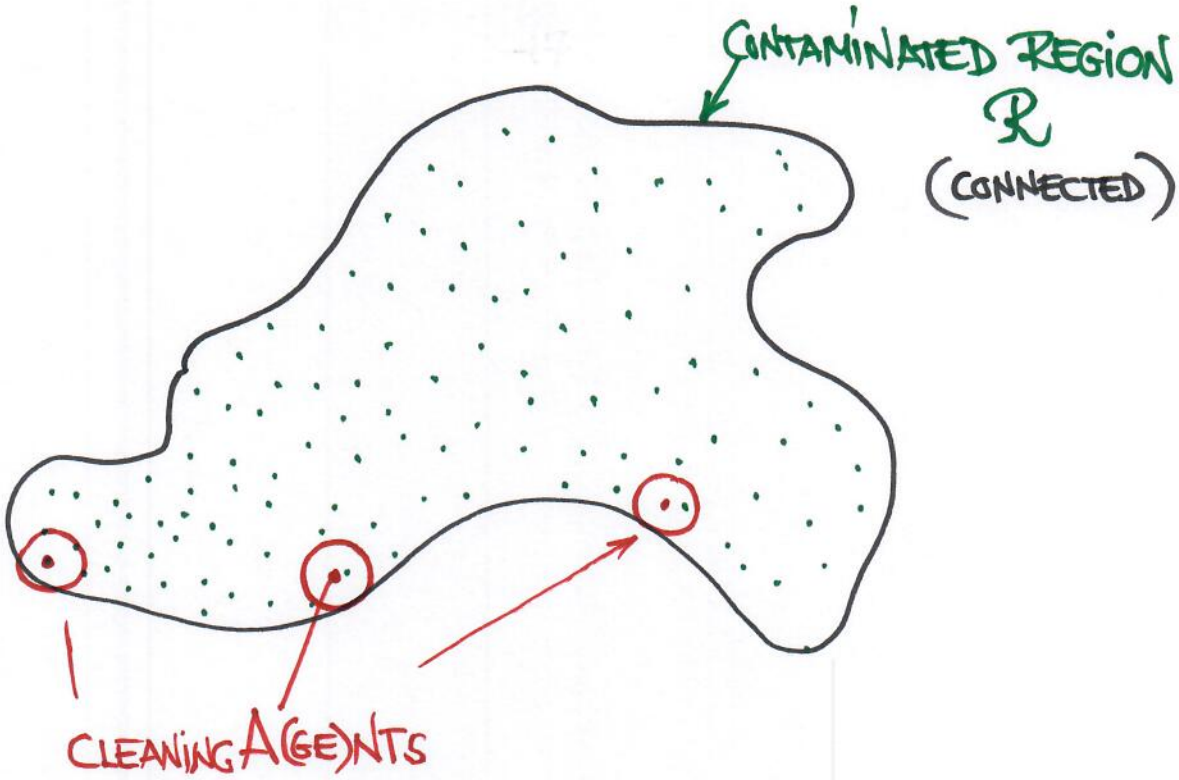
$$\mathcal{L}(t) = \sum_{k=0}^{N-1} \text{distance}\,(A_k A_{k+1 (\text{mod } N)})$$

as a Lyapunov function, and showing that while the agents are not collocated

$-\frac{d}{dt}\mathcal{L}(t) \geq \delta > 0$, hence finite time convergence to a meeting point.

DEMO of ANTS in CYCLIC PURSUIT

"COOPERATIVE CLEANING"



- AGENTS CAN SENSE "DIRT" AND CLEAN LOCALY
- AGENTS ALL APPLY THE SAME RULE
    - CLEAN BOUNDARY PATCH IF THIS DOESN'T DISCONNECT R (IF ALONE ON PATCH)
    - MOVE TO NEARBY PATCH ON BOUNDARY
    - IF (OTHER AGENT MET) WAIT A RANDOM TIME INTERVAL & MOVE ON.

TWO VERSIONS

- STATIC CONTAMINATION
- SPREADING CONTAMINATION
  (R expands!)

RESULTS:

- BOUNDS ON TIME TO CLEAN for STATIC CONTAMINATION

  R-shrinks to a patch where all agents find themselves at the end. # Agents Control the rate of shrinking

- # OF AGENTS NECESSARY FOR (POSSIBLY) EXTINGUISHING THE "SPREADING FIRE".

  given initial area ($R_{(t=0)}$) & rates of spread & agent work.

- # OF AGENTS SUFFICIENT FOR EXTINGUISHING "THE SPREADING FIRE"

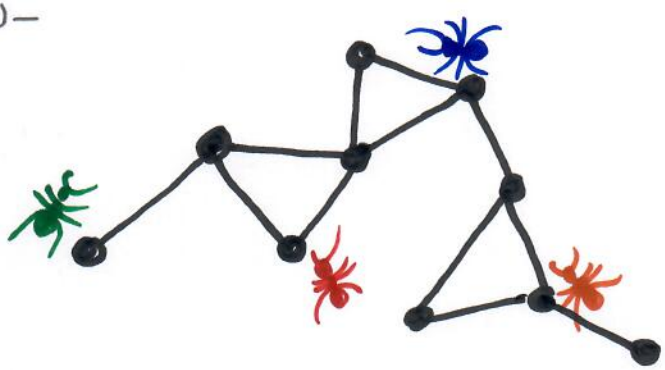
  given initial area ($R_{(t=0)}$) and rates of spread & cleaning work.

DEMO OF COOPERATIVE CLEANING

"FAIR, BALOON-PATROLLING"

Here the ENVIRONMENT is a GRAPH (which has, by assumption, a Hamiltonian path). A(GE)NTS are using pheromones which enable them

- to leave traces at vertices and/or edges, traces that evaporate in time
- traces enable a(ge)nts to tell whether they or others visited a location, and how long ago.
- all agents run the same algorithm: try to expand "your connected patrol region" by conquering new vertices if "your pressure" higher than "other agent pressure - measured by other pheromone intensity"



RESULTS:

- AS PATROL-REGIONS EXPAND and A(GE)NT PHERONONE PRESSURES EQUALIZE, WE OBTAIN A FAIR (ALMOST EQUAL-SIZE) PARTITION OF THE ENVIRONMENT GRAPH INTO K(=# of A(GE)NTS) CONNECTED SUB-GRAPHS.
- CONVERGENCE TO A STABLE PARTITION IS GUARANTEED!

BALOON PATROLLING DEMO

CONCLUDING REMARKS

- MULTI-A(GE)NT SWARMS & DISTRIBUTED ANT-ROBOTICS IS AN EXCITING INFINITELY EXPANDABLE RESEARCH AREA.
- THE PROBLEMS ARISING ARE DIFFICULT, FUN & INTERESTING
- LOTS OF APPLICATIONS CAN BE ENVISIONED

SO.... Come & join the field