BCAM seminar – March 04, 2011

A Robotic Model Describing The Formation Of Wolf-Pack Hunting Behavioural Patterns

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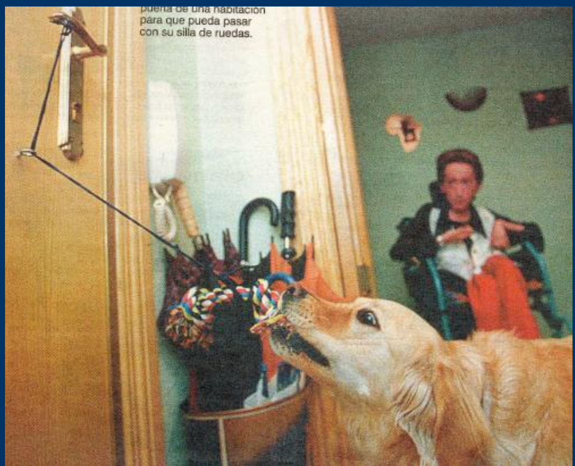


Collective animal behaviour

1. Examples:

   birds, fishes, ants, mammals

2. Wolf-pack hunting ethogram explained

   1. The mathematical model
   2. The patterns explained
   3. Predictions

Collective animal behaviour

Seminal work:

Flocks, Herds, and Schools: A Distributed Behavioral Model
C. Reynolds, 1987

Flocks (birds)

http://www.vex3d.com/stills.html

http://shanghailectures.org

Individual behaviors give rise to complex group behaviors

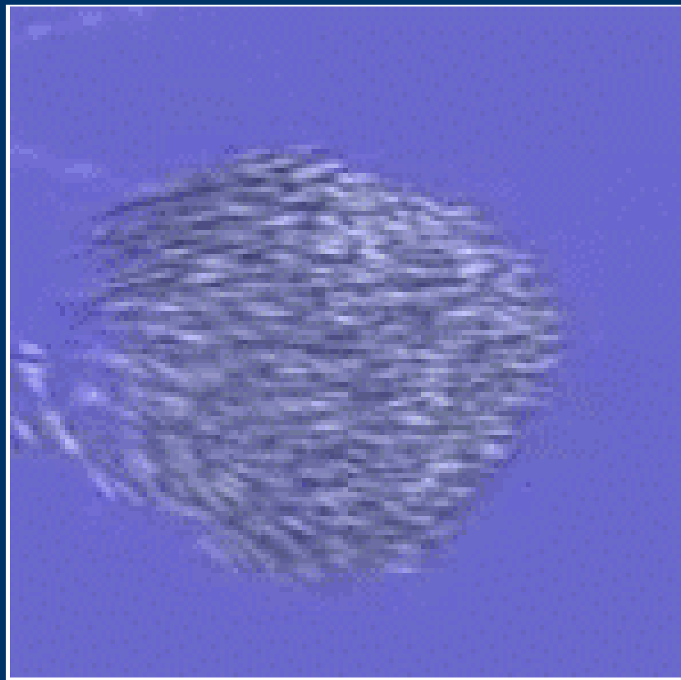
Collective animal behaviour

Seminal work:

Flocks, Herds, and Schools: A Distributed Behavioral Model
C. Reynolds, 1987

Schools (fishes)

A school of striped salemas evades a sea lion via the "burst effect"
Galapagos, Ecuador, 1997 – Photo David Doubilet.



http://videos.drole.ch/video/kJiKKNCQorQ/Boids-schools-of-fish.html

Individual behaviors give rise to complex group behaviors

All these emergent behaviors and patterns have already been described by means of **mathematical and robotics models**

Patterns are reproduced, explained and predicted, and new situations can be anticipated by the models.

Other disciplines involved:

Scientific computation, Boids simulation, Artificial intelligence, Network Science, Control Theory, Cybernetics, etc.

Are all these intelligent behaviors relying on high level cognitive capacities of the individuals of the species?

We have studied:

Paradigmatic example:

The wolf-pack social structure

Especially:

Paradigmatic behavior:

The wolf-pack hunting strategy

The way in which wolf-packs hunt is often used as a proof that a social structure and a system of communication sustain the relation between pack members, and, still, that this social structure is based on hierarchical rules.

Wolf-Pack Hunting Behavior

Classical interpretation

For a successful hunt, two elements must be present:

1 A social structure (hierarchical, family)

- a centralized individual, a coordinator
- other individuals wait for instructions

2 A system of communication

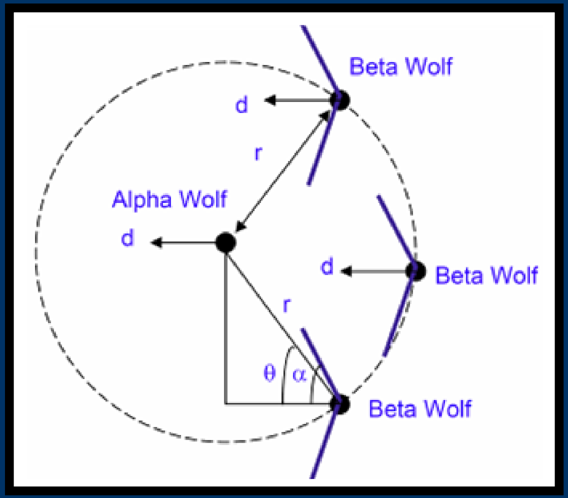
allowing the transmission of information, which is essential for the coordination of individual movements, and for sustaining the social structure.

Wolf-Pack Hunting Behavior

Classical interpretation

1 Social structure

- Alpha male theory (old fashioned, see D. Mech webpage)



A Biologically-Inspired Wolf Pack Multiple Robot Hunting Model
A. Weitzenfeld, A. Vallesa and H. Flores

Robotics Symposium, 2006. LARS '06. IEEE 3rd Latin American ISBN: 1-4244-0537-8 120–127.

The wolf pack hunting model described in this work includes the following important assumptions:
a) Wolf teams are conformed by a group leader (*alpha* wolf) and at least one follower (*beta* wolf).
b) *Beta* wolves group around the *alpha* wolf keeping a certain distance from the leader and among themselves.

- Wolf-packs are families

The breeding pair leads the hunt

Wolf-Pack Hunting Behavior

➡ Classical interpretation

2 System of communication

- Howling

  ➢ 98% of howls serve intra-pack communication

  70% related with reunion

  30% related with pre- or post- hunting activities:

  (25% setting out for the hunt + 5% after a fresh kill)

  Howling activity of free-ranging wolves (Canis lupus) in the Białowieza Primeval Forest and the Western Beskidy Mountains (Poland)
  S. Nowak, W. Jezdrzejewski, K. Schmidt, J. Theuerkauf, R. W. Mysłajek, B. Jezdrzejewska
  J. Ethol. 25 (2007) 231–237

- Referential signals in animal communication?

  ➢ Important challenge

  C. Evans (1997) in: Perspectives in Ethology
  D. H. Owins, M. D. Beecher and N. S. Thompson (Eds.)
  Vol. 12, Plenum, New York (1997) 99–143

Wolf-Pack Hunting Behavior

Classical interpretation

Moreover:

Candidates for high-level mental processes

Possible Use of Foresight, Understanding, and Planning by Wolves Hunting Muskoxen
D. L. Mech, Arctic **60** (2007) 145–149

- Understanding: comprehending complex relationships
- Planning: deciding to behave considering information relevant to a perceived outcome
- Foresight: behaving appropriately for dealing with a future event
- Insight: the perceiving of a solution
- Purposiveness: deliberate behavior with an objective

Also observed by Mech:

… and reported in the same publication

- Apparent communication by Wolf A to Wolf B
- Waiting-in-ambush behavior
- Understanding that waiting in hiding improves the chance of getting nearer to the prey

Wolf-Pack Hunting Ethogram

Phases of the ethogram

Typical predatory behavior:

SEARCH → PURSUE → CAPTURE

Wolf hunting ethogram:

APPROACH & WATCH → ATTACK GROUP → ATTACK INDIVIDUAL → HARASS

A proposed ethogram of large-carnivore predatory behavior, exemplified by the wolf
D. R. MacNulty, D. L. Mech & D. W. Smith, Journal of Mammology **88** (2007)

Wolf-Pack Hunting Ethogram

Phases of the ethogram

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Robotic model:

PURSUIT (APPROACH & WATCH, ATTACK GROUP, ATTACK INDIVIDUAL)

ENCIRCLING (ATTACK INDIVIDUAL, HARASS)

HYPOTHESIS:

The pursuit and the encircling behaviors are in fact

EMERGENT BEHAVIORS

which arise from the combination of two simple rules for the individual behavior of each wolf, without any coordination or centralized action, nor communication between individuals.

