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Inferential Erotetic Logic in Modelling of Cooperative Problem Solving Involving Questions in the QuestGen Game[1]

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ABSTRACT: In the paper problem solving processes that involve reasoning with question are analysed. These reasonings with questions are compared to normative solution scenarios based on A. Wiśniewski's Inferential Erotetic Logic. An on-line game with a purpose QuestGen has been used to gather data for the analysis.

KEYWORDS: Erotetic implication – erotetic search scenario – games with a purpose (GWAP) – inferential erotetic logic – questions – scientific discovery games.

0. Introduction

The main aim of this paper is to present our analysis of solutions of tasks retrieved form the on-line game QuestGen. The game has been designed for collecting the data for research focused on problem solving with

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questioning involved.[2] QuestGen consists of detective-like stories, where players have to solve a presented puzzle – initial problem. They collaborate to achieve the solution playing against the game rules within a time limit. What is crucial from our perspective is that for each story in the game there exists a pre-defined normative solution of a given puzzle which is based on certain logical concepts.

The underpinning of QuestGen stories is Inferential Erotetic Logic (hereafter IEL; see Wiśniewski 1995; 2013b). IEL is a logic which focuses on inferences whose premises and/or conclusions are questions (so called *erotetic inferences*), and which gives criteria of validity of such inferences. Thus it offers a very useful and natural framework for analyses of the questioning process. We can point here to IEL's applications in modelling cognitive goal-directed processes (see Wiśniewski 2003; 2001; 2012; and Urbański & Łupkowski 2010). As a consequence of this line of research, IEL is also used as a theoretical background in the context of empirical research. Moradlou & Ginzburg (2014) present a corpus study aimed at characterising the learning process by means of which children learn to understand questions. The authors assume that for some stages of this process children are attuned to a very simple erotetic logic. Urbański et al. (2014) present research on correlations between the level of fluid intelligence and fluencies in two kinds of deductions: simple (syllogistic reasoning) and difficult ones (erotetic reasoning). The tool used to investigate erotetic reasoning is the Erotetic Reasoning Test which exploits IEL concepts (such as erotetic implication) – see Urbański et al. (2016).[3] Our research reported in this paper is in line with these studies. We explore how the normative yardstick, established with the use of IEL, relates to the real solutions of certain (well defined) problems. The novelty of our approach is the use of an on-line game to collect the necessary language data. Such a solution is

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2 The idea of QuestGen is presented in Łupkowski (2011b). Details of the implementation may be found in Łupkowski & Wietrzycka (2015); see also Łupkowski et al. (2015).

3 It is worth mentioning that IEL-based concepts have proven useful for many other domains, including the Turing test's adequacy (cf. Łupkowski 2011a; Łupkowski & Wiśniewski 2011); abductive reasoning (see Komosinski et al. 2014); or proof-theory (see Wiśniewski 2004b; Leszczyńska 2004; 2007; Wiśniewski & Shangin 2006; Urbański 2001a; 2001b; 2002).

inspired by a successful use of game-like elements in the scientific domain (see e.g. *Foldit* (Cooper et al. 2010), *Galaxy Zoo* (Darg et al. 2010), or *Wordrobe* (Venhuizen et al. 2013)). What these games have in common is that when playing the game (and having fun) players solve a serious scientific problem (or rather well defined parts of it). Games of this type are referred to as *games with a purpose* (GWAP – Von Ahn 2006) or s*cientific discovery games* (see Cooper et al. 2010).[4]

The outline of the paper is the following. In the first section we introduce basic notions and concepts from IEL, which are used for the QuestGen design and in the following modelling of solutions. Second section covers the game and the tasks used as well as overview of the collected data. In the third section we model and discuss selected solutions of QuestGen tasks. In the last section we address possibilities of future developments and improvements of our approach.

1. Erotetic inferences and their modelling in Inferential Erotetic Logic

1.1. Language $L^{?}_{cpl}$

In what follows, we will use propositional language with questions. The reason for this is that the expressive power of such a language is just-sufficient for the analysis presented.[5]

We will use Q, Q^*, Q_1, … as metalinguistic variables for questions and A, B, C, D, possibly with subscripts, as metalinguistic variables for declarative well-formed formulas, X, Y, … represent sets of declarative well-formed formulas. We will use $\mathbf{d}Q$ for the set of direct answers to a question Q.

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4 See also an overview of such games presented in Kleka & Łupkowski (2014); Łupkowski & Dziedzic (2016); and Dziedzic (2016).

5 IEL introduces a series of semantic concepts about questions. Semantics for questions are provided by the means of the so called Minimal Erotetic Semantics (MiES for short) – for more details see Wiśniewski (2013b, Chap. 4). It is worth stressing that MiES allows for enriching any formal language with questions, provided that this language allows for partitioning declarative formulas into true and untrue ones (cf. Wiśniewski 1996; 2001; 2013b).

Following Wiśniewski (2013b, Chap. 2) we present language $L^?_{cpl}$. Let us start with L_{cpl} which is the language of Classical Propositional Logic (CPL, for short). Language L_{cpl} contains the following primitive connectives: ¬ (negation), → (implication), ∨ (disjunction), ⊥ (exclusive disjunction), ∧ (conjunction), ↔ (equivalence). The concept of a *well-formed formula* (wff for short) is defined in a traditional manner.

