Spherical cows
and other modelling issues

Afonso Loureiro

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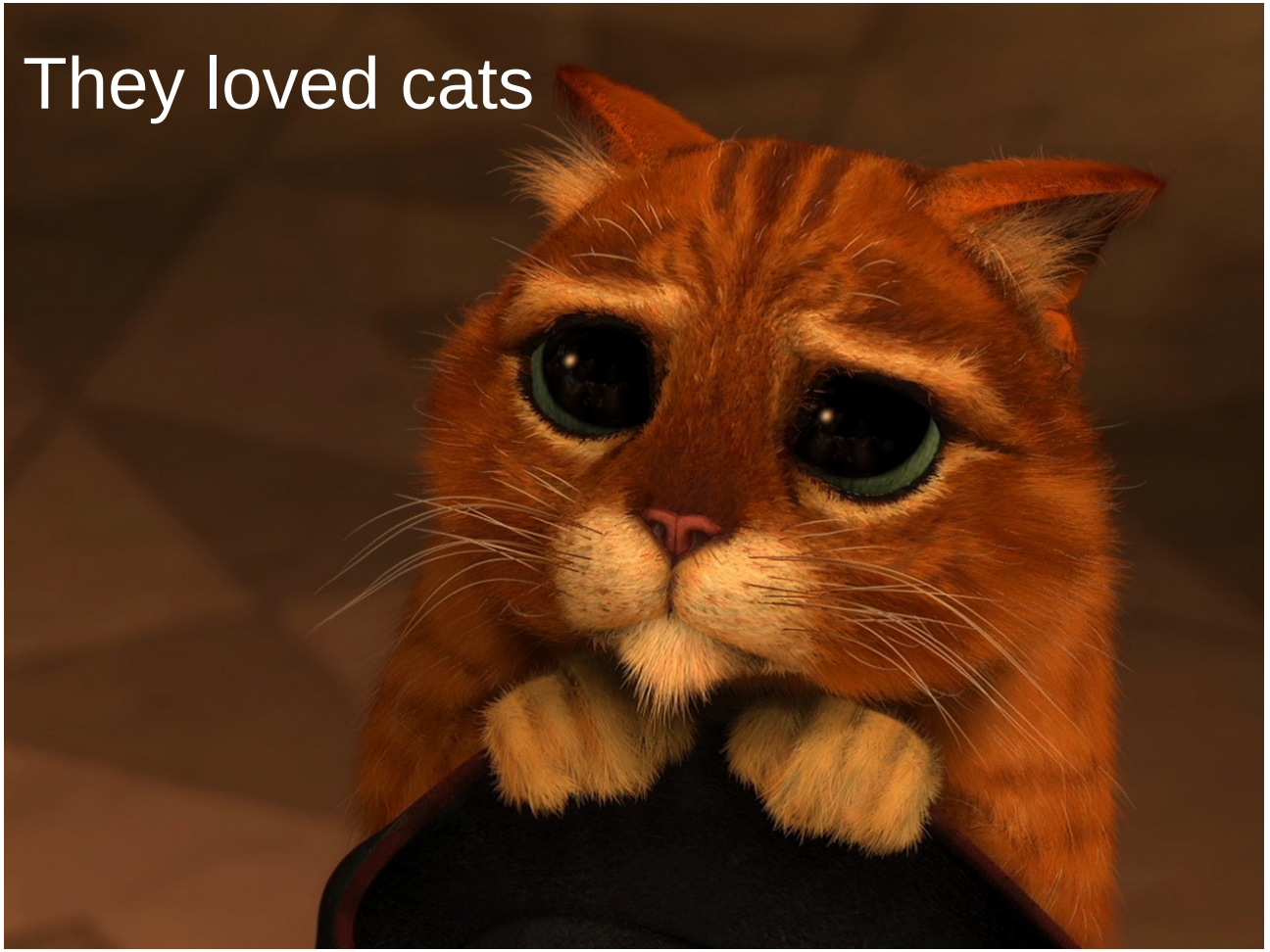
Motivation

Once upon a time I had a paper ~~once~~ ~~twice~~ thrice rejected because some reviewers preferred a different type of model

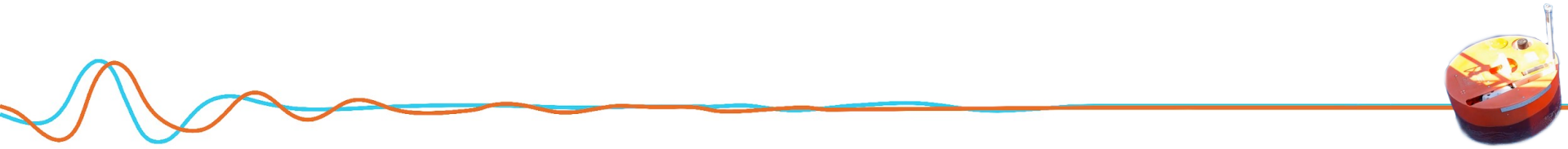
My paper was about dogs
(I like dogs)


They loved cats

Actually…

I was doing crustal seismic imaging with layered models

The reviewers did tomography using smooth models



Smooth vs Layered Models (tomo vs forward modelling)

Some tomographers oppose layered models because:

- They insist that the Earth is a continuous medium
  - That's why they use a discrete grid (!)
- A layered Earth doesn't make sense
  - Well logs show layers
  - Seismic data shows reflections and conversions
- Tomo makes pretty pictures (!)
  - Similar to those from numerical modelling
- Tomo does not require operator intervention
  - Errors are spontaneously generated (!)

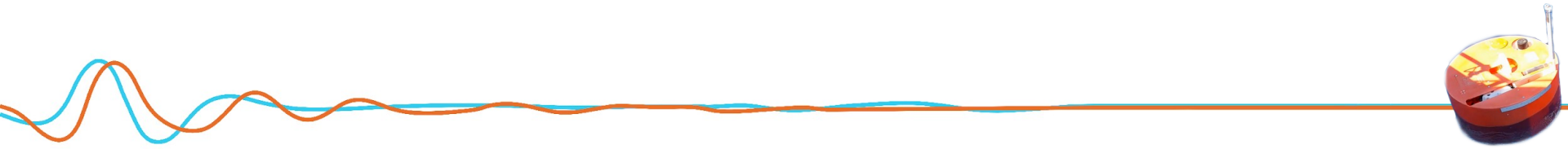
Smooth vs Layered Models (tomo vs forward modelling)

It's a somewhat empty discussion

- We are debating parametrizations
- Different data sets are used
- Distinct resolutions and goals

It could be regarded as a cats and dogs issue, but it's really an issue between:

Spherical cats and spherical dogs.

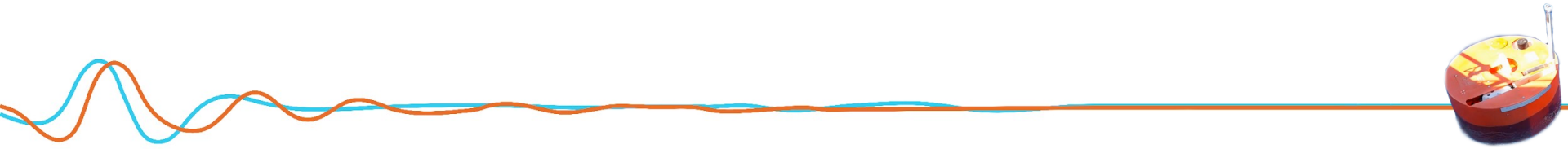


Cats and dogs

Are both nice models for small carnivore animals
(results may vary for model fish)

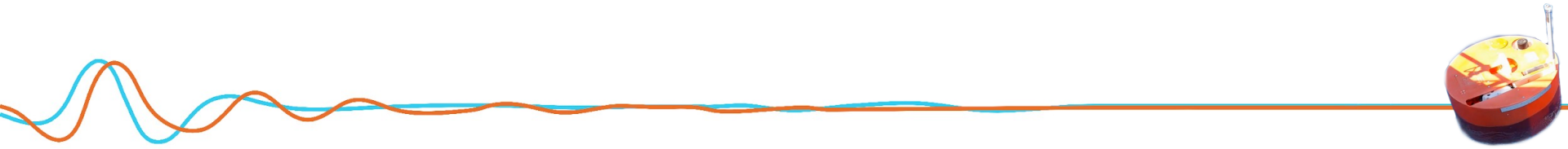
What is a model?

