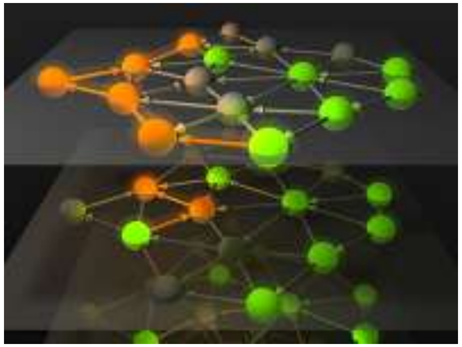
Outdoor flocking and formation flight with autonomous aerial robots

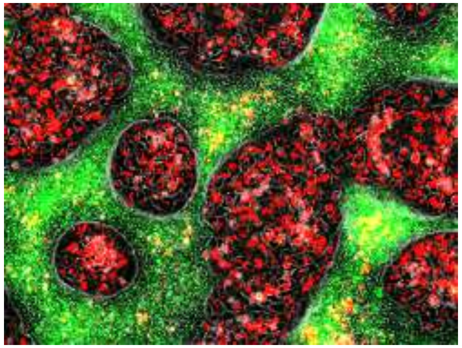
Gábor Vásárhelyi[1,2], Csaba Virágh[1], Gergő Somorjai[1,2], Norbert Tarcai[1], Tamás Szörényi[1], Tamás Nepusz[1,2], Tamás Vicsek[1,2],

[1]Eötvös University, Budapest, Hungary
[2]MTA-ELTE Research Group for Statistical and Biological Physics

Flynet Workshop, 2014.11.04., Zürich



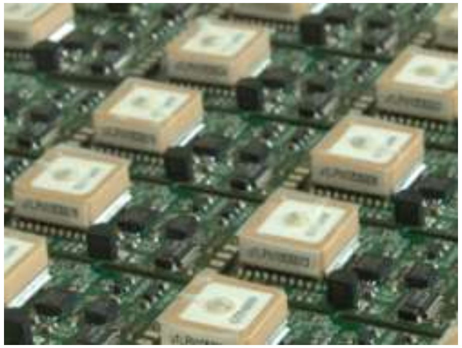
networks: controllability, hierarchy, data mining



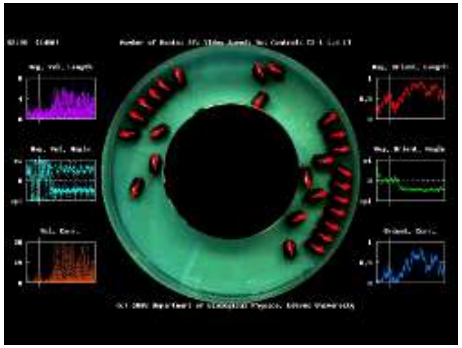
cells, tissues: patterns, segregation, percolation

birds, mammals: social dynamics, leadership

simulations: collective decisions, optimal hierarchy



hardware, software: GPS, INS, optic flow



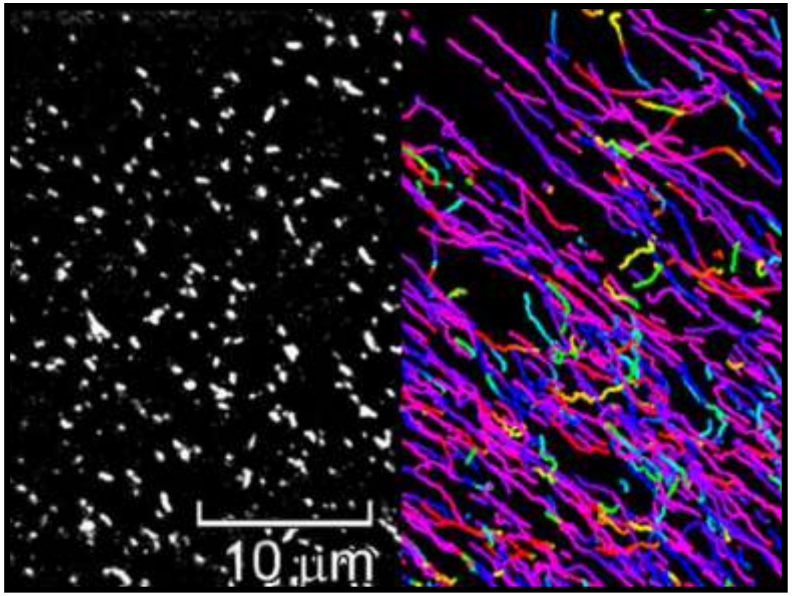
robots, drones: autonomy, leadership

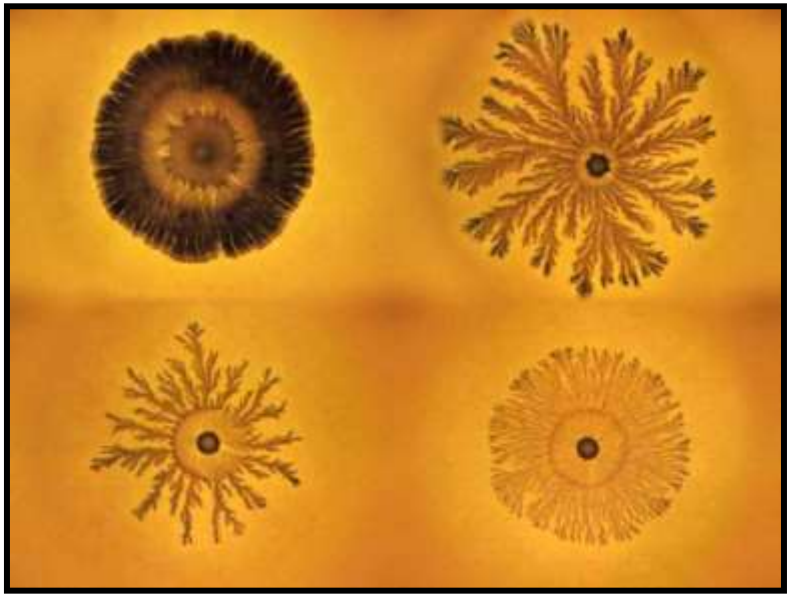
Challenges in multi robot research

- **Multidisciplinarity, terminology** (distributed vs. decentralized, Coordination-Cooperation-Collaboration, etc.)
- **Scalability** is challenging (1-2-3-5-10-100-1000):
  - Computation
  - Communication
  - Control
- **Outdoor** is challenging: there is environment, noise, delay, uncertainty, no guarantees, harsh conditions ↔ system always has to work!

