

A qualitative approach for modelling complex ecological systems

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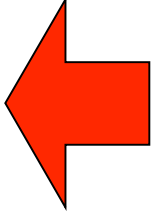
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Overview

- Context and objectives 
- Qualitative theory of population dynamics
- Interactions between two populations
- Cerrado succession hypothesis
- Concluding remarks...

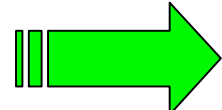
Why are models important? *(in ecology)*

- Understand the structure of an ecological system
- Predict the behaviour of quantities and of the whole system
- Control variables in order to obtain specific results

What are models used for? (*in Ecology*)

- □ Scientific research
- □ Supporting management decisions
- □ Educational and training purposes



 *Requirements for each use are different*

Why QR & Ecology ?

In ecology it is difficult to collect data and run experiments

- Available data is incomplete, inexact, and often expressed in qualitative terms
- Theoretical foundations and laws (first principles) are still being developed.

QR provides means to create and capture important ecological knowledge

Objectives

Construct *qualitative* models and simulations of complex ecological systems, that:

- *conceptually* clarify ecological insights
- can be used research / training / teaching

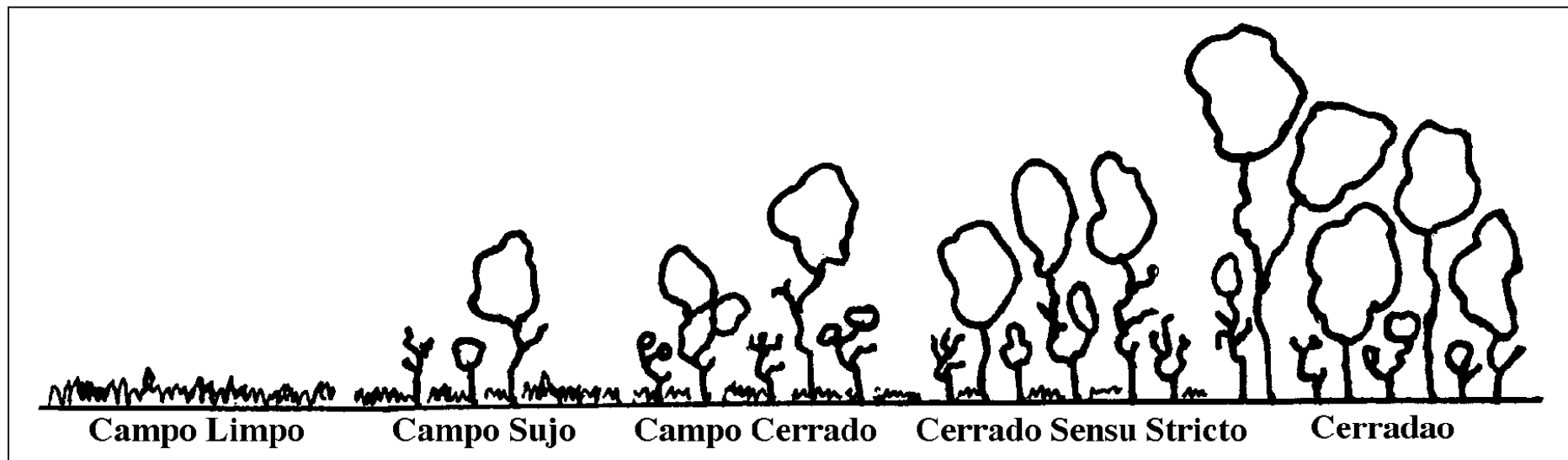
Our focus: population and community behaviour

Case study: Ecology

Fire management in the Brazilian Cerrado

Publication details, see e.g.:

Moreira, A. (1992) *Fire Protection and Vegetation Dynamics in the Brazilian Cerrado*. PhD thesis, Cambridge, Mass, Harvard University.



Cerrado Succession Hypothesis (*CSH*)

In general...

different physiognomies are determined by

- fire
- soil type
- nutrients
- water availability
- human actions

Cerrado Succession Hypothesis (*CSH*)

Influence of fire ... a common sense theory...

- If fire frequency **increases**, then the vegetation becomes **less** dense
- If fire frequency **decreases**, then the vegetation becomes **more** dense

Current studies support this idea, although more (long term) research is required

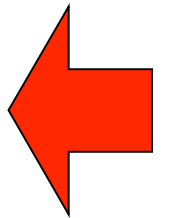
Cerrado Succession Hypothesis (*CSH*)

Because... according to Experts...

- Tree seeds and seedlings do better in shaded and colder micro environments
- Grass seeds and seedlings do better in lighter and warmer micro environments

Overview

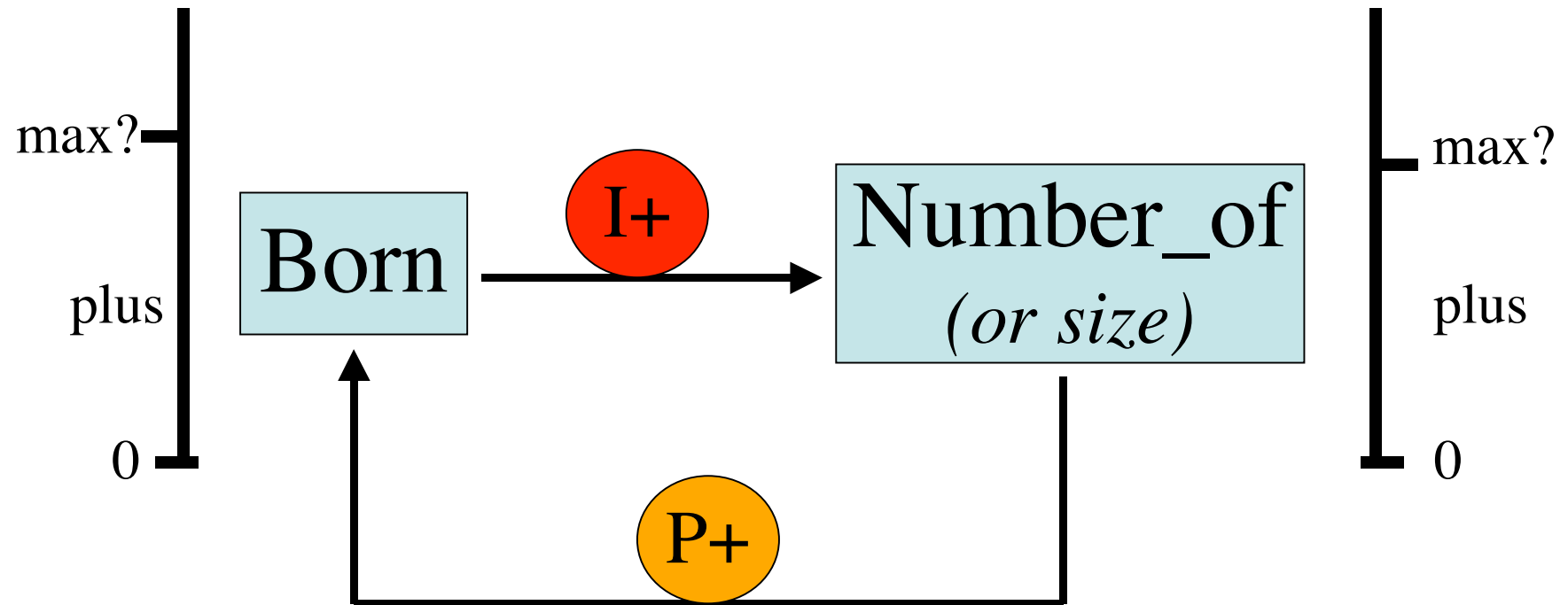
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A starting point...

