TeLLer: Linear Logic based Interactive Storytelling
–
A Case for Support

Anne-Gwenn Bosser

1 Track Record

1.1 Applicant's Background

Dr Anne-Gwenn Bosser has a background in logic and theoretical computer science, including proof theory and Linear Logic, after studying Philosophical Logic at Paris 1 University – La Sorbonne and Logic and Foundations of Computer Science at Paris 7 – Denis Diderot.

Dr Bosser holds a post-graduate degree in Industrial Software Engineering, and a PhD in Computer Science [2], awarded by Paris 7 University – Denis Diderot. The research undertaken during her PhD studies, offering a solution to the issues faced by the development of Massively Multiplayer Online Games [1], was awarded the prize of the Young Researcher in Games by a jury composed of representatives from the computer game industry and academia at the international Imagina 2005 festival [3].

1.2 Expertise in Computer Games Development and Interactive Storytelling

Dr Bosser has experience of the creative industry and in particular the computer game industry. She was for two years part of the R & D team for former Online Game Development Company Cryo-Networks where she was responsible for part of the online game technology developments, regularly acting as a technical project manager for small teams of programmers. In addition, she was involved as a Research Assistant for the laboratory PPS – University of Paris 7, in the French Ministry-funded collaborative research project EDICA. The project involved industrial partners providing middleware for the computer game industry (Cryo-Networks and Virtools). Launched at a time when the lack of adequate high-level software tools made the development of persistent virtual worlds a challenge for the creative industry, the aim of the EDICA project was to develop a high-level development environment for the design of agents evolving in multi-user virtual worlds. Dr Bosser's involvement was related to the design of a framework facilitating the design of co-existing distributed objects with varying quality of services, which ultimately led to a PhD and the publication of [1] and [3].

Dr Bosser collaborated in the design of several Interactive Storytelling (IS) systems. She contributed to the development of an authoring tool for the generation of Japanese fairy-tales [6], based on structural heuristics. This was during a one-year post-doctorate position at the Kwansei Gakuin University for Pr Ryohei Nakatsu lab, funded by the Japanese Society for the Promotion of Science.

As a research assistant at the Conservatoire des Arts et Métiers for 6 months, she also contributed to the design of an authoring tool for providing narrative design control and maintenance of a knowledge base for Non Player Characters [5]. This IS system was built in the context of the French Ministry-funded collaboration project DEEP involving computer games companies Quantic Dreams and Spirops, and LIP6 – University of Paris 6, thus strengthening an understanding about interactive storytelling related issues in the creative industry.

Dr Bosser joined the Intelligent Virtual Environments (IVE) [1] Group at Teesside University in 2007. The IVE is recognised as a leading group in Interactive Storytelling having developed over 5 prototypes in the

[1] http://ive.scm.tees.ac.uk/

past years and has published some of the most cited papers in the field. The group also acts as the co-ordinator of the only FP7 Network of Excellence entirely dedicated to that topic [2]. Dr Bosser has also developped strong collaboration links with the Formal Methods research group through joint supervision of three PhD students.

Dr Bosser's most recent work in the field of Interactive Storytelling concerns the use of Linear Logic as a conceptual model for Interactive Narratives. This proposed research takes as a starting point the early results, presented recently at ECAI [4], showing that interactive narratives can be represented through Linear Logic Sequent Calculus, and that such a model allows to express easily their key fundamental properties. The IVE has developed a number of planning-based Interactive Storytelling prototypes, which will allow the evaluation of the proposed research project, as well as provide an expert research environment.

1.3 Plans for Developing Research Career

Dr Bosser plans to explore new applications of logical formalisms to interactive systems and new media. These are new areas which could benefit from more rigorous formalisations to cope with some of the technical challenges they are currently facing, in view of the complexity of systems and development process.

This project will allow Dr Bosser to establish a strong research profile in this exploration, within the University (making the link between two research groups, respectively in formal methods and intelligent virtual environments) as well as at an internationally recognised academic level.

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[2] http://iris.scm.tees.ac.uk/

2 Project Description

2.1 Rationale and Aims for the Project

Narrative representations have always played a prominent role in AI research and Cognitive Science (see [27] for a recent review and current trends, and [1] to appear). More recently, the emergence of new media has created an opportunity for real-world applications of computational models of narratives [16; 22]. One such example is the use of narrative models to describe game-play in most recent computer games and the perspectives offered by Interactive Storytelling.

Recent research in Interactive Storytelling has converged on the use of AI techniques (mostly Planning) to generate consistent plots, but has paradoxically failed to capitalise on narrative representations. With most of Interactive Storytelling research being empirical there is a need to provide some theoretical foundations that would allow the exploration of basic issues such as narrative causality.