What is collective motion like?

http://www.wired.com/wiredscience/2013/03/powers-of-swarms/all/





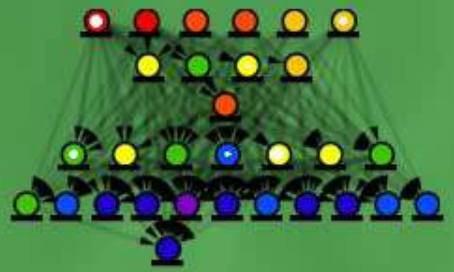
U
n
i
v
e
r
s
a
l

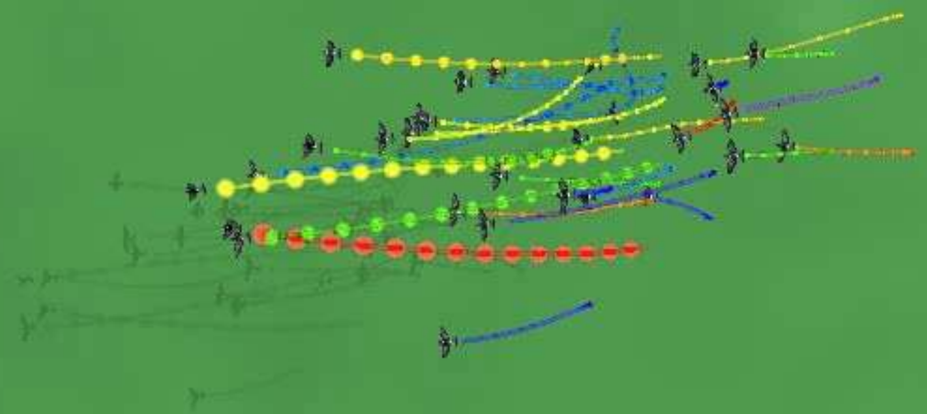
Efficient, robust, self-organized

Self propelled, non-equilibrium

Easy to model locally,
Gets complex globally…

Stable hierarchy in the collective flight of 30 homing pigeons





Lets create a **flock of drones**, that is…

- **Bio-inspired:** What can we adapt from the collective motion of animals?
- **Autonomous, decentralized** (all HW+SW, except for onboard GPS)
- **Scalable** through local inter-agent communication
- Works **outdoor**, i.e., **noise** + **delay** tolerant (VICON-free flocking algorithms)
- Fleet is controlled as a **meta unit** and performs tasks in a **self-organized** manner
- Helps us **understand** animal collective motion

Main achievements

- Realistic simulation framework
- FlockCtrl high-level autopilot hardware
- Stable and error-tolerant flocking algorithms
- Stable outdoor drone fleet of 10 units
- Efficient flock-level control setup

MikroKopter L4-ME

http://mikrokopter.de/

- ~ $$$ laptop
- Open source software / hardware
- ~ 20 min flight time
- ~1 kg load
- stable operation with manual control
- replaceable parts

Inter-unit communication: XBee

- ~ 20 $
- ~ 100 m range
- Small, lightweight, low power
- Acceptable performance with 10-12 units in simple **broadcast** mode

