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Three computer-based models of storytelling: BRUTUS, MINSTREL and MEXICA

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Abstract

This paper attempts to establish criteria to analyse and evaluate computer models of creativity in writing. The paper provides a brief review of the antecedents of automatic story-generation and offers a proposal for the analysis and evaluation of computer models of creativity in writing. It reviews three major projects to develop computer-based storywriters published between 1993 and 2000 and analyses their approach, similarities, differences and contributions. It compares the three approaches and discusses implications for the modelling of creativity in writing and the design of future story generation systems.

Keywords: BRUTUS; MINSTREL; MEXICA; Computer-based storytelling; Creativity; C-creativity; Predefined structures; Story-predictability; Structure-predictability; Content-predictability; Engagement; Reflection; Transform Recall Adapt Methods; Creative distance

1. Introduction

Computer-based text generation has been an area of interest for many AI researchers. Although there were attempts in the 1960s and 70s to generate stories and poems by computer [1–3], the origin of AI-based computerised storytellers can be traced to TALE-SPIN and the story-grammar approach. TALE-SPIN [4] was a program that produced stories by setting goals for characters and then recording their attempts to reach the goal. It demonstrated how computer techniques in problem-solving can be applied to storytelling. The problem-solving approach introduced by TALE-SPIN became the model to follow for other AI researchers working within storytelling and some related areas. Although it was successful in showing the ability of computers to generate very short coherent stories, it was only able to generate a limited range of stories within a rigid pre-defined structure. Another important limitation, which has been employed to criticise the system, is its lack of differentiation between the goals of characters and the author. Because TALE-SPIN was driven solely by the goals of its characters to solve particular problems, uninteresting stories can arise, such as: “John Bear is hungry, John Bear gets some berries, John Bear eats the berries, John Bear is not hungry anymore, the end”.

Story grammars were developed with the objective of creating a theory of story understanding. They represent stories as linguistic objects which have a constituent structure that can be represented by a grammar, e.g. Refs. [5–7][1]. Although this approach was originally developed in the context of story understanding, some researchers have employed story-grammars to produce automatic story-tellers. For example, GESTER [11] is a program that generates story outlines based on a story-grammar derived from medieval French epics. Its main shortcoming (which is shared by other programs based on this approach) is its rigidity. GESTER is only able to produce stories that satisfy its grammar and is not able to modify its knowledge to generate different outcomes.

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[1] Story grammars have been the centre of a polemic. While some authors believe that story grammars are important for story understanding, others argue that they are incapable of generating all and only valid stories. For example, see Refs. [8–10].

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The main contribution of these pioneer works was in showing how a computer program can produce coherent and well structured texts that, in some limited respects, resemble human stories. Programs based on story-grammars indicate how grammars could be employed to generate interesting plots, a characteristic that TALE-SPIN lacks. What the early programs revealed is that generating well-formed text is necessary but not sufficient. Other characteristics of successful human stories must be explicitly addressed, such as novelty and interestingness. MINSTREL, in 1993, was the first attempt to implement an explicit computer model of creativity in writing. After MINSTREL, two significant models of computerised storytellers have been MEXICA in 1999 and BRUTUS in 2000. These three models are analysed in this work.

This paper is organised as follows: Section 2 introduces general criteria for evaluation of automatic storytellers; Sections 3–5 offer general descriptions of the three programs under analysis; Section 6 compares and evaluates the three programs in terms of the criteria exposed in Section 2; Section 7 offers final conclusions.

2. Evaluation of a computer model of writing

This section discusses the elements that a computer model of creativity in writing should have, and how they can be evaluated. An essential requirement for such computerised storytellers is that they should be based on a clearly explicated analysis of creativity. It is generally accepted that the creative process consists in generating appropriate and novel outputs, e.g. Refs. [12–14]. A text is considered appropriate when its content and style satisfy the constraints of the task, in particular the characteristics of the audience and the purpose of the text [15, p. 41]. As found by the first automatic storytellers, to be appropriate a computer-generated story should be interesting, coherent and well structured.

Boden defines two types of creativity. The first is psychological creativity (p-creativity) and “concerns ideas…that are fundamentally novel with respect *to the individual mind* which had the idea.” [16, p. 32]. The second is historical creativity (h-creativity) and is related to “ideas that are fundamentally novel with respect to *the whole of human history*.” [16, p. 32]. We suggest that computer models of creativity should initially be evaluated from the perspective of an adaptation of p-creativity. A computer model might be considered as representing a creative process if it generates knowledge that does not explicitly exist in the original knowledge-base of the system and which is relevant to (i.e. is an important element of) the produced output. Note that this definition involves inspection of both the output of the program and its initial data structures. Following Boden, we refer to this type of creativity as computerised creativity (c-creativity). The definition of c-creativity is wide since a computer model of writing might include several types of knowledge, for example knowledge about the story-structure and knowledge about the content. Two programs cannot be considered equally c-creative if one of the systems generates new knowledge about the structure and content of texts, and the second only produces new knowledge about the content. This point must be considered when evaluating c-creativity. When the system cannot produce new and relevant knowledge of a specific type represented in the system, we say that the structures representing such knowledge are predefined. *Predefined-structures* are established by the designer, cannot be modified and are developed to produce a particular effect in the output.

We shall introduce the term *story-predictability* to indicate the degree to which the output of a computerised-storyteller can be predicted when the content of the system’s knowledge-structures are known. Since predefined structures imply known output features, we propose that the output’s predictability depends strongly on the amount of predefined knowledge structures. The notion of story-predictability can be split into at least two elements: the structure and the content. Structure-predictability indicates the degree to which the story-structure can be predicted, and content-predictability indicates the degree to which a sequence of events in a story in progress can be foretold. Thus, story-predictability depends on the values of structure-predictability and content-predictability. We suggest that if the story-predictability is low, the system is more likely to be evaluated as representing a creative process.

As a consequence, we propose some issues to be considered while studying a computer model of story writing. It is not suggested that these are the only important aspects to consider, but they provide a good starting point for an analysis. Knowledge data-bases are at the heart of story-development. The content and style of stories depends on the type of knowledge stored by the system, including rhetorical-knowledge, story-world knowledge and common-sense knowledge. Thus, when analysing a computerised storyteller it is important to determine:

- What type of knowledge is represented, how it is represented and the percentage of predefined structures employed by the system. All this information helps to clarify the story predictability.
- How knowledge is updated (in order to keep on producing novel outputs it is necessary to constantly update the system’s knowledge).

Regarding the processes involved in story-development, it is necessary to establish:

- How events that form a story are retrieved from memory, i.e. how the system progress the story.
- How the system maintains the coherence of the whole story.
- How the system ensures interestingness.

- How the system ensures novelty.
- How the system generates natural language structure and meaning.

Interestingness is an important characteristic and central to a critique of computer-generated stories. It can either be created explicitly by the human designer and encoded into a database of story elements, or it can be constructed by computer through an appropriate combination of content, coherence, suspense and originality.

Lastly, it is necessary to evaluate the story output. To be acceptable as a tellable story, a piece of text should satisfy certain minimum requirements. It must introduce characters and setting and advance one or more key characters through activities within the setting to produce a plot. It must show a coherence and narrative flow between activities and settings over time. It should display an overall integrity and closure, for example with a problem posed in an early part of the text being resolved by the conclusion. It should generate suspense by setting up difficulties faced by the characters or tension in the plot. It should display originality, with successive stories being substantially different. These elements, of interestingness, appropriate content, narrative flow, coherence, suspense and originality cannot be captured by objective measures (for example of syntactic complexity). They are the elements of literary criticism and in order to provide a comparative measure they need to be assessed, either singly or in combination, by human readers. This does not preclude attempts to program story generation systems to assess and improve the interestingness and novelty of their outputs (see sections describing MINSTREL and MEXICA in this paper).

