Huddle-behavior simulation of emperor penguins

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Huddle behavior

(D. Zitterbart)

- Huddle conserves energy (outer temperatures -50^oC wind speed 200km/h)
- Male breeding eggs in abdominal pouch above feet within 3-4 months without foot
- Penguins live 90% of life in huddles
- Exchange of positions in huddles by collective motion

Questions

1. How is collective motion created?
2. What laws are obeyed by individuals to cause collective motion?
3. Dynamical model as simple as possible able to draw conclusions?

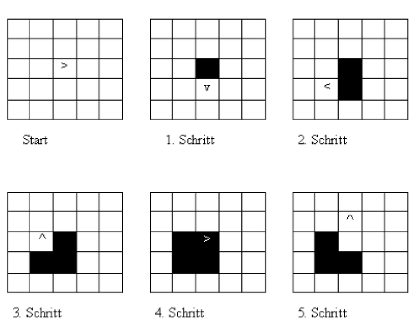
Time evolution

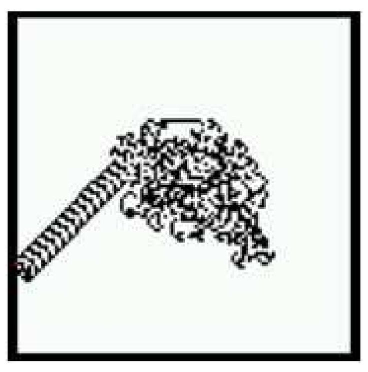
Snapshots of huddle (D. Zitterbart 2014)

Cellular automates

Theoretical world of objects obeying simple rules
known examples: Langton's ant on black/white checkerboard
two rules:

- arriving white field, turn it black, rotate yourself 90^o clockwise and go one field ahead
- arriving black field turn it white, rotate anticlockwise and go one step





After about 10000 chaotic steps, ant forms street to infinity

Other example Game of Life

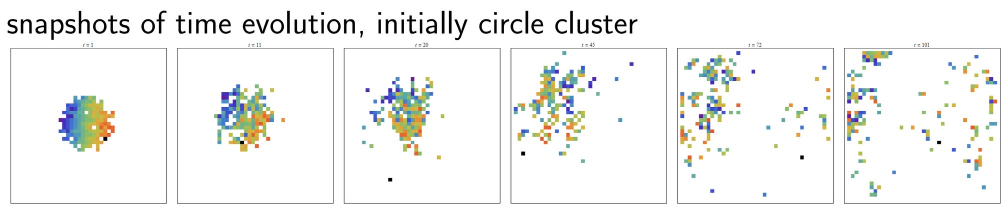
Our model

1. Each individual penguin is marked with color, can proceed one step in one of 8 directions
2. Choice of direction of next step given by maxim of sum of neighbors (count number of two adjacent directions) → reason for attraction
3. If place is occupied, (a) do nothing (b) push this individual if he can step with rule

Different experiments: nearest, next nearest neighbors, choice of direction starting from one side deterministically or stochastically

1. Experiment: only next nearest neighbors

snapshots of time evolution, initially circle cluster

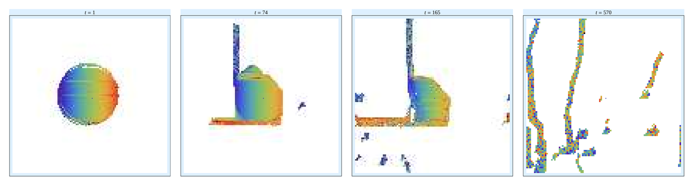


- no stable cluster, no attraction
- need to see next but next nearest neighbors

Possible other scenario: no action if place already occupied, results into:
- circle remains circle, no collective motion
- need pushing and attraction

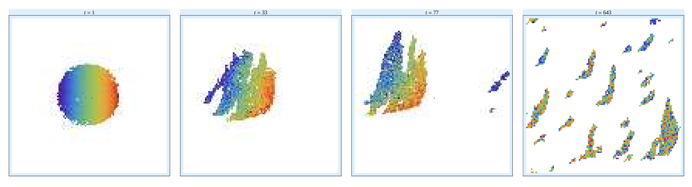
2. Experiment: if occupied push away

(a) Chose among directions with maximal next neighbors starting from left (not stochastically chosen)



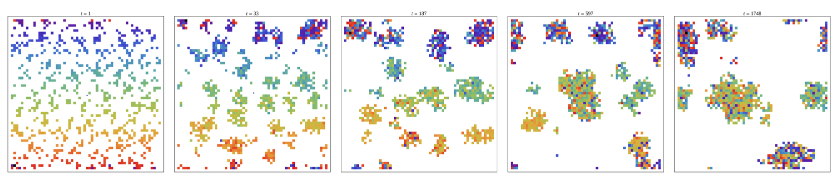
- formation of streets

(b) Chose among directions with maximal next neighbors stochastically, but pushed penguin checked free space starting from left to right



