# Animal Farm: An Eco-Grammar System

Maurice H. ter Beek

Leiden Institute for Advanced Computer Science, Universiteit Leiden
P.O. Box 9512, 2300 RA Leiden, The Netherlands, mtbeek@liacs.nl

**Abstract**

An eco-grammar system is used to model George Orwell's *Animal Farm: A Fairy Story.*

## 1 Introduction

Eco-grammar systems were originally introduced in [2] as a framework motivated by Artificial Life (cf. [8]) able to model life-like interactions. Consequently many variants have been introduced and studied (for an extensive survey cf. [5]) mostly with a strong focus on their generative power. The articles in [16] constitute a nice overview.

This note illustrates a glimpse of the modelling power of eco-grammar systems through a rather enhanced eco-grammar system that models George Orwell's acclaimed *Animal Farm: A Fairy Story*. The reason for this note is manyfold.

To begin with, I hope to inspire those working on eco-grammar systems to pursue further research on them with a perspective other than generative power in mind. A return to the original motivation of eco-grammar systems calls for their use in modelling issues stemming from Artificial Life. Even though I merely provide a humourous example in the style of Jürgen Dassow's eco-grammar system modelling MIT's Herbert as a can collecting robot ([6]), it is my belief that also more scientifically challenging issues from Artificial Life can be modelled by eco-grammar systems. Valeria Mihalache set a good example in this direction in [10] by using eco-grammar systems for simulating games.

This note also hints at the use of eco-grammar systems for generating stories. One of the postulates of the multidisciplinary research field Narratology — the study of narrative structure (cf. [1]) — is that stories within the same literary genre follow a common pattern. In [15] Vladimir Propp interpreted a hundred fairy tales in terms of their smallest narrative units, so-called "narratemes", and found that all of them displayed the same narrative structure. This led to the field Semiotic Narratology, on the crossroads of Narratology and Semiotics — the science of signs (cf. [11]) — which has a strong focus on minimal narrative units constituting the so-called "grammar of the plot" or "story grammars".

Closer to home and more recently Solomon Marcus and others associated formal languages to many Romanian fairy tales (cf. [9]). Hierarchies known from Formal Language Theory consequently allowed the classification of certain fairy tales as being more sophisticated than others (cf. [7]). The above considerations show that it would be interesting to model more stories by eco-grammar systems and to search for structural equivalences between them. The same naturally holds for games.

Finally, I celebrate Gheorghe Păun's 50th birthday by bringing together two of Gheorghe Păun's "hobbies". For it is Gheorghe who is the (co-)author of many of the papers on eco-grammar systems — among which the one that introduced the framework — and it is Gheorghe who wrote a sequel ([14]) to George Orwell's other classic novel: *Nineteen Eighty-Four* ([13]).

## 2 Eco-grammar systems

I assume the reader to be familiar with Formal Language Theory (otherwise cf. [17]) — in particular with eco-grammar systems (otherwise cf. [5]) — and to have read George Orwell's *Animal Farm: A Fairy Story* (otherwise read [12]).

Since the specific eco-grammar system used here is based on variants that are well known from the literature — e.g. simple eco-grammar systems ([4]) and reproductive eco-grammar systems ([3]) — the definition is given without much intuitive explanation.

An *eco-grammar system* (of degree $n$, $n \geq 0$) is a construct $\Sigma = (E, \mathcal{A}_1, \mathcal{A}_2, \ldots, \mathcal{A}_n)$, where

- $E = (V_E, P_E)$, where
  - $V_E$ is a finite alphabet, the *environmental alphabet*, and
  - $P_E$ is a finite and complete set of P0L rewriting rules of the form $x \to y$ with $x \in V_E$ and $y \in V_E^+$, the *environmental evolution rules*,

