Grammar Systems as Interfaces

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Abstract

Basing human-computer interaction on human conversation can provide flexible and effective user interfaces. Conversational interfaces would provide the opportunity for the user to interact with the computer just as they would do to person. In this paper, we introduce a gammar systems model that may contribute to the building of better human-computer interfaces through a simulation of human language use.

1. Introduction

According to [1], human language technology plays a central role in providing an interface that will drastically change the human-machine communication paradigm from *programming* to *conversation*, enabling users to efficiently access, process, manipulate and absorb a vast amount of information. Effective conversational interfaces must incorporate extensive and complex dialogue modelling. In this paper, we introduce a Grammar System interface that may contribute to the building of more effective and efficient human-computer interaction tools through the simulation of human-human conversations.

Human-computer interfaces require models of dialogue structure that capture the variability and unpredictability within dialogue. The study of human-human conversation and the application of its features to human-machine interaction can provide valuable insights, as has been recognized by many authors (cf. [1], [2], [3], [4]). To be truly conversation-like, a human-computer dialogue has to have much of the freedom and flexibility of human-human conversations.

Even though many researchers agree that a complete simulation of human conversation is very difficult (maybe impossible) to be reached, it seems clear that knowledge of human language use can help in the design of efficient human-computer dialogues. It can be argued that users could feel more comfortable with an interface that has some of the features of a human agent. Therefore, our model is based on human-human interactions. The result is a highly formalized dialogue-based interface.

Throughout the paper, we assume that the reader is familiar with the basics of formal language theory, for more information see [5].

2. A GS Interface

In this section, we introduce a Grammar System Interface (GSI) that may contribute to the building of better human-computer dialogues through a simulation of human language use. Note that we do not intend to fully simulate human language use, but only to take advantage from research on human language in order to improve interfaces. Our formal model tries to capture human-conversation main features and is based on Eco-Grammar Systems (EGS).

Eco-grammar systems theory is a subfield of grammar systems theory, a consolidated and active branch in the field of formal languages [6]. Eco-grammar systems have been introduced in [7] and provide a syntactical framework for eco-systems, this is, for communities of evolving agents and their interrelated environment. Taking as starting point the notion of eco-grammar system, we introduce the notion of *Grammar Systems Interface* (GSI). GSI present several advantages useful for human computer interaction, we emphasize here only several aspects like the following: *a)* it is highly modularized by a distributed system of contributing agents; *b)* it is contextualized permitting to linguistic agents to re-define their capabilities according to context conditions given by mappings; *c)* it is emergent, from current competence of the collection of active agents emerges a more complex behaviour.

Definition 1 *A Grammar System Interface (GSI) of degree n, $n \geq 2$, is an $(n+1)$-tuple:*

$$\Sigma = (E, A_1, ..., A_n),$$

where:

- $E = (V_E, P_E)$,
  - V_E *is an alphabet;*
  - P_E *is a finite set of rewriting rules over* V_E.
- $A_i = (V_i, P_i, R_i, \varphi_i, \psi_i, \pi_i, \rho_i)$, $1 \leq i \leq n$,
  - V_i *is an alphabet;*
  - P_i *is a finite set of rewriting rules over* V_i;
  - R_i *is a finite set of rewriting rules over* V_E;
  - φ_i*:* $V_E^* \rightarrow 2^{P_i}$;
  - ψ_i*:* $V_E^* \times V_i^+ \rightarrow 2^{R_i}$;
  - π_i *is the start condition;*
  - ρ_i *is the stop condition;*
  - π_i *and* ρ_i *are predicates on* V_E^*.

