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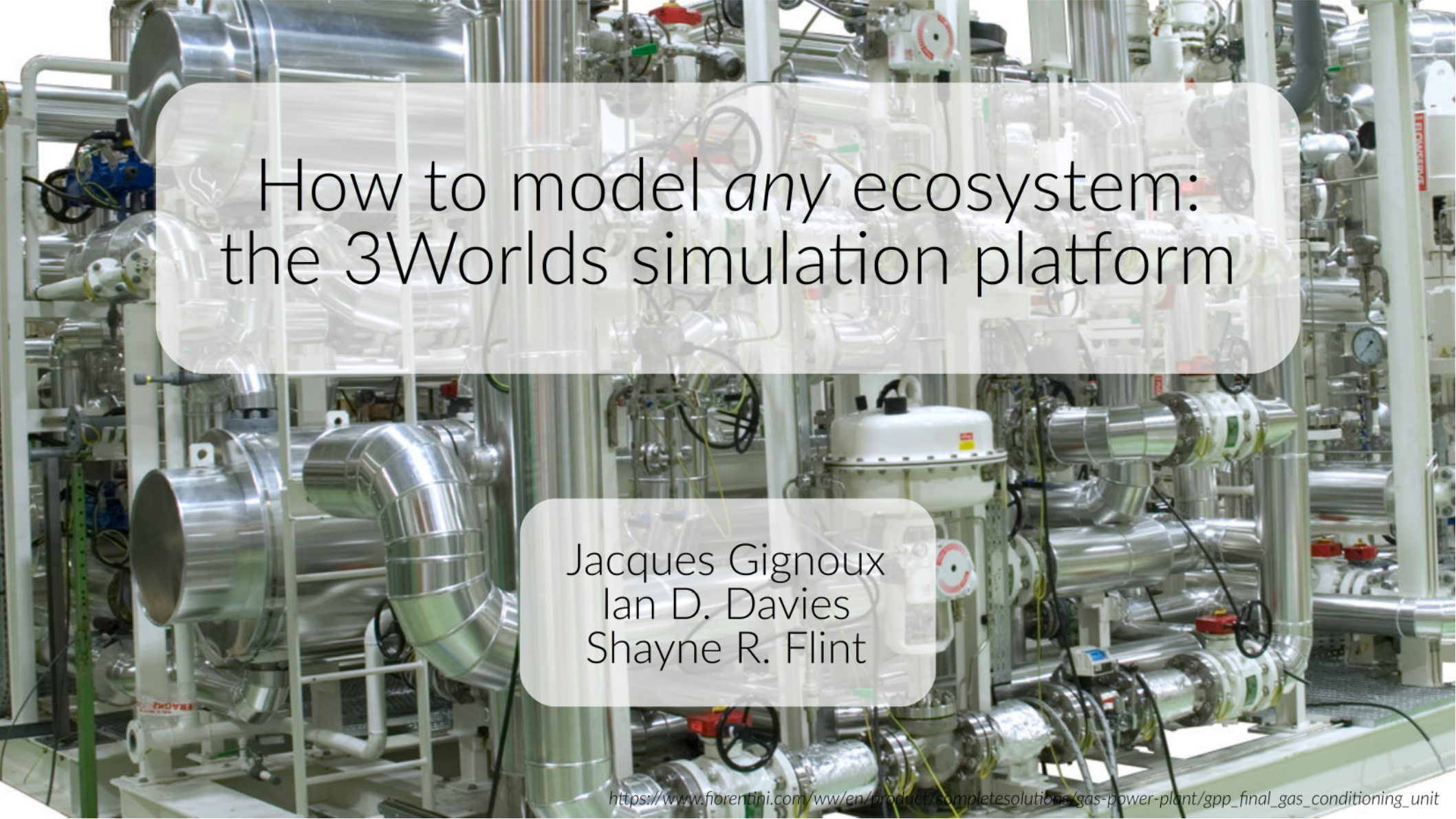
Australian National University

How to model *any* ecosystem: the 3Worlds simulation platform

Jacques Gignoux
Ian D. Davies
Shayne R. Flint



https://www.fiorentini.com/ww/en/product/completesolutions/gas-power-plant/gpp_final_gas_conditioning_unit

Three difficulties of Ecology

Ecology:

- studies very different objects
- addresses very difficult questions
- uses many different methods

Ecology looks at incredibly different objects

Southern Ocean

photo Michel de Saint Blanquat

Central Australia

photo Jacques Gignoux


Indonesia

photo Jacques Gignoux

https://www.science-et-vie.com/questions-reponses/d-ou-viennent-les-fumeurs-noirs-9787

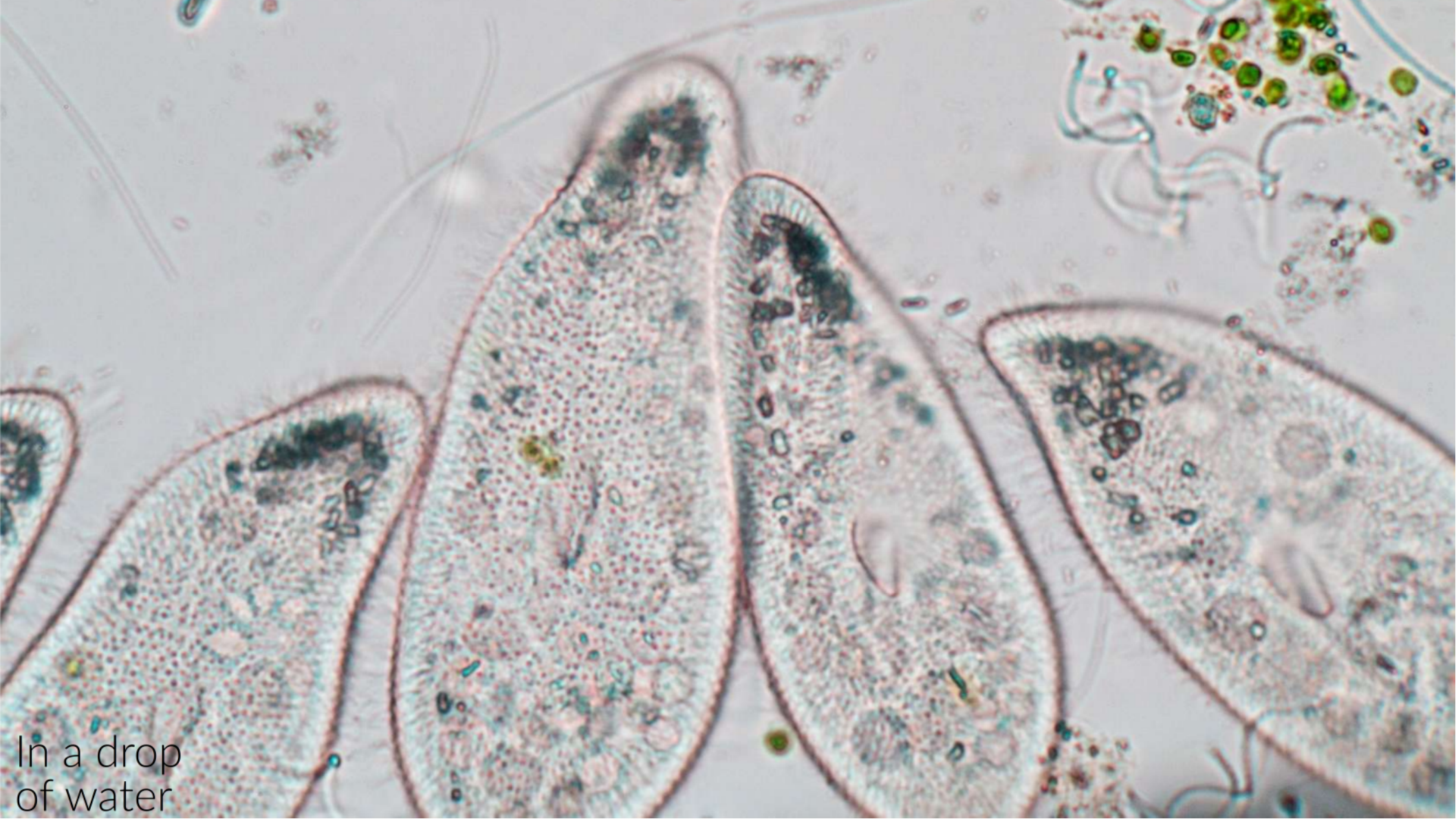
Brazil

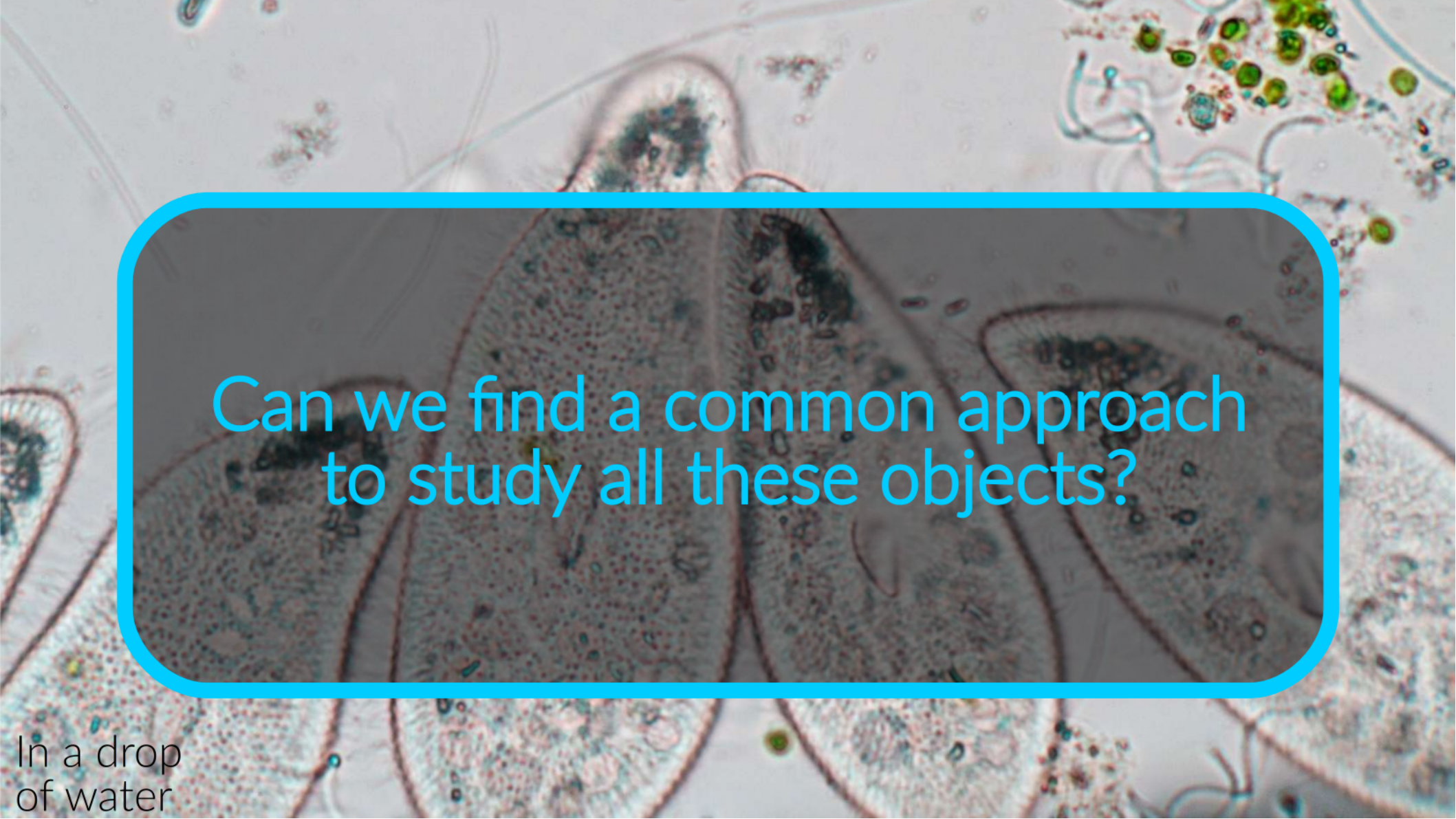
https://news.bloomberglaw.com/environment-and-energy/soy-and-the-cerrado-exports-ecology-collide-in-brazils-savanna


a puddle in
Germany
https://atoptics.wordpress.com/tag/bacteria-colours/

Local group,
The Galaxy,
Orion arm,
Solar system

NASA AS17-148-22727


In a drop
of water


Can we find a common approach
to study all these objects?
In a drop
of water

Ecology addresses *difficult* questions:

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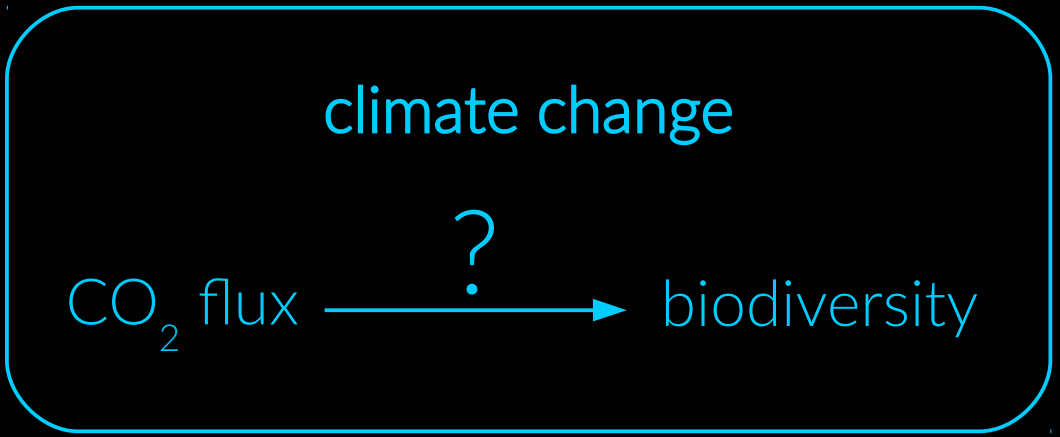

