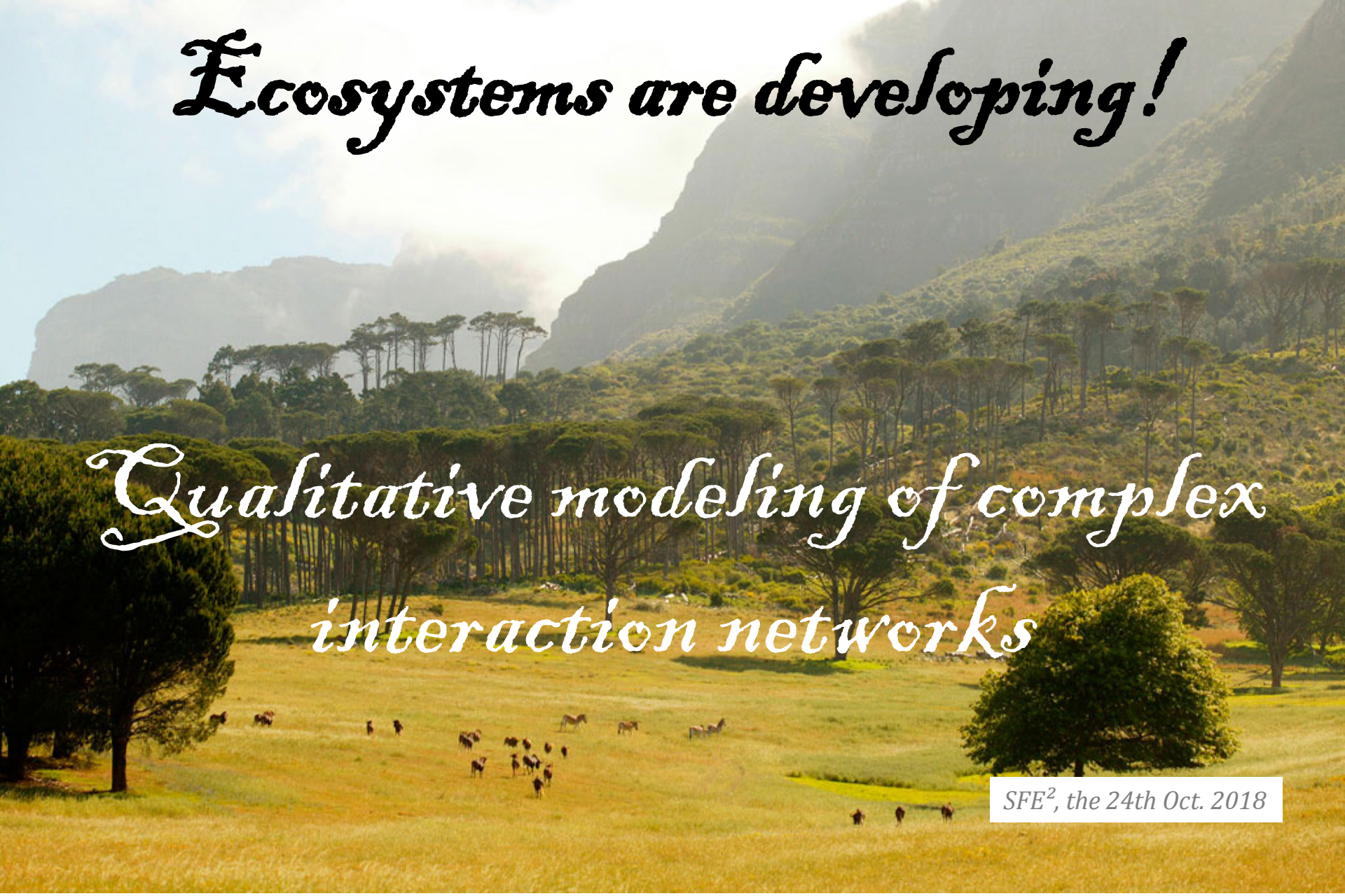


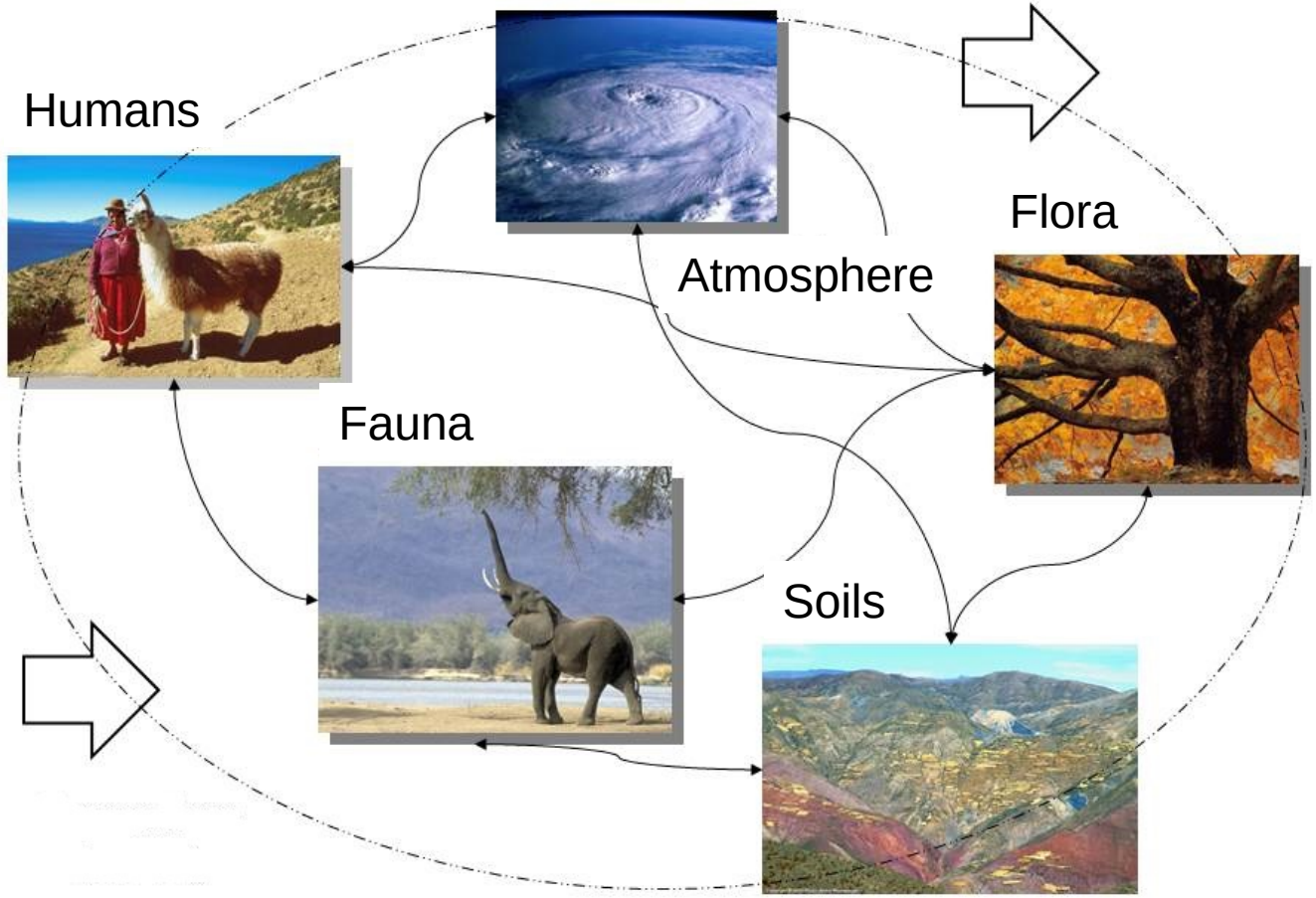
Ecosystems are developing!