http://www.digi.com/

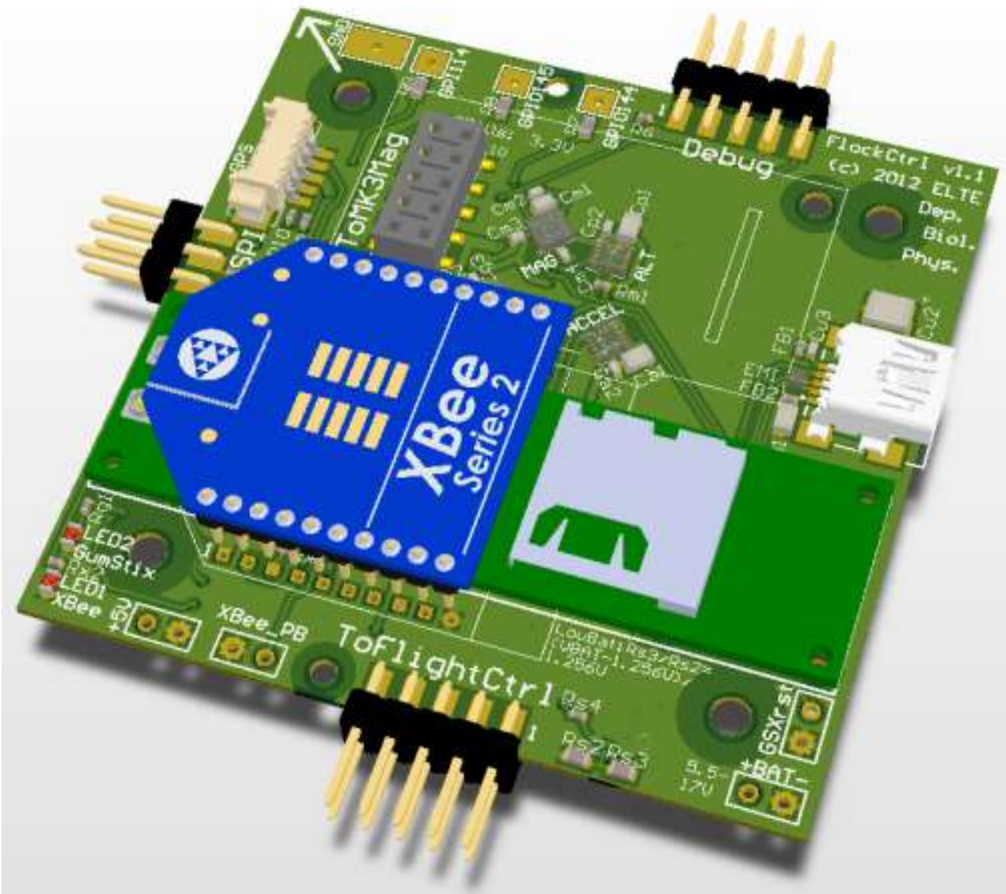
Onboard computer: GumStix

Overo Fire

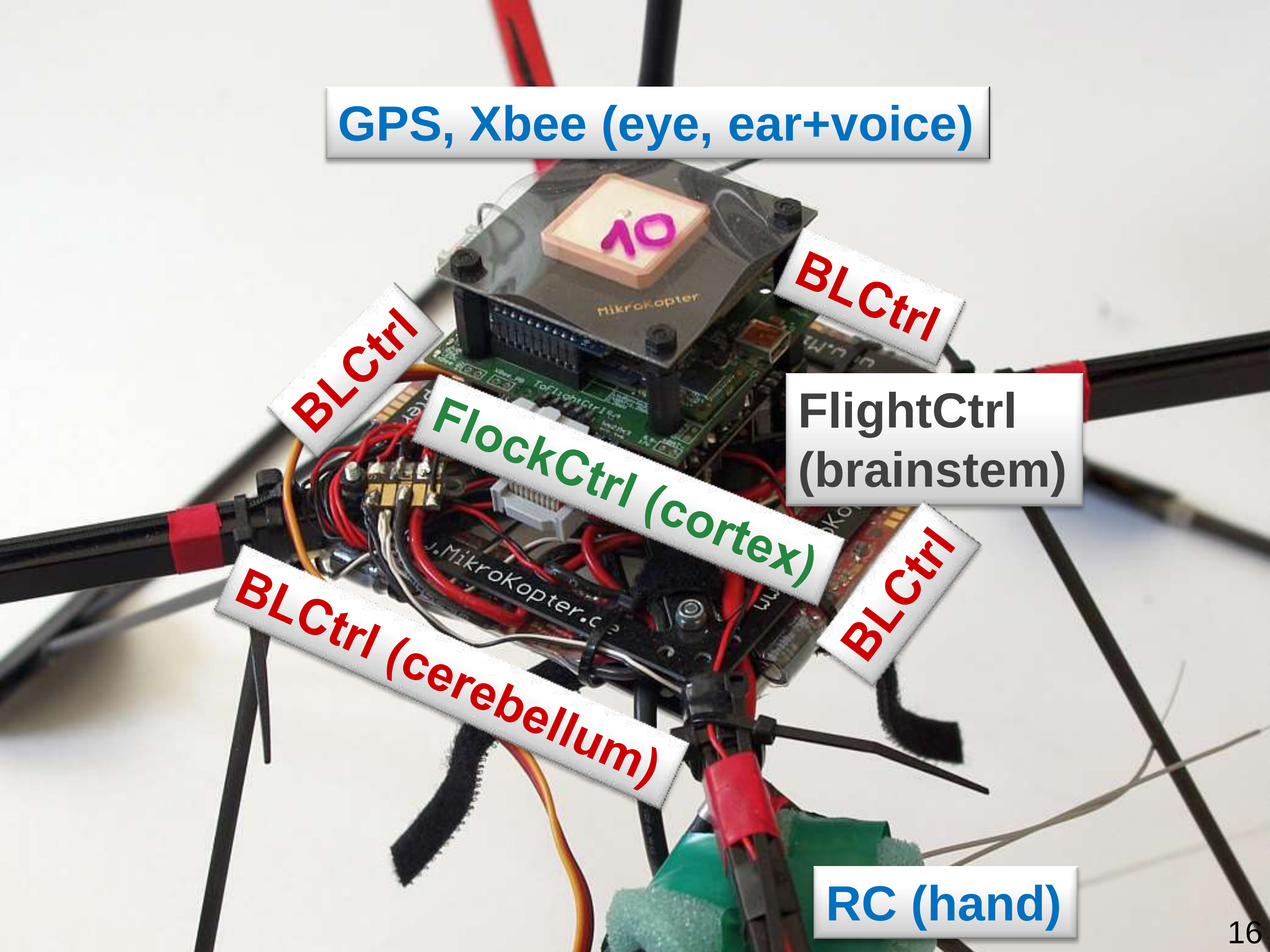
http://www.gumstix.com/

- ~ $$$ smart phone
- ultra light (5.6g)
- ultra small (fingertip size)
- Low power (<1.5W)
- 600 MHz CPU clock
- 512 MB RAM + SD card
- Bluetooth/Wifi/USB/Eth
- SPI, I2C, UART, GPIO
- Linux kernel

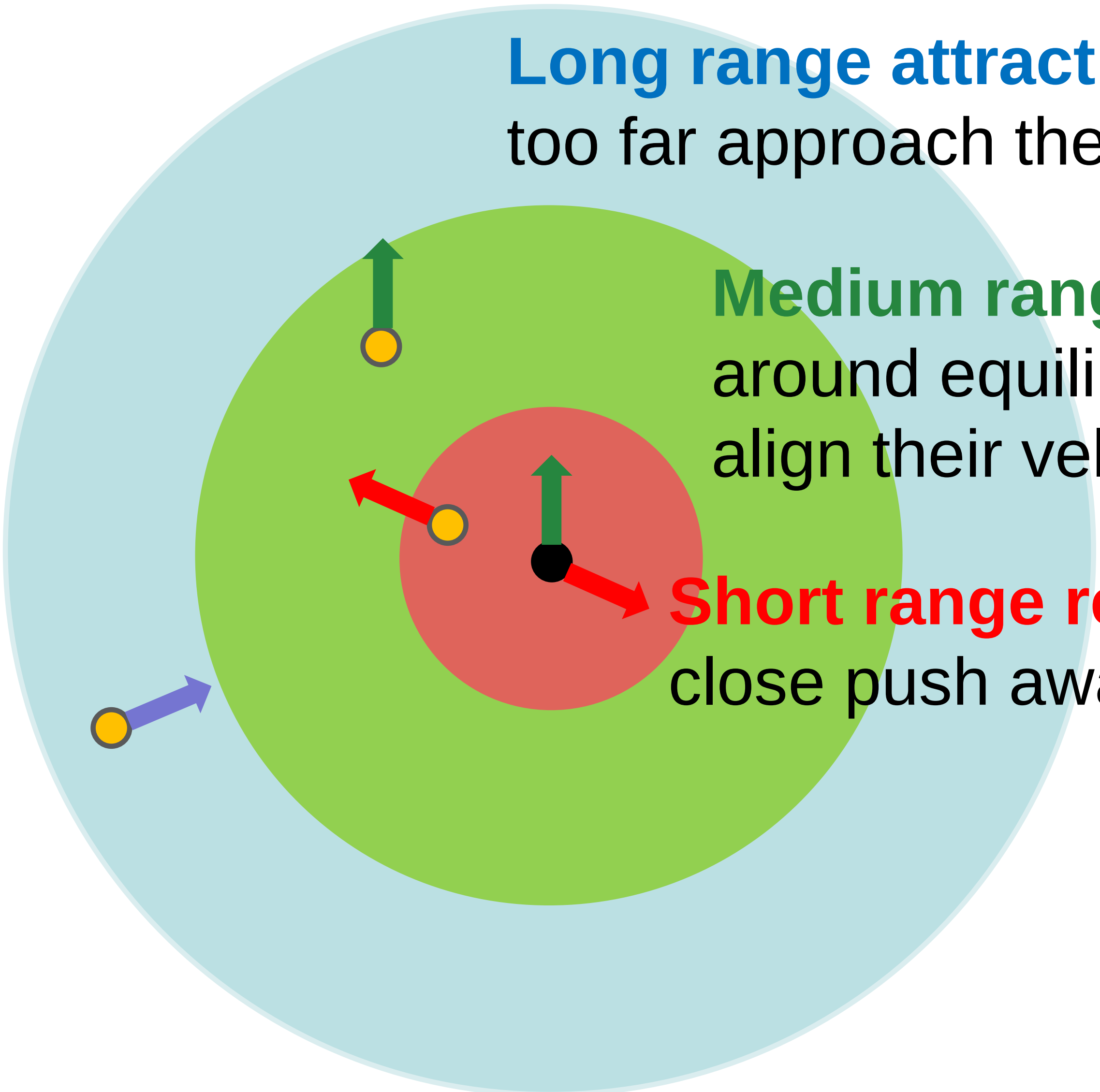
FlockCtrl – a high-level autopilot board



- (GPS)
- Redundant sensors: IMU, magnetometer, pressure sensor
- Wireless inter-agent communication: **XBee**
- Onboard processing: **GumStix**, 600MHz, ARM Linux
- 6x6 cm, 100 g, 2W


GPS, Xbee (eye, ear+voice)
BLCtrl
BLCtrl
FlightCtrl
(brainstem)
FlockCtrl (cortex)
BLCtrl
BLCtrl (cerebellum)
RC (hand)
MikroKopter

Flocking algorithm essentials



Long range attraction: units too far approach the flock

Medium range alignment: units around equilibrium distance try to align their velocities