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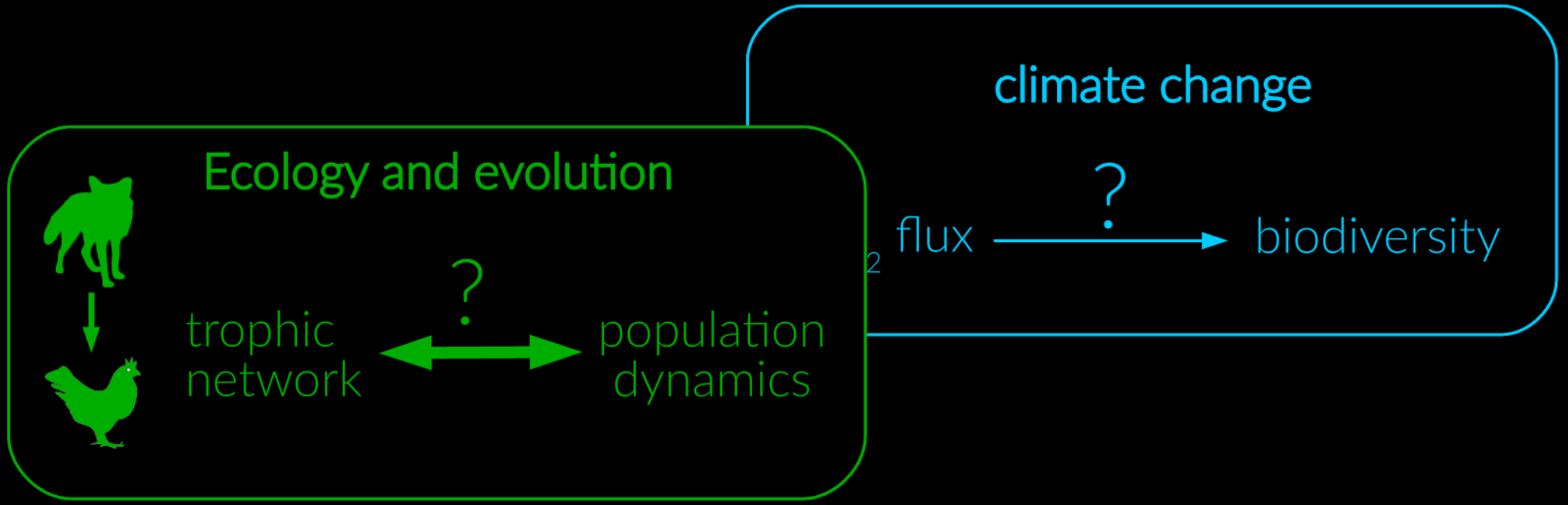

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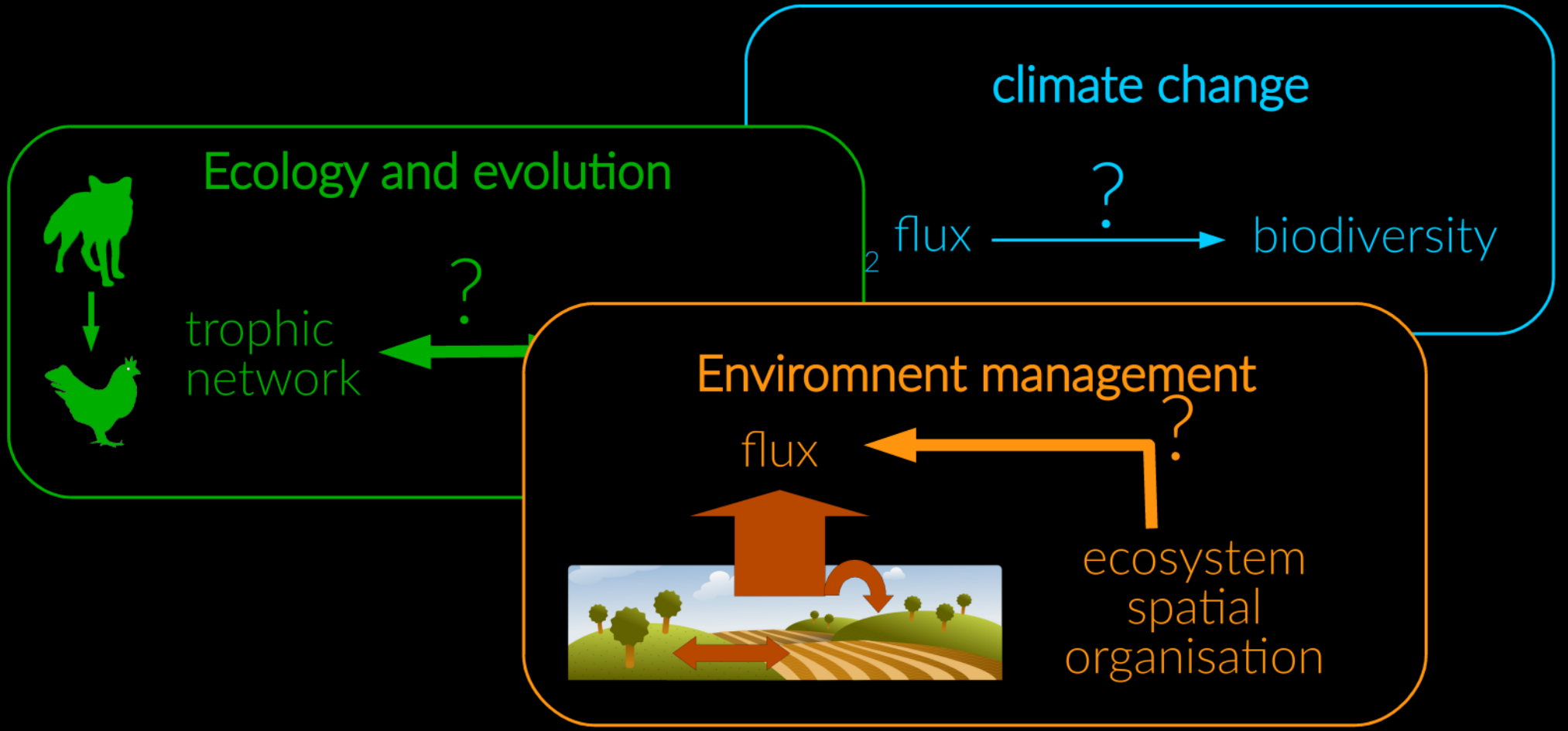

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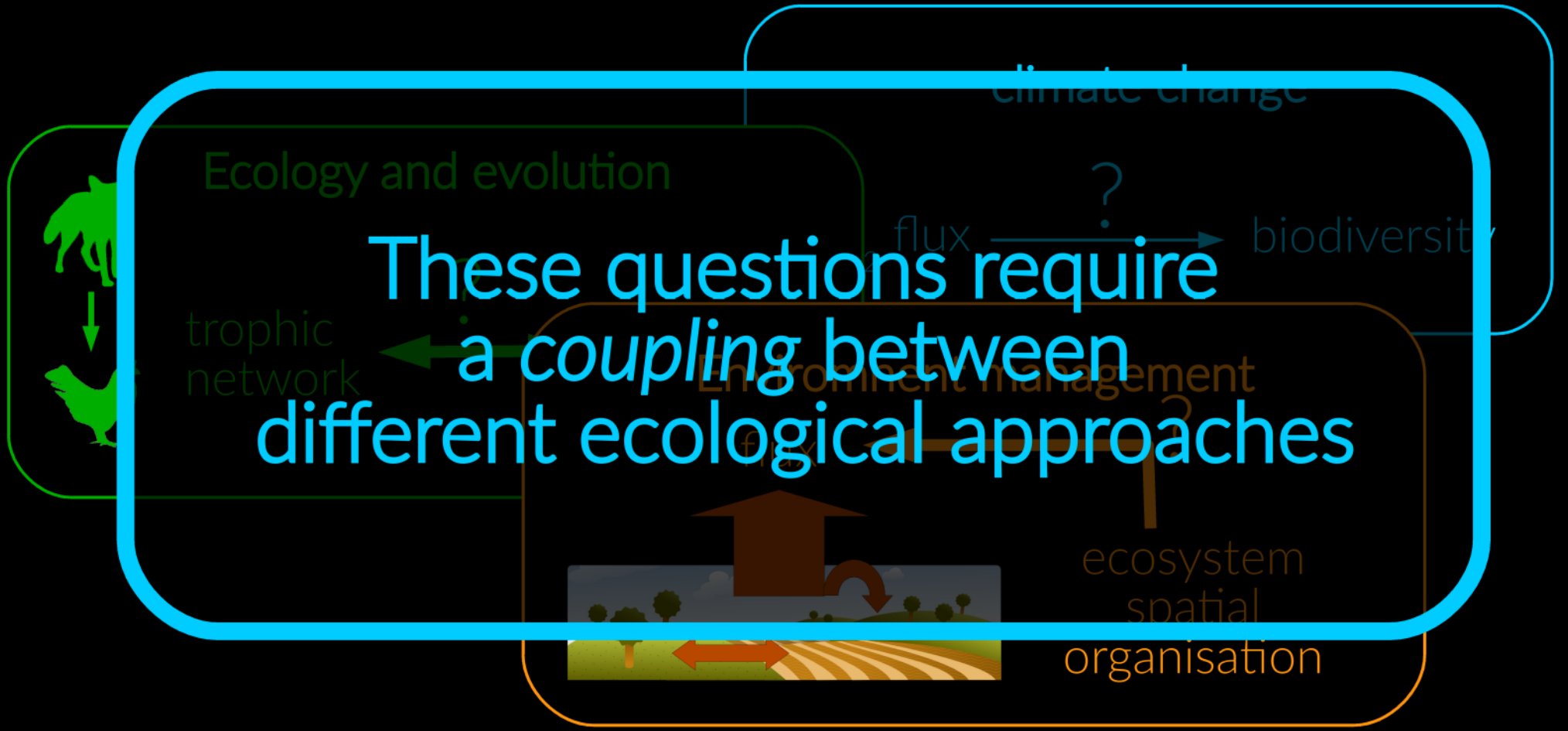
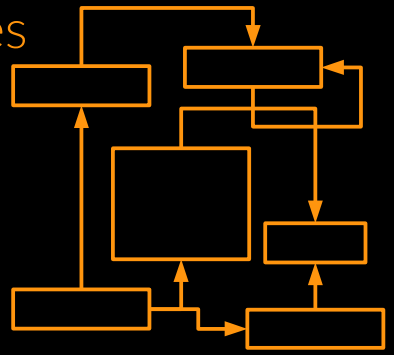



Ecology is an *integrative* science:
administrativology
etc.
immunology
endocrinology
pedology
histology
etc.
entomology
oceanography
absolutivity
geometry
animal behaviour
[bio]geography
systematics
quantum physics
statistics
etc.
genetics
relativity
etc.
geology
law
gastromony
demography
chinese astrology
hydrology
relativity
physiology
ecology
[bio][geo]chemistry
evolution
beerology
etc.
[micro]meteorology
cell biology
political sciences
game design
graph theory
programming
climatology
plant architecture
thermodynamics
game theory
topography
paleo-whatever-ology
smallestpublishablebitology
system dynamics
etc.
applied epistemology
projectology
... borrowing methods from other sciences

Ecological sub-fields use poorly compatible representations:

Matter and energy fluxes
Ecophysiology
Ecosystems



Dynamic systems

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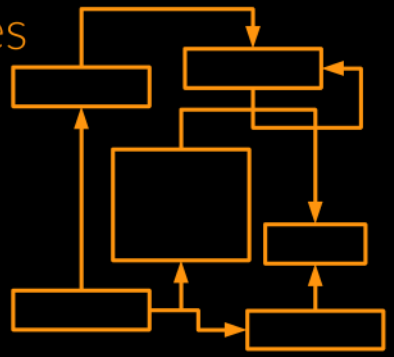

Dynamic systems

Demography
Genetics
Evolution

Population models
Individual-based models

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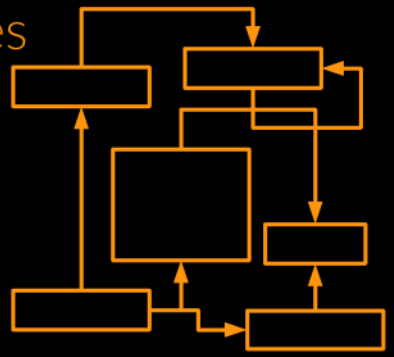

Dynamic systems

Interaction networks

Graphs

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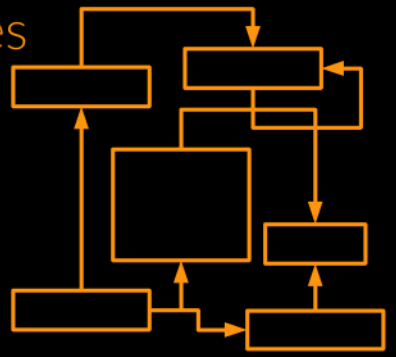

Dynamic systems

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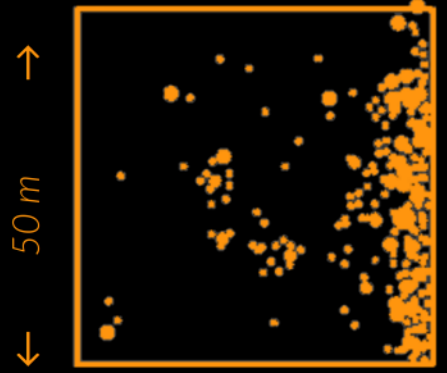


Landscape ecology
Ecosystem structure

Cellular automata

Ecological sub-fields use poorly compatible representations:

How can we make these work together?

Ecology focuses on *interactions*

From various definitions:

Ecology studies **interactions** among living beings and between them and their milieu (*https://**fr.wikipedia**.org/wiki/Écologie*)

Ecology - the study of the environment and the **relationships** between things in it (*https://**dictionary.cambridge**.org/dictionary/english-french/ecology*)

Ecology - the **relation** of plants and living creatures to each other and to their environment; the study of this
(*https://www.**oxford**learners**dictionaries**.com/definition/english/ecology?q=ecology*)

... that may help

I. The solution to the diversity of objects

The *ecosystem* concept (Tansley, 1935)

> *'Though the organisms may claim our primary interest, when we are trying to think fundamentally we cannot separate them from their special environment, with which they form one physical system.'*

Ecosystems

- combine physics and biology into a single object
- are scale-independent
- are observer-dependent
- focus on interactions

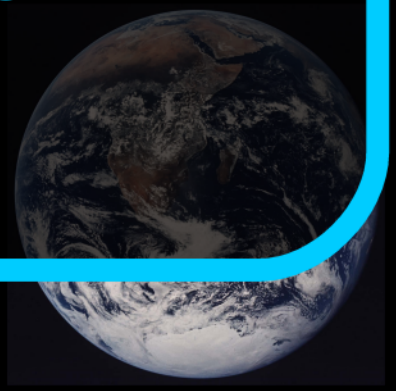
Gignoux et al. 2011. Ecosystems 14:1039-1054

The *ecosystem* concept (Tansley, 1935)

Ecosystems

- combine physics and biology into a single object
- are scale-independent
- are observer-dependent

Ecology consists in viewing *everything* as an ecosystem



Gignoux et al. 2011. Ecosystems 14:1039-1054

even this:

somewhere on the internet

or this:

somewhere else on the internet

II. The solution to the difficulty of these questions

Impossible is not French.