3. BRUTUS

BRUTUS [17] is a program that writes short stories about pre-defined themes like betrayal. The system is built on a Prolog-based system that allows defining frame-structures, relations between frames and production rules, all in an English-like format. Figs. 1 and 2 [17, pp. 200, 201] show two stories developed by BRUTUS.

In BRUTUS the development of a story consists of the following core processes:

- The instantiation of a thematic-frame.
- A simulation-process where characters attempt to achieve a set of pre-defined goals (development of a plot).
- The expansion of story-grammars to produce the final output.

3.1. Instantiation of a thematic frame

In BRUTUS, story elements like characters, characters' goals, events, etc. are represented by structures that we referrer to as story-frames. The slots that constitute story-frames contain explicit data employed by BRUTUS to develop a story. For example, for the story in Fig. 1, the system has an explicit list of actions to perform in order to achieve Hart's goal of preventing Dave from obtaining his PhD. A second type of structure employed by BRUTUS during the instantiation process is known as story-theme. This structure is designed to group all the elements (story-frames) that conform a specific story-theme. All these structures are transformed into standard Prolog programs.

3.2. Development of a plot

Plot development consists of performing a set of character-actions that might modify the story-world. Such modifications can result in new actions being performed by the same or different characters, and so on. The process ends when no more actions can be executed. The development of a plot is formed by two sub-processes:

Activation of Proactive behaviour. In BRUTUS, characters are associated with a set of explicit actions, referred to as plans, to achieve a particular goal. Each action includes a set of preconditions and a set of consequences that might modify the story-world. When the preconditions for an action are satisfied, its consequences, associated with the character's plans, are performed and the story-world might be modified.

Activation of Reactive behaviour. Reactive behaviour consists of actions performed by characters when the requirements of a production rule in the knowledge database are satisfied and therefore the rule is triggered.

Thus, during the development of a plot, the system first attempts to enact characters' plans (proactive behaviour). Then, it attempts to trigger rules in the knowledge database (reactive behaviour). The process is repeated until no more actions can be triggered.

3.3. Expansion of the story-grammar and generation of the final output

BRUTUS employs story-grammars to represent the structure of the stories it produces. The outputs produced during the instantiation of the theme and the development of a plot are employed by the grammars during its expansion to generate the sentences and words that form the final output of the system. To achieve this goal BRUTUS makes use of, inter alia:

- A group of previously defined words to instantiate the grammars.
- Structures that explicitly link words representing objects with other words that are related, e.g. the word university is typically related to clocktowers, brick, ivy, youth, etc.
- Structures that explicitly link words representing objects with other words that modify the object (e.g. 'green' can modify 'football pitch').
- Structures that explicitly represents analogies.

> Dave Striver loved the university. He loved its ivy-covered clocktowers, its ancient and sturdy brick, and its sun-splashed verdant greens and eager youth. He also loved the fact that the university is free of the stark unforgiving trials of the business world —only this isn't a fact: academia has its own tests, and some are as merciless as any in the marketplace. A prime example is the dissertation defense: to earn the PhD, to become a doctor, one must pass an oral examination on one's dissertation.
>
> Dave wanted desperately to be a doctor. But he needed the signatures of three people on the first page of his dissertation, the priceless inscription which, together, would certify that he had passed his defense. One the signatures had to come from Professor Hart. Well before the defense, Striver gave Hart a penultimate copy of his thesis. Hart read it and told Striver that it was absolutely first-rate, and that he would gladly sign it at the defense. They even shook hands in Hart's book-lined office. Dave noticed that Hart's eyes were bright and trustful, and his bearing paternal.
>
> At the defense, Dave thought that he eloquently summarized Chapter 3 of his dissertation. There were two questions, one from Professor Rodman and one from Dr. Teer; Dave answered both, apparently to everyone's satisfaction. There were no further objections. Professor Rodman signed. He slid the tome to Teer; she too signed, and then slid it in front of Hart. Hart didn't move. "Ed?" Rodman said. Hart still sat motionless. Dave felt slightly dizzy. "Edward, are you going to sign?" Later, Hart sat alone in his office, in his big leather chair, underneath his framed PhD diploma.

Fig. 1. Simple Betrayal (a story developed by BRUTUS published in Ref. [17, p. 200]).

3.4. Discussion about BRUTUS

Although BRUTUS is the most recent of the three systems to be published, it does not incorporate innovative elements in its architecture. Instead, it merges methods employed in other programs to generate its outputs. For example, it employs frames to represent characters, places, events, goals, actions, etc. which are used to instantiate a theme-frame (c.f. MINSTREL, see Section 4); depending on the selected theme, the system develops a plot through planning and simulation (c.f. TALE-SPIN); the system employs story-grammars to establish the structure of the stories that it produces (c.f. GESTER); reactive behaviour fires rules until quiescence is reached (c.f. SOAR [18]). Thus, BRUTUS' contribution consists of merging different known methodologies into one program.

The way the authors compare BRUTUS with other similar systems is not very clear. As it is explained later (see Section 5), MEXICA was evaluated by means of a questionnaire. An interesting feature observed from the questionnaire's results is a possible correlation between those stories rated as the best and their length in lines and words. This type of information is relevant when comparing stories produced by different systems. For example, Bringsjord and Ferrucci [17, pp. 122, 124] compare the interestingness of a 36 lines story developed by BRUTUS against a 2 lines narrative found in a introductory book to AI [19, p. 592] and against 9 lines of a larger story developed by TALE-SPIN (it is not clear why they only present a fragment of the story. The original story has 37 lines. See Ref. [4, p. 200]).

4. MINSTREL

MINSTREL is a computer program that writes short stories about King Arthur and his Knights of the round table. MINSTREL is a very complex program and this

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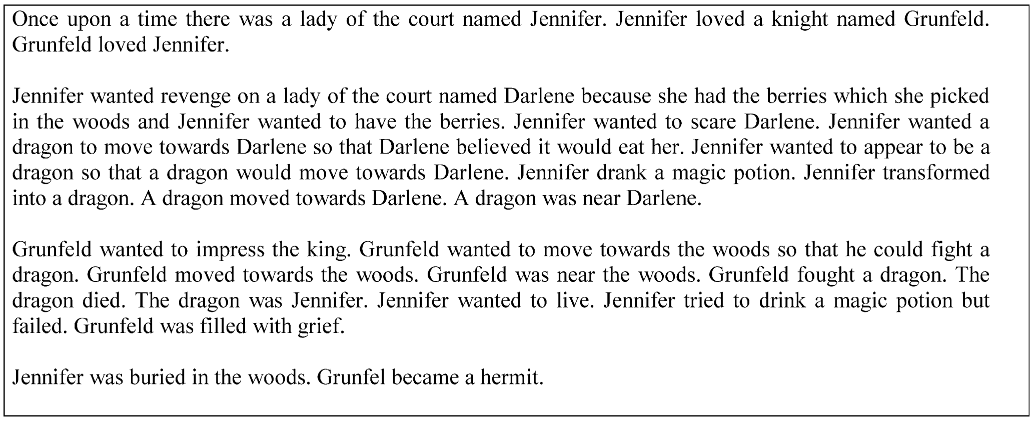
Fig. 2. Betrayal in Self-Deception (a story developed by BRUTUS published in Ref. [17, p. 201]).



Once upon a time there was a lady of the court named Jennifer. Jennifer loved a knight named Grunfeld. Grunfeld loved Jennifer.

Jennifer wanted revenge on a lady of the court named Darlene because she had the berries which she picked in the woods and Jennifer wanted to have the berries. Jennifer wanted to scare Darlene. Jennifer wanted a dragon to move towards Darlene so that Darlene believed it would eat her. Jennifer wanted to appear to be a dragon so that a dragon would move towards Darlene. Jennifer drank a magic potion. Jennifer transformed into a dragon. A dragon moved towards Darlene. A dragon was near Darlene.