Short range repulsion: units too close push away each other

But life is not so easy…

Short range repulsion of cranes

source: http://www.youtube.com/watch?v=qu-PsYiI7_8

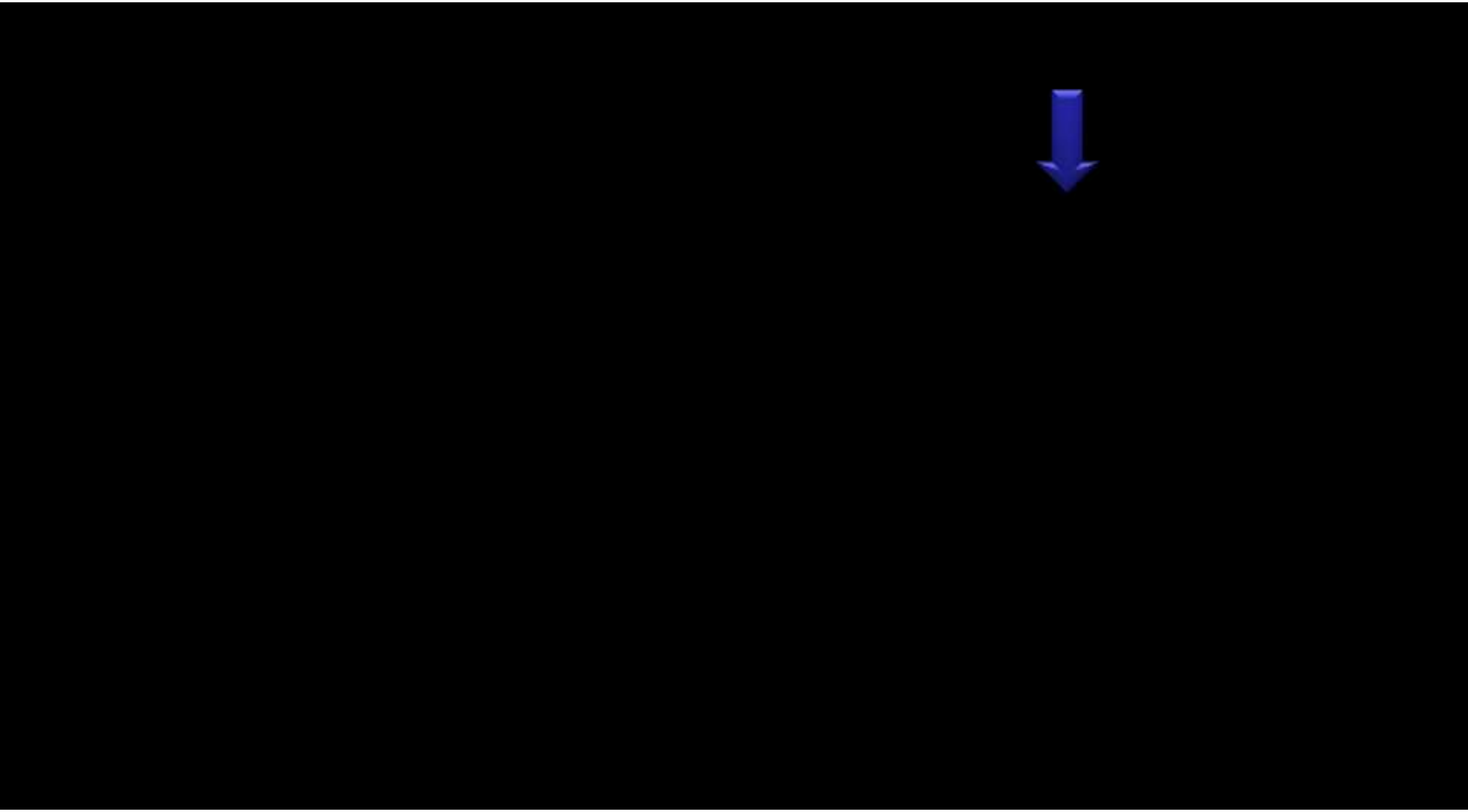
Repulsion is a complex and dynamic aerial maneuver that **takes time!!!**

Delayed local response of cranes

source: http://www.youtube.com/watch?v=Cj_NeOtehqM

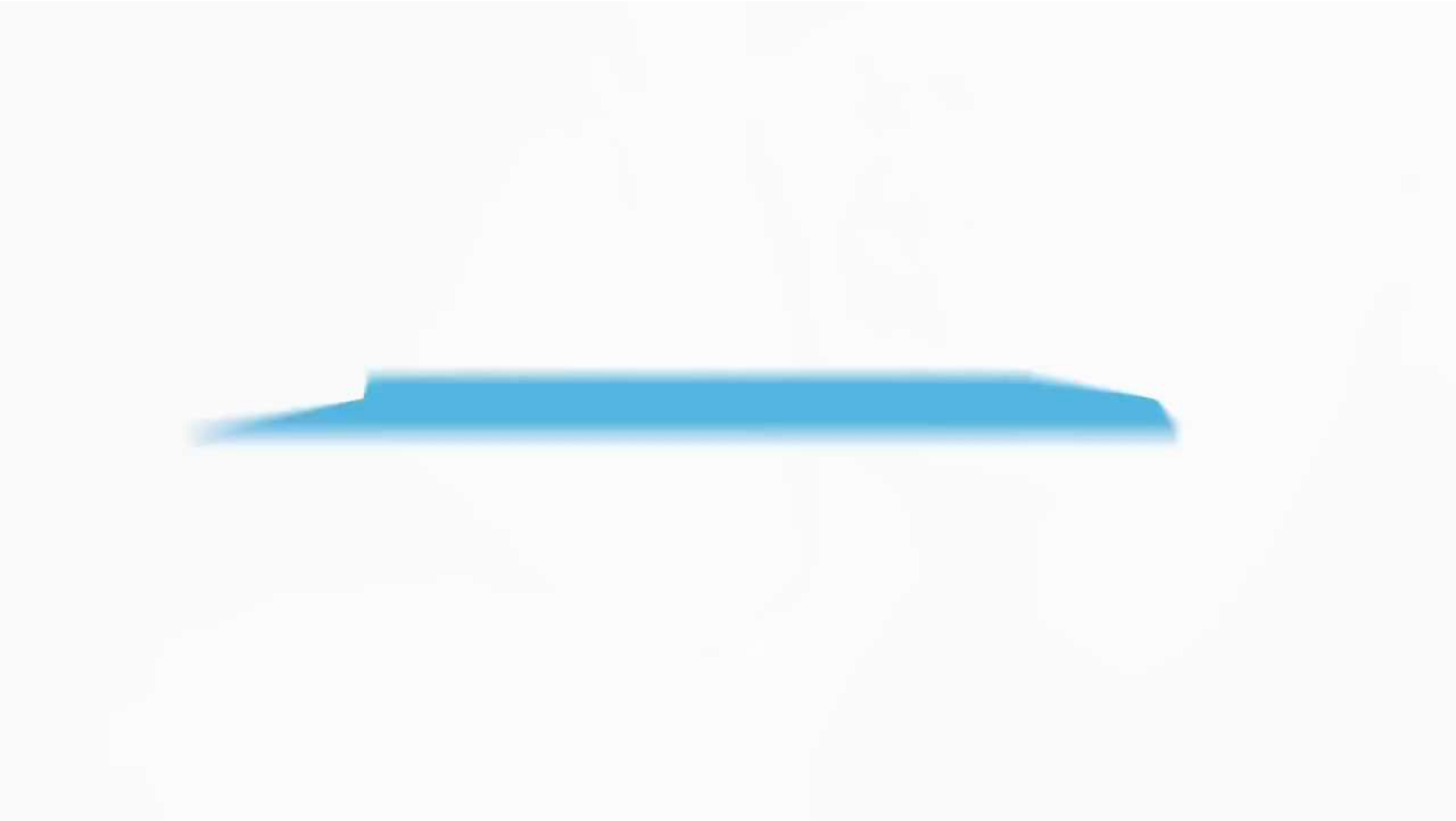
Local delay = 13s / 16 bird ≈ **0.8 sec/bird!!!**

