

immune cell chasing a bacteria



coordinated motion of bird flocks



How physics makes biology work

or

Statistical biological Physics

or

Statistical physics of Living Matter

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reproduce = evolve (rare events)

compute = integrate, differentiate

sense = transmit information

make decisions = irreversible
(nonequilibrium) process

How **do** living organisms **work**?

work = live, reproduce, compute,
sense, make decisions, communicate



do = physical constraints: noise,
timescales, energetic costs,
molecular costs, space

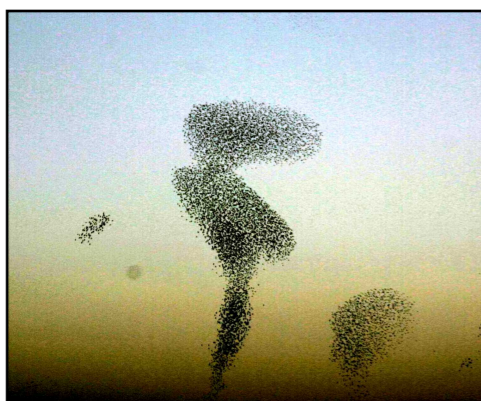
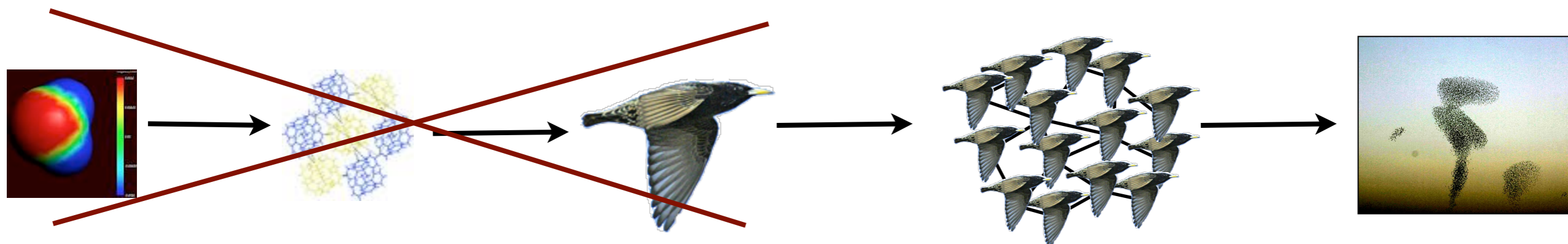
more is different

Phillip W Anderson, Science, **177**, 393 (1972)

- reproducibility vs randomness
- critical phenomena
- emergence
- self-organization
- effective interactions

Statistical Physics and Condensed Matter

More is Different



relevant scales
relevant variables



effective models
abstraction

fundamentally new
observed behaviour

infotaxis or pushing physical limits

diluted concentrations

how can you find the source ?

make a probabilistic map of the sources

→ based on observations

→ maximize entropy reduction rate

$$\Delta S(\mathbf{r} \rightarrow \mathbf{r}_j) = P_t(\mathbf{r}_j) [-S] \begin{matrix} \text{exploitation - max likelihood} \\ \text{search} \end{matrix}$$