- The conceptual representation of phenomena
- A simplification of a problem into the most relevant aspects
- The translation of complex formulas into a global picture
- A tool to help us understand something we cannot see directly



What are the limitations of Earth models?

- We cannot know the “true Earth”
- Models attempt to recreate observations
  - Observations are band-limited
- Models are based on simplifications
  - We may not understand the whole problem
  - Computational issues



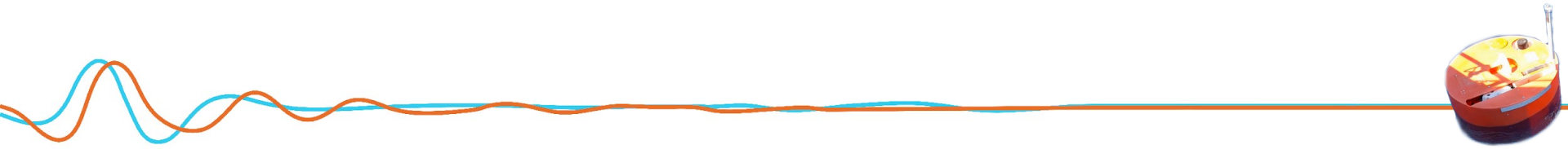
What is a good model?

- A good model should
  - Recreate all the data within a given error range
  - Not contradict other data sources
  - One that you can invalidate

- Often, a good model is only something that
  - Supports our hypothesis (!)
  - Looks good (!)
    - χ^2 by eye

Do the data help?

- Current imaging techniques have limited resolution in the spatial, temporal and frequency domains
- Data may be corrupted by ambient noise
- Data is best described as inaccurate, insufficient and inconsistent (Jackson, 1972)



We keep forgetting that

- Models are not reality
- Models may allow impossible scenarios
- Some parts of the problem may not be known
  - Simplifications and shortcuts (!)

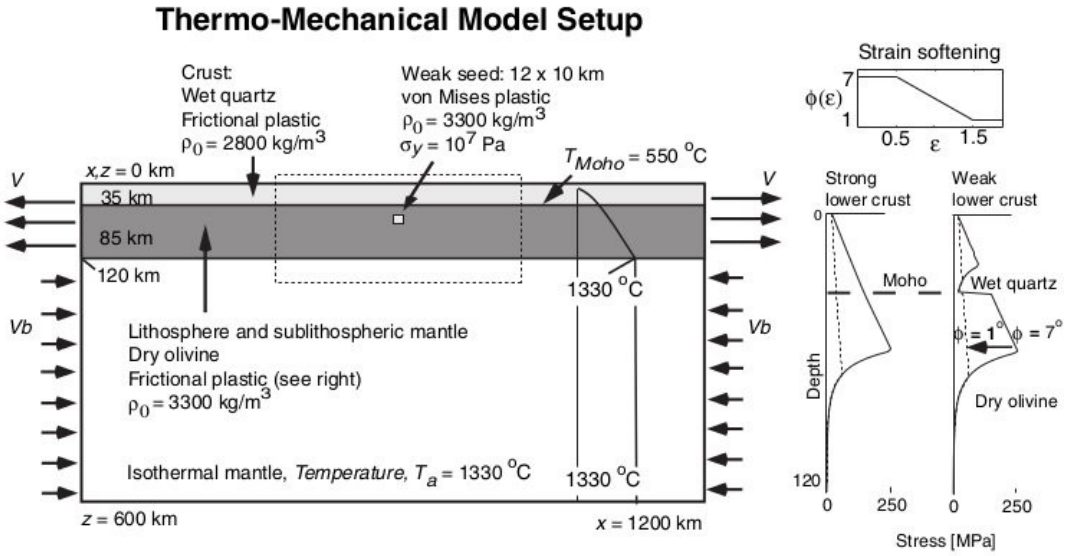
Roles of lithospheric strain softening and heterogeneity in determining the geometry of rifts and continental margins

R. S. HUISMANS[1,2] & C. BEAUMONT[1]

[1]*Geodynamics Group, Department of Oceanography, Dalhousie University, Halifax (Nova Scotia), Canada, B3H 4J1*

Lithospheric-scale numerical modelling, for example, use extremely simplified models to recreate large scale features

Assumptions, simplifications, and shortcuts are required to calculate the solutions in a reasonable time frame



We keep forgetting that

- Again, models are not reality
- A model is a single solution of a very under-determined problem
  - Should mostly be used to disprove hypothesis

Although numerically complex and looking good (pretty and supporting some hypothesis), passive margin models are not the true crust

Rifting is forced by a mechanical seed, not a rheological one

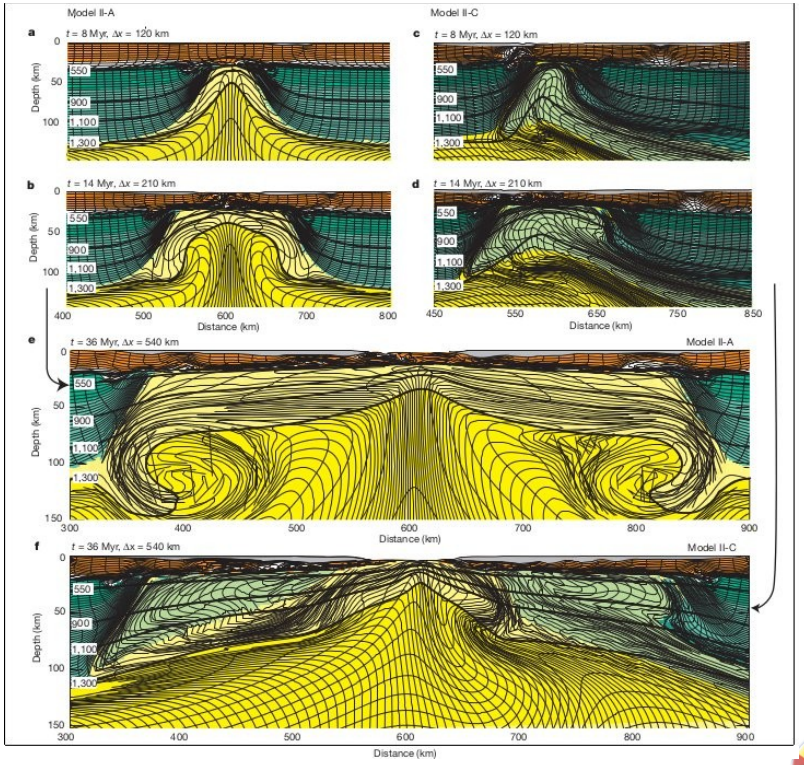
Extensional settings are sometimes unrealistic (10-20cm/y)

LETTER

doi:10.1038/nature09988

Depth-dependent extension, two-stage breakup and cratonic underplating at rifted margins

Ritske Huismans[1] & Christopher Beaumont[2]