Wolf hunting ethogram:

APPROACH & WATCH → ATTACK GROUP → ATTACK INDIVIDUAL → HARASS

PURSUIT (APPROACH & WATCH, ATTACK GROUP, ATTACK INDIVIDUAL)

ENCIRCLING (ATTACK INDIVIDUAL, HARASS)

→ Robotic model:

Joint work with:

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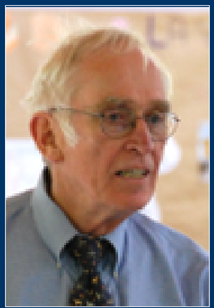

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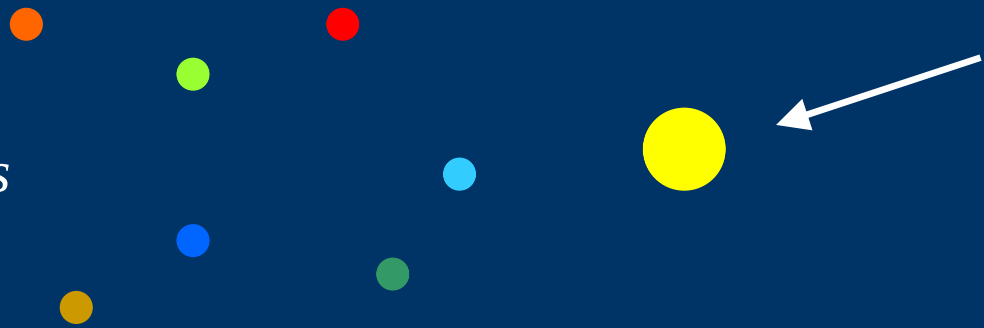
School of Cognitive Sciences
Hampshire College, Amherst – United States

The Robotic model – Two kinds of agents

- The agents:

A prey P and a set of N wolves W_i :

The wolves



The prey (a caribou)

1. Agents are homogeneous and interchangeable.

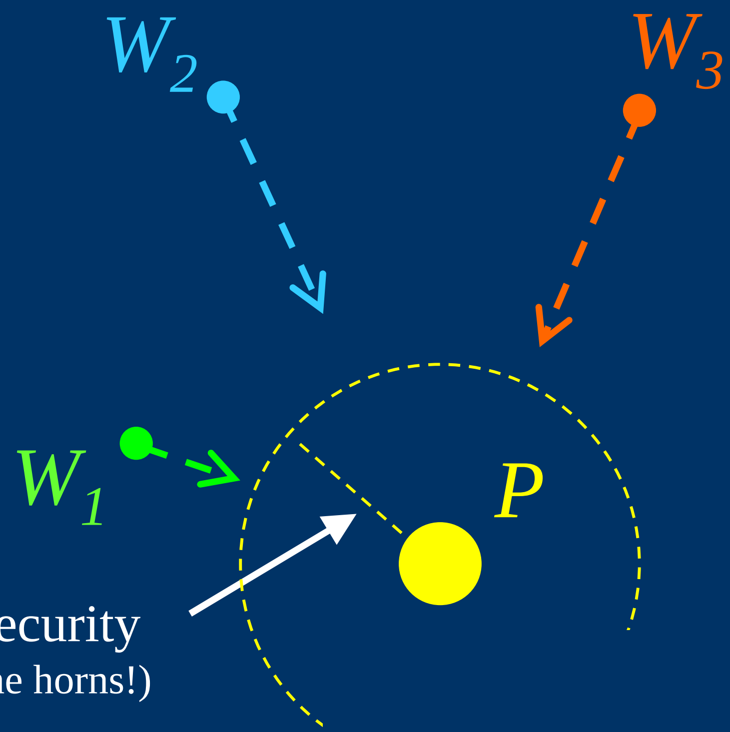
No leaders or followers exist.

2. Agents do not use one–to–one communication.

All communication is based only on sensing the external state of nearby agents.

The Robotic model

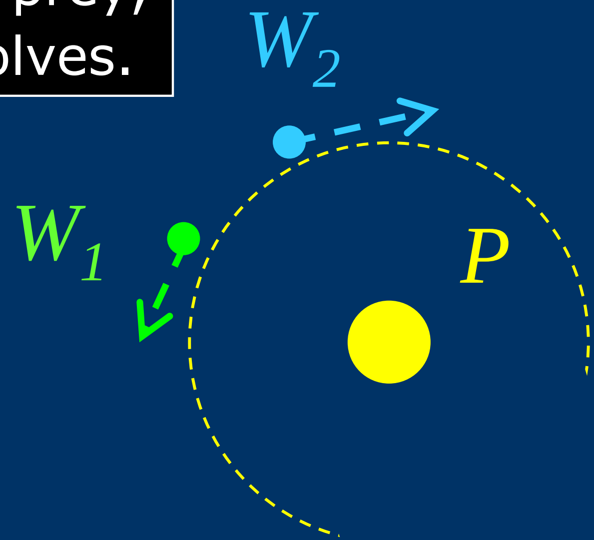
- The rules:



1 Move towards the prey until a critical distance is reached.

Critical distance of security
(depending on the size of the horns!)

2 When close enough to the prey, move away from other wolves.



This wolf is far from the prey so it moves towards P according to rule nº 1.

The Robotic model – Mathematical formulation

Coordinates of the agents:

$$\vec{p}(t) = \Big(x_p(t), y_p(t)\Big), \quad \vec{u}_i(t) = \Big(x_i(t), y_i(t)\Big), \quad i = 1, \ldots, N.$$

The interaction between agents is described by a force

$$\vec{F}_{i,j} = \begin{cases} \text{force that } P \text{ exercises on } W_i & \text{if } i = j, \\ \text{force that } W_j \text{ exercises on } W_i & \text{if } i \neq j, \end{cases}$$

where $\vec{F}_{i,j} = f_x^{i,j}\vec{e}_1 + f_y^{i,j}\vec{e}_2,$ and $(\vec{e}_1, \vec{e}_2)$ is an orthonormal basis.

The compounds $f_x^{i,j}$ and $f_y^{i,j}$ are given by

$$\begin{aligned} f_x^{i,j} &= \sigma_{i,j}\, s_{i,j}\, \mathrm{sign}(x_i - x_j)\, \cos\alpha_{i,j}, \\ f_y^{i,j} &= \sigma_{i,j}\, s_{i,j}\, \mathrm{sign}(y_i - y_j)\, \sin\alpha_{i,j}, \end{aligned}$$

Where →

The Robotic model – Mathematical formulation

→

- If $i \neq j$, then $\alpha_{i,j} = \begin{cases} \left|\arctan\left(\frac{y_i - y_j}{x_i - x_j}\right)\right| & \text{if } x_i \neq x_j, \\ \pi/2 & \text{if } x_i = x_j, \end{cases}$
- If $i = j$, then $\alpha_{i,i} = \begin{cases} \left|\arctan\left(\frac{y_i - y_p}{x_i - x_p}\right)\right| & \text{if } x_i \neq x_p, \\ \pi/2 & \text{if } x_i = x_j. \end{cases}$

$\sigma_{i,j} = ||\vec{F}_{i,j}||$ is the modulus of the force

$S_{i,j}$ denotes if the force is repulsive or attractive

The Robotic model – Mathematical formulation

Then, the agent i is subject to the following resultant force:

$$\vec{\mathcal{F}}_i = \vec{F}_{i,1} + \vec{F}_{i,2} + \ldots + \vec{F}_{i,i} + \ldots + \vec{F}_{i,N} = \sum_{j=1}^{N} \vec{F}_{i,j}.$$

Time evolution is thus simulated by solving the following System of Ordinary Differential Equations with appropriate initial conditions:

$$\frac{d\vec{u}_i(t)}{dt} = \beta_w \sum_{j=1}^{N} \vec{F}_{i,j}, \quad i = 1, \ldots, N,$$

$$\frac{d\vec{p}(t)}{dt} = \beta_p \sum_{i=1}^{N} \vec{F}_{i,i}.$$

Here b_w and b_p are used to ensure that prey and wolves velocities are bounded:

$$\beta_w = \min\left(1, v_w \left\|\sum_{j=1}^{N} \vec{F}_{i,j}\right\|^{-1}\right) \sum_{j=1}^{N} \vec{F}_{i,j}, \quad \beta_p = \min\left(1, v_p \left\|\sum_{i=1}^{N} \vec{F}_{i,i}\right\|^{-1}\right) \sum_{i=1}^{N} \vec{F}_{i,i}.$$

The Robotic model – Results

A large variety of situations has been considered:

I. Wolf-pack size ranging from $N = 2$ to 20

II. Different kinds of prey movement:

1. Stationary prey
2. Moving prey describing a circle
3. Moving prey escaping from wolves

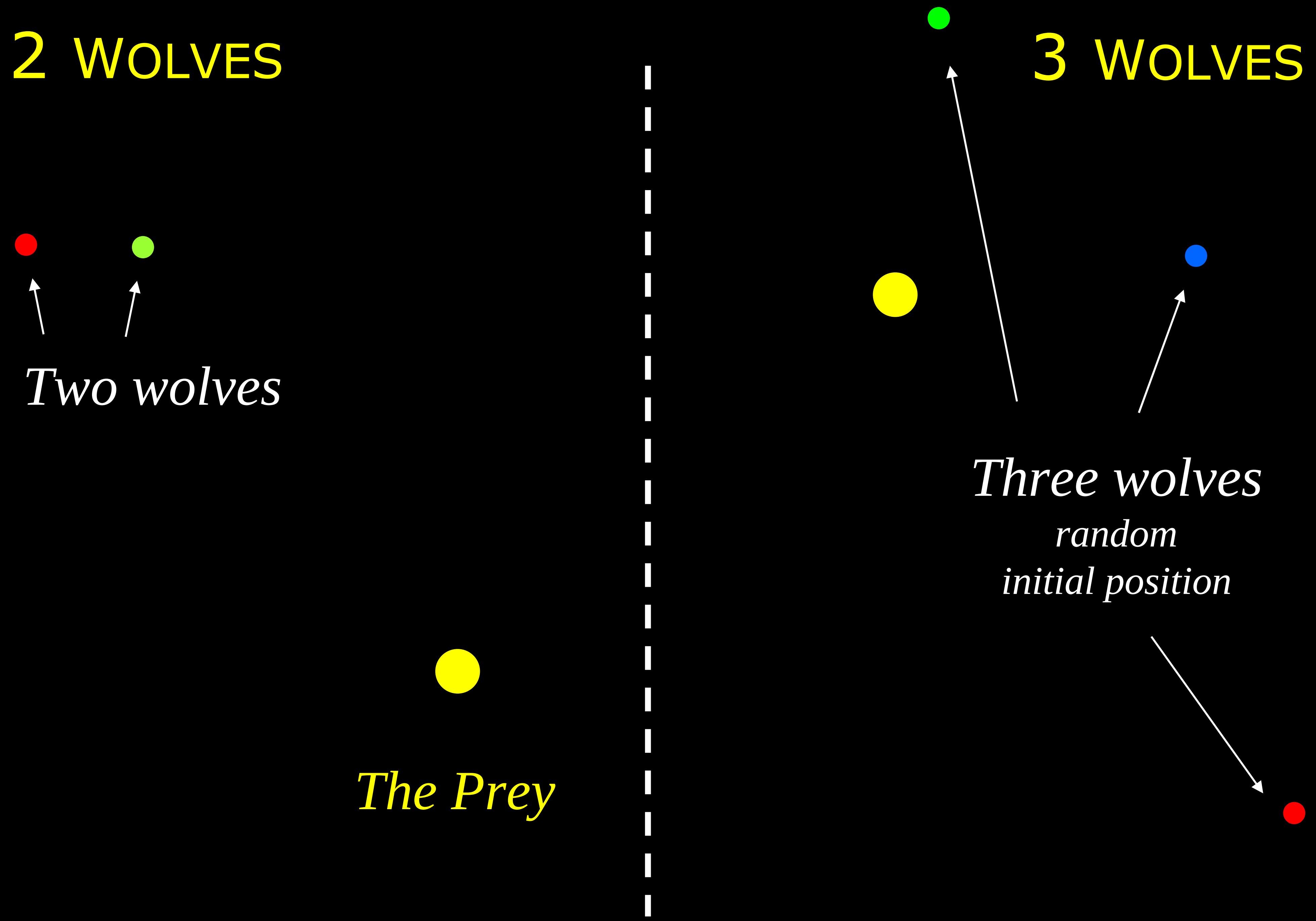
III. Different values of the parameters:

1. Relative prey/wolves velocities
2. Critical distances
3. Initial distribution

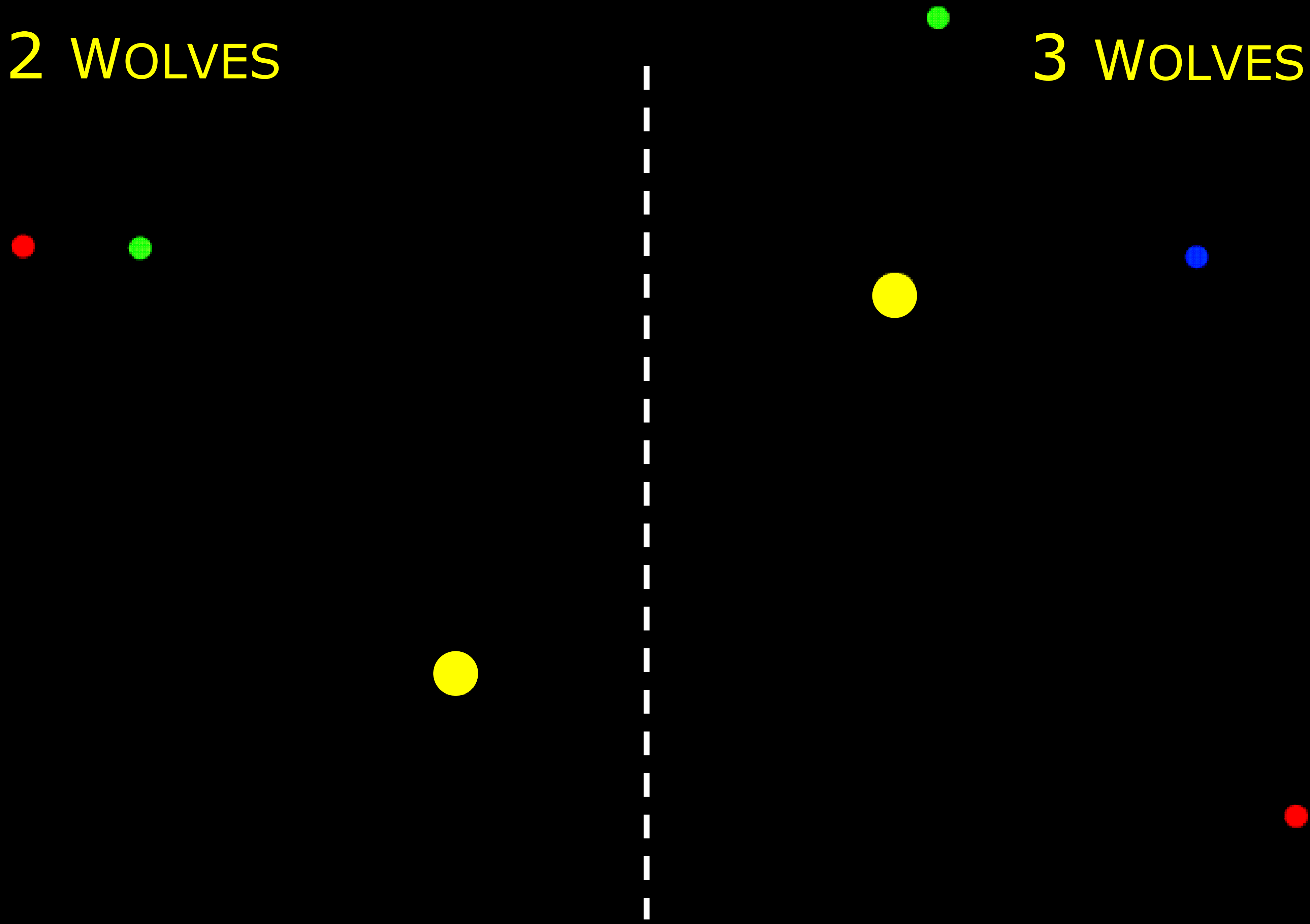
Notice that what we are modeling is how wolves move.

This is not a model of prey behavior.

