Environmental model of Giant Panda population in Chengdu Research Base of Giant Panda Breeding

A tool for supporting decision making based on information

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1 Problem identification and specification

1.1 Model purpose

A model is a simplification of the reality that is constructed to gain some insights about a particular system.

The model presented in this document is aimed to provide an integrated view of the processes related to Giant Panda individuals in the Giant Panda Breeding Base (GPBB for short) of Chengdu, enabling the study the population dynamics of the species under different conditions.

The purposes of a model of this kind can be categorized in the following way:

- Diagnosis: analyze and assess what happened, examining the causes and precursor conditions of some known present or past facts or events.
- Prediction: simulate the behavior of the system under possible future scenarios of interest for the experts, in order to study possible responses to potential future events affecting the species

Whether or not applied to current/past conditions of potential future circumstances, models play an important role in environmental management. They can provide an important tool to analyze environmental and human action related to possible events and their consequences, thus characterizing situations that cannot be empirically studied (obviously, we are not going to, for instance, produce some disease, a lack of food, changes in the air quality, alterations in mortality rates or climatic fluctuations in the real life to check the response of the system under those potential scenarios).

Environmental models can be a useful source of integrated information for decision makers [9]. As they can simultaneously consider many objectives and factors, they effectively provide a tool for assisting decision making based on more integrated information and studies coming from the simulation of possible scenarios. Moreover, working with these models prevents taking blind decisions, which possibly can negatively affect the dynamics of the systems under study.

As stated above, in this document we will deal with a first proposed version of a model which main goal is the study of the population dynamics of the Giant Panda in the Chengdu Research Base of Giant Panda Breeding, including the main processes and factors involved in the biology of the species (births, growth, feeding, mortality, etc.) and phenomena derived from GPBB activity (rescues, rents, etc.). We will show the context where the proposed model can be applied, the description of the processes under analysis, the details of the model and its associated simulation tools, the evaluation and validation of this first version and its results and, finally, the applicability of the model to support decision making.

1.2 Modeling context

The spatial environment studied in the presented model is focused on the Chengdu Research Base of Giant Panda Breeding, including the data about the population of Giant Pandas in Chengdu Zoological Garden and those who were born in GPBB but are living outside of GPBB.

The statistical data needed to estimate parameters (such as mortality rates, average number of new births, number of rescued individuals per year) were provided by the Breeding Base, providing these data for the individuals from 2005 to 2014 in the same group mentioned above. That is, the parameters used were extracted from the same sample that will be used for validation. These parameters could be considered somehow over-adjusted, too linked with the specific scenario to study.

Some historical tables were available, collecting information for every Giant Panda in the total captive population (that is, including every Giant Panda spread over zoos and centers over the world) since the moment of the base creation, in 1987, to 2013. These data were more stable and less over-adjusted to provide average values we can trust in. However, the analysis of the current data about more recent years in the specific area under study showed a significant difference in the data and the behavior between the historical general data and the current specific ones. For instance, mortality rates of 27% and 34% were provided by historical tables for individuals in their first year (age 0), for females and males respectively, while the more recent data, specific for the area under study, show rates below 5% and below 10%, respectively. This difference is somehow reasonable, given the improvement in the care of the babes, due to medical, technological and infrastructure reasons, along the years, leading to a decreasing mortality rate. The model is obviously very sensitive to this kind of parameters, so the accuracy of this data respect to the current specific data was considered crucial, even when possibly producing some over-adjustment.

Once the model was developed, real data about population of panda per gender and age were provided, for the living individuals in the studied area at the end of 2005. Thus, the corresponding simulations could be performed, covering a period of time from 2006 to 2014, and then the output of the simulations could be validated by contrast with these real data.

The model studies population dynamics of the Giant Panda species in captivity, taking into account the factors involved in the evolution of the species in this particular situation. However, further study should be conducted in order to adapt such model to expand its scope to cover the wild environment. This would require the study of additional processes involved in the population dynamics of wild individuals, maybe affected by different threats, feeding problems, competitors, diseases, lower life expectancy, etc.

Despite not considering wild environments, this first model could yet be useful for the managers of the GPBB to analyze past events or consider possible future scenarios of interest, by means of the simulation of the system under different conditions and subsequently reviewing the expected output in terms of population dynamics.

With respect to the input of the model, population of males and female pandas per age is required, also providing the possibility of changing the parameters affecting average births, mortality rates, number or distribution of rescued individuals, etc.

Section 2 covers the model general description and specific details. Modeled processes are explained, along with the model theoretical inspiration and background.

In order to evaluate the reliability of the model and its consistency with the phenomena under study, the model evaluation is shown in section 3. The experimental validation is performed by contrast between simulation and real data. Furthermore, some uncertainty and sensitivity analysis are provided, studying the influence of the variability of some input parameters in the output.

2 Model development

2.1 Conceptual model

The processes under study are intrinsically stochastic, presenting an inherent non determinism due to the natural variability of the parameters involved and the many factors affecting the health of individuals, mortality and biological phenomena in general. Most of these processes are commonly considered probabilistic, with parameters following some probabilistic density function.

The attention will be centered in the study of the population dynamics, showing the evolution in the number of males and females per age, from an initial population provided by the manager (end user of the model and simulation environment), analyzing a real present/past scenario or a hypothetical future one, by simulating the behavior of the system under study making use of the provided model and data. The model presents a cyclic structure, corresponding each cycle with the course of a natural year.

The main processes/modules included in the present model are the following:

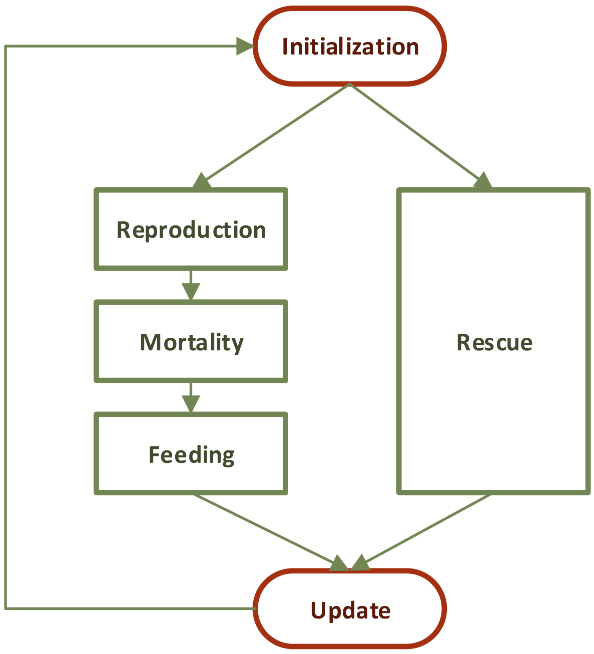
- **Reproduction**: every year a number of new individuals are born in the Breeding Base and other centers coordinated from there. The number of new individuals per year presents a strong variance, from 2 individuals per sex to a number close to 9. In addition, this number is not correlated to the number of total individuals in reproductive age, so an average number of males and females is taken as a reference instead of a fertility ratio. This fact is probably derived from the controlled nature of the studied system, since in general in wild environmental models for animals, the number of new births is correlated with natural factors as the fertility ratio, the number of individuals in fertile age, the probability to meet depending on the surface, etc. In a later model these or other factors could be considered. The natural growth of the individuals in the population is trivially modelled by increasing the age of the individuals when not affected by diseases or natural facts producing their death.

- **Mortality**: different factors influence the mortality of the individuals in the population, but in a captive environment these are mainly under control. However, as any species, Giant Panda has natural factors conditioning its maximum life expectancy, and different mortality ratios depending on the age of the individual. Historical data has been provided, thus permitting statistical data analysis to get curated data for the model. As explained in the previous section, the local data from 2005 to 2014 in GPBB and the studied area were preferred to the global historical data from 1987 about the whole population of captive individuals around the world.

- **Feeding**: every Giant Panda has some feeding needs along the year, mainly bamboo, bamboo shoots and other minor sources of food (i.e. apples, meat and milk). An average need of food is considered per individual, taking into account that these needs are different in different groups of age. The system should provide the necessary amount of food for the living individuals, which seems to be guaranteed in the captive environment in Chengdu Breeding Base and controlled zoos but could not be guaranteed in wild environment.

- **Rescue**: the total number of Giant Pandas per age can evolve not only by the births and deaths of individuals; it can also be influenced by the rescue of new individuals increasing the population of the GPBB. This number presents a big natural variability among different years, but it was historically inside a range from a minimum to a maximum number of rescued individuals. Based on a series of real data from Breeding Base, the average and variance in the total number of rescued individuals has been obtained, and the model simulates the rescue of individuals following this normal probability density distribution. In addition, there exists a historical proportion of rescued individuals per gender, and the age of the rescued Giant Pandas is not random, it follows a distribution. All these factors are considered in the model, along with the fact that the lifespan of wild individuals is significantly smaller than in captive individuals (20-25 instead of 34-36), so a proportional increase in the age of the rescued individuals is simulated depending on the years the individual lived in the wild environment.

In what follows, the conceptual schema is depicted showing the main processes involved in the model, adding some needed initialization and update modules to the natural processes, in order to synchronize and prepare for the next cycle.



2.2 Computational model development

This section describes the details of the model presented in this document. There are several different frameworks that can be used for modelling environmental phenomena, each one with its own features making them a better or worse choice depending on the nature of the processes under study, the required level of detail, the goal of the model and other factors.

As indicated above, in the present work some inherently stochastic process and factors are involved. Besides, a small number of individuals are involved in natural terms (tens to few hundred individuals, not millions or hundreds of thousands ones), so a modelling framework based on individuals, discrete elements instead of classical models based on differential equations, could be a good choice, given they have some known problems when dealing with a small number of individuals. Our work is based on a bioinspired computing modelling framework called Population Dynamics P Systems (PDP systems, for short), a variant of P systems, that in addition to discrete elements present a probabilistic dynamics coming from the probabilities embedded in the rules defining their behavior (see [4, 5, 6] for details).

Apart from the soundness of the framework for dealing with the nature of the processes we aim to model, it presents some desirable features in the context of our study. Among other features, this framework has some qualitative advantages with respect to the differential equations approach. For instance, it is characterized by its modularity in such a way that once a initial version of the model is designed, the introduction of new features, processes, parameters, etc. abstracted from the reality implies a small change in the model, which makes it quite different from other modelling frameworks where small changes in the phenomena under study frequently involves reformulating many pre-design formulas or elements in the model. In the case of PDP systems, this introduction of new elements of variations over previous ones usually involves really small changes.

This feature is very interesting in a context where many uncertainties take place, coming from the inner variability in parameters, changing environmental conditions, data uncertainty derived from possible measurement errors or deviations producing analytical imprecision, small sample size to extract statistical data, lack of knowledge about natural processes or increase of the knowledge year by year, etc. These and many other factors point towards the interest in using frameworks flexible enough to allow the progressive inclusion or variation of elements in the model while increasing the knowledge in the research center about data and processes involved.

2.2.1 Model definition

Next pages show the model, including some notations, the parameters involved, the symbols used in the model, and then the syntax and semantics of the model, following PDP systems schema.

Notations:

Related with Giant Pandas (for male $i = 1$, for female $i = 2$):

- $k_{i,1}$: age at which subadult size is reached.
- $k_{i,2}$: age at which youth adult size is reached.
- $k_{i,3}$: age at which mid-adult size is reached.
- $k_{i,4,1}$: age at which elderly (from 17 to 26) size is reached ($k_{i,4,1} = 17$).
- $k_{i,4,2}$: age at which elderly (from 27 to 35) size is reached ($k_{i,4,2} = 27$).
- $k_{i,5}$: maximum life expectancy in the ecosystem under feeding conditions.

- $k_{i,6}$: mortality ratio in infancy giant pandas.
- $k_{i,7}$: mortality ratio in subadult giant pandas.
- $k_{i,8}$: mortality ratio in youth adult giant pandas.
- $k_{i,9}$: mortality ratio in mid-adult giant pandas.
- $k_{i,10}$: mortality ratio in elderly (from 17 to 26) giant pandas.
- $k_{i,11}$: mortality ratio in elderly (from 27 to 35) giant pandas.
- g_1: number of male descendants per year.
- g_2: number of female descendants per year.
- g_3: amount of bamboo shoots supplied in the GPBB (kg) during a year.
- g_4: amount of bamboo supplied in the GPBB (kg) during a year.
- g_5: amount of other food (i.e. apple, meat, milk) supplied in the GPBB (kg) during a year.
- $f_{i,1}$: amount of bamboo shoots necessary per year (kg) according to the energetic requirements of the infancy giant pandas.
- $f_{i,2}$: amount of bamboo necessary per year (kg) according to the energetic requirements of the infancy giant pandas.
- $f_{i,3}$: amount of other foods necessary per year (kg) according to the energetic requirements of the infancy giant pandas.
- $f_{i,4}$: amount of bamboo shoots necessary per year (kg) according to the energetic requirements of the subadult giant pandas.
- $f_{i,5}$: amount of bamboo necessary per year (kg) according to the energetic requirements of the subadult giant pandas.
- $f_{i,6}$: amount of other foods necessary per year (kg) according to the energetic requirements of the subadult giant pandas.
- $f_{i,7}$: amount of bamboo shoots necessary per year (kg) according to the energetic requirements of the adult and elderly giant pandas.
- $f_{i,8}$: amount of bamboo necessary per year (kg) according to the energetic requirements of the adult and elderly giant pandas.

- $f_{i,9}$: amount of other foods necessary per year (kg) according to the energetic requirements of the adult and elderly giant pandas.

- $cmin$: minimum number of rescued giant pandas per year.

- $cmax$: maximum number of rescued giant pandas per year.

- $cmaxage$: maximum age of rescued giant pandas.

- pc_c: probability to have c rescued individuals.

- pg_i: probability for rescued individuals to have gender i.

- pa_j: probability for rescued individuals to have age j.

Symbols in the model (for male $i = 1$, for female $i = 2$):

- $q_{i,j}$: the number of giant pandas of age j.

- $X_{i,j}$: individuals of age j before reproduction module.

- $Y_{i,j}$: individuals of age j within mortality module.

- $Z_{i,j}$: survived individuals of age j.

- $W_{i,j}$: individuals of age j after feeding module.

- $C_{i,j}$: rescued individuals of "age" j.

- S: bamboo shoots.

- B: bamboo.

- O: other food.

- F: auxiliary object to generate new quantity of food at the beginning of each time cycle.

- N: auxiliary object to generate newborns when beginning each time cycle.

- A: auxiliary object to trigger the rescue

Membrane structure

$\mu = [\ [\ ]_2\ ]_1$

Initial multisets

$\mathcal{M}_1 = \{X_{i,j}^{q_{i,j}} \ : \ 1 \le i \le 2,\ 1 \le j \le k_{i,5}\}, \quad \mathcal{M}_2 = \{F\ N\ A\}.$

Sets of rules

Initialization rule

- Generation of objects associated with the food:

$$r_1 \equiv [\, F \,]_2^0 \longrightarrow F \; [\, S^{g_3} \; B^{g_4} \; O^{g_5} \,]_2^+,$$

Reproduction rules

- Rules associated with newborns:

$$r_2 \equiv [\, N \,]_2^0 \longrightarrow N \; [\, Y_{1,0}^{g_1} \; Y_{2,0}^{g_2} \,]_2^+,$$

- Growth rules:

$$r_3 \equiv [\, X_{i,j} \,]_2^0 \longrightarrow [\, Y_{i,j} \,]_2^+, \text{ for } \begin{cases} 1 \le i \le 2 \\ 1 \le j \le k_{i,5} \end{cases}$$

Rescued giant pandas rules

- Probability to have c rescued individuals:

$$r_4 \equiv [\, A \,]_2^0 \xrightarrow{pc_c} A \; C^c \, [\,]_2^+, \text{ for } cmin \le c \le cmax.$$

- Probability for rescued individuals to have gender i:

$$r_5 \equiv [\, C \xrightarrow{pg_i} C_i \,]_1^0, \text{ for } 1 \le i \le 2$$

- Probability for rescued individuals to have age j:

$$r_6 \equiv [\, C_i \xrightarrow{pa_j} C_{i,j+1+\lfloor \frac{j}{3} \rfloor} \,]_1^0, \text{ for } \begin{cases} 1 \le i \le 2 \\ 0 \le j < cmaxage \end{cases}$$

Mortality rules

- Infancy giant pandas that survive:

$$r_7 \equiv [\, Y_{i,j} \xrightarrow{1-k_{i,6}} Z_{i,j} \,]_2^+, \text{ for } \begin{cases} 1 \le i \le 2 \\ 0 \le j < k_{i,1} \end{cases}$$

- Infancy giant pandas that die:

$$r_8 \equiv [\, Y_{i,j} \xrightarrow{k_{i,6}} \lambda \,]_2^+, \text{ for } \begin{cases} 1 \le i \le 2 \\ 0 \le j < k_{i,1} \end{cases}$$

- Subadult giant pandas that survive:

$$r_9 \equiv [\, Y_{i,j} \xrightarrow{1-k_{i,7}} Z_{i,j} \,]_2^+, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,1} \le j < k_{i,2} \end{cases}$$

- Subadult giant pandas that die:

$$r_{10} \equiv [\, Y_{i,j} \xrightarrow{k_{i,7}} \lambda \,]_2^+, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,1} \le j < k_{i,2} \end{cases}$$

- Youth adult giant pandas that survive:

$$r_{11} \equiv [\, Y_{i,j} \xrightarrow{1-k_{i,8}} Z_{i,j} \,]_2^+, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,2} \le j < k_{i,3} \end{cases}$$

- Youth adult giant pandas that die:

$$r_{12} \equiv [\, Y_{i,j} \xrightarrow{k_{i,8}} \lambda \,]_2^+, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,2} \le j < k_{i,3} \end{cases}$$

- Mid-adult giant pandas that survive:

$$r_{13} \equiv [\, Y_{i,j} \xrightarrow{1-k_{i,9}} Z_{i,j} \,]_2^+, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,3} \le j < k_{i,4} \end{cases}$$

- Mid-adult giant pandas that die:

$$r_{14} \equiv [\, Y_{i,j} \xrightarrow{k_{i,9}} \lambda \,]_2^+, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,3} \le j < k_{i,4} \end{cases}$$

- Elderly (from 17 to 26) giant pandas that survive:

$$r_{15} \equiv [\, Y_{i,j} \xrightarrow{1-k_{i,10}} Z_{i,j} \,]_2^+, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,4,1} \le j < k_{i,4,2} \end{cases}$$

- Elderly (from 17 to 26) giant pandas that die:

$$r_{16} \equiv [\, Y_{i,j} \xrightarrow{k_{i,10}} \lambda \,]_2^+, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,4,1} \le j < k_{i,4,2} \end{cases}$$

- Elderly (from 27 to 35) giant pandas that survive:

$$r_{17} \equiv [\, Y_{i,j} \stackrel{1-k_{i,11}}{\longrightarrow} Z_{i,j} \,]_2^+, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,4,2} \le j < k_{i,5} \end{cases}$$

- Elderly (from 27 to 35) giant pandas that die:

$$r_{18} \equiv [\, Y_{i,j} \stackrel{k_{i,11}}{\longrightarrow} \lambda \,]_2^+, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,4,2} \le j < k_{i,5} \end{cases}$$

- Giant pandas which reach the maximum life expectancy:

$$r_{19} \equiv [\, Y_{i,k_{i,5}} \longrightarrow \lambda \,]_2^+, \text{ for } 1 \le i \le 2$$

Feeding rules

- Feeding process for infancy giant pandas:

$$r_{20} \equiv [\, Z_{i,j} \; S^{f_{i,1}} \; B^{f_{i,2}} \; O^{f_{i,3}} \,]_2^+ \longrightarrow [\, W_{i,j} \,]_2^0, \text{ for } \begin{cases} 1 \le i \le 2 \\ 0 \le j < k_{i,1} \end{cases}$$

- Feeding process for subadult giant pandas:

$$r_{21} \equiv [\, Z_{i,j} \; S^{f_{i,4}} \; B^{f_{i,5}} \; O^{f_{i,6}} \,]_2^+ \longrightarrow [\, W_{i,j} \,]_2^0, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,1} \le j < k_{i,2} \end{cases}$$

- Feeding process for adult and elderly giant pandas:

$$r_{22} \equiv [\, Z_{i,j} \; S^{f_{i,7}} \; B^{f_{i,8}} \; O^{f_{i,9}} \,]_2^+ \longrightarrow [\, W_{i,j} \,]_2^0, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,2} \le j < k_{i,5} \end{cases}$$

Updating rules

- Removal of the remaining food.