Modelling is done inside a “box” with limited outside mass and energy transfers

Jelly sandwich and crème brulé are really good model descriptions

LETTER

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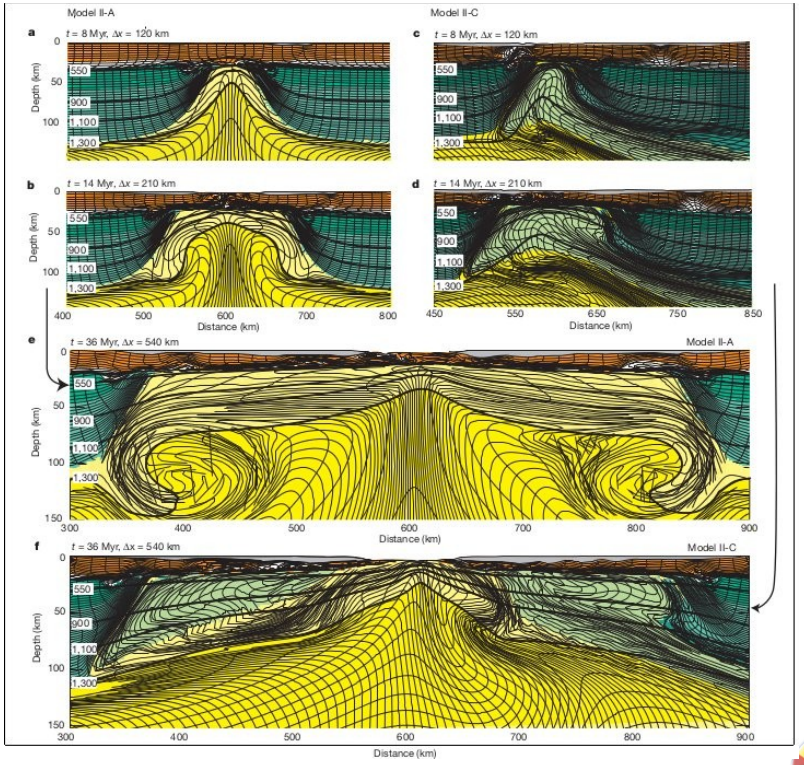
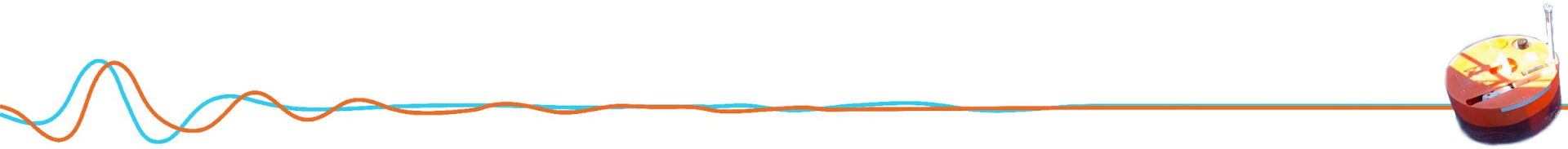


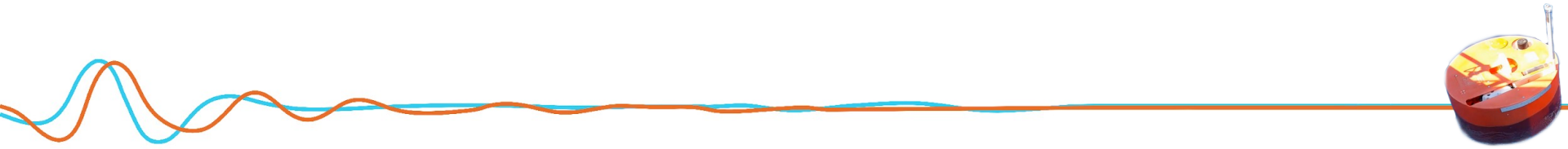
We keep forgetting that

- Again, models are not reality
- A model is a single solution of a very under-determined problem
- Models must conform to the true Earth!
  (and not the other way around)



Parametrizations

- Any given parametrization is based on our imaging capabilities (Gallardo & Meju, 2011)
- They are based on assumptions and simplifications
- Different parametrizations may explain equally well the same data (Wigner, 1960)



Spherical cows (finally)

What is a spherical cow?

What is a spherical cow?

- Its an extremely simplified model of complex phenomena
- Tends to focus on the simplest theoretical case
- Makes calculations easier
- Mostly useless when confronted with reality
- But it's a start when we don't know how to begin

Spherical cows

Are the physicist's approach to raising cattle

- We have limited information about cattle and farming
- There is a medium – the meadow
- There are objects – the cows
- The cows are free to move in the medium to do cow stuff (we don’t exactly know what they do or think about)

Definitions: The medium

What the meadow looks like

Definitions: The cow

What a cow looks like

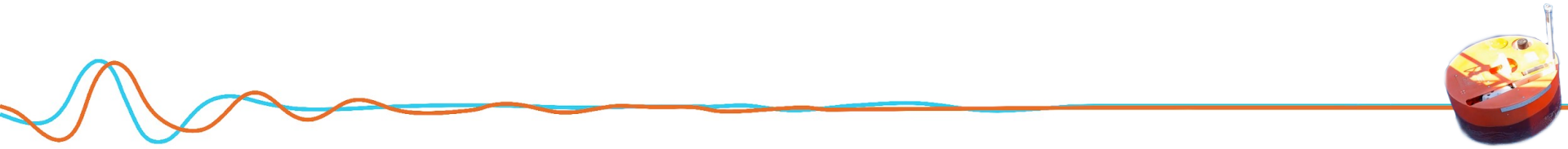
How we hope to describe the problem

Simplification

Our description of the problem is still too complicated

We need to simplify it before even dreaming of:

- Full-cow waveform inversion
- Generate high-resolution synthetic cow images with FD or FE methods
- Producing milk



Spherical cows

A first model is established:

- Cows are spherical
- Their mass is concentrated on a single a point
- Coincident with the centre of mass
- They move in a frictionless plane
- In a vacuum
  - Do cows breathe? Who knows? At this point, who cares?

The first model – COW 1.0

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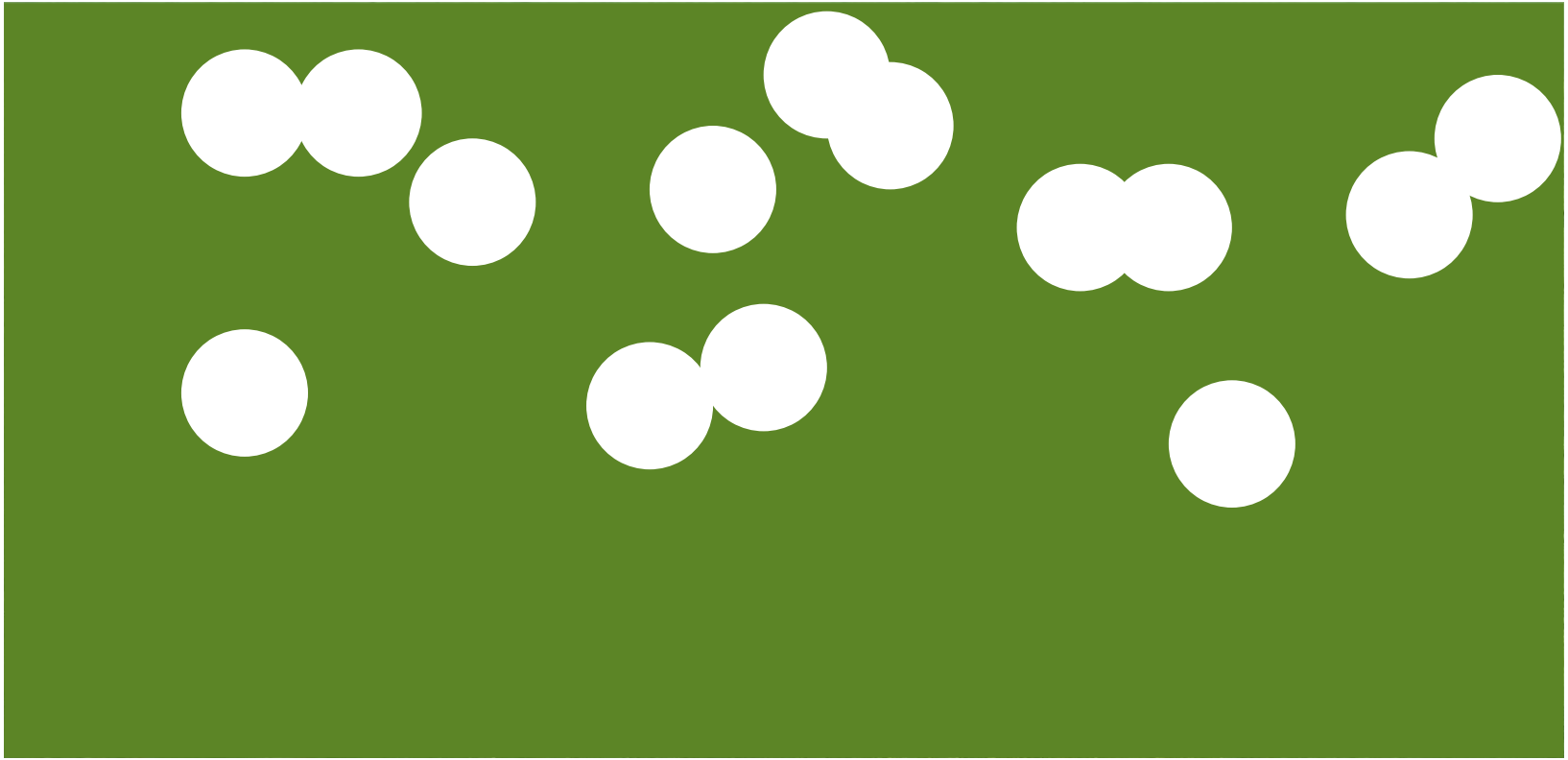