motion:
reduce entropy

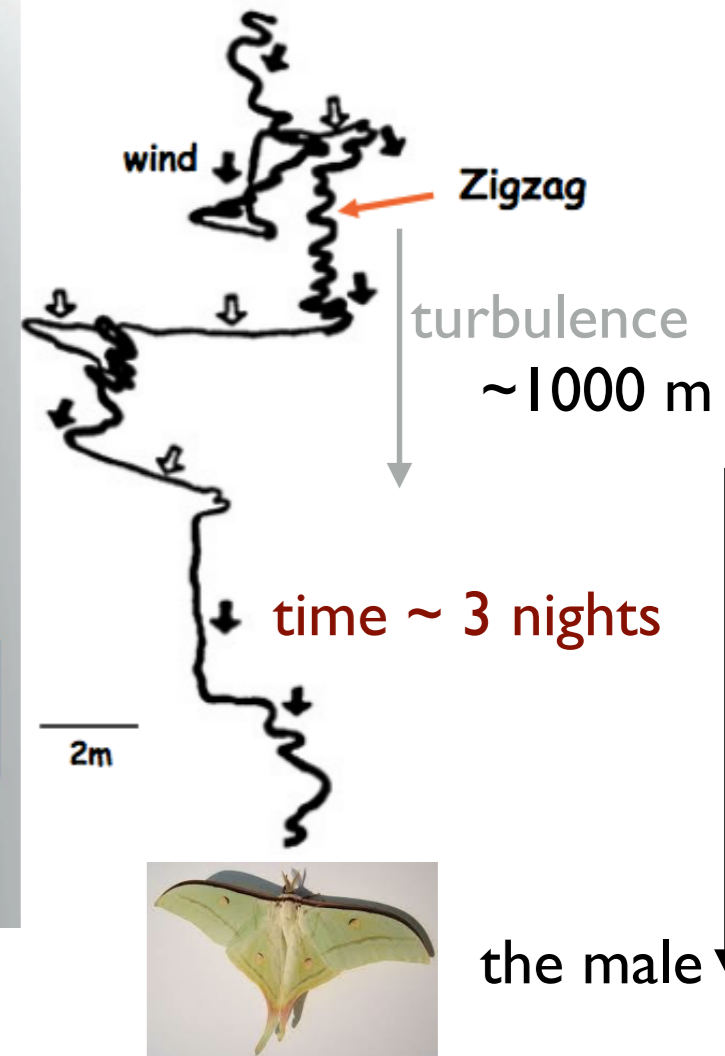
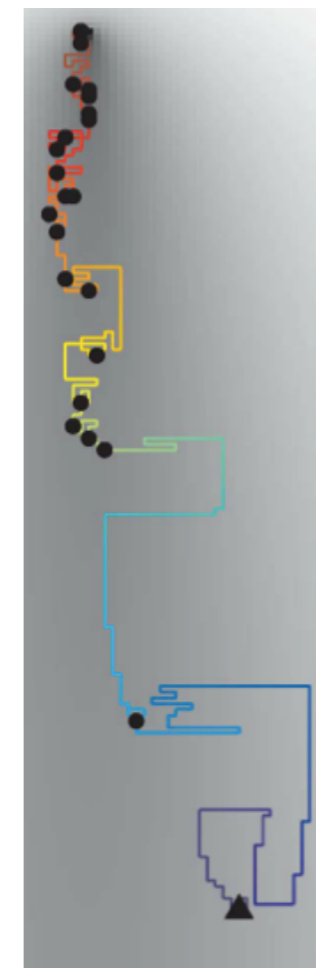
$$+ \sum_{k: \text{no de detections}} P(k \text{ detections}) \Delta S_k \text{ detections}$$

exploration - gathering data
update

goal: reproduction



goal: the female



the male

memory

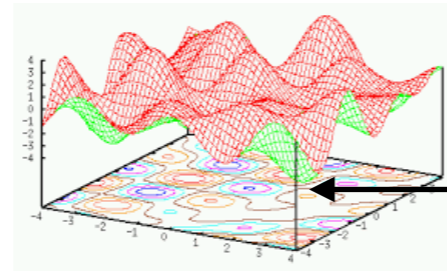
neuron relaxation rate $\sim 10 - 100$ ms