$$r_{23} \equiv [\, S \longrightarrow \lambda]_2^0$$
$$r_{24} \equiv [\, B \longrightarrow \lambda]_2^0$$
$$r_{25} \equiv [\, O \longrightarrow \lambda]_2^0$$

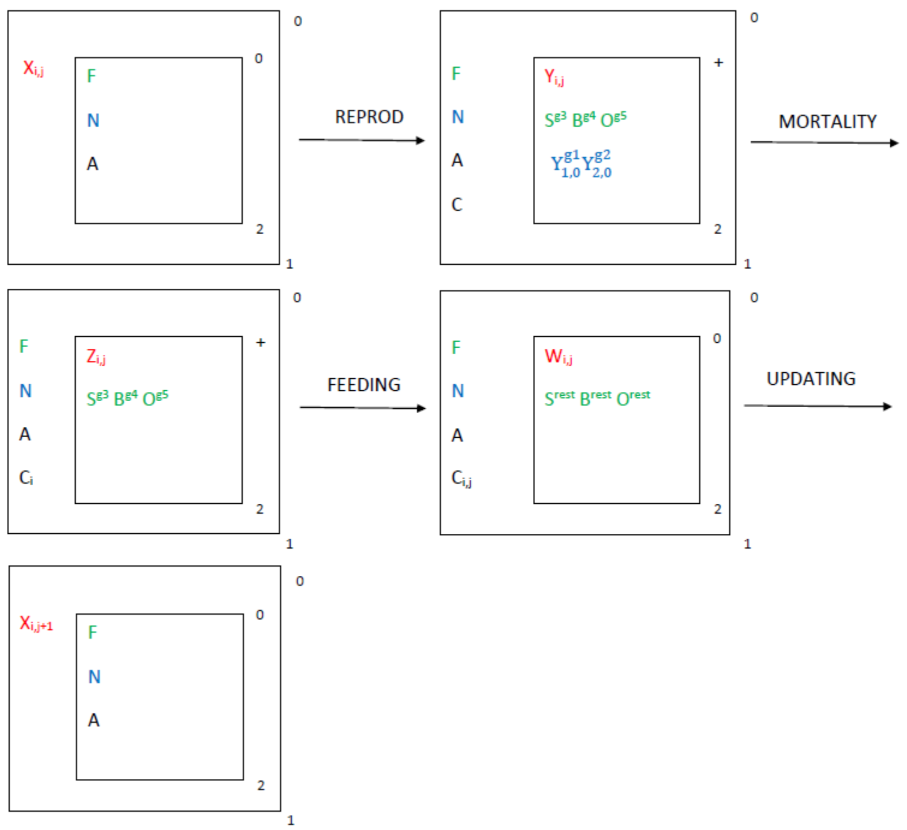
- Preparation for the beginning of a new cycle.

$$r_{26} \equiv [\, W_{i,j} \,]_2^0 \longrightarrow X_{i,j+1} [\;]_2^0, \text{ for } \begin{cases} 1 \le i \le 2 \\ 0 \le j < k_{i,5} \end{cases}$$

$$r_{27} \equiv F \; [\;\;]_2^0 \longrightarrow [\, F \,]_2^0,$$

$$
\begin{aligned}
r_{28} &\equiv C_{i,j}\ [\ ]_2^0 \longrightarrow X_{i,j+1}\ [\ ]_2^0, \text{ for } \begin{cases} 1 \le i \le 2 \\ 0 \le j < k_{i,5} \end{cases} \\
r_{29} &\equiv N\ [\ ]_2^0 \longrightarrow [N\ ]_2^0, \\
r_{30} &\equiv A\ [\ ]_2^0 \longrightarrow [A\ ]_2^0,
\end{aligned}
$$

This is the formalization of the model based on PDP systems. "Notations" section lists the parameters the user can interact with in order to make virtual experiments to study the evolution of the system under different scenarios of interest. The evolution of the elements in the system for a single cycle of simulation is as follows:

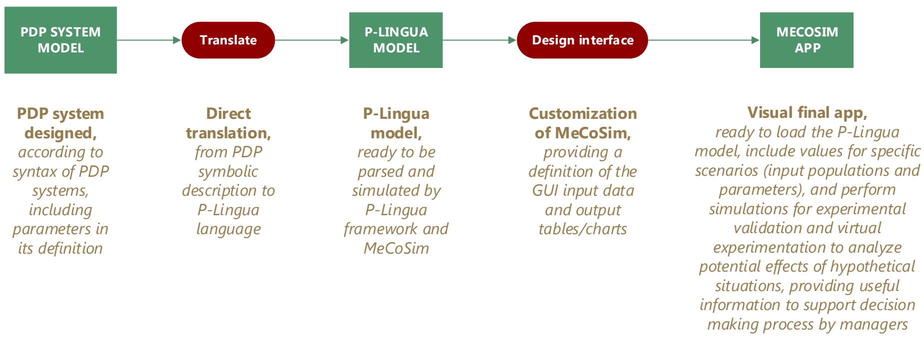


2.2.2 Software application development

The intended use of the model presented in this work is to provide useful information to support decision making process by managers of the system under study, by means of appropriate tools allowing the formulation of potential scenarios and the analysis of the expected results from the model, thus anticipating the possible effects of the actions studied by managers.

The final tool should be a visual environment usable for managers, probably not interested in technical details of the model and the software but in providing data about each potential scenario, population, parameters, actions, etc. and in analyzing the expected results of his possible actions under the given circumstances and parameters. To do so, given the description of the model described above, two simple steps are needed taking with the general purpose tools available.

The process is outlined in the following diagram:



In general, the process to convert the design of a model in an effective tool to support decision making may result quite tedious. Fortunately, when working with P systems we do not need to develop ad-hoc programs to perform the related tasks.

There exist general purpose tools, in the framework of PDP systems, that dramatically eases that part of the conventional process when a manager needs model based software tools to use the model for making decisions (not only having the model to present it in a conference or journal). In this sense, P-Lingua language and framework [7, 2] provide a general purpose language very close to the natural definition of the model presented above, along with simulation engines for many variants of P systems. In addition, MeCoSim [8, 1] provides a visual environment allowing the **definition** of **custom** software **applications** for working with models based on P systems, including visual tools to:

- Load P-Lingua models and parse them, by using MeCoSim visual environment and P-Lingua framework parsers.
- Enter input data and parameters for scenarios of interest, by using the input tables defined in MeCoSim custom app config file.
- Debug a model and its data for the given scenario, by collecting data from MeCoSim input tables, converting them into parameters for P-Lingua model and parsing the composed "data+model" file by using P-Lingua framework parsers.
- Perform simulations for the loaded model and scenario, by using P-Lingua framework simulation engines (or external simulators) for the given model.
- Provide custom output tables and charts showing the evolution of the population resulting from the simulation of the model for the given values for input populations and parameters.

Thus, the translation from the syntax shown above to P-Lingua code is pretty straightforward. P-Lingua code for the work presented here is shown next:

```
@model<probabilistic>

def main()
{
    call init_membrane_structure();
    call init_multisets();
    call init_rules();
}

def init_membrane_structure()
{
    @mu= [[[[]'2]'1]'101,101]'0;
}

def init_multisets()
{
    @ms(1) += X{i,j}*q{i,j} : 1<=j<=k{i,5},1<=i<=2;
    @ms(2) = F,N,A;
}

def init_rules()
{
    /*** <Initialization> ***/
        /*Generation of objects associated with the food*/
        /* r1 */  [F]'2 --> F+[S*g{3},B*g{4},O*g{5}]'2  :: 1;
    /*** <End Initialization> ***/

    /*** <Reproduction> ***/
        /*Rules associated with newborns*/
        /* r2 */  [N]'2 --> N +[ Y{1,0}*g{1}, Y{2,0}*g{2} ]'2  :: 1;

        /*Growth rules*/
```

```
    /* r3 */  X{i,j} [ ]'2 --> +[ Y{i,j} ]'2  :: 1 : 1<=j<=k{i,5}, 1<=i<=2;
/*** <End Reproduction> ***/

/*** <Rescue> ***/
    /* 1- New rescued individuals.
    pc{c}: probability to have c rescued individuals. It
           is considered a normal distribution with mean 2,78,
           deviation 2,20 and values 0 to 10 summing 1. */
    /* r4 */  [A]'2 --> A,C*c+[]'2 :: pc{c} : cmin<=c<=cmax;

    /* 2- Gender assignment.
    pg{i}: probability for a rescued individual to have gender i.*/
    /* r5 */  [C]'1 --> [C{i}]'1 :: pg{i} : 1<=i<=2;

    /* 3- Age assignment.
    pa{j}: probability for a rescued individual to have
           age j. Different groups of ages were considered, with
           probabilities "pag" 0.5, 0.5, 0 and 0, and
           inside each group the probability is considered
           uniform, so for an individual age inside the group the
           probability is pa = (pag/nag), being nag the number of
           elements in the group. We introduce the pag's and
           nag's in a table, thus being pa calculated from
           them.*/
    /* r6 */  [C{i}]'1 --> [C{i,j+1+@floor(j/3)}]'1 :: pa{j} : 0<=j<cmaxage, 1<=i<= 2;
/*** <End Rescue> ***/

/*** <Mortality> ***/
    /*Infancy giant pandas that survive */
    /* r7 */  +[Y{i,j}]'2 --> +[Z{i,j}]'2  :: 1-k{i,6} : 0<=j<k{i,1}, 1<=i<=2;
    /*Infancy giant pandas that die */
    /* r8 */  +[Y{i,j}]'2 --> +[]'2  :: k{i,6} : 0<=j<k{i,1}, 1<=i<=2;

    /*Sub-adult giant pandas that survive */
    /* r9 */  +[Y{i,j}]'2 --> +[Z{i,j}]'2  :: 1-k{i,7} : k{i,1}<=j<k{i,2}, 1<=i<=2;
    /*Sub-adult giant pandas that die */
    /* r10 */ +[Y{i,j}]'2 --> +[ ]'2  :: k{i,7} : k{i,1}<=j<k{i,2}, 1<=i<=2;

    /*Youth adult giant pandas that survive */
    /* r11 */ +[Y{i,j}]'2 --> +[Z{i,j}]'2  :: 1-k{i,8} : k{i,2}<=j<k{i,3}, 1<=i<=2;
    /*Youth adult giant pandas that die */
    /* r12 */ +[Y{i,j}]'2 --> +[ ]'2  :: k{i,8} : k{i,2}<=j<k{i,3}, 1<=i<=2;

    /*Mid-adult giant pandas that survive */
    /* r13 */ +[Y{i,j}]'2 --> +[Z{i,j}]'2  :: 1-k{i,9} : k{i,3}<=j<k{i,4,1}, 1<=i<=2;
    /*Mid-adult giant pandas that die */
    /* r14 */ +[Y{i,j}]'2 --> +[ ]'2  :: k{i,9} : k{i,3}<=j<k{i,4,1}, 1<=i<=2;

    /*Elderly giant pandas (from k{i,4,1} to k{i,4,2}-1) that survive*/
    /* r15 */ +[Y{i,j}]'2 --> +[Z{i,j}]'2  :: 1-k{i,10} : k{i,4,1}<=j<k{i,4,2}, 1<=i<=2;
    /*Elderly giant pandas (from k{i,4,1} to k{i,4,2}-1) that die*/
    /* r16 */ +[Y{i,j}]'2 --> +[ ]'2  :: k{i,10} : k{i,4,1}<=j<k{i,4,2}, 1<=i<=2;

    /*Elderly giant pandas (from k{i,4,2} to k{i,5}-1) that survive*/
    /* r17 */ +[Y{i,j}]'2 --> +[Z{i,j}]'2  :: 1-k{i,11} : k{i,4,2}<=j<k{i,5}, 1<=i<=2;
    /*Elderly giant pandas (from k{i,4,2} to k{i,5}-1) that die*/
    /* r18 */ +[Y{i,j}]'2 --> +[ ]'2  :: k{i,11} : k{i,4,2}<=j<k{i,5}, 1<=i<=2;

    /*Giant pandas which reach the maximum life expectancy*/
    /* r19 */ +[Y{i,k{i,5}}]'2--> +[ ]'2  :: 1 : 1<=i<=2;
/*** <End Mortality> ***/

/*** <Feeding> ***/
    /*Feeding process for infancy giant pandas*/
    /* r20 */ +[Z{i,j},S*f{i,1},B*f{i,2},O*f{i,3}]'2--> [W{i,j}]'2  :: 1 : 0<=j<k{i,1}, 1<=i<=2;
    /*Feeding process for subadult giant pandas*/
    /* r21 */ +[Z{i,j},S*f{i,4},B*f{i,5},O*f{i,6}]'2--> [W{i,j}]'2  :: 1 : k{i,1}<=j<k{i,2}, 1<=i<=2;
```

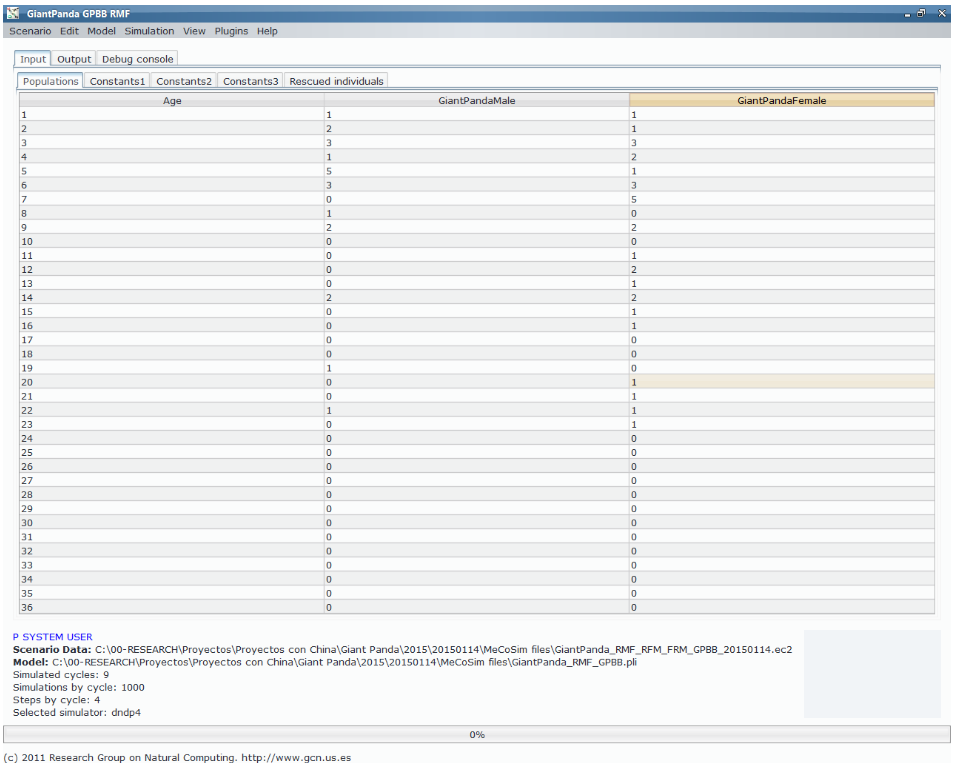
```
        /*Feeding process for adult and elderly giant pandas*/
        /* r22 */ +[Z{i,j},S*f{i,7},B*f{i,8},O*f{i,9}]'2--> [W{i,j}]'2  :: 1 : k{i,2}<=j<k{i,5}, 1<=i<=2;
    /*** <End Feeding> ***/

    /*** <Update> ***/
        /*Elimination of the remaining food*/
        /* r23 */ [S]'2 --> []'2  :: 1;
        /* r24 */ [B]'2 --> []'2  :: 1;
        /* r25 */ [O]'2 --> []'2  :: 1;

        /*Preparation for the beginning of a new cycle*/
        /* r26 */ [W{i,j}]'2 --> X{i,j+1}[]'2  :: 1 : 0<=j<k{i,5}, 1<=i<=2;
        /* r27 */ F[ ]'2 --> [F]'2  :: 1;
        /* r28 */ C{i,j}[]'2 --> X{i,j+1}[]'2  :: 1 : 0<=j<k{i,5}, 1<=i<=2;
        /* r29 */ N[ ]'2 --> [N]'2  :: 1;
        /* r30 */ A[ ]'2 --> [A]'2  :: 1;
    /*** <End Update> ***/
}
```

This model written in P-Lingua language is ready to be loaded in MeCoSim, but there are a number of parameters that will need custom input tables to be entered. The definition of a custom application based on MeCoSim involves the filling of a configuration of an `.xls` file with the following information:

- General data about the application: a name, default paths for data and model files, default number of cycles and simulations to perform, etc.
- Tabs hierarchy: tree structure to visually distribute the inputs and outputs to show to the end user, manager of the system under study.
- Input/output tables: default number of columns and rows along with the names of the columns to show. In addition, the desired output tables can be marked to generate pie, line, column and/or stacked charts.
- Simulation parameters: information about the processing of input data to generate parameters for P-Lingua model.
- Simulation results: definition of the output results to get from the whole simulation. They represent partial views of the raw data obtained from the computation of a number of simulations involving a series of cycles with a number steps, each one of them containing configurations of the systems with different elements in different parts of the system being modelled.

The simple `.xls` configuration defines the custom app to be added to MeCoSim. Once this custom app is running, it is ready to load the corresponding P-Lingua model file, and wait for the managers or any potential users to introduce specific data for each scenario under study. Some screenshots illustrate the appearance of MeCoSim Giant Panda custom app and the kind of input and output information present in its tabs.

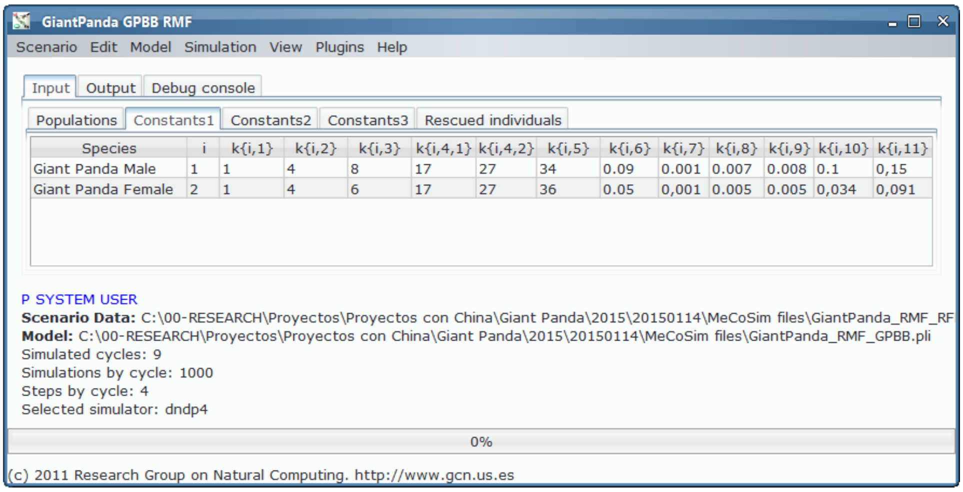
- Initial populations:

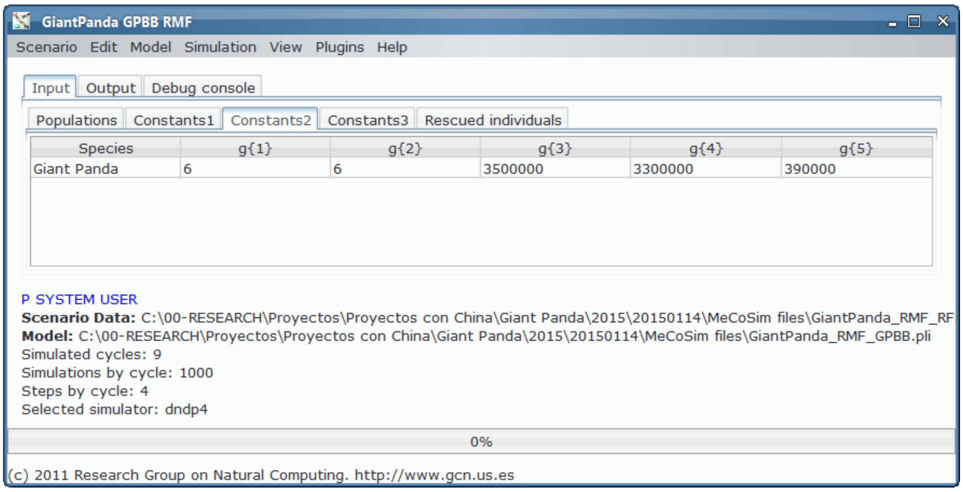


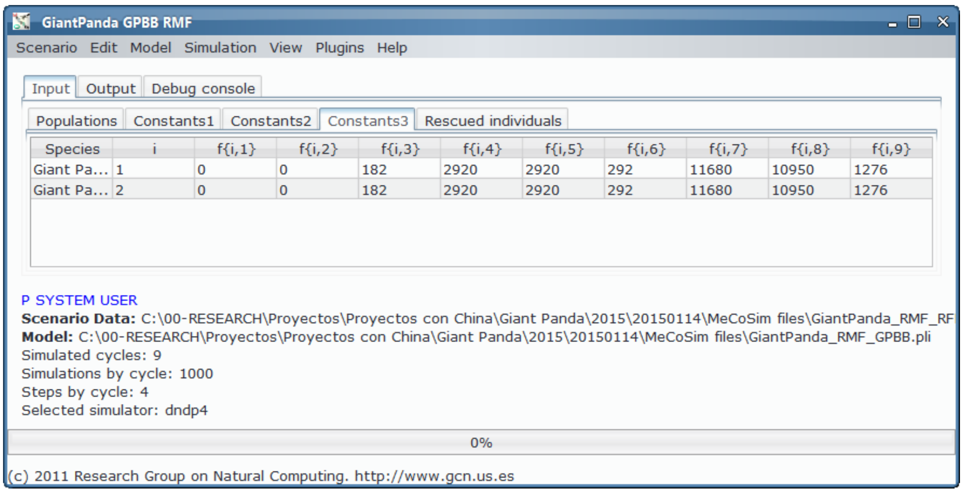
  As shown in the screenshot, the interface is divided in a series of tabs organizing the information. There exists always a Debug console tab for debugging the model, along with the desired tabs defined for the user in the configuration file tabs hierarchy explained before. In this case, two tabs, Input and Output, were defined at the top level. The remaining information is configured as children of these tabs, allowing the definition of as many number of levels as required. This first table is defined to be a direct child of the Input tab, and enables the user to introduce the number of initial male and female individuals per age.