Linear Logic (LL) has had an impact in several areas of computer science, with Girard's [10] seminal article now reaching more than 3400 citations. We have recently described in [2] how LL can also provide a suitable conceptual model for Interactive Narratives. Interactive Narratives are modelled as proofs of a sequent written in Linear Logic which describes initial resources and possible narrative actions. This allows to express easily the key properties for Interactive Narratives: generativity (generation of a variety of different interactive narratives from the same specification), variability (taking into account the impact of external events for an interactive narrative taking place in an open-world assumption), narrative drive (driving the user/reader through specific sequences of narrative actions).

Objectives The aim of this project is to provide solid foundations to the IS endeavour, taking as our starting point the early results presented at ECAI in terms of narrative formalisation using LL: to support a return to the first principles of narrative action description which contrasts with the current proliferation of ad-hoc ontologies while providing a robust framework for interactive narratives. This is a novel approach to the evaluation and validation of interactive narratives extending some of the work which has been done in the past regarding game-design validation [5].

The next step of this research is to extend the LL-based formalisation and support the analysis of IS phenomena with a first level of automated reasoning in the form of a tool (TeLLer) relying on LL Sequent Calculus and Proof-Assistant-based technologies. Not only is the approach novel, but relying on assisted theorem proving technologies also allows for the validation of interactive narratives or game-designs. This will involve addressing issues related to the representation, generation and manipulation of interactive narratives modelled as proof trees in Linear Logic.

2.1.1 Research Hypothesis

Our first research hypothesis is that LL can provide a complete representation of narratives, expressive enough to capture essential dependencies between narrative components, and can thus serve as the foundation of an IS system for specifying and validating interactive narratives using proof-assistant technologies.

Our second research hypothesis is that the interpretation of LL proofs as interactive narratives provides a point of view allowing local and dedicated answers to the traditional issues of proof representation and proof search. Indeed, early results indicate that the LL connectors required by our interpretation might prevent a restriction to fragments offering computationally practicable complexity and decidability results. Defining heuristics, usage patterns, based on the specificities of the encoding of narratives in LL (both at the sequent and proof representation levels) is thus necessary for the design of a proof-assistant-based IS system to support the analysis of the fundamental properties of interactive narratives and to provide automated assistance to narrative generation. A similar approach, based on the identification of restricted patterns of use, has been used successfully in the field of computational linguistics for ensuring computationally practicable analysis for meaning assembly [6; 15].

2.1.2 Evaluation

The project we propose regards the application of formal methods in the field of IS. Such an approach is self-consistent and the validity of the obtained results is in its very nature. However, it is still necessary to empirically evaluate these results by comparing them with what can be obtained via other approaches. Relying on the correlation between LL proofs and plans, we will contrast the results obtained through TeLLer with an existing typical planning-based system for which a set of working examples is available to us, such as [24] or [23] developed as previous work in IS in our group. By modelling in TeLLer the base-stories specifications used as working examples for an existing system, we will be able to compare the set of resulting interactive narratives to what has been previously obtained. We will use the three fundamental dimensions of IS introduced earlier (generativity, variability, and narrative drive) to characterise and compare the results obtained with respective systems.

2.1.3 Deliverables

On successful completion of the project, TeLLer will comprise a set of integrated tools, relying on existing proof-assistant technologies:

- a **dedicated proof-search engine**, relying on heuristics specific to our use of LL for modelling interactive narratives;
- a **front-end** for the encoding and manipulation of interactive narrative specifications into a LL sequent;
- a **visualisation tool**, for the representation of proofs-as-stories, focusing on the features of a proof which are relevant to their interpretation as stories;
- **user-documentation**, targeting the identified beneficiaries;
- **working-examples** of models.

2.1.4 Academic Impact

While IS is a recent research topic, the academic community is fast growing and can be estimated in the hundreds of researchers, thus comparable in size with many sub-fields of digital technologies. Today, research in Interactive Storytelling is represented across several communities dealing with virtual agents, AI and interactivity, virtual reality or entertainment computing. These are represented through such conferences as ACM IUI, ACM Multimedia or AAMAS which regularly include IS contributions. For the Interactive Storytelling community, the main benefit of TeLLer will be the introduction of practicable and relevant formal methods. Research in this field is influenced by narrative theories, which are more ontologies than formalisms, and dominated by empirical models. This project will constitute a step towards the acceptance of a robust theoretical approach to interactive narratives, while faithfully representing the fundamentals of narrative theories. For instance, there are currently no formal definition for generativity, variability, and narrative drive.

For the applied logic research community, the project will provide a novel application of LL as a theory for representing narrative actions. This extends the philosophy which has led to the use of LL for the representation of actions semantic in natural languages, in the field of computational linguistic [7].