We don't care!

It's more fun if questions are not easy!

Plus, practical environmental problems are *always* going to be *difficult*, *complex*, *wicked*, *multi-faceted*, without a unique clear definite solution. **We must get used to this**.

Impossible is not French.

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Plus, practical environmental problems are *always* going to be *difficult*, *complex*, *wicked*, *multi-faceted*, without a unique clear definite solution. **We must get used to this**.

huh... maybe a method would help

Systems thinking

Churchman, C. W., 1968; Kramer, N., 1977; Checkland, P. & J. Scholes, 1999; Senge, P., 1992.

Shayne Flint

Australian National University

- a set of approaches that can be used to learn about / make decisions on *dynamically complex systems*
- focuses on *the whole* and the *interactions* among the *parts* of a system
- this way we can understand *emergent properties* of an entire system

Flint, S 2008, 'Rethinking Systems Thinking', in David Cook (ed.), Proc. 14th ANZSYS Conference, ECU, Perth.

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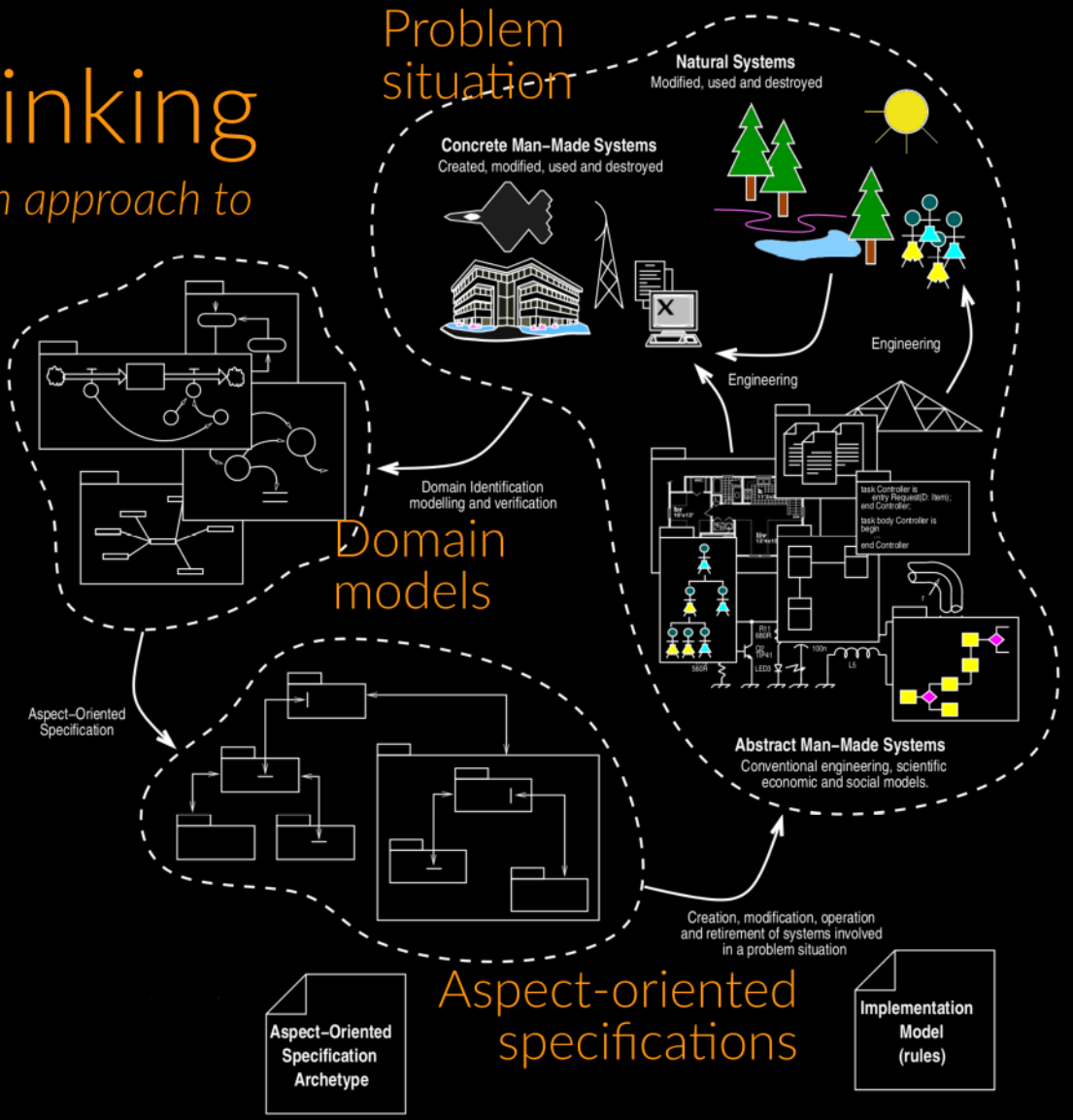
sorry... do you call *this* a method?

Flint, S 2008, 'Rethinking Systems Thinking', in David Cook (ed.), Proc. 14th ANZSYS Conference, ECU, Perth.

Aspect-oriented thinking

Flint SR, 2006. Aspect-Oriented Thinking - An approach to bridging the disciplinary divides. PhD, ANU.

- independently model *aspects* of a problem
  - e.g. *physics* and *biology* in an ecosystem
- rules for combining these aspects into a new system
  - e.g. a model of **my favourite ecosystem**
- that can be used to improve the problem situation
  - e.g. test if **my favourite ecosystem** is stable or resilient



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- independently model *aspects* of a problem
  e.g. *physics* and *biology* in an ecosystem
- rules for combining the aspects into a new system
  e.g. *ecological economics* ecosystem
- that can be used to improve the problem situation
  e.g. test if my favourite ecosystem is stable or resilient

1. We will *not* build the ultimate synthesis of all ecological knowledge rather,
2. We provide *a method to specify an ecological model* addressing any particular problem

III. The solution to the incompatibility of methods

http://www.lecreusot.com/site/decouvrir/patrimoine/pilon/pilon.php

Make them compatible!

Use good concepts that can be shared

e.g. the system, the ecosystem, etc...

... easy !

(use a steam hammer?)

1. Ecosystems are commonly considered as *complex systems*

1. Ecosystems are commonly considered as *complex systems*

2. Complex systems are assumed to display *emergent properties*

But what is an...

emergent property?

What does that mean?
(does it hurt?)

Not much:

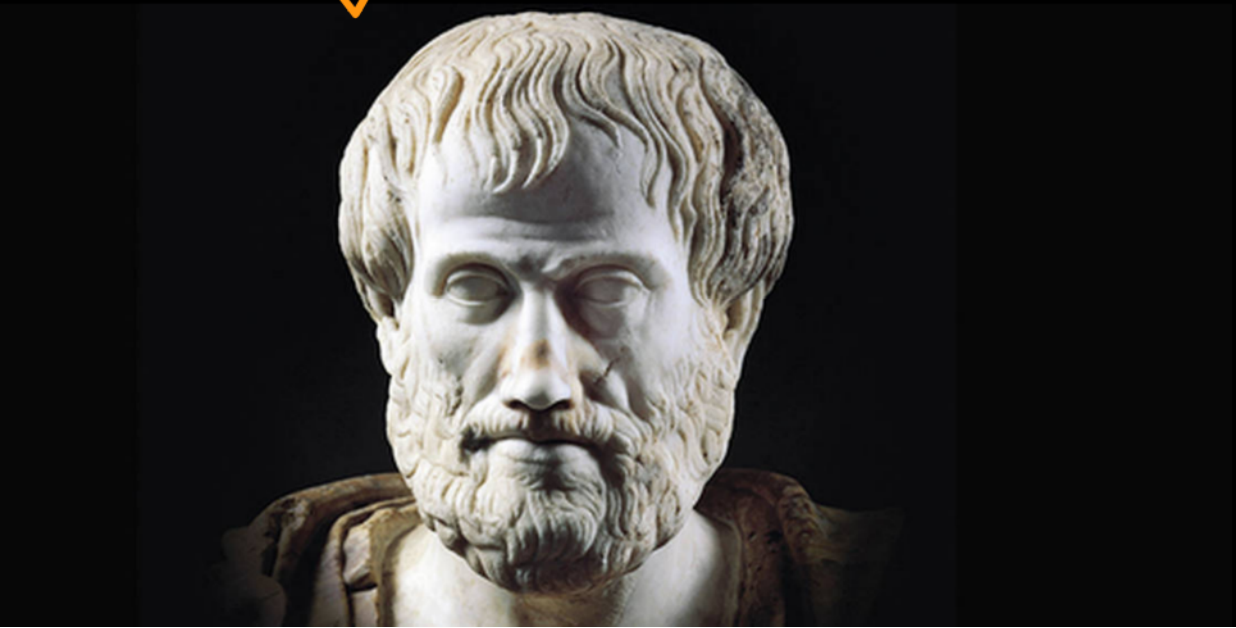
The whole is more than the sum of its parts

Αριστοτέλης (-335)

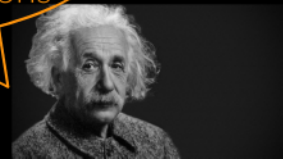
Not much:

The whole is more than the sum of its parts

Αριστοτέλης (-335)



Einstein (1915): 'the mass of an atom is *smaller* than the sum of the masses of its nucleons'



Thank you, old chap, but this is not very helpful.
Modern specialists have much better definitions:

Bedau 1997: Macrostate P of S with microdynamic D is weakly emergent iff P can be derived from D and S 's external conditions but ***only by simulation***.

Ryan 2007: A property is weakly emergent iff it is present in a macrostate but it is not apparent in the microstate, and this macrostate differs from the microstate only in resolution. A weak emergent property is ***a limitation of the observer***, not a property of the system.

Müller 2003: A phenomenon is emergent iff we have (1) a system of entities in interaction whose expression of the states and dynamics is made in an ontology or theory *D* ; (2) the production of a phenomenon [...] which is necessarily ***global*** regarding the system of entities ; (3) the interpretation of this global phenomenon ***by an observer*** [...] in another ontology or theory *D'* ; (4) *D'* is ***irreducible*** to *D*.

Chalmers 2006: We can say that a high-level phenomenon is weakly emergent with respect to a low-level domain when the high-level phenomenon arises from the low-level domain, but truths concerning that phenomenon are ***unexpected*** given the principles governing the low-level domain.

...

[gurgling]

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5. All emergence definitions imply a system with a *microscopic* and a *macroscopic* level of description

6. With a formal definition of the system, we may be able to clearly define emergence.

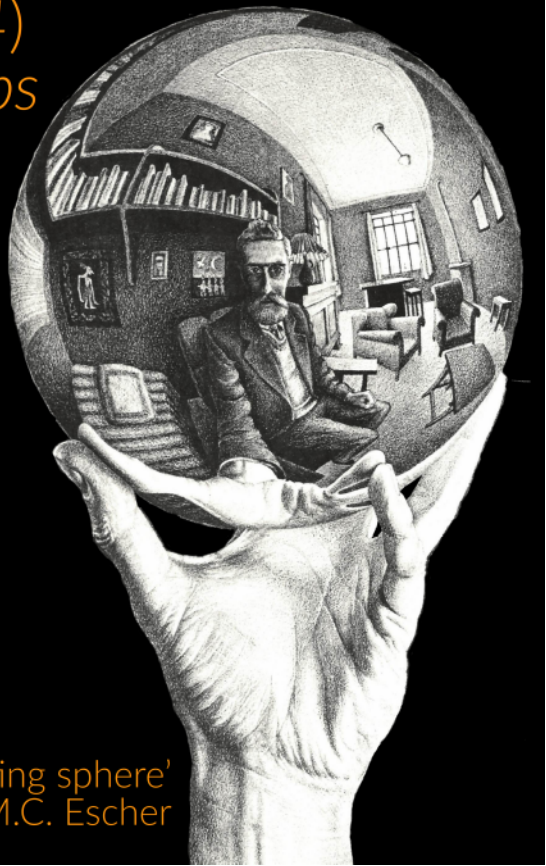
Gignoux et al. 2017. Ecological Complexity 31:34-49

The hierarchical system

A **system** is
- a part of the world under consideration (*Carnot 1824*)
- composed of identifiable entities *and their relationships* (*Jordan 1981*)

All emergence definitions imply that a system has a *microscopic* and a *macroscopic* description

Let's call **Hierarchical System** a system ('macro'-scale) made of inter-related parts ('micro'-scale)



'Hand with reflecting sphere' lithograph by M.C. Escher

Gignoux et al. 2017. Ecological Complexity 31:34-49

A hierarchical system is best represented by a mathematical graph

A hierarchical system S is defined as the graph:

$$S := (C,\ R,\ \gamma)$$

where C is the set of components (nodes) of the system:

$$C := \{c_u\}\ u \leq n_c < \infty\ ,\ c_u \in \mathsf{W}$$

R is the set of relations (edges) between components of the system:

$$R := \{r_v\}\ v \leq n_r < \infty\ ,\ r_v \in \mathsf{W}^{\,2}$$

and γ is the incidence function, which assigns a relation to a pair of components:

$$\gamma : R \rightarrow C \times C$$
$$r_v \rightarrow (c_i\ ,\ c_j\ )\ i \leq n_c\ ,\ j \leq n_c$$

n_c is the number of components and n_r the number of relations of the system; $\mathsf{W}^{\,2}$ is the set of applications from W to W .