Delayed local response of geese



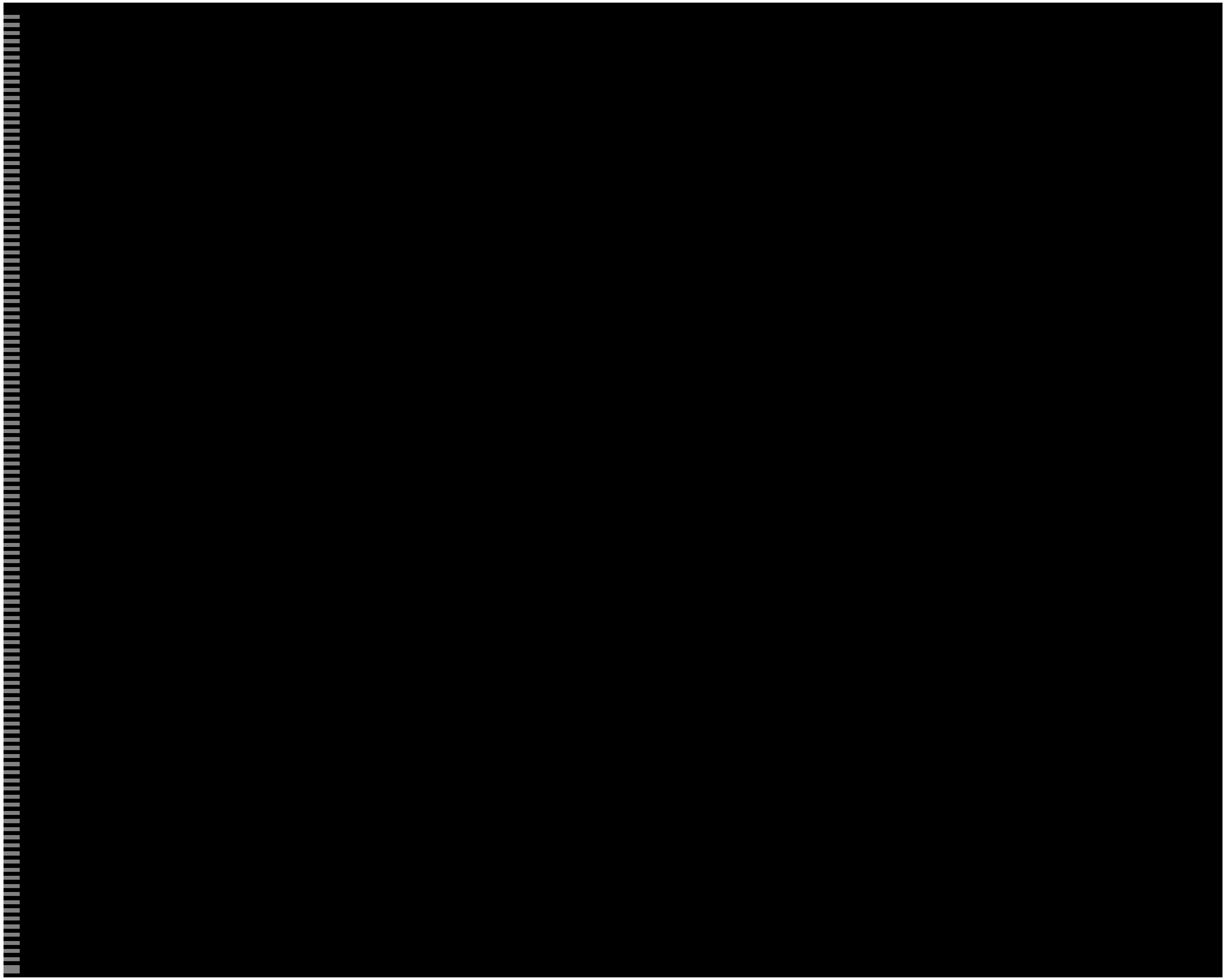
J. Cluzaud, M. Debats and J. Perrin: Winged migration (Le Peuple Migrateur)
http://www.youtube.com/watch?v=Q40h8dPmgwQ

Delayed response + drive =



self-excited oscillation

Delayed response + drive =

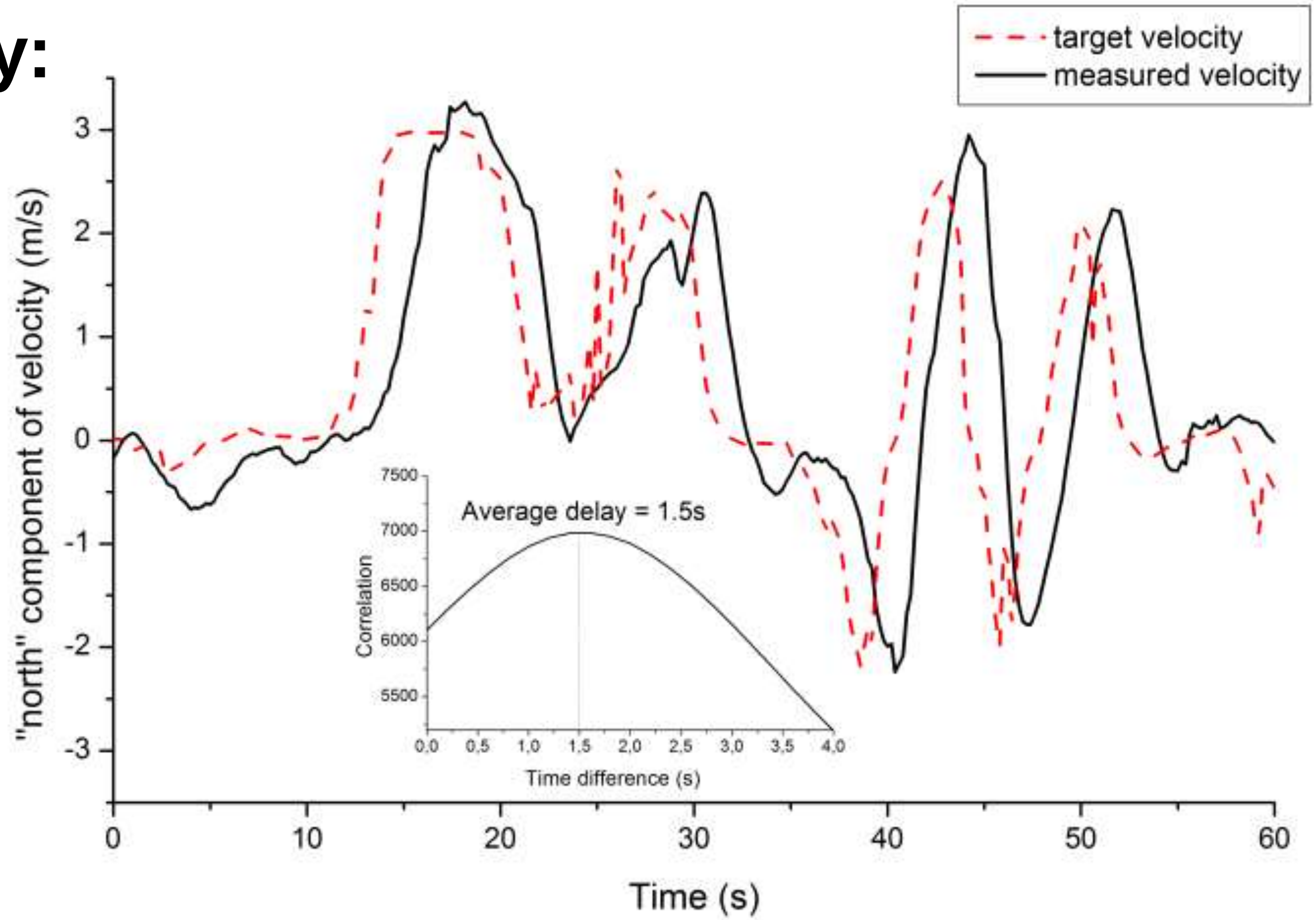


self-excited oscillation

Delay is a very serious problem!