We dedicate a phase of the project to the production of adequate dissemination material for the applied logic, planning, and game and interactive storytelling communities. A dedicated web-page will be deployed to present this material on line on the IVE Storytelling website which counts more than 14000 hits to this day [3]. We have also planned for preparing two academic publications during the timeline of the project. The first one will describe the theoretical model while the second one will provide an evaluation of the system. Due to uncertainties with regards to the starting date of the project, it is difficult to name exact venues: we will target venues suitable to Applied Logics in Artificial Intelligence (such as ECAI, IJCAI

[3] http://www.scm.tees.ac.uk/f.charles/

JELIA, or Journal of Applied Logics for instance) and to the Interactive Theorem Proving community (such as ITP for instance), as well as other venues for the IS community (such as ICIDS or AAMAS) [4].

2.2 Project Background

2.2.1 Current Research Issues in Interactive Storytelling

While narratives have always played an important role in artificial intelligence research (see [27] for a recent review), research in Interactive Storytelling, whose long-term goal is to create stories which can respond and adapt in real time to user's reaction, has recently become a sustained interest within the AI community [19; 18].

A typical Interactive Storytelling system uses a planner [29] to dynamically generate a sequence of actions, corresponding to the backbone of the narrative, which can subsequently be visualised using computer gaming technology or computer animation techniques.

In an effort to depart from empirical approaches and to develop more robust theoretical foundations, IS has recently revived the search for narrative formalisms, initially developed in the field of humanities [14; 3]. However, initial hopes of developing computational narratology on the same bases as computational linguistics using such models have been dashed by the finding that they were closer to ontologies than to proper logical or computational formalisms (see [4] for a recent review).

2.2.2 Related Work

Logical Approaches to Interactive Storytelling Grasbon and Braun [13] have used standard logic programming to support the generation of narratives. However their system still relied on a narrative ontology (inspired from Vladimir Propp's narrative funtions [26]), rather than on logical properties as first principles. The only previous use of LL in a closely related application has been reported by [5], and used the multiplicative fragment of LL for scenario analysis, in particular for computer games. Their approach aimed at a priori game/scenario design validation, through compilation into Petri Nets, with an emphasis on evidencing reachable states and dead-ends. While providing a relatively friendly computational model, such a fragment is not expressive enough for our purpose. Apart from these two noticeable attempts, AI work in IS has mostly been based on some form of planning [29] albeit with an empirical approach to action representation, most often directly formalising main narrative actions as planning operators.

Related Applications of Linear Logic Masseron et al. [21; 20] have established how LL formalisation could support planning and how the fundamental properties of LL (in particular the absence of weakening) allows a proof in LL to be equated to a plan. While the Intuitionistic fragment of Linear Logic is undecidable, Dixon et al. [8; 9] use proof-assistant technologies to build and validate plans for dialogues between agents in a Multi-Agents System, which is the orientation we propose for this project. In the field of computational linguistics, [15] identifies usage patterns of LL in meaning assembly analysis [6] ensuring better complexity results than the full considered fragment. Although the development of our project will necessarily rely on different interpretations, which we will base on dedicated encoding and heuristics, this work demonstrates the potential of such a domain-specific approach.

2.2.3 Applicant's Previous Work

In an attempt to return to the representation of core properties of narratives, regardless of story genres, we have recently proposed to use Linear Logic [10; 11] and in particular Intuitionistic Linear Logic [12] (ILL) as a conceptual model [2]. In this work, we represent interactive narratives through an ILL sequent. Such a representation naturally encompasses key narrative phenomena, involving causality, narrative time, and the ability to reason about action and change. While the obvious qualities of Linear Logic for

[4]Because of the short duration of this project, only one publication in an International Conference is taken into account in the costing of this grant

modelling causality made it an ideal candidate, we found out that the explicit management of resources allowed by the ILL sequent calculus helps to support, in a unified way, the action theory identified as the centre of narrative description following previous work in narratology (see for instance [14]). While continuous time is not naturally represented in ILL, the discrete, implicit narrative time corresponding to the occurrence of narrative actions is easily captured.

An ILL sequent thus represents a particular Interactive Narrative, embedding all the possible unfoldings, where the application of the linear implication rule corresponds to the occurrence of narrative actions. We have been able to describe how the key characteristics of Interactive Narratives (generativity, variability, narrative drive) can be expressed and studied through the angle of proof generation and analysis.

LL's $\multimap$ and $\oplus$ connectors are central in the interpretation provided in this early work. The first one is used for the description of narrative actions semantics, and the second one used to model the impact of external events in an open-world assumption (for instance, user interaction). This sets us clearly outside of the multiplicative fragment (MLL), and our use of ! also prevents a restriction to Multiplicative Additive Linear Logic (MALL). This places us, a priori, in a context where traditional means to represent LL proofs (such as proof-nets) will not be suitable, and where provability is undecidable and proof-search costly (see [17] for a review of complexity and decidability results for various fragments).