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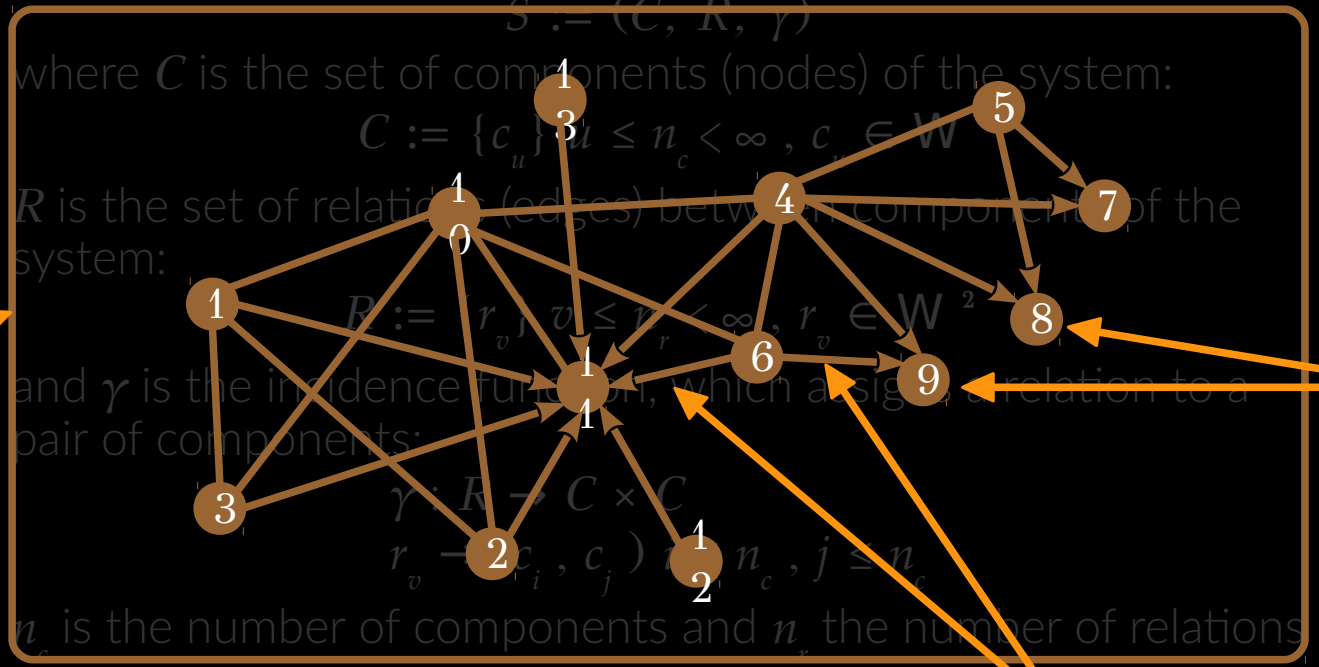


the system

the components

the interactions

Gignoux et al. 2017. Ecological Complexity 31:34-49

A hierarchical system is best represented by a mathematical graph

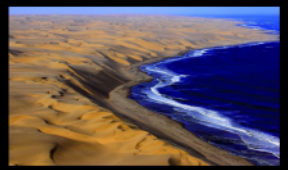
state = descriptors

structure = graph

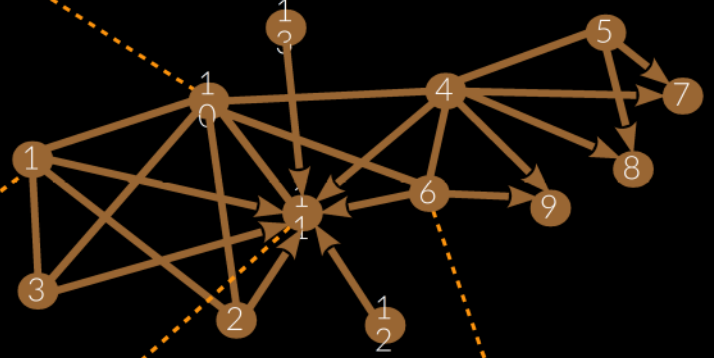
D_{10}

label	*beach*
surface	$s \in]0;+\infty[$
location	$M_b = (L,l) \in [0;90] \times [-180;180]$

D_S

label	*The Namib desert ecosystem*
location	$M_b = (L,l) \in [0;90] \times [-180;180]$
productivity	$P \in]0;+\infty[$
biomass	$w \in]0;+\infty[$
monthly rainfall	$p = (p_i)_{i \leq 12}, p_i \in \mathbb{R}^+$
photo	

S_2 = an ecosystem of interest



D_1

label	*lion No.1*
biomass	$w \in]0;+\infty[$
sex	$s \in \{m,f\}$
age	$a \in \mathbb{N}$
location	$M = (x,y) \in \mathbb{R}^2$
mating probability	$p \in [0;1]$
photo	

D_{11}

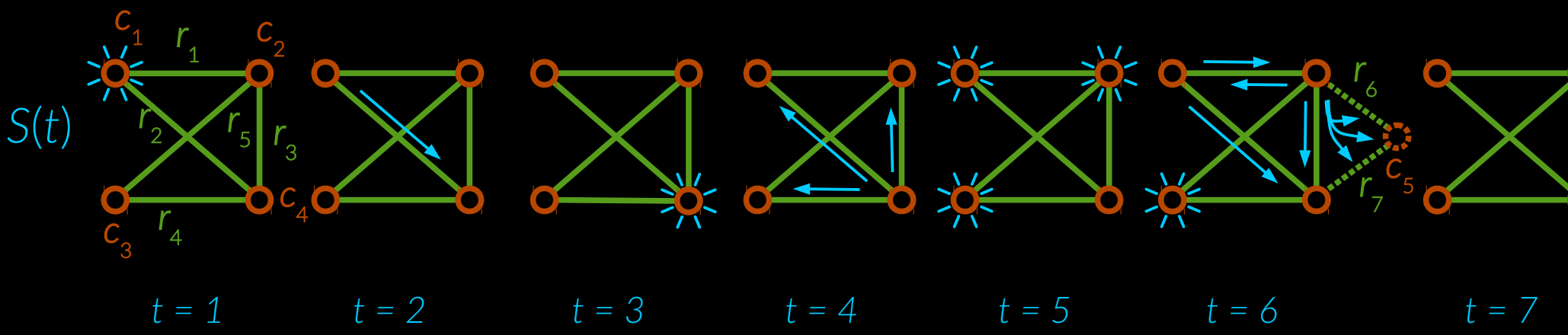
label	*whale*
biomass	$w \in]0;+\infty[$
edible fraction	$\alpha \in [0;1]$
decay rate	$t_d \in \mathbb{R}^+$
location	$M = (x,y) \in \mathbb{R}^2$
photo	

D_6

label	*lion No.6*
biomass	$w \in]0;+\infty[$
sex	$s \in \{m,f\}$
age	$a \in \mathbb{N}$
location	$M = (x,y) \in \mathbb{R}^2$
mating probability	$p \in [0;1]$
photo	

A *dynamic* graph

Harary & Gupta 1997. Dynamic graph models, Math. Comp. Model. 7:79-87

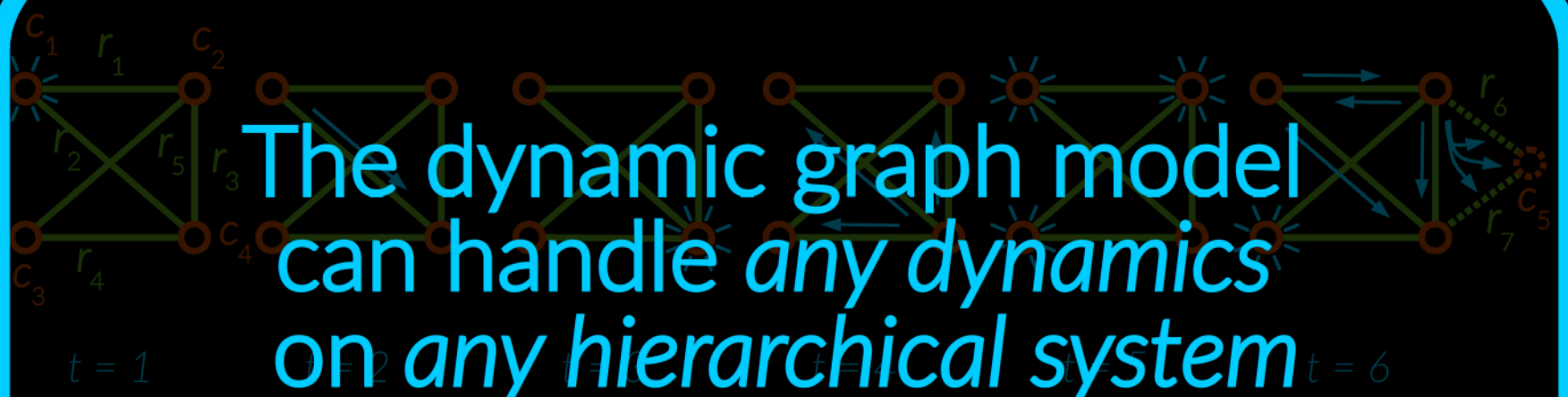


Changes propagate locally
State changes may be continuous
Structural changes are always discrete
Causality may be analysed

A *dynamic* graph

Harary & Gupta 1997. Dynamic graph models, Math. Comp. Model. 7:79-87

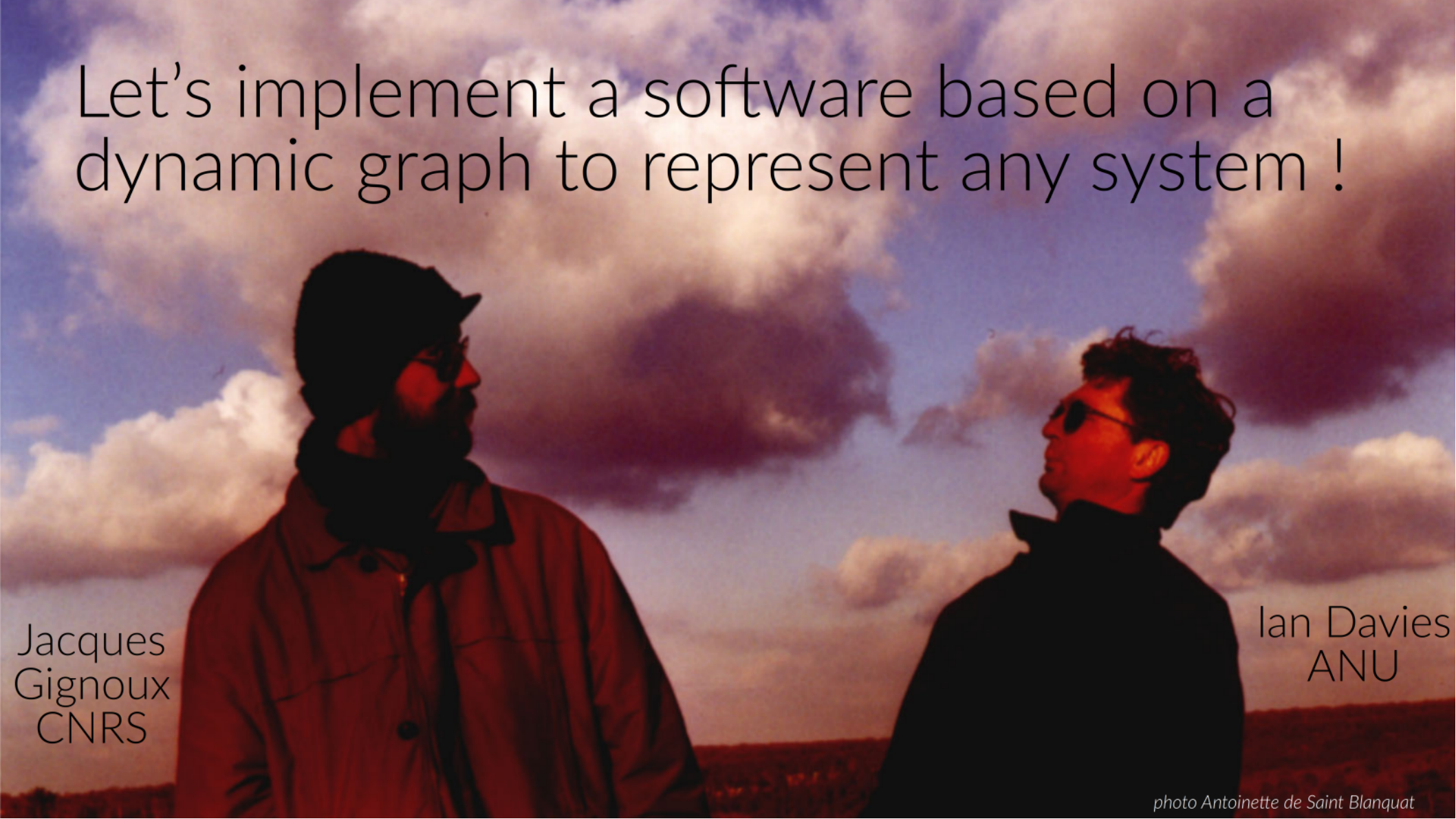
$S(t)$



The dynamic graph model can handle *any dynamics* on *any hierarchical system*

Changes propagate locally
State changes may be continuous
Structural changes are always discrete
Causality may be analysed

Let's implement a software based on a dynamic graph to represent any system !



Jacques Gignoux
CNRS

Ian Davies
ANU

photo Antoinette de Saint Blanquat

Let’s implement a software based on a dynamic graph to represent any system !

Gotlib, M. (1971) Incorrigibles rêveurs, Rubrique à brac, 2:26-27

FYC, automatic translation:
‘Then my dear, you are in the middle of science fiction!’

My translation:
‘Sorry my dear, this is pure science-fiction!’

Or, more direct:
‘Bullshit!’

Let’s implement a software based on a dynamic graph to represent any system !