long term

\sim days - years

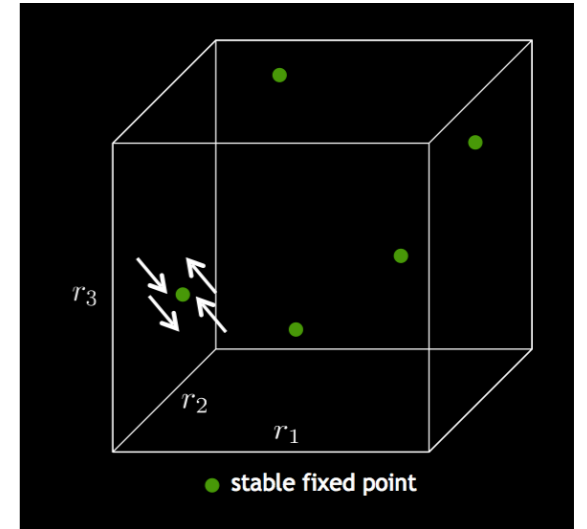
metastable states

Hopfield model

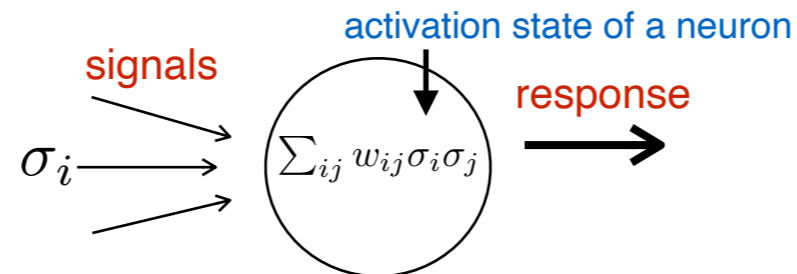


memories

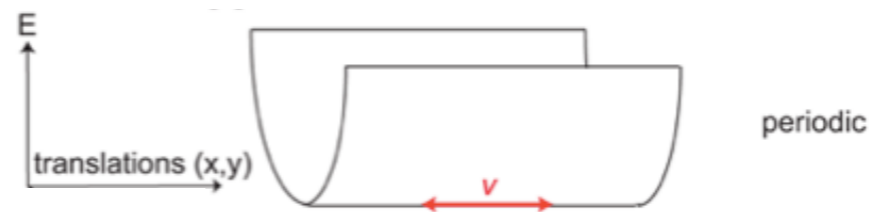
point attractor



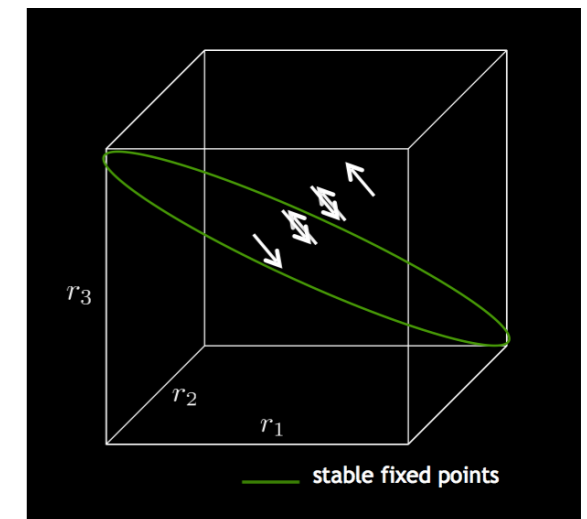
Hopfield



a continuum of solutions



continuous attractor



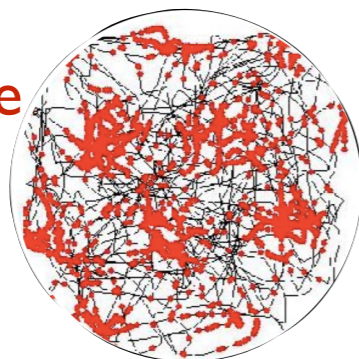
Fiete, Sompolinsky, Seung et al

short term

$\sim 10 - 100$ s

zero modes

neuron response



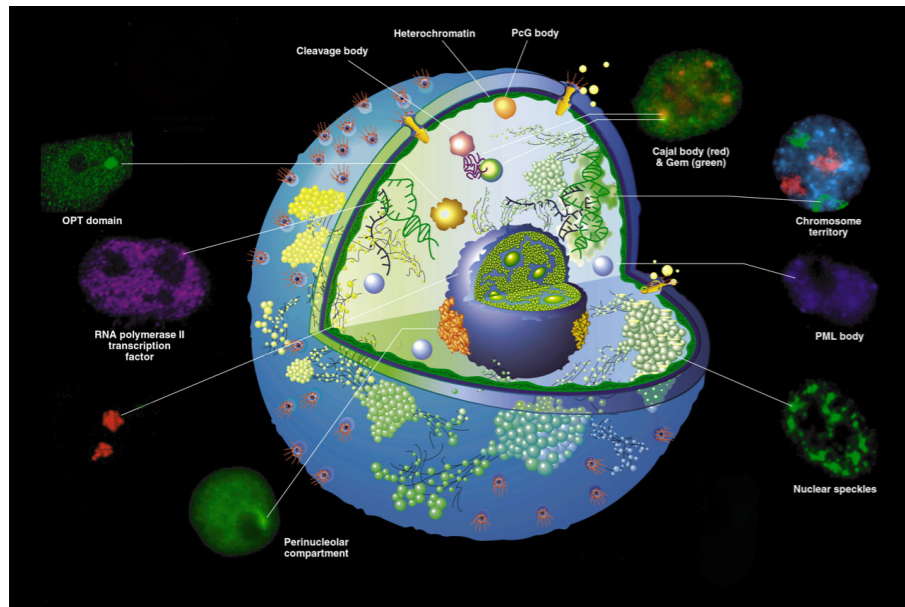
rat trajectory

neural representations ?