- mixing, rotation starts, but cluster tears apart

(c) Chose among directions with maximal next neighbors stochastically, if occupied, push once in stochastic direction



stochastically distributed, added artificially a rotation off-set to right

- attraction of initially stochastic distribution

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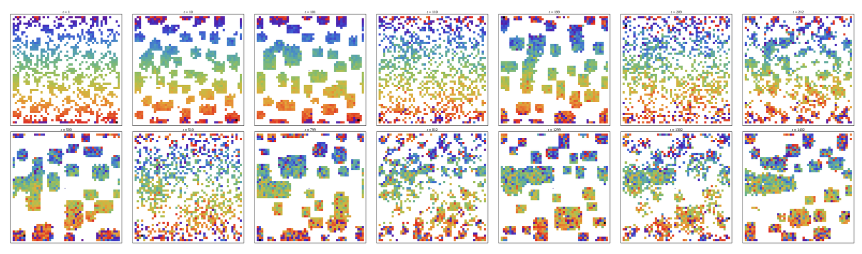
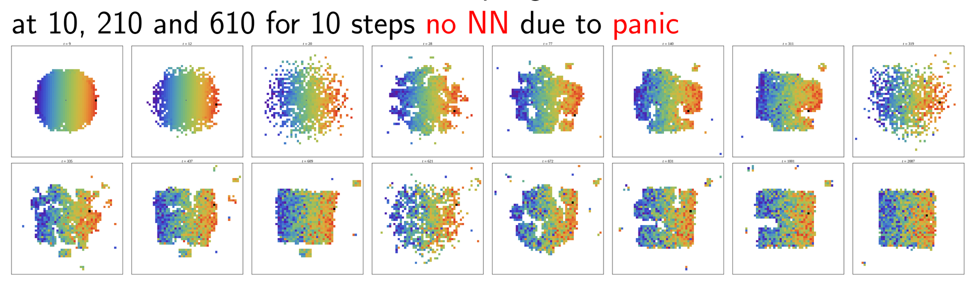
3. Experiment: realistic scenario

- choose stochastically penguin for motion in direction of most nearest and next-but-next nearest neighbors
- checking free space stochastically
- if occupied push stochastically

1. run: attraction of initially stochastic distribution of 708 penguins at 100, 200, 500, 800, 1300 for 10 steps no NN due to panic



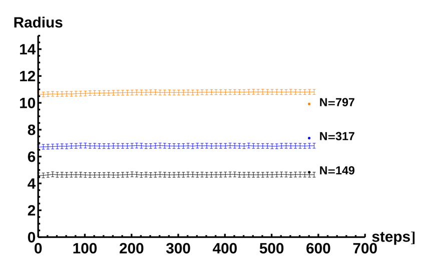
2. run: initial circular huddle of 708 penguins at 10, 210 and 610 for 10 steps no NN due to panic

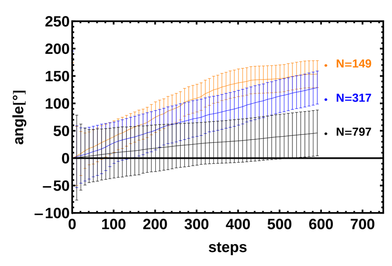


- huddle remains stable, mixing
- if panic and no NN visible, explosive motion and mixing

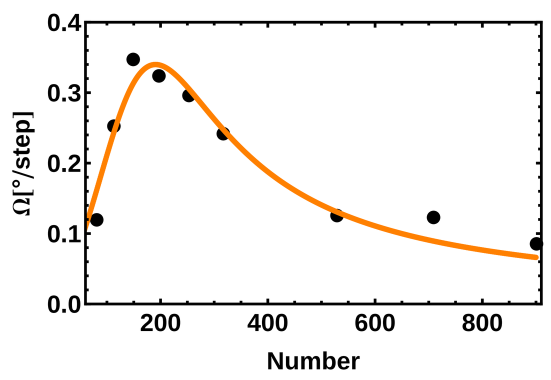
Results

- One time step corresponds to one Monte Carlo sweep (n^2 steps)
- Angle and radius average over penguin positions at each time step





- Angular velocity in dependence on huddle number



- Fit: $\Omega = \left(\frac{0.80120N}{(N-123.16)^2+21188}\right)\frac{\text{rad}}{\text{steps}}$
- maximal rotation at a specific size of huddle

Summary

1. Penguins move in direction of maximal number of neighbors:
   - no stable cluster if only nearest neighbor interaction considered
   - minimally next and next-nearest neighbor interaction necessary for clustering
2. Pushing needed otherwise clustering without motion
3. If pre-determined order of checking for free places (e.g. from left to right) causes street formations
4. Pushing and stochastic direction among maxim of neighbors creates circular motion with compact cluster
5. Interplay of attraction to cluster and stochasticity of pushing leads to collective circular motion
6. Mixing by panic where no next neighbours are seen
7. Radius and angular velocity extracted as function of huddle size