The items of the above definition have been interpreted as follows: a) E represents the environment described at any moment of time by a string w_E, over alphabet V_E, called the *state of the environment*. The state of the environment is changed both by its own evolution rules P_E and by the actions of the agents of the system, A_i, $1 \leq i \leq n$. b) A_i, $1 \leq i \leq n$, represents an agent. It is identified at any moment by a string of symbols w_i, over alphabet V_i, which represents its current state. This state can be changed by applying evolution rules from P_i, which are selected according to mapping φ_i and depend on the state of the environment. A_i can modify the state of the environment by applying some of its action rules from R_i, which are selected by mapping ψ_i and depend both on the state of the environment and on the state of the agent itself. Start/Stop conditions of A_i are determined by π_i and ρ_i, respectively. A_i starts/stops its actions if context matches π_i and ρ_i.

GSIs intend to describe dialogue as a sequence of *context-change-actions* allowed by the current environment and performed by two or more *agents.*

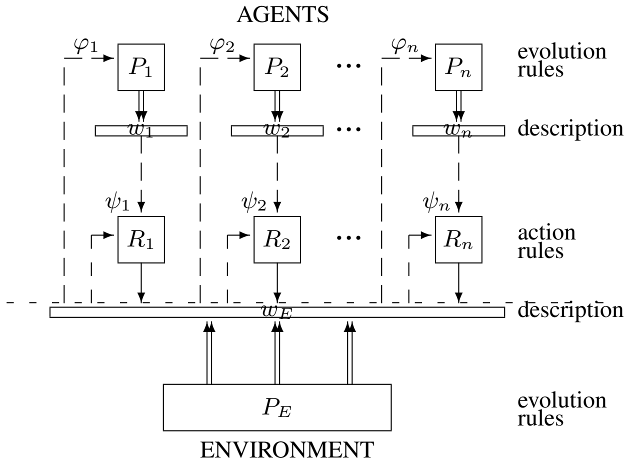

Figure 1: Grammar Systems Interface based on EGS

Definition 2 *By an action of an active agent A_i in state $\sigma = (w_E; w_1, w_2, \dots, w_n)$ we mean a direct derivation step performed on the environmental state w_E by the current action rule set $\psi_i(w_E, w_i)$ of A_i.*

Definition 3 *A state of a GSI $\Sigma = (E, A_1, \dots, A_n)$, $n \geq 2$, is an $n+1$-tuple:*

$$\sigma = (w_E; w_1, \dots, w_n),$$

where $w_E \in V_E^*$ is the state of the environment, and $w_i \in V_i^*$, $1 \leq i \leq n$, is the state of agent A_i.

This rule is applied *by an active agent* and it is a rule selected by $\psi_i(w_E, w_i)$. We define an *active agent* in relation to the allowable actions it has at a given moment. That is, an agent can participate in conversation –being, thus, active– only if its set of allowable actions at that moment is nonempty:

Definition 4 *An agent A_i is said to be active in state $\sigma = (w_E; w_1, w_2, \dots, w_n)$ if the set of its current action rules, that is, $\psi_i(w_E, w_i)$, is a nonempty set.*

Since conversation in GSI is understood in terms of *context changes*, we have to define how the environment passes from one state to another as a result of agents' actions:

Definition 5 *Let $\sigma = (w_E; w_1, \dots, w_n)$ and $\sigma' = (w'_E; w'_1, \dots, w'_n)$ be two states of a GSI $\Sigma = (E, A_1, \dots, A_n)$. We say that σ' arises from σ by a simultaneous action of active agents $A_{i_1}, \dots, A_{i_r}$, where $\{i_1, \dots, i_r\} \subseteq \{1, \dots, n\}$, $i_j \neq i_k$, for $j \neq k$, $1 \leq j, k \leq r$, onto the state of the environment w_E, denoted by $\sigma \stackrel{a}{\Longrightarrow}_\Sigma \sigma'$, iff:*