STATIONARY PREY



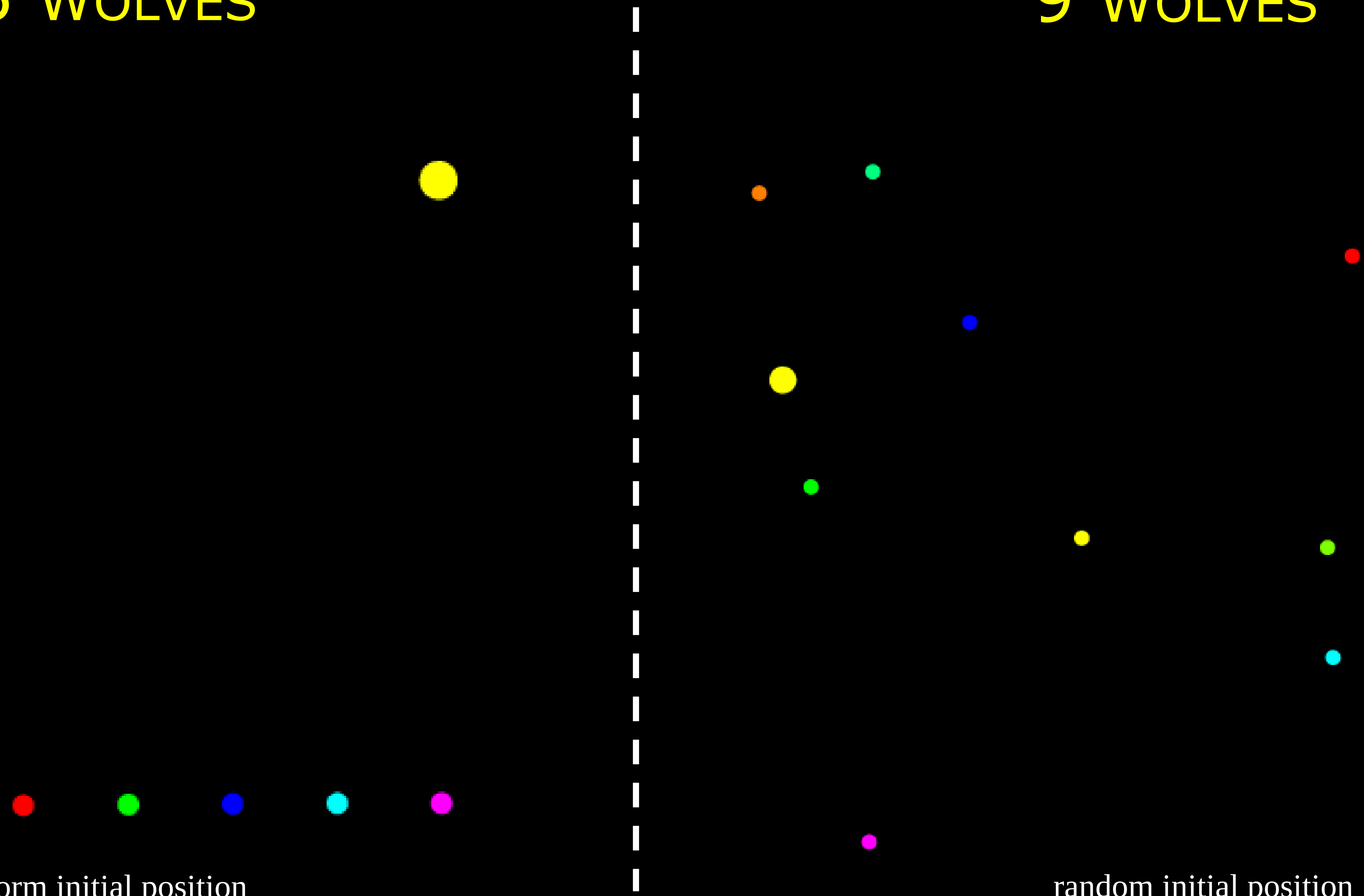
STATIONARY PREY



STATIONARY PREY

5 WOLVES

9 WOLVES

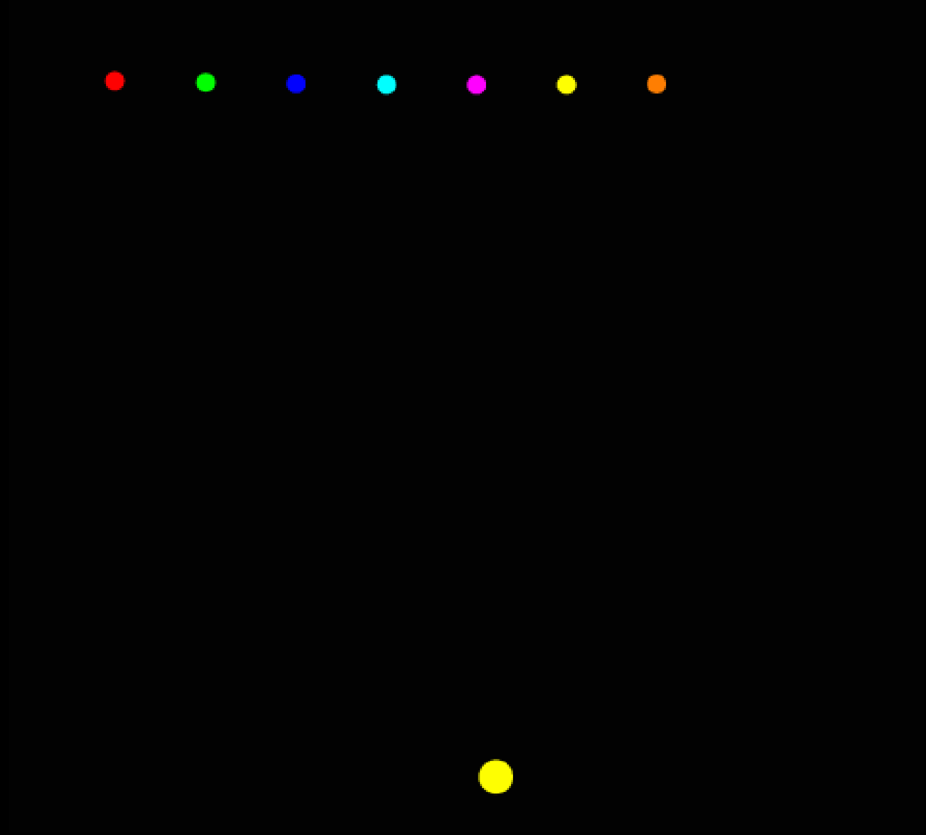


uniform initial position

random initial position

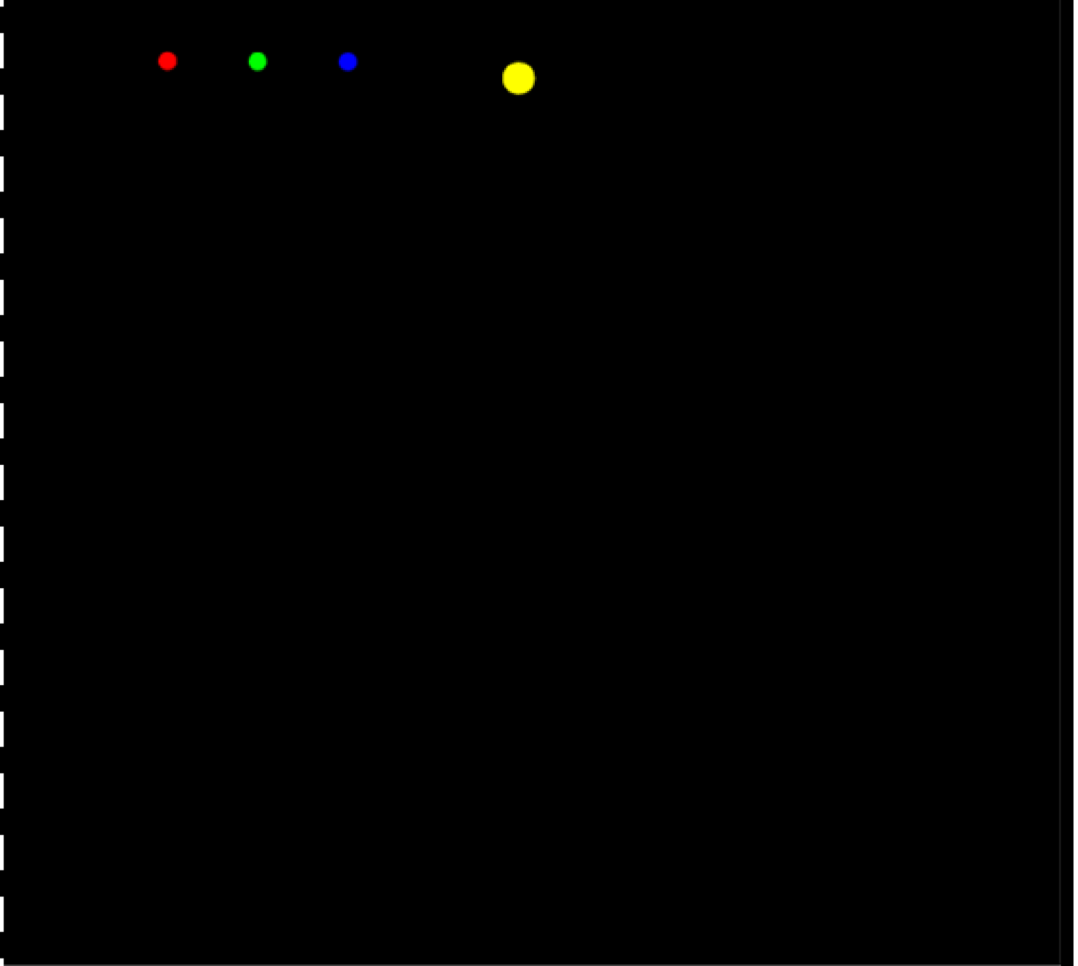
CIRCLING PREY (decreasing speed)

7 Wolves



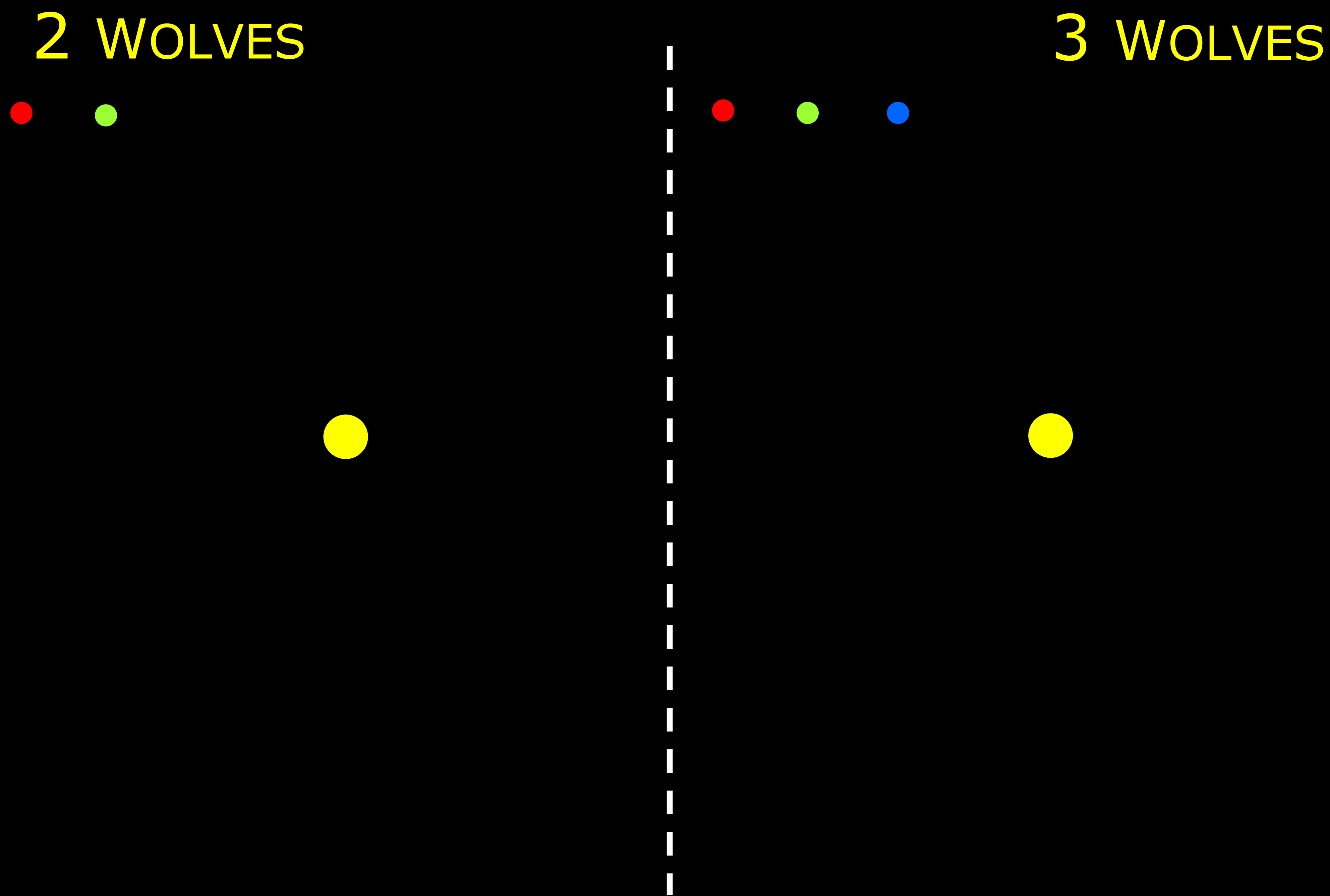
Note the emergent "relay running" pattern: the orange wolf is the first being in front of the prey, then the red one seems to take the relay, and then the green one.