Grunfeld wanted to impress the king. Grunfeld wanted to move towards the woods so that he could fight a dragon. Grunfeld moved towards the woods. Grunfeld was near the woods. Grunfeld fought a dragon. The dragon died. The dragon was Jennifer. Jennifer wanted to live. Jennifer tried to drink a magic potion but failed. Grunfeld was filled with grief.

Jennifer was buried in the woods. Grunfel became a hermit.

Fig. 3. The Vengeful Princess (a story developed by MINSTREL published in Ref. [20, p. 9]).

paper only presents a brief summary of the core elements of the system. A detailed explanation of the model can be found in Ref. [20] and particularly in Ref. [21]. The system is a case-based problem-solver where past cases are stored in a episodic memory. Figs. 3 and 4 [20, p. 9; 21, p. 622] show two examples of stories created by MINSTREL:

4.1. Schemas in MINSTREL

In MINSTREL, all the elements that comprise a story are represented as schemas. In this paper, schemas are divided in two classes: (1) those employed by the system to satisfy rhetorical constraints, referred to as author-schemas; (2) those employed by the system to represent events in a story, referred to as character-schemas.

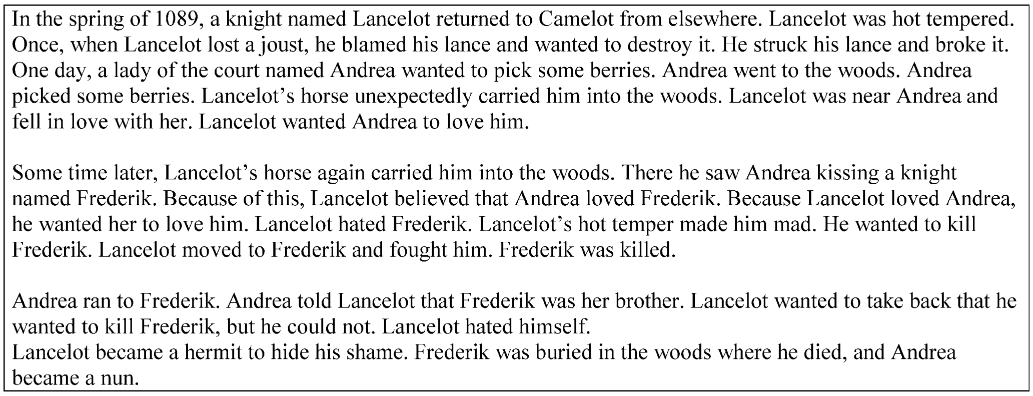
Examples of author-schemas are author-level goals, e.g. the goal of developing a theme, and the goal of including suspense in a story. Author-level goals have associated instructions to achieve their goals. These instructions are independent blocks of Lisp code, and are referred to as Author-Level Plan (ALP). ALPs explicitly indicate how to create scenes to include revenge, deception, beliefs, and so on.

Examples of character-schemas are character-level goals (e.g. satisfying one's hunger, finding a romantic love), representations of humans, physical objects, and emotions. Character-schemas can be linked to establish relationships between them. In this way, it is possible to construct elaborated scenes.

MINSTREL develops stories about six predefined schema-themes known as Planning Advice Themes (PATs). PATs, and therefore stories in MINSTREL, have the following structure:

- Introduction scenes.
- Theme scenes
  - World-facts (preconditions)
  - Decision (plan to achieve a goal)
  - Connection
  - Consequence (consequences of performing the plan)
- Denouement scenes.

World-facts scenes are facts about the world that must be true in order that a PAT-schema can be applied (i.e. they are preconditions). Decision scenes are formed by



In the spring of 1089, a knight named Lancelot returned to Camelot from elsewhere. Lancelot was hot tempered. Once, when Lancelot lost a joust, he blamed his lance and wanted to destroy it. He struck his lance and broke it. One day, a lady of the court named Andrea wanted to pick some berries. Andrea went to the woods. Andrea picked some berries. Lancelot's horse unexpectedly carried him into the woods. Lancelot was near Andrea and fell in love with her. Lancelot wanted Andrea to love him.

Some time later, Lancelot's horse again carried him into the woods. There he saw Andrea kissing a knight named Frederik. Because of this, Lancelot believed that Andrea loved Frederik. Because Lancelot loved Andrea, he wanted her to love him. Lancelot hated Frederik. Lancelot's hot temper made him mad. He wanted to kill Frederik. Lancelot moved to Frederik and fought him. Frederik was killed.

Andrea ran to Frederik. Andrea told Lancelot that Frederik was her brother. Lancelot wanted to take back that he wanted to kill Frederik, but he could not. Lancelot hated himself.
Lancelot became a hermit to hide his shame. Frederik was buried in the woods where he died, and Andrea became a nun.

Fig. 4. Lancelot Story (a story developed by MINSTREL published in Ref. [21, p. 622]).

character-schemas that represent a plan to achieve a goal. Consequence scenes are formed by character-schemas that represent the consequences of performing the plan. Connections are scenes employed to make the transition from the Decision scenes to the Consequence scenes.

To develop a new story MINSTREL performs two main processes: (a) the planning process, which controls author-level goals (during this process the author-level goal to tell a story is triggered; it breaks down into sub-goals such as selecting a story-theme and illustrating the theme); (b) the problem-solving process, which is focused on in achieving each of these goals. MINSTREL's main author-level goals during the development of a story are:

1. Selecting and illustrating a story-theme schema. Once a theme (i.e. a PAT) has been selected it is necessary to satisfy the author-level goal of illustrating the theme. PATs are formed from a set of character-schemas representing incomplete scenes: one, two or even all the slots in each of the structures associated with the PAT might not have an assigned value. Thus, the goal of illustrating a theme consists in employing those partially filled schemas as a search-specification or index to retrieve scenes from episodic memory and in this way instantiate the schemas that make up the theme.
2. Generating the introduction and denouement of the story.
3. Linking the schemas that conform the story with predefined words and phrases in English to produce the final output.

As part of the process of developing a new story, MINSTREL employs what is referred to as opportunistic goals. Each time a new scene is created the system tests if an opportunistic goal can be triggered. This type of goals is used: (a) to verify the consistency of the story in progress (e.g. when the system attempts to use a PAT but its preconditions are not satisfied, a consistency opportunistic goal is triggered in order for MINSTREL to insert scenes that fulfil these requirements); (b) to find opportunities to include dramatic elements in the story (e.g. to include suspense).

4.2. Creativity in MINSTREL: TRAMS

MINSTREL's main feature is its representation of the creative process. Writing consists of instantiating all the schemas that make up the theme. When MINSTREL cannot find events in episodic memory to instantiate the theme, or all available events have been employed twice in previous stories (in MINSTREL, a scene that has been used more than once in a story does not satisfy novelty requirements), a set of heuristics called Transform Recall Adapt Methods (TRAMS) are employed to create novel scenes.

TRAMS are divided into two groups. The first group consists of one member: TRAM:Standard-Problem-Solving. This is always the first TRAM the system employs during the searching process. Its purpose is to retrieve schemas from episodic memory that can be employed to instantiate a scene. Only when this TRAM fails, are the second group of TRAMS employed (comprising the rest of the TRAMS in the system).