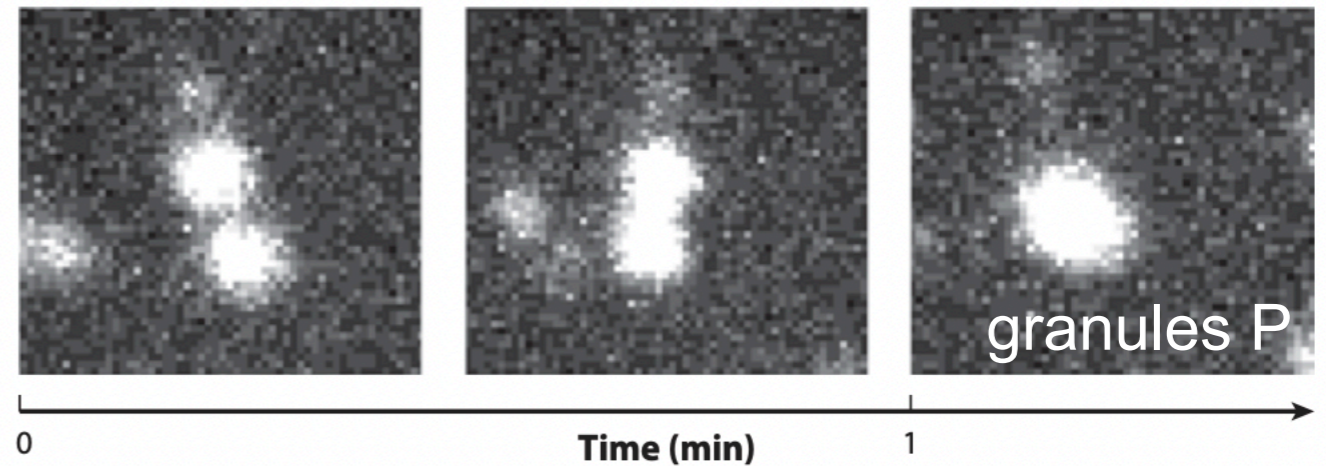
how is the real world encoded in neural networks?

cellular membraneless self-organisation

many membraneless compartments

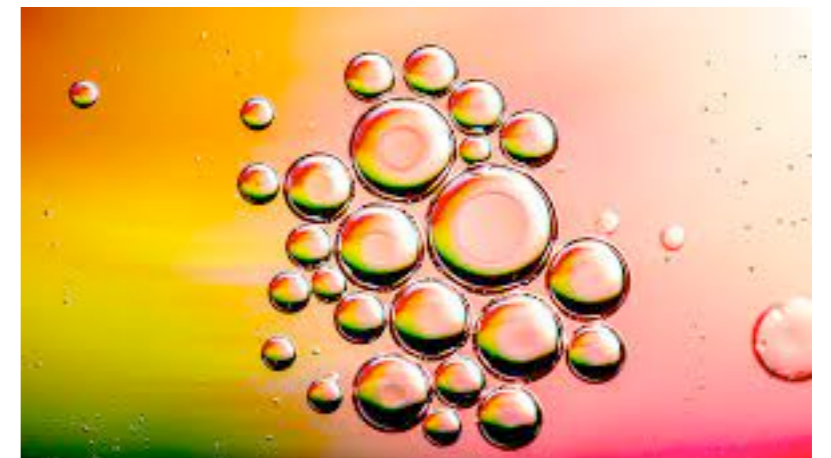
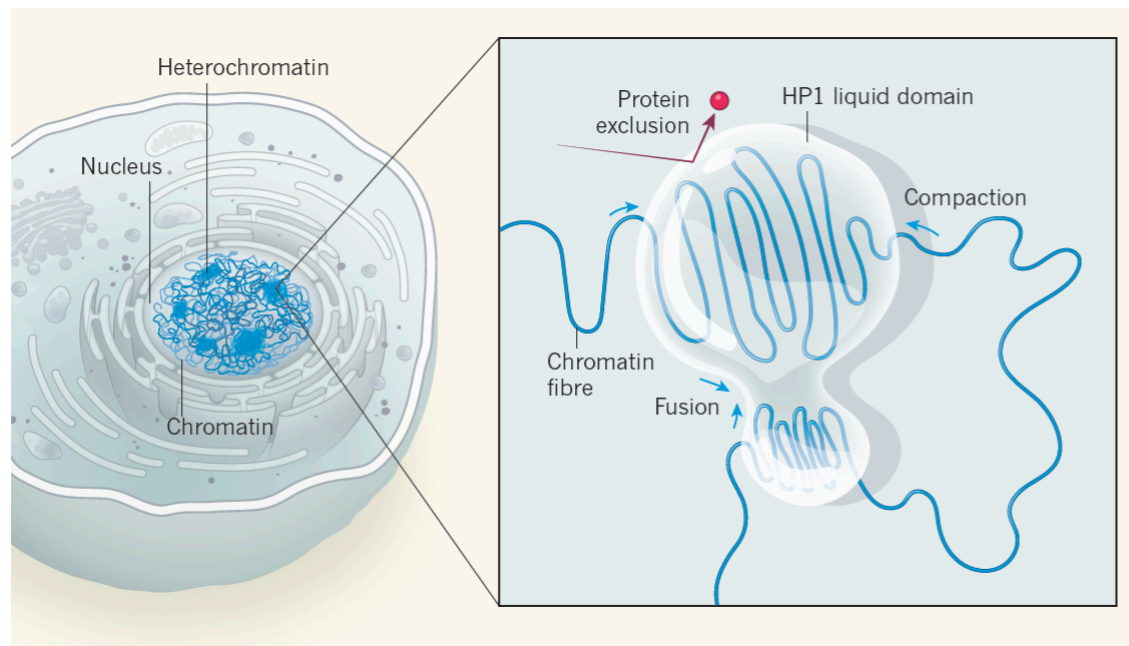