Gotlib, M. (1971) Incorrigibles rêveurs, Rubrique à brac, 2:26-27

Fundings:

PHC 2003-2004
CNRS LIA 2003-2006
ANR 2007-2011
CNRS 2008-2009

Nananèreuh…

IV. The 3Worlds simulation platform

‘Three worlds’ lithograph by M.C. Escher 1955

Aims of 3Worlds

To provide ecological modellers with a simulation tool able to :

1. Deal equally well with physics and biology
2. Handle multiple spatial and temporal scales
3. Play with the level of detail in system description
4. Enable modelling of any ecological problem one can think of
5. Provide quick feedback while building a model
6. Smoothly scale up to large scale simulation experiments
7. Facilitate model intercomparison

...all this without reinventing the wheel too many times, if possible

Aspect-oriented approach

The system to model: the Ecosystem

A selection of aspects: the ecosystem as…
…a hierarchical system
…a set of taxonomic (=classifiable) entities
…a dynamic system at all sorts of time scales
…a (possibly spatially) organised system
…an abstract representation at different levels of detail
…an easy-to-use functional concept
…a scientific object (that can be experimented on)

a *specification archetype* + code to interpret it

The build system: a **software** that can be further specialised for particular problems

Aspect 1: a hierarchical system

The modelled system is a *dynamic graph* =
{ *components*, *relations* }

a generalisation for

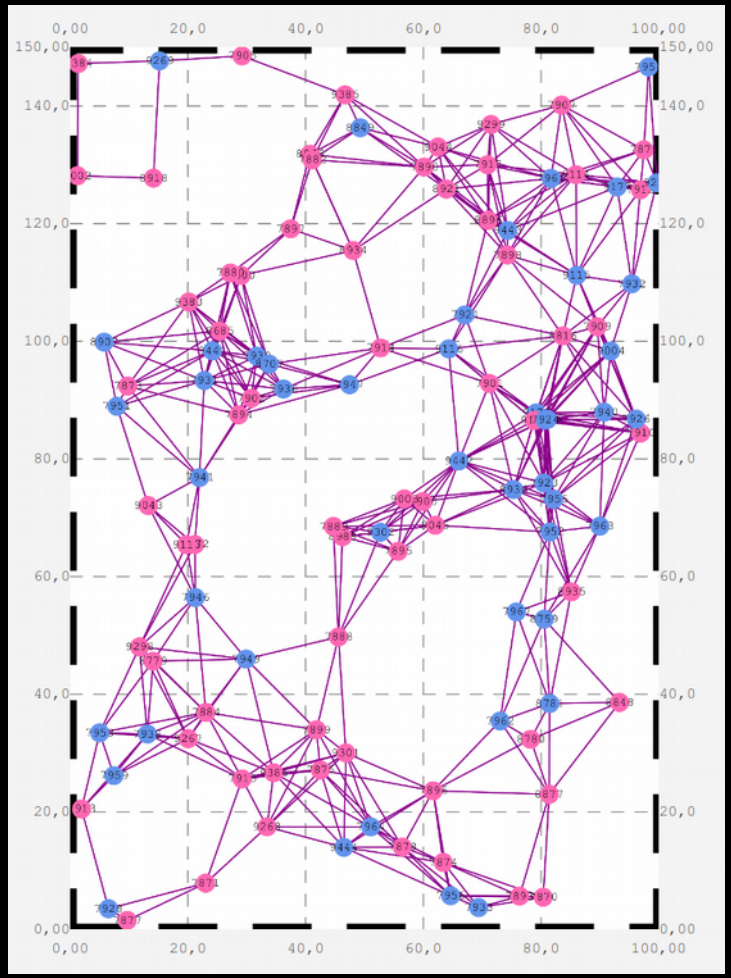
individual-based models (IBMs)

Grimm V. & Railsback S. 2005. Individual-based modelling and ecology. Princeton U.P.

multi-agent systems (MASs)

Bousquet F. & Le Page C. 2004. Multi-agent simulations and ecosystem management: a review. Ecol. Model. 176:313–332.

…but with ***explicit*** relations



3Worlds screen capture

Aspect 2: classification

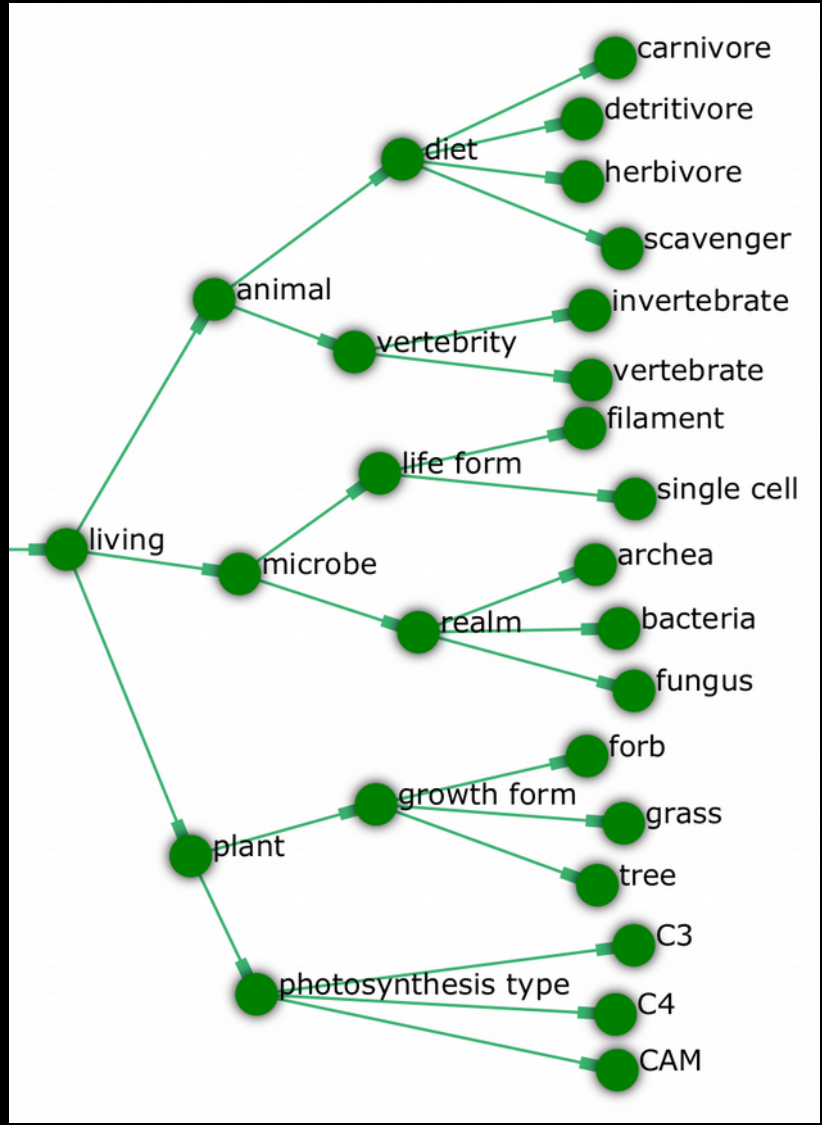
Categories to group components ‘that look like each other’

Members of a category:

- have the same descriptors
- are affected by the same processes

cf. the *class* concept in UML and OOP

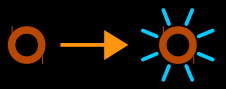
http://uml.org/what-is-uml.htm
https://en.wikipedia.org/wiki/Object-oriented_programming



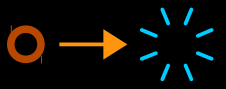
3Worlds screen capture

Aspect 3: a dynamic system

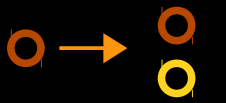
Every possible *local* change in the graph state or structure is modelled by a specific function that can be modified to suit user needs:



changeState & setInitialState: changes the descriptor values of a component



deleteDecision: a component decides to delete itself



createOther: a component creates other components

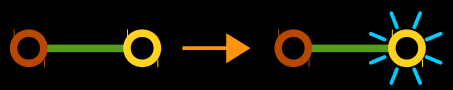
changeCategoryDecision: a component becomes member of other categories

Aspect 3: a dynamic system

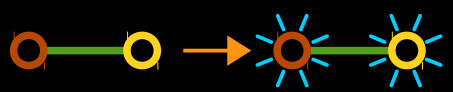
Every possible *local* change in the graph state or structure is modelled by a specific function that can be modified to suit user needs:

relateTo: component establishes a relation to another component

maintainRelationDecision: a component decides to keep/delete a relation



changeOtherState & setOtherInitialState: a component changes the descriptor values of another component to which it is related



changeRelationState: components at both ends of a relation change their descriptor values

Aspect 3: a dynamic system

Multiple *time models*

Simultaneous events as the rule

(contrary to MASs)

MONO_UNIT
: single time unit, calendar-compatible (default value)

GREGORIAN
: real calendar time

YEAR_365D
: 365-day years, no weeks, no months

YEAR_13M
: 28-day months, 13-month/52-week years

WMY
: 28-day months, 12-month/48-week years

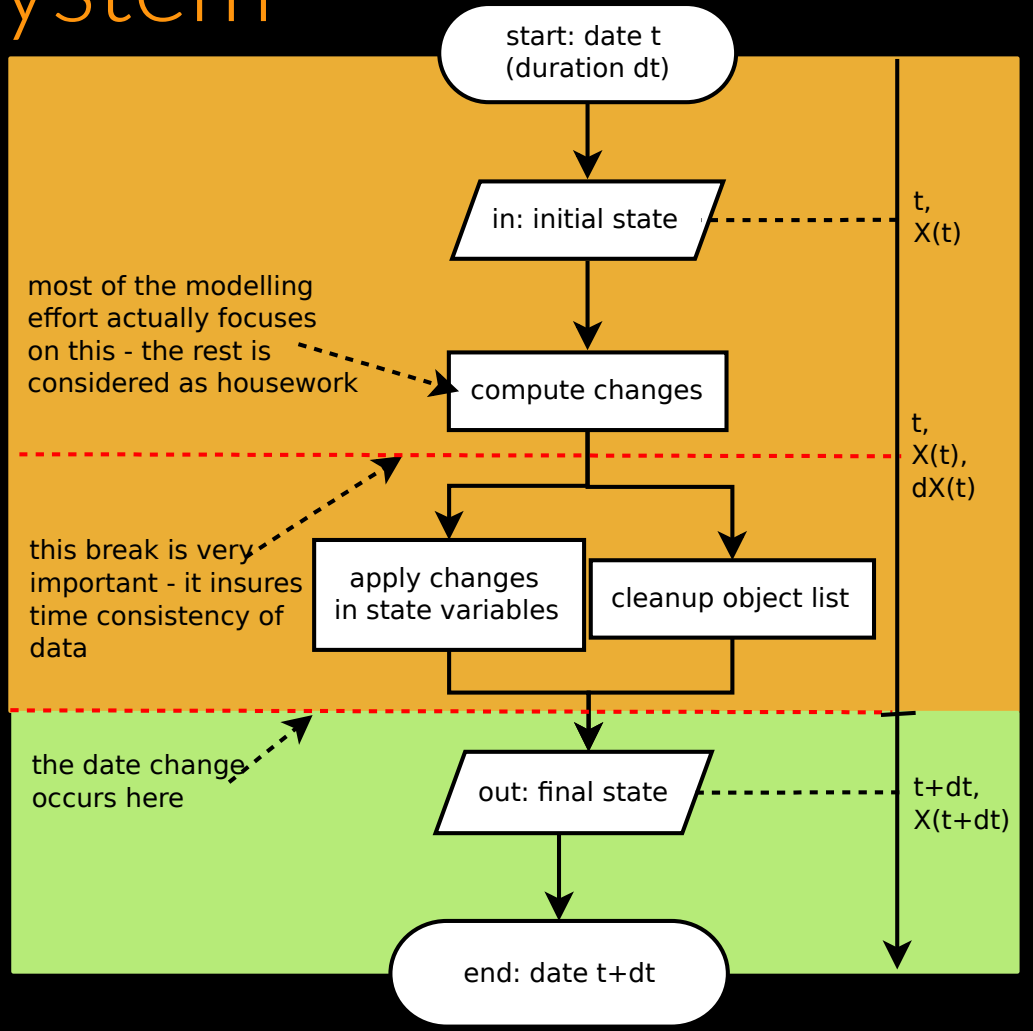
MONTH_30D
: 30-day months, weeks replaced by 15-day fortnights

YEAR_366D
: 366-day year, months replaced by 61-day bi-months

LONG_TIMES
: long time units only (month or longer), calendar-compatible

SHORT_TIMES
: short time units only (week or shorter), calendar-compatible

ARBITRARY
: arbitrary time units with no predefined name



Aspect 4: a (spatially) organised system

Space *optional*

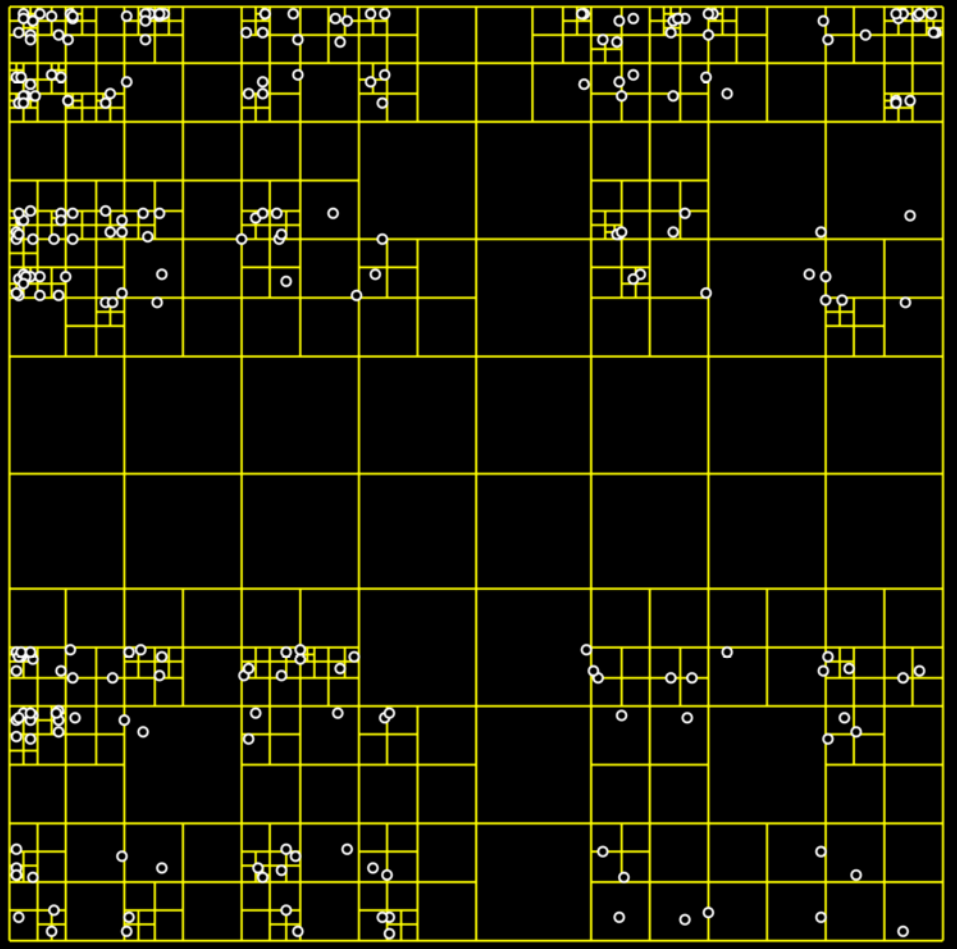
Uses *Kd-trees* to optimize searches for establishing relations

Samet H. 1984. The Quadtree and Related Hierarchical Data Structures. Computing Surveys 16:187–260

6 different types of edge-effect correction

2 different types of space

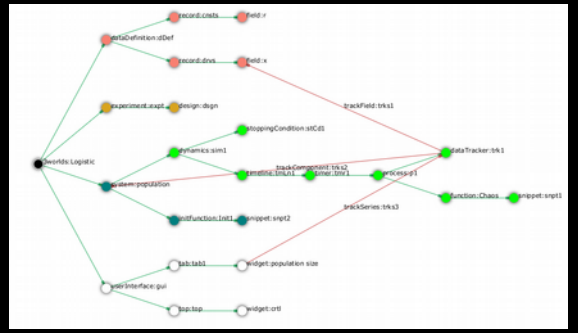
[many more to come!]