3 Wolves



The prey changes direction abruptly.
Note again how emerges the relay-like running …

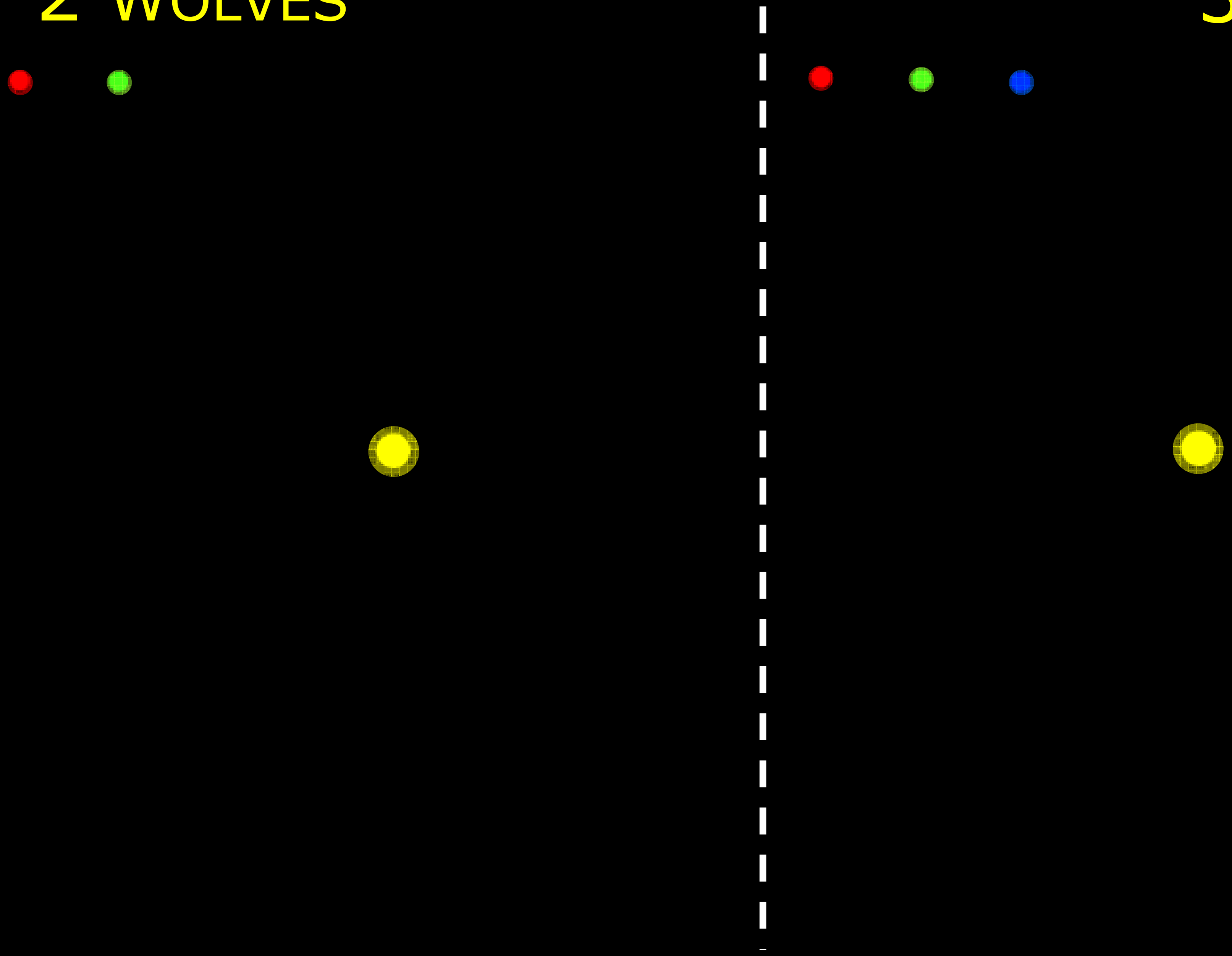
ESCAPING PREY



ESCAPING PREY

2 Wolves

3 Wolves



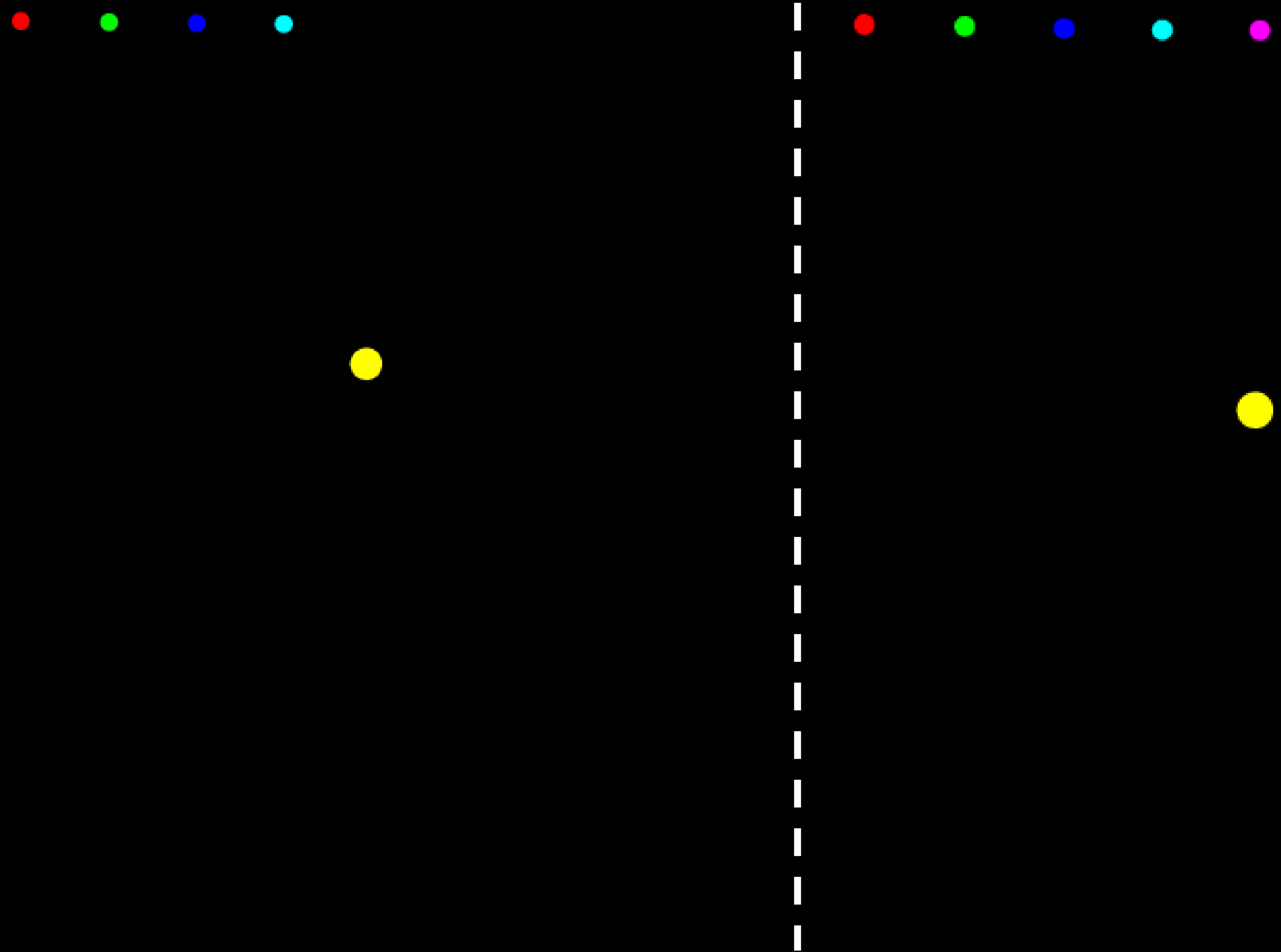
The prey moves in the opposite direction of the resultant of the forces that the prey exercises on the wolves.