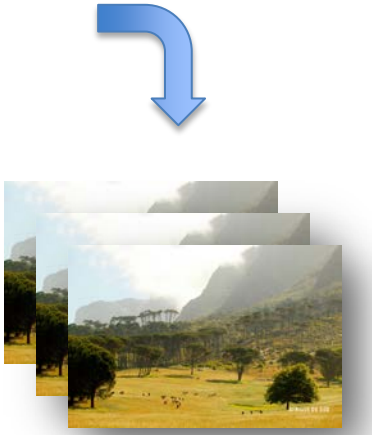
Qualitative modeling of complex interaction networks

SFE², the 24th Oct. 2018

C. GAUCHEREL

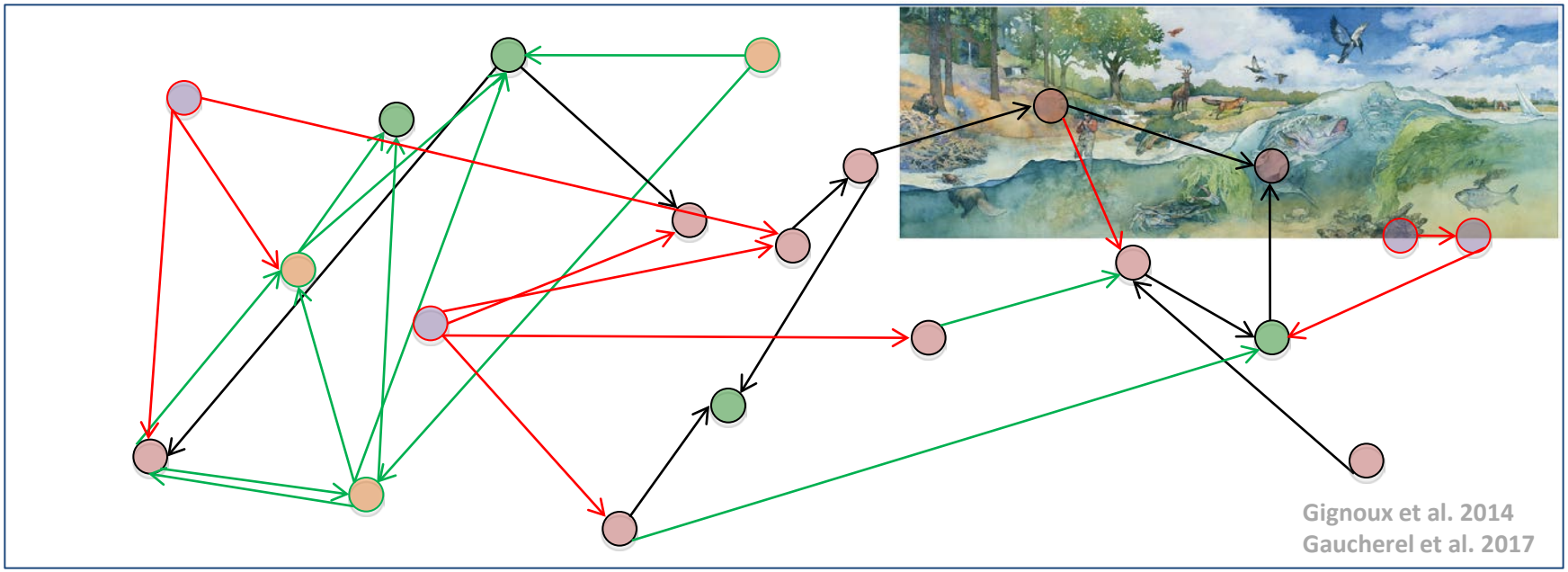
What is an ecosystem!





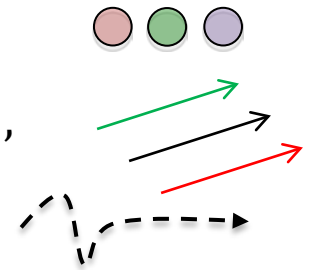
Various components/processes and changing structure…

Changing interaction network



Ecosystemic specificities:

- E. **components** are diversified (alive, inert, human-related…),
- E. **processes** are diversified too (trophic, physicochemical, human…),
- Ecosystem **topology** is changing too (stable, unstable, collapse…).