- General parameters:

  The following screenshots show the input tables where the user can introduce the values for the different parameters involved in the model, as described at the beginning of section2.2 of this document. The header of each column is auto-explicative, given its name is the same described in the mentioned section.


GiantPanda GPBB RMF
Scenario Edit Model Simulation View Plugins Help
Input Output Debug console
Populations Constants1 Constants2 Constants3 Rescued individuals
Species i k{i,1} k{i,2} k{i,3} k{i,4,1} k{i,4,2} k{i,5} k{i,6} k{i,7} k{i,8} k{i,9} k{i,10} k{i,11}
Giant Panda Male 1 1 4 8 17 27 34 0.09 0.001 0.007 0.008 0.1 0,15
Giant Panda Female 2 1 4 6 17 27 36 0.05 0,001 0.005 0.005 0,034 0,091
P SYSTEM USER
Scenario Data: C:\00-RESEARCH\Proyectos\Proyectos con China\Giant Panda\2015\20150114\MeCoSim files\GiantPanda_RMF_RF
Model: C:\00-RESEARCH\Proyectos\Proyectos con China\Giant Panda\2015\20150114\MeCoSim files\GiantPanda_RMF_GPBB.pli
Simulated cycles: 9
Simulations by cycle: 1000
Steps by cycle: 4
Selected simulator: dndp4
0%
(c) 2011 Research Group on Natural Computing. http://www.gcn.us.es

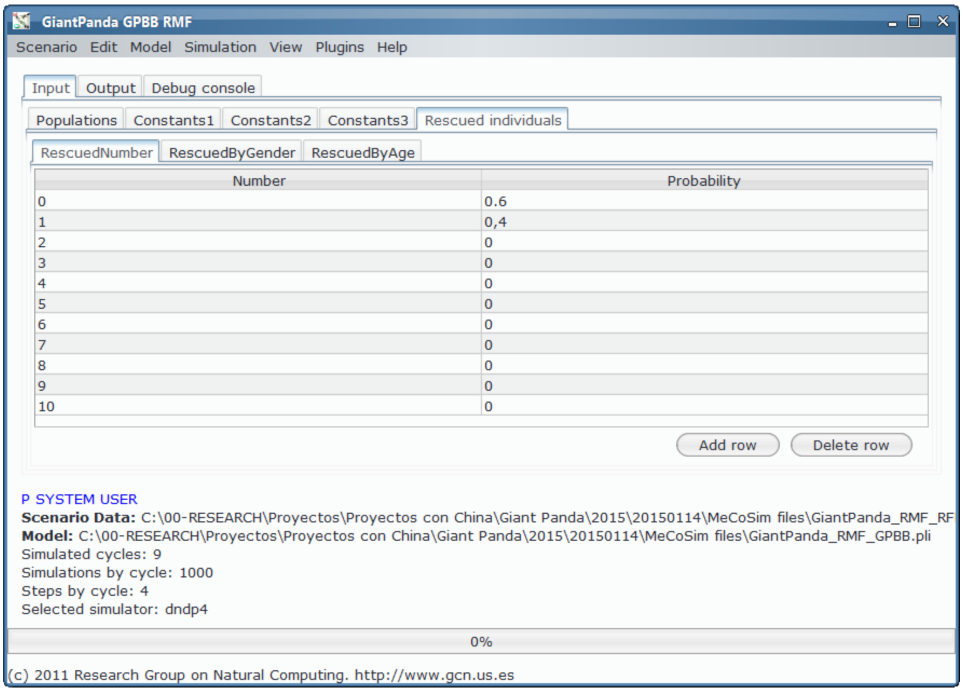

GiantPanda GPBB RMF
Scenario Edit Model Simulation View Plugins Help
Input Output Debug console
Populations Constants1 Constants2 Constants3 Rescued individuals
Species g{1} g{2} g{3} g{4} g{5}
Giant Panda 6 6 3500000 3300000 390000
P SYSTEM USER
Scenario Data: C:\00-RESEARCH\Proyectos\Proyectos con China\Giant Panda\2015\20150114\MeCoSim files\GiantPanda_RMF_RF
Model: C:\00-RESEARCH\Proyectos\Proyectos con China\Giant Panda\2015\20150114\MeCoSim files\GiantPanda_RMF_GPBB.pli
Simulated cycles: 9
Simulations by cycle: 1000
Steps by cycle: 4
Selected simulator: dndp4
0%
(c) 2011 Research Group on Natural Computing. http://www.gcn.us.es


GiantPanda GPBB RMF
Scenario Edit Model Simulation View Plugins Help
Input Output Debug console
Populations Constants1 Constants2 Constants3 Rescued individuals
Species i f{i,1} f{i,2} f{i,3} f{i,4} f{i,5} f{i,6} f{i,7} f{i,8} f{i,9}
Giant Pa… 1 0 0 182 2920 2920 292 11680 10950 1276
Giant Pa… 2 0 0 182 2920 2920 292 11680 10950 1276
P SYSTEM USER
Scenario Data: C:\00-RESEARCH\Proyectos\Proyectos con China\Giant Panda\2015\20150114\MeCoSim files\GiantPanda_RMF_RF
Model: C:\00-RESEARCH\Proyectos\Proyectos con China\Giant Panda\2015\20150114\MeCoSim files\GiantPanda_RMF_GPBB.pli
Simulated cycles: 9
Simulations by cycle: 1000
Steps by cycle: 4
Selected simulator: dndp4
0%
(c) 2011 Research Group on Natural Computing. http://www.gcn.us.es

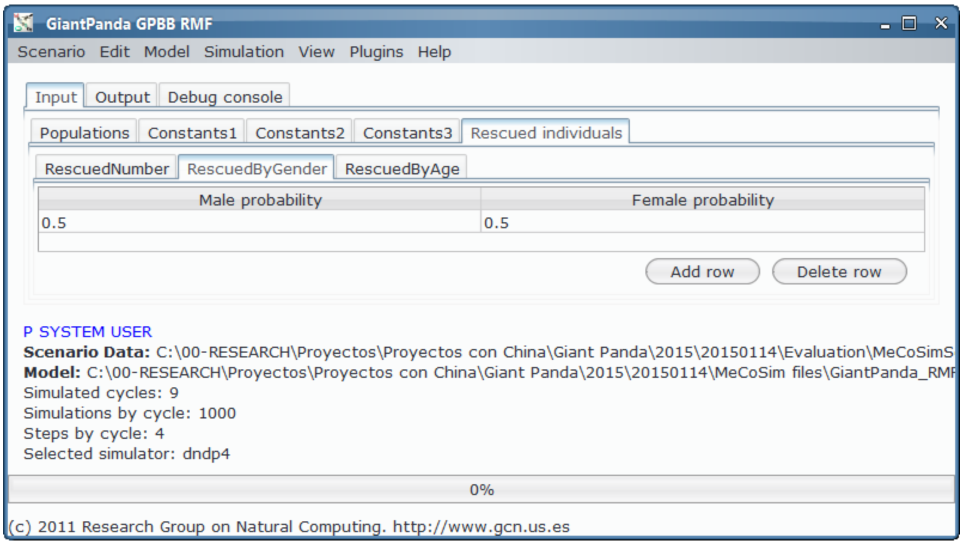
- Rescue:

  The following three tabs show the input tables to enable the user introducing parameters related to Rescue module. These tabs are:

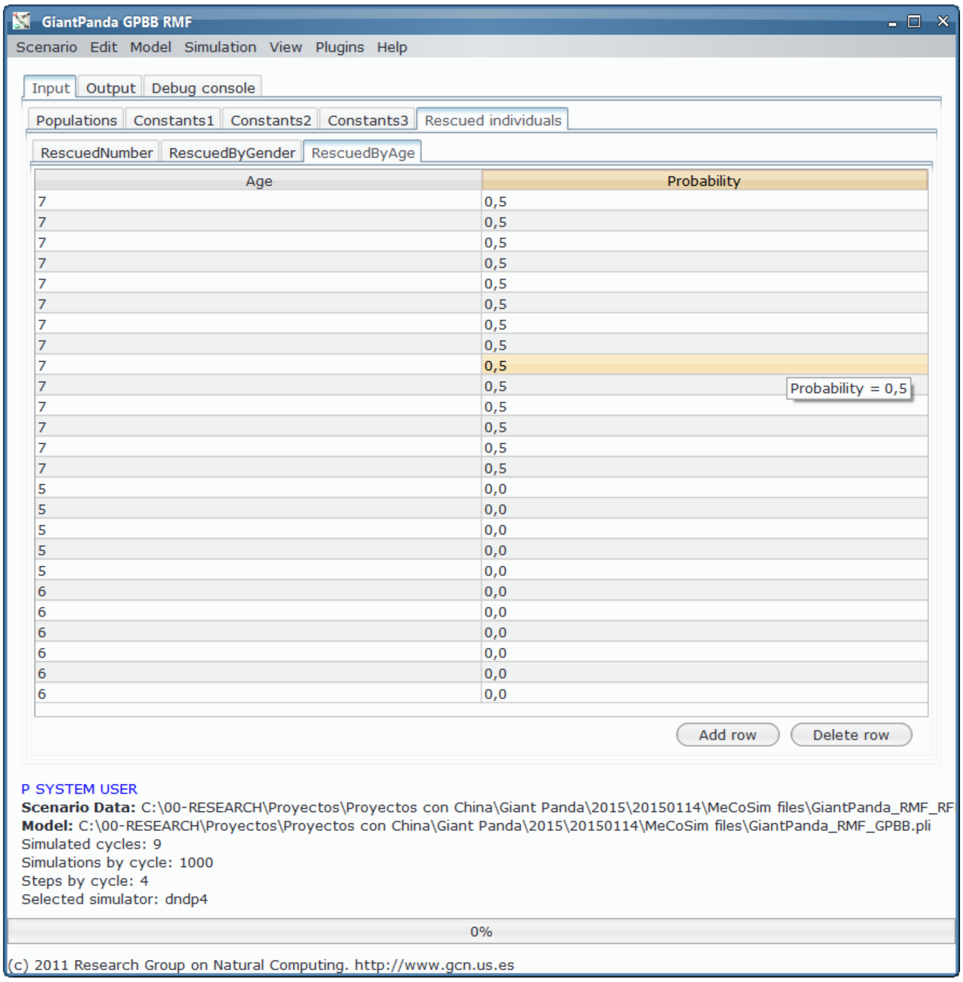
  - Rescued number: the values for probabilities of rescued individuals (default from a minimum zero to a maximum 10, following a normal distribution of probability).



– Rescued by gender: enables the modification of the probability for a rescued individual to be male or female.



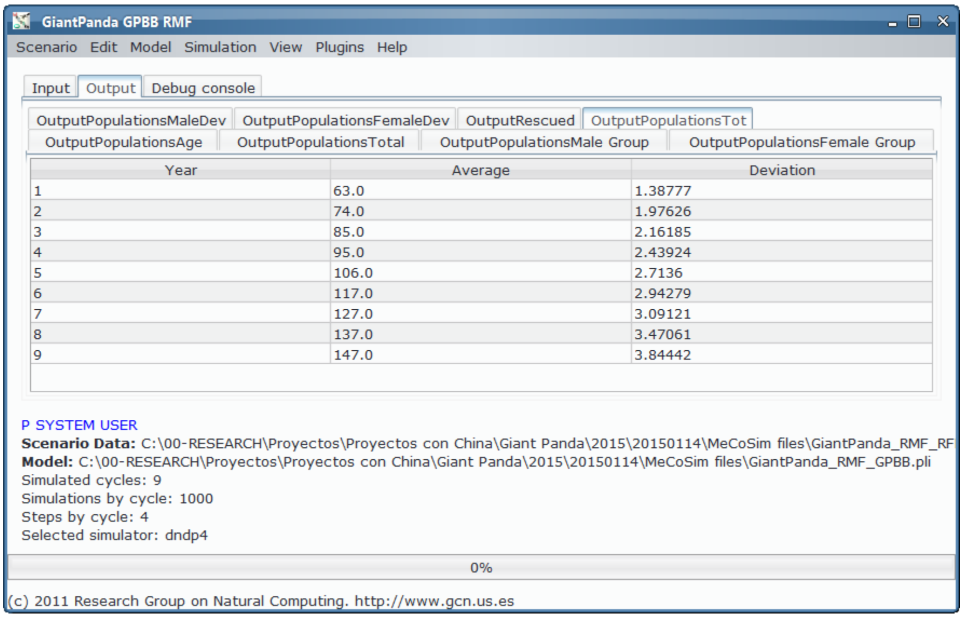
– Rescued by age: enables the introduction of groups of probability for the rescued individuals to have a certain age. Given the small number of individuals, the probability to find an individual of a certain age is not very significant, so instead of that groups of probability are calculated. For each group of age (for instance, from 1 to 7), a proportion of rescued individuals have been extracted from real data (50% of rescued individuals were 1-7 years old); inside the group, the probability for each age is considered uniform (for 1-year-old, 2-year-old, etc.), so if n different ages are included then the probability of each one inside the group is $\frac{1}{n}$. For instance for 3 year-old, the probability is $\frac{0.50}{7}$. This value 7 is provided for each row (each row represents an age from 1 to $cmaxage$) along with the probability of the group.



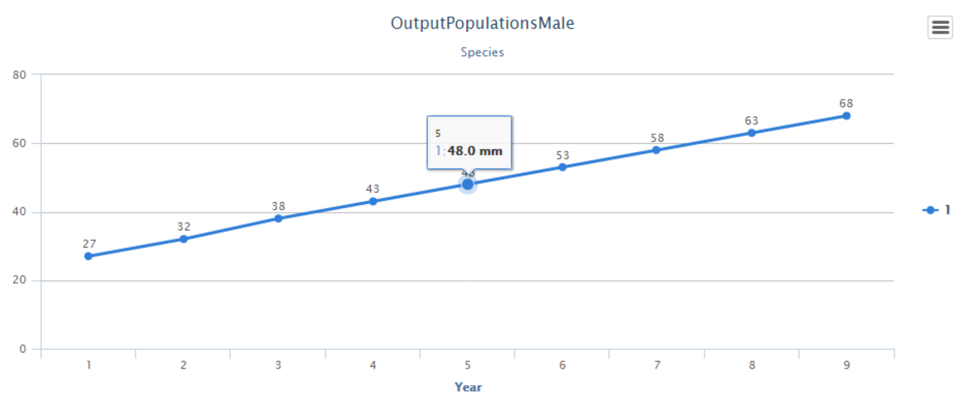
- Simulation results - Output tables and charts

  After introducing the values for the populations and parameters for a scenario under study (or after loading these data from a pre-saved scenario file), the user (manager) is ready to simulate the system by menu option Simulation > Simulate. The number of simulations, cycles or steps can be visually changed by Model and Simulation menu options. After the simulation halts, the custom outputs previously defined in the app configuration file are shown. Some examples are provided in the following screenshots:

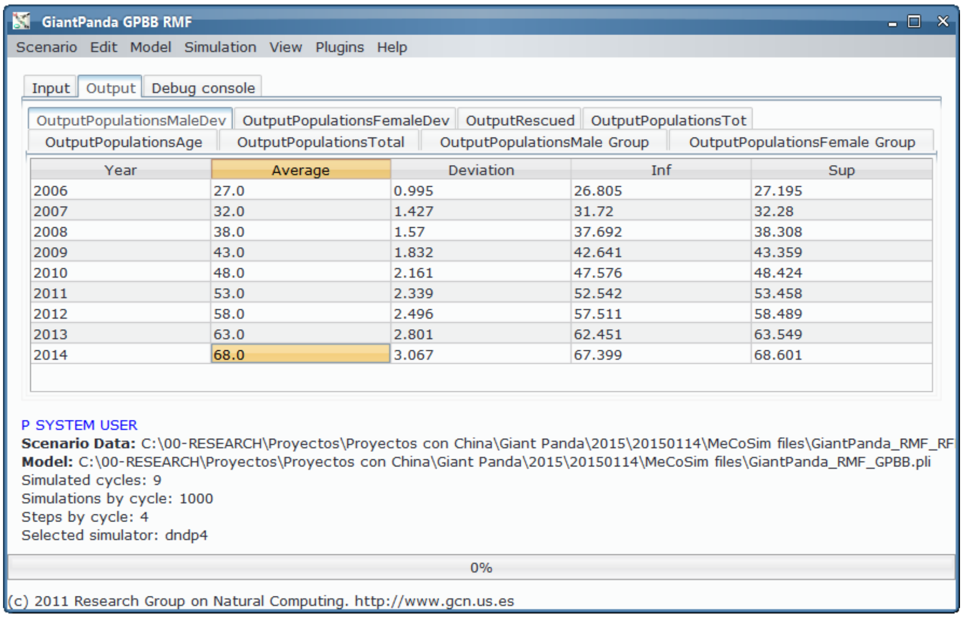
  – Output table with total number of individuals per simulated year.



  – Output line chart with the population of males per simulated year.



– Output table with the population of male individuals per simulated year, including average, deviation, and confidence interval 95%.



Year	Average	Deviation	Inf	Sup
2006	27.0	0.995	26.805	27.195
2007	32.0	1.427	31.72	32.28
2008	38.0	1.57	37.692	38.308
2009	43.0	1.832	42.641	43.359
2010	48.0	2.161	47.576	48.424
2011	53.0	2.339	52.542	53.458
2012	58.0	2.496	57.511	58.489
2013	63.0	2.801	62.451	63.549
2014	68.0	3.067	67.399	68.601

3 Model evaluation

3.1 Robustness

In order to consider the presented model a robust one, and therefore an interesting tool for predicting the population evolution under possible scenarios, an important property it should fulfill is robustness. This means that the conceptual model, presented as a main sequence of modules (Reproduction (R) -> Mortality (M) -> Feeding (F)), does not depend on such sequencing, since this sequencing is a necessary artificial construction as in reality all the process take place at the same time, during the whole year, being not sequenced. To prove the robustness of model, several different variants have been generated, each corresponding to a specific ordering made by swapping the elements of the given sequence. In this way, if we name the sequencing Reproduction (R) -> Mortality (M) -> Feeding (F) as RMF, the other variants are RFM, MFR, MRF, FRM and FMR. To assure robustness of the model, proving that the six variants give similar results when inputting the same scenarios is required.

The detailed description of each variant has been included within an appendix at the end of this document.

3.2 Experimental validation

Results of the model have been corroborated by contrast between the real data from 2006 to 2014, and the output of the simulation. Simulation data results are found to be very close to the real ones, presenting very low deviation. Smaller differences can be easily explained from the natural variability inherent to the processes under study, in such a way that the years whose real data are farer from their own averages are the ones that present an equivalent deviation in the simulation results. Since in the experimental validation 1000 simulations are performed and average values are taken, simulation results should be very similar to the expected average result, but obviously not to each possible real occurrence in our probabilistic scenario.