The heuristics from the second set are grouped in memory according to their characteristics, forming pools of available TRAMs. They work in the following way: TRAMs have explicit instructions on how to make small modifications to the schema's specifications used as indexes to recall items from episodic memory (i.e. how to modify the value of one or more schema slots). Those instructions are executed, creating a new slightly different index. A recursive call to the searching process is made, TRAM: Standard-Problem-Solving is performed, and MINSTREL searches memory to find an event which matches the new specifications. If no scene is found, a new TRAM is selected from the pool producing new slightly different specifications, and a recursive call to the searching process is made to try a new attempt to match schemas in memory. This process continues until an event is matched or a processing limit is reached. Once an event is matched, MINSTREL goes back layer by layer, adapting the event found to the original specifications in each layer, until it finally reaches the top level.

The following example illustrates how TRAMS work. The goal is to create a scene where *a knight kills himself*. The episodes in memory are: (1) a *Knight fights and kills a troll* and (2) *a Princess makes herself intentionally ill by drinking a potion*. One of the solutions MINSTREL comes across when solving the problem is that a Knight intentionally drinks a potion in order to kill himself. To achieve this result MINSTREL employs two TRAMS as follows. The searching process starts and TRAM:Standard-Problem-Solving is triggered. It fails and the system calls TRAM:Similar-Outcomes-Partial-Change which "recognizes that being killed is similar to being injured…[that is, it] 'guesses' that an action which is known to result in injury might also result in death" [21, p. 116]. So, the TRAM substitutes for the original description "a knight kills himself" the new description "a knight makes himself ill". A recursive call to the searching process is triggered. TRAM:Standard-Problem-Solving fails so a second TRAM is applied. TRAM:Generalize-Constraint substitutes the character "knight" by "anyone"; in this way, the new specification is "someone does something to injure themself". A recursive call to the searching process is made, TRAM:Standard-Problem-Solving is triggered and the episode where the Princess makes herself ill is recalled. The system returns layer by layer and princess is substituted by knight and a potion to make someone ill by a potion to kill someone. This produces the scene where the knight kills himself by drinking the potion.

4.3. Evaluation

A story produced by MINSTREL (see Fig. 4) was evaluated by means of an Internet questionnaire. Nine subjects responded to it. They did not know that the story they were evaluating was written by a computer program. The subjects were asked to answer questions related to the age, education and sex of the hypothetical author of the story, as well as questions regarding the quality of the story. The following lines show the mean scores for some of the answers regarding the author: author-age 15.8; author-education: 0.9 ($0 =$ grade school, $1 =$ high school, $2 =$ college, $3 =$ Graduate school); sex: 0.4 ($0 =$ female, $1 =$ male). The following lines show the results obtained for the story (in a scale from 1 to 5 where 5 indicates best): Overall rating of story: 1.5; Clever plot: 2.5; Attention to details: 2.8; Coherency: 3.6; Use of language: 2.1 (the whole questionnaire and results can be consulted in Chapter 15 in Ref. [21]).

4.4. Discussion about MINSTREL

MINSTREL is a powerful and complex system capable of producing interesting and novel outputs. It is an important advance on TALE-SPIN in terms of the complexity of the program and sophistication of the output:

- MINSTREL is arguably the first computerised storyteller that explicitly represents a computer model of the creative process of writing.
- MINSTREL's main contribution to the computational creativity in writing is the concept of TRAMs, which demonstrate the potential power of small changes in story schemas.
- MINSTREL is one of the first computerised storytellers to explicitly employ author-level goals, combined with character-level goals, to generate adequate and interesting outputs.
- MINSTREL generates novel stories by transforming “old” episodes stored in memory.

However, there are important aspects to be improved. Although TRAMs seem to be a powerful tool, they sometimes appear to be written for the special purpose of achieving a specific scene. For example, in the case of the Knight who wants to commit suicide (see Section 4.2), it is difficult to picture how TRAM:Similar-Outcomes-Partial-Change, which guesses or “recognizes that being killed is similar to being injured” [21, p. 116], can work in a different context. To illustrate this situation, the reader can imagine a Knight who is sewing his socks and pricked himself by accident; in this case, because the action of sewing produced an injury in the Knight, MINSTREL would treat sewing as a method to kill someone. Something similar occurs with TRAM:Similar-Outcomes-Implicit, another heuristic to interchange story-elements. This heuristic suggests that “two outcomes are interchangeable in *every* situation if it [the system] can recall [retrieve] *any* situation in which they are interchangeable” [21, p. 120]. Thus, if in episodic memory there is a scene where a knight kills a monster, and another scene where a knight kills a dragon, MINSTREL guesses that monsters and dragons are interchangeable. One wonders what happens if in memory there is a scene where a knight kisses his horse after a battle, and in the following scene the knight kisses his girlfriend. Would MINSTREL guess that girlfriends and horses are interchangeable? Turner is aware of the possibility of producing strange outputs and explains it saying that “A creative problem-solver *should* make errors.” [21, p. 120]. However, this does not justify the fact that some TRAMs only work in very concrete situations and clearly seem to be designed to produce a particular scene.

One of the most impressive characteristics of MINSTREL is its capacity to create stories where revenge, deception, mistaken beliefs, etc. take place. However, these situations are not really created by the system. MINSTREL has 10 ALP heuristics that explicitly indicate the structure that such scenes have and the way to construct them. So, again procedures with precise information on how to achieve particular events play a considerable role in MINSTREL's outcomes. Another important limitation comes from its lack of flexibility in the organisation of its tales: MINSTREL can only produce stories with four different themes, which are structurally predefined and which only can turn around a planning process.

MINSTREL is a very complex program which has pointed out the utility of small modifications as a way to solve problems. Although TRAMs in MINSTREL seem at times to be too specific, they can be a powerful tool during problem solving. Also, MINSTREL indicates the importance of author-level goals in storytelling, particularly theme, consistency, drama and presentation's goals. The most important limitations of MINSTREL are TRAMS tailored to the specific genre of the story, inflexibility in story's structure, and rigidity in the structure of some scenes.

5. MEXICA

MEXICA is a computer model based on an engagement–reflection cognitive account of creative writing that produces stories about the MEXICAS (the former inhabitants of what today is México city, also wrongly known as Aztecs). During the engagement-mode the system produces material driven by content and rhetorical constraints avoiding the use of explicit goal-states or story-structure information. During the reflection-mode the system breaks impasses generated during engagement, satisfies coherence requirements, and evaluates the novelty and interestingness of the story in progress. If the results of the evaluation are not satisfactory, MEXICA can modify the constraints that

Jaguar knight was an inhabitant of the great Tenochtitlan. Princess was an inhabitant of the great Tenochtitlan. From the first day they met, princess felt a special affection for jaguar knight. Although at the beginning princess did not want to admit it, princess fell in love with jaguar knight. Princess respected and admired artist because artist's heroic and intrepid behaviour during the last Flowery-war. For long time jaguar knight and princess had been flirting. Now, openly they accepted the mutual attraction they felt for each other. Jaguar knight was an ambitious person and wanted to be rich and powerful. So, jaguar knight kidnapped artist and went to Chapultepec forest. Jaguar knight's plan was to ask for an important amount of cacauatl (cacao beans) and quetzalli (quetzal) feathers to liberate artist. *Princess had ambivalent thoughts towards jaguar knight. On one hand princess had strong feelings towards jaguar knight but on the other hand princess abominated what jaguar knight did. Suddenly, the day turned into night and after seconds the sun shone again. Princess was scared. The Shaman explained to princess that Tonatiuh (the divinity representing the sun) was demanding princess to rescue artist and punish the criminal. Otherwise princess's family would die. Early in the morning princess went to Chapultepec forest.* Princess thoroughly observed jaguar knight. Then, princess took a dagger, jumped towards jaguar knight and attacked jaguar knight. *Jaguar knight was shocked by princess's actions and for some seconds jaguar knight did not know what to do.* Suddenly, princess and jaguar knight were involved in a violent fight. In a fast movement, jaguar knight wounded princess. An intense haemorrhage arose which weakened princess. Jaguar knight felt panic and ran away. Thus, while Tlahuizcalpantecuhtli (the god who affected people's fate with his lance) observed, princess cut the rope which bound artist. Finally, artist was free again! *Princess was emotionally affected and was not sure if what princess did was right. Princess was really confused.* The injuries that princess received were very serious. So, while praying to Mictlantecuhtli (the lord of the land of the dead) princess died.