We can predict the distribution of cows in the meadow

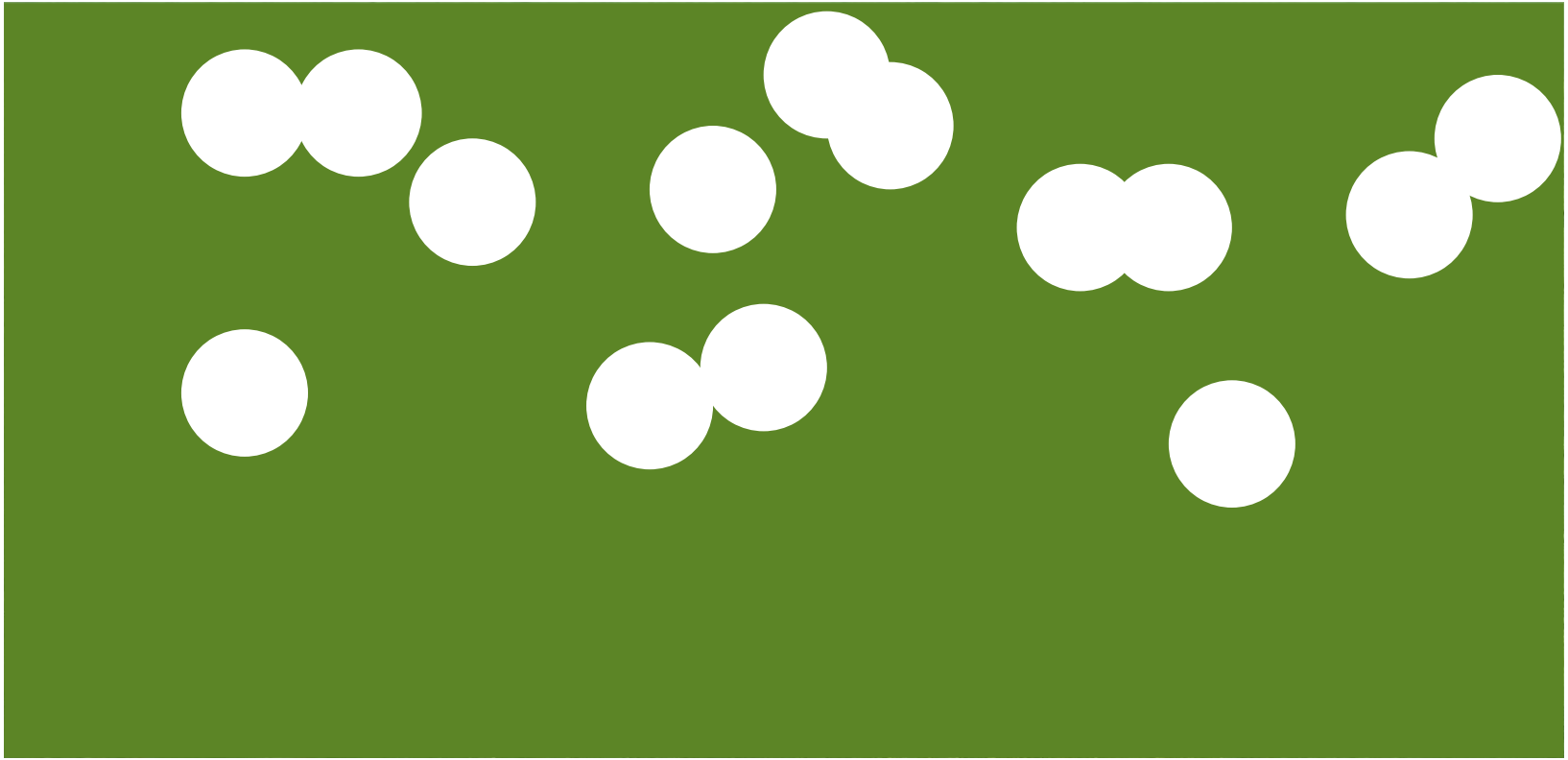
The first model – COW 1.0

Improving the model:

- Cows can have different radii
- They multiply at a given rate
- Milk is somewhat like hydrocarbons
  - it has economical interest

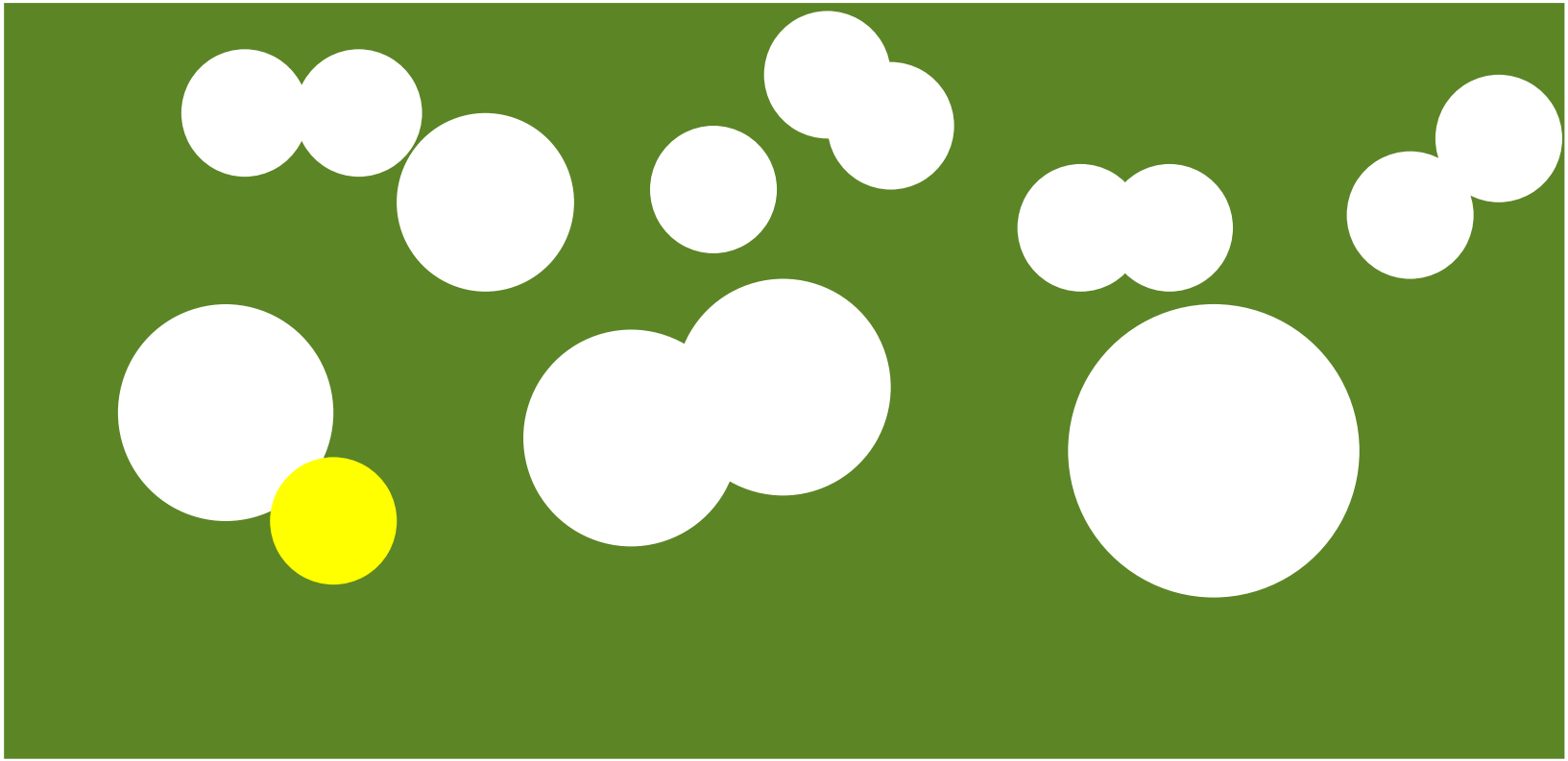
(according to David Schlaphorst, spherical cows should produce spherical milk, at least at zero-g)

The first model – COW 1.0



Simple cow distribution and density

More parameters – COW 1.1



Our cow/meadow density estimations have improved

Meanwhile...