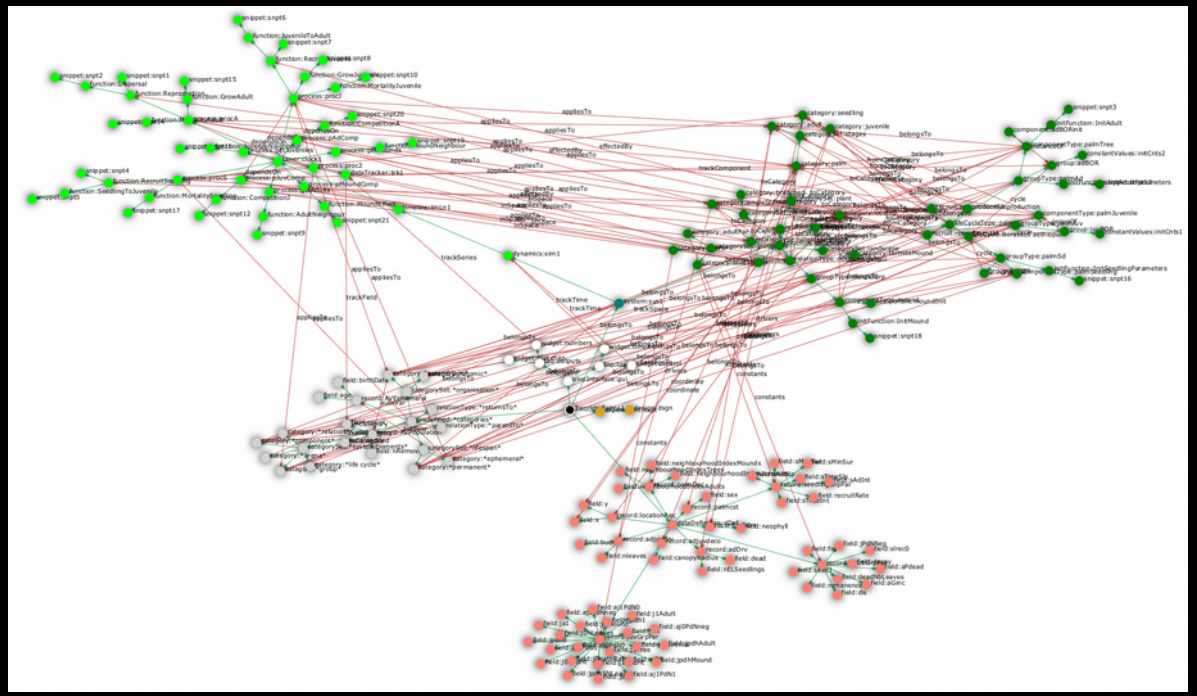
https://fr.wikipedia.org/wiki/Quadtree

Aspect 5: a *representation* of a system

the smallest configuration graph in 3Worlds



a bigger one



Configuration

- is a *graph* (static but editable)
- is checked against an archetype

Flint S.R. 2006. Aspect-Oriented Thinking - An approach to bridging the disciplinary divides. PhD, Australian National University

- ‘s can be **compared**

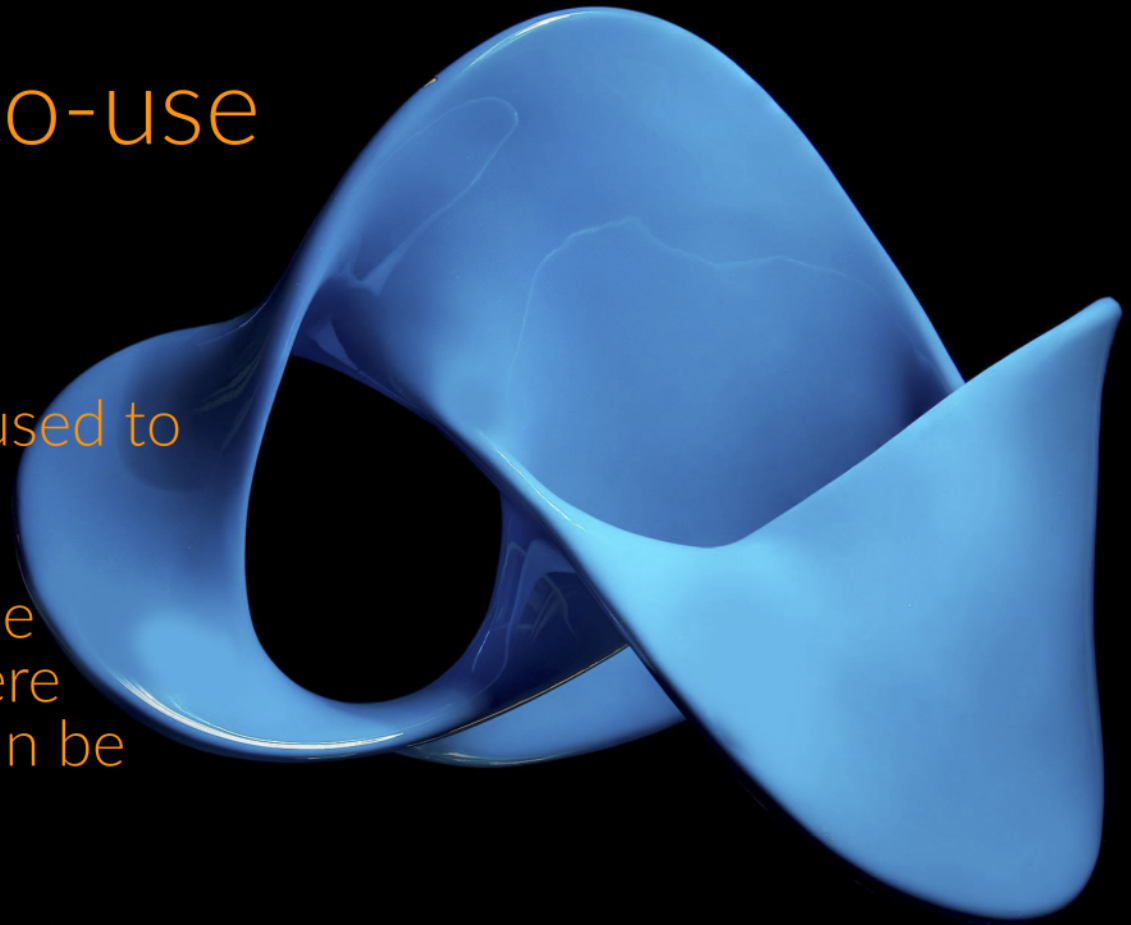
3Worlds screen captures

Aspect 6: an easy-to-use functional concept

Flexibility: any function can be used to represent an ecological process

For each 3Worlds model, a single ‘user-code’ file is generated where code for ecological processes can be edited

A complex IBM can be setup in one week of work.



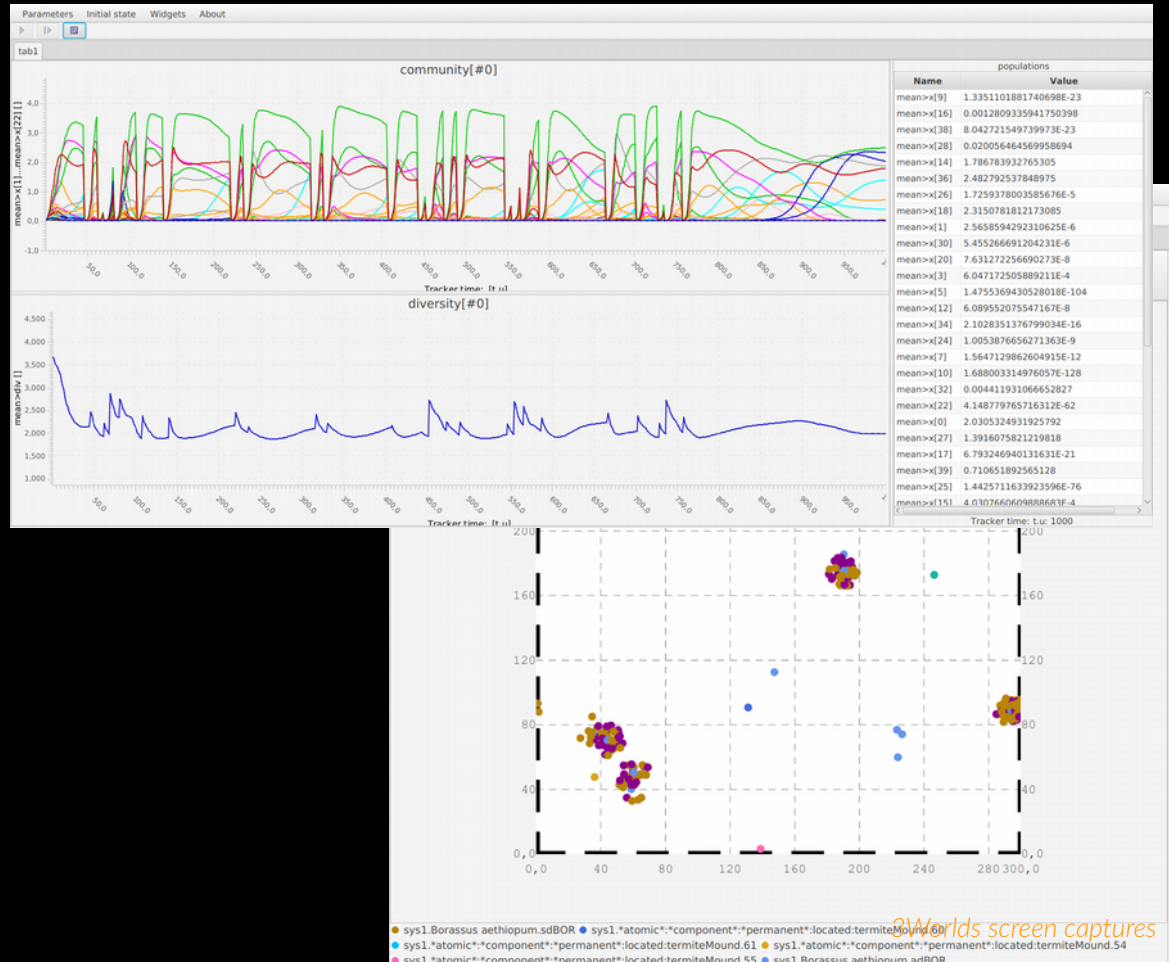
this magnificent illustration of a ‘figure eight knot’ symbolizes the perfection and elegance of the 3Worlds software solutions.

Of course it has nothing to do here

https://en.wikipedia.org/wiki/Figure-eight_knot_(mathematics)#/media/File:Superf%C3%ADcie_-_bordo_n%C3%B3_figura-oito.jpg

Aspect 7: a scientific object

Use case 1 :
developing model
quick feedback on outputs

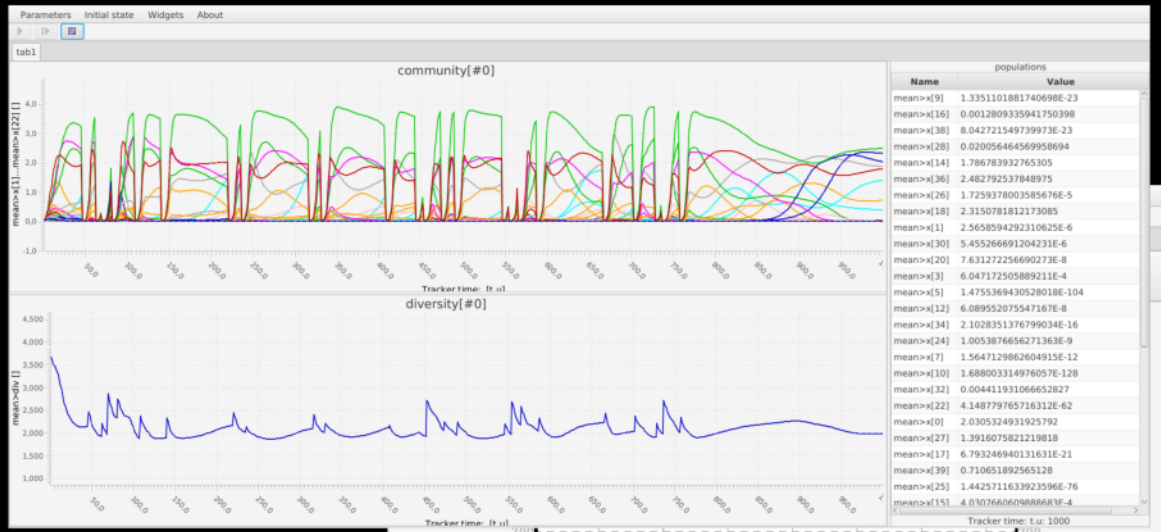


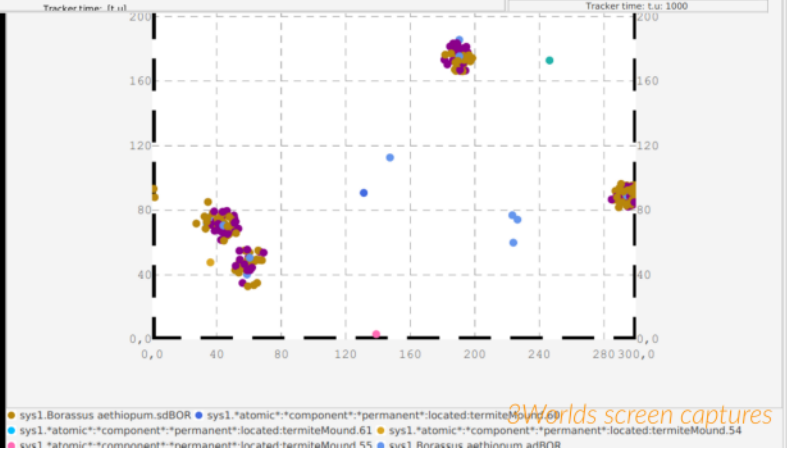
Aspect 7: a scientific object

Use case 1 :
developing model
quick feedback on outputs

Use case 2 :
simulation experiment
parallel computing

[coming soon :
OpenMole integration
https://openmole.org/]