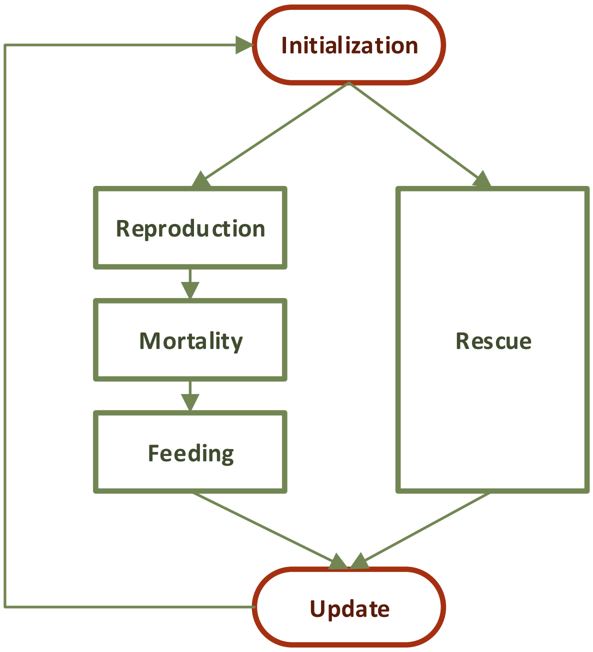


Figure 3.1: *RMF sequencing variant*

Natural deviation from average (Average - Annual) difference in births and deaths		Experimental validation								
		MALES			FEMALES			TOTALS		
MALES	FEMALES	Simulation	Real Data	Dev.	Simulation	Real Data	Dev.	Simulation	Real Data	Dev.
-10,37%	4,90%	27	30	-10,00%	35	34	2,94%	62	64	-3,13%
2,51%	3,33%	32	31	3,23%	41	40	2,50%	73	71	2,82%
-10,32%	4,44%	38	42	-9,52%	46	45	2,22%	84	87	-3,45%
1,32%	5,44%	43	42	2,38%	52	49	6,12%	95	91	4,40%
-5,11%	10,26%	48	50	-4,00%	57	52	9,62%	105	102	2,94%
0,64%	0,00%	53	52	1,92%	63	62	1,61%	116	114	1,75%
5,86%	4,10%	58	55	5,45%	68	65	4,62%	126	120	5,00%
0,17%	-2,25%	63	64	-1,56%	73	74	-1,35%	136	138	-1,45%
0,00%	0,00%	68	68	0,00%	78	78	0,00%	146	146	0,00%
		430	434	0,92%	513	499	2,81%	943	933	1,07%

Figure 3.2: *Experimental validation statistics*

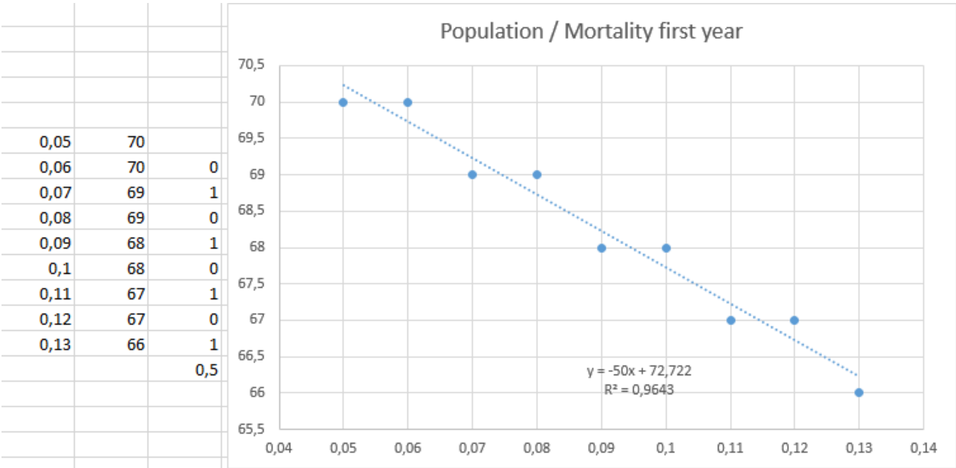


Figure 3.3: *Correlation between the mortality ratio at early ages (horizontal axis) against the total population at the end of the simulation (vertical axis)*

Data presented in Figure 3.2 come from the simulation outputs for period 2006-2014, by using as input the population in the Breeding Base at the end of 2005. The parameters for rescue were estimated by statistically averaging real data from the same years. The rest of parameters (birth rates, mortality ratios, etc.) has been extracted from the historical data of the Breeding Base, thus being more reliable and sound for calibrating the model against the period 2006-2014.

3.3 Uncertainty and Sensitivity Analysis

No matter what the quality of model and simulation tools is, some uncertainty rises from the inherent variability of processes and parameters, along with imprecisions or errors coming from data analysis. Consequently, the pertinent uncertainty and sensitivity analysis has to be conducted over the parameters, in order to determine the influence of the variation of each input parameter on the output results, possibly listing and sorting the influence of each factor or even quantifying it. The latter would provide a tool to put the focus over parameters that are specially relevant and therefore should be considered for a more detailed calibration, study, or work field measurements depending on the nature of the data.

An example of this kind of sensitivity analysis is shown for a very relevant parameter, the mortality ratio for males, in chart 3.3.

The strong correlation among the variance of this ratio and the influence in the output population is shown in the fragment of the table and the chart in Figure 3.3.

As a future work, further analysis over different parameters are planned to be performed for forthcoming model design stages, including both local and global analysis.

4 Model application

In order to assure the accuracy of the model, it has been validated for its use in scenarios similar to the one studied, that is, with similar parameter values and environment, such as captive conditions, pairing system, cares, etc.

However, both the framework and tools involved in the model design, and the theoretical model itself, allow easy customization since they are parameterized, thus enabling their use in different contexts or even the addition of many other features of interest.

Since the goal of this model is to provide a reliable tool for supporting decision making, further efforts will be conducted in terms of parameter estimation, uncertainty and sensitivity analysis plus an iterative refinement process involving designers, experts and managers. This will point our efforts towards the right direction to improve the performance of the model by means of fine tuning of parameters, and the addition of new progressively growing knowledge about processes.

5 Considerations

1. The module of **reproduction** has been initially modelled considering a *fixed number of new individuals being born per year and per gender*, independently of the number of total individuals or the ones in reproductive age every year. This is not a usual way for modeling reproduction, and its motivation comes from the following facts:

   - According to the real data, the evolution in the number of new births is being quite changing, apparently at random, **not** showing a **progressive increase nor decrease in correlation with** the number of **individuals** in the population or those in reproductive age. For instance, we found that 4 new individuals were born a specific year and 17 new ones in another one, not being those values correlated with the number of individuals or their reproductive ages.
   - The **human action** on captive Pandas is very significant, having an influence big enough to avoid the natural process of breeding with respect to the wild state, where the number of births is usually correlated with the number of individuals in reproductive age meeting in a specific environment and the fecundity ratios affecting the species. There exists a strong influence of human decisions, so that Giant Pandas are artificially mating by human interaction in most cases.

2. The number of new individuals per year that is being currently set for simulating reproduction is 6 males and 6 females. Let us concentrate on males. The chosen number (6) has been estimated by analyzing real data (from 2005 to 2014) of living individuals of age 0 after first year, along with mortality rate in the first age (0.08). This number has been therefore estimated with some uncertainty. In fact, the average number of males being born during this range of years was approximately 5.5, but an integer number of individuals should be born, so 6 males being born were considered, but increasing the mortality to 0.09 instead of

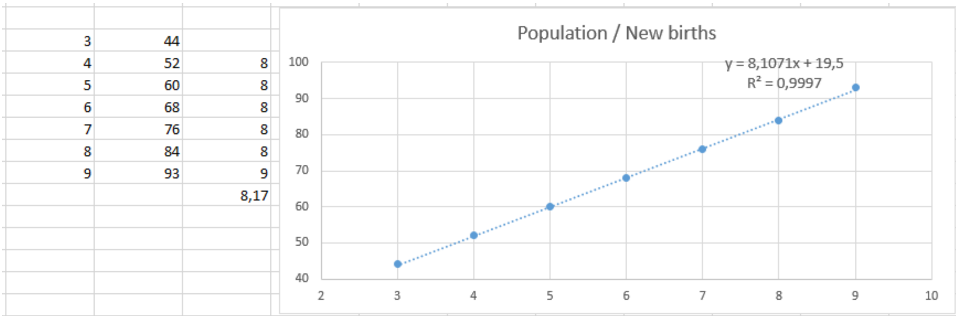


Figure 5.1: *Correlation between the number of male newborns (horizontal axis) against the total number of male Giant pandas at the end of the simulation (vertical axis)*

0.08. How much does the precision of this parameter influence the results of the model in terms of population of males after simulating period 2006-2014? We performed several simulations setting values for the number of males being born per year ranging from 3 to 9 being the corresponding results shown in chart 5.1.

A strong correlation exists between x (number of new males) and y (population of males in 2014). For each additional new birth per year, at least 8 additional individuals are expected after 9 simulated years. Thus, is very important to determine this data precisely.

3. The module of **mortality** requires the application of mortality rates for individuals at different ages. The corresponding evolution rules applied by the presented model take the rates from the local data for the area under study, during the years [2005-2014]. For instance, mortality rates of males and females are 0.09 and 0.05 respectively in the first year of life. The precision of these rates is very important, due to the influence in the output results as shown in the *Sensitivity Analysis* section.

4. The process of **rescue** in the model is based on the description provided by Prof. Zhang and the support of data of the last years involving the number of males/females of different ages rescued from 2005 to 2014. From this data, we got a possible annual number of rescued individuals averaging 0.40 with a deviation of 0.66. The numbers are so small that no complex probability distributions have been considered, by only a probability of 0.4 of having one rescued individual, with the remaining 0.6 percent of not having any rescue.

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Appendices

A Model variants description

Description of the six presented variants.

Feeding - Mortality - Reproduction

Notations:

Related with Giant Pandas (for male $i = 1$, for female $i = 2$):

- $k_{i,1}$: age at which subadult size is reached.
- $k_{i,2}$: age at which youth adult size is reached.
- $k_{i,3}$: age at which mid-adult size is reached.
- $k_{i,4,1}$: age at which elderly (from 17 to 26) size is reached ($k_{i,4,1} = 17$).
- $k_{i,4,2}$: age at which elderly (from 27 to 35) size is reached ($k_{i,4,2} = 27$).
- $k_{i,5}$: maximum life expectancy in the ecosystem under feeding conditions.
- $k_{i,6}$: mortality ratio in infancy giant pandas.
- $k_{i,7}$: mortality ratio in subadult giant pandas.
- $k_{i,8}$: mortality ratio in youth adult giant pandas.
- $k_{i,9}$: mortality ratio in mid-adult giant pandas.
- $k_{i,10}$: mortality ratio in elderly (from 17 to 26) giant pandas.
- $k_{i,11}$: mortality ratio in elderly (from 27 to 35) giant pandas.
- g_1: number of male descendants per year.
- g_2: number of female descendants per year.
- g_3: amount of bamboo shoots supplied in the GPBB (kg) during a year.
- g_4: amount of bamboo supplied in the GPBB (kg) during a year.
- g_5: amount of other food (i.e. apple, meat, milk) supplied in the GPBB (kg) during a year.
- $f_{i,1}$: amount of bamboo shoots necessary per year (kg) according to the energetic requirements of the infancy giant pandas.
- $f_{i,2}$: amount of bamboo necessary per year (kg) according to the energetic requirements of the infancy giant pandas.

- $f_{i,3}$: amount of other foods necessary per year (kg) according to the energetic requirements of the infancy giant pandas.

- $f_{i,4}$: amount of bamboo shoots necessary per year (kg) according to the energetic requirements of the subadult giant pandas.

- $f_{i,5}$: amount of bamboo necessary per year (kg) according to the energetic requirements of the subadult giant pandas.

- $f_{i,6}$: amount of other foods necessary per year (kg) according to the energetic requirements of the subadult giant pandas.

- $f_{i,7}$: amount of bamboo shoots necessary per year (kg) according to the energetic requirements of the adult and elderly giant pandas.

- $f_{i,8}$: amount of bamboo necessary per year (kg) according to the energetic requirements of the adult and elderly giant pandas.

- $f_{i,9}$: amount of other foods necessary per year (kg) according to the energetic requirements of the adult and elderly giant pandas.

- $cmin$: minimum number of rescued giant pandas per year.

- $cmax$: maximum number of rescued giant pandas per year.

- $cmaxage$: maximum age of rescued giant pandas.

- pc_c: probability to have c rescued individuals.

- pg_i: probability for rescued individuals to have gender i.

- pa_j: probability for rescued individuals to have age j.

Symbols in the model (for male $i = 1$, for female $i = 2$):

- $q_{i,j}$: the number of giant pandas of age j.

- $X_{i,j}$: individuals of age j before feeding module.

- $Y_{i,j}$: individuals of age j within feeding module.

- $Z_{i,j}$: individuals of age j within mortality module.

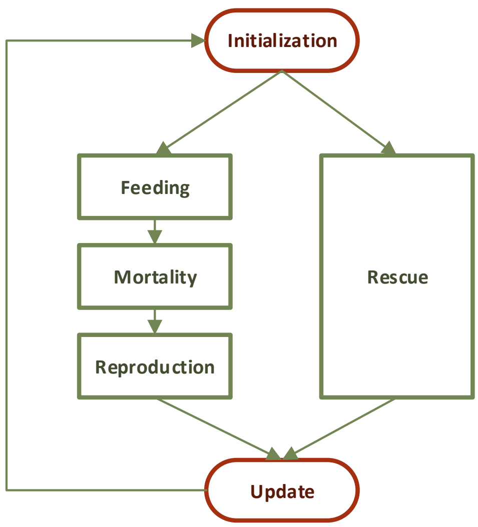
- $T_{i,j}$: survived individuals of age j.

- $W_{i,j}$: Individuals of age j after reproduction module.

- $C_{i,j}$: rescued individuals of "age" j.

- S: bamboo shoots.
- B: bamboo.
- O: other food.
- F: auxiliary object to generate new food at the beginning of each time cycle.
- N: auxiliary object to generate newborns at the beginning of each time cycle.
- A: auxiliary object to trigger the rescue

The flow diagram with the modules of the design:



MEMBRANE STRUCTURE

$\mu = [\ [\ ]_2\ ]_1$

INITIAL MULTISETS

$\mathcal{M}_1 = \{X_{i,j}^{q_{i,j}} : 1 \leq i \leq 2,\ 1 \leq j \leq k_{i,5}\}, \quad \mathcal{M}_2 = \{F\ N\ A\}.$

INITIALIZATION RULE

- Generation of objects associated with the food:

$$r_1 \equiv [\, F \,]_2^0 \longrightarrow F \; [\, S^{g_3} \; B^{g_4} \; O^{g_5} \,]_2^+,$$

RESCUED GIANT PANDAS RULES

- Probability to have c rescued individuals:

$$r_2 \equiv [\, A \,]_2^0 \xrightarrow{pc_c} A \; C^c \, [\;]_2^+, \text{ for } cmin \leq c \leq cmax.$$

- Probability for rescued individuals to have gender i:

$$r_3 \equiv [\, C \xrightarrow{pg_i} C_i \,]_1^0, \text{ for } 1 \leq i \leq 2$$

- Probability for rescued individuals to have age j:

$$r_4 \equiv [\, C_i \xrightarrow{pa_j} C_{i,j+1+\lfloor \frac{j}{3} \rfloor} \,]_1^0, \text{ for } \begin{cases} 1 \leq i \leq 2 \\ 0 \leq j < cmaxage \end{cases}$$

FEEDING RULES

- Giant pandas enter in the zone to feed:

$$r_5 \equiv X_{i,j} \; [\;]_2^0 \longrightarrow [\, Y_{i,j} \,]_2^+, \text{ for } \begin{cases} 1 \leq i \leq 2 \\ 0 \leq j \leq k_{i,5} \end{cases}$$

- Feeding process for infancy giant pandas:

$$r_6 \equiv [\, Y_{i,j} \; S^{f_{i,1}} \; B^{f_{i,2}} \; O^{f_{i,3}} \longrightarrow Z_{i,j} \,]_2^+, \text{ for } \begin{cases} 1 \leq i \leq 2 \\ 0 \leq j < k_{i,1} \end{cases}$$

- Feeding process for subadult giant pandas:

$$r_7 \equiv [\, Y_{i,j} \; S^{f_{i,4}} \; B^{f_{i,5}} \; O^{f_{i,6}} \longrightarrow Z_{i,j} \,]_2^+, \text{ for } \begin{cases} 1 \leq i \leq 2 \\ k_{i,1} \leq j < k_{i,2} \end{cases}$$

- Feeding process for adult and elderly giant pandas:

$$r_8 \equiv [\, Y_{i,j} \; S^{f_{i,7}} \; B^{f_{i,8}} \; O^{f_{i,9}} \longrightarrow Z_{i,j} \,]_2^+, \text{ for } \begin{cases} 1 \leq i \leq 2 \\ k_{i,2} \leq j \leq k_{i,5} \end{cases}$$

MORTALITY RULES

- Infancy giant pandas that survive:

$$r_9 \equiv [\, Z_{i,j} \,]_2^+ \xrightarrow{1-k_{i,6}} [\, T_{i,j} \,]_2^-, \text{ for } \begin{cases} 1 \le i \le 2 \\ 0 \le j < k_{i,1} \end{cases}$$

- Infancy giant pandas that die:

$$r_{10} \equiv [\, Z_{i,j} \,]_2^+ \xrightarrow{k_{i,6}} \lambda [\,]_2^-, \text{ for } \begin{cases} 1 \le i \le 2 \\ 0 \le j < k_{i,1} \end{cases}$$

- Subadult giant pandas that survive:

$$r_{11} \equiv [\, Z_{i,j} \,]_2^+ \xrightarrow{1-k_{i,7}} [\, T_{i,j} \,]_2^-, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,1} \le j < k_{i,2} \end{cases}$$

- Subadult giant pandas that die:

$$r_{12} \equiv [\, Z_{i,j} \,]_2^+ \xrightarrow{k_{i,7}} \lambda [\,]_2^-, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,1} \le j < k_{i,2} \end{cases}$$

- Youth adult giant pandas that survive:

$$r_{13} \equiv [\, Z_{i,j} \,]_2^+ \xrightarrow{1-k_{i,8}} [\, T_{i,j} \,]_2^-, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,2} \le j < k_{i,3} \end{cases}$$

- Youth adult giant pandas that die:

$$r_{14} \equiv [\, Z_{i,j} \,]_2^+ \xrightarrow{k_{i,8}} \lambda [\,]_2^-, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,2} \le j < k_{i,3} \end{cases}$$

- Mid-adult giant pandas that survive:

$$r_{15} \equiv [\, Z_{i,j} \,]_2^+ \xrightarrow{1-k_{i,9}} [\, T_{i,j} \,]_2^-, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,3} \le j < k_{i,4,1} \end{cases}$$

- Mid-adult giant pandas that die:

$$r_{16} \equiv [\, Z_{i,j} \,]_2^+ \xrightarrow{k_{i,9}} \lambda [\,]_2^-, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,3} \le j < k_{i,4,1} \end{cases}$$

- Elderly (from 17 to 26) giant pandas that survive:

$$r_{17} \equiv [\, Z_{i,j} \,]_2^+ \xrightarrow{1-k_{i,10}} [\, T_{i,j} \,]_2^-, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,4,1} \le j < k_{i,4,2} \end{cases}$$

- Elderly (from 17 to 26) giant pandas that die:

$$r_{18} \equiv [\, Z_{i,j}\,]_2^{+} \xrightarrow{k_{i,11}} \lambda\, [\;]_2^{-}\,,\ \text{for} \begin{cases} 1 \le i \le 2 \\ k_{i,4,1} \le j < k_{i,4,2} \end{cases}$$

- Elderly (from 27 to 35) giant pandas that survive:

$$r_{19} \equiv [\, Z_{i,j}\,]_2^{+} \xrightarrow{1-k_{i,11}} [\, T_{i,j}\,]_2^{-}\,,\ \text{for} \begin{cases} 1 \le i \le 2 \\ k_{i,4,2} \le j < k_{i,5} \end{cases}$$

- Elderly (from 27 to 35) giant pandas that die:

$$r_{20} \equiv [\, Z_{i,j}\,]_2^{+} \xrightarrow{k_{i,11}} \lambda\, [\;]_2^{-}\,,\ \text{for} \begin{cases} 1 \le i \le 2 \\ k_{i,4,2} \le j < k_{i,5} \end{cases}$$

- Giant pandas which reach the maximum life expectancy:

$$r_{21} \equiv [\, Z_{i,k_{i,5}}\,]_2^{+} \longrightarrow \lambda\, [\;]_2^{-}\,,\ \text{for } 1 \le i \le 2$$