We use p, q, r, s, p_1, … for propositional variables. CPL-valuation (v) is understood in a standard way.

At this point, we introduce another object-level language – $L^?_{cpl}$. The vocabulary of the new language is the vocabulary of L_{cpl} extended with the following signs: ?, {, }, and the comma. This allows us to represent the *erotetic formulas* (e-formulas) of the language. Consequently we say that $L^?_{cpl}$ has two categories of well-formed expressions: *declarative well-formed formulas* (hereafter d-wffs) and *erotetic well-formed formulas* (i.e. questions, hereafter e-wffs). The categories of d-wffs and e-wffs are disjoint. D-wffs of $L^?_{cpl}$ are simply well-formed formulas of L_{cpl}, and e-wffs of $L^?_{cpl}$ are expressions of the form:

(1) $?\{A_1, \ldots, A_n\}$

where $n > 1$ and $A_1, \ldots, A_n$ are nonequiform (i.e. pairwise syntactically distinct) d-wffs of $L^?_{cpl}$ (i.e. CPL-wffs). If $?\{A_1, \ldots, A_n\}$ is a question, then each of the d-wffs $A_1, \ldots, A_n$ is called a direct answer to the question. As we can see, each question of $L^?_{cpl}$ has a finite set of direct answers and each question has at least two direct answers.[6]

Any question of the form (1) may be read (informally):

Is it the case that A_1, or …, or is it the case that A_n?

In what follows, for the sake of simplicity, we will adopt some notational conventions.

A simple yes-no question (i.e. a question whose set of direct answers consists of a sentence and its classical negation) of the form:

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[6] It is worth mentioning that in IEL also other types of questions (including the ones with infinite sets of possible answers) are considered – see Wiśniewski (1995, Chap. 3).

(2) $?\{A, \neg A\}$

are simply presented as:

(3) $?A$

Questions of the form (3) can be read (informally):

Is it the case that A?

1.2. Erotetic implication

In IEL erotetic inferences of two kinds are analysed:

1. *Erotetic inferences of the first kind*, where a set of premises consists of declarative sentence(s) only, and an agent passes from it to a question – grasped under the notion of *question evocation* (see Wiśniewski 2013b, Chap. 6); and
2. *Erotetic inferences of the second kind*, where a set of premises consists of a question and possibly some declarative sentence(s) and an agent passes from it to another question – grasped under the notion of *erotetic implication* (e-implication for short).

In this paper we will be interested only in the erotetic inferences of the second kind. E-implication is a semantic relation between a question Q, a (possibly empty) set of declarative well-formed formulas X, and a question Q_1. It is an ordered triple $\langle Q;X;Q_1\rangle$, where Q is called an interrogative premise or simply initial question, the elements of X are declarative premises and the question Q_1 is the conclusion or the implied question – see Wiśniewski (2013b, 51-52).

The intuition behind e-implication might be expressed as follows. Let us imagine an agent who is trying to solve a certain (possibly) complex problem. The problem is expressed by her initial question (Q). We assume that the agent does not have resources to answer the initial question on her own. Thus the initial question has to be processed/decomposed. This decomposition is aimed at replacing the initial question with an auxiliary question – Q_1. The auxiliary question obtained as a result of the decomposition process should have certain characteristics. First of all, it should stay on the main topic. In other words, no random questions should appear here.

However, the main characteristic that we are aiming at here is that the answer provided to the auxiliary question should be at least a partial answer to the initial question (i.e. it should narrow down the set of direct answers to the initial question, see Wiśniewski 2013b, 43). It should bring our agent closer to solving the initial problem. Summing up, we can perceive the discussed process of replacing one question with an auxiliary one as a well-motivated step from the problem-solving perspective. Before we provide a formal definition of e-implication we will introduce the necessary concepts of MiES. The basic semantic notion to be used here is that of a partition (see Wiśniewski 2013b, 25-30).

Definition 1 (Partition of the set of d-wffs)

Let $D_{L^?_{cpl}}$ designate the set of d-wffs of $L^?_{cpl}$. A partition of $D_{L^?_{cpl}}$ is an ordered pair:

$$\mathsf{P} = \langle \mathsf{T_P}, \mathsf{U_P} \rangle$$

where $\mathsf{T_P} \cap \mathsf{U_P} = \emptyset$ and $\mathsf{T_P} \cup \mathsf{U_P} = D_{L^?_{cpl}}$.

Intuitively, $\mathsf{T_P}$ consists of all d-wffs which are true in P, and $\mathsf{U_P}$ is made up of all the d-wffs which are untrue in P (see Wiśniewski 2013b, 25).

Definition 2 (Partition of the language $L^?_{cpl}$)

By a partition of the language $L^?_{cpl}$ we mean a partition of $D_{L^?_{cpl}}$.

The concept of the partition is very general, thus Wiśniewski (2013b, 26, 30) introduces the class of admissible partitions being a non-empty subclass of all partitions of the language. This step allows for defining useful semantic concepts.