- *$w_E = x_1 x_2 \dots x_r$ and $w'_E = y_1 y_2 \dots y_r$, where x_j directly derives y_j by using current rule set $\psi_i(w_E, w_{i_j})$ of agent A_{i_j}, $1 \leq j \leq r$;*
- *there is a derivation:*
  $w_E = w_0 \stackrel{a}{\Longrightarrow}^*_{A_{i_1}} w_1 \stackrel{a}{\Longrightarrow}^*_{A_{i_2}} w_2 \stackrel{a}{\Longrightarrow}^*_{A_{i_3}} \dots \stackrel{a}{\Longrightarrow}^*_{A_{i_r}} w_r = w'_E$

  such that, for $1 \leq j \leq r$, $\pi_{i_j}(w_{j-1}) =$ true and $\rho_{i_j}(w_j) =$ true. And for $f \in \{t, \leq k, \geq k\}$ the derivation is:
  $w_E = w_0 \stackrel{a}{\Longrightarrow}^f_{A_{i_1}} w_1 \stackrel{a}{\Longrightarrow}^f_{A_{i_2}} w_2 \stackrel{a}{\Longrightarrow}^f_{A_{i_3}} \dots \stackrel{a}{\Longrightarrow}^f_{A_{i_r}} w_r = w'_E$

  such that, for $1 \leq j \leq r$, $\pi_{i_j}(w_{j-1}) =$ true[1], and
- *$w'_i = w_i$, $1 \leq i \leq n$.*

Definition 6 *Let $\Sigma = (E, A_1, ..., A_n)$ be a GSI. And let $w_E = x_1 x_2 ... x_r$ and $w'_E = y_1 y_2 ... y_r$ be two states of the environment. Let us consider that w'_E directly derives from w_E by action of active agent A_i, $1 \leq i \leq n$, as shown in definition 5. We write that:*

$w_E \stackrel{a}{\Longrightarrow}^{\leq k}_{A_i} w'_E$ iff $w_E \stackrel{a}{\Longrightarrow}^{\leq k'}_{A_i} w'_E$, for some $k' \leq k$;

$w_E \stackrel{a}{\Longrightarrow}^{\geq k}_{A_i} w'_E$ iff $w_E \stackrel{a}{\Longrightarrow}^{\leq k'}_{A_i} w'_E$, for some $k' \geq k$;

$w_E \stackrel{a}{\Longrightarrow}^{*}_{A_i} w'_E$ iff $w_E \stackrel{a}{\Longrightarrow}^{k}_{A_i} w'_E$, for some k;

$w_E \stackrel{a}{\Longrightarrow}^{t}_{A_i} w'_E$ iff $w_E \stackrel{a}{\Longrightarrow}^{*}_{A_i} w'_E$ and there is no $z \neq y$ with $y \stackrel{a}{\Longrightarrow}^{*}_{A_i} z$.

In words, $\leq k$-derivation mode represents a time limitation where A_i can perform at most k successive actions on the environmental string. $\geq k$-derivation mode refers to the situation in which A_i has to perform at least k actions whenever it participates in the derivation process. With $*$-mode, we refer to such situations in which agent A_i performs as many actions as it wants to. And finally, t-derivation mode represents such cases in which A_i has to act on the environmental string as long as it can.

However, in the course of a dialogue, agents' states are also modified and the environmental string is subject to changes due to reasons different from agents' actions. So, in order to complete our formalization of dialogue development, we add the following definition:

Definition 7 *Let $\sigma = (w_E; w_1, \dots, w_n)$ and $\sigma' = (w'_E; w'_1, \dots, w'_n)$ be two states of a GSI $\Sigma = (E, A_1, \dots, A_n)$. We say that σ' arises from σ by an evolution step, denoted by $\sigma \stackrel{e}{\Longrightarrow}_\Sigma \sigma'$, iff the following conditions hold:*

- *w'_E can be directly derived from w_E by applying rewriting rule set P_E;*
- *w'_i can be directly derived from w_i by applying rewriting rule set $\varphi_i(w_E)$, $1 \leq i \leq n$.*

[1] In this latter case the stop condition $\rho_i(w_j) =$ true is replaced by the stop condition given the f-mode.