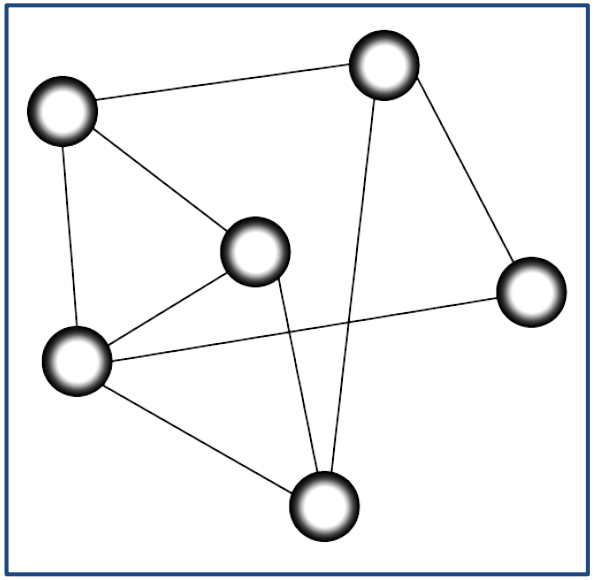


→ How to integrate the whole dynamical socio-ecosystem?

The qualitative model

Network representations

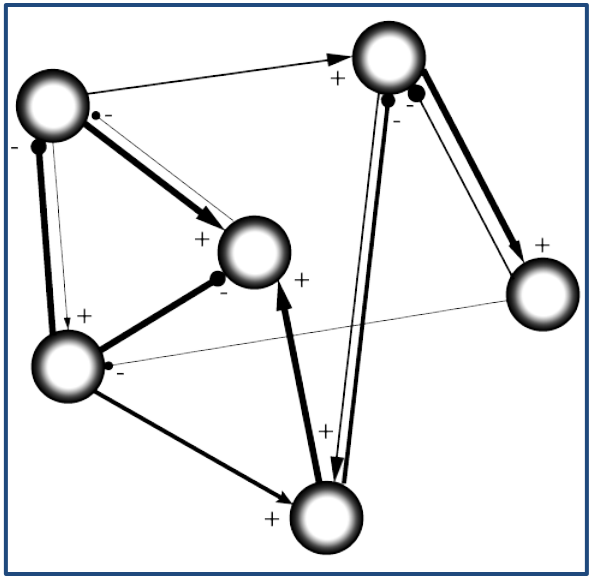
Qualitative ⟷ Quantitative



CONNECTED WEB

Topological analysis
(degree distribution, network robustness

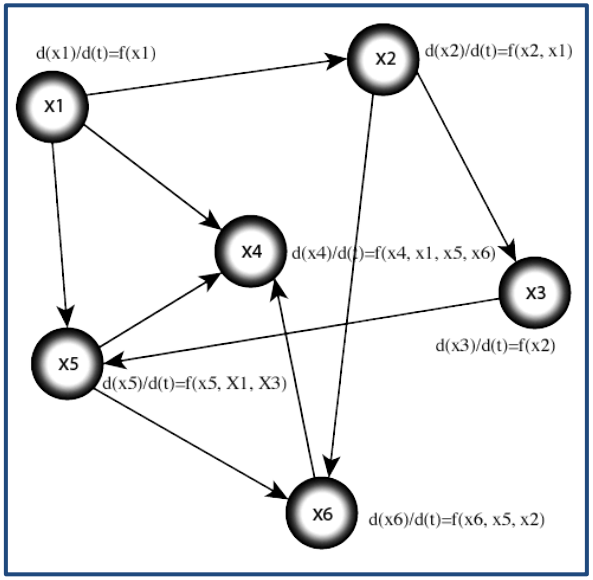
Proulx 2009
Gaucherel et al. 2017…



WEIGHTED SIGNED DIGRAPH

- Loop analysis
- Impacts of node appearance/disappearance

Puccia et al. 1986; Dunne et al. 2002
Dambacher et al. 2007

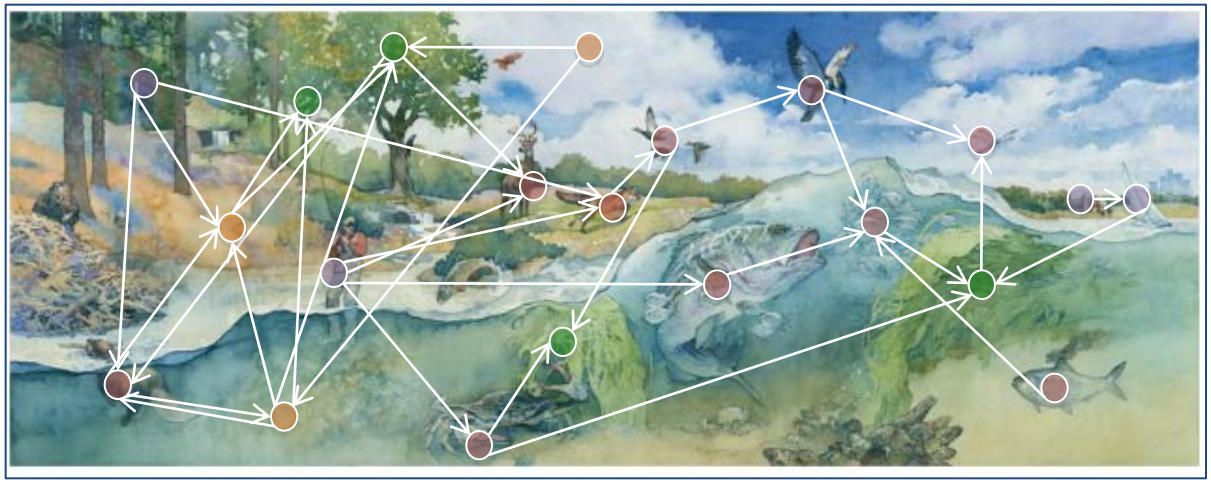


DIFFERENTIAL EQUATIONS

- Population dynamics
- System stability
- Extinctions

Strogatz 1994; Brose et al. 2012
Thébault & Fontaine 2010

ECOSERVE – THE PETRI NET



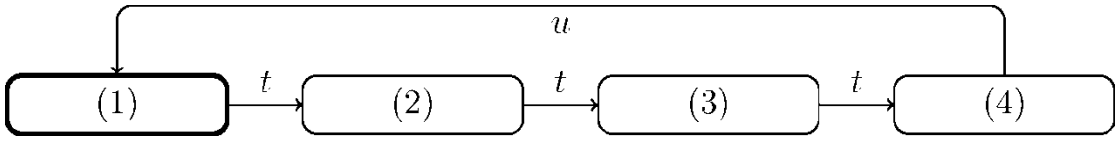
A discrete and qualitative model integrating biotic, abiotic and anthropogenic components and all interactions, over the long term