Intrinsic delay:

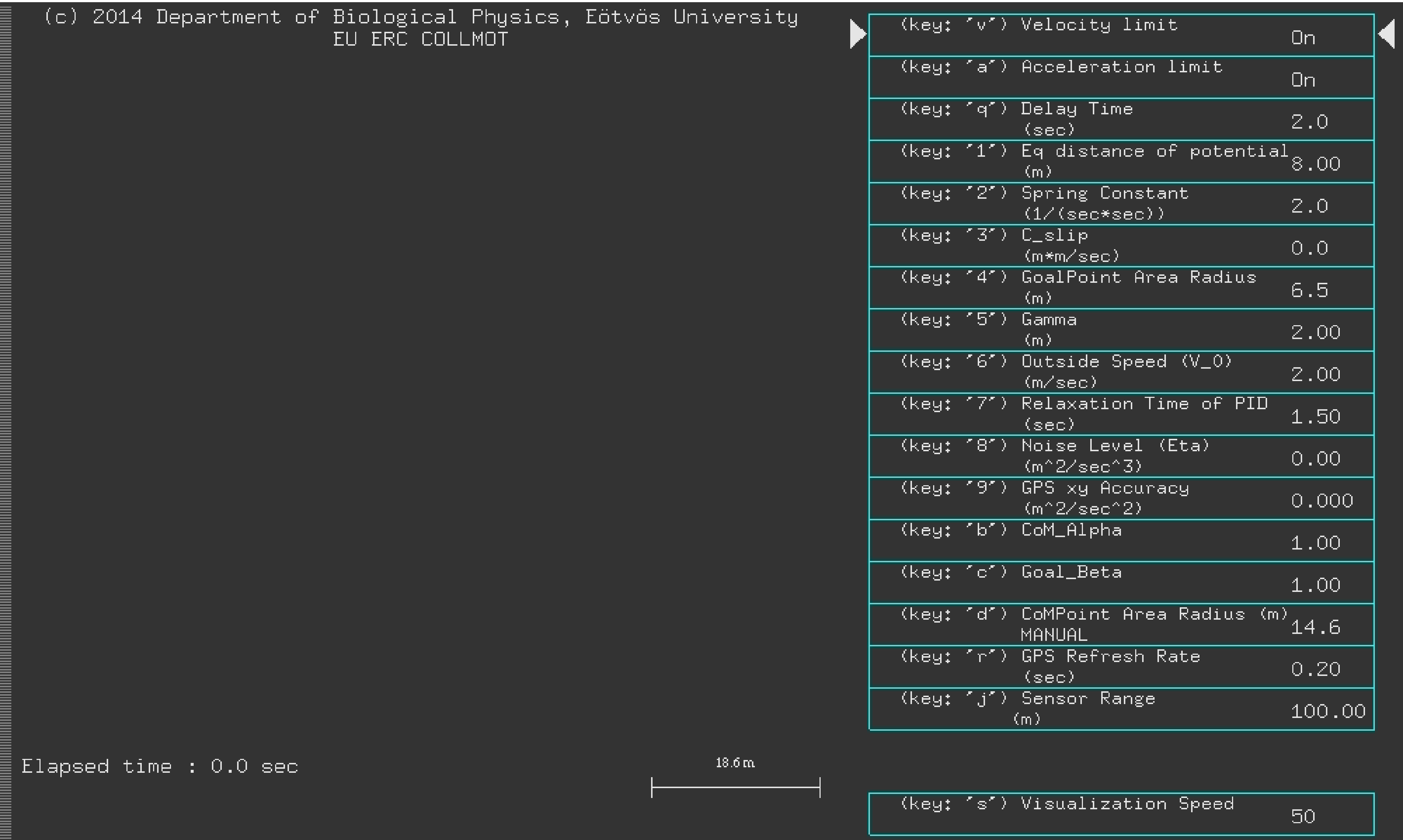
- Inertia
- GPS
- Compass
- PID control
- Data processing
- Linux



Delayed communication: XBee

Delay induced chaotic oscillations

(realistic simulation framework)



Noise, uncertainty, error

Inner noises

- GPS errors: ~2.5 m position, ~0.1 m/s velocity
- Raw sensory errors (height, acceleration, angular velocity)
- Compass/attitude errors (from fusion of magnetometer, gyroscope, accelerometer, GPS)

Outer noises

- Wind, thermals
- Pressure, temperature
- Solar flare

Hints:
- **smooth and gentle** transfer functions,
- **dead zone** around equilibrium
- **flock** consensus

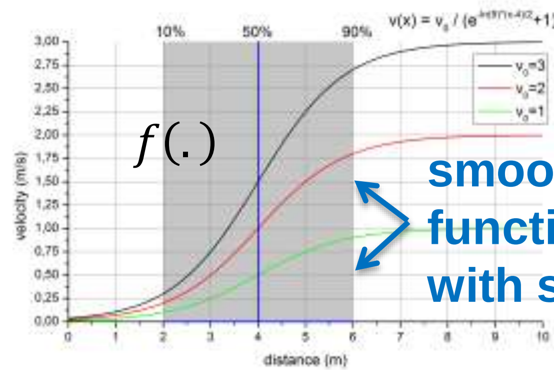
The only slide with equations

$$\vec{a}^i_{pot} = \begin{cases} -D \sum_{j \neq i} \left(\left| \vec{x}^j - \vec{x}^i \right| - r_0 \right) \dfrac{\vec{x}^j - \vec{x}^i}{\left| \vec{x}^j - \vec{x}^i \right|}, & \text{if } \left| \vec{x}^j - \vec{x}^i \right| < r_0 \\ 0 \text{ otherwise,} & \end{cases}$$

repulsion (induces osc.)

$$\vec{a}^i_{damp} = C \sum_{j \neq i} \frac{\vec{v}^j - \vec{v}^i}{(\vec{x}^j - \vec{x}^i)^2}$$

alignment (reduces osc.)



smooth functions with slack

$$\vec{v}^i_{COM} = \beta v_0 f\left(\left| \vec{x}_{COM} - \vec{x}^i \right| \right) \frac{\vec{x}_{COM} - \vec{x}^i}{\left| \vec{x}_{COM} - \vec{x}^i \right|}$$

attraction

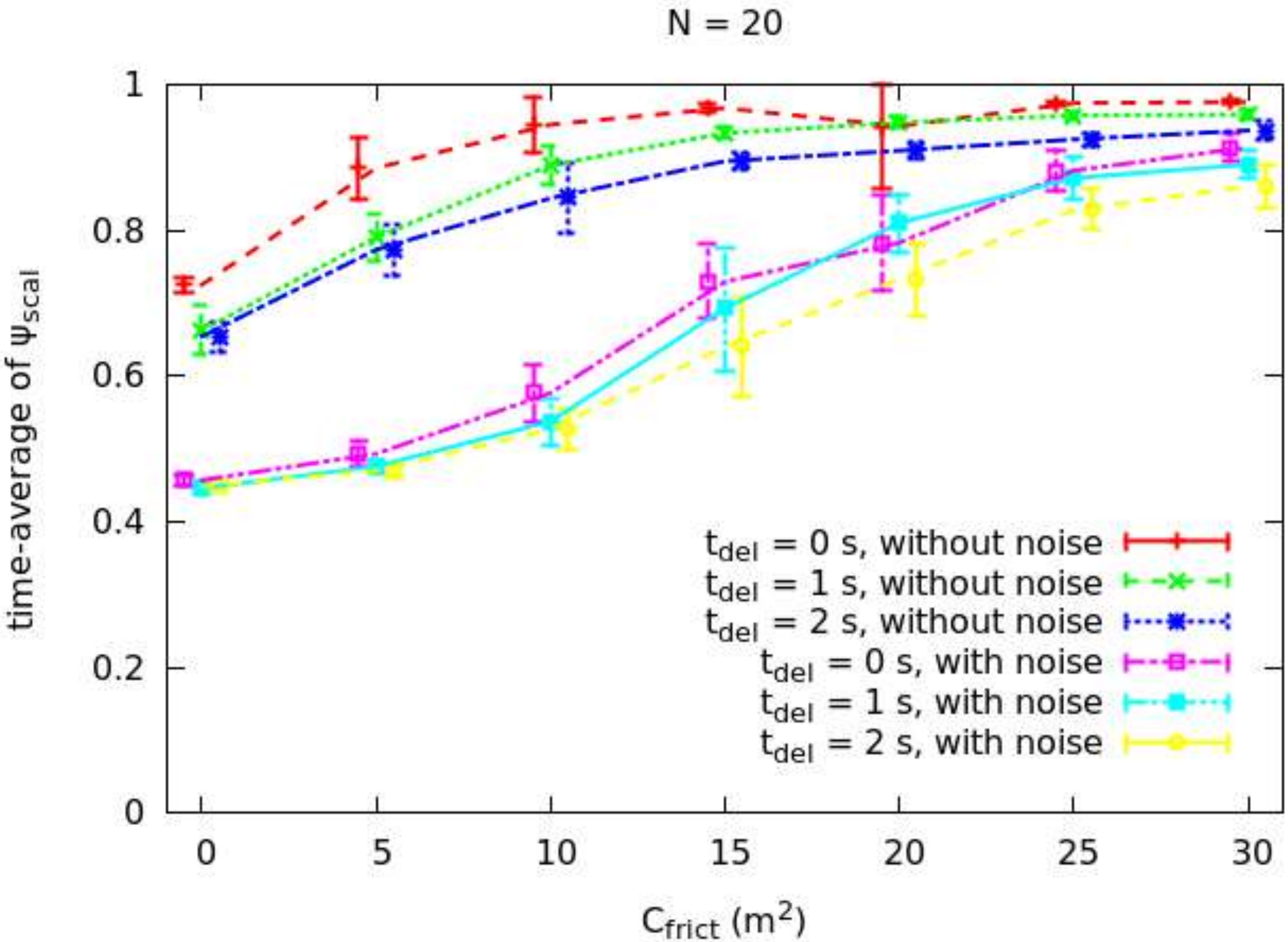
$$\vec{v}^i_{trg} = \alpha v_0 f\left(\left| \vec{x}_{trg} - \vec{x}_{COM} \right| \right) \frac{\vec{x}_{trg} - \vec{x}_{COM}}{\left| \vec{x}_{trg} - \vec{x}_{COM} \right|}$$