post-translational regulation hubs: first examples of droplets



→ liquid-like :

- spherical shape
- possibility of rearranging the interior
- can merge



behavior of droplets in cells?

criteria for droplet formation ?



check
against data

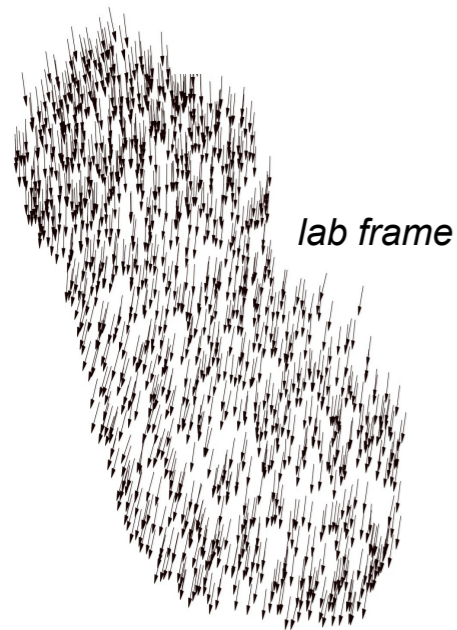
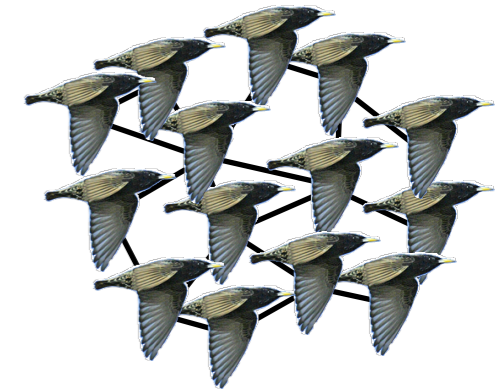


learn from
data

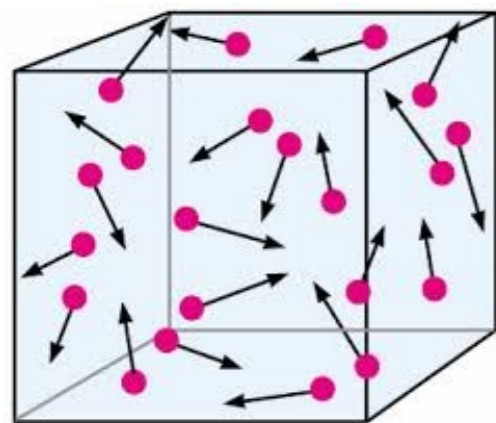


scale free bird flocking

local interactions → global order ?