The model is a triplet *(E, s_0, R)* such that:

Gaucherel et al., EC 2017
Gaucherel & Pommereau, Submitted

- *E* is the **set of components** ⟺ Petri net *places*
- s_0 is the **initial state** ⟺ Initial *Marking*
- *R* is a **set of rules** ⟺ *Transitions*

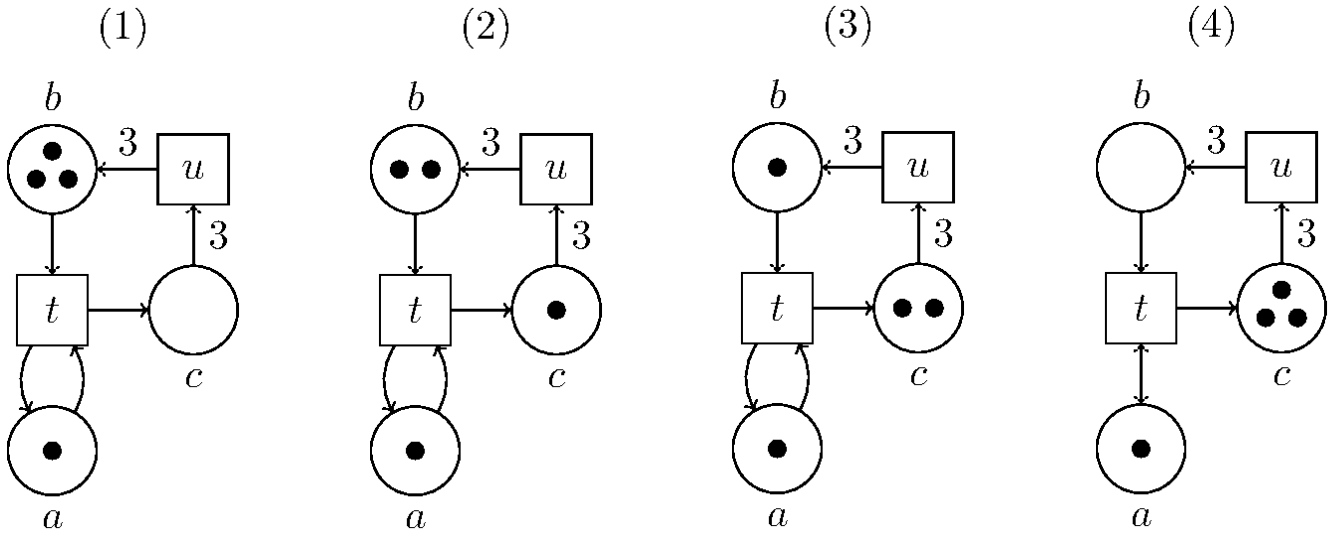
The formalism behind



Reisig, 2010 ; Pommereau, 2008

A marked Petri net (PN) is a set $N \stackrel{\text{def}}{=} (S, T, W, M)$ *such that:*

- S *is a finite set of* ***places*** *(nodes);*
- T*, disjoint from* S*, is a finite set of* ***transitions*** *(edges - interactions);*
- $W\colon (S \times T) \cup (T \times S) \to \mathbb{N}$ *is the weight function defining* ***arcs****;*
- $M \in S^*$ *is the* ***marking****, a multiset of places represent. the state of PN*



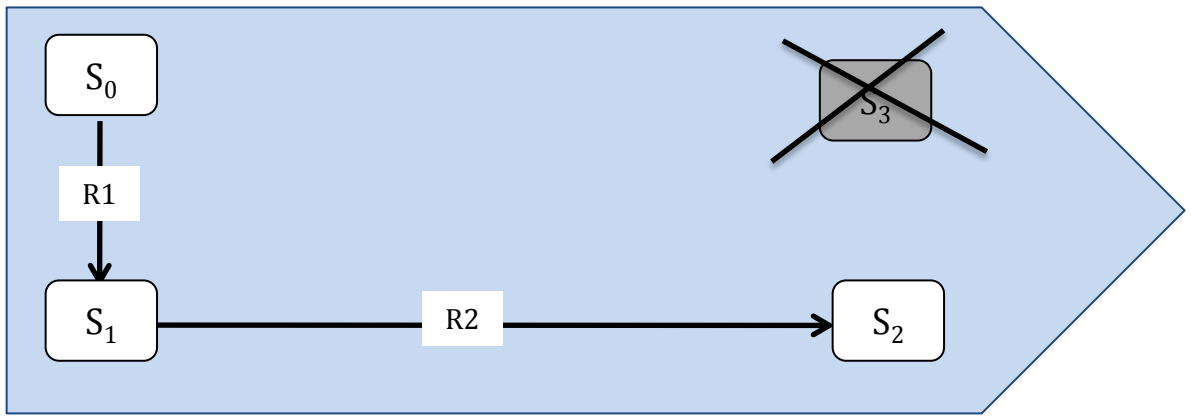
A prey-predator Petri Net

A simplistic PP system: $E = \{P, N\}$, $S_0 = \{P, N\}$, $R = \{R1, R2\}$

R1: *The predator eats the prey*

R2: *Without any prey, the predator dies*

The Petri net automatically (and rigorously) computes ***all*** *possible states*



To study the *total* *State Space* is equivalent to study the Petri net.