Definition 3 (Admissible partition of $L^?_{cpl}$)

A partition $\mathsf{P} = \langle \mathsf{T_P}, \mathsf{U_P} \rangle$ of $L^?_{cpl}$ is admissible iff for some CPL-valuation v:

(i) $\mathsf{T_P} = \{A \in D_{L^?_{cpl}}: v(A) = \mathbf{1}\}$, and
(ii) $\mathsf{U_P} = \{B \in D_{L^?_{cpl}}: v(B) = \mathbf{0}\}$.

The set of truths of an admissible partition of $L^?_{cpl}$ equals the set of d-wffs which are true under the corresponding CPL-valuation.

Partitioning of the language concerns only declarative formulas. A question is neither in T_P nor in U_P, for any partition P – MiES does not presuppose that questions are true or false (cf. Wiśniewski 2013b, 26). As a counterpart of truth for declarative formulas, for questions we introduce the notion of soundness (see Wiśniewski 2013b, 37).

Definition 4 (Soundness)

A question Q is sound in a partition P iff $\mathbf{d}Q \cap \mathsf{T}_\mathsf{P} \neq \emptyset$.

A question is sound (in a partition) iff at least one direct answer to this question is true in the partition.

Now we need to introduce the definition of multiple-conclusion entailment (mc-entailment) – see Shoesmith & Smiley (1978) and Wiśniewski (2013b, 33).

Definition 5 (Multiple-conclusion entailment)

Let X and Y be sets of d-wffs of language $L^?_{cpl}$. We say that X mc-entails Y in $L^?_{cpl}$ (in symbols $X \Vdash_{L^?_{cpl}} Y$) iff there is no admissible partition $\mathsf{P} = \langle \mathsf{T}_\mathsf{P}, \mathsf{U}_\mathsf{P} \rangle$ of $L^?_{cpl}$ such that $X \subseteq \mathsf{T}_\mathsf{P}$ and $Y \subseteq \mathsf{U}_\mathsf{P}$.

The intuition behind mc-entailment is that it holds between the sets of d-wffs X and Y iff the truth of all d-wffs in X warrants the presence of at least one true d-wff in Y.

Now we may introduce the definition of erotetic implication (see Wiśniewski 2013b, 68).

Definition 6 (Erotetic implication)

A question Q implies a question Q_1 on the basis of a set of d-wffs X (in symbols, $\mathsf{Im}(Q,X,Q_1)$) iff:

(1) for each $A \in \mathbf{d}Q$: $X \cup \{A\} \Vdash_{L^?_{cpl}} \mathbf{d}Q_1$, and
(2) for each $B \in \mathbf{d}Q_1$ there exists a non-empty proper subset Y of $\mathbf{d}Q$ such that $X \cup \{B\} \Vdash_{L^?_{cpl}} Y$.

The first clause of the above definition warrants the *transmission of soundness* (of the implying question Q) and truth (of the declarative premises in X) into soundness (of the implied question Q_1). The second clause expresses the property of *open-minded cognitive usefulness* of e-implication, that is, the fact that each answer to the implied question Q_1 narrows down the set of direct answers to the implying question Q.

If a set X of declarative formulas is empty, an e-implication of this sort is called a *pure e-implication* (see Wiśniewski 2013b, 76).

Let us now consider simple examples of e-implication, starting with a pure one.

(4) $\mathsf{Im}(?\{A, B \vee C\}, \varnothing, ?\{A, B, C\})$

In (4) Q is $?\{A, B \vee C\}$, Q_1 is $?\{A, B, C\}$ and set X is empty. The first condition for a pure e-implication is met. The same applies to the second condition. One may observe that the proper subset Y of the set of direct answers to the question Q is the following: (*i*) for the direct answer A to question Q_1 it is $\{A\}$, (*ii*) when it comes to the answer B it is $\{B \vee C\}$, and (*iii*) for the answer C it is also $\{B \vee C\}$.

Let us consider another example:

(5) $\mathsf{Im}(?A, A \leftrightarrow B; ?B)$

In (5) we may also notice that two conditions of e-implication are met. $?A$ is a simple yes-no question, thus the set of direct answers to this question is $\{A, \neg A\}$. The set of direct answers to the implied question $?B$ is $\{B, \neg B\}$. For each direct answer to $?A$, if it is true and the premise is true, then at least one direct answer to $?B$ is true (it is B for A and $\neg B$ for $\neg A$). As for the second condition of the e-implication, it is also met. The required proper subset Y of the set of direct answers to the implying question $?A$ is the following: (*i*) for the direct answer B to the question $?B$ it is $\{A\}$, and (*ii*) for the direct answer $\neg B$ to the question $?B$ it is $\{\neg A\}$.

1.3. Erotetic search scenarios

When we think about e-implication used for decomposing questions as described above it is easy to imagine that it might be repetitively applied while solving a particular complex problem. The intuition behind such a process is perfectly grasped under Wiśniewski (2013b, 103):

> **EDP** (*Erotetic Decomposition Principle*) Transform a principal question into auxiliary questions in such a way that: (a) consecutive auxiliary questions are dependent upon the previous questions and, possibly,

answers to previous auxiliary questions, and (b) once auxiliary questions are resolved, the principal question is resolved as well.