Fig. 5. The Lovers (a story generated by MEXICA published in Ref. [23]; text in italics shows those parts produced in 'reflection' mode).

drive the production of material during engagement. In this way, the stories produced by the program are the result of interaction between engagement and reflection. Figs. 5 and 6 show two stories developed by MEXICA. For reasons of space it is impossible to describe the entire system. A detailed description of the whole MEXICA system can be found in Ref. [22]; a detailed description of the core processes in MEXICA can be found in Ref. [23]. A detailed description of the engagement–reflection account of writing can be found in Ref. [15].

MEXICA performs two core processes: creation of knowledge structures in memory; production of stories through the engagement–reflection cycle.

5.1. Knowledge structures

MEXICA builds its knowledge mainly from stories provided by the user. In MEXICA, stories are formed by sequences of actions. Thus, it is first necessary that the user defines a set of valid story-actions, and then writes a group

Jaguar knight was an inhabitant of the great Tenochtitlan. Princess was an inhabitant of the great Tenochtitlan. Tlaloc —the god of the rain— was angry and sent a storm. The heavy rain damaged the old wooden bridge. When jaguar knight tried to cross the river the bridge collapsed injuring badly jaguar knight's head. Princess knew that jaguar knight could die and that princess had to do something about it. Princess had heard that the tepescohuitle was an effective curative plant. So, princess prepared a plasma and applied it to jaguar knight's wounds. It worked and jaguar knight started to recuperate! Jaguar knight realised that princess's determination had saved jaguar knight's life.

During the last war princess's father humiliated enemy's family. Now, it was time of revenge and enemy kidnapped princess. They went to the forest where enemy tied princess to a huge rock. Exactly at midnight enemy would cut princess up. Although it was very dangerous jaguar knight decided to do something in order to liberate princess. For some minutes jaguar knight prayed to Quetzalcoatl —the feathered snake, the god between the gods— and asked for wisdom and braveness. Now jaguar knight was ready to find out its fate.

Princess was really angry for what had happened and affronted enemy. Enemy's frame of mind was very volatile and without thinking about it enemy charged against princess. Meanwhile jaguar knight decided to start a search for enemy. After hard work and difficult moments jaguar knight could finally find enemy. Jaguar knight, full of anger, took a dagger and attacked enemy. Jaguar knight threw some dust in enemy's face. Then, using a dagger jaguar knight perforated enemy's chest. Imitating the sacred ceremony of the sacrifice, jaguar knight took enemy's heart with one hand and raised it towards the sun as a sign of respect to the gods.

Jaguar knight walked towards princess. Full of admiration for all the braveness that princess had shown in those hard moments jaguar knight liberated princess! Although at the beginning princess did not want to admit it, princess fell in love with jaguar knight. Princess was kissing jaguar knight when suddenly princess recognised jaguar knight's tattoo. It was the same as the one used by the fraternity which had murdered princess's father some months ago. At once all those terrible memories were present again. Princess had ambivalent thoughts towards jaguar knight. On the one hand princess had strong feelings for jaguar knight but on the other hand princess abominated what jaguar knight did. Princess felt a deeply odium for jaguar knight. Invoking Huitzilopochtli, god of the dead, princess cut jaguar knight's jugular. The blood covered the floor. Princess took a dagger and cut princess's throat. Princess bled to death while Tonatiu (the god representing the sun) disappeared in the horizon.

Fig. 6. The Princess who Cured the Jaguar Knight (a story generated by MEXICA published in [22, p. 103]).

of stories named Previous Stories. MEXICA processes the Previous Stories to build structures in memory representing content and rhetorical knowledge. Story-actions and Previous Stories are defined in a text file through a set of syntactic rules known as definition languages designed for that purpose.

One of the main problems in story generation is the production of a coherent sequence of actions. In previous models this problem has been solved by predefining the structure of the story to be developed, or by predefining the actions a character can perform (or a combination of both), assuring in this way that events in the story in progress follow a logical path. MEXICA presents an alternative approach. It is assumed that characters' reactions to any particular event are conditioned by the story-world context (SWC) at the moment the action occurred. For example, if a knight walking in the forest suddenly perceives a dangerous situation, this character may react by walking fast in order to avoid it. The context in the forest conditioned the behaviour of this hypothetical walker. In the MEXICA system, it is assumed that a coherent sequence of actions can be produced by linking events through the SWC surrounding them, avoiding in this way the use of explicit goal states or pre-defined story structures.

In MEXICA, stories are formed by explicit and tacit information: the former consists of actions performed by characters that are registered in structures representing story-events and which later are transformed into the words that form the written story; the latter is formed by consequences or post-conditions of story-actions that modify the story-world, which are registered in structures referred to as the SWC and which are never shown as part of the narrative. An example of explicit information is the action *Princess cured Jaguar Knight's wounds after the battle*. As a consequence of the performance of this explicit action the knight felt an enormous gratitude towards the princess. This consequence is tacit information classified as an emotional link between characters in the story. Since each character in the story has its own SWC, a single action might produce different SWCs, which are all stored in memory. Consequences (or post-conditions) are specified by the user during the story-actions definition. SWCs are also modified by routines called inferred post-conditions, which are designed to detect specific situations: for example, the system notices if two characters are in love with the same third character (this situation is known as love competition), and alters the SWCs to reflect this situation.

In order to load content and rhetorical knowledge in memory, MEXICA executes each of the story-actions that form the previous stories, building SWC structures and linking to each of these structures the consequent action in the previous story. In other words, the system associates groups of actions to perform with specific SWCs. In this way, during the engagement–reflection cycle MEXICA employs the SWCs of the story in progress as cues to probe memory and retrieve a next event. The group of SWCs and associated following next actions built from the Previous Stories are known as the Abstract Representation.

In MEXICA, stories are formed by actions that might lead characters to a degraded or improved state [24]. During a degradation process the dramatic tension in the story increases due to the presence of obstacles that prevent a character from achieving a more satisfactory state. Conversely, an improvement process is characterised by actions that eliminate those conditions that stand against a more satisfactory state. In MEXICA, a story is classified as interesting when it includes degradation-improvement processes. The system includes a variable known as Tension to the Reader that represents numerically the dramatic tension in the story at any specific moment. The Tension to the Reader can increase or decrement its value as a result of actions' consequences or inferred post-conditions. A structure referred to as Tensional Representation captures the value of the Tension to the Reader over time (see Fig. 7). MEXICA compares the Tensional Representation of the story in progress against the Tensional Representation of the Previous Stories during the evaluation of interestingness of the story in progress (see Section 5.2).

5.2. The engagement–reflection cycle

During engagement MEXICA retrieves actions from memory avoiding the use of explicit goal-states or predefined story-structures. The engagement cycle is formed by the following steps:

1. An action is performed by a character (the first action in the story is given by the user).
2. The consequences of this action modify characters' SWC.
3. MEXICA employs the SWCs as cues to probe memory.
4. When an SWC matches a structure in memory (in the abstract representation), the system retrieves the set of possible next actions associated with it.
5. Routines, known as Filters, eliminate all those possible next actions that do not satisfy a group of constraints known as guidelines (see below for an explanation of filters and guidelines).