REPRODUCTION RULES

- Rules associated with newborns:

$$r_{22} \equiv [\, N\,]_2^{-} \;\longrightarrow\; N\, [\, W_{1,-1}^{g_1}\ W_{2,-1}^{g_2}\,]_2^{0},$$

- Growth rules:

$$r_{23} \equiv [\, T_{i,j}\,]_2^{-} \;\longrightarrow\; [\, W_{i,j}\,]_2^{0},\ \text{for} \begin{cases} 1 \le i \le 2 \\ 0 \le j < k_{i,5} \end{cases}$$

UPDATING RULES

- Elimination of the remaining food.

$$r_{24} \equiv [\, S \longrightarrow \lambda]_2^{0}$$
$$r_{25} \equiv [\, B \longrightarrow \lambda]_2^{0}$$
$$r_{26} \equiv [\, O \longrightarrow \lambda]_2^{0}$$

- Preparation for the beginning of a new cycle.

$$r_{27} \equiv [\, W_{i,j}\ ]_2^{0} \longrightarrow X_{i,j+1}\, [\;]_2^{0},\ \text{for} \begin{cases} 1 \le i \le 2 \\ -1 \le j < k_{i,5} \end{cases}$$

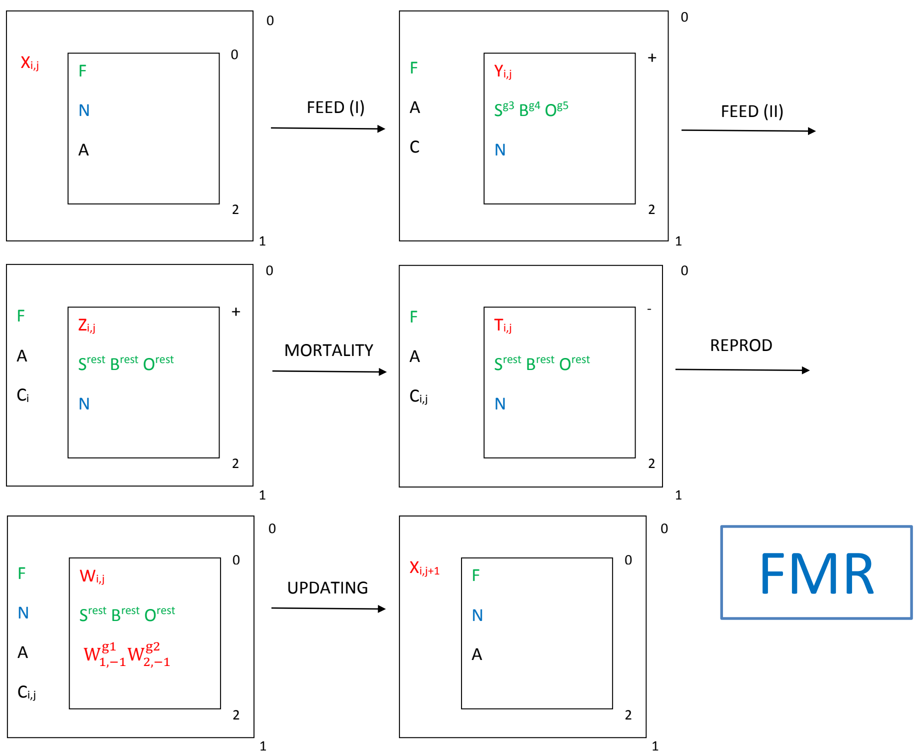
$$r_{28} \equiv F\ [\ \ ]_2^{0} \longrightarrow [\, F\ ]_2^{0},$$

$$r_{29} \equiv C_{i,j}\ [\ ]_2^0 \longrightarrow X_{i,j+1}\ [\ ]_2^0, \text{ for } \begin{cases} 1 \le i \le 2 \\ 0 \le j < k_{i,5} \end{cases}$$

$$r_{30} \equiv A\ [\ ]_2^0 \longrightarrow [\ A\ ]_2^0,$$

$$r_{31} \equiv N\ [\ ]_2^0 \longrightarrow [\ N\ ]_2^0,$$

EXECUTION OF THE MODEL



Feeding - Reproduction - Mortality

Notations:

Related with Giant Pandas (for male $i = 1$, for female $i = 2$):

- $k_{i,1}$: age at which subadult size is reached.
- $k_{i,2}$: age at which youth adult size is reached.
- $k_{i,3}$: age at which mid-adult size is reached.
- $k_{i,4,1}$: age at which elderly (from 17 to 26) size is reached ($k_{i,4,1} = 17$).
- $k_{i,4,2}$: age at which elderly (from 27 to 35) size is reached ($k_{i,4,2} = 27$).
- $k_{i,5}$: maximum life expectancy in the ecosystem under feeding conditions.
- $k_{i,6}$: mortality ratio in infancy giant pandas.
- $k_{i,7}$: mortality ratio in subadult giant pandas.
- $k_{i,8}$: mortality ratio in youth adult giant pandas.
- $k_{i,9}$: mortality ratio in mid-adult giant pandas.
- $k_{i,10}$: mortality ratio in elderly (from 17 to 26) giant pandas.
- $k_{i,11}$: mortality ratio in elderly (from 27 to 35) giant pandas.
- g_1: number of male descendants per year.
- g_2: number of female descendants per year.
- g_3: amount of bamboo shoots supplied in the GPBB (kg) during a year.
- g_4: amount of bamboo supplied in the GPBB (kg) during a year.
- g_5: amount of other food (i.e. apple, meat, milk) supplied in the GPBB (kg) during a year.
- $f_{i,1}$: amount of bamboo shoots necessary per year (kg) according to the energetic requirements of the infancy giant pandas.
- $f_{i,2}$: amount of bamboo necessary per year (kg) according to the energetic requirements of the infancy giant pandas.

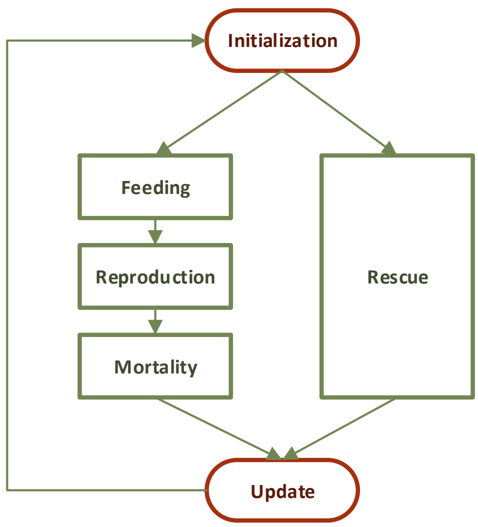
- $f_{i,3}$: amount of other foods necessary per year (kg) according to the energetic requirements of the infancy giant pandas.
- $f_{i,4}$: amount of bamboo shoots necessary per year (kg) according to the energetic requirements of the subadult giant pandas.
- $f_{i,5}$: amount of bamboo necessary per year (kg) according to the energetic requirements of the subadult giant pandas.
- $f_{i,6}$: amount of other foods necessary per year (kg) according to the energetic requirements of the subadult giant pandas.
- $f_{i,7}$: amount of bamboo shoots necessary per year (kg) according to the energetic requirements of the adult and elderly giant pandas.
- $f_{i,8}$: amount of bamboo necessary per year (kg) according to the energetic requirements of the adult and elderly giant pandas.
- $f_{i,9}$: amount of other foods necessary per year (kg) according to the energetic requirements of the adult and elderly giant pandas.
- $cmin$: minimum number of rescued giant pandas per year.
- $cmax$: maximum number of rescued giant pandas per year.
- $cmaxage$: maximum age of rescued giant pandas.
- pc_c: probability to have c rescued individuals.
- pg_i: probability for rescued individuals to have gender i.
- pa_j: probability for rescued individuals to have age j.

Symbols in the model (for male $i = 1$, for female $i = 2$):

- $q_{i,j}$: the number of giant pandas of age j.
- $X_{i,j}$: individuals of age j before feeding module.
- $Y_{i,j}$: individuals of age j within feeding module.
- $Z_{i,j}$: individuals of age j after feeding module.
- $T_{i,j}$: individuals of age j after reproduction module.
- $W_{i,j}$: survived individuals of age j.
- $C_{i,j}$: rescued individuals of “age” j.

- S: bamboo shoots.
- B: bamboo.
- O: other food.
- F: auxiliary object to generate new food at the beginning of each time cycle.
- N: auxiliary object to generate newborns at the beginning of each time cycle.
- A: auxiliary object to trigger the rescue

The flow diagram with the modules of the design:



MEMBRANE STRUCTURE

$\mu = [\ [\ ]_2\ ]_1$

INITIAL MULTISETS

$\mathcal{M}_1 = \{X_{i,j}^{q_{i,j}} \,:\, 1 \leq i \leq 2,\ 1 \leq j \leq k_{i,5}\}, \quad \mathcal{M}_2 = \{F\ N\ A\}.$

INITIALIZATION RULE

- Generation of objects associated with the food:

$$r_1 \equiv [\,F\,]_2^0 \longrightarrow F\ [\,S^{g_3}\ B^{g_4}\ O^{g_5}\,]_2^+,$$

RESCUED GIANT PANDAS RULES

- Probability to have c rescued individuals:

$$r_2 \equiv [\,A\,]_2^0 \xrightarrow{pc_c} A\ C^c\,[\ ]_2^+, \text{ for } cmin \leq c \leq cmax.$$

- Probability for rescued individuals to have gender i:

$$r_3 \equiv [\,C \xrightarrow{pg_i} C_i\,]_1^0, \text{ for } 1 \leq i \leq 2$$

- Probability for rescued individuals to have age j:

$$r_4 \equiv [\,C_i \xrightarrow{pa_j} C_{i,j+1+\lfloor \frac{j}{3} \rfloor}\,]_1^0, \text{ for } \begin{cases} 1 \leq i \leq 2 \\ 0 \leq j < cmaxage \end{cases}$$

FEEDING RULES

- Giant pandas enter in the zone to feed:

$$r_5 \equiv X_{i,j}\ [\ ]_2^0 \longrightarrow [\,Y_{i,j}\,]_2^+, \text{ for } \begin{cases} 1 \leq i \leq 2 \\ 1 \leq j \leq k_{i,5} \end{cases}$$

- Feeding process for infancy giant pandas:

$$r_6 \equiv [\,Y_{i,j}\ S^{f_{i,1}}\ B^{f_{i,2}}\ O^{f_{i,3}}\,]_2^+ \longrightarrow [\,Z_{i,j}\,]_2^-, \text{ for } \begin{cases} 1 \leq i \leq 2 \\ 0 \leq j < k_{i,1} \end{cases}$$

- Feeding process for subadult giant pandas:

$$r_7 \equiv [\,Y_{i,j}\ S^{f_{i,4}}\ B^{f_{i,5}}\ O^{f_{i,6}}\,]_2^+ \longrightarrow [\,Z_{i,j}\,]_2^-, \text{ for } \begin{cases} 1 \leq i \leq 2 \\ k_{i,1} \leq j < k_{i,2} \end{cases}$$

- Feeding process for adult and elderly giant pandas:

$$r_8 \equiv [\,Y_{i,j}\ S^{f_{i,7}}\ B^{f_{i,8}}\ O^{f_{i,9}}\,]_2^+ \longrightarrow [\,Z_{i,j}\,]_2^-, \text{ for } \begin{cases} 1 \leq i \leq 2 \\ k_{i,2} \leq j \leq k_{i,5} \end{cases}$$

REPRODUCTION RULES

- Rules associated with newborns:

$$r_9 \equiv [\,N\,]_2^- \longrightarrow N\,[\,T_{1,0}^{g_1}\;T_{2,0}^{g_2}\,]_2^-,$$

- Growth rules:

$$r_{10} \equiv [\,Z_{i,j} \longrightarrow T_{i,j}\,]_2^-, \text{ for } \begin{cases} 1 \le i \le 2 \\ 1 \le j \le k_{i,5} \end{cases}$$

MORTALITY RULES

- Infancy giant pandas that survive:

$$r_{11} \equiv [\,T_{i,j}\,]_2^- \xrightarrow{1-k_{i,6}} [\,W_{i,j}\,]_2^0, \text{ for } \begin{cases} 1 \le i \le 2 \\ 0 \le j < k_{i,1} \end{cases}$$

- Infancy giant pandas that die:

$$r_{12} \equiv [\,T_{i,j}\,]_2^- \xrightarrow{k_{i,6}} \lambda\,[\;]_2^0, \text{ for } \begin{cases} 1 \le i \le 2 \\ 0 \le j < k_{i,1} \end{cases}$$

- Subadult giant pandas that survive:

$$r_{13} \equiv [\,T_{i,j}\,]_2^- \xrightarrow{1-k_{i,7}} [\,W_{i,j}\,]_2^0, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,1} \le j < k_{i,2} \end{cases}$$

- Subadult giant pandas that die:

$$r_{14} \equiv [\,T_{i,j}\,]_2^- \xrightarrow{k_{i,7}} \lambda\,[\;]_2^0, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,1} \le j < k_{i,2} \end{cases}$$

- Youth adult giant pandas that survive:

$$r_{15} \equiv [\,T_{i,j}\,]_2^- \xrightarrow{1-k_{i,8}} [\,W_{i,j}\,]_2^0, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,2} \le j < k_{i,3} \end{cases}$$

- Youth adult giant pandas that die:

$$r_{16} \equiv [\,T_{i,j}\,]_2^- \xrightarrow{k_{i,8}} \lambda\,[\;]_2^0, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,2} \le j < k_{i,3} \end{cases}$$

- Mid-adult giant pandas that survive:

$$r_{17} \equiv [\,T_{i,j}\,]_2^- \xrightarrow{1-k_{i,9}} [\,W_{i,j}\,]_2^0, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,3} \le j < k_{i,4,1} \end{cases}$$

- Mid-adult giant pandas that die:

$$r_{18} \equiv [\,T_{i,j}\,]_2^- \xrightarrow{k_{i,9}} \lambda\,[\;]_2^0, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,3} \le j < k_{i,4,1} \end{cases}$$

- Elderly (from 17 to 26) giant pandas that survive:

$$r_{19} \equiv [\,T_{i,j}\,]_2^- \xrightarrow{1-k_{i,10}} [\,W_{i,j}\,]_2^0, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,4,1} \le j < k_{i,4,2} \end{cases}$$

- Elderly (from 17 to 26) giant pandas that die:

$$r_{20} \equiv [\,T_{i,j}\,]_2^- \xrightarrow{k_{i,11}} \lambda\,[\;]_2^0, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,4,1} \le j < k_{i,4,2} \end{cases}$$

- Elderly (from 27 to 35) giant pandas that survive:

$$r_{21} \equiv [\,T_{i,j}\,]_2^- \xrightarrow{1-k_{i,11}} [\,W_{i,j}\,]_2^0, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,4,2} \le j < k_{i,5} \end{cases}$$

- Elderly (from 27 to 35) giant pandas that die:

$$r_{22} \equiv [\,T_{i,j}\,]_2^- \xrightarrow{k_{i,11}} \lambda\,[\;]_2^0, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,4,2} \le j < k_{i,5} \end{cases}$$

- Giant pandas which reach the maximum life expectancy:

$$r_{23} \equiv [\,T_{i,k_{i,5}}\,]_2^- \longrightarrow \lambda\,[\;]_2^0, \text{ for } 1 \le i \le 2$$

UPDATING RULES

- Elimination of the remaining food.

$$r_{24} \equiv [\,S \longrightarrow \lambda]_2^0$$
$$r_{25} \equiv [\,B \longrightarrow \lambda]_2^0$$
$$r_{26} \equiv [\,O \longrightarrow \lambda]_2^0$$

- Preparation for the beginning of a new cycle.

$$r_{27} \equiv [\,W_{i,j}\,]_2^0 \longrightarrow X_{i,j+1}\,[\;]_2^0, \text{ for } \begin{cases} 1 \le i \le 2 \\ 0 \le j < k_{i,5} \end{cases}$$

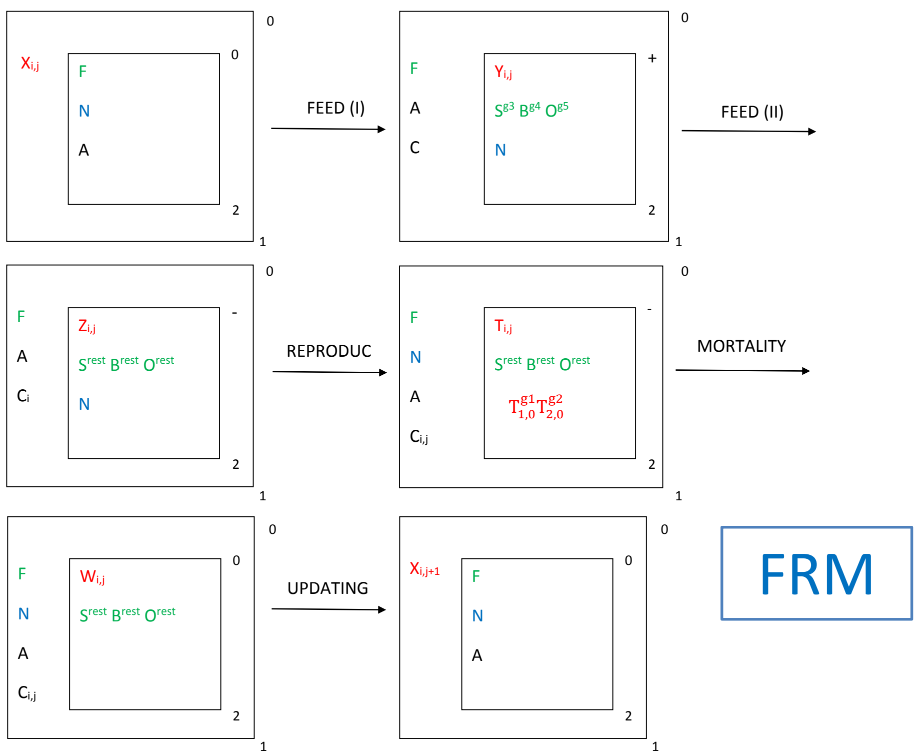
$$r_{28} \equiv F\ [\ ]_2^0 \longrightarrow [F\ ]_2^0,$$

$$r_{29} \equiv C_{i,j}\ [\ ]_2^0 \longrightarrow X_{i,j+1}\ [\ ]_2^0, \text{ for } \begin{cases} 1 \le i \le 2 \\ 0 \le j < k_{i,5} \end{cases}$$

$$r_{30} \equiv A\ [\ ]_2^0 \longrightarrow [A\ ]_2^0,$$

$$r_{31} \equiv N\ [\ ]_2^0 \longrightarrow [N\ ]_2^0,$$

EXECUTION OF THE MODEL



Mortality - Feeding - Reproduction

Notations:

Related with Giant Pandas (for male $i = 1$, for female $i = 2$):

- $k_{i,1}$: age at which subadult size is reached.
- $k_{i,2}$: age at which youth adult size is reached.
- $k_{i,3}$: age at which mid-adult size is reached.
- $k_{i,4,1}$: age at which elderly (from 17 to 26) size is reached ($k_{i,4,1} = 17$).
- $k_{i,4,2}$: age at which elderly (from 27 to 35) size is reached ($k_{i,4,2} = 27$).
- $k_{i,5}$: maximum life expectancy in the ecosystem under feeding conditions.
- $k_{i,6}$: mortality ratio in infancy giant pandas.
- $k_{i,7}$: mortality ratio in subadult giant pandas.
- $k_{i,8}$: mortality ratio in youth adult giant pandas.
- $k_{i,9}$: mortality ratio in mid-adult giant pandas.
- $k_{i,10}$: mortality ratio in elderly (from 17 to 26) giant pandas.
- $k_{i,11}$: mortality ratio in elderly (from 27 to 35) giant pandas.
- g_1: number of male descendants per year.
- g_2: number of female descendants per year.
- g_3: amount of bamboo shoots supplied in the GPBB (kg) during a year.
- g_4: amount of bamboo supplied in the GPBB (kg) during a year.
- g_5: amount of other food (i.e. apple, meat, milk) supplied in the GPBB (kg) during a year.
- $f_{i,1}$: amount of bamboo shoots necessary per year (kg) according to the energetic requirements of the infancy giant pandas.
- $f_{i,2}$: amount of bamboo necessary per year (kg) according to the energetic requirements of the infancy giant pandas.

- $f_{i,3}$: amount of other foods necessary per year (kg) according to the energetic requirements of the infancy giant pandas.

- $f_{i,4}$: amount of bamboo shoots necessary per year (kg) according to the energetic requirements of the subadult giant pandas.