Definition 8 *Let $\Sigma = (E, A_1, ..., A_n)$ be a GSI as in definition 1. Derivation in Σ terminates in:*

- *Style (ex) iff for $A_1, ..., A_n$, $\exists A_i : w_i \in T_i, 1 \leq i \leq n$;*
- *Style (all) iff for $A_1, ..., A_n$, $\forall A_i : w_i \in T_i, 1 \leq i \leq n$;*
- *Style (one) iff for $A_1, ..., A_n$, $A_i : w_i \in T_i, 1 \leq i \leq n$.*

According to the above definition, a derivation process ends in style *(ex)* if there is *some* agent A_i that has reached a terminal string. It ends in style *(all)* if *every* agent in the system has a terminal string as state. And it finishes in style *(one)* if there is *one* distinguished agent whose state contains a terminal string. Styles *(all)*, *(ex)* and *(one)* might account for three different ways of closing a dialogue.

In GSI, the development of dialogue implies that both the *state of the environment* and *state of agents* change. Such changes take place thanks to two different types of processes: *action steps* and *evolution steps*. At the end, what we have is a *sequence of states* reachable from the initial state by performing, alternatively, action and evolution derivation steps:

Definition 9 *Let $\Sigma = (E, A_1, \ldots, A_n)$ be a GSI and let σ_0 be a state of Σ. By a state sequence (a derivation) starting from an initial state σ_0 of Σ we mean a sequence of states $\{\sigma_i\}_{i=0}^{\infty}$, where:*

- $\sigma_i \overset{a}{\Longrightarrow}_{\Sigma} \sigma_{i+1}$, *for* $i = 2j, j \geq 0$; *and*
- $\sigma_i \overset{e}{\Longrightarrow}_{\Sigma} \sigma_{i+1}$, *for* $i = 2j + 1, j \geq 0$.

Definition 10 *For a given GSI Σ and an initial state σ_0 of Σ, we denote the set of state sequences of Σ starting from σ_0 by $Seq(\Sigma, \sigma_0)$.*

The set of environmental state sequences is:

$Seq_E(\Sigma, \sigma_0) = \{\{w_{Ei}\}_{i=1}^{\infty} \mid \{\sigma_i\}_{i=0}^{\infty} \in Seq(\Sigma, \sigma_0), \sigma_i = (w_{Ei}; w_{1i}, \ldots, w_{ni})\}$.

The set of state sequences of the j-th agent is defined by:

$Seq_j(\Sigma, \sigma_0) = \{\{w_{ji}\}_{i=1}^{\infty} \mid \{\sigma_i\}_{i=0}^{\infty} \in Seq(\Sigma, \sigma_0), \sigma_i = (w_{Ei}; w_{1i}, \ldots, w_{ji}, \ldots, w_{ni})\}$.

3. An Example

The following fragment of a dialogue illustrates how the dialogue-based interaction system we have introduced above works. Dialogues of this type can be handled by our system in a simple way. Let us consider the following dialogue that can take place between a customer (the user) who wants to buy a table and the shop assistant (the system) that guides the customer in his choice. The interaction is collaborative, with neither the system nor the user being in control of the whole interaction. Each of them contributes to the interaction when they can.

User: Good morning.

System: Good morning. Can I help you?

User: Yes, I would like to buy a table.

System: Which type of table, for which room?

User: I need a living room table.

System: We have different shapes, which do you prefer?

User: I would like a rectangular table.

System: What about the material?

User: I would like a glass table.

System: We have different glass colours, any preference?

User: I would like a transparent glass table.

System: I guess this is the table you are looking for.

User: Yes, it is wonderful. Thank you very much.

System: Your are welcome.

Starting from this example, we develop the following GSI with two agents.

The alphabet of the environment is:

- I is the initial state,
- h stands for "Hello",
- Q, for "Can I help you?",
- t, for "I need a table",
- R for "What kind of room?",
- ℓ, for "A living room",
- S for "What shape?",
- r for "Rectangular.",
- M for "What material?",
- g for "Glass",
- C for "Colour?",
- w for "White",
- K for "OK, something else?",
- e for "End of my request, bye",
- B for "Bye".