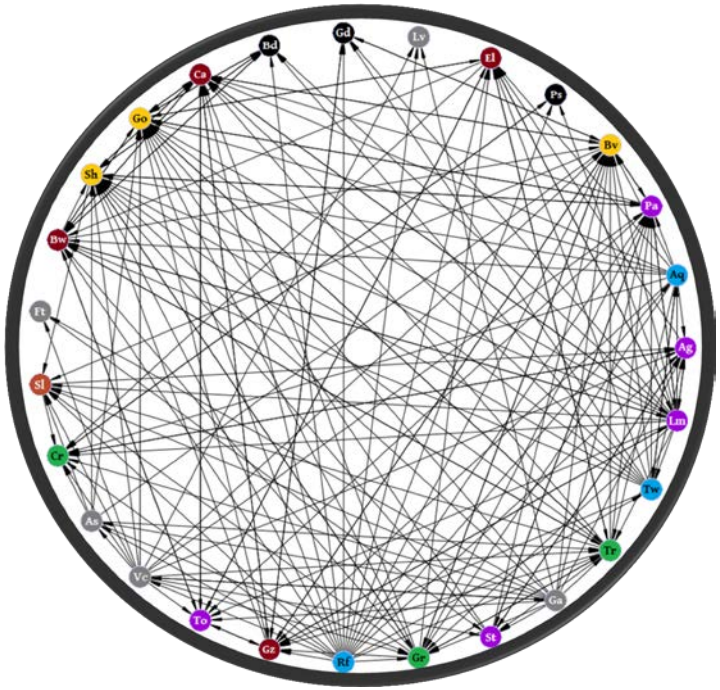
Gaucherel & Pommereau, Submitted

Illustration in Africa

African Savana (pastoralism)

Question: May the system “collapse”?