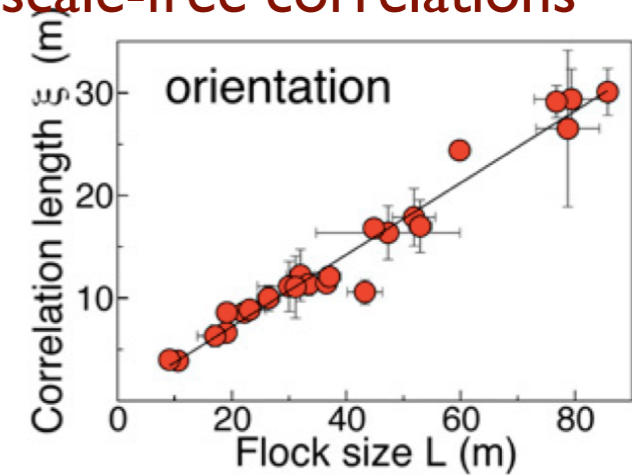
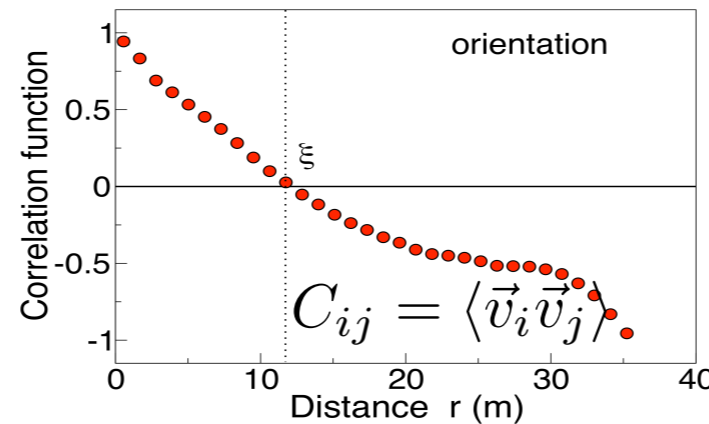
amazing coordination
in flight direction



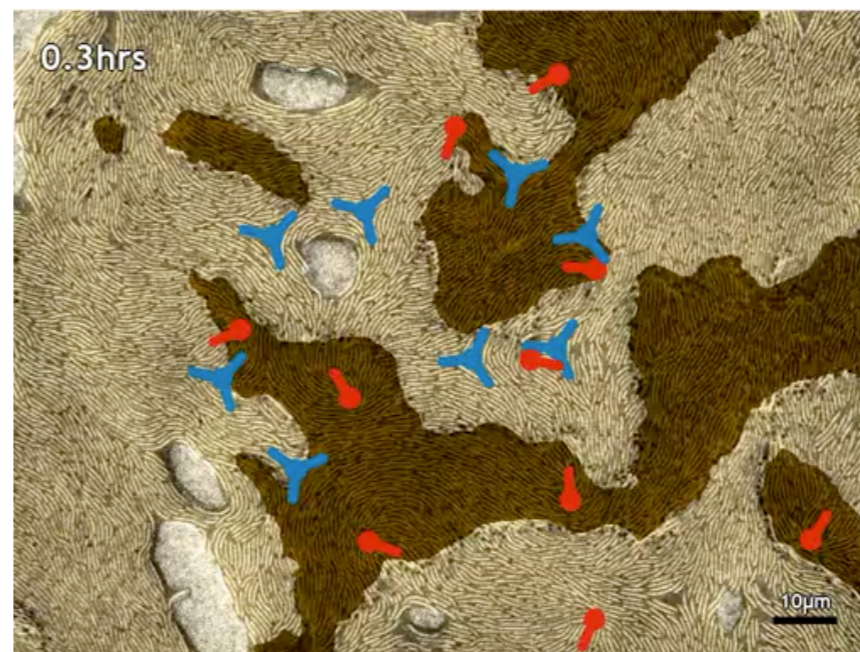
Maxwell-Boltzmann distribution

$$P(\vec{v})d\vec{v}$$

statistical mechanics:
local interactions → scale-free correlations



- random flock direction → symmetry breaking → zero mode
dynamically changing interaction network
→ stochastic eqs. of motion ↔ social interaction model