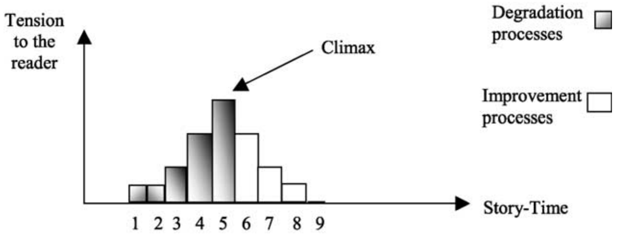


Fig. 7. Tensional Representation of a given story.

6. One of the retrieved actions is selected at random as the next action in the story.
7. Such an action is performed by a character, modifying the SWCs, and the cycle starts again in step 3.

Filters are a set of routines whose main function is to remove those possible next actions retrieved from memory which do not satisfy the requirements imposed by the guidelines (the guidelines are a group of constraints set during reflection; see below for an explanation). Through them MEXICA assures that those recommendations regarding novelty and interest set by the Reflective State are followed during engagement. If no action can be retrieved from memory or all retrieved actions are eliminated by the Filters, MEXICA employs different strategies to try to match structures in memory. Basically, they consist of (1) modifying the SWC used as cue and probing memory again; (2) instantiating the characters of the retrieved possible next actions in unusual ways (a detailed explanation of how cues are modified and how character-instantiation routines work can be found in Ref. [22]). In this way the system is able to produce novel sequences of actions. The engagement cycle ends when a fixed number of actions have been retrieved and performed or when no more actions can be retrieved from memory provoking an impasse.

During reflection MEXICA performs two main processes: (a) verification of the coherence of the story in progress; (b) evaluation of the novelty and interest of the story in progress.

In order to explain how MEXICA verifies the coherence of the story in progress, it is necessary to introduce a new element: an action's preconditions. When a story-action is defined, the user can include a set of preconditions as part of its definition. They represent requirements that must be satisfied before a story-action can be performed. Since during engagement preconditions are ignored, it is during reflection that MEXICA verifies coherence by checking that preconditions in all actions forming the story in progress are fulfilled. Thus, if during reflection an action with unsatisfied preconditions is detected, the system inserts an event in the story in progress whose consequences satisfy the unfulfilled preconditions.

Before describing the way MEXICA evaluates the story in progress it is necessary to introduce the concept of guidelines. After an evaluation is performed, MEXICA determines if the story in progress is developing adequately. When the evaluation is not satisfactory MEXICA employs a group of structures, known as the guidelines, to constrain the type of actions retrieved from memory during engagement (see above how filters work during engagement). MEXICA evaluates originality by comparing the content of the current story with the previous stories. If they are similar, the system sets the guidelines to constrain the retrieval of actions from memory during engagement to more original events. MEXICA evaluates interestingness by comparing the changes in the dramatic tension (Tensional Representation) of the current story with those of the Previous Stories. If, for example, as result of this comparison it is detected that the story is boring (i.e. there is not an increment of the tension) the system sets the guidelines to constrain the retrieval of actions from memory during engagement to those that increment the tension to the reader. Guidelines are only updated during reflection and they only affect the retrieval of actions during engagement. In this way, the evaluation process affects the retrieval of actions during engagement.

In MEXICA, all the story-actions have associated one or more phrases that are employed to produce the final output in English-like format, instantiating slots in the phrases with the names of characters.

MEXICA was evaluated by means of an Internet questionnaire. Fifty subjects from twelve different countries answered it. They were asked to rate stories on a 5 point scale (from 'very poor' to 'very good') for narrative flow and coherence, narrative structure, content, suspense and overall quality. Four stories developed by MEXICA under different operations mode were provided for evaluation (MEXICA includes different operation modes that allow it to produce stories that follow different writing strategies; see Table 1). These comprised one each of the stories was generated under the E2 operation mode (engaged mode only with filters), E2-boring (engaged mode only with filters and with the variable "tension to the reader" forced to have low values), ER2 (the complete model with engaged and reflective mode and the full set of constraints, see Fig. 5), and ER2-boring (engaged and reflective mode with the variable tension to the reader forced to have low values). It was hypothesised that ER2 would gain the highest rates while E2-boring would gain the lowest rates. No prediction was made about the order of the ratings for E2 and ER2 boring. For comparison reasons, a story generated by MINSTREL (see Fig. 3) and a story outline produced by GESTER [11] were included. Finally, a story written by a human in a computer-like

Table 1
Operation modes in MEXICA

Operation mode	Filtering process active	Guidelines active
Engaged state 1 (E1)	No	No
Engaged state 2 (E2)	Yes	Yes (guidelines are set with pre-defined values that never change)
Engaged and reflective states 1 (ER1)	No	No
Engaged and reflective states 2 (ER2)	Yes	Yes (guidelines are always updated during the Reflective State)

Table 2
Results of MEXICA's evaluation on a 5 point scale from 'very poor' to 'very good'

	ER2	Human	MINSTREL	ER2-boring	E2	E2-boring	GESTER
Narrative flow	3.8	3.5	2.9	3.5	2.2	2.8	2.1
Narrative structure	3.7	3.7	3.2	3.2	2.6	2.7	2.1
Content	4.1	3.7	3.6	2.8	2.8	2.4	2.6
Suspense	3.8	3.8	3.3	2.3	2.3	2.0	2.1
Overall quality	3.8	3.6	3.3	2.9	2.6	2.5	2.4

language but aimed to satisfy requirements of originality and interest was also included in the questionnaire. The results can be seen in Table 2. ER2 obtained the highest rates in all categories. The ER2 story got the highest rate in the suspense category while the ER2-boring and E2-boring stories obtained two of the lowest rates. These results suggest that the degradation-improvement process employed by MEXICA to produce interesting stories works correctly. It is interesting to notice that the ER2 story was rated higher than the human-generated story. From these results it is not possible to conclude that MEXICA is a better storywriter than a human author, but perhaps that the human was less effective in accomplishing the task of creating a somewhat unnatural story.

5.3. Discussion about MEXICA

MEXICA is one of the first storytelling programs to be based on a cognitive account of writing. The system achieves two important goals: it embeds a general cognitive account of writing into a computer model and it demonstrates the plausibility of the engagement–reflection cognitive account of writing.

The system demonstrates several innovations:

- It employs a new method to generate novel outputs based on previous stories.
- It employs three different structures to represent content and rhetorical knowledge at different level of abstraction. This knowledge-structure allows a good level of flexibility at the moment of developing new stories.
- It avoids the use of explicit goals or predefined structures to drive the generation of material. This point is important since many AI and cognitive sciences researchers have seen the creative process as a problem solving activity where explicit initial and final-goal states drive the generation of material.
- It is the first system that avoids the use of predefined structures to ensure interestingness. Therefore, MEXICA employs routines that not only evaluate the novelty but also the interestingness of the story in progress.
- It has an explicit management of the story's characters. Based on the characteristics of the story in progress, the system decides when to introduce a new character, when to employ an old one, etc.
- It is simple to modify the group of available story-actions and previous stories loaded in memory, allowing the user to have control of the system's knowledge.

The system also has limitations. A feature of this research is the ability of the computer model to adapt its store of previous stories to create novel ones but, as B. du Boulay has pointed out (personal communication) a weak point is the partial analysis of the theoretical limits of this approach. It is necessary to have a deeper understanding of its possibilities to generate novel stories.

Predefined elements, which usually imply rigidity, are always a delicate point in an automatic storyteller. In MEXICA, inferred post-conditions (e.g. love competition) are specified as part of the code. Therefore, they are fixed and lack flexibility. This can be a problem, since one of MEXICA's important characteristics is its facility to modify story-actions. If new events are added to the system which generate new and obvious inferred post-conditions, MEXICA would not be able to handle this situation without modifying the code. In the same way, although most of the filters are very flexible (they have the capacity of adapting to the story in progress), the number and type of filters are fixed in the code. Since filters are an essential part of engagement, this situation might prevent the system from generating stories in a different genre due to unforeseen problems solved by filters.