This leads us to the notion of an erotetic search scenario (e-scenario in short). As the name suggests it is a scenario for solving a problem expressed in the form of a question. The pragmatic intuition behind the e-scenario is that it

> (…) provides information about possible ways of solving the problem expressed by its principal question: it shows what additional data should be collected if needed and when they should be collected. What is important, an e-scenario provides the appropriate instruction for every possible and just-sufficient, i.e. direct answer to a query: there are no "dead ends". (Wiśniewski 2013a, 110)

In this paper – following Wiśniewski (2013b) – we will present the e-scenario as a family of interconnected sequences of the so-called erotetic derivations.[7] It is worth mentioning that e-scenarios can also be viewed as labelled trees (see Leszczyńska-Jasion 2013).

Erotetic derivation is defined as follows (cf. Wiśniewski 2013b, 110–111):

Definition 7 (Erotetic derivation)

A finite sequence $\mathbf{s} = \mathtt{s}_1, \ldots, \mathtt{s}_n$ of wffs is an erotetic derivation (e-derivation for short) of a direct answer A to question Q on the basis of a set of d-wffs X iff $\mathtt{s}_1 = Q$, $\mathtt{s}_n = A$, and the following conditions hold:

(1) for each question $\mathtt{s}_k$ of $\mathbf{s}$ such that $k > 1$:
   (a) $\mathbf{d}\mathtt{s}_k \neq \mathbf{d}Q$,
   (b) $\mathtt{s}_k$ is implied by a certain question $\mathtt{s}_j$ which precedes $\mathtt{s}_k$ in $\mathbf{s}$ on the basis of the empty set, or on the basis of a non-empty set of d-wffs such that each element of this set precedes $\mathtt{s}_k$ in $\mathbf{s}$, and
   (c) $\mathtt{s}_{k+1}$ is either a direct answer to $\mathtt{s}_k$ or a question;

[7] See also Wiśniewski (2001; and 2003) where the idea of e-scenarios has been presented for the first time.

(2) for each d-wff $\mathtt{s}_i$ of **s**:
   (a) $\mathtt{s}_i \in X$, or
   (b) $\mathtt{s}_i$ is a direct answer to $\mathtt{s}_{i\text{-}1}$, where $\mathtt{s}_{i\text{-}1} \neq Q$, or
   (c) $\mathtt{s}_i$ is entailed by a certain non-empty set of d-wffs such that each element of this set precedes $\mathtt{s}_i$ in **s**.

The e-derivation is *goal-directed*: it leads from an initial question Q to a direct answer to this question. Clause (1a) of the above definition requires that an auxiliary question (i.e. a question of an e-derivation different from Q) appearing in an e-derivation should have different direct answers than the initial question Q. Clause (1b) amounts to the requirement that each question of the e-derivation which is different from the initial question Q must be e-implied by some earlier item(s) of the e-derivation. Clause (1c) requires that an immediate successor of an auxiliary question in the e-derivation must be a direct answer to that question or a further auxiliary question. Clause (2) enumerates reasons for which a d-wff may enter an e-derivation. Such a d-wff may be: (2a) an element of a set of d-wffs X; (2b) a direct answer to an auxiliary question; (2c) a consequence of earlier d-wffs.

Definition 8 (Erotetic search scenario)

A finite family Σ of sequences of wffs is an erotetic search scenario (e-scenario for short) for a question Q relative to a set of d-wffs X iff each element of Σ is an e-derivation of a direct answer to Q on the basis of X and the following conditions hold:

(1) $\mathbf{d}Q \cap X = \emptyset$;
(2) contains at least two elements;
(3) for each element $\mathbf{s} = \mathtt{s}_1, \ldots, \mathtt{s}_n$ of Σ, for each index k, where $1 \leq k < n$:
   (a) if $\mathtt{s}_k$ is a question and $\mathtt{s}_{k+1}$ is a direct answer to $\mathtt{s}_k$, then for each direct answer B to $\mathtt{s}_k$: the family contains certain e-derivation $\mathbf{s^*} = \mathtt{s^*}_1, \mathtt{s^*}_2, \ldots \mathtt{s^*}_m$ such that $\mathtt{s}_j = \mathtt{s^*}_j$ for $j = 1, \ldots, k$, and $\mathtt{s^*}_{k+1} = B$;
   (b) if $\mathtt{s}_k$ is a d-wff, or $\mathtt{s}_k$ is a question and $\mathtt{s}_{k+1}$ is not a direct answer to $\mathtt{s}_k$, then for each e-derivation $\mathbf{s^*} = \mathtt{s^*}_1, \mathtt{s^*}_2, \ldots \mathtt{s^*}_m$ in Σ such that $\mathtt{s}_j = \mathtt{s^*}_j$ for $j = 1, \ldots, k$ we have $\mathtt{s}_{k+1} = \mathtt{s^*}_{k+1}$.

E-derivations being elements of an e-scenario will be called *paths* of this e-scenario.

For our purposes notions of query of an e-derivation (cf. Wiśniewski 2013b, 112) and query of an e-scenario (cf. Wiśniewski 2013b, 113) will also be needed.

Definition 9 (Query of an e-derivation)

An element $\mathtt{s}_k$ (where $1 < k < n$) of an e-derivation $\mathbf{s} = \mathtt{s}_1, \ldots, \mathtt{s}_n$ is a query of $\mathbf{s}$ if $\mathtt{s}_k$ is a question and $\mathtt{s}_{k+1}$ is a direct answer to $\mathtt{s}_k$.