$$\vec{v}^i_{track} = \begin{cases} v_0 \dfrac{\vec{v}^i_{COM} + \vec{v}^i_{trg}}{\left| \vec{v}^i_{COM} + \vec{v}^i_{trg} \right|} & if \left| \vec{v}^i_{COM} + \vec{v}^i_{trg} \right| > v_0 \\ \vec{v}^i_{COM} + \vec{v}^i_{trg} \; otherwise & \end{cases}$$

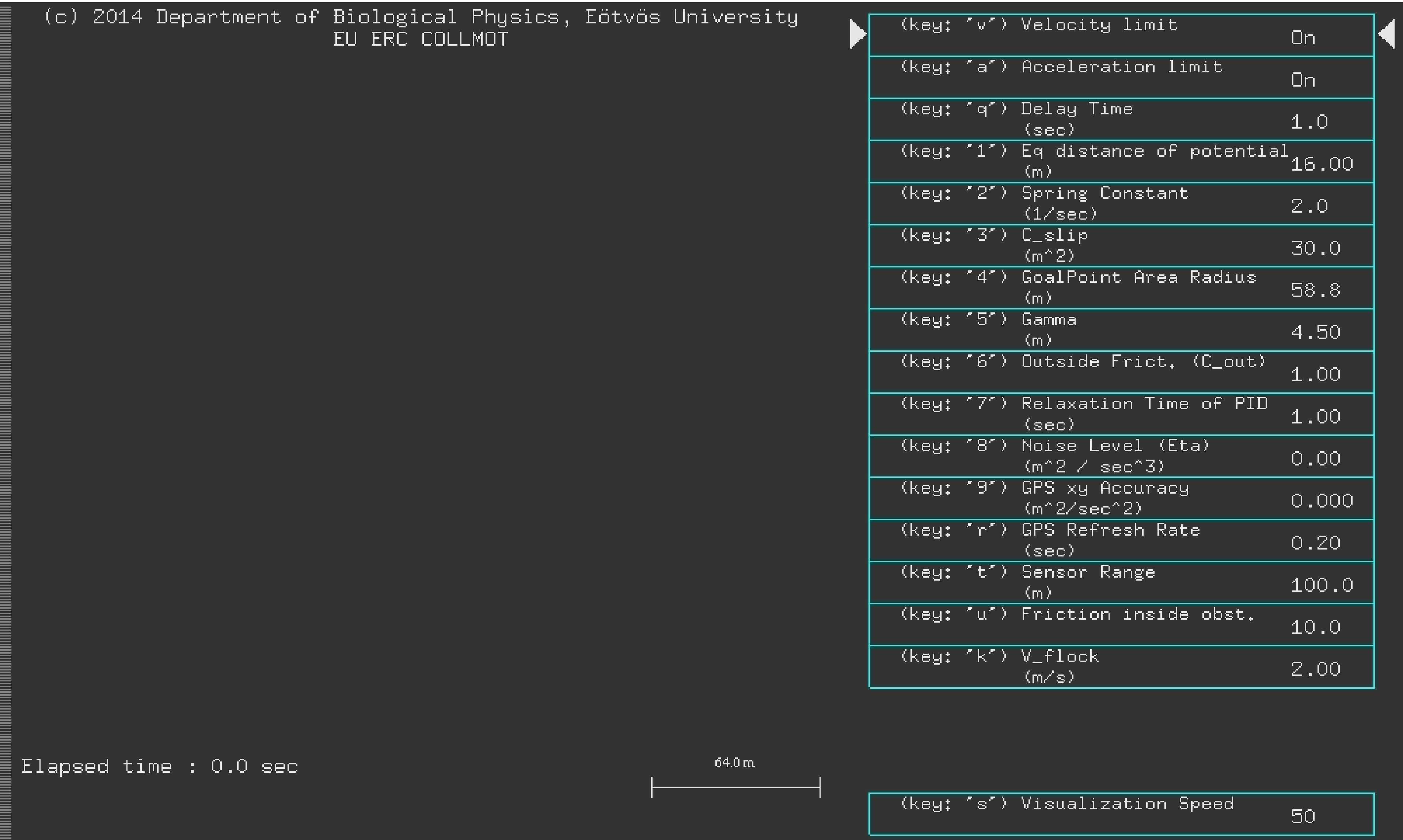
formation + target tracking

$$\vec{v}^i(t + \Delta t) = \vec{v}^i(t) + \frac{1}{\tau} \left(\vec{v}^i_{track} - \vec{v}^i(t) \right) \Delta t + \vec{a}^i_{pot} \Delta t + \vec{a}^i_{damp} \Delta t$$