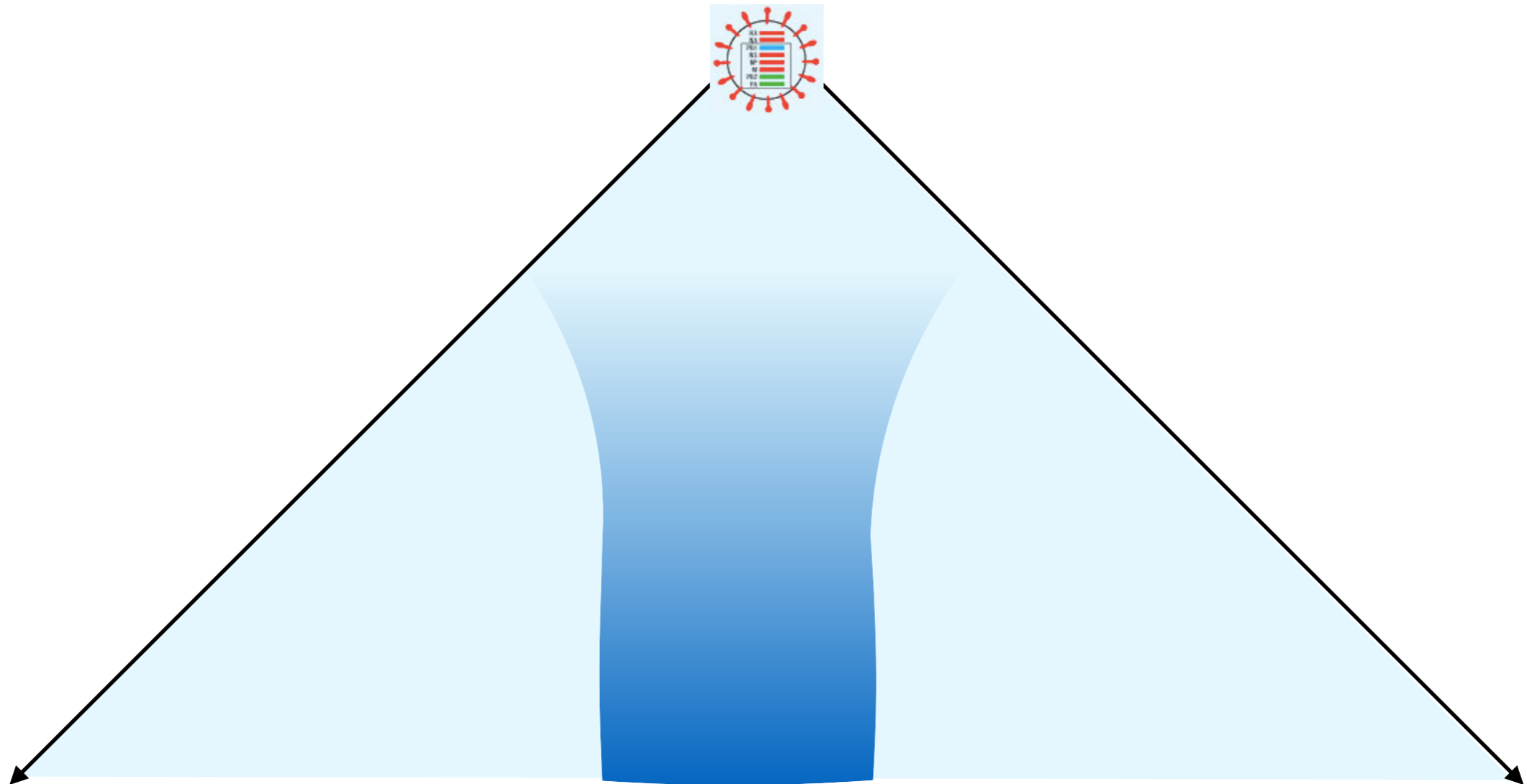


topological defects

evolution generates **diversity**

is the space of diverse solutions *infinite*?