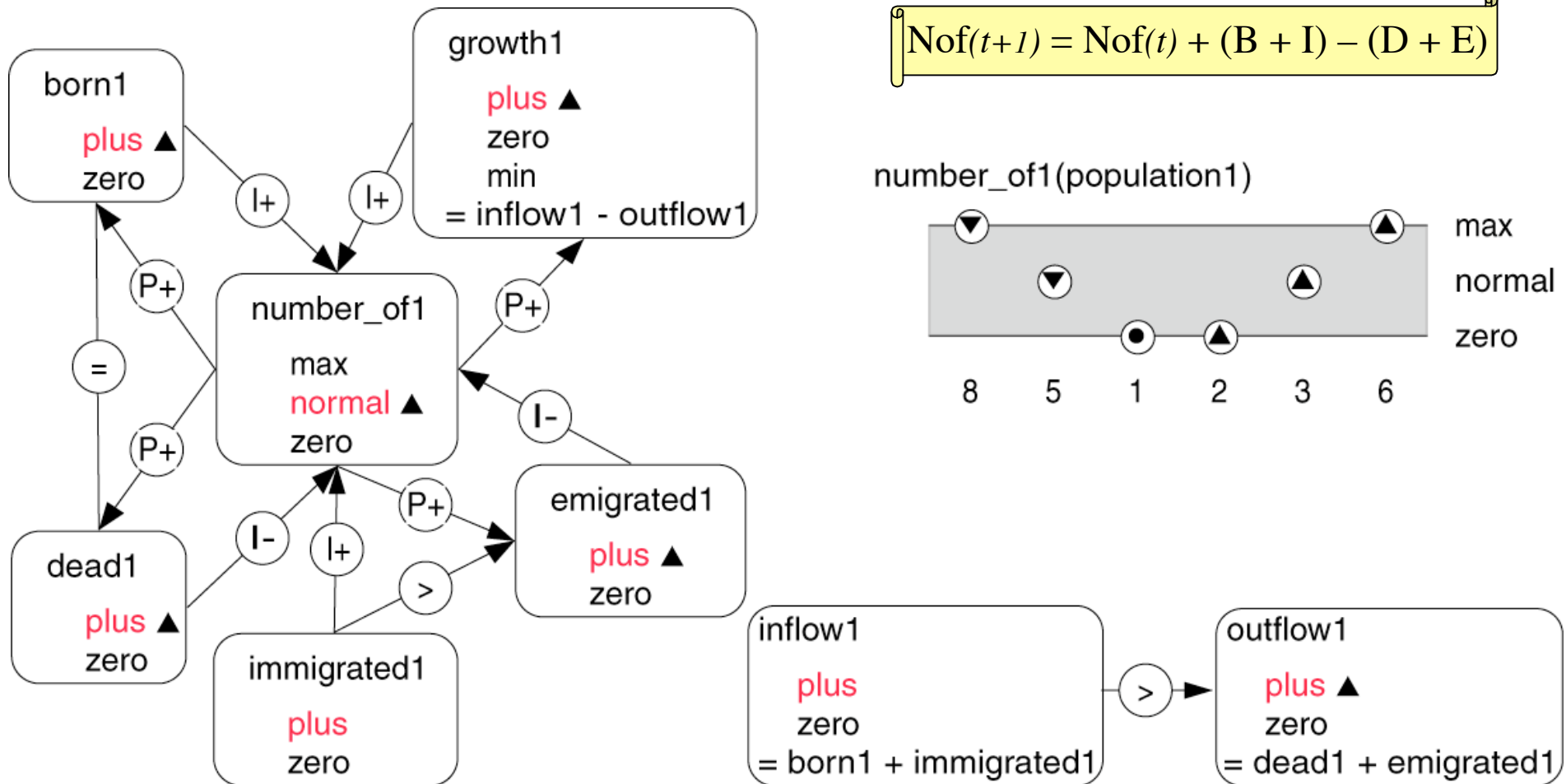
$$\text{Nof}(t+1) = \text{Nof}(t) + (B + I) - (D + E)$$

If a **Population** exists... (an entity)



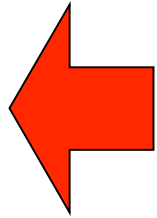
- Dead, Immigrated & Emigrated
- Colonisation (*subtype of Immigrated: Nof=0*)
- Inflow = Born + Immigrated, Outflow = Dead + Emigrated
- Growth = Inflow - Outflow
- Assumptions: Open / Closed population (*Immigrated=Emigrated=0*)

Population dynamics (*basic processes*)



Notice: 'first principles' in population ecology

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Population interaction types

Neutralism	(0,0)
Amensalism	(0,-)
Comensalism	(0,+)
Predation	(+,-)
Parasitism	(+,-)
Herbivory	(+,-)
Protocooperation [□]	(+,+)
Mutualism*	(+,+)
Competition	(-,-)

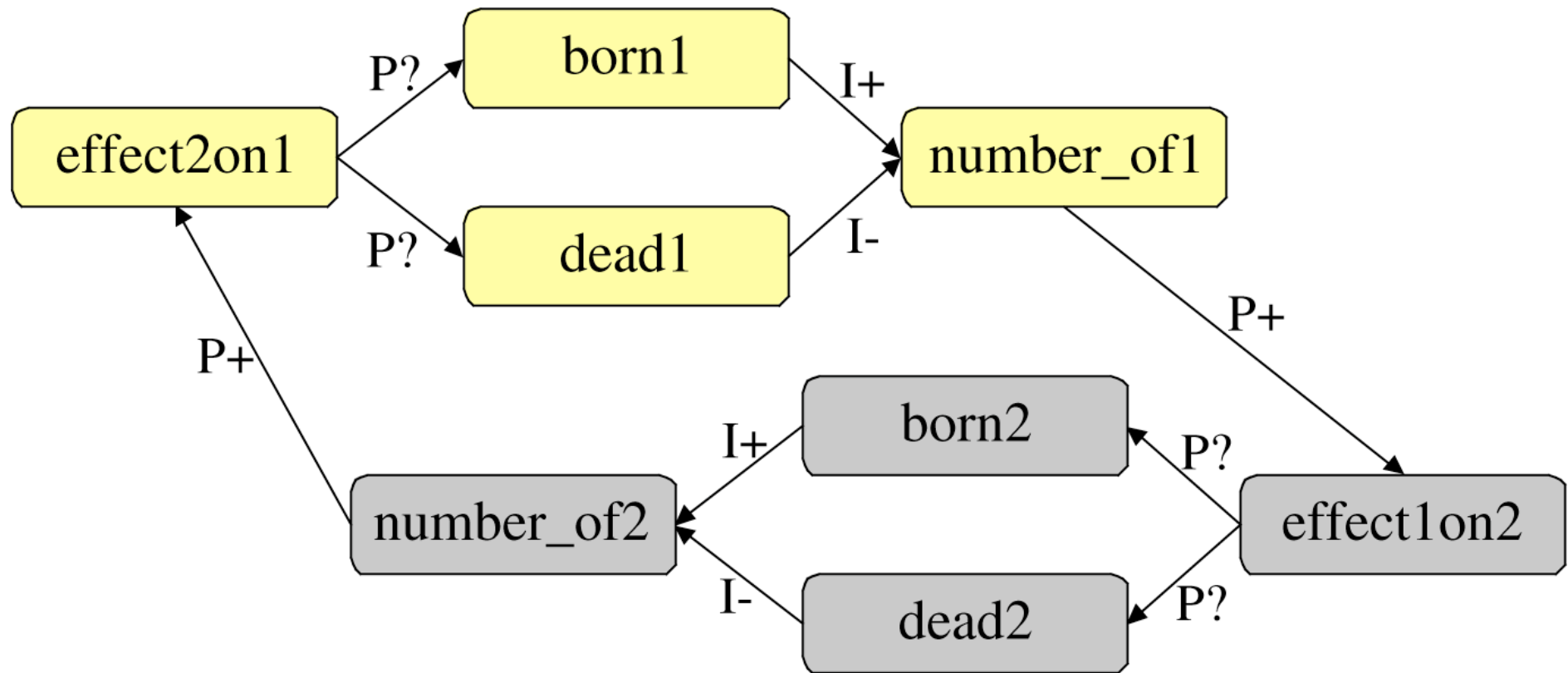
Relevant for:

- Ecological theory
- Practical purposes

Odum, 1985

*Protocooperation and mutualism are also called symbiosis.

Base model *(for representing interactions)*



Next, add constraints to restrict the possible behaviours

Adding critical knowledge

Constraints
captured in
model fragments

1. identify relevant quantities
2. establish causality and typical features
3. add assumptions
 - simplifying assumptions
 - operating assumptions
4. deal with non-existing population(s)

Each interaction type is different in this respect

Representing the interactions

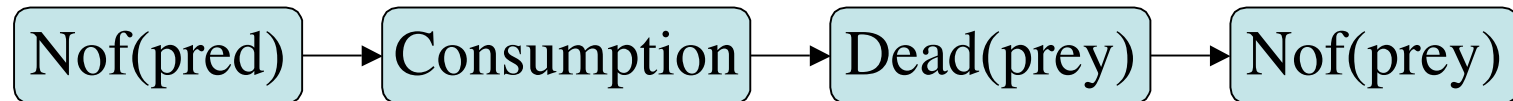
Interaction	Influences	Models
Competition (-,-)	Effect1on2 is negative Effect2on1 is negative	P-(Born2, Effect1on2) P+(Dead2, Effect1on2) P-(Born1, Effect2on1) P+(Dead1, Effect2on1)
Amensalism (0,-)	Effect1on2 is negative Effect2on1 none	P-(Born2, Effect1on2) P+(Dead2, Effect1on2)
Neutralism (0,0)	Effect1on2 none Effect2on1 none	no relations between the two populations
PredatorPrey (+, -)	Effect1on2 is negative Effect2on1 is positive	P+(Dead2, Effect1on2) P+(Born1, Effect2on1) P-(Dead1, Effect2on1)
Comensalism (0,+)	Effect1on2 is positive Effect2on1 none	P+(Born2, Effect1on2) P-(Dead2, Effect1on2)
Symbiosis (+, +)	Effect1on2 is positive Effect2on1 is positive	P+(Born2, Effect1on2) P-(Dead2, Effect1on2) P+(Born1, Effect2on1) P-(Dead1, Effect2on1)

Critical knowledge: *Predator/Prey*

1. Quantities:

Consumption & Supply

2. Causality and features:



$\text{Nof}(\text{prey}) \geq \text{Nof}(\text{predator})$

3. Assumptions:

Simplifying

- Consumption corresponds to Number of Predator
- Supply corresponds to Number of Prey

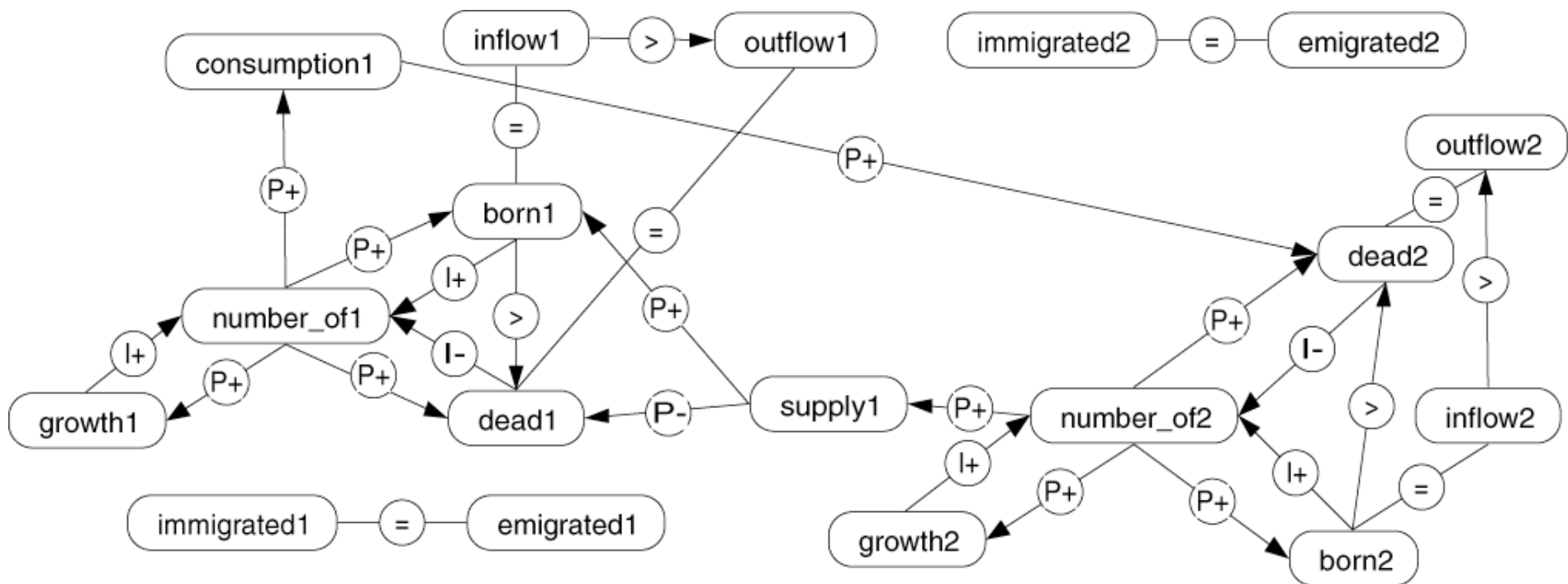
Operating

- Closed population (*e.g.* $\text{Emigrated} = \text{Immigrated} = 0$)