The environment is in the initial state I. For this dialogue we do not need special functions φ, they just copy the environment to the agents' status.

The function ψ_1 adds a single rule R_1 to its set of rules, as follows:

- $R_1 = \{I \rightarrow h\}$ for $\omega_E = xI, x \in V_E^*$,
- $R_1 = \{Q \rightarrow Qt\}$ for $\omega_E = xQ, x \in V_E^*$,
- $R_1 = \{R \rightarrow R\ell\}$ for $\omega_E = xR, x \in V_E^*$,
- $R_1 = \{S \rightarrow Sr\}$ for $\omega_E = xS, x \in V_E^*$,
- $R_1 = \{M \rightarrow Mg\}$ for $\omega_E = xM, x \in V_E^*$,
- $R_1 = \{C \rightarrow Cw\}$ for $\omega_E = xC, x \in V_E^*$,
- $R_1 = \{K \rightarrow Ke\}$ for $\omega_E = xK, x \in V_E^*$,
- $R_1 = \{b \rightarrow bB\}$ for $\omega_E = xb, x \in V_E^*$.

The function ψ_2 is defined in a similar way as follows:

- $R_2 = \{h \rightarrow hhQ\}$ for $\omega_E = xh, x \in V_E^*$,
- $R_2 = \{t \rightarrow tR\}$ for $\omega_E = xt, x \in V_E^*$,
- $R_2 = \{\ell \rightarrow \ell S\}$ for $\omega_E = x\ell, x \in V_E^*$,
- $R_2 = \{r \rightarrow rM\}$ for $\omega_E = xr, x \in V_E^*$,
- $R_2 = \{g \rightarrow gC\}$ for $\omega_E = xg, x \in V_E^*$,
- $R_2 = \{w \rightarrow wK\}$ for $\omega_E = xw, x \in V_E^*$,
- $R_2 = \{e \rightarrow eb\}$ for $\omega_E = xe, x \in V_E^*$.

This implementation gives only one possible dialogue that is: $I \rightarrow hhQtRlSrMgCwKebB$. If we want to get more diverse dialogues on the same topic, we can imagine that after asking the about the table, the dialogue continues with the specifications of details, colour, shape, material, room in an arbitrary order like: $I \rightarrow hhQtRlCwMgSrKebB$ or $I \rightarrow hhQtSrRlMgCwKebB$. To do this, we keep the definition of the function ψ_1 and we should modify a little bit the function ψ_2 in this way. $R_2 = \{a \rightarrow aB\}$ for $\omega_E = xa, x \in V_E^*$, $a \in \{t, l, r, g, m, w\}$ and B randomly selected from the set $\{R, S, M, C\}$.

4. Final Remarks

Many researchers believe that natural language interfaces can provide the most useful and efficient way for people to interact with computers. According to [1], "for information to be truly accessible to all anytime, anywhere, one must seriously address the problem of user interfaces. A promising solution to this problem is to impart human-like capabilities onto machines, so that they can speak and hear, just like the users with whom they need to interact."

The Grammar System Interface we have introduced can be considered a mixed-initiative interaction model in which there is a dynamic exchange of control of the dialogue flow. GSI are able to model interfaces with a high degree of flexibility, what means that they are able to accept new concepts and modify rules, protocols and settings during the computation. The main characteristic of the model is the use of simple grammars in order to generate a dialogue structure. It should not to be seen as a psychologically realistic cognitive model, but as a model that might successfully emulate human linguistic behaviour in some specific situations such as natural language interfaces.

Up to now, we have developed the formal model and we have worked on the comparison and interplay between GSI and other multi-agent dialogue systems. The formal properties of GSI, obtained by the mathematical analysis of the model, show the flexibility required for modelling dialogue. Moreover, since the definition of the framework is based on features that characterize human-human conversation, GSI capture and simulates (in a very abstract and formal way) human language use. Currently, we are working on the implementation of the model. This phase of our research will provide us a definite answer about the GSI adequacy for building a conversation-like human-computer interface.

5. References

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