and for $1 \leq i \leq n$

- $\mathcal{A}_i$ is a multiset $\langle A_{i_1}, A_{i_2}, \ldots, A_{i_{k_i}} \rangle$ of *animals* $A_{i_j} = (V_{i_j} \cup \{\sqcup, \dagger\}, P_{i_j}, R_{i_j})$ *of the i-th type*, $1 \leq j \leq k_i$, where
  - $V_{i_j}$ are finite alphabets, the *alphabets of the animals of the i-th type*, $\sqcup \notin V_{i_j}$ is the *reproduction symbol*, and $\dagger \notin V_{i_j}$ is the *death symbol*,
  - $P_{i_j}$ are finite and complete sets of P0L rewriting rules of the form $x \to y$ with $x \in V_{i_j} \cup \{\dagger\}$ and $y \in V_{i_j} \cup \{\dagger\}$, united with pure context-free productions of the form $\alpha \to \beta_1 \sqcup \beta_2 \sqcup \cdots \sqcup \beta_p$ with $\alpha, \beta_f \in V_{i_j}$, $p \geq 2$, and $1 \leq f \leq p$, the *evolution rules of the animals of the i-th type*, and
  - $R_{i_j}$ is a finite set of pure context-sensitive productions of the form $\alpha \to \beta$ for $\alpha, \beta \in V_E^+$, the *action rules of the animals of the i-th type*.

A *state* of $\Sigma$ is a construct $\sigma = (w_E, W_1, W_2, \ldots, W_n)$, where $w_E \in V_E^+$ and each $W_i$, $1 \leq i \leq n$, is a multiset $\langle w_{i_1}, w_{i_2}, \ldots, w_{i_{k_i}} \rangle$ of symbols $w_{i_j} \in V_{i_j} \cup \{\dagger\}$, $1 \leq j \leq k_i$. This $w_E$ is the *environmental state* and these $w_{i_1}$ to $w_{i_{k_i}}$ are the *states of the currently existing animals of the i-th type*.

A change of state of $\Sigma$ is achieved by evolution of the state of every animal as well as by evolution of the environment at each position, except for those positions where animals perform actions. Note that the application of a production containing the reproduction symbol results in an increase of the number of symbols in the multisets of animals.

A state $\sigma = (w_E, W_1, W_2, \ldots, W_n)$ of $\Sigma$ derives a state $\sigma' = (w'_E, W'_1, W'_2, \ldots, W'_n)$ in one step, written as $\sigma \Longrightarrow_\Sigma \sigma'$, iff

- $w_E = x_1 \alpha_{r_1} x_2 \alpha_{r_2} \cdots x_s \alpha_{r_s} x_{s+1}$ and $w'_E = y_1 \beta_{r_1} y_2 \beta_{r_2} \cdots y_s \beta_{r_s} y_{s+1}$, where
  - $\{r_1, r_2, \ldots, r_s\} \subseteq \{i_j \mid 1 \leq j \leq k_i,\ 1 \leq i \leq n\}$,
  - $\alpha_{r_l} \to \beta_{r_l} \in R_{r_l}$, for $1 \leq l \leq s$, and
  - $y_1 y_2 \cdots y_s y_{s+1}$ is the result of applying rules from $P_E$ to $x_1 x_2 \cdots x_s x_{s+1}$,

and for $1 \leq i \leq n$

- $W'_i$ is the multiset obtained from $W_i = \langle w_{i_1}, w_{i_2}, \ldots, w_{i_{k_i}} \rangle$ by putting in $W'_i$ for each $w_{i_j}$, $1 \leq j \leq k_i$, either
  - $w'_{i_j}$ if $w_{i_j} \to w'_{i_j} \in P_{i_j}$ with $w'_{i_j} \in V_{i_j} \cup \{\dagger\}$, or
  - $w_{i_j}^{[1]}, w_{i_j}^{[2]}, \ldots$, and $w_{i_j}^{[p]}$ if $w_{i_j} \to w_{i_j}^{[1]} \sqcup w_{i_j}^{[2]} \sqcup \cdots \sqcup w_{i_j}^{[p]} \in P_{i_j}$ with $w_{i_j}^{[f]} \in V_{i_j}$, for $1 \leq f \leq p$.

Given $\Sigma$ and an initial state $\sigma_0$, the set of state sequences of $\Sigma$ is defined by $Seq(\Sigma, \sigma_0) = \{\{\sigma_i\}_{i=0}^{\infty} \mid \sigma_0 \Longrightarrow_\Sigma \sigma_1 \Longrightarrow_\Sigma \sigma_2 \Longrightarrow_\Sigma \cdots\}$. This set thus contains the *evolution stages* (a.k.a. the *developmental behaviour*) of both the environment and the animals.

## 3 Animal Farm

In this section I present an eco-grammar system $\mathsf{A}$ modelling *Animal Farm: A Fairy Story*.