OpenMOLE
the model exploration software

3Worlds screen captures

Aspect 7: a scientific object

Provenance made easy:

2 files fully describe a model (possibly more if input data): the configuration graph and the user java code

```
treegraph // saved by OmugiGraphExporter on Fri Feb 26 15:07:36 CET 2021

    edge factory = java.lang.String(au.edu.anu.twcore.root.TwConfigFactory)
    node factory = java.lang.String(au.edu.anu.twcore.root.TwConfigFactory)
// TREE
3worlds Palms
    authors = au.edu.anu.rscs.aot.collections.tables.StringTable(([1]""))
    brief history = java.lang.String(Vignoux (21 déc. 2020))
    contacts = au.edu.anu.rscs.aot.collections.tables.StringTable(([1]""))
    precis = java.lang.String()
    publication = au.edu.anu.rscs.aot.collections.tables.StringTable(([1]""))
    version = java.lang.String()
    predefined *categories*
        categoryset *organisation*
            category *assemblage*
            category *atomic*
        record AVEphemeral
            field birthDate
                interval = fr.ens.biologie.generic.utils.Interval(]-∞,+∞[)
                precision = java.lang.Double(0.0)
                type = fr.cnrs.iees.twcore.constants.DataElementType(Double)
                units = java.lang.String()
            field age
                interval = fr.ens.biologie.generic.utils.Interval([0.0,+∞[)
                precision = java.lang.Double(0.0)
                type = fr.cnrs.iees.twcore.constants.DataElementType(Double)
                units = java.lang.String()
        record AVPopulation
            field count
                range = au.edu.anu.rscs.aot.util.IntegerRange(0..*)
                type = fr.cnrs.iees.twcore.constants.DataElementType(Integer)
                units = java.lang.String(#)
            field nRemoved-
```

Aspect 7: a scientific object

Provenance made easy:

2 files fully describe a model (possibly more if input data): the configuration graph and the user java code

ODD (Overview, Design, Details): a standard for model description

Grimm et al. 2006. Ecol. Model. 198:115–126.
Grimm et al. 2010. Ecol. Model. 221:2760–2768.

3Worlds automatically generates an ODD skeleton for any model as an OpenOffice file

Overview	1. Purpose 2. Entities, state variables, and scales 3. Process overview and scheduling
Design concepts	4. Design concepts • Basic principles • Emergence • Adaptation • Objectives • Learning • Prediction • Sensing • Interaction • Stochasticity • Collectives • Observation
Details	5. Initialization 6. Input data 7. Submodels

...it doesnt yet write the article, though.

In practice so far...

java language for portability

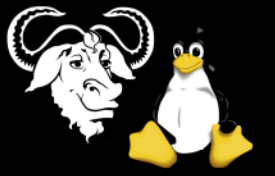
~125,000 lines of code (GCMs 50-750,000)

2 applications:
ModelMaker to edit configurations
ModelRunner to launch a simulation experiment
a **java IDE***, e.g. **eclipse** to write function details

runs on Linux, Mac, Windows

curently 15+ models [many more to come]

[optimisation to come]



We couldnt reproduce the Windows and MacOS logos because they are not free

* integrated development environment. A 'user friendly' software to write code

In practice so far...

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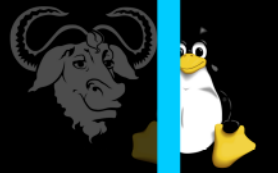
ModelMaker to edit configurations
ModelRunner to launch a simulation experiment
a **java IDE***, e.g. **eclipse** to write function details

runs on Linux, Mac, Windows

currently 15+ models [many more to come]

[optimisation to come]

This is no science-fiction but more tests are needed



We couldnt reproduce the Windows and MacOS logos because they are not free

* integrated development environment. A 'user friendly' software to write code

V. Some applications

'The garden of earthly delights' triptych (closed) by H. Bosch, 1503

The starling (*Sturnus vulgaris*).

Flies.

Loves being in a (huge) group.

Is very noisy and shits while perching.

A flock of starlings

https://www.leprogres.fr/multimedia/2017/12/01/les-cliches-insolites-du-mois-de-decembre-a-travers-le-monde

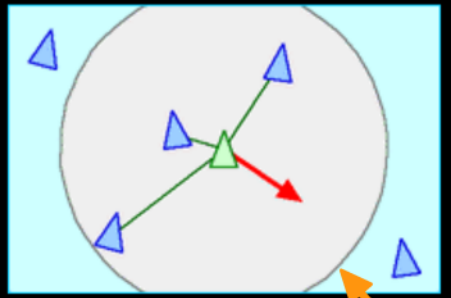
Fish also do it

(so one need not be very smart)

http://www.plongee-libre.fr/slideshow/banc-de-poissons-en-indonesie/

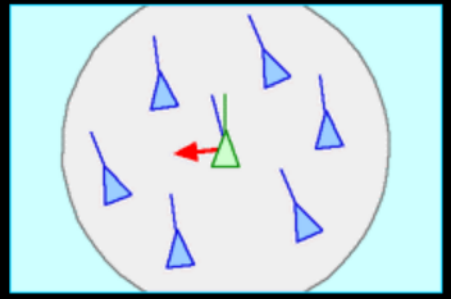
And it's very easy to model with only 3 rules:

1 **separation**: avoid flockmates (close neighbours)

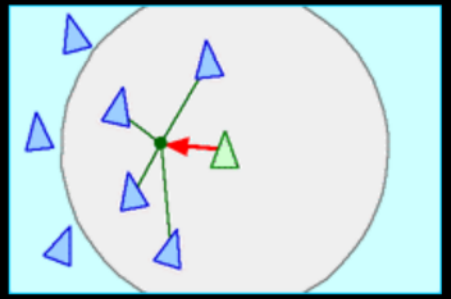


visual field

2 **alignment**: follow average heading of flockmates



3 cohesion: move towards barycentre of local flockmate group



Reynolds, 1987. Computer Graphics 21:25-34

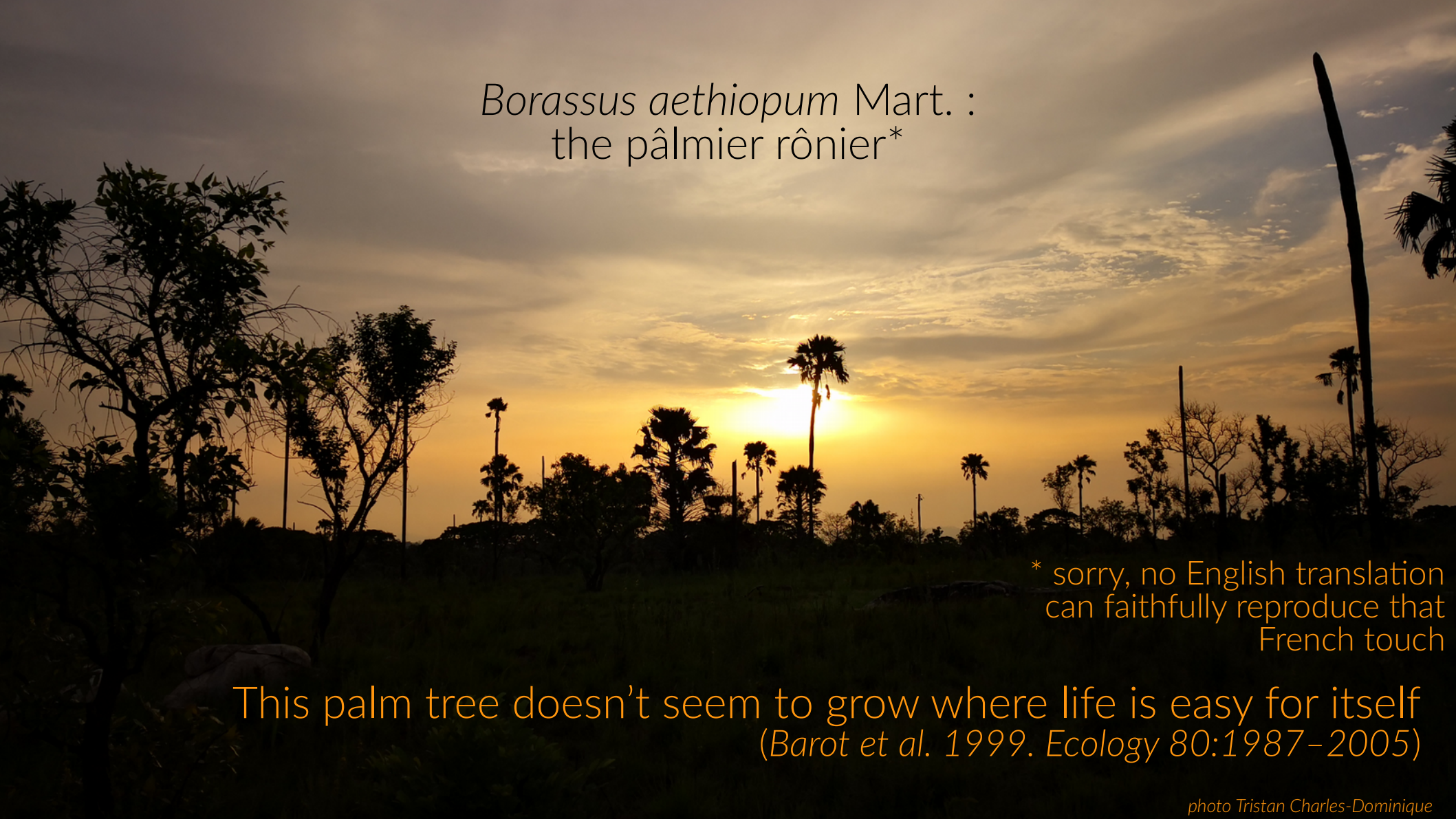
figures from https://en.wikipedia.org/wiki/Boids

Configuration:

size	153
drivers	5
constants	3
decorators	8
component types	1

User code: 97 lines

```
move(...)
double x = xx;
double y = yy;
double incR = 0.0;
double incT = 0.0;
// default movement based on inertia, ie in the same direction as before + some random tilt
incR = speed;
incT = (random.nextDouble()*PI/4 - PI/8)/speed;
double radHeading = heading*PI/180+incT;
double moveX = incR*cos(radHeading);
double moveY = incR*sin(radHeading);
// if there are visible birds, add corrections:
if (nLocal>0) {
        // rule 1: cohesion - flying towards the barycentre of the local group
        // move 1% towards the centre
        moveX += (avgX/nLocal-x)/100;
        moveY += (avgY/nLocal-y)/100;
        // rule 2: separation - avoid collision with other boids
        moveX += focalDec.avoidX/nLocal;
        moveY += focalDec.avoidY/nLocal;
        // rule 3: match movement to others
        moveX += (avgdX/nLocal-dX)/8;
        moveY += (avgdY/nLocal-dY)/8;
}
focalDrv.xx = x+moveX;
focalDrv.yy = y+moveY;
focalDrv.dX = moveX;
focalDrv.dY = moveY;
focalDrv.heading = acos(moveX/euclidianDistance(0.0,0.0,moveX,moveY))*180/PI;
if (moveY<0.0)
        focalDrv.heading = 360-focalDrv.heading;

prepareMove(...)
focalDec.avgHeading += other_heading;
focalDec.avgX += other_xx;
focalDec.avgY += other_yy;
focalDec.avgdX += other_dX;
focalDec.avgdY += other_dY;
focalDec.nLocal++;
// rule 2: avoid collisions
if (squaredEuclidianDistance(xx,yy,other_xx,other_yy)<safetyRange*safetyRange) {
        focalDec.avoidX -= (other_xx-xx);
        focalDec.avoidY -= (other_yy-yy);
}
focalDrv.xx = xx;
focalDrv.yy = yy;
otherDrv.xx = other_xx;
otherDrv.yy = other_yy;
```


Borassus aethiopum Mart. :
the pâlmier rônier*
* sorry, no English translation
can faithfully reproduce that
French touch
This palm tree doesn't seem to grow where life is easy for itself
(*Barot et al. 1999. Ecology 80:1987–2005*)
photo Tristan Charles-Dominique

A data-supported model

3 stages : seedling, juvenile, adult (categories)	*Barot & Gignoux 1999, Biotropica*
adults reduce seedling and juvenile survival	*Barot et al. 1999, Oikos*
termite mounds increase growth	*Barot & Gignoux 2003, JVS*
reproduction starts at adult stage	*Barot & Gignoux 1999, Biotropica*
seed dispersal is very short ranged	*Barot et al. 1999, Oikos*
spatial pattern gets less agregated with palm age	*Barot et al. 1999, Ecology*

Hypotheses

1. *B. aethiopum* is lacking former dispersers (elephants and baboons) and its spatial pattern will change