4. No Prey  Predator cannot exist

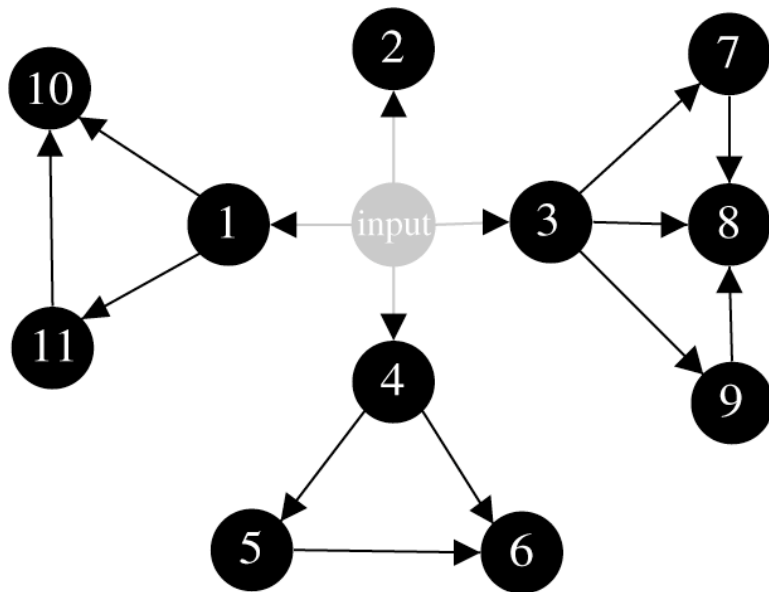
Dependencies: *Predator/Prey*

Simulated using GARP
Visualized by VisiGARP



Running a simulation: *Predator/Prey*

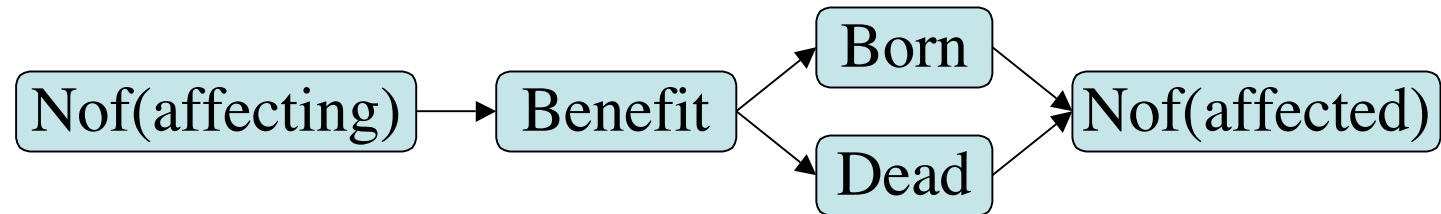
Starting with
Number_of1 =<normal,?>
Number_of2 =<normal,?>



Generated by the domain independent simulator GARP; visualized by VisiGARP

Other models: *Comensalism (0,+)*

What causes the benefit?



- **Impact of population size**

e.g. $Nof(affected) = \max \mathbf{IF} \text{ Benefit} = \max$

$Nof(affected) < \max \mathbf{IF} \text{ Benefit} = \text{normal}$

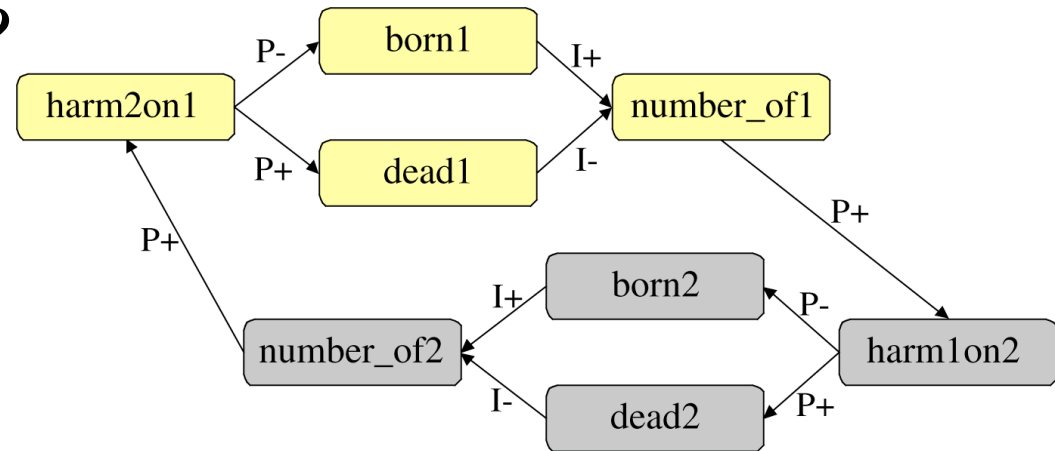
- **impact of population change**

e.g. $\partial \text{Benefit} = \partial Nof(affected)$

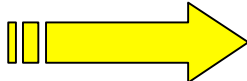
$\partial \text{Benefit} \geq \partial Nof(affected)$

Other models: *Competition (-,-)*

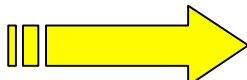
Strong versus weak?



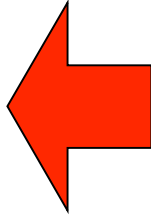
Harm:

$P1 \text{ on } P2 > P2 \text{ on } P1$  exclusion of P2

$P1 \text{ on } P2 = P2 \text{ on } P1$  coexistence

$P1 \text{ on } P2 < P2 \text{ on } P1$  exclusion of P1

Overview

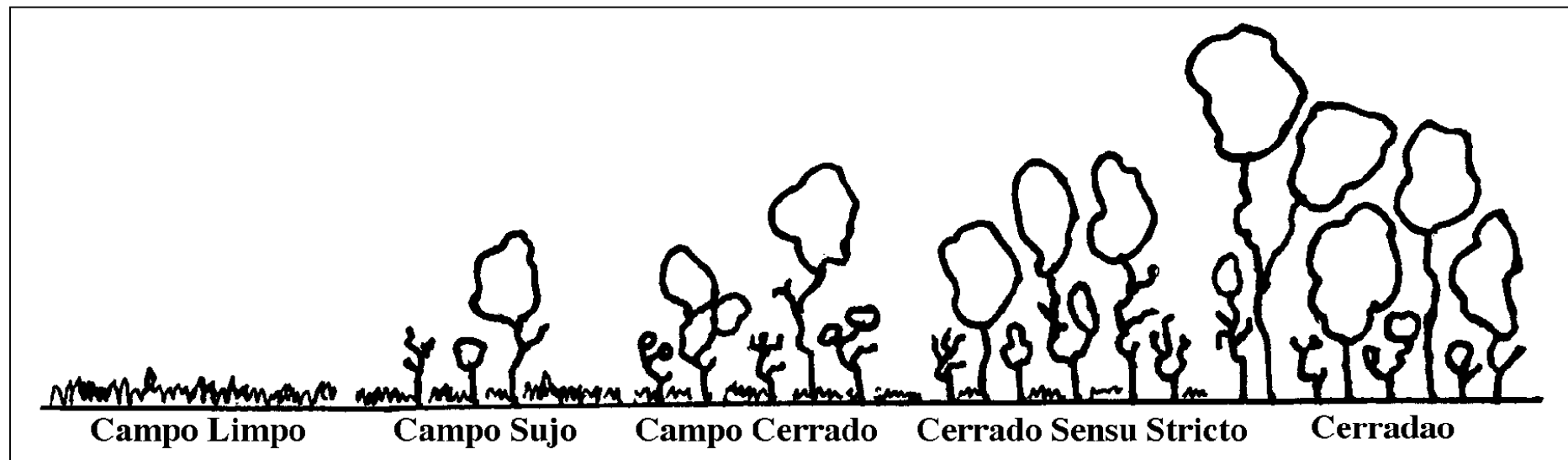
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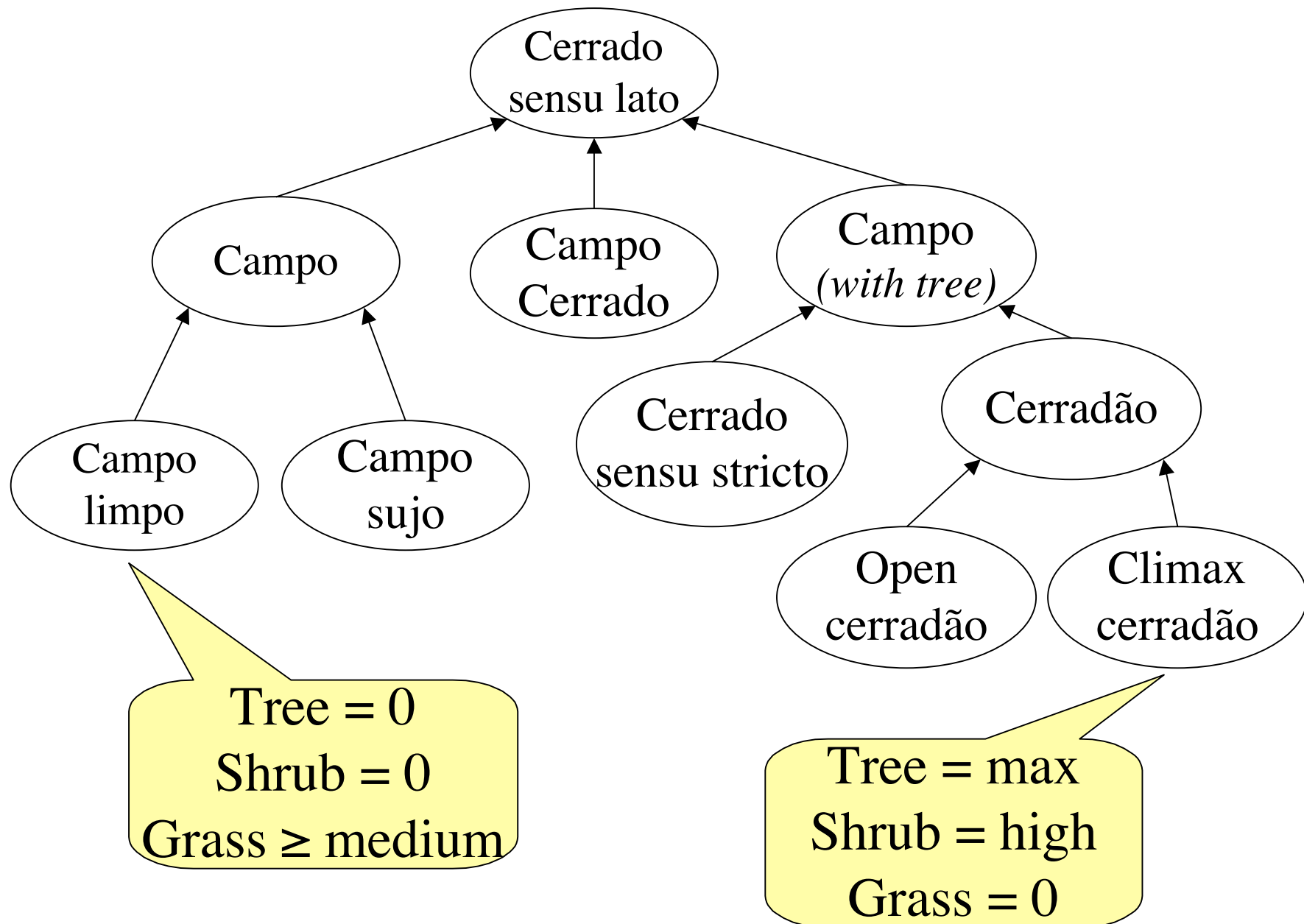