The original researcher behind COW 1.1 found a permanent position and left without making any further advances

The code was left untouched in a Github repository until a PhD student was tasked with making it work

The new fork was renamed to something more scientific-sounding

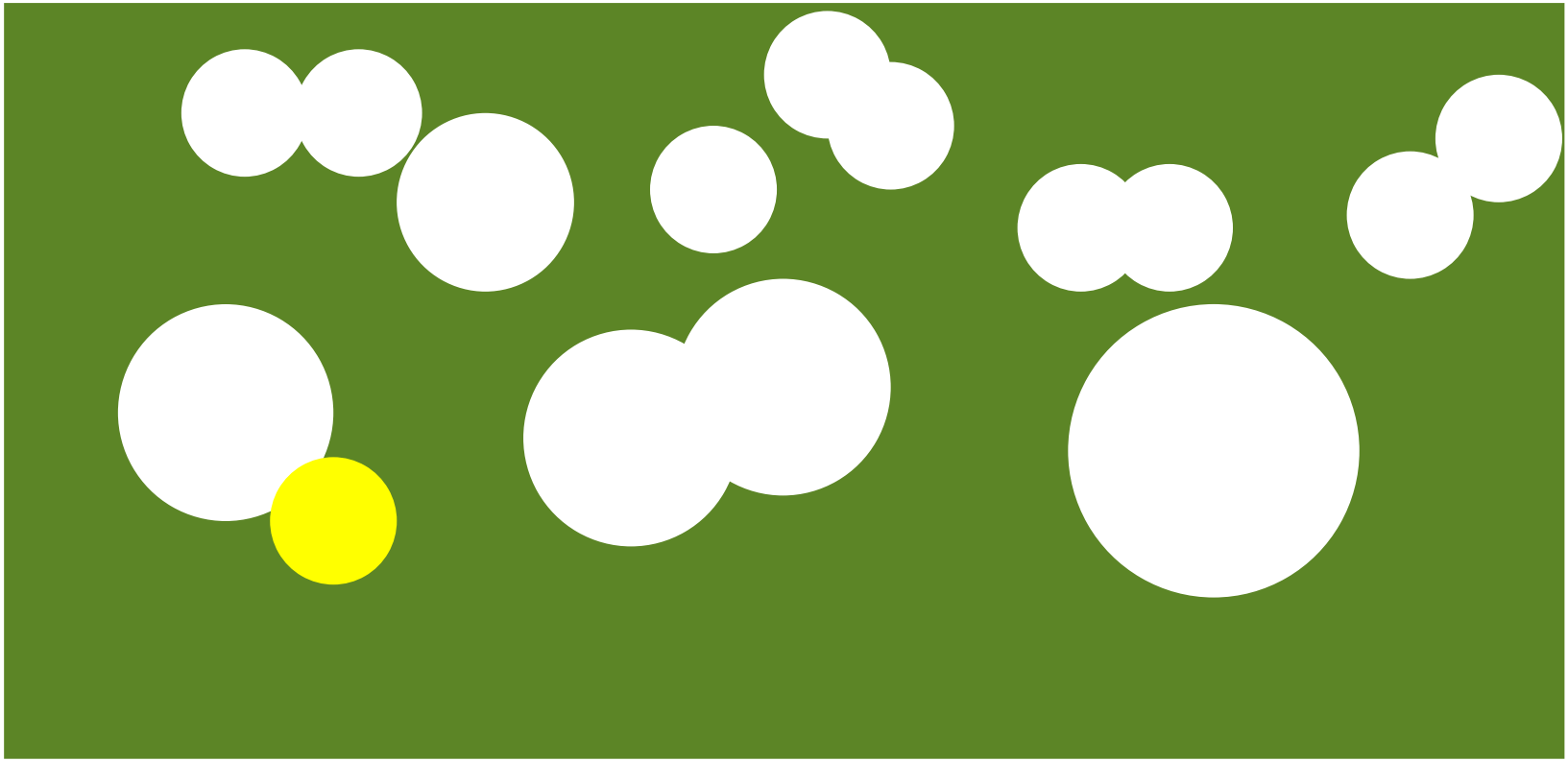
BOVINE 2.0

Bovine-**O**riented **V**irtual **I**nterface for **N**umerical **E**valuation – BOVINE

Further improving the model:

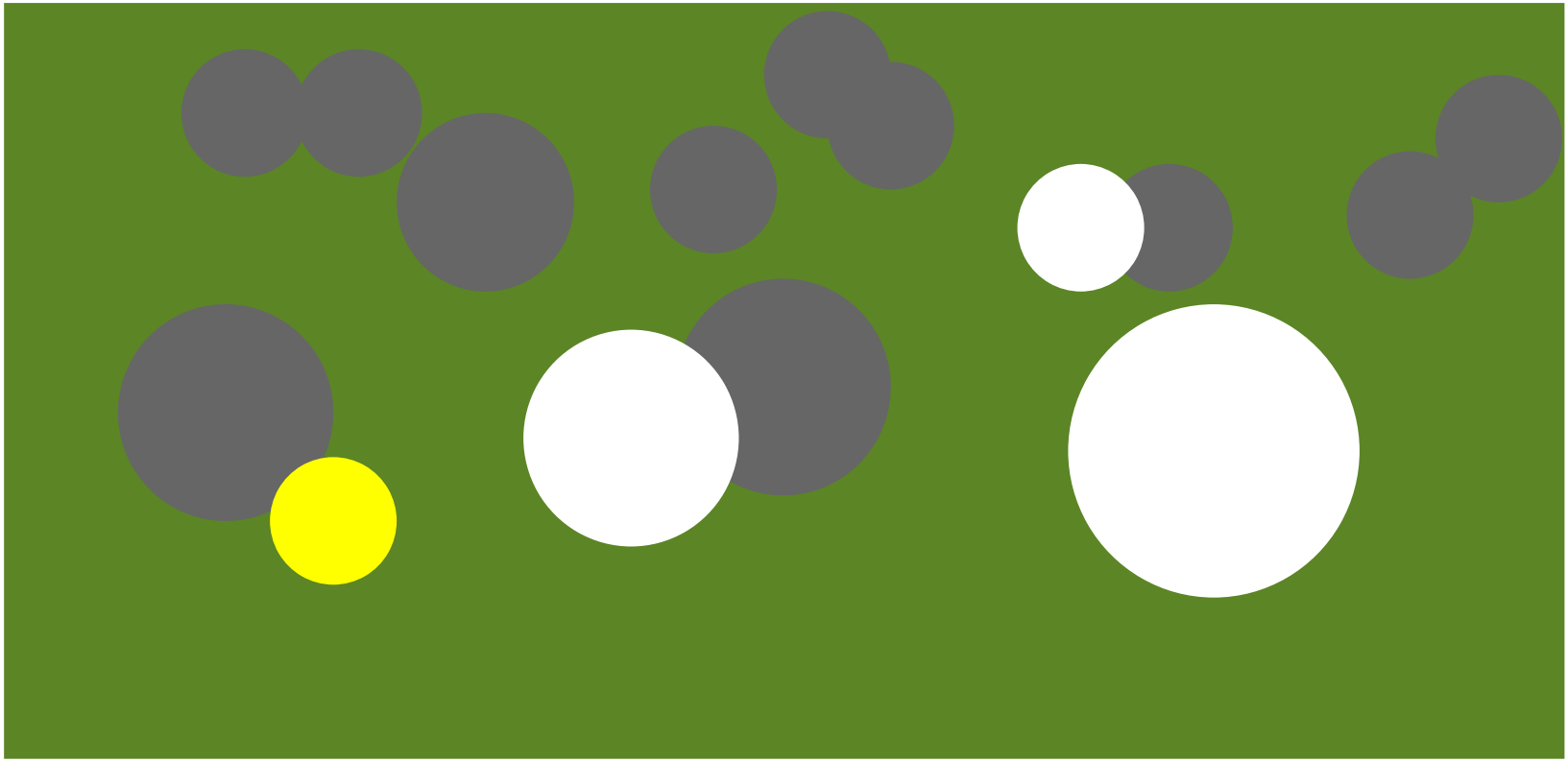
- There are black and white cows – BOVINE 2.1