6. General discussion

This paper has analysed three large projects to develop computer-based models of storytelling. In this section the three systems are compared and evaluated according to requirements proposed in Section 2: knowledge updating and representation, interestingness, retrieval of adequate and coherent events, originality and story predictability, natural language production and evaluation of the systems' output.

Knowledge Updating. It is important when designing knowledge-based systems to allow for easy updating of their knowledge data-bases. This easy-updating characteristic seems particularly relevant in computerised storytellers, which depend on their knowledge to develop new stories. The following lines illustrate how knowledge structures are created and updated in the three programs that are analysed in this paper. Knowledge structures in BRUTUS are constructed through a program called FLEX that allows, in an English-like format, the defining of frame-structures, relations between frames and production rules. The steps that the designers follow to load knowledge into the system are: (a) they create a story; (b) they represent the story in terms of frames, rules and grammars in an English-like format; (c) they employ FLEX to load that knowledge into the system. Knowledge structures in MINSTREL are largely entered by a graphical interface that allows selecting frames from a menu and interconnecting them with relationships. Although scenes might be formed by complex nets of linked schemas, once they have been designed it is easy to build and load them into the system. Scenes created by MINSTREL during the developing of a new story can be stored as part of the episodic memory and used in the future to create novel material. In MEXICA, knowledge structures are constructed out of the sequence of actions represented in the previous stories. A user of the system can add, remove or modify the group of story-actions and previous stories. This information is stored in text files and follows a simple set of syntax rules. Any new story created by the system can be incorporated into the previous stories file and therefore into the system's knowledge structures. Thus, MEXICA and MINSTREL are able to feed back the stories they create as part of their knowledge data-bases.

Interestingness. The production of interesting and coherent sequences of actions represents one of the main problems in story-generation. TALE-SPIN has been criticized for producing boring stories. MINSTREL and BRUTUS address this problem by predefining story-structures and assuring in this way the production of interesting material. Turner explains how "by structuring the stories it tells around themes, MINSTREL assures that they will have the purpose that was missing from stories told by TALESPIN" [21, p. 213]. Since the structure of stories are explicitly encoded in the themes, structure-predictability in BRUTUS and MINSTREL can be classified as high. MEXICA employs a different tactic to solve this problem. It uses SWCs to link actions in a logical succession of events and the tensional representation to generate interesting stories, avoiding in this way the use of explicit predefined structures. Therefore, its structure-predictability can be classified as lower. The implementation of routines to assess the interestingness of the story in progress indicates that it has not been explicitly codified as part of the knowledge structures by the designer (see Table 3).

Table 3
Comparison of evaluation routines

	MINSTREL	MEXICA	BRUTUS
Evaluates novelty	√	√	X
Evaluates interestingness	X	√	X

Notice that to employ pre-defined structures assures that the story in progress will satisfy the desired level of interestingness. However, the high structure-predictability of this approach brings as a consequence an important lack of flexibility at the moment of developing a new story. This is an important limitation since a computer model of creativity in writing must be able to produce different types of interesting stories. The improvement-degradation method employed by MEXICA is more flexible in this respect. However, the use of this method is only one of several possible ways of evaluating the adequacy of stories. For example, a story which does not include any degradation-improvement process can catch the interest of an audience by describing a novel perspective of a known social fact (e.g. an ecological disaster). MEXICA cannot be asked to produce a story with this characteristic. Evidently, it is necessary to continue studying different options to generate interesting stories.

Retrieval of adequate and coherent events. The next aspect to consider is how the systems retrieve appropriate and coherent material from its knowledge-base so as to progress the story. MINSTREL does not develop a story by retrieving a succession of actions. Instead, it employs a set of partially instantiated episodic schemas as indexes to retrieve episodes from memory. MEXICA employs a different strategy. It builds in memory, from the set of previous stories, a group of SWCs and associated logical next actions to perform. Then, it calls on the SWCs of the story in progress to probe memory, find a similar context and retrieve an associated and adequate next action. MINSTREL and MEXICA employ a set of preconditions to ensure the coherence of the story in progress. In MINSTREL, preconditions are associated with PATs while in MEXICA preconditions are coupled with story-actions. In both cases, events are inserted into the story in progress to satisfy the preconditions and assure the consistency of the output. In this way, MEXICA and MINSTREL represent writing as a non-linear process; e.g. in MEXICA the first event generated by the system might be the last one in the story. This contrasts with BRUTUS, which produces its material in an ordered way. BRUTUS selects a frame-theme, then searches for elements to instantiate the theme with characters and actions. The system then expands its story-grammar to allocate each element of the story in the right place. In this way, it is able to employ adequate and coherent actions.

Originality and Story Predictability. How does the system ensure originality of output? As with TALE-SPIN, BRUTUS does not include a process that can be considered as representing a creative process. It does not incorporate any evaluation routine to assess novelty, since all elements that comprise its output are previously predefined. MINSTREL evaluates novelty by registering the number of times an episode has been employed in previous stories. When the counter exceeds a threshold, MINSTREL employs TRAMs to transform episodes in memory to generate novel outputs. MEXICA evaluates novelty by comparing the content of

Table 4
Story predictability in the three systems

	MINSTREL	MEXICA	BRUTUS
Structure-predictability	Yes	No	Yes
Content-predictability	No	No	Yes

the story in progress with all the previous stories. When it detects that they are too similar (and therefore it is necessary to improve the novelty), guidelines are set to obtain novel actions during engagement. MEXICA then employs different methods to produce novel stories, such as modifying SWCs to retrieve original actions from memory and attempting to employ characters in ways that might produce novel situations. In general terms, BRUTUS has a high story predictability, since both the structure of the story and the actions that characters perform are predefined. In MINSTREL, predefined schemas establish the structure of the story in progress. Thus, it has a high structure predictability, but there is novelty in the content because the actions that characters perform are not predefined. In MEXICA, neither the structure nor the events are cast as predefined structures (see Table 4).

There is an important aspect related to content-predictability in MINSTREL and MEXICA that must be pointed out. Both systems are able to produce novel scenes. However, the schemas that represent those scenes are fixed and neither MINSTREL nor MEXICA can modify them to create novel structures. For example, in MINSTREL a character's plan is always represented by a goal-schema, act-schema and state-schema. MINSTREL cannot invent new types of schemas, novel ways of link them or new values to fill the schemas' slots. In MEXICA, story-actions have a fixed organisation and they cannot be altered: e.g. a story-action involves only a maximum of three characters. The system cannot create new story-actions or produce novel consequences of actions (this aspect is important because story-world actions are employed to link sequences of events, and they are formed by actions' consequences). How much does this situation affect the content-predictability? There may come a point where the content of the outputs produced by these systems would no longer be original. This leads to the idea that, in order to evaluate a computerised storyteller, it might be necessary to subdivide content-predictability into three new divisions: content-structure predictability (how predictable—static or flexible—are the structures that represent the events in a story and how do they affect the content of the text?), content-value predictability (how predictable are the possible values employed to instantiate a schema, that is, can the system produce novel values to fill schema's slots?) and content-action predictability (how predictable are the actions that a character might perform in a given situation?). Thus, MINSTREL and MEXICA have a high content-structure predictability and content-value predictability, and a low content-actions predictability. This type of analysis could result in endless subdivisions and requires a deeper study, which is outside the scope of this paper. In this work we keep the original content-predictability definition and leave the study of the subdivisions for later works.