Ecosystemic graph



- *Eau*
- *Faune sauvage*

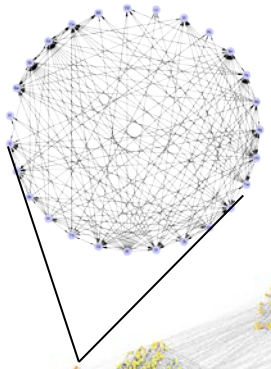
- *Bétail*
- *Végétation et cultures*

- *Populations humaines et infrastructures*

- *Sol*

- *Volcanisme et sismologie*
- *Pathogènes et ravageurs*

State space analysis

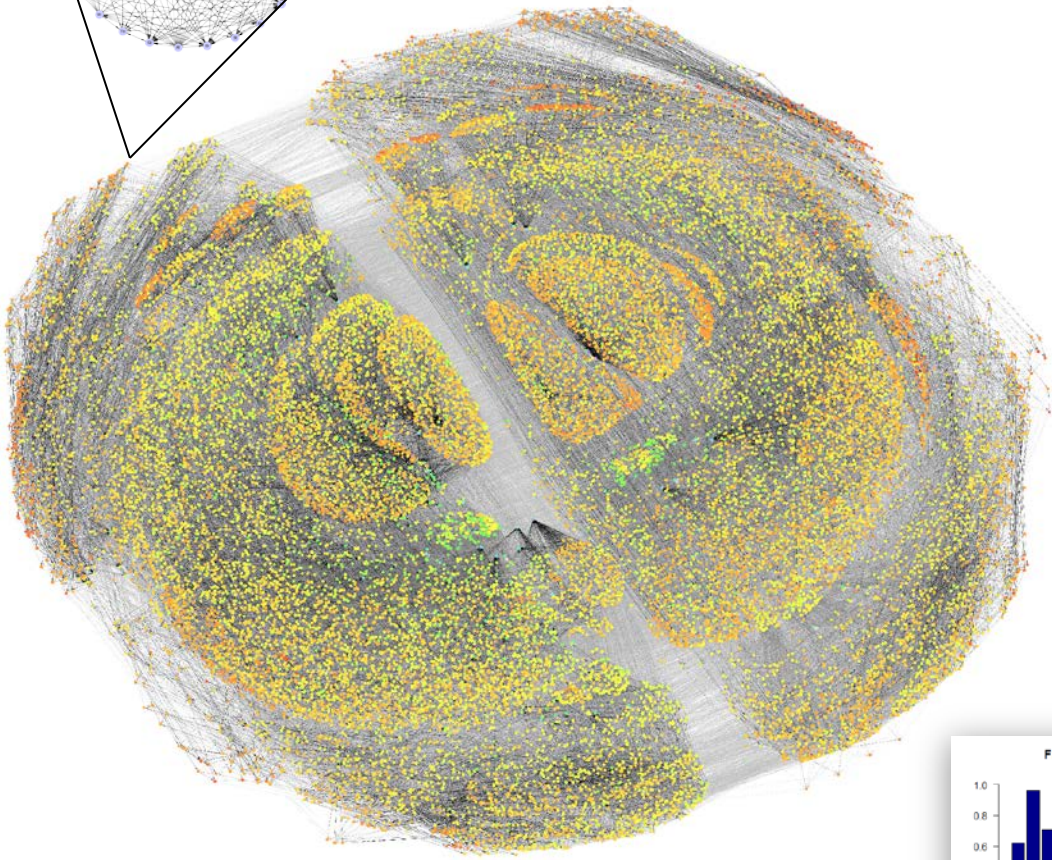


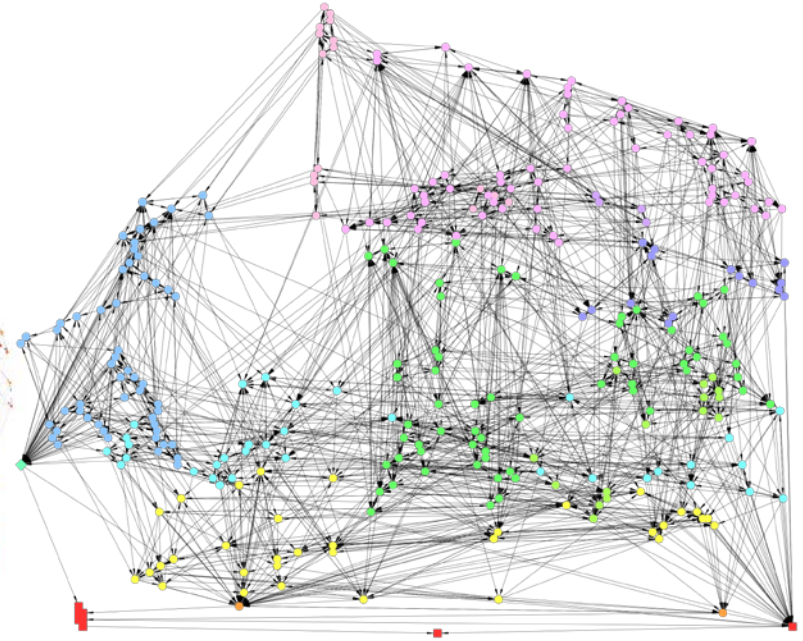
Full State space

No collapse

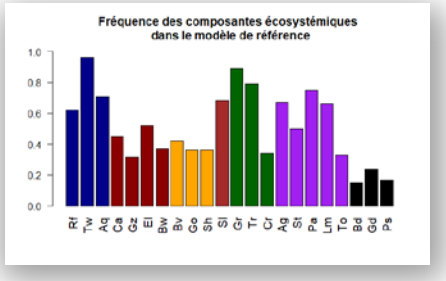
NEW full State space

No more return to rainy season:





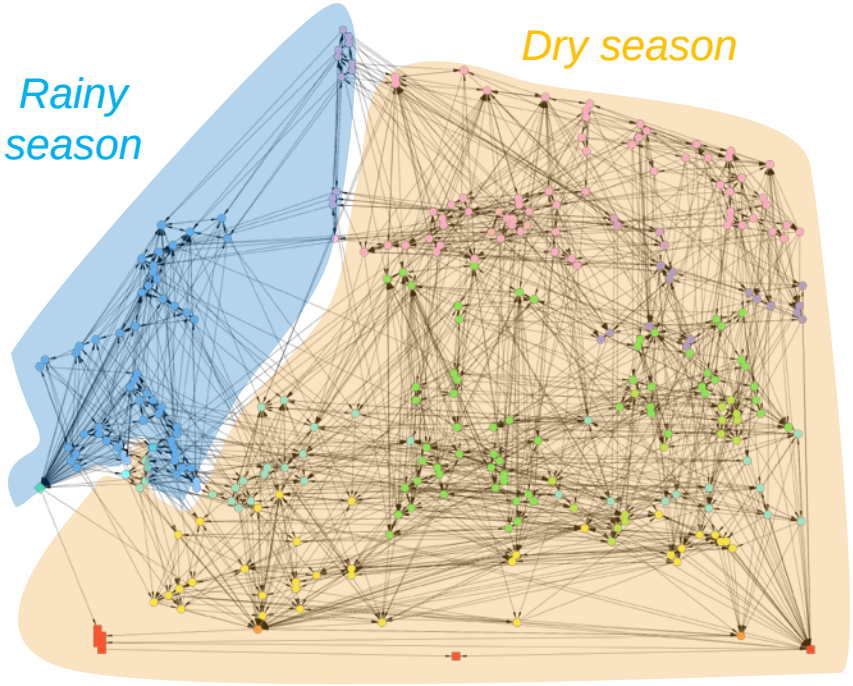
Total = 24 444 states, All reversible (one stability), Averaged composition