Viscous friction-like alignment



SPP model, obstacle avoidance *(realistic simulation framework)*



The first take-off…

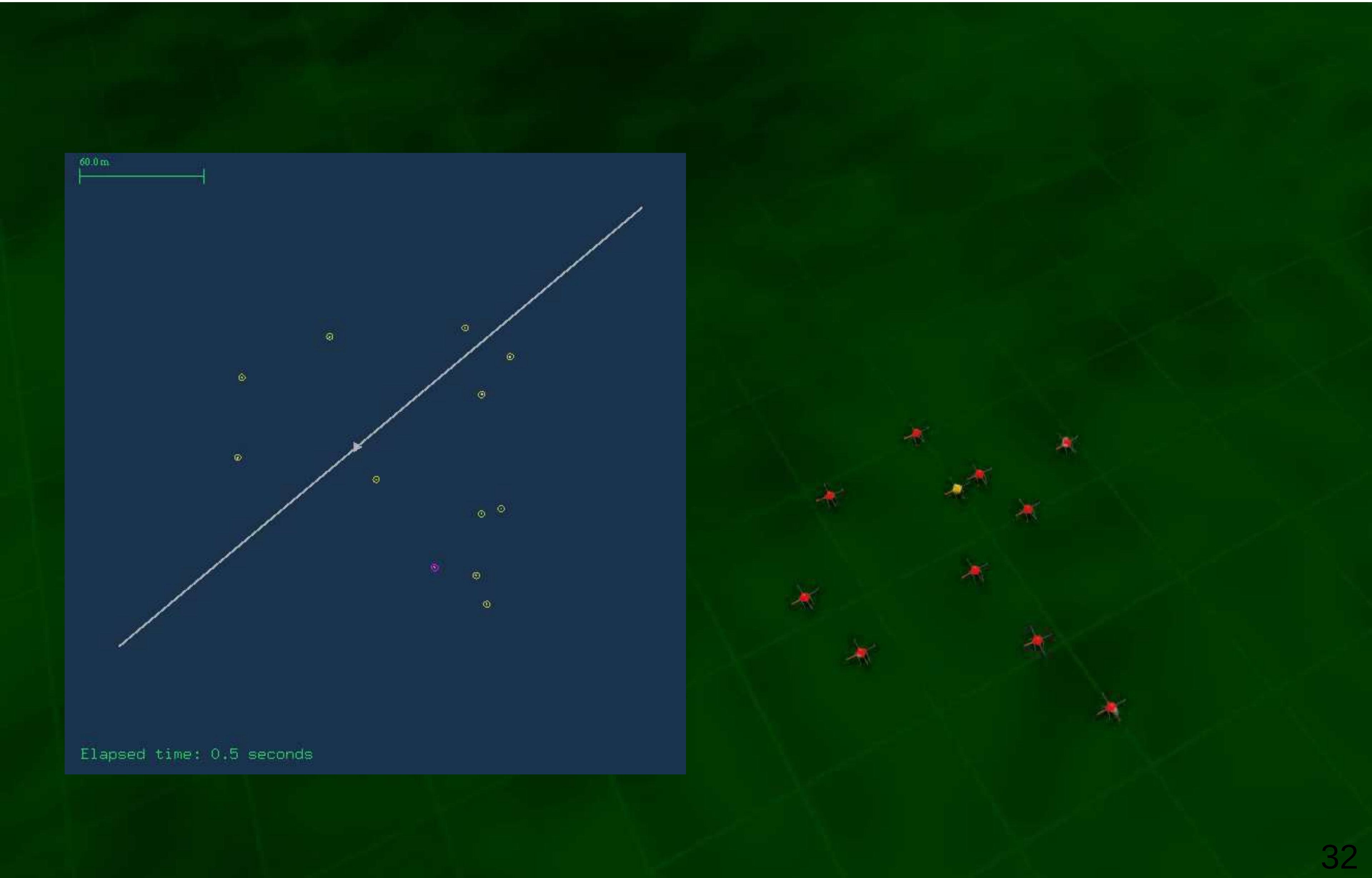
Footage: Attila Korbely

SPP model

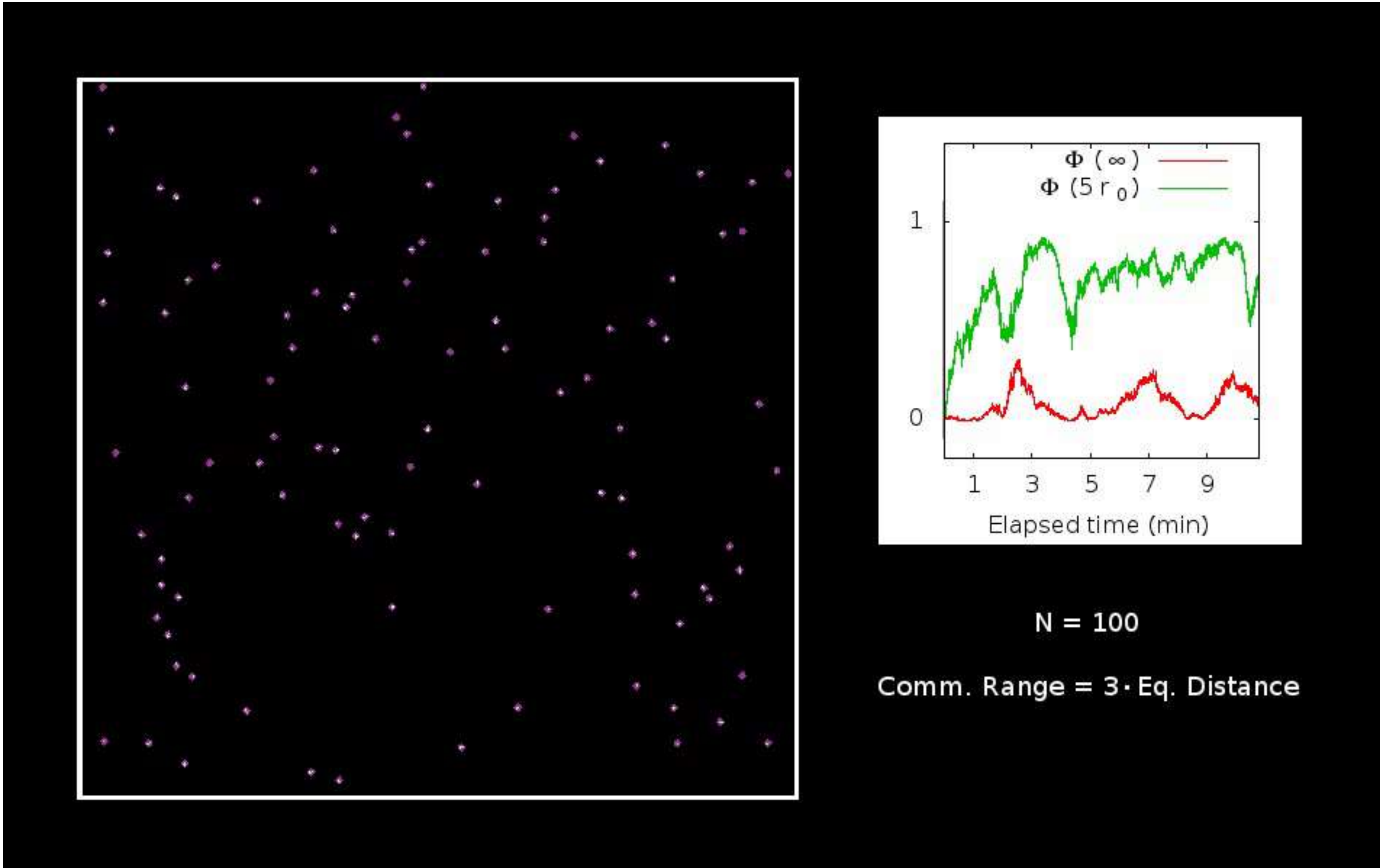
Visualization of real GPS data)

Collective "follow-me"

Formation flights



Simulation of 100 agents



Dancing with Drones

DwD raw video link

EU ICT&ART Connect

References

- Cs. Virágh, G. Vásárhelyi, N. Tarcai, T. Szörényi, G. Somorjai, T. Nepusz and T. Vicsek (2014) Flocking algorithm for autonomous flying robots, Bioinspiration & Biomimetics 9 025012

- G. Vásárhelyi, Cs. Virágh, N. Tarcai, T. Szörényi, G. Somorjai, T. Nepusz and T. Vicsek, Outdoor flocking and formation flight with autonomous aerial robots, IROS 2014

- Cs. Virágh, G. Vásárhelyi and T. Vicsek (2014) Csoportos mozgás drónokkal Természet Világa 145 242—245

Videos and Materials

http://hal.elte.hu/drones/

We are open to H2020 collaboration
contact: vasarhelyi@hal.elte.hu

EU ERC COLLMOT (2009-2014)

http://hal.elte.hu/flocking