The environment $\mathsf{E}$ of $\mathsf{A}$ consists of a house — originally named **M**anor Farm — and plenty of **c**orn, **h**ay, and **s**traw. Hence $\mathsf{V_E} = \{M, c, h, s\}$ can serve as the environmental alphabet. Naturally the quantity of corn, hay and straw continuously grows. The evolution of the environment can thus be captured well by the environmental evolution rules $\mathsf{P_E} = \{c \to c, c \to cc, h \to h, h \to hh, s \to s, s \to ss\}$.

Next I describe the animals. They all have essentially the same basic structure, i.e. the same alphabet, the same evolution rules, and the same action rules. However, some of the leading animals — i.e. animals with a name — undertake some more actions throughout the book and thus have some more action rules.

Let $\mathsf{L}$ be an animal. This animal is either alive on the farm (modelled by $L$), or it is alive outside the farm (modelled by ?), or it is dead (modelled by †). The alphabet of $\mathsf{L}$ is thus $\mathsf{V_L} = \{L, ?\}$, and its mortality and mobility are guaranteed by its evolution rules $\mathsf{P_L} = \{L \to L, L \to ?, L \to \dagger, ? \to ?, ? \to L, ? \to \dagger, \dagger \to \dagger\}$. In the course of the book, all animals participate in harvesting corn and hay, and they use straw. I thus choose the actions of $\mathsf{L}$ to be $\mathsf{R_L} = \{ccc \to c, hhh \to h, ss \to s\}$. Hence $\mathsf{L} = (\mathsf{V_L} \cup \{\sqcup, \dagger\}, \mathsf{P_L}, \mathsf{R_L})$. Consequently I build the multisets of animals of $\mathsf{A}$ by replacing $\mathsf{L}$ and $L$ by symbols modelling the animals of the book.

Consider, e.g., the most featured animals in the book: pigs. The vast majority of them are not leading animals and the multiset $\mathsf{Pig}$ thus contains quite a number of animals $\mathsf{P} = (\mathsf{V_P} \cup \{\sqcup, \dagger\}, \mathsf{P_P}, \mathsf{R_P})$, where $\mathsf{V_P} = \{P, ?\}$, $\mathsf{P_P} = \{P \to P, P \to ?, P \to \dagger, ? \to ?, ? \to P, ? \to \dagger, \dagger \to \dagger\}$, and $\mathsf{R_P} = \{ccc \to c, hhh \to h, ss \to s\}$. Moreover the pigs Minimus, Pinkeye, and Squealer are also well described by $\mathsf{Minimus} = \mathsf{Pinkeye} = \mathsf{Squealer} = (\mathsf{V_P} \cup \{\sqcup, \dagger\}, \mathsf{P_P}, \mathsf{R_P})$. However, the main leading animals — the pigs Snowball and Napoleon — are not. For it is Snowball who in Chapter 2 paints out Manor Farm and in its place paints Animal Farm, and it is Napoleon who makes it Manor Farm again in Chapter 10. Hence they are well described by $\mathsf{Snowball} = (\mathsf{V_P} \cup \{\sqcup, \dagger\}, \mathsf{P_P}, \mathsf{R_P} \cup \{M \to A\})$ and $\mathsf{Napoleon} = (\mathsf{V_P} \cup \{\sqcup, \dagger\}, \mathsf{P_P}, \mathsf{R_P} \cup \{A \to M\})$.

To keep $\mathsf{A}$ as simple as possible I do not model birth even though I model death. The only exception is the birth of nine puppies between the dogs Bluebell and Jessie in Chapter 3, as this is an important event in the book. Therefore, the animals $\mathsf{Bluebell}$ and $\mathsf{Jessie}$ are added to the multiset $\mathsf{Dog}$. Compared to other dogs $\mathsf{D}$ they have an augmented set of evolution rules, viz. $\mathsf{Bluebell} = (\mathsf{V_D} \cup \{\sqcup, \dagger\}, \mathsf{P_D} \cup \{D \to D \sqcup D \sqcup D \sqcup D\}, \mathsf{R_D})$ and $\mathsf{Jessie} = (\mathsf{V_D} \cup \{\sqcup, \dagger\}, \mathsf{P_D} \cup \{D \to D \sqcup D \sqcup D \sqcup D \sqcup D\}, \mathsf{R_D})$.