Definition 10 (Query of an e-scenario)

A query of an e-scenario is a query of a path of the e-scenario.

As an illustration of the above concepts, let us consider a simple example – see Figure 1. The initial question of our exemplary e-scenario is $?p$. Only one declarative premise is employed here, namely $p \leftrightarrow q$. This e-scenario contains two paths (i.e. two e-derivations):

(6a) $?p, p \leftrightarrow q, ?q, q, p$

(6b) $?p, p \leftrightarrow q, ?q, \neg q, \neg p$

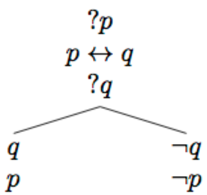


Figure 1: Example of an e-scenario for the question $?p$ relative to the premise $p \leftrightarrow q$

The e-scenario has only one query, i.e. $?q$. The query is e-implied by the initial question and the declarative premise (see e-implication scheme (5)).

An e-scenario might be viewed as providing a search plan for an answer to the initial question. This plan is relative to the premises a questioner has, and leads through auxiliary questions (and the answers to them) to the answer to the initial question. Each path of an e-scenario leading from the root to one of the leaves represents one of the ways in which the process of solving the initial problem might go. This allows us to consider issues referred to as *distributed internal question processing* (see Wiśniewski 2013b, 105).

The key feature of e-scenarios is that auxiliary questions appear in them on the condition that they are e-implied. Thus we may use e-scenarios to provide some insights into questioning strategies. This approach is efficient for contexts where a questioner wants to obtain an answer to the initial question, which should not be asked directly (as e.g. in the Turing test situation, where asking a direct question 'Are you a human or a machine?' would be fruitless as a satisfactory way of obtaining a solution to the problem of agent identification).[8] To obtain an answer to the initial question, a questioner usually asks a series of auxiliary questions in these situations. Answers to these auxiliary questions build up to be an answer to the initial one. It is easy to imagine a context such as this in real life situations, as for example while teaching, when we want to check if our student really understands a given problem. Figure 2 presents a natural language example of a questioning plan which has the structure of an e-scenario.

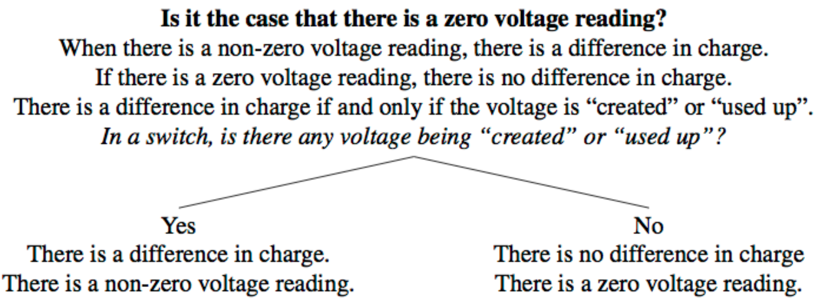


Figure 2: Example of a questioning plan with an e-scenario structure.
The example is based on a tutor-student dialogue from The Basic Electricity and Electronics Corpus (see Rosé et al. 1999), file BEE(F), stud37

8 See Łupkowski (2011a), Urbański & Łupkowski (2010); and also Genot (2009) and Genot & Jacot (2012) for the discussion of these issues in the framework of Interrogative Games.

2. QuestGen – the game with a purpose used for collecting the data

The idea of the game was presented in Łupkowski (2011b, 89-91). The aim of the QuestGen game is to engage players in generating a large collection of questions for a certain piece of story written in natural language. What is crucial from our point of view is that each story used in QuestGen is based on an e-scenario, which serves as a normative yardstick for the pre-established solution of this story. This allows us to compare and discuss the normative view on a given solution and real solutions retrieved via the game.

An important disclaimer is needed at this point. Our claim here is not that logical concepts are the ultimate explanation of the gathered linguistic data (i.e. that people are/or should process questions according to IEL) – see the detailed discussion in Łupkowski (2016). Our approach here is rather that logic provides a very useful normative yardstick to study, describe and analyse these phenomena (see Stenning & Van Lambalgen 2008, 130). Logic may be, and is, successfully applied within research concerning actual human reasoning as reviewed and discussed by Urbański (2011) or Sedlár & Šefránek (2014). For this context, IEL offers convenient tools for modelling natural language phenomena and for their better understanding. Using these tools we will consider the issue of motivation for certain moves in the game (or in a broader context, in a dialogue). On the other hand, empirical data (like that retrieved from language corpora) allows for *better tailored logical concepts* – see e.g. concepts of weak erotetic implication introduced by Urbański et al. (2016) as a consequence of analysis of solutions to Erotetic Reasoning Test tasks.

In the QuestGen game, two randomly chosen players are engaged in solving a detective puzzle. One of them plays as the Detective, while the other is called the Informer. The aim for the Detective is to solve the presented puzzle by questioning the Informer. Each story in the game has two formulations (one for the Detective and one for the Informer), containing all the additional data necessary to solve the puzzle. Each story should be solved within a given time limit.

The basic rules for the game are the following:

1. The Detective is allowed only simple yes/no questions.

2. The Detective is not allowed to ask directly for the solution to a puzzle.
3. The Detective may ask as many questions as she/he wants (within the time limit).
4. The Informer should provide information accordingly to her/his version of the story.