COW 1.1



Our cow/meadow density estimations have improved

BOVINE 2.1



Lots of work to define a suitable parametrization for colour

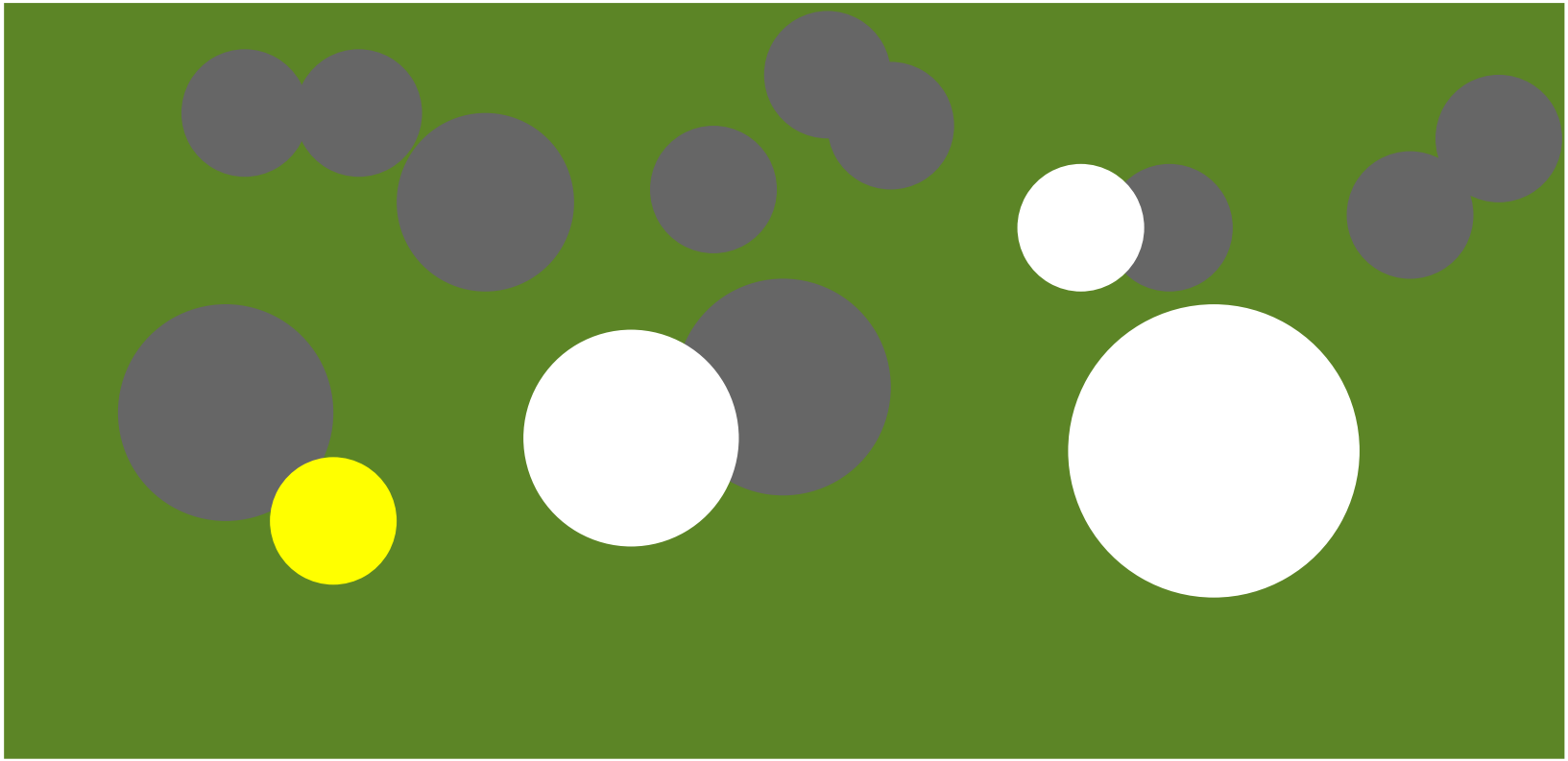
BOVINE 2.2

Bovine-**O**riented **V**irtual **I**nterface for **N**umerical **E**valuation – BOVINE

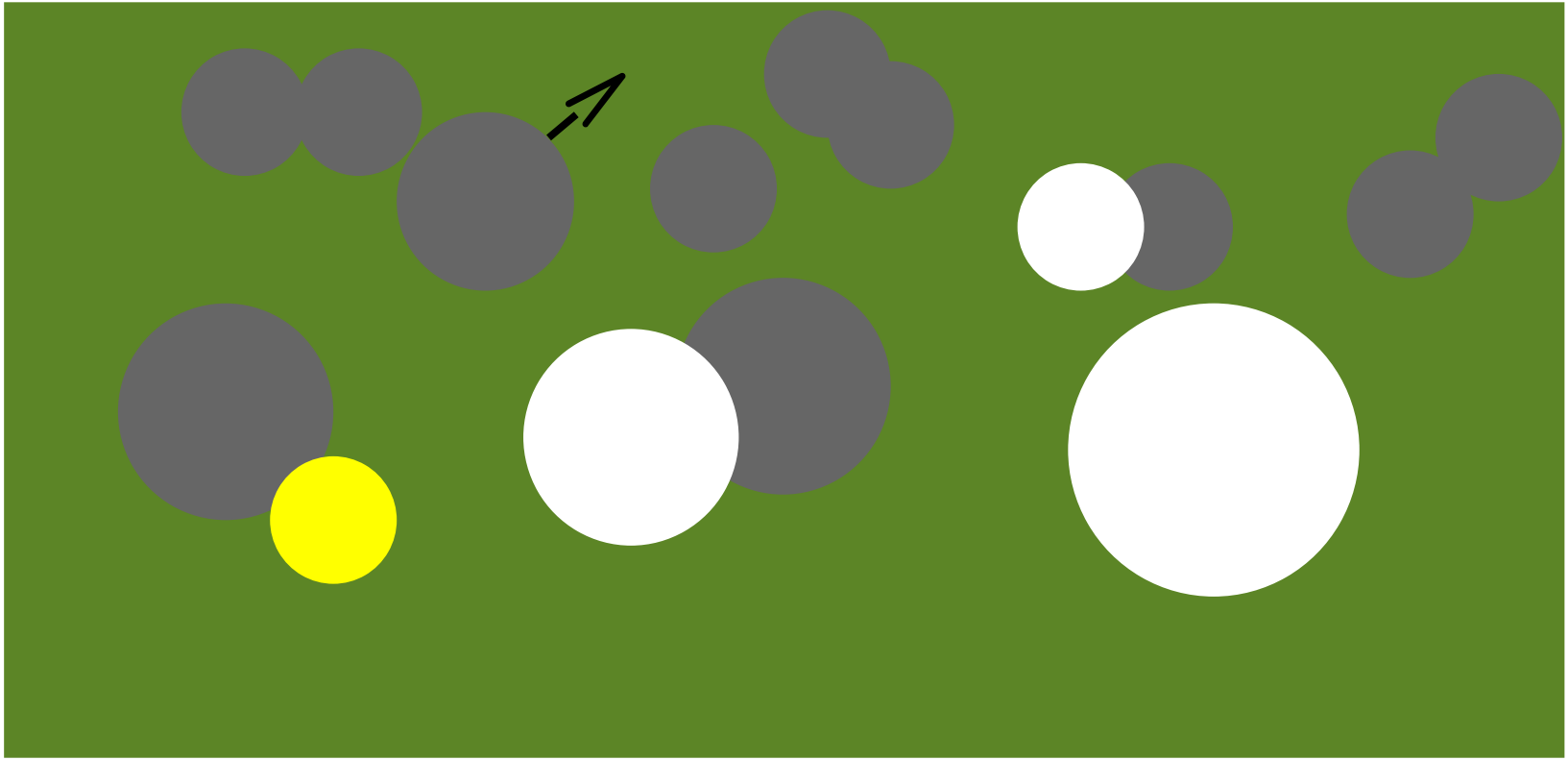
Further improving the model:

- There are black and white cows – BOVINE 2.1
- A new type of cow was defined: bull – BOVINE 2.2

BOVINE 2.1



BOVINE 2.2



Updates to cow Class

BOVINE 2.2

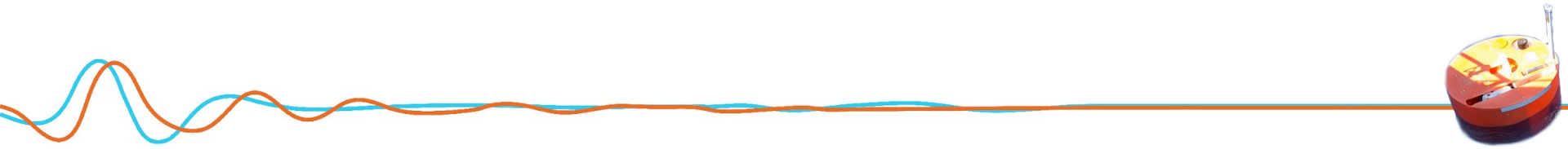
Bovine-**O**riented **V**irtual **I**nterface for **N**umerical **E**valuation – BOVINE

Further improving the model:

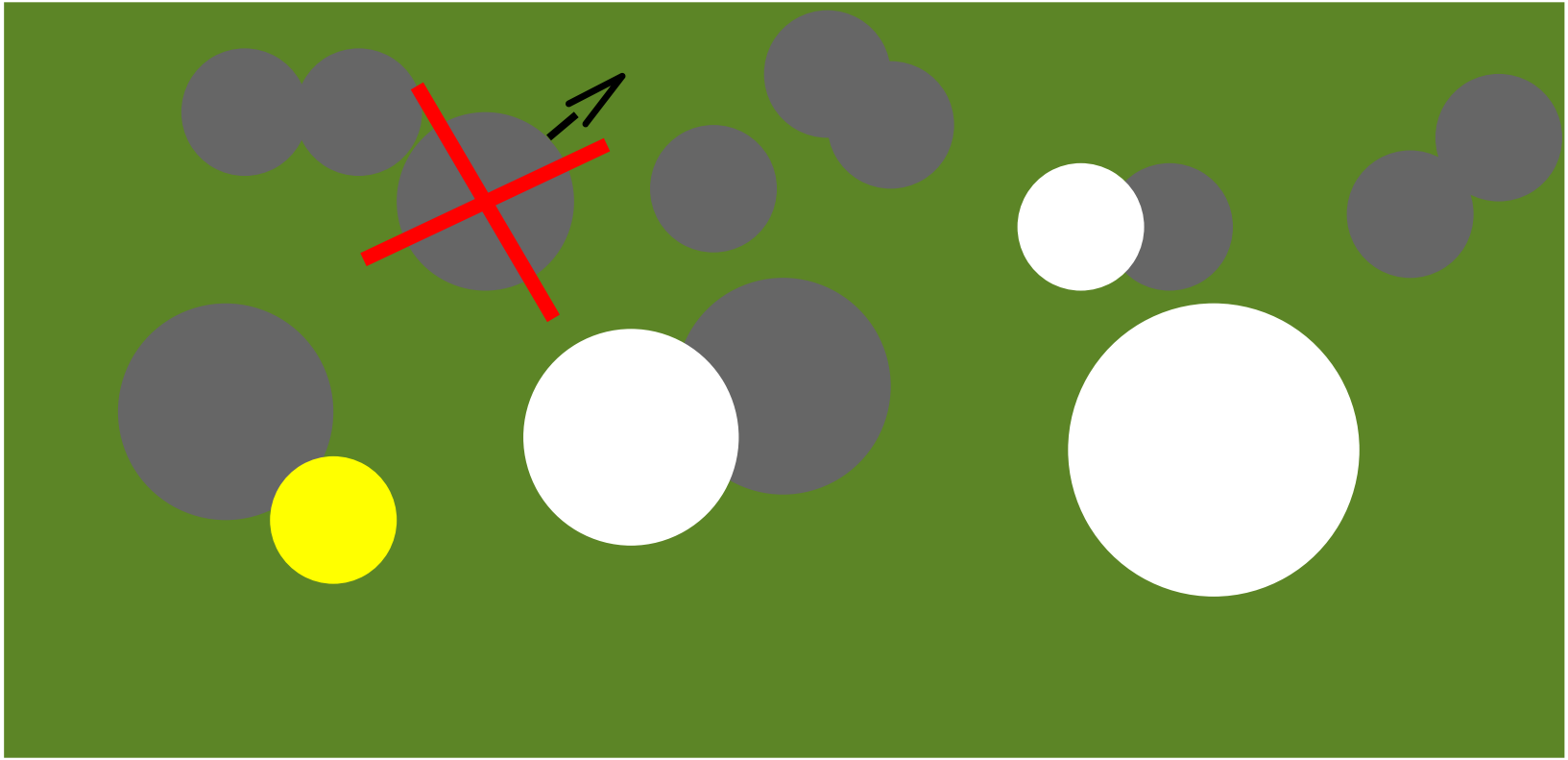
- There are black and white cows – BOVINE 2.1
- A new type of cow was defined: bull – BOVINE 2.2

And after much debate about wrong predictions:

- Bulls do not produce milk – removed in BOVINE 2.3



BOVINE 2.3



Unnecessary parameters removed

BOVINE 2.3

Bovine-**O**riented **V**irtual **I**nterface for **N**umerical **E**valuation – BOVINE (now in Python)