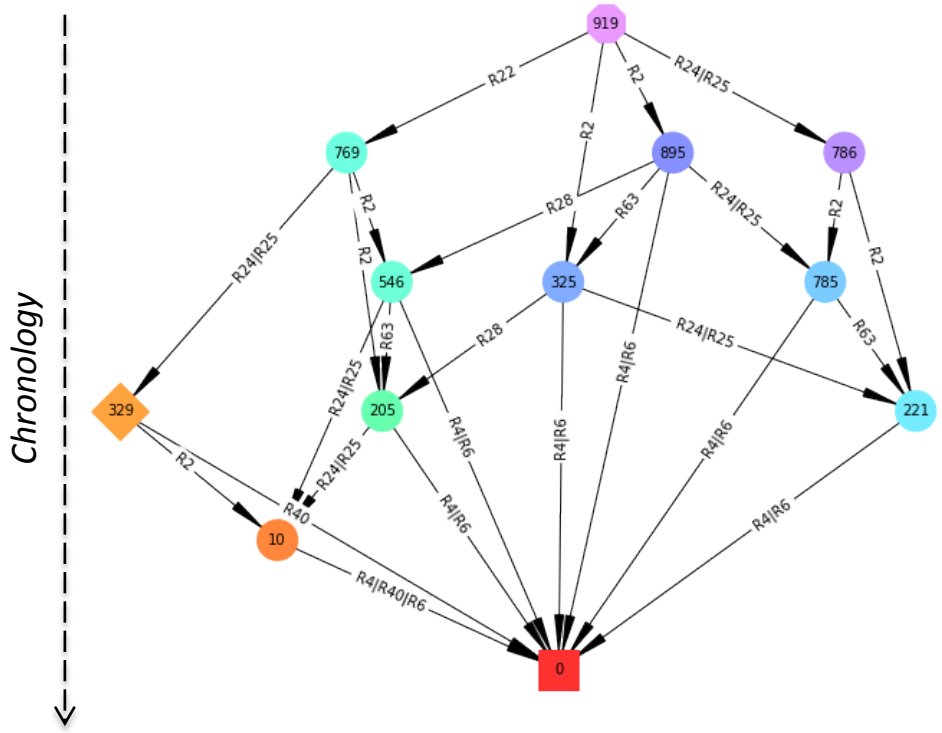


State space analysis

NEW full State space

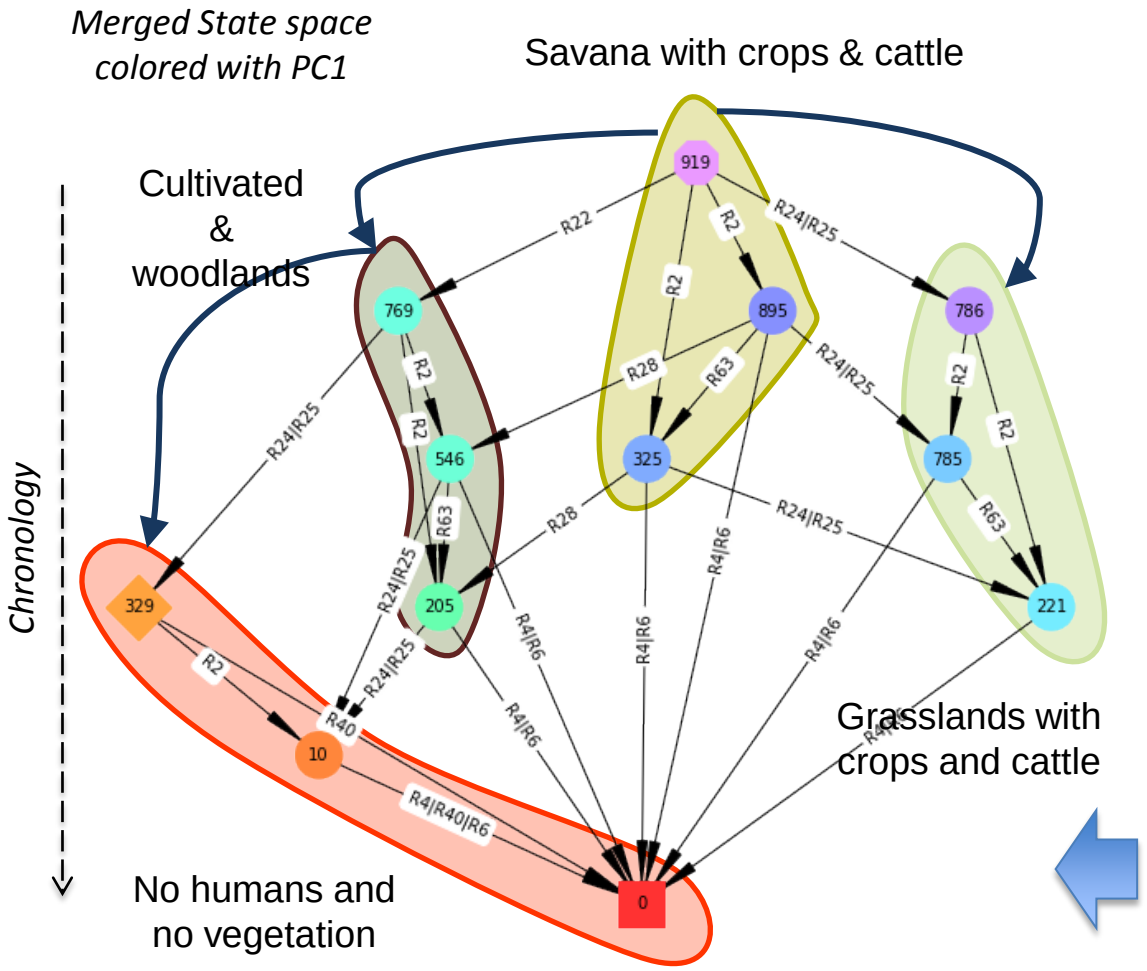
Merged State space

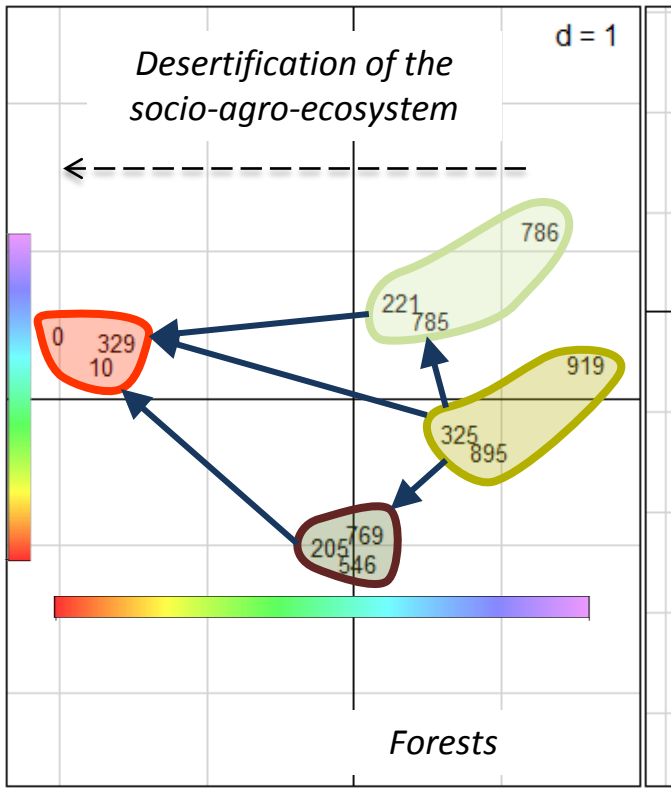




Global trajectories of the socio-ecosystem, to be statistically analyzed (with a global collapse without the return of rainy season).