In order to go further, it is useful to find heuristics based on usage patterns regarding narrative encodings into LL and focusing on the aspect of proofs which are relevant to their interpretations as narratives only. This will allow a reduction of the scope of the proof-search and provide a local and dedicated solution to the proof-as-story representation. This is an approach which has proven successful in the past in computational linguistics [15], where efficient meaning assembly was obtained through patterns of use of the Linear Logic fragment considered. This is the first stage of the proposed project.

2.3 Project Organisation and Methodology

This 16 months-long project is divided into three major phases. After developing the full theoretical model, we will review existing proof-assistant technologies from the perspective of the findings of this first phase, in order to identify the most suitable for the construction of TeLLer. The last 8 months of the project will be dedicated to the actual development of TeLLer and associated dissemination material. The project will require the involvement of the Principal Investigator one day a week, and of a full-time Research Assistant.

2.3.1 Phase 1 – 6 months: Theoretical Model

This phase is dedicated to the definition of the theoretical model for the TeLLer system. It will consist of two to three iterations of a cycle of three inter-dependent tasks.

Task 1 – total 2.5 months This task is dedicated to the definition of a class of sequent which specify interactive narratives, and of an equivalence relationship between proofs. When considering proofs as representing stories in our modelisation, only the occurrence of a few rules and connectors are of significance. This introduces a restricted point-of-view which is dedicated to our interpretation of proofs as interactive narratives. Our working hypothesis is that such a restriction will allow us to solve satisfyingly representational issues while not limiting the expressiveness in terms of interactive narratives. We will also investigate the formal evaluation of the variability of the generated narratives, i.e. assess the importance of the impact of external events in terms of story variation.

Task 2 – total 1 months This task is dedicated to representational issues. The representation of complex proof-trees for human readability is traditionally difficult, and Linear Logic makes no exception apart from very specific subsets such as the multiplicative fragment [11]. However, building on the boundaries defined during task 1, we will provide a local and dedicated answer to interactive proof representation and manipulation. This task is thus more than defining the adequate dose of "syntactic sugar" for beneficiaries acceptance.

Task 3 – total 2.5 months During this task, we will define proof-search strategies for generating, or assisting the generation of validated interactive narratives. The boundaries of our interpretation, defined during task 1, will serve as heuristics to reduce the search domain, and to account for the generation/assisted generation of different levels of variability.

Milestone 1 – Completion of the Theoretical Model At the end of this phase, we will have provided:

- a fine characterisation of proofs in LL which represent interactive narratives, together with an equivalence relationship, and a formal definition of narrative variability thus providing boundaries and patterns of use necessary for the definition of the rest of the theoretical model;
- a dedicated solution to the issue of proof representation, relying on this interpretation of proofs-as-stories;
- proof-search algorithms for the generation of interactive narratives relying on the identified boundaries and heuristics.

2.3.2 Phase 2: Evaluation of Proof-Assistant Systems – 2 months

Task 4 – 2 months This task consists in reviewing the existing proof-assisting tools available for Linear Logic. The aim of the review is to identify existing software which could simplify the actual implementation of our theoretical model. This will start with a review of the most community-active proof assistants which have previously been used successfully for linear logic, such as Coq [25] and Isabelle [8], as they are the most susceptible to offer front-ends for proof-terms which can be adapted to our model. If the results of this first review are not satisfying, linear logic theorem provers such as LLP [28] which are available with adequate licensing for code reuse will be considered.

Milestone 2 – Choice of Underlying Technology An underlying technology has been chosen, and actual implementation tasks for the next phase have been identified.

2.3.3 Phase 3: Implementation and Dissemination – 8 months

Task 5 – 6 months This task concerns the actual implementation of TeLLer. Deliverables will consist of: a front-end allowing the encoding of LL sequents representing stories, a graphical visualisation tool for the generated interactive narratives, dedicated proof-search tactics and evaluation material (TeLLer models for a specification of an interactive narrative).

The models are developed for evaluation purposes: they will consist in reusing the specifications used for the working-examples of existing typical planning based systems, such as [24] or [23]. The generated narratives obtained using TeLLer will then be compared to the output of the chosen planning-based system.

Task 6 – 2 months This task concerns the development of end-user material and dissemination means. It will consist in end-user documentation for the target audience (applied logic, planning, and game and interactive storytelling communities), complete examples of modelisation of typical interactive narratives, and of the packaging of TeLLer for online distribution.

Milestone 3 – Project Completion TeLLer and associated artefacts are available online.

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