PREY ESCAPES

PREY DOES NOT ESCAPE

4 WOLVES

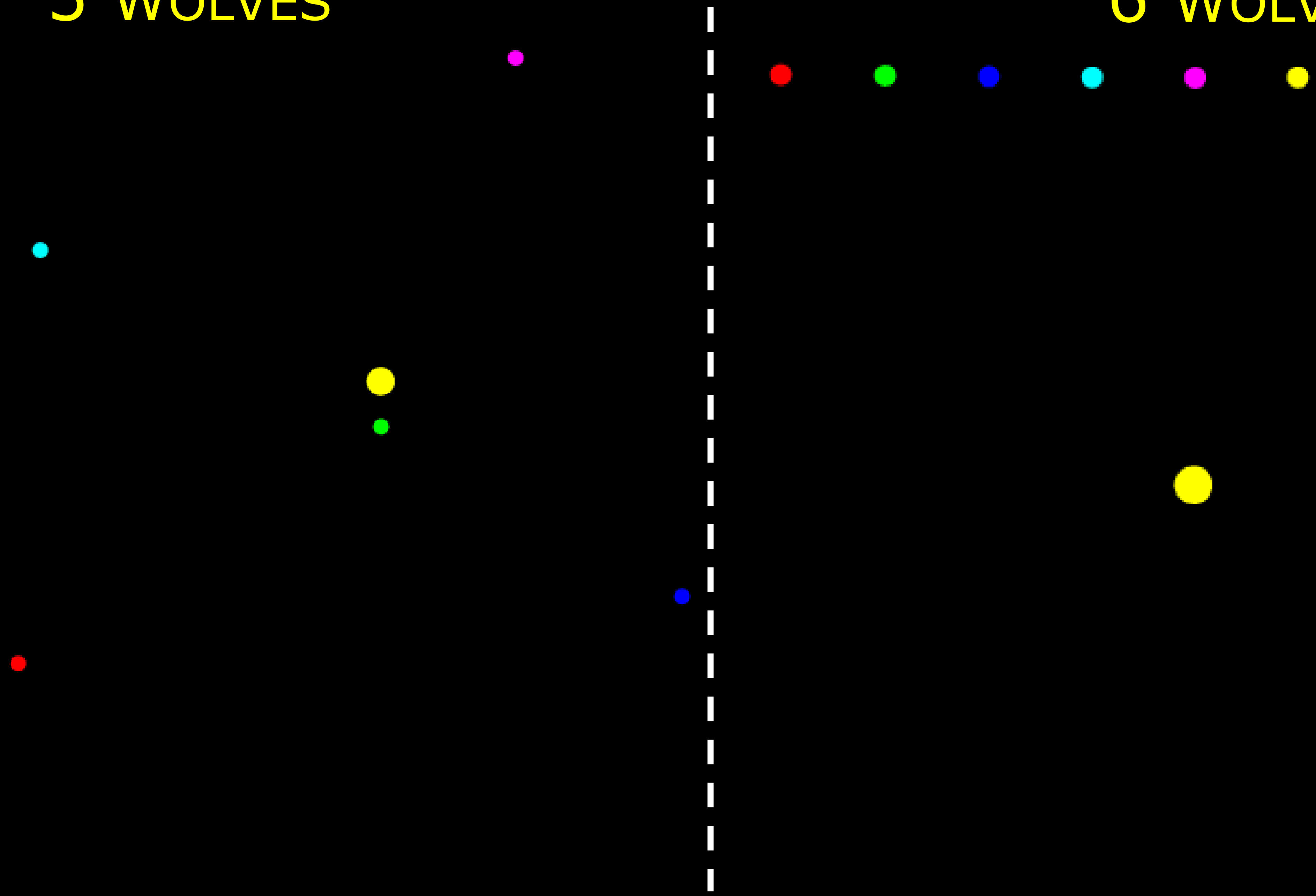
5 WOLVES



PREY DOES NOT ESCAPE

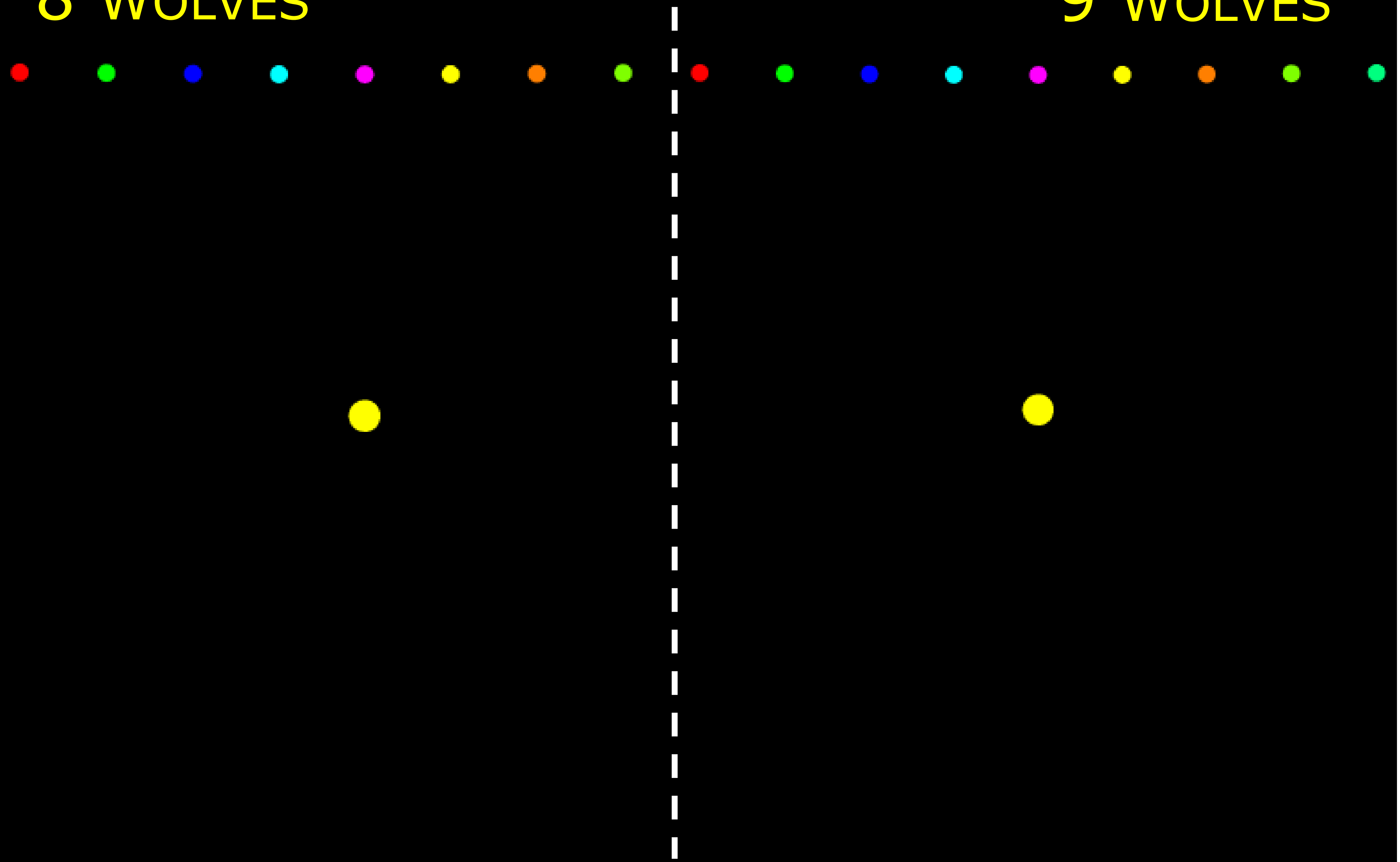
5 WOLVES

6 WOLVES

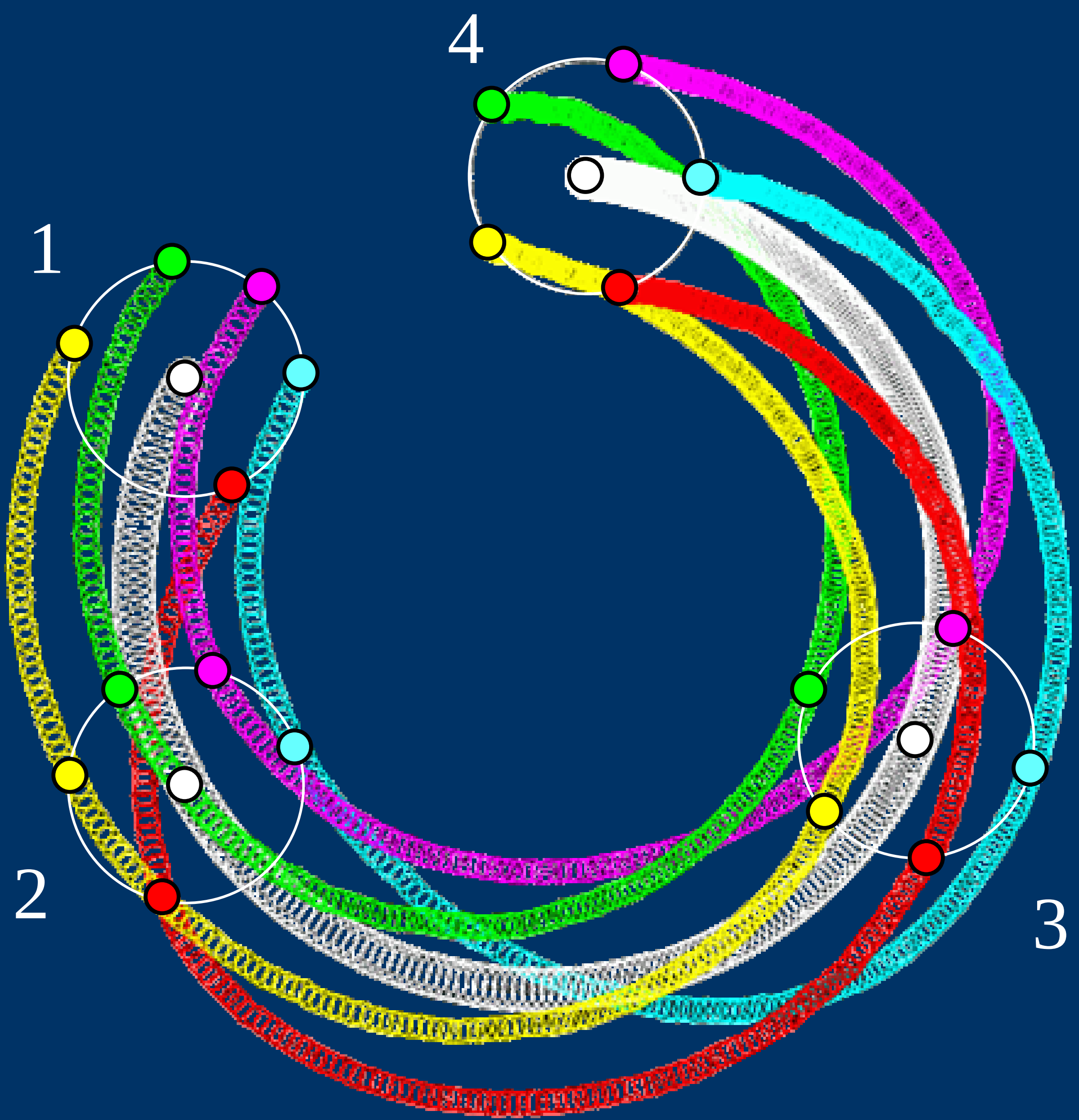


PREY DOES NOT ESCAPE

8 WOLVES | 9 WOLVES

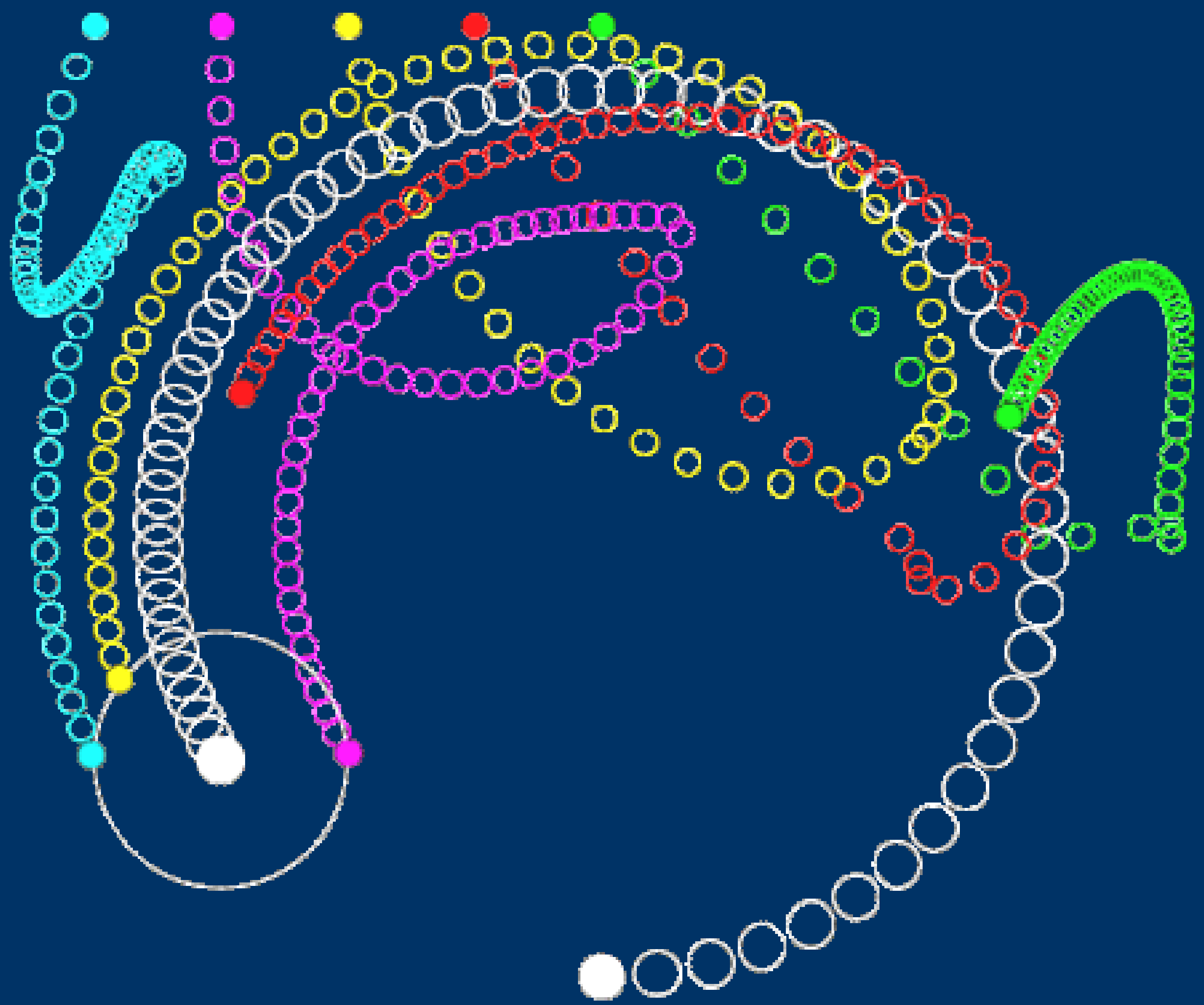


THE COMPLEX PATTERNS



- Foresight ?
- Relays ?
- Leader ?
- Coordination ?

THE COMPLEX PATTERNS



- Foresight ?
- Relays ?
- Leader ?
- Coordination ?

THE COMPLEX PATTERNS

So, which ones are the complex patterns?