Validated trajectories



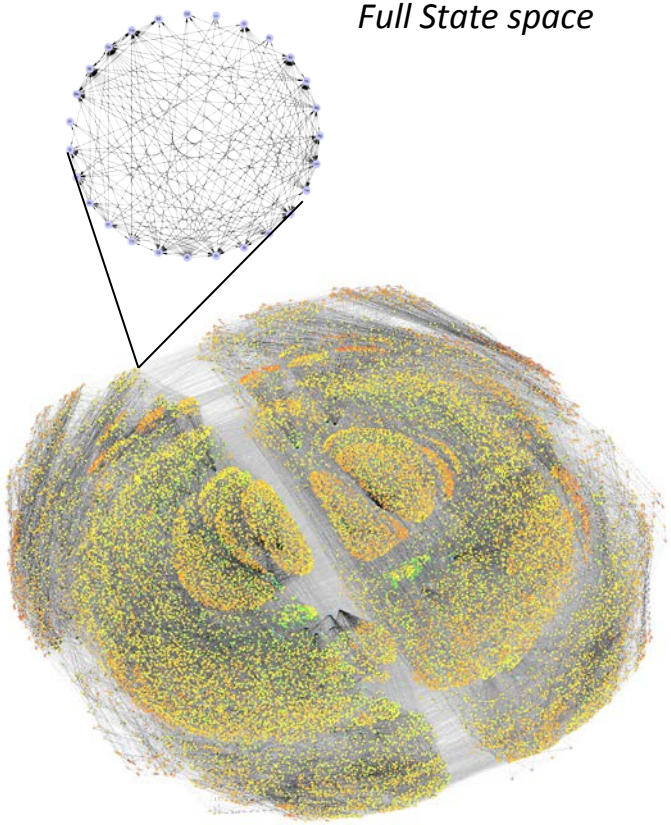


Cosme, Hély, Pomereau, Gaucherel, In prep.

Global trajectories of the socio-agroecosystem statistically analyzed
(various sustainable stabilities + collapse towards desertification)

State space analysis

Full State space



Total = 24 444 states, All reversible (one stability)

Resilient! No collapse

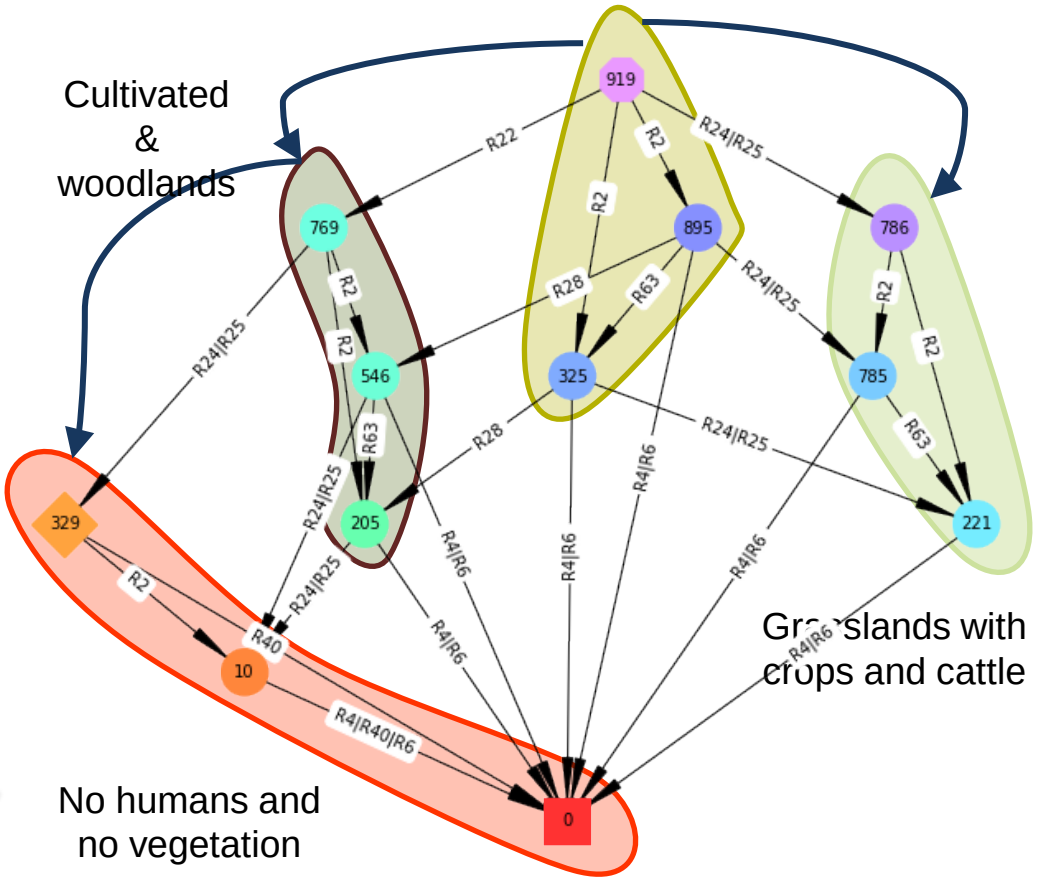
Merged State space

No more return to rainy season:

Savana with crops & cattle

Cultivated & woodlands

Chronology

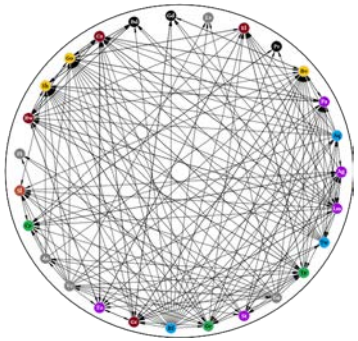
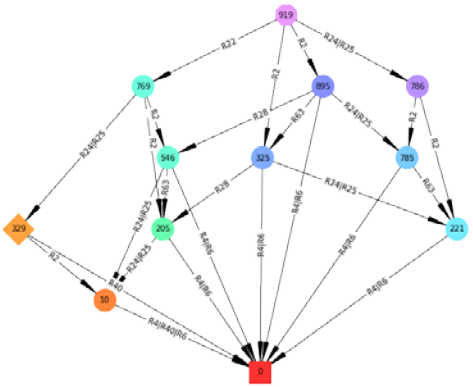


Grasslands with crops and cattle

No humans and no vegetation

Conclusions

1. ***Petri nets:*** *An integrated model of a new kind, handling biotic, abiotic as well as human components and all their related processes;*
2. *Any ecosystem* ***develops*** *(birth, growth and death), with dynamical interaction networks (topology) and internal perturbations;*

3. *State space****:*** *We know how to quantify ecosystem dynamics, trajectories, and* ***structural stabilities*** *→ to recommend sustainable scenarios;*
4. *The potential metaphor seems today inappropriate → we should try to identify dynamics of the* ***state-space****.*