Bringsjord and Ferrucci suggest a different way to evaluate computer creativity. They introduce the term *creative distance* as the difference between a program's initial data and the output it can generate. In this way, they suggest that "if we look 'under the hood' of a program and find it trivial for a human to transform the program's initial data to the program's output, we are less likely to consider the program creative" [17, p. 161]. Can the creative distance be useful to evaluate how creative is a computerised storyteller? We believe the answer is no and we use an analogy to explain why. Imagine that you paint a beautiful landscape and transform it into a 1000 piece jigsaw-puzzle. Now, imagine that each of these pieces is marked with a special code that indicates the order in which each of them must be assembled. If someone mixes all the pieces and, by following the code, re-creates the landscape, would you consider it a creative process? Probably no, even when the initial data (the 1000 mixed small pieces) is very different to the final result (the beautiful landscape). The reason is that the result of the process has been previously established and therefore one knows the final output. That is the way BRUTUS works and that is why we do not consider it to be a model that represents the creative process. In an analogous way, all the story-elements that comprise BRUTUS have been marked with a special code and the system follows that code to assemble those elements and re-create a story. Thus, it can be described as a system focused in assembling predefined story-elements. In this way, BRUTUS belongs to the group of computerised storytellers like TALE-SPIN and GESTER which are not focused on representing the creative process but on generating well-structured narrative texts.

But, do not MINSTREL and MEXICA also assemble predefined schemas or story-actions to produce their outputs? The answer is yes. The main difference consists in the number of predefined elements employed by each system (see the definition of predefined structures in Section 2). In BRUTUS, all the story elements are predefined. By contrast, MINSTREL and MEXICA are able to produce some relevant knowledge for the stories in progress which originally was not present in their knowledge-base. Therefore, their process not only consists in assembling predefined elements but also in generating novel situations which are relevant for the new story.

Natural Language. The final consideration is the production of natural language. In all the models of writing mentioned in this paper, the words and phrases output by the programs have been predefined by the designers. They are canned words. MINSTREL and BRUTUS employ complex phrasal generators to produce the final version of their stories. MEXICA associates with each story-action a set of phrases that are employed by the system to produce the final output. None of the systems analysed in this paper generate as part of its creative process the words and sentences that form the story. We suggest that the production of well-formed language is an integral part of the creative process of writing and it has a strong interaction with the generation of coherent and interesting sequences of events during the development of a story. This is a major limitation of all systems analysed in this paper and it is important to address this aspect in future designs of computer models of writing.

Story evaluation. Regarding the evaluation of the systems' outputs, Turner employs a questionnaire where a story by MINSTREL is presented to nine subjects who are asked to evaluate it. The subjects are not told that the story was written by a computer program and they are asked to answer different questions regarding the age, education and sex of the hypothetical author of the story, as well as questions about the quality of the story. Pérez y Pérez designed a questionnaire where 50 subjects were asked to compare different aspects of computer-made stories, such as narrative flow and coherence, structure, content and suspense. The authors of BRUTUS do not report an evaluation. Questionnaires like those employed by Turner and Pérez y Pérez seem to be a good option for assessing the output of story generation programs. However, one significant difficulty in assessing computer models of story generation is that there is no generally agreed basis for comparison. To assist future research, we would propose a set of basic benchmarks, as follows:

1. The program's knowledge base should be available for inspection, in human readable form.
2. The designers should state those aspects of creativity that the program is intended to model.
3. The designers should state the intended audience for the stories.
4. The program should be capable of generating at least ten stories from the same knowledge base, without human alteration of the program.
5. The designers may then select three outputs from the ten for evaluation.
6. The three stories should be rated for novelty with respect to the original knowledge base (either by the designers or an independent assessor).
7. The same three stories should be judged for overall quality, originality and interestingness by independent ratters who might be unaware that the output is machine-generated.

Finally, it is interesting noticing that although MINSTREL and MEXICA represent the creative process in very different ways, they share some features:

1. Predefined opportunistic goals (MINSTREL), inferred post-conditions (MEXICA);
2. Predefined preconditions (PATs in MINSTREL and story-actions in MEXICA);
3. When necessary, both systems insert events in the story in progress to satisfy preconditions;
4. Evaluation of story coherence;
5. Evaluation of story novelty;
6. Similar content-predictability;

These characteristics might be employed as starting points in the design of future models of creativity and writing.

7. Conclusions

The development of computer models of writing allow us to explore possible mechanisms for creativity in human beings, as well as enabling a study of alternative computer systems to generate novel outputs. If a program component contributes towards generating an interesting or novel story, that alone is not proof of its existence in human cognition but it does point to a possible mechanism for creativity and also provides a demonstration that aspects of creativity can be modelled by computer. At present, it is only possible to simulate a small part of the creative process of writing and as a result computerized storytellers are far from producing human-like stories. However, the possibility of observing how the models work and how their different parts interact with each other to generate a story, is a valuable resource to test the plausibility of writing models and to gain a clear picture of their limitations. Meehan notes that "Stories are certainly *more* than problem-solving narratives, but they may not be less" [4, p. 203]. Pemberton states that "We need a much richer model of story processing than that which could be offered by either the story grammar or the goal directed model alone" (Pemberton cited in Ref. [25, p. 149]). Thus, much more research is needed in this area. We suggest that these tentative findings are a more accurate depiction of the current state of research that the more conclusive pronouncements. Turner, for example, claims that MINSTREL is a "prima facie evidence that artistic ability can be explained in terms of problem-solving, and that *no further or different cognitive process need be stipulated*" [emphasis added] [21, p. 244]. This claim would appear to be precipitate. Furthermore, this statement is later contradicted when Turner claims that his phrasal generator

> reflects the intuitive difference between explicit, reasoned decisions about how a story will be presented to the reader and the implicit, unconscious use of language…[T]he author's language generation capability is at least partly at the conscious level and at least partly below the conscious level. Explicit author-level presentation goals [which are an essential part of MINSTREL] capture conscious reasoning …while knowledge [i.e. predefined knowledge-structures] in the phrasal lexicon captures the author's fluent, automatic language generation capability [21, p. 447].

Thus, Turner appears to concede that other cognitive processes than those explicitly addressed by MINSTREL are involved in writing. Bringsjord and Ferrucci assert that "human (literary) creativity is beyond computation" [17, p. 149]. It would appear that BRUTUS is not intended to model a creative process: "BRUTUS did not and does not originate…stories." [17, p. 102]. However, systems like MINSTREL and MEXICA suggest that, at least in part, creativity can be represented in computer terms. Bringsjord and Ferrucci also assert that "…our ability to decide whether stories are interesting is one that mere computing machines must forever lack" [17, p. 106]. However, the results obtained from MEXICA's evaluation challenge this claim. Table 2 shows how stories with a low tensional representation are evaluated as lacking suspense and boring. We do not claim that the method of the tensional representation can accurately conclude if a story is interesting, but that it suggest that at least part of the process to evaluate the interestingness of a story can be represented in computational terms.

The analysis of MINSTREL, MEXICA and BRUTUS point out the importance of:

1. How events that form a story are chosen and how the system ensures that they fit together (i.e. that they produce coherent sequences of events) in the story in progress.
2. How the system ensures interestingness in the story in progress.
3. How the system ensures novelty in the story in progress.
4. How the system ensures an adequate story-structure.
5. How much the system depends on predefined structures to produce adequate outputs.
6. The kind of evaluation that the system performs on its output.

In general, it is possible to conclude the following. BRUTUS is built on the assumption that creativity cannot be represented in computer terms and it produces stories by assembly of pre-defined story elements. MINSTREL is built on the assumption that problem solving is sufficient to explain creativity, and the method it employs is to produce stories by the achievement of explicit goals. MEXICA is built on the assumption that problem solving is only a part of the creative process and that engagement plays an important role in writing; the method employed to produce stories is the engagement–reflection cycle.

Creativity is a fascinating area where there are many things waiting to be discovered. Hopefully, this paper will encourage further work in computer models of creativity.

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