Following the basic structure of animals $\mathsf{L}$ sketched above, the nearly complete list of animals featuring in *Animal Farm: A Fairy Story* — with the capitalized letter in the sort name indicating the symbol replacing $\mathsf{L}$ and $L$, and with leading animals of that sort name added between brackets — becomes Chicken, Dog (Bluebell, Jessie, Pincher), goosE, Goat (Muriel), Horse (Mollie, Boxer, Clover), Man (Mr. Jones, Mrs. Jones, Mr. Frederick, Mr. Whymper, Mr. Pilkington), Pig (Old Major, Snowball, Napoleon, Minimus, Pinkeye, Squealer), Raven (Moses), Sheep, coW, and donkeY (Benjamin). For reasons of space I only mention the generic names of the animals, i.e. I do not use the specific names for the female and for the male.

Finally, note that Bluebell, Jessie, and Pincher are the only dogs, Muriel is the only goat, Moses is the only raven, and Benjamin is the only donkey. Then the eco-grammar system $\mathsf{A}$ modelling *Animal Farm: A Fairy Story* is

$$\mathsf{A} = ((\mathsf{V_E}, \mathsf{P_E}), \mathsf{Chicken}, \mathsf{Dog}, \mathsf{goosE}, \langle \mathsf{Muriel} \rangle, \mathsf{Horse}, \mathsf{Man}, \mathsf{Pig}, \langle \mathsf{Moses} \rangle, \mathsf{Sheep}, \mathsf{coW}, \langle \mathsf{Benjamin} \rangle),$$

where

$\mathsf{Chicken} = \langle C, C, \ldots, C \rangle$,
$\mathsf{Dog} = \langle \mathsf{Bluebell}, \mathsf{Jessie}, \mathsf{Pincher} \rangle$,
$\mathsf{goosE} = \langle E, E, \ldots, E \rangle$,
$\mathsf{Horse} = \langle \mathsf{Mollie}, \mathsf{Boxer}, \mathsf{Clover}, \mathsf{H}, \mathsf{H}, \ldots, \mathsf{H} \rangle$,
$\mathsf{Man} = \langle \mathsf{Mr.\ Jones}, \mathsf{Mrs.\ Jones}, \mathsf{Mr.\ Frederick}, \mathsf{Mr.\ Whymper}, \mathsf{Mr.\ Pilkington}, \mathsf{M}, \ldots, \mathsf{M}, \mathsf{M} \rangle$,
$\mathsf{Pig} = \langle \mathsf{Old\ Major}, \mathsf{Snowball}, \mathsf{Napoleon}, \mathsf{Minimus}, \mathsf{Pinkeye}, \mathsf{Squealer}, \mathsf{P}, \mathsf{P}, \ldots, \mathsf{P} \rangle$,
$\mathsf{Sheep} = \langle S, S, \ldots, S \rangle$, and
$\mathsf{coW} = \langle W, W, \ldots, W \rangle$.

# 4 A Fairy Story

In this section I show how $\mathsf{A}$ can generate the fairy story of the book.

In the beginning there is Manor Farm and plenty — where plenty is modelled by the presence of 9 symbols — of corn, hay, and straw. Of the men only Mr. Jones, Mrs. Jones and their four men are present. Hence

$$\sigma_0 = (Mc^9h^9s^9, \langle C,\dots,C\rangle, \langle D,D,D\rangle, \langle E,\dots,E\rangle, \langle G\rangle, \\ \langle H,\dots,H\rangle, \langle M,M,M,M,M,M,?,\dots,?\rangle, \langle P,\dots,P\rangle, \langle R\rangle, \langle S,\dots,S\rangle, \langle W,\dots,W\rangle, \langle Y\rangle).$$

Next I summarize Chapter 1 to 10 of the book and for some I display the state modelling the situation after that chapter. I leave it to the reader to display the others and to spell out precisely which rules must be applied to obtain them.

In Chapter 1 — as in all chapters — the corn, hay, and straw naturally grow a little, while at the same time some straw is used. Hence $\sigma_1$ is the same as $\sigma_0$ except that the environmental state has become $Mc^{13}h^{13}s^9$. From now on I will no longer mention the growth of corn, hay, and straw, nor the decrease of straw.

In Chapter 2 Old Major dies. The rebellion then causes Mr. Jones, Mrs. Jones, and their four men to flee from the farm, and causes Snowball to change the name of the farm to Animal Farm. Moreover a hay harvest takes place.