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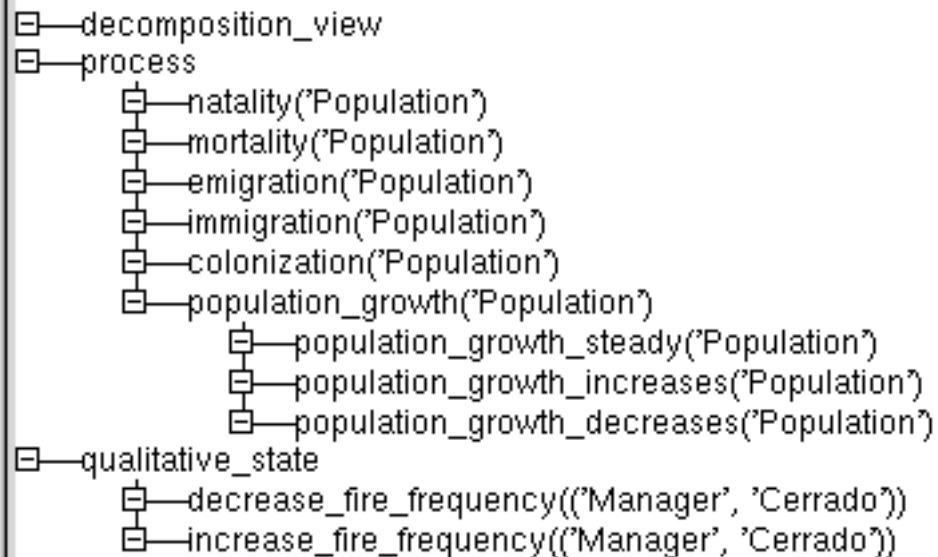
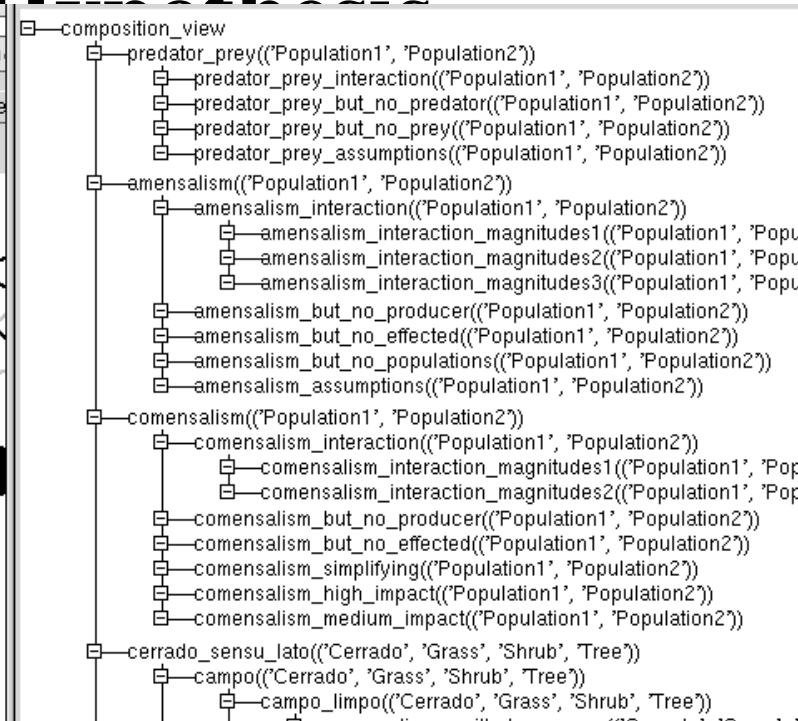
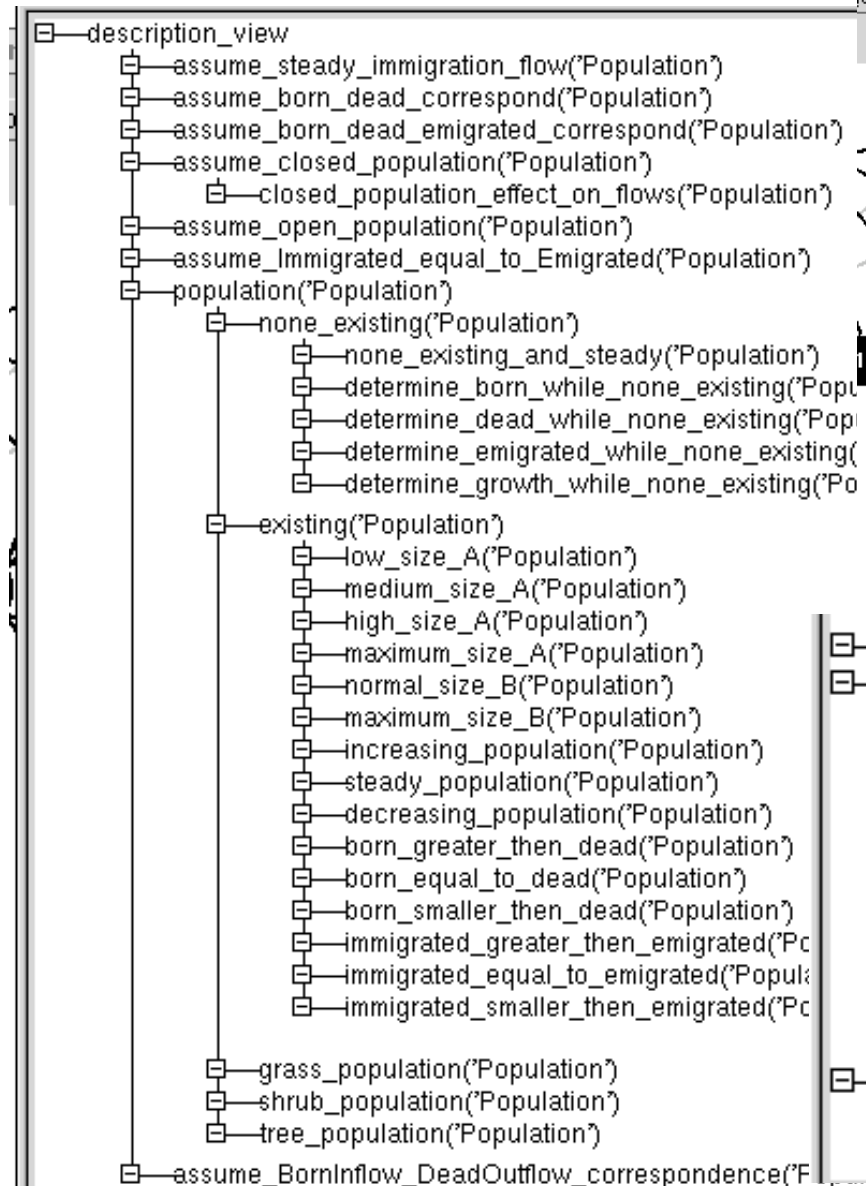
Moreira, A. (1992) *Fire Protection and Vegetation Dynamics in the Brazilian Cerrado*. PhD thesis, Cambridge, Mass, Harvard University.