2. Without termite mounds there will be no more palm trees in Lamto

photo Jacques Gignoux

Hypotheses

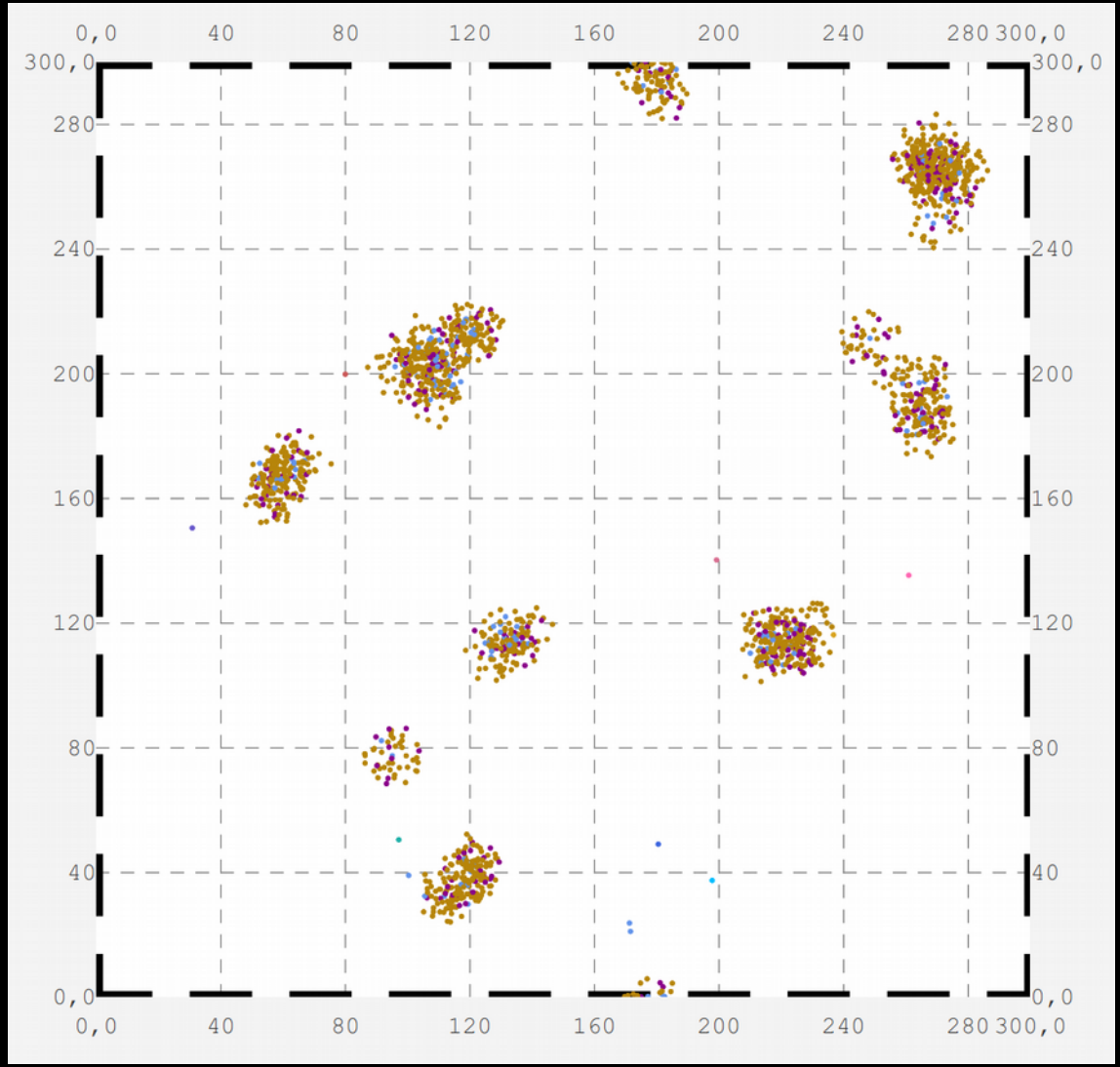
1. *B. aethiopum* is lacking former dispersers (elephants and baboons) and its spatial pattern will change

...

seedling and juveniles are still clumped around adults,

but

adults are much more clumped than in reality



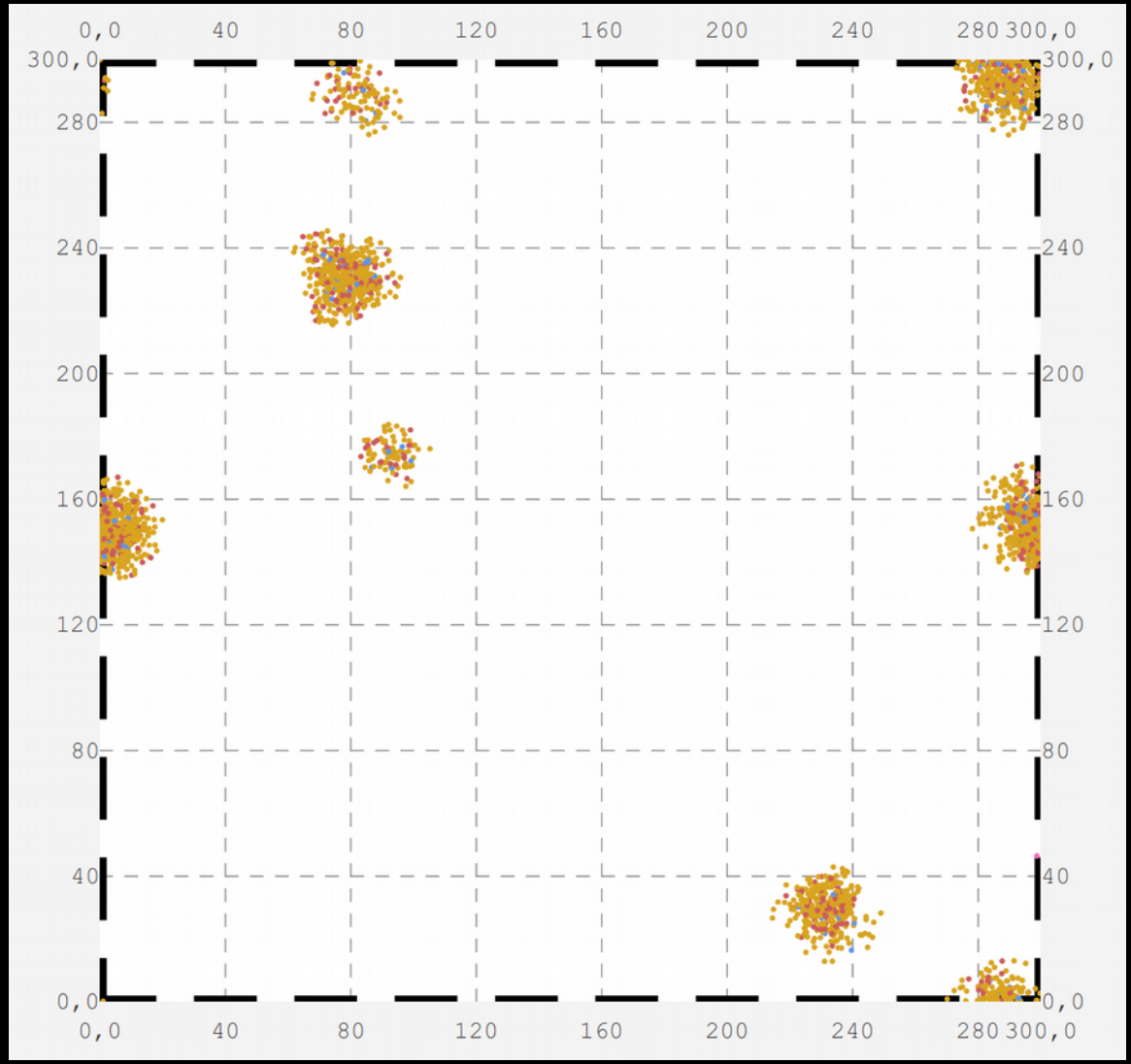
3Worlds screen capture

Hypotheses

2. Without termite mounds there will be no more palm trees in Lamto

...

The difference is not obvious. A formal simulation experiment is needed.



3Worlds screen capture

Configuration:

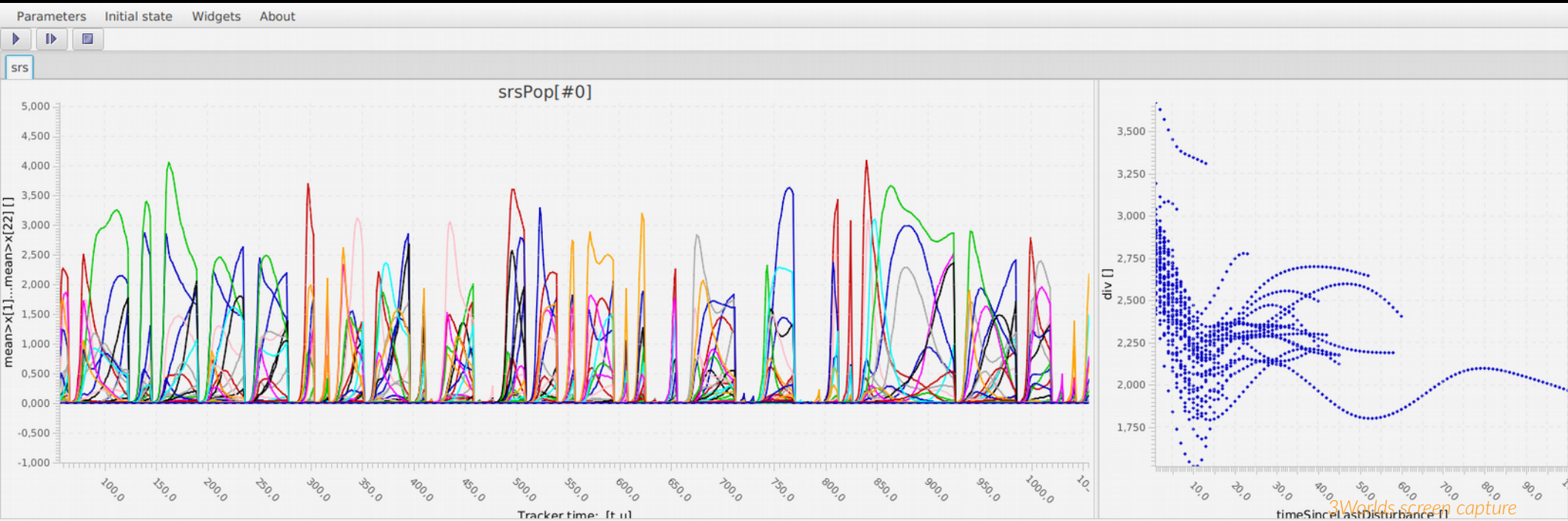
size	627
drivers	5
constants	43
decorators	5
component types	4
relation types	3

User code: 217 lines

```
moundEffect(...)
// relativedistance weight, ie = 1 if at focal location, =0 at searchRadius distance
double weight = 1-euclidianDistance(x,y,other_x,other_y)/searchRadius;
focalDec.neighbourhoodIndexMounds += weight;

mortalityAdult(...)
if (dead>=group_remanence)
	return true;
else
	return false;

juvenileNeighbour(...)
return true;

growJuvenile(...)
double crownSurface = PI*sqr(canopyRadius);
double niMound = neighbourhoodIndexMounds/crownSurface; // TODO: replace by
neighbourhood index
double niTree=0;
double niAdult = neighbourhoodIndexAdults/crownSurface;
double niJuv = neighbourhoodIndexJuveniles/crownSurface;
// increment in number of leaves
double[] proba = new double[3];
if (budHt>0.0) {
	double neighb = group_j0Mound*niMound + group_j0NLeaves*nleaves;
	double logit = neighb + group_aj0PdNneg;
	proba[0] = 1/(1+exp(-logit));
	logit = neighb + group_aj0PdN0;
	proba[1] = 1/(1+exp(-logit));
	logit = neighb + group_aj0PdN1;
	proba[2] = 1/(1+exp(-logit));
}
else {
	double neighb = group_j1Tree*niTree + group_j1Adult*niAdult +
group_j1Juvenile*niJuv + group_j1BudHt*budHt;
	double logit = neighb + group_aj1PdNneg;
	proba[0] = 1/(1+exp(-logit));
	logit = neighb + group_aj1PdN0;
	proba[1] = 1/(1+exp(-logit));
	logit = neighb + group_aj1PdN1;
	proba[2] = 1/(1+exp(-logit));
}
double real = random.nextDouble();
int result = 3;
for (int i=0; i<3; i++)
	if (real<proba[i]) {
		result = i;
		break;
}
int dN = result-1; // possible outcomes: -1,0,1,2
```

Testing the intermediate disturbance hypothesis

40 species following Lotka-Volterra competition model (random parameters), 2 disturbances.



Configuration:

size	127
drivers	41
constants	122
decorators	2
component types	2

User code: 57 lines

```
effects(...)
for (int i=0; i<other_x.size(); i++) {
        if (other_x.getByInt(i)>other_K.getByInt(i)*intensity/100000)
                otherDrv.x.setByInt(otherDrv.x.getByInt(i)*other_K.getByInt(i)*intensity/
10000, i);
}
otherDrv.lastDistT = t;

initComm(...)
double initfreq = 1.0/x.size();
focalDrv.x.fillWith(initfreq);
for (int i=0; i<r.size(0); i++) {
        focalCnt.r.setByInt(random.nextDouble(),i);
        focalCnt.K.setByInt(5.0+initfreq+random.nextDouble(),i);
        for (int j=0; j<alpha.size(1); j++) {
                if (i==j)
                        focalCnt.alpha.setByInt(1.0,i,j);
                else
                        focalCnt.alpha.setByInt(max(0.0001,random.nextDouble()),i,j);
        }
}
focalDrv.lastDistT = 0.0;

setup(...)
return true;

growth(...)
// population growth
double[] dxdt = new double[x.size(0)];
for (int i=0; i<x.size(0); i++) {
double sum = 0;
for (int j=0; j<alpha.size(1); j++)
        sum += alpha.getByInt(i,j) * x.getByInt(j);
        dxdt[i] = r.getByInt(i) * x.getByInt(i) * (1-sum/K.getByInt(i));
}
for (int i=0; i<dxdt.length; i++)
        focalDrv.x.setByInt(max(x.getByInt(i)+dxdt[i]*dt,0.0), i);
// compute diversity
double xtot = 0.0;
for (int i=0; i<focalDrv.x.size(0);i++)
        xtot += focalDrv.x.getByInt(i);
focalDec.div = 0.0;
for  (int i=0; i<focalDrv.x.size(0);i++)
        if (focalDrv.x.getByInt(i)>0.0)
                focalDec.div -= (focalDrv.x.getByInt(i)/xtot) *
log(focalDrv.x.getByInt(i)/xtot);
// compute time since last disturbance
focalDec.timeSinceLastDisturbance = t-lastDistT;

initDist(...)
```

VI. Conclusions

1. to couple approaches of a complex system, use aspect-oriented thinking

2. any ecosystem can be modelled with a dynamic graph

3Worlds is there*, use it!

*Well… come and see me after the talk

VII. Needs & future plans

testers:
- develop models
- check GUIs
- check checks

programmers:
- space library
- openMole integration
- optimisation
- graph analysis

https://valerianpierret.artstation.com/projects/e0m4eJ

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- check checklists

programmers:
- space library
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- graph analysis

And, anyway, what do you have against science-fiction when people spend billions to grow tomatoes on Mars?