QuestGen, in the version described in this paper, consists of six stories, entitled: *Hrabina* (Countess), *Teleturniej* (Quiz), *Zaginiony chłopak* (Lost boyfriend), *Tablet*, *Arsen L.*, *Bomba* (Bomb). The stories were written (or adapted) by the second author of the paper.

The process of preparing all these stories started with an appropriate e-scenario. In what followed the plot was built on the basis of the e-scenario structure. The *Arsen L.* story is a slightly modified example of the e-scenario in action taken from Wiśniewski (2003, 392). The *Bomb* is adapted from one of the aforementioned Erotetic Reasoning Test tasks presented in Urbański et al. (2016, 4-6). Story *Countess* is based on the e-scenario from Łupkowski (2010, 78); *Quiz* uses the e-scenario from Wiśniewski (2013b, 110). Stories *Lost boyfriend* and *Tablet* are both based on the same e-scenario taken from Wiśniewski (2004a, 16). The idea behind this decision, was to check whether two stories with the same logical structure will be solved in a similar manner. Table 1 presents the basic characteristics of stories used in QuestGen.

Table 1: Stories used in QuestGen: Informer (I), Detective (D)

Title	Premises	Facts (I)	Words (D)	Words (I)	Time limit
Countess	3	3	150	146	3 min
Quiz	3	3	113	110	3 min
Lost boyfriend	3	4	146	118	3 min
Tablet	3	4	111	132	3 min
Arsen L.	4	3	155	113	4 min
Bomb	6	6	169	169	6 min

Let us now take a closer look on one of the stories. Due to the space restrictions we will not be able to present all six stories, they can be found at the project's webpage.[9] It is also worth mentioning that all the data collected with the use of QuestGen are now included in the Erotetic Reasoning Corpus (ERC)[10]. ERC constitutes a data set for research on natural question processing – see Łupkowski et al. (2017). All the data is in Polish, however the tag-set used for the annotation allows for the data analysis for English-speaking researchers. For this paper we have decided to present the story *Bomb*. The reasons for this are twofold. Firstly, it is the most complex story in QuestGen (with the highest number of premises for Detective and facts for Informer – see Table 1). Secondly, the story has been adapted from the Erotetic Reasoning Test task (see Urbański et al. 2016, 4-6), and thus it is possible to compare and discuss the results from the test and from QuestGen. Changes to the original version cover different names used in the story and different wires colours (changed from green, red and orange to purple, orange and pink, in order to avoid popular references to e.g. films). Let us remind that each QuestGen story has its two formulations, one for Detective and one for Informer. Below we present a translation of the story from the game.

Bomb: Detective version

There was a bomb planted in the main train station of Nibyjunkcja. You coordinate actions of the sapper unit. The chief of the local police managed to establish the following evidence, which he is sharing with you now:

1. There are three wires in the bomb: purple, orange and pink.
2. To disarm the bomb either the purple or the orange wire must be cut. Cutting the wrong wire will cause an explosion.
3. If the bomb has been planted by Anthony, cutting the purple wire will disarm it.
4. If the bomb has been planted by Roger, cutting the orange wire will disarm it. Moreover, no one but Roger would have used the orange wire.

9 https://plupkowski.wordpress.com/projects/questgen-game/.

10 https://ercorpus.wordpress.com/.

5. If the bomb has not been planted on an even day of the month, the culprit is Anthony.
6. The bomb has been planted by Anthony, or by Roger, or by someone else.

Which wire should be cut to disarm the bomb?

Before you will make a decision you can ask questions to the chief of security, who is responsible for the place where the bomb is planted. Remember the time is limited. You can ask only yes/no questions. There is no sense to ask directly which wire should be cut to disarm the bomb, because the chief of security does not know this.

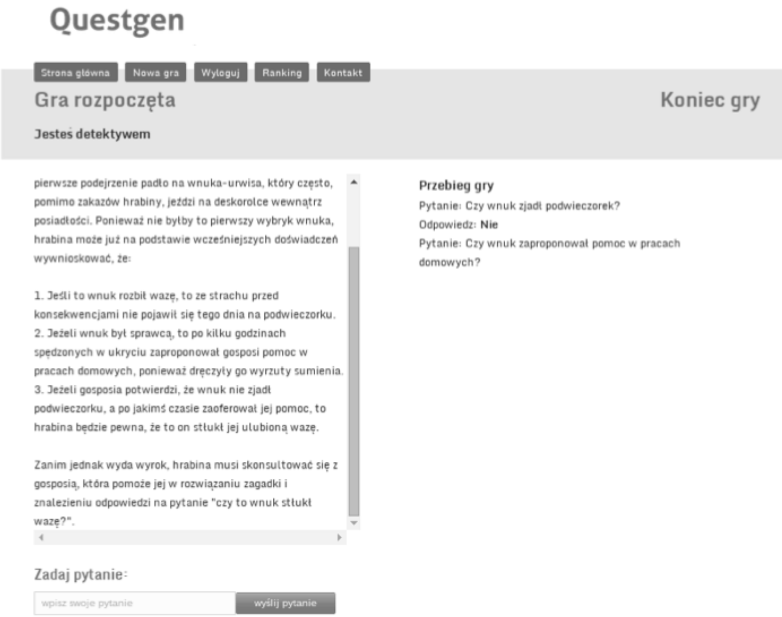
Bomb: Informer version

You are the chief of security at the train station where the bomb was planted. The coordinator of the sapper unit is trying to establish which wire to cut in order to disarm the bomb. He has the following facts at his disposal:

1. There are three wires in the bomb: purple, orange and pink.
2. To disarm the bomb either the purple or the orange wire must be cut. Cutting the wrong wire will cause an explosion.
3. If the bomb has been planted by Anthony, cutting the purple wire will disarm it.
4. If the bomb has been planted by Roger, cutting the orange wire will disarm it. Moreover, no one but Roger would have used the orange wire.
5. If the bomb has not been planted on an even day of the month, the culprit is Anthony.
6. The bomb has been planted by Anthony, or by Roger, or by someone else.

After checking security cameras you know the following:

1. The bomb was planted by Roger YES
2. The bomb was planted by Anthony NO
3. The bomb was planted on an odd day of the month. NO
4. The bomb was planted on an even day of the month. YES
5. The bomb was planted by someone else. NO
6. To disarm the bomb the orange wire should be cut. YES


Questgen
Strona główna
Nowa gra
Wyloguj
Ranking
Kontakt
Gra rozpoczęta
Koniec gry
Jesteś detektywem
pierwsze podejrzenie padło na wnuka-urwisa, który często, pomimo zakazów hrabiny, jeździ na deskorolce wewnątrz posiadłości. Ponieważ nie byłby to pierwszy wybryk wnuka, hrabina może już na podstawie wcześniejszych doświadczeń wywnioskować, że:
1. Jeśli to wnuk rozbił wazę, to ze strachu przed konsekwencjami nie pojawił się tego dnia na podwieczorku.
2. Jeżeli wnuk był sprawcą, to po kilku godzinach spędzonych w ukryciu zaproponował gosposi pomoc w pracach domowych, ponieważ dręczyły go wyrzuty sumienia.
3. Jeżeli gosposia potwierdzi, że wnuk nie zjadł podwieczorku, a po jakimś czasie zaoferował jej pomoc, to hrabina będzie pewna, że to on stłukł jej ulubioną wazę.
Zanim jednak wyda wyrok, hrabina musi skonsultować się z gosposią, która pomoże jej w rozwiązaniu zagadki i znalezieniu odpowiedzi na pytanie "czy to wnuk stłukł wazę?".
Przebieg gry
Pytanie: Czy wnuk zjadł podwieczorek?
Odpowiedz: Nie
Pytanie: Czy wnuk zaproponował pomoc w pracach domowych?
Zadaj pytanie:
wpisz swoje pytanie
wyślij pytanie

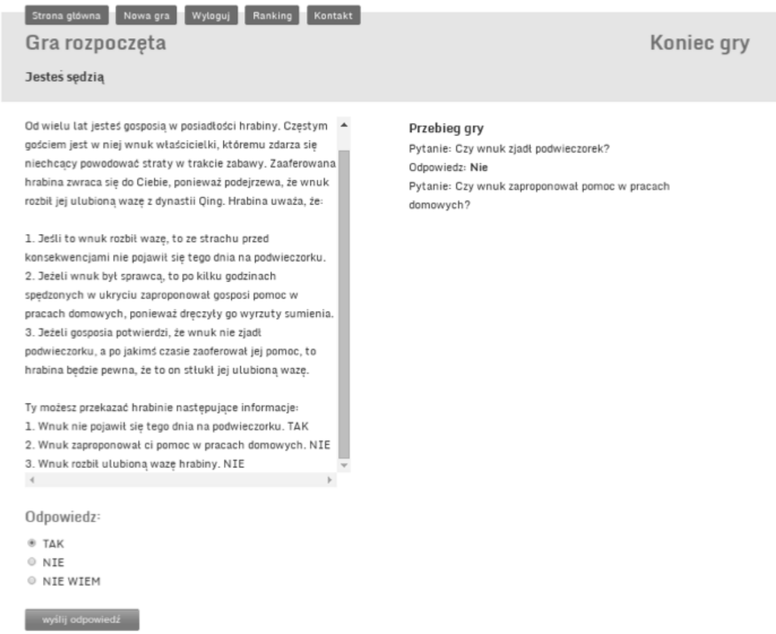

Strona główna
Nowa gra
Wyloguj
Ranking
Kontakt
Gra rozpoczęta
Koniec gry
Jesteś sędzią
Od wielu lat jesteś gosposią w posiadłości hrabiny. Częstym gościem jest w niej wnuk właścicielki, któremu zdarza się niechcący powodować straty w trakcie zabawy. Zaaferowana hrabina zwraca się do Ciebie, ponieważ podejrzewa, że wnuk rozbił jej ulubioną wazę z dynastii Qing. Hrabina uważa, że:
1. Jeśli to wnuk rozbił wazę, to ze strachu przed konsekwencjami nie pojawił się tego dnia na podwieczorku.
2. Jeżeli wnuk był sprawcą, to po kilku godzinach spędzonych w ukryciu zaproponował gosposi pomoc w pracach domowych, ponieważ dręczyły go wyrzuty sumienia.
3. Jeżeli gosposia potwierdzi, że wnuk nie zjadł podwieczorku, a po jakimś czasie zaoferował jej pomoc, to hrabina będzie pewna, że to on stłukł jej ulubioną wazę.
Ty możesz przekazać hrabinie następujące informacje:
1. Wnuk nie pojawił się tego dnia na podwieczorku. TAK
2. Wnuk zaproponował ci pomoc w pracach domowych. NIE
3. Wnuk rozbił ulubioną wazę hrabiny. NIE
Przebieg gry
Pytanie: Czy wnuk zjadł podwieczorek?
Odpowiedz: Nie
Pytanie: Czy wnuk zaproponował pomoc w pracach domowych?
Odpowiedz:
TAK
NIE
NIE WIEM
wyślij odpowiedź

Figure 3: A screenshot of QuestGen game. The Detective's screen is visible on the top, while the Informer's screen is presented below. For the Detective's part the story is presented in the left column. Below the story there is a field for typing question. The right column presents the game as it is progressing. For the Informer's screen we also have the story in the left column, but below it there are pre-established answers to Detective's question to be used by the Informer.

As we have stressed above the structure of the story is based on the e-scenario, which is presented in Figure 4 (see Urbański et al. 2016, 38). Propositional variables represent the following sentences:

p – Cutting the purple wire disarms the bomb.
q – Cutting the orange wire disarms the bomb.
v – Cutting the pink wire disarms the bomb.
s – The bomb has been planted by Anthony.
r – The bomb has been planted by Roger.
t – The bomb has been planted on an even day of the month.
u – The bomb has been planted by someone else.

$$?\{p, q, v\}$$
$$p \vee q$$
$$s \rightarrow p$$
$$r \leftrightarrow q$$
$$\neg t \rightarrow s$$
$$r \bot s \bot u$$
$$?\{r, \neg r\}$$

r	$\neg r$
q	$\neg q$
	p

Figure 4: E-scenario for the *Bomb* story

We treat the e-scenario as presenting the normative solution for the given puzzle. For our Detective it will be enough to ask only one question, namely *Was the bomb planted by Roger*? ($?\{r, \neg r\}$). After obtaining the affirmative answer from the Informer (r), the Detective would reach the answer to the initial question – the orange wire should be cut in order to disarm the bomb (q). Such a procedure is optimal in the sense that no spare, non-necessary auxiliary questions are asked. Auxiliary question $?\{r, \neg r\}$ is e-implied by the initial question $?\{p,q,v\}$ on the basis of premises $p \vee q$ and $r \leftrightarrow q$.

In what follows, we will say that the solution to a given puzzle in QuestGen is *correct and normative*, when the Detective will provide pre-established solution and, what is more, she/he will reach this solution by asking auxiliary questions accordingly to e-scenario used as an underpinning for the story. (It is worth mentioning that there are puzzles in QuestGen that require asking more than one auxiliary question, in these cases the order of asking auxiliary questions is not important.) We would say that the solution to a given QuestGen puzzle is *correct but non-normative* in cases, when Detective will reach the pre-established solution, however the process of reaching this solution does not involve asking auxiliary questions from the appropriate e-scenario. In cases where more than one auxiliary question is required also solutions where Detective does not ask all the required auxiliary questions are counted as non-normative. For cases where the answer to the puzzle is different than the pre-established one, we say that the solution is *not correct*.

To improve readability in the following analysis we propose to present solutions in form of schemata based on an e-scenario. Such a schema for the normative solution of the *Bomb* puzzle is presented in Figure 5. In the root we have auxiliary question that should be asked by the Detective. Below the root we have answers that might be provided by the Informer (Y – 'yes', N – 'no'). Information that should be provided accordingly to the Informer's version of the story is circled. At the leaf a solution to the initial question (which is delivered by the Detective) is presented.

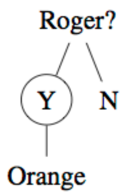


Figure 5: The schema of the normative solution for the Bomb puzzle. See e-scenario in Figure 4

3. An analysis of solutions to QuestGen tasks

The data analysed in this paper has been recorded during February 2015. QuestGen was published on-line. Anyone, who completed the registration could play the game. Each randomly chosen pair of players went through all six stories of QuestGen. For each story the players switched roles, from the Detective to the Informer and *vice versa*. Players were not supervised in any way, they were just playing the game. (Although an information about the scientific aim of the game was provided in the *Contact* section of the game web-site). Overall we have collected 116 game transcripts from 40 players. The general solution statistics for the study sample (all six stories) is the following: 91 solutions are *correct*, out of which 44 are *normative*, i.e. solved exactly accordingly to the e-scenario underpinning a given story. In 18 cases Detectives provided *incorrect* solutions and in 7 they did not provided *any solution* (mostly due to the time constraints).

There are several regularities which may be observed across the collected data. First of all, for all six stories we observe solutions which may be classified as correct and normative. What is more for each story there are *more* correct than incorrect solutions, but the majority of correct solutions are not normative (let us remind here that this means, that Detectives gave the correct answer to the initial question but they reached it not in the way which is predicted by the underlying e-scenario). The summary of this data is presented in Table 2.

Table 2: Number of correct and correct and normative solutions to the QuestGen stories

Title	Correct solutions	Correct and normative solutions