evolution = rare events

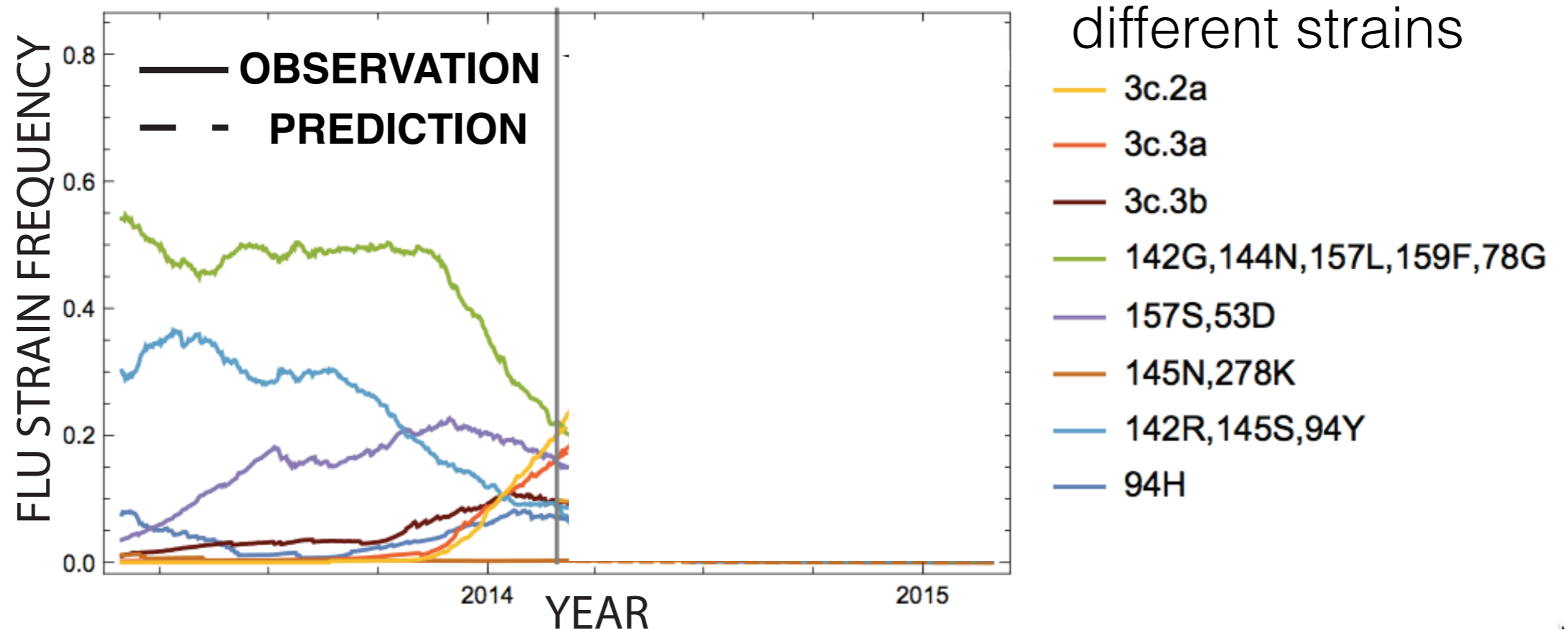


co - evolution = *constrained* rare events

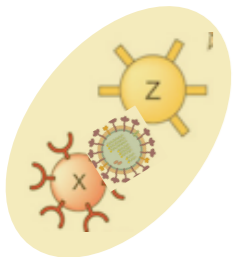
are evolutionary paths reproducible/predictable?

probabilistic flu prediction

prediction for winter 2014/2015



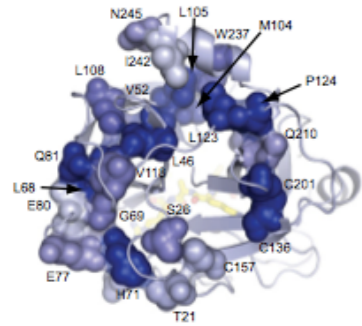
$$P(\text{strains } i, t + 1) = \sum_{\text{trajectories}} \sum_{\text{other strains}} P(\{\text{strains}\}, t)$$



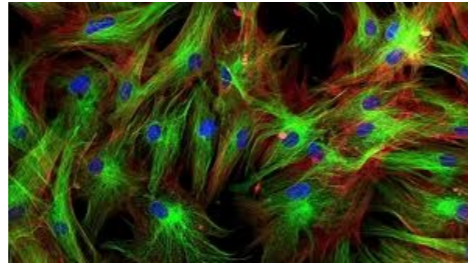
co-evolution → timescales of constraints

life across scales

molecular



cellular



organismal



ecological



cascading layers: can we understand one scale without the others?

same **laws** of physics

- limits
- strategies



new **laws** ?



observations → phenomenology → theory → **applications**

strong interactions / stochasticity / non linearity



reproducibility vs predictability?