- Forming a circle around the prey

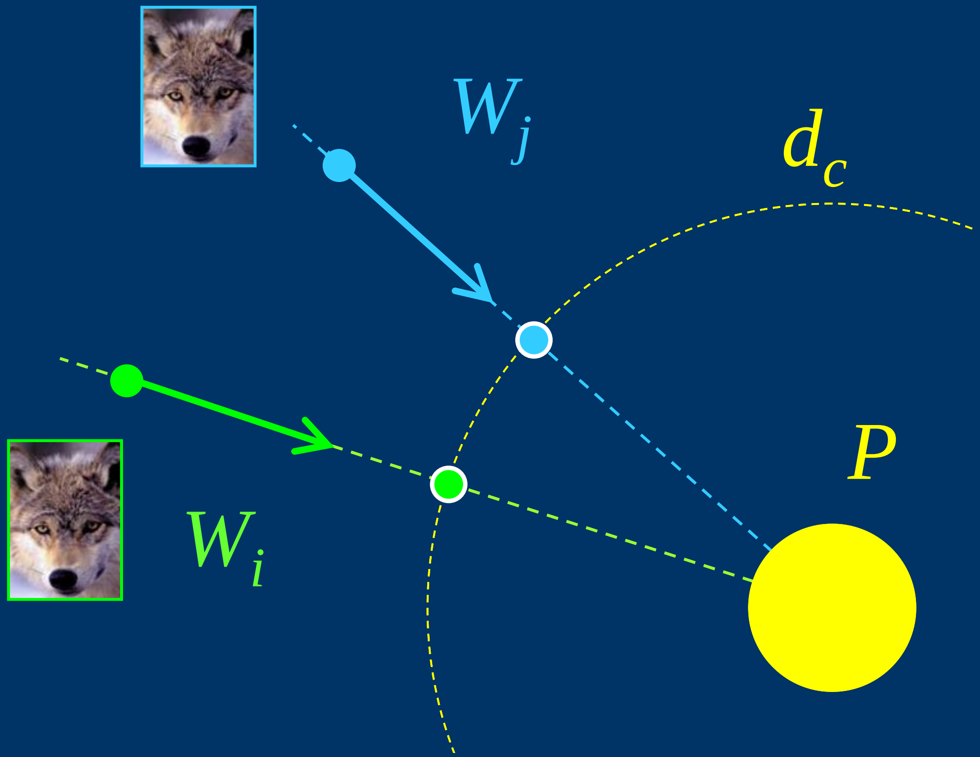
- Capturing the prey, keeping it in the center of the circle

THE COMPLEX PATTERN “ENCIRCLING”

The complex pattern is

Form a circle around the prey

and it emerges from the combination of the two simple rules:



1 Move towards P until d_c is reached.

d_c : critical distance

THE COMPLEX PATTERN "ENCIRCLING"

The complex pattern is

Form a circle around the prey

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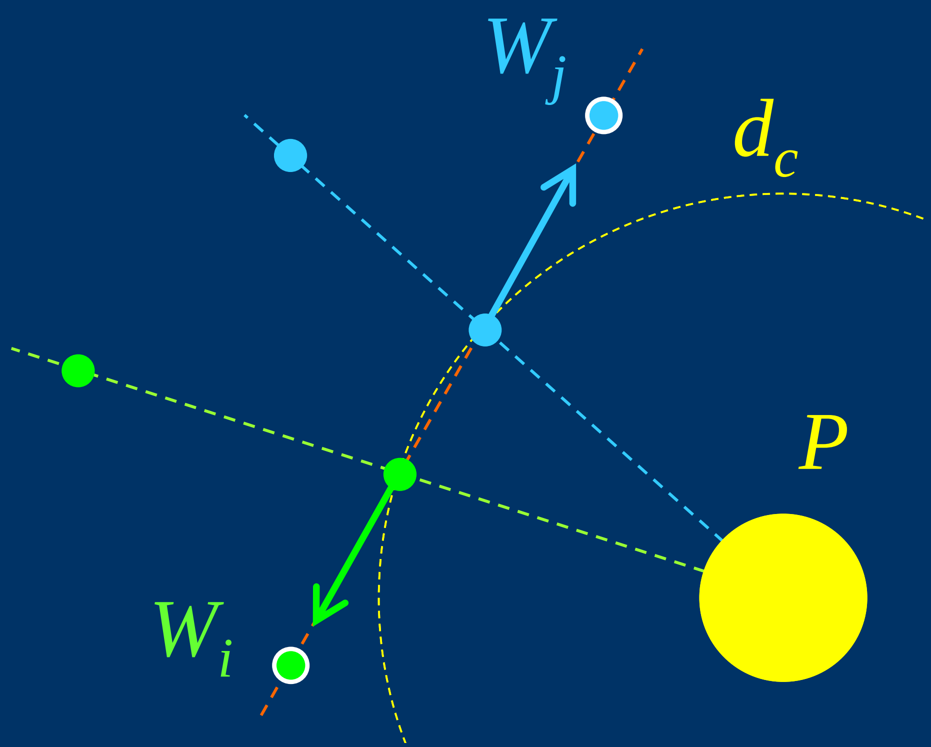