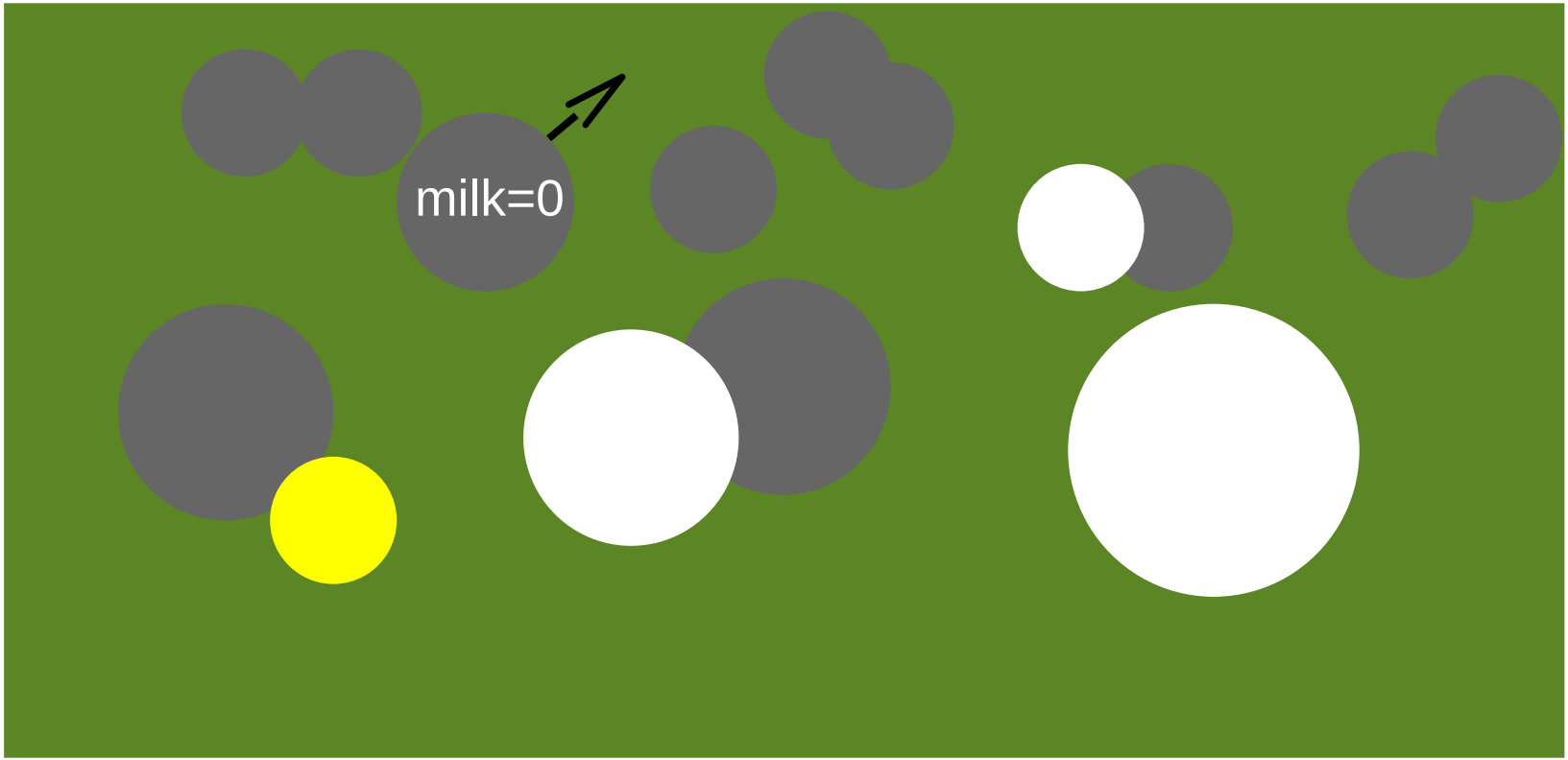
Further improving the model:

- There are black and white cows – BOVINE 2.1
- A new type of cow was defined: bull – BOVINE 2.2

And after much debate about wrong predictions:

- Bulls do not produce milk – removed in BOVINE 2.3
  - But they are needed for reproduction – reintroduced in BOVINE 2.4 (extra parameters in the model)

BOVINE 2.4



Which parameters are affected when cow.sex=’male’ ?

Moving forward

By this stage, no one really remembers that we are modelling cows

- Cow modelling has turned into an exciting research line, and new models try to emulate previous models' results

- Discussion begins about what is the right cow colour to model
  - alternative models include features with fancy names such as

    “bovine-albedo restitution function”

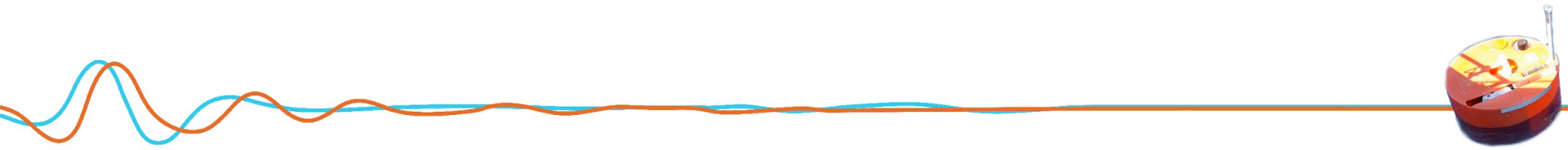
    “non-newtonian parametrization of cow dung”

  - Fermi estimations are used to determine the number of limbs
    - Biologists adapt the cow model to study millipedes

Moving forward

CowPy, a Python wrapper for BOVINE, gains traction

```
pip install cowpy
```



Spherical cows

We care more about solving problems within the model than between model and data

Spherical cows – BOVINE 2.5.1

Impossible, according to model data

Spherical cows – BOVINE 2.5.1

Cows cannot climb a frictionless plane!

Spherical cows

We care more about solving problems within the model than between model and data

According to model data, cows fall the bottom of an inclined frictionless plane (BOVINE 3.0 – meadow orientation parameters)

- The obvious solution is:
  - Immerse the cows in a viscous fluid where they are neutrally buoyant (BOVINE 3.1)
  - Define cows as incompressible (BOVINE 3.1.4)
    (version 3.2 will deal with the breathing problem)

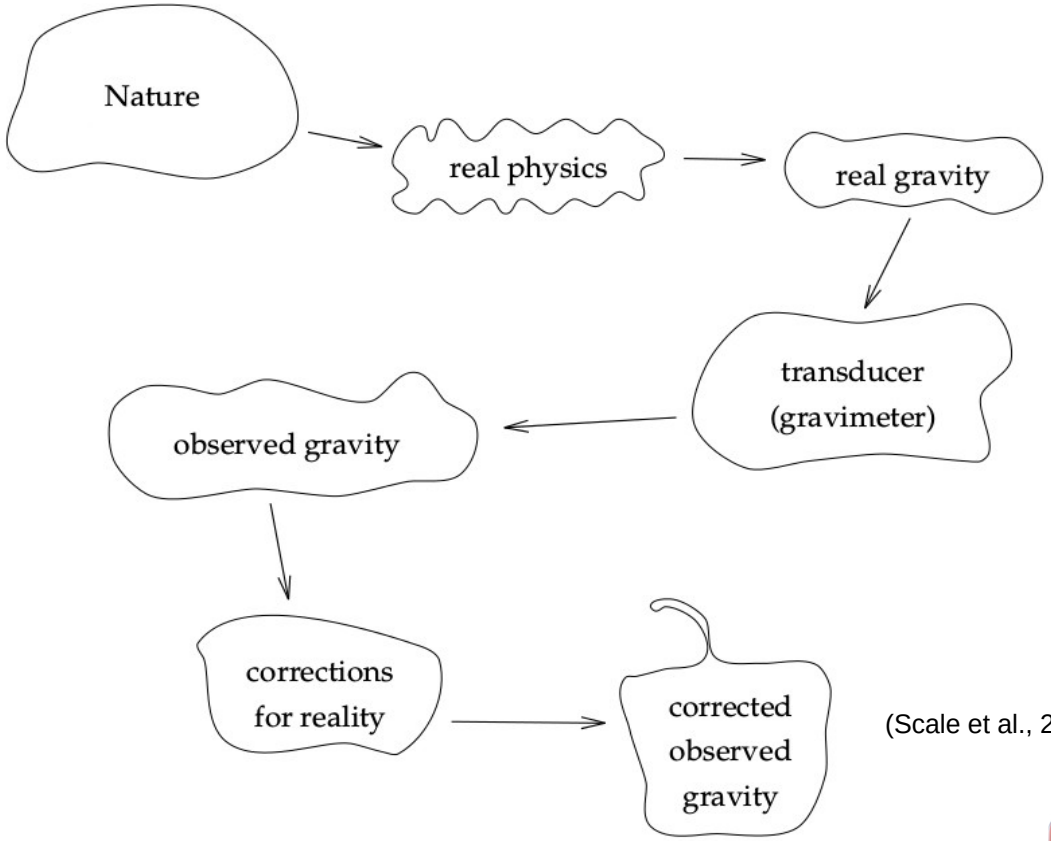
Spherical cows – BOVINE 3.1.4

Still impossible, according to model data

Spherical cows – BOVINE 3.1.4

Because brown cows do not exist

Spherical cows are unavoidable



Our models are always incomplete and are based on what we can measure.

(Scale et al., 2001)

But there is hope

≠

We must be aware that even our best models cannot fully represent reality

But there is hope

=

+ ε

However, models are always accurate within a given error margin (even the worst ones)

But there is hope

=

+ ε

We should carefully quantify the uncertainty of our models

Spherical cow on an inclined plane