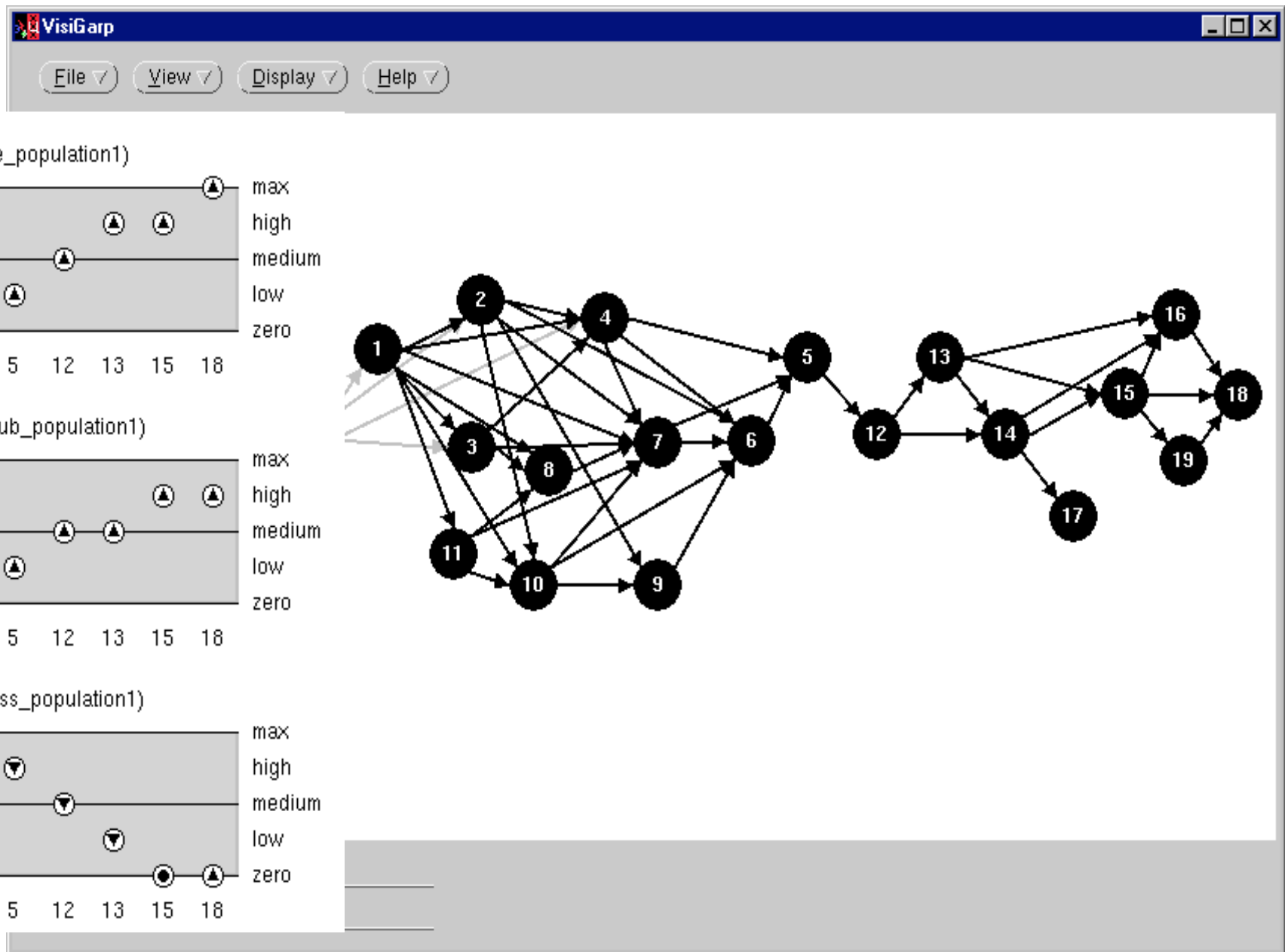
Cerrado types



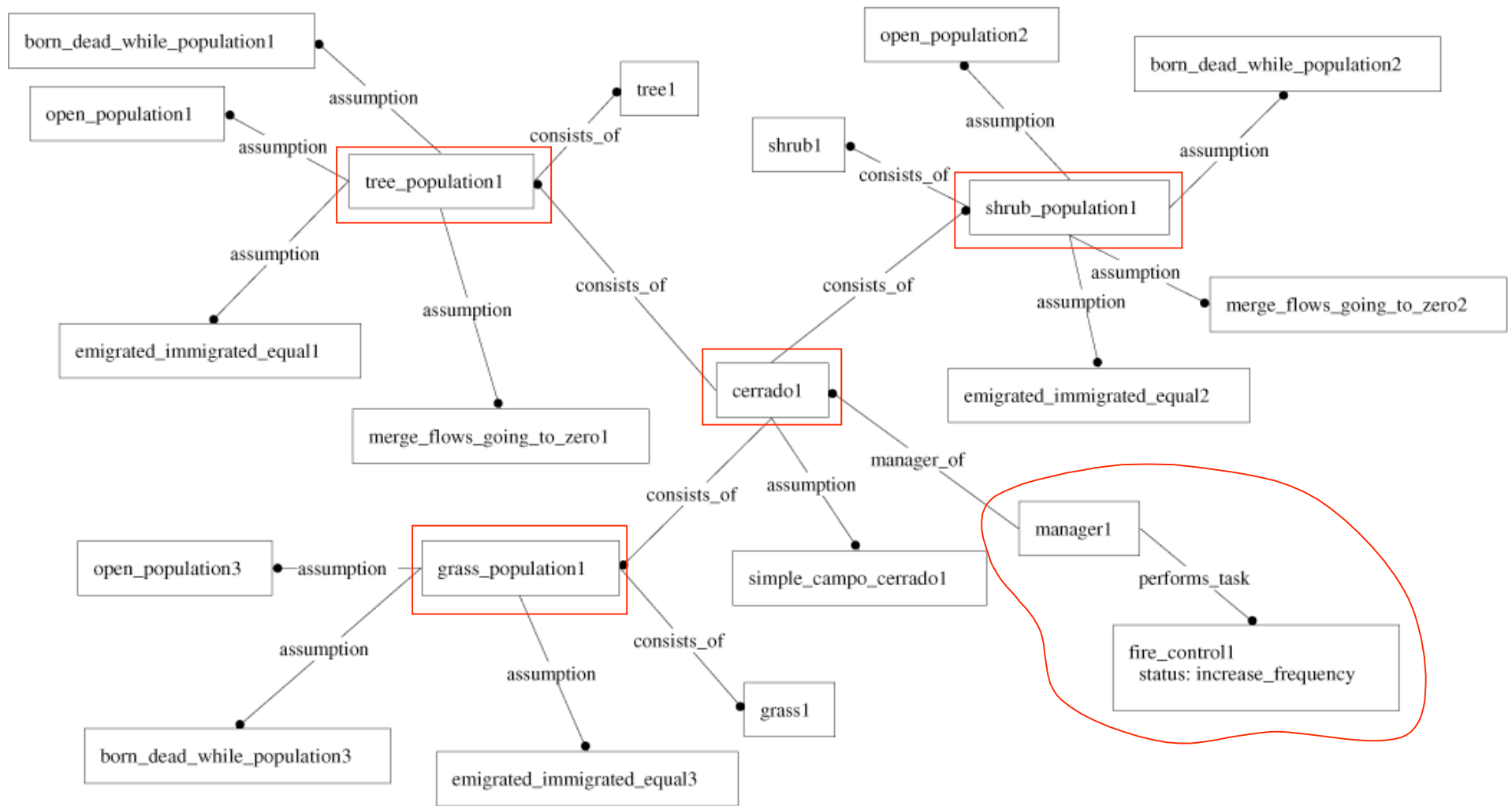
Cerrado Succession Hypothesis



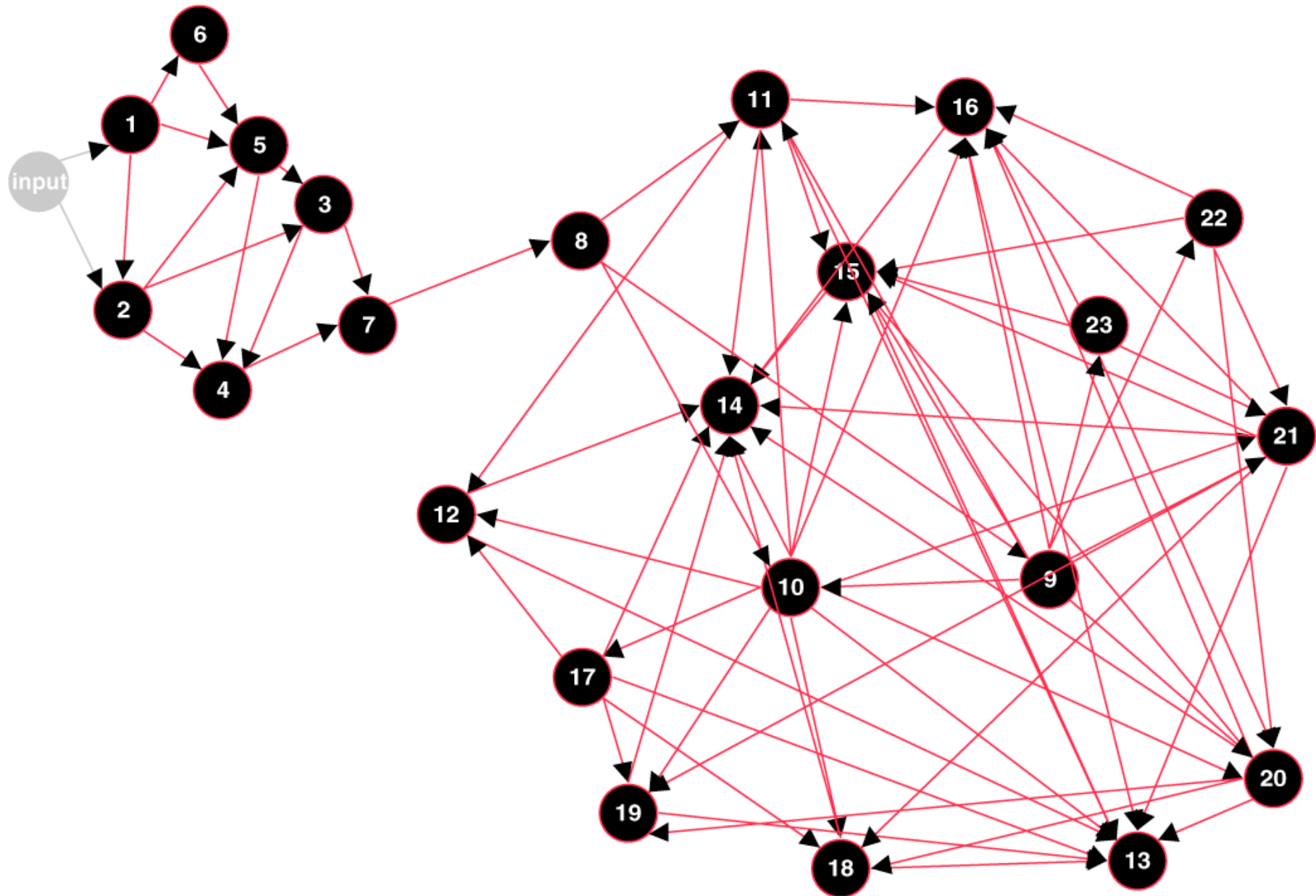
CSH - Typical simulation



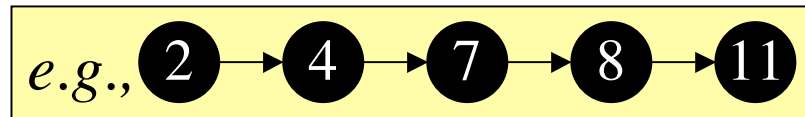
CSH - structure model



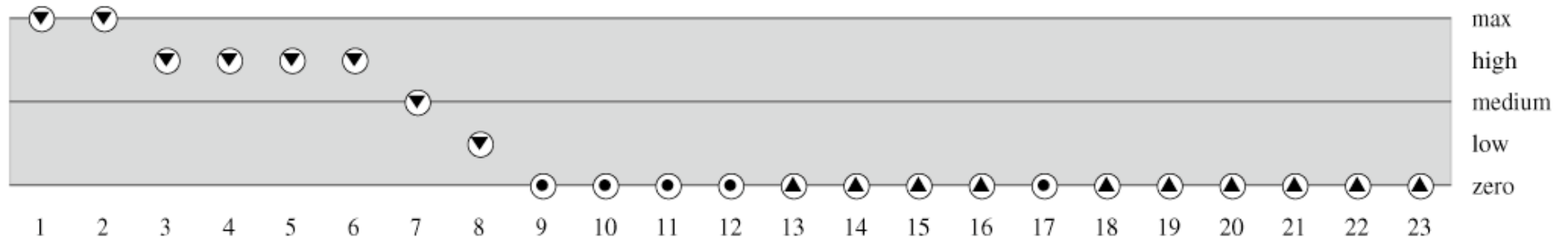
CSH - starting in Cerradão *(bad management)*



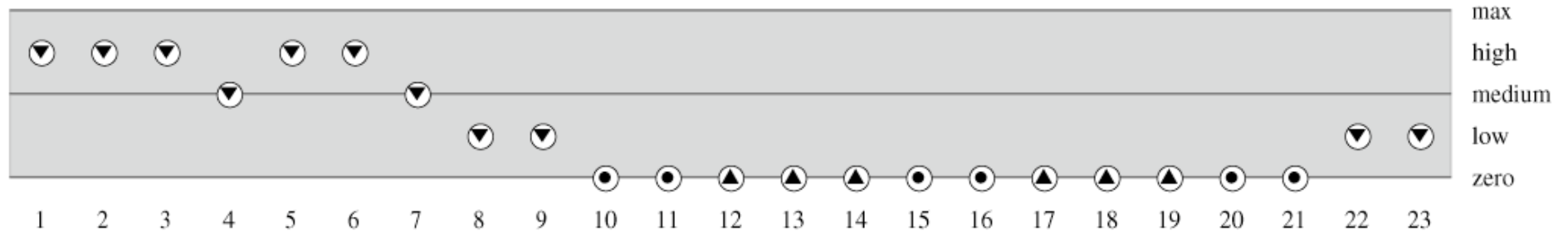
CSH - Value history *(bad management)*



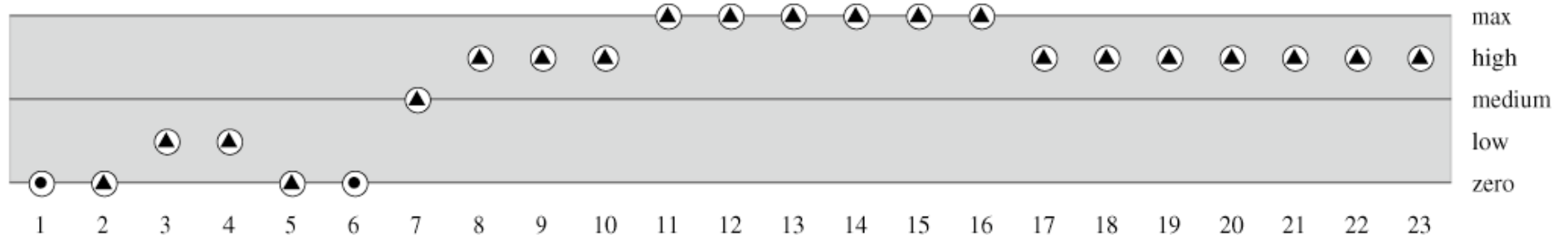
number_of1(tree_population1)



number_of2(shrub_population1)



number_of3(grass_population1)



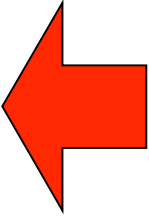
Size and Complexity...

- Library has currently a 120 MFs and a 100 scenario's

Considering e.g. state 12 of the CSH simulation

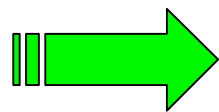
- It consist of 61 MFs (*incl. 18 processes MFs & 1 agent MF*)
- 20 entities, associated with 32 quantities
- Quantities are constrained by 127 different relations.
 - 39 inequality relations among quantity values
 - 13 inequalities between derivatives of quantities.
 - 16 correspondences
 - 16 direct influences on quantities
 - 43 indirect influences via qualitative proportionalities.

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Concluding remarks...

- Modelling is an important activity to understand systems structure and their behaviour;
- Using only qualitative representations of relevant concepts it is possible to build models and simulations about complex ecological systems;
- Explicit representation of causal relations and other features facilitate communication between modellers and users.



*QR is a promising approach
to ecological modelling!*

Ongoing research

- Building models about more complex interactions between populations (>3)
- Models for ‘water management support’
(water cycle, global heating, river continuum concept, ...)
- Model building methodology
& collaborative model building
- Applications in education and training