1. Move towards P until d_c is reached.
2. When close enough to P, move away from others W_i.

THE COMPLEX PATTERN "ENCIRCLING"

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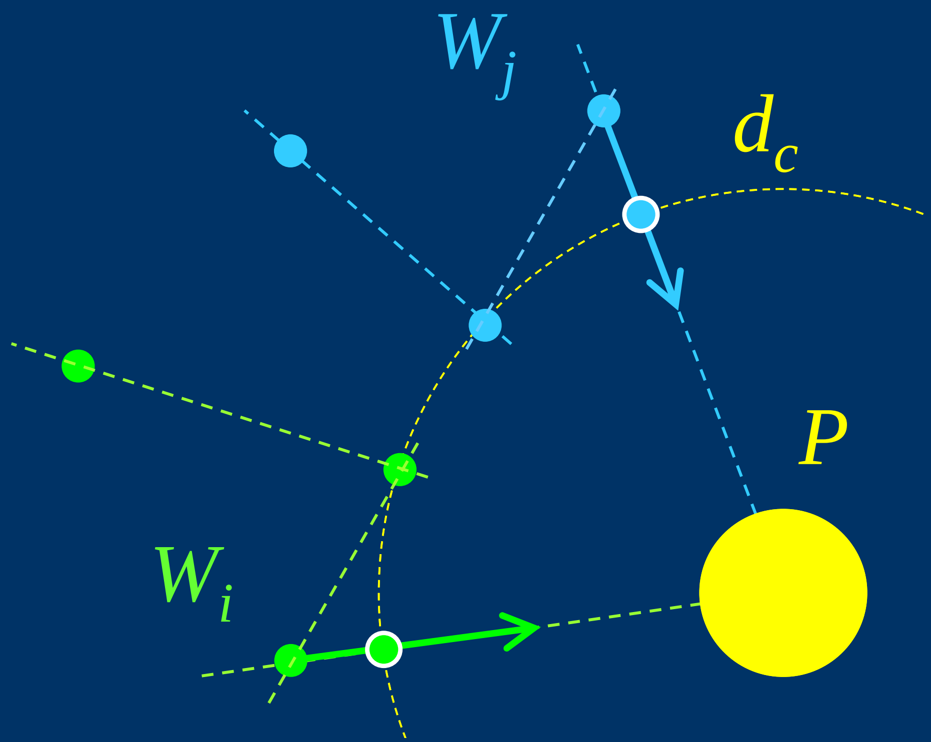


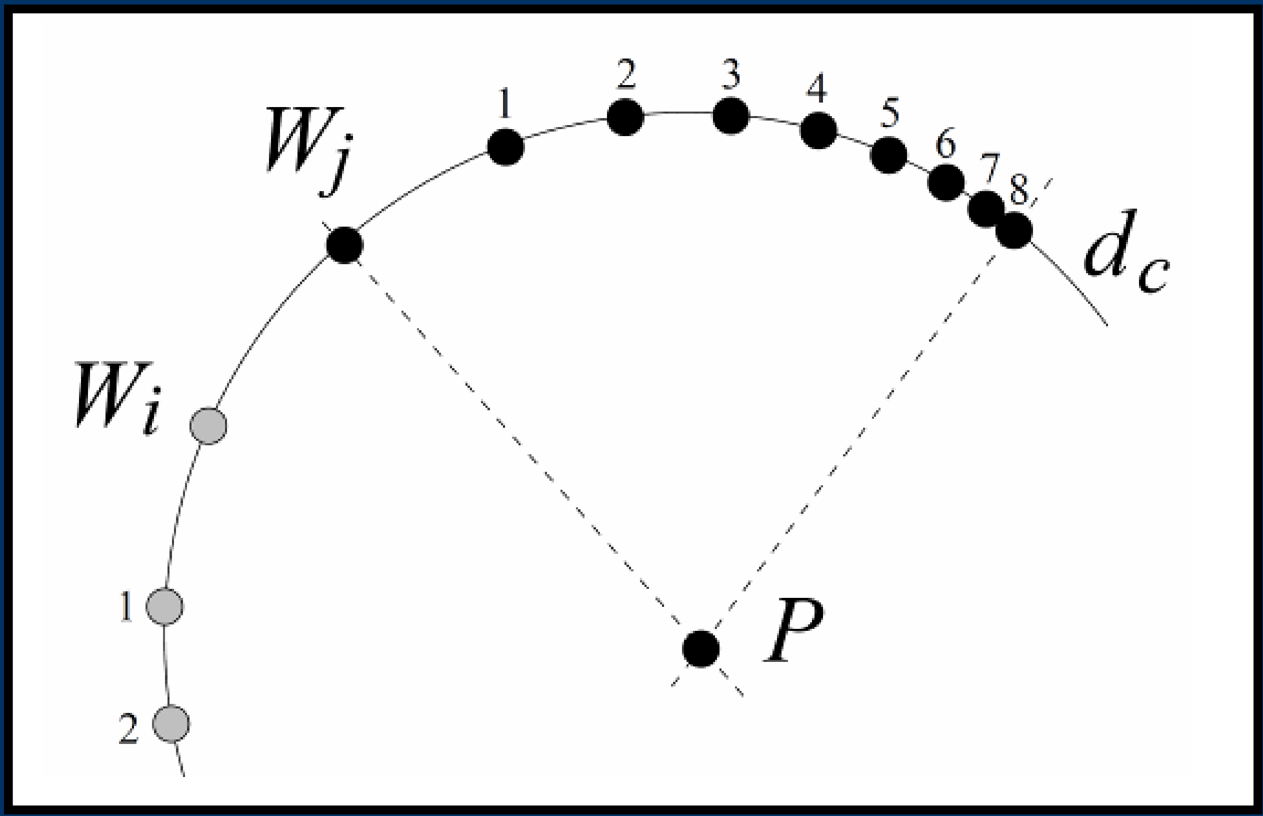
1	Move towards P until d_c is reached.
2	When close enough to P, move away from others W_i .
1	Move towards P until d_c is reached.

THE COMPLEX PATTERN “ENCIRCLING”

The complex pattern is

Form a circle around the prey

and it emerges from the combination of the two simple rules:



Successive positions describe a circle

THE COMPLEX PATTERN "CAPTURING"

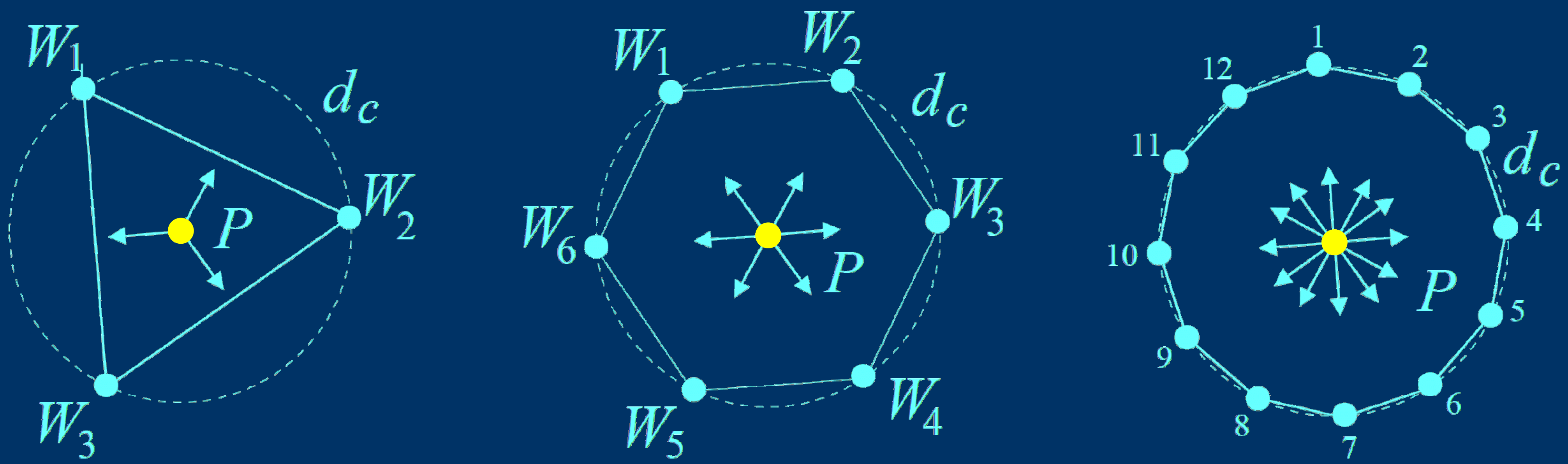
The complex pattern is

Capture the prey

and it emerges from the combination of the two simple rules:

Final configurations:

$N = 3$ $N = 6$ $N = 12$



CONCLUSION

The Robotic model shows that

1. No centralized agent is needed
2. No communication is needed for a successful hunt

for a successful hunt.

This allows us to formulate an hypothesis:

Wolf-pack hunting behaviors are emergent patterns resulting from the combination of two simple rules applied by each individual.

In the aim of Occam's razor principle –the simplest explanation is the correct one– we would suggest that social behaviors like wolf hunting might be better described as emergent behaviors rather than complex cognitive abilities.

Main references

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Possible Use of Foresight, Understanding, and Planning by Wolves Hunting Muskoxen
D. L. Mech, Arctic **60** (2007) 145–149

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A proposed ethogram of large-carnivore predatory behavior, exemplified by the wolf
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Computer Graphics **21** (1987) 25–34

Most of the videos from youtube seem to be from D. R. MacNulty.

THANK YOU VERY MUCH

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More simulations at:
http://personales.unican.es/escobedo/w.html