In Chapter 3 Bluebell and Jessie whelp and there is a corn harvest. Hence

$$\sigma_3 = (Ac^6h^{10}s^9, \langle C,\dots,C\rangle, \langle D,D,D,D,D,D,D,D,D,D,D,D\rangle, \langle E,\dots,E\rangle, \langle G\rangle, \\ \langle H,\dots,H\rangle, \langle ?,\dots,?\rangle, \langle \dagger,P,\dots,P\rangle, \langle R\rangle, \langle S,\dots,S\rangle, \langle W,\dots,W\rangle, \langle Y\rangle).$$

In Chapter 4 Mr. Jones and his four men return to the farm only to be expelled again by the animals — at the cost of only one sheep — during the Battle of the Cowshed. Around this time, Moses flies off.

In Chapter 5 Mollie disappears, and at the height of Animalism Snowball is chased off the farm by the nine puppies of Bluebell and Jessie — that have grown tremendously under Napoleon's control. Hence

$$\sigma_5 = (Ac^{20}h^{20}s^9, \langle C,\dots,C\rangle, \langle D,D,D,D,D,D,D,D,D,D,D,D\rangle, \langle E,\dots,E\rangle, \langle G\rangle, \\ \langle ?,H,\dots,H\rangle, \langle ?,\dots,?\rangle, \langle \dagger,?,P,\dots,P\rangle, \langle ?\rangle, \langle S,\dots,S,\dagger\rangle, \langle W,\dots,W\rangle, \langle Y\rangle).$$

In Chapter 6 nothing much happens.

In Chapter 7 nine hens die due to a starvation ordered by Comrade Napoleon, who also orders his dogs to kill the four pigs, three hens, one goose, and three sheep that confess to have rebelled against him. Hence

$$\sigma_7 = (Ac^{30}h^{28}s^9, \langle \dagger,\dagger,\dagger,C,\dots,C\rangle, \langle D,D,D,D,D,D,D,D,D,D,D,D\rangle, \langle E,\dots,E,\dagger\rangle, \langle G\rangle, \\ \langle ?,H,\dots,H\rangle, \langle ?,\dots,?\rangle, \langle \dagger,?,P,\dots,P,\dagger,\dagger,\dagger,\dagger\rangle, \langle ?\rangle, \langle S,\dots,S,\dagger,\dagger,\dagger,\dagger\rangle, \langle W,\dots,W\rangle, \langle Y\rangle).$$

In Chapter 8 there are more harvests and another battle — at the cost of one cow, three sheep, and two geese this time — after Mr. Frederick and his men attacked the farm.

In Chapter 9 Moses reappears and Boxer dies. Hence

$$\sigma_9 = (Ac^{10}h^{11}s^9, \langle \dagger,\dagger,\dagger,C,\dots,C\rangle, \langle D,D,D,D,D,D,D,D,D,D,D,D\rangle, \langle E,\dots,E,\dagger,\dagger,\dagger\rangle, \langle G\rangle, \\ \langle ?,\dagger,H,\dots,H\rangle, \langle ?,\dots,?\rangle, \langle \dagger,?,P,\dots,P,\dagger,\dagger,\dagger,\dagger\rangle, \langle R\rangle, \langle S,\dots,S,\dagger,\dots,\dagger\rangle, \langle W,\dots,W,\dagger\rangle, \langle Y\rangle).$$

In Chapter 10 Bluebell, Jessie, Pincher, Muriel, three horses, and Mr. Jones die. Furthermore Mr. Pilkington is now an appreciated neighbour, in whose presence Napoleon changes the name of the farm back to Manor Farm. Hence

$$\sigma_{10} = (Mc^{20}h^{22}s^9, \langle \dagger,\dagger,\dagger,C,\dots,C\rangle, \langle \dagger,\dagger,\dagger,D,D,D,D,D,D,D,D,D\rangle, \langle E,\dots,E,\dagger,\dagger,\dagger\rangle, \langle \dagger\rangle, \\ \langle ?,\dagger,H,\dots,H,\dagger,\dagger,\dagger\rangle, \langle \dagger,M,?,\dots,?\rangle, \langle \dagger,?,P,\dots,P,\dagger,\dagger,\dagger,\dagger\rangle, \langle R\rangle, \langle S,\dots,S,\dagger,\dots,\dagger\rangle, \langle W,\dots,W,\dagger\rangle, \langle Y\rangle).$$

The story of the book naturally is only one of the possible stories that $\mathsf{A}$ can generate. I leave it to the reader to play with $\mathsf{A}$ and to enjoy other outcomes of this fairy story.

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