- $f_{i,5}$: amount of bamboo necessary per year (kg) according to the energetic requirements of the subadult giant pandas.

- $f_{i,6}$: amount of other foods necessary per year (kg) according to the energetic requirements of the subadult giant pandas.

- $f_{i,7}$: amount of bamboo shoots necessary per year (kg) according to the energetic requirements of the adult and elderly giant pandas.

- $f_{i,8}$: amount of bamboo necessary per year (kg) according to the energetic requirements of the adult and elderly giant pandas.

- $f_{i,9}$: amount of other foods necessary per year (kg) according to the energetic requirements of the adult and elderly giant pandas.

- $cmin$: minimum number of rescued giant pandas per year.

- $cmax$: maximum number of rescued giant pandas per year.

- $cmaxage$: maximum age of rescued giant pandas.

- pc_c: probability to have c rescued individuals.

- pg_i: probability for rescued individuals to have gender i.

- pa_j: probability for rescued individuals to have age j.

Symbols in the model (for male $i = 1$, for female $i = 2$):

- $q_{i,j}$: the number of giant pandas of age j.

- $X_{i,j}$: individuals of age j before mortality module.

- $Y_{i,j}$: survived individuals of age j.

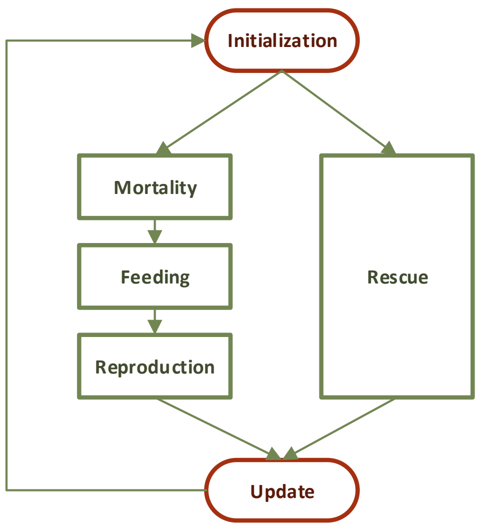
- $Z_{i,j}$: individuals of age j after feeding module.

- $W_{i,j}$: individuals of age j after reproduction module (newborns are denoted as $W_{i,-1}$ for technical reasons).

- $C_{i,j}$: rescued individuals of "age" j.

- S: bamboo shoots.
- B: bamboo.
- O: other food.
- F: auxiliary object to generate new food at the beginning of each time cycle.
- N: auxiliary object to generate newborns at the beginning of each time cycle.
- A: auxiliary object to trigger the rescue

The flow diagram with the modules of the design:



MEMBRANE STRUCTURE

$\mu = [\ [\ ]_2\ ]_1$

INITIAL MULTISETS

$\mathcal{M}_1 = \{X_{i,j}^{q_{i,j}}\ N\ :\ 1 \leq i \leq 2,\ 0 \leq j \leq k_{i,5}\}, \quad \mathcal{M}_2 = \{F\ A\}.$

INITIALIZATION RULE

- Generation of objects associated with the food:

$$r_1 \equiv [\, F \,]_2^0 \longrightarrow F \; [\, S^{g_3} \; B^{g_4} \; O^{g_5} \,]_2^+,$$

RESCUED GIANT PANDAS RULES

- Probability to have c rescued individuals:

$$r_2 \equiv [\, A \,]_2^0 \xrightarrow{pc_c} A \; C^c \, [\;]_2^+, \text{ for } cmin \leq c \leq cmax.$$

- Probability for rescued individuals to have gender i:

$$r_3 \equiv [\, C \xrightarrow{pg_i} C_i \,]_1^0, \text{ for } 1 \leq i \leq 2$$

- Probability for rescued individuals to have age j:

$$r_4 \equiv [\, C_i \xrightarrow{pa_j} C_{i,j+1+\lfloor \frac{j}{3} \rfloor} \,]_1^0, \text{ for } \begin{cases} 1 \leq i \leq 2 \\ 0 \leq j < cmaxage \end{cases}$$

MORTALITY RULES

- Infancy giant pandas that survive:

$$r_5 \equiv X_{i,j} \, [\;]_2^0 \xrightarrow{1-k_{i,6}} [\, Y_{i,j} \,]_2^+, \text{ for } \begin{cases} 1 \leq i \leq 2 \\ 0 \leq j < k_{i,1} \end{cases}$$

- Infancy giant pandas that die:

$$r_6 \equiv X_{i,j} \, [\;]_2^0 \xrightarrow{k_{i,6}} \lambda \, [\;]_2^+, \text{ for } \begin{cases} 1 \leq i \leq 2 \\ 0 \leq j < k_{i,1} \end{cases}$$

- Subadult giant pandas that survive:

$$r_7 \equiv X_{i,j} \, [\;]_2^0 \xrightarrow{1-k_{i,7}} [\, Y_{i,j} \,]_2^+, \text{ for } \begin{cases} 1 \leq i \leq 2 \\ k_{i,1} \leq j < k_{i,2} \end{cases}$$

- Subadult giant pandas that die:

$$r_8 \equiv X_{i,j} \, [\;]_2^0 \xrightarrow{k_{i,7}} \lambda \, [\;]_2^+, \text{ for } \begin{cases} 1 \leq i \leq 2 \\ k_{i,1} \leq j < k_{i,2} \end{cases}$$

- Youth adult giant pandas that survive:

$$r_9 \equiv X_{i,j}\,[\;]_2^0 \xrightarrow{1-k_{i,8}} [\,Y_{i,j}\,]_2^+, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,2} \le j < k_{i,3} \end{cases}$$

- Youth adult giant pandas that die:

$$r_{10} \equiv X_{i,j}\,[\;]_2^0 \xrightarrow{k_{i,8}} \lambda\,[\;]_2^+, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,2} \le j < k_{i,3} \end{cases}$$

- Mid-adult giant pandas that survive:

$$r_{11} \equiv X_{i,j}\,[\;]_2^0 \xrightarrow{1-k_{i,9}} [\,Y_{i,j}\,]_2^+, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,3} \le j < k_{i,4,1} \end{cases}$$

- Mid-adult giant pandas that die:

$$r_{12} \equiv X_{i,j}\,[\;]_2^0 \xrightarrow{k_{i,9}} \lambda\,[\;]_2^+, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,3} \le j < k_{i,4,1} \end{cases}$$

- Elderly (from 17 to 26) giant pandas that survive:

$$r_{13} \equiv X_{i,j}\,[\;]_2^0 \xrightarrow{1-k_{i,10}} [\,Y_{i,j}\,]_2^+, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,4,1} \le j < k_{i,4,2} \end{cases}$$

- Elderly (from 17 to 26) giant pandas that die:

$$r_{14} \equiv X_{i,j}\,[\;]_2^0 \xrightarrow{k_{i,11}} \lambda\,[\;]_2^+, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,4,1} \le j < k_{i,4,2} \end{cases}$$

- Elderly (from 27 to 35) giant pandas that survive:

$$r_{15} \equiv X_{i,j}\,[\;]_2^0 \xrightarrow{1-k_{i,11}} [\,Y_{i,j}\,]_2^+, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,4,2} \le j < k_{i,5} \end{cases}$$

- Elderly (from 27 to 35) giant pandas that die:

$$r_{16} \equiv X_{i,j}\,[\;]_2^0 \xrightarrow{k_{i,11}} \lambda\,[\;]_2^+, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,4,2} \le j < k_{i,5} \end{cases}$$

- Giant pandas which reach the maximum life expectancy:

$$r_{17} \equiv X_{i,k_{i,5}}\,[\;]_2^0 \longrightarrow \lambda\,[\;]_2^+, \text{ for } 1 \le i \le 2$$

FEEDING RULES

- Feeding process for infancy giant pandas:

$$r_{18} \equiv [\, Y_{i,j} \; S^{f_{i,1}} \; B^{f_{i,2}} \; O^{f_{i,3}} \;\longrightarrow\; Z_{i,j} \,]_2^+, \text{ for } \begin{cases} 1 \le i \le 2 \\ 0 \le j < k_{i,1} \end{cases}$$

- Feeding process for subadult giant pandas:

$$r_{19} \equiv [\, Y_{i,j} \; S^{f_{i,4}} \; B^{f_{i,5}} \; O^{f_{i,6}} \;\longrightarrow\; Z_{i,j} \,]_2^+, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,1} \le j < k_{i,2} \end{cases}$$

- Feeding process for adult and elderly giant pandas:

$$r_{20} \equiv [\, Y_{i,j} \; S^{f_{i,7}} \; B^{f_{i,8}} \; O^{f_{i,9}} \;\longrightarrow\; Z_{i,j} \,]_2^+, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,2} \le j < k_{i,5} \end{cases}$$

REPRODUCTION RULES

- Preparing for reproduction:

$$r_{21} \equiv N \; [\;\;]_2^+ \longrightarrow [\, N \,]_2^+,$$

- Rules associated with newborns:

$$r_{22} \equiv [\, N \,]_2^+ \longrightarrow N \, [\, W_{1,-1}^{g_1} \; W_{2,-1}^{g_2} \,]_2^0,$$

- Growth rules:

$$r_{23} \equiv [\, Z_{i,j} \,]_2^+ \longrightarrow [\, W_{i,j} \,]_2^0, \text{ for } \begin{cases} 1 \le i \le 2 \\ 0 \le j < k_{i,5} \end{cases}$$

UPDATING RULES

- Elimination of the remaining food.

$$r_{24} \equiv [\, S \longrightarrow \lambda]_2^0$$
$$r_{25} \equiv [\, B \longrightarrow \lambda]_2^0$$
$$r_{26} \equiv [\, O \longrightarrow \lambda]_2^0$$

- Preparation for the beginning of a new cycle.

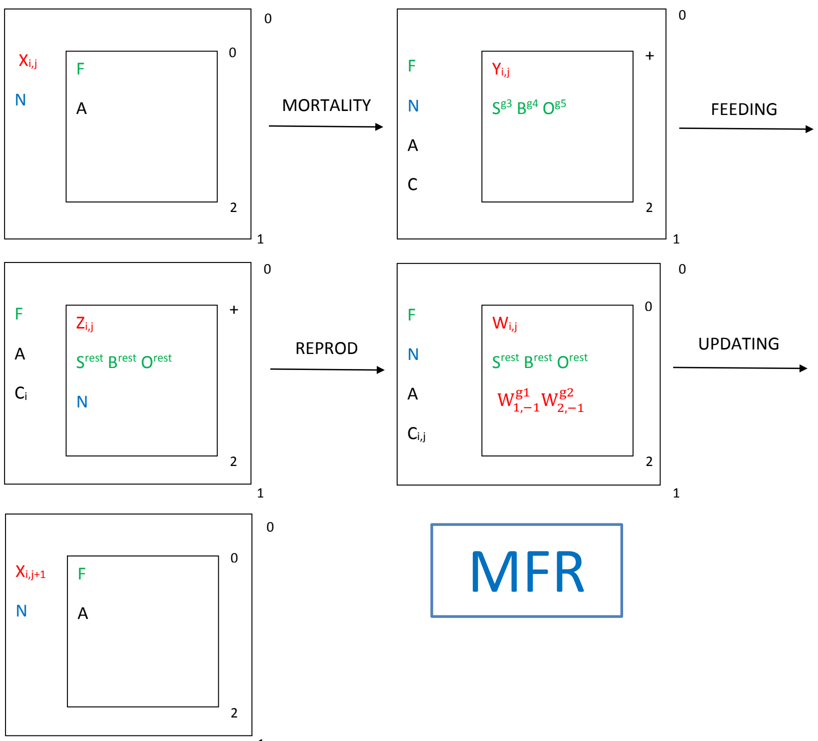
$$r_{27} \equiv [\, W_{i,j}\,]_2^0 \longrightarrow X_{i,j+1}\, [\ ]_2^0, \text{ for } \begin{cases} 1 \leq i \leq 2 \\ -1 \leq j < k_{i,5} \end{cases}$$

$$r_{28} \equiv F\ [\ ]_2^0 \longrightarrow [\, F\,]_2^0,$$

$$r_{29} \equiv C_{i,j}\ [\ ]_2^0 \longrightarrow X_{i,j+1}\, [\ ]_2^0, \text{ for } \begin{cases} 1 \leq i \leq 2 \\ 0 \leq j < k_{i,5} \end{cases}$$

$$r_{30} \equiv A\ [\ ]_2^0 \longrightarrow [\, A\,]_2^0,$$

EXECUTION OF THE MODEL



Mortality - Reproduction - Feeding

Notations:

Related with Giant Pandas (for male $i = 1$, for female $i = 2$):

- $k_{i,1}$: age at which subadult size is reached.
- $k_{i,2}$: age at which youth adult size is reached.
- $k_{i,3}$: age at which mid-adult size is reached.
- $k_{i,4,1}$: age at which elderly (from 17 to 26) size is reached ($k_{i,4,1} = 17$).
- $k_{i,4,2}$: age at which elderly (from 27 to 35) size is reached ($k_{i,4,2} = 27$).
- $k_{i,5}$: maximum life expectancy in the ecosystem under feeding conditions.
- $k_{i,6}$: mortality ratio in infancy giant pandas.
- $k_{i,7}$: mortality ratio in subadult giant pandas.
- $k_{i,8}$: mortality ratio in youth adult giant pandas.
- $k_{i,9}$: mortality ratio in mid-adult giant pandas.
- $k_{i,10}$: mortality ratio in elderly (from 17 to 26) giant pandas.
- $k_{i,11}$: mortality ratio in elderly (from 27 to 35) giant pandas.
- g_1: number of male descendants per year.
- g_2: number of female descendants per year.
- g_3: amount of bamboo shoots supplied in the GPBB (kg) during a year.
- g_4: amount of bamboo supplied in the GPBB (kg) during a year.
- g_5: amount of other food (i.e. apple, meat, milk) supplied in the GPBB (kg) during a year.
- $f_{i,1}$: amount of bamboo shoots necessary per year (kg) according to the energetic requirements of the infancy giant pandas.
- $f_{i,2}$: amount of bamboo necessary per year (kg) according to the energetic requirements of the infancy giant pandas.

- $f_{i,3}$: amount of other foods necessary per year (kg) according to the energetic requirements of the infancy giant pandas.

- $f_{i,4}$: amount of bamboo shoots necessary per year (kg) according to the energetic requirements of the subadult giant pandas.

- $f_{i,5}$: amount of bamboo necessary per year (kg) according to the energetic requirements of the subadult giant pandas.

- $f_{i,6}$: amount of other foods necessary per year (kg) according to the energetic requirements of the subadult giant pandas.

- $f_{i,7}$: amount of bamboo shoots necessary per year (kg) according to the energetic requirements of the adult and elderly giant pandas.

- $f_{i,8}$: amount of bamboo necessary per year (kg) according to the energetic requirements of the adult and elderly giant pandas.

- $f_{i,9}$: amount of other foods necessary per year (kg) according to the energetic requirements of the adult and elderly giant pandas.

- $cmin$: minimum number of rescued giant pandas per year.

- $cmax$: maximum number of rescued giant pandas per year.

- $cmaxage$: maximum age of rescued giant pandas.

- pc_c: probability to have c rescued individuals.

- pg_i: probability for rescued individuals to have gender i.

- pa_j: probability for rescued individuals to have age j.

Symbols in the model (for male $i = 1$, for female $i = 2$):

- $q_{i,j}$: the number of giant pandas of age j.

- $X_{i,j}$: individuals of age j before mortality module.

- $Y_{i,j}$: survived individuals of age j.

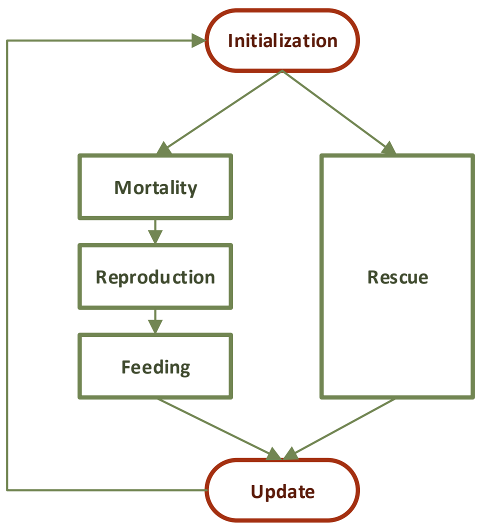
- $Z_{i,j}$: individuals of age j after reproduction module (newborns are denoted as $Z_{i,-1}$ for technical reasons).

- $W_{i,j}$: individuals of age j after feeding module (newborns are denoted as $W_{i,-1}$ for technical reasons).

- $C_{i,j}$: rescued individuals of "age" j.

- S: bamboo shoots.
- B: bamboo.
- O: other food.
- F: auxiliary object to generate new food at the beginning of each time cycle.
- N: auxiliary object to generate newborns at the beginning of each time cycle.
- A: auxiliary object to trigger the rescue

The flow diagram with the modules of the design:



MEMBRANE STRUCTURE

$\mu = [\ [\ ]_2\ ]_1$

INITIAL MULTISETS

$\mathcal{M}_1 = \{X_{i,j}^{q_{i,j}} : 1 \leq i \leq 2,\ 0 \leq j \leq k_{i,5}\}, \quad \mathcal{M}_2 = \{F\ N\ A\}.$

INITIALIZATION RULE

- Generation of objects associated with the food:

$$r_1 \equiv [\, F \,]_2^0 \longrightarrow F \; [\, S^{g_3} \; B^{g_4} \; O^{g_5} \,]_2^+,$$

RESCUED GIANT PANDAS RULES

- Probability to have c rescued individuals:

$$r_2 \equiv [\, A \,]_2^0 \xrightarrow{pc_c} A \; C^c \, [\;]_2^+, \text{ for } cmin \le c \le cmax.$$

- Probability for rescued individuals to have gender i:

$$r_3 \equiv [\, C \xrightarrow{pg_i} C_i \,]_1^0, \text{ for } 1 \le i \le 2$$

- Probability for rescued individuals to have age j:

$$r_4 \equiv [\, C_i \xrightarrow{pa_j} C_{i,j+1+\lfloor \frac{j}{3} \rfloor} \,]_1^0, \text{ for } \begin{cases} 1 \le i \le 2 \\ 0 \le j < cmaxage \end{cases}$$

MORTALITY RULES

- Infancy giant pandas that survive:

$$r_5 \equiv X_{i,j} \, [\;]_2^0 \xrightarrow{1-k_{i,6}} [\, Y_{i,j} \,]_2^+, \text{ for } \begin{cases} 1 \le i \le 2 \\ 0 \le j < k_{i,1} \end{cases}$$

- Infancy giant pandas that die:

$$r_6 \equiv X_{i,j} \, [\;]_2^0 \xrightarrow{k_{i,6}} \lambda \, [\;]_2^+, \text{ for } \begin{cases} 1 \le i \le 2 \\ 0 \le j < k_{i,1} \end{cases}$$

- Subadult giant pandas that survive:

$$r_7 \equiv X_{i,j} \, [\;]_2^0 \xrightarrow{1-k_{i,7}} [\, Y_{i,j} \,]_2^+, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,1} \le j < k_{i,2} \end{cases}$$

- Subadult giant pandas that die:

$$r_8 \equiv X_{i,j} \, [\;]_2^0 \xrightarrow{k_{i,7}} \lambda \, [\;]_2^+, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,1} \le j < k_{i,2} \end{cases}$$

- Youth adult giant pandas that survive:

$$r_9 \equiv X_{i,j} \, [\;]_2^0 \xrightarrow{1-k_{i,8}} [\, Y_{i,j} \,]_2^+, \text{ for } \begin{cases} 1 \leq i \leq 2 \\ k_{i,2} \leq j < k_{i,3} \end{cases}$$

- Youth adult giant pandas that die:

$$r_{10} \equiv X_{i,j} \, [\;]_2^0 \xrightarrow{k_{i,8}} \lambda \, [\;]_2^+, \text{ for } \begin{cases} 1 \leq i \leq 2 \\ k_{i,2} \leq j < k_{i,3} \end{cases}$$

- Mid-adult giant pandas that survive:

$$r_{11} \equiv X_{i,j} \, [\;]_2^0 \xrightarrow{1-k_{i,9}} [\, Y_{i,j} \,]_2^+, \text{ for } \begin{cases} 1 \leq i \leq 2 \\ k_{i,3} \leq j < k_{i,4,1} \end{cases}$$

- Mid-adult giant pandas that die:

$$r_{12} \equiv X_{i,j} \, [\;]_2^0 \xrightarrow{k_{i,9}} \lambda \, [\;]_2^+, \text{ for } \begin{cases} 1 \leq i \leq 2 \\ k_{i,3} \leq j < k_{i,4,1} \end{cases}$$

- Elderly (from 17 to 26) giant pandas that survive:

$$r_{13} \equiv X_{i,j} \, [\;]_2^0 \xrightarrow{1-k_{i,10}} [\, Y_{i,j} \,]_2^+, \text{ for } \begin{cases} 1 \leq i \leq 2 \\ k_{i,4,1} \leq j < k_{i,4,2} \end{cases}$$

- Elderly (from 17 to 26) giant pandas that die:

$$r_{14} \equiv X_{i,j} \, [\;]_2^0 \xrightarrow{k_{i,11}} \lambda \, [\;]_2^+, \text{ for } \begin{cases} 1 \leq i \leq 2 \\ k_{i,4,1} \leq j < k_{i,4,2} \end{cases}$$

- Elderly (from 27 to 35) giant pandas that survive:

$$r_{15} \equiv X_{i,j} \, [\;]_2^0 \xrightarrow{1-k_{i,11}} [\, Y_{i,j} \,]_2^+, \text{ for } \begin{cases} 1 \leq i \leq 2 \\ k_{i,4,2} \leq j < k_{i,5} \end{cases}$$

- Elderly (from 27 to 35) giant pandas that die:

$$r_{16} \equiv X_{i,j} \, [\;]_2^0 \xrightarrow{k_{i,11}} \lambda \, [\;]_2^+, \text{ for } \begin{cases} 1 \leq i \leq 2 \\ k_{i,4,2} \leq j < k_{i,5} \end{cases}$$

- Giant pandas which reach the maximum life expectancy:

$$r_{17} \equiv X_{i,k_{i,5}} \, [\;]_2^0 \longrightarrow \lambda \, [\;]_2^+, \text{ for } 1 \leq i \leq 2$$

REPRODUCTION RULES

- Rules associated with newborns:

$$r_{18} \equiv [\,N\,]_2^{+} \longrightarrow \; N\,[\,Z_{1,-1}^{g_1}\; Z_{2,-1}^{g_2}\,]_2^{+},$$

- Growth rules:

$$r_{19} \equiv [\,Y_{i,j} \;\longrightarrow\; Z_{i,j}\,]_2^{+}, \text{ for } \begin{cases} 1 \le i \le 2 \\ 0 \le j < k_{i,5} \end{cases}$$

FEEDING RULES

- Feeding process for infancy giant pandas:

$$r_{20} \equiv [\,Z_{i,j}\; S^{f_{i,1}}\; B^{f_{i,2}}\; O^{f_{i,3}}\,]_2^{+} \;\longrightarrow\; [\,W_{i,j}\,]_2^{0}, \text{ for } \begin{cases} 1 \le i \le 2 \\ 0 \le j < k_{i,1} \end{cases}$$

- Feeding process for subadult giant pandas:

$$r_{21} \equiv [\,Z_{i,j}\; S^{f_{i,4}}\; B^{f_{i,5}}\; O^{f_{i,6}}\,]_2^{+} \;\longrightarrow\; [\,W_{i,j}\,]_2^{0}, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,1} \le j < k_{i,2} \end{cases}$$

- Feeding process for adult and elderly giant pandas:

$$r_{22} \equiv [\,Z_{i,j}\; S^{f_{i,7}}\; B^{f_{i,8}}\; O^{f_{i,9}}\,]_2^{+} \;\longrightarrow\; [\,W_{i,j}\,]_2^{0}, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,2} \le j < k_{i,5} \end{cases}$$

- Individuals that will be considered as newborn in the next loop:

$$r_{23} \equiv [\,Z_{i,-1}\,]_2^{+} \;\longrightarrow\; [\,W_{i,-1}\,]_2^{0}, \text{ for } 1 \le i \le 2.$$

UPDATING RULES

- Elimination of the remaining food.

$$r_{24} \equiv [\,S \longrightarrow \lambda]_2^{0}$$
$$r_{25} \equiv [\,B \longrightarrow \lambda]_2^{0}$$
$$r_{26} \equiv [\,O \longrightarrow \lambda]_2^{0}$$

- Preparation for the beginning of a new cycle.

$$r_{27} \equiv [\, W_{i,j} \,]_2^0 \longrightarrow X_{i,j+1} [\ ]_2^0, \text{ for } \begin{cases} 1 \leq i \leq 2 \\ -1 \leq j < k_{i,5} \end{cases}$$

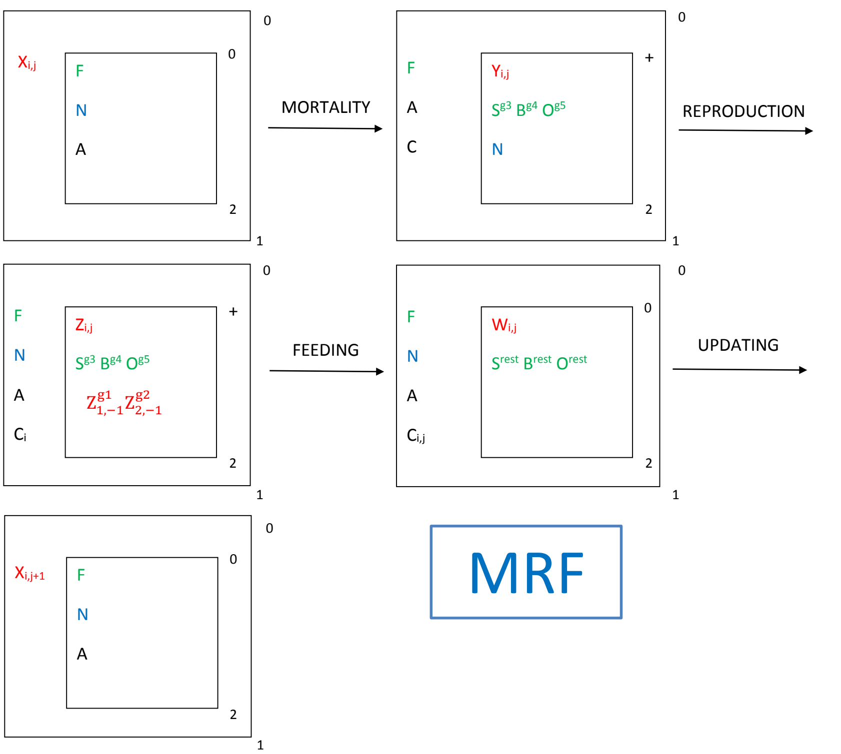
$$r_{28} \equiv F\ [\ ]_2^0 \longrightarrow [\, F \,]_2^0,$$

$$r_{29} \equiv C_{i,j}\ [\ ]_2^0 \longrightarrow X_{i,j+1} [\ ]_2^0, \text{ for } \begin{cases} 1 \leq i \leq 2 \\ 0 \leq j < k_{i,5} \end{cases}$$

$$r_{30} \equiv A\ [\ ]_2^0 \longrightarrow [\, A \,]_2^0,$$

$$r_{31} \equiv N\ [\ ]_2^0 \longrightarrow [\, N \,]_2^0,$$

EXECUTION OF THE MODEL



Reproduction - Feeding - Mortality

Notations:

Related with Giant Pandas (for male $i = 1$, for female $i = 2$):

- $k_{i,1}$: age at which subadult size is reached.
- $k_{i,2}$: age at which youth adult size is reached.
- $k_{i,3}$: age at which mid-adult size is reached.
- $k_{i,4,1}$: age at which elderly (from 17 to 26) size is reached ($k_{i,4,1} = 17$).
- $k_{i,4,2}$: age at which elderly (from 27 to 35) size is reached ($k_{i,4,2} = 27$).
- $k_{i,5}$: maximum life expectancy in the ecosystem under feeding conditions.
- $k_{i,6}$: mortality ratio in infancy giant pandas.
- $k_{i,7}$: mortality ratio in subadult giant pandas.
- $k_{i,8}$: mortality ratio in youth adult giant pandas.
- $k_{i,9}$: mortality ratio in mid-adult giant pandas.
- $k_{i,10}$: mortality ratio in elderly (from 17 to 26) giant pandas.
- $k_{i,11}$: mortality ratio in elderly (from 27 to 35) giant pandas.
- g_1: number of male descendants per year.
- g_2: number of female descendants per year.
- g_3: amount of bamboo shoots supplied in the GPBB (kg) during a year.
- g_4: amount of bamboo supplied in the GPBB (kg) during a year.
- g_5: amount of other food (i.e. apple, meat, milk) supplied in the GPBB (kg) during a year.
- $f_{i,1}$: amount of bamboo shoots necessary per year (kg) according to the energetic requirements of the infancy giant pandas.
- $f_{i,2}$: amount of bamboo necessary per year (kg) according to the energetic requirements of the infancy giant pandas.

- $f_{i,3}$: amount of other foods necessary per year (kg) according to the energetic requirements of the infancy giant pandas.

- $f_{i,4}$: amount of bamboo shoots necessary per year (kg) according to the energetic requirements of the subadult giant pandas.

- $f_{i,5}$: amount of bamboo necessary per year (kg) according to the energetic requirements of the subadult giant pandas.

- $f_{i,6}$: amount of other foods necessary per year (kg) according to the energetic requirements of the subadult giant pandas.

- $f_{i,7}$: amount of bamboo shoots necessary per year (kg) according to the energetic requirements of the adult and elderly giant pandas.

- $f_{i,8}$: amount of bamboo necessary per year (kg) according to the energetic requirements of the adult and elderly giant pandas.

- $f_{i,9}$: amount of other foods necessary per year (kg) according to the energetic requirements of the adult and elderly giant pandas.

- $cmin$: minimum number of rescued giant pandas per year.

- $cmax$: maximum number of rescued giant pandas per year.

- $cmaxage$: maximum age of rescued giant pandas.

- pc_c: probability to have c rescued individuals.

- pg_i: probability for rescued individuals to have gender i.

- pa_j: probability for rescued individuals to have age j.

Symbols in the model (for male $i = 1$, for female $i = 2$):

- $q_{i,j}$: the number of giant pandas of age j.

- $X_{i,j}$: individuals of age j before reproduction module.

- $Y_{i,j}$: individuals of age j within feeding module.

- $Z_{i,j}$: individuals of age j within mortality module.

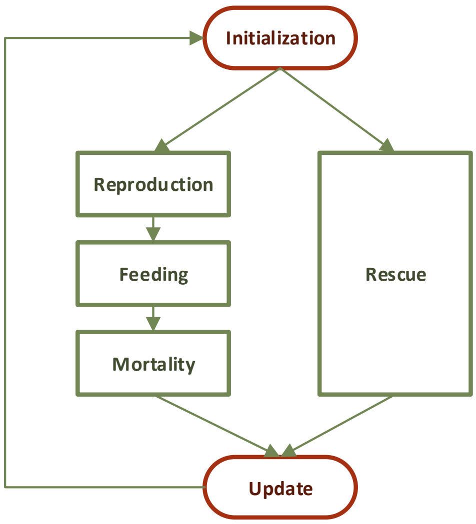
- $W_{i,j}$: survived individuals of age j.

- $C_{i,j}$: rescued individuals of “age” j.

- S: bamboo shoots.

- B: bamboo.
- O: other food.
- F: auxiliary object to generate new food at the beginning of each time cycle.
- N: auxiliary object to generate newborns at the beginning of each time cycle.
- A: auxiliary object to trigger the rescue

The flow diagram with the modules of the design:



MEMBRANE STRUCTURE

$\mu = [\;[\;]_2\;]_1$

INITIAL MULTISETS

$\mathcal{M}_1 = \{X_{i,j}^{q_{i,j}} : 1 \le i \le 2,\ 1 \le j \le k_{i,5}\}, \quad \mathcal{M}_2 = \{F\ N\ A\}.$

INITIALIZATION RULE

- Generation of objects associated with the food:

$$r_1 \equiv [\, F \,]_2^0 \longrightarrow F \; [\, S^{g_3} \; B^{g_4} \; O^{g_5} \,]_2^+,$$

REPRODUCTION RULES

- Rules associated with newborns:

$$r_2 \equiv [\, N \,]_2^0 \longrightarrow \; N \, [\, Y_{1,0}^{g_1} \; Y_{2,0}^{g_2} \,]_2^+,$$

- Growth rules:

$$r_3 \equiv X_{i,j} \; [\;]_2^0 \longrightarrow [\, Y_{i,j} \,]_2^+, \text{ for } \begin{cases} 1 \le i \le 2 \\ 1 \le j \le k_{i,5} \end{cases}$$

RESCUED GIANT PANDAS RULES

- Probability to have c rescued individuals:

$$r_4 \equiv [\, A \,]_2^0 \xrightarrow{pc_c} A \; C^c \, [\;]_2^+, \text{ for } cmin \le c \le cmax.$$

- Probability for a rescued individuals to have gender i:

$$r_5 \equiv [\, C \xrightarrow{pg_i} C_i \,]_1^0, \text{ for } 1 \le i \le 2$$

- Probability for a rescued individuals to have age j:

$$r_6 \equiv [\, C_i \xrightarrow{pa_j} C_{i,j+1+\lfloor \frac{j}{3} \rfloor} \,]_1^0, \text{ for } \begin{cases} 1 \le i \le 2 \\ 0 \le j < cmaxage \end{cases}$$

FEEDING

- Feeding process for infancy giant pandas:

$$r_7 \equiv [\, Y_{i,j} \; S^{f_{i,1}} \; B^{f_{i,2}} \; O^{f_{i,3}} \longrightarrow \; Z_{i,j} \,]_2^+, \text{ for } \begin{cases} 1 \le i \le 2 \\ 0 \le j < k_{i,1} \end{cases}$$

- Feeding process for subadult giant pandas:

$$r_8 \equiv [\, Y_{i,j} \; S^{f_{i,4}} \; B^{f_{i,5}} \; O^{f_{i,6}} \longrightarrow Z_{i,j} \,]_2^0, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,1} \le j < k_{i,2} \end{cases}$$

- Feeding process for adult and elderly giant pandas:

$$r_9 \equiv [\, Y_{i,j} \; S^{f_{i,7}} \; B^{f_{i,8}} \; O^{f_{i,9}} \longrightarrow Z_{i,j} \,]_2^0, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,2} \le j \le k_{i,5} \end{cases}$$

MORTALITY RULES

- Infancy giant pandas that survive:

$$r_{10} \equiv [\, Z_{i,j} \,]_2^+ \xrightarrow{1-k_{i,6}} [\, W_{i,j} \,]_2^0, \text{ for } \begin{cases} 1 \le i \le 2 \\ 0 \le j < k_{i,1} \end{cases}$$

- Infancy giant pandas that die:

$$r_{11} \equiv [\, Z_{i,j} \,]_2^+ \xrightarrow{k_{i,6}} \lambda [\;]_2^0, \text{ for } \begin{cases} 1 \le i \le 2 \\ 0 \le j < k_{i,1} \end{cases}$$

- Subadult giant pandas that survive:

$$r_{12} \equiv [\, Z_{i,j} \,]_2^+ \xrightarrow{1-k_{i,7}} [\, W_{i,j} \,]_2^0, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,1} \le j < k_{i,2} \end{cases}$$

- Subadult giant pandas that die:

$$r_{13} \equiv [\, Z_{i,j} \,]_2^+ \xrightarrow{k_{i,7}} \lambda [\;]_2^0, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,1} \le j < k_{i,2} \end{cases}$$

- Youth adult giant pandas that survive:

$$r_{14} \equiv [\, Z_{i,j} \,]_2^+ \xrightarrow{1-k_{i,8}} [\, W_{i,j} \,]_2^0, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,2} \le j < k_{i,3} \end{cases}$$

- Youth adult giant pandas that die:

$$r_{15} \equiv [\, Z_{i,j} \,]_2^+ \xrightarrow{k_{i,8}} \lambda [\;]_2^0, \text{ for } \begin{cases} 1 \le i \le 2 \\ k_{i,2} \le j < k_{i,3} \end{cases}$$

- Mid-adult giant pandas that survive:

$$r_{16} \equiv [\, Z_{i,j} \,]_2^+ \xrightarrow{1-k_{i,9}} [\, W_{i,j} \,]_2^0, \text{ for } \begin{cases} 1 \leq i \leq 2 \\ k_{i,3} \leq j < k_{i,4,1} \end{cases}$$

- Mid-adult giant pandas that die:

$$r_{17} \equiv [\, Z_{i,j} \,]_2^+ \xrightarrow{k_{i,9}} \lambda [\ ]_2^0, \text{ for } \begin{cases} 1 \leq i \leq 2 \\ k_{i,3} \leq j < k_{i,4,1} \end{cases}$$

- Elderly (from 17 to 26) giant pandas that survive:

$$r_{18} \equiv [\, Z_{i,j} \,]_2^+ \xrightarrow{1-k_{i,10}} [\, W_{i,j} \,]_2^0, \text{ for } \begin{cases} 1 \leq i \leq 2 \\ k_{i,4,1} \leq j < k_{i,4,2} \end{cases}$$

- Elderly (from 17 to 26) giant pandas that die:

$$r_{19} \equiv [\, Z_{i,j} \,]_2^+ \xrightarrow{k_{i,10}} \lambda [\ ]_2^0, \text{ for } \begin{cases} 1 \leq i \leq 2 \\ k_{i,4,1} \leq j < k_{i,4,2} \end{cases}$$

- Elderly (from 27 to 35) giant pandas that survive:

$$r_{20} \equiv [\, Z_{i,j} \,]_2^+ \xrightarrow{1-k_{i,11}} [\, W_{i,j} \,]_2^0, \text{ for } \begin{cases} 1 \leq i \leq 2 \\ k_{i,4,2} \leq j < k_{i,5} \end{cases}$$

- Elderly (from 27 to 35) giant pandas that die:

$$r_{21} \equiv [\, Z_{i,j} \,]_2^+ \xrightarrow{k_{i,11}} \lambda [\ ]_2^0, \text{ for } \begin{cases} 1 \leq i \leq 2 \\ k_{i,4,2} \leq j < k_{i,5} \end{cases}$$

- Giant pandas which reach the maximum life expectancy:

$$r_{22} \equiv [\, Z_{i,k_{i,5}} \,]_2^+ \longrightarrow \lambda [\ ]_2^+, \text{ for } 1 \leq i \leq 2$$

UPDATING RULES

- Elimination of the remaining food.

$$r_{23} \equiv [\, S \longrightarrow \lambda]_2^0$$
$$r_{24} \equiv [\, B \longrightarrow \lambda]_2^0$$
$$r_{25} \equiv [\, O \longrightarrow \lambda]_2^0$$

- Preparation for the beginning of a new cycle.

$$r_{26} \equiv [\, W_{i,j} \,]_2^0 \longrightarrow X_{i,j+1} [\ ]_2^0, \text{ for } \begin{cases} 1 \leq i \leq 2 \\ 0 \leq j < k_{i,5} \end{cases}$$

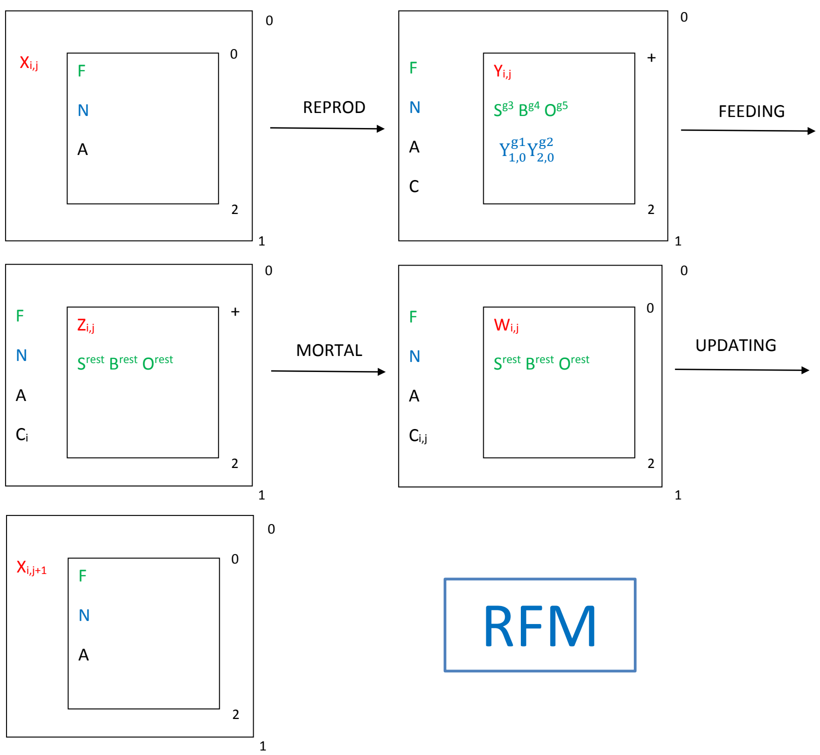
$$r_{27} \equiv F\ [\ ]_2^0 \longrightarrow [\, F \,]_2^0,$$

$$r_{28} \equiv C_{i,j}\ [\ ]_2^0 \longrightarrow X_{i,j+1} [\ ]_2^0, \text{ for } \begin{cases} 1 \leq i \leq 2 \\ 0 \leq j < k_{i,5} \end{cases}$$

$$r_{29} \equiv N\ [\ ]_2^0 \longrightarrow [\, N \,]_2^0,$$

$$r_{30} \equiv A\ [\ ]_2^0 \longrightarrow [\, A \,]_2^0,$$

EXECUTION OF THE MODEL



Reproduction - Mortality - Feeding

Notations:

Related with Giant Pandas (for male $i = 1$, for female $i = 2$):

- $k_{i,1}$: age at which subadult size is reached.
- $k_{i,2}$: age at which youth adult size is reached.
- $k_{i,3}$: age at which mid-adult size is reached.
- $k_{i,4,1}$: age at which elderly (from 17 to 26) size is reached ($k_{i,4,1} = 17$).
- $k_{i,4,2}$: age at which elderly (from 27 to 35) size is reached ($k_{i,4,2} = 27$).
- $k_{i,5}$: maximum life expectancy in the ecosystem under feeding conditions.
- $k_{i,6}$: mortality ratio in infancy giant pandas.
- $k_{i,7}$: mortality ratio in subadult giant pandas.
- $k_{i,8}$: mortality ratio in youth adult giant pandas.
- $k_{i,9}$: mortality ratio in mid-adult giant pandas.
- $k_{i,10}$: mortality ratio in elderly (from 17 to 26) giant pandas.
- $k_{i,11}$: mortality ratio in elderly (from 27 to 35) giant pandas.
- g_1: number of male descendants per year.
- g_2: number of female descendants per year.
- g_3: amount of bamboo shoots supplied in the GPBB (kg) during a year.
- g_4: amount of bamboo supplied in the GPBB (kg) during a year.
- g_5: amount of other food (i.e. apple, meat, milk) supplied in the GPBB (kg) during a year.
- $f_{i,1}$: amount of bamboo shoots necessary per year (kg) according to the energetic requirements of the infancy giant pandas.
- $f_{i,2}$: amount of bamboo necessary per year (kg) according to the energetic requirements of the infancy giant pandas.

- $f_{i,3}$: amount of other foods necessary per year (kg) according to the energetic requirements of the infancy giant pandas.

- $f_{i,4}$: amount of bamboo shoots necessary per year (kg) according to the energetic requirements of the subadult giant pandas.

- $f_{i,5}$: amount of bamboo necessary per year (kg) according to the energetic requirements of the subadult giant pandas.

- $f_{i,6}$: amount of other foods necessary per year (kg) according to the energetic requirements of the subadult giant pandas.

- $f_{i,7}$: amount of bamboo shoots necessary per year (kg) according to the energetic requirements of the adult and elderly giant pandas.

- $f_{i,8}$: amount of bamboo necessary per year (kg) according to the energetic requirements of the adult and elderly giant pandas.

- $f_{i,9}$: amount of other foods necessary per year (kg) according to the energetic requirements of the adult and elderly giant pandas.

- $cmin$: minimum number of rescued giant pandas per year.

- $cmax$: maximum number of rescued giant pandas per year.

- $cmaxage$: maximum age of rescued giant pandas.

- pc_c: probability to have c rescued individuals.

- pg_i: probability for rescued individuals to have gender i.

- pa_j: probability for rescued individuals to have age j.

Symbols in the model (for male $i = 1$, for female $i = 2$):

- $q_{i,j}$: the number of giant pandas of age j.

- $X_{i,j}$: individuals of age j before reproduction module.

- $Y_{i,j}$: individuals of age j within mortality module.

- $Z_{i,j}$: survived individuals of age j.

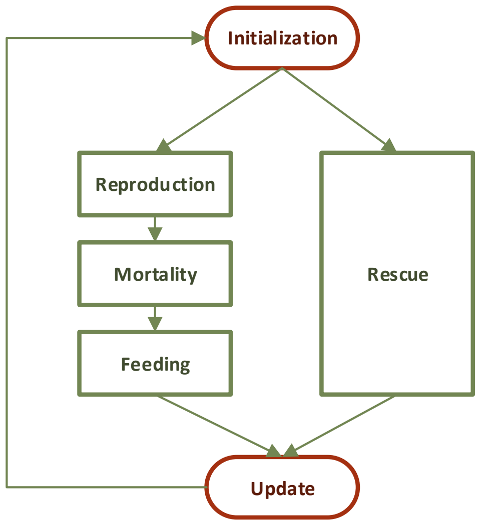
- $W_{i,j}$: individuals of age j after feeding module.

- $C_{i,j}$: rescued individuals of “age” j.

- S: bamboo shoots.

- B: bamboo.
- O: other food.
- F: auxiliary object to generate new food at the beginning of each time cycle.
- N: auxiliary object to generate newborns at the beginning of each time cycle.
- A: auxiliary object to trigger the rescue

The flow diagram with the modules of the design:



MEMBRANE STRUCTURE

$\mu = [\ [\ ]_2\ ]_1$

INITIAL MULTISETS

$\mathcal{M}_1 = \{X_{i,j}^{q_{i,j}} : 1 \leq i \leq 2,\ 1 \leq j \leq k_{i,5}\}, \quad \mathcal{M}_2 = \{F\ N\ A\}.$

INITIALIZATION RULE

- Generation of objects associated with the food:

$$r_1 \equiv [\, F \,]_2^0 \longrightarrow F \; [\, S^{g_3} \; B^{g_4} \; O^{g_5} \,]_2^+,$$

REPRODUCTION RULES

- Rules associated with newborns:

$$r_2 \equiv [\, N \,]_2^0 \longrightarrow \; N \; [\, Y_{1,0}^{g_1} \; Y_{2,0}^{g_2} \,]_2^+,$$

- Growth rules:

$$r_3 \equiv [\, X_{i,j} \,]_2^0 \; \longrightarrow \; [\, Y_{i,j} \,]_2^+, \text{ for } \begin{cases} 1 \le i \le 2 \\ 1 \le j \le k_{i,5} \end{cases}$$

RESCUED GIANT PANDAS RULES

- Probability to have c rescued individuals:

$$r_4 \equiv [\, A \,]_2^0 \xrightarrow{pc_c} A \; C^c \, [\;]_2^+, \text{ for } cmin \le c \le cmax.$$

- Probability for rescued individuals to have gender i:

$$r_5 \equiv [\, C \; \xrightarrow{pg_i} C_i \,]_1^0, \text{ for } 1 \le i \le 2$$

- Probability for rescued individuals to have age j:

$$r_6 \equiv [\, C_i \; \xrightarrow{pa_j} C_{i,j+1+\lfloor \frac{j}{3} \rfloor} \,]_1^0, \text{ for } \begin{cases} 1 \le i \le 2 \\ 0 \le j < cmaxage \end{cases}$$

MORTALITY RULES

- Infancy giant pandas that survive:

$$r_7 \equiv [\, Y_{i,j} \; \xrightarrow{1-k_{i,6}} \; Z_{i,j} \,]_2^+, \text{ for } \begin{cases} 1 \le i \le 2 \\ 0 \le j < k_{i,1} \end{cases}$$

- Infancy giant pandas that die:

$$r_8 \equiv [\, Y_{i,j} \xrightarrow{k_{i,6}} \lambda\,]_2^+ \text{, for } \begin{cases} 1 \le i \le 2 \\ 0 \le j < k_{i,1} \end{cases}$$

- Subadult giant pandas that survive:

$$r_9 \equiv [\, Y_{i,j} \xrightarrow{1-k_{i,7}} Z_{i,j}\,]_2^+ \text{, for } \begin{cases} 1 \le i \le 2 \\ k_{i,1} \le j < k_{i,2} \end{cases}$$

- Subadult giant pandas that die:

$$r_{10} \equiv [\, Y_{i,j} \xrightarrow{k_{i,7}} \lambda\,]_2^+ \text{, for } \begin{cases} 1 \le i \le 2 \\ k_{i,1} \le j < k_{i,2} \end{cases}$$

- Youth adult giant pandas that survive:

$$r_{11} \equiv [\, Y_{i,j} \xrightarrow{1-k_{i,8}} Z_{i,j}\,]_2^+ \text{, for } \begin{cases} 1 \le i \le 2 \\ k_{i,2} \le j < k_{i,3} \end{cases}$$

- Youth adult giant pandas that die:

$$r_{12} \equiv [\, Y_{i,j} \xrightarrow{k_{i,8}} \lambda\,]_2^+ \text{, for } \begin{cases} 1 \le i \le 2 \\ k_{i,2} \le j < k_{i,3} \end{cases}$$

- Mid-adult giant pandas that survive:

$$r_{13} \equiv [\, Y_{i,j} \xrightarrow{1-k_{i,9}} Z_{i,j}\,]_2^+ \text{, for } \begin{cases} 1 \le i \le 2 \\ k_{i,3} \le j < k_{i,4,1} \end{cases}$$

- Mid-adult giant pandas that die:

$$r_{14} \equiv [\, Y_{i,j} \xrightarrow{k_{i,9}} \lambda\,]_2^+ \text{, for } \begin{cases} 1 \le i \le 2 \\ k_{i,3} \le j < k_{i,4,1} \end{cases}$$

- Elderly (from 17 to 26) giant pandas that survive:

$$r_{15} \equiv [\, Y_{i,j} \xrightarrow{1-k_{i,10}} Z_{i,j}\,]_2^+ \text{, for } \begin{cases} 1 \le i \le 2 \\ k_{i,4,1} \le j < k_{i,4,2} \end{cases}$$

- Elderly (from 17 to 26) giant pandas that die:

$$r_{16} \equiv [\, Y_{i,j} \xrightarrow{k_{i,10}} \lambda \,]_2^+, \text{ for } \begin{cases} 1 \leq i \leq 2 \\ k_{i,4,1} \leq j < k_{i,4,2} \end{cases}$$

- Elderly (from 27 to 35) giant pandas that survive:

$$r_{17} \equiv [\, Y_{i,j} \xrightarrow{1-k_{i,11}} Z_{i,j} \,]_2^+, \text{ for } \begin{cases} 1 \leq i \leq 2 \\ k_{i,4,2} \leq j < k_{i,5} \end{cases}$$

- Elderly (from 27 to 35) giant pandas that die:

$$r_{18} \equiv [\, Y_{i,j} \xrightarrow{k_{i,11}} \lambda \,]_2^+, \text{ for } \begin{cases} 1 \leq i \leq 2 \\ k_{i,4,2} \leq j < k_{i,5} \end{cases}$$

- Giant pandas which reach the maximum life expectancy:

$$r_{19} \equiv [\, Y_{i,k_{i,5}} \longrightarrow \lambda \,]_2^+, \text{ for } 1 \leq i \leq 2$$

FEEDING RULES

- Feeding process for infancy giant pandas:

$$r_{20} \equiv [\, Z_{i,j} \; S^{f_{i,1}} \; B^{f_{i,2}} \; O^{f_{i,3}} \,]_2^+ \longrightarrow [\, W_{i,j} \,]_2^0, \text{ for } \begin{cases} 1 \leq i \leq 2 \\ 0 \leq j < k_{i,1} \end{cases}$$

- Feeding process for subadult giant pandas:

$$r_{21} \equiv [\, Z_{i,j} \; S^{f_{i,4}} \; B^{f_{i,5}} \; O^{f_{i,6}} \,]_2^+ \longrightarrow [\, W_{i,j} \,]_2^0, \text{ for } \begin{cases} 1 \leq i \leq 2 \\ k_{i,1} \leq j < k_{i,2} \end{cases}$$

- Feeding process for adult and elderly giant pandas:

$$r_{22} \equiv [\, Z_{i,j} \; S^{f_{i,7}} \; B^{f_{i,8}} \; O^{f_{i,9}} \,]_2^+ \longrightarrow [\, W_{i,j} \,]_2^0, \text{ for } \begin{cases} 1 \leq i \leq 2 \\ k_{i,2} \leq j < k_{i,5} \end{cases}$$

UPDATING RULES

- Elimination of the remaining food.

$$r_{23} \equiv [\, S \longrightarrow \lambda]_2^0$$
$$r_{24} \equiv [\, B \longrightarrow \lambda]_2^0$$
$$r_{25} \equiv [\, O \longrightarrow \lambda]_2^0$$

- Preparation for the beginning of a new cycle.

$$r_{26} \equiv [\, W_{i,j} \ ]_2^0 \longrightarrow X_{i,j+1} [\ ]_2^0, \text{ for } \begin{cases} 1 \leq i \leq 2 \\ 0 \leq j < k_{i,5} \end{cases}$$

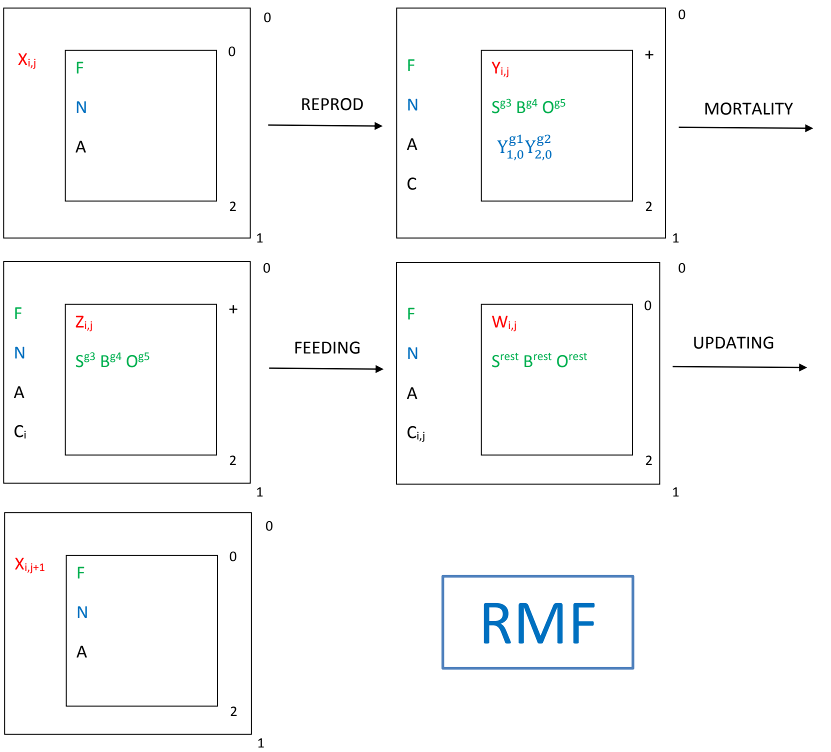
$$r_{27} \equiv F \ [\ ]_2^0 \longrightarrow [\, F \ ]_2^0,$$

$$r_{28} \equiv C_{i,j} \ [\ ]_2^0 \longrightarrow X_{i,j+1} [\ ]_2^0, \text{ for } \begin{cases} 1 \leq i \leq 2 \\ 0 \leq j < k_{i,5} \end{cases}$$

$$r_{29} \equiv N \ [\ ]_2^0 \longrightarrow [\, N \ ]_2^0,$$

$$r_{30} \equiv A \ [\ ]_2^0 \longrightarrow [\, A \ ]_2^0,$$

EXECUTION OF THE MODEL



B Model Robustness

Results provided by simulating each of the six variants with real input data from 2006 to 2014.

			FMR					
MALES			FEMALES			TOTALS		
Simulation	Real Data	Dev.	Simulation	Real Data	Dev.	Simulation	Real Data	Dev.
27	30	-10,00%	35	34	2,94%	62	64	-3,13%
32	31	3,23%	41	40	2,50%	73	71	2,82%
38	42	-9,52%	46	45	2,22%	84	87	-3,45%
43	42	2,38%	52	49	6,12%	95	91	4,40%
48	50	-4,00%	57	52	9,62%	105	102	2,94%
53	52	1,92%	63	62	1,61%	116	114	1,75%
58	55	5,45%	68	65	4,62%	126	120	5,00%
63	64	-1,56%	73	74	-1,35%	136	138	-1,45%
68	68	0,00%	78	78	0,00%	146	146	0,00%
430	434	0,92%	513	499	2,81%	943	933	1,07%

Figure 1: *FMR*

			FRM					
MALES			FEMALES			TOTALS		
Simulation	Real Data	Dev.	Simulation	Real Data	Dev.	Simulation	Real Data	Dev.
27	30	-10,00%	35	34	2,94%	62	64	-3,13%
32	31	3,23%	41	40	2,50%	73	71	2,82%
38	42	-9,52%	46	45	2,22%	84	87	-3,45%
43	42	2,38%	52	49	6,12%	95	91	4,40%
48	50	-4,00%	57	52	9,62%	105	102	2,94%
53	52	1,92%	63	62	1,61%	116	114	1,75%
58	55	5,45%	68	65	4,62%	126	120	5,00%
63	64	-1,56%	73	74	-1,35%	136	138	-1,45%
68	68	0,00%	78	78	0,00%	146	146	0,00%
430	434	0,92%	513	499	2,81%	943	933	1,07%

Figure 2: *FRM*

			MFR					
MALES			FEMALES			TOTALS		
Simulation	Real Data	Dev.	Simulation	Real Data	Dev.	Simulation	Real Data	Dev.
27	30	-10,00%	35	34	2,94%	62	64	-3,13%
32	31	3,23%	41	40	2,50%	73	71	2,82%
38	42	-9,52%	46	45	2,22%	84	87	-3,45%
43	42	2,38%	52	49	6,12%	95	91	4,40%
48	50	-4,00%	57	52	9,62%	105	102	2,94%
53	52	1,92%	63	62	1,61%	116	114	1,75%
58	55	5,45%	68	65	4,62%	126	120	5,00%
63	64	-1,56%	73	74	-1,35%	136	138	-1,45%
68	68	0,00%	78	78	0,00%	146	146	0,00%
430	434	0,92%	513	499	2,81%	943	933	1,07%

Figure 3: *MFR*

			MRF					
MALES			FEMALES			TOTALS		
Simulation	Real Data	Dev.	Simulation	Real Data	Dev.	Simulation	Real Data	Dev.
27	30	-10,00%	35	34	2,94%	62	64	-3,13%
32	31	3,23%	41	40	2,50%	73	71	2,82%
38	42	-9,52%	46	45	2,22%	84	87	-3,45%
43	42	2,38%	52	49	6,12%	95	91	4,40%
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53	52	1,92%	63	62	1,61%	116	114	1,75%
58	55	5,45%	68	65	4,62%	126	120	5,00%
63	64	-1,56%	73	74	-1,35%	136	138	-1,45%
68	68	0,00%	78	78	0,00%	146	146	0,00%
430	434	0,92%	513	499	2,81%	943	933	1,07%

Figure 4: *MRF*

			RFM					
MALES			FEMALES			TOTALS		
Simulation	Real Data	Dev.	Simulation	Real Data	Dev.	Simulation	Real Data	Dev.
27	30	-10,00%	35	34	2,94%	62	64	-3,13%
32	31	3,23%	41	40	2,50%	73	71	2,82%
38	42	-9,52%	46	45	2,22%	84	87	-3,45%
43	42	2,38%	52	49	6,12%	95	91	4,40%
48	50	-4,00%	57	52	9,62%	105	102	2,94%
53	52	1,92%	63	62	1,61%	116	114	1,75%
58	55	5,45%	68	65	4,62%	126	120	5,00%
63	64	-1,56%	73	74	-1,35%	136	138	-1,45%
68	68	0,00%	78	78	0,00%	146	146	0,00%
430	434	0,92%	513	499	2,81%	943	933	1,07%

Figure 5: *RFM*

			RMF					
MALES			FEMALES			TOTALS		
Simulation	Real Data	Dev.	Simulation	Real Data	Dev.	Simulation	Real Data	Dev.
27	30	-10,00%	35	34	2,94%	62	64	-3,13%
32	31	3,23%	41	40	2,50%	73	71	2,82%
38	42	-9,52%	46	45	2,22%	84	87	-3,45%
43	42	2,38%	52	49	6,12%	95	91	4,40%
48	50	-4,00%	57	52	9,62%	105	102	2,94%
53	52	1,92%	63	62	1,61%	116	114	1,75%
58	55	5,45%	68	65	4,62%	126	120	5,00%
63	64	-1,56%	73	74	-1,35%	136	138	-1,45%
68	68	0,00%	78	78	0,00%	146	146	0,00%
430	434	0,92%	513	499	2,81%	943	933	1,07%

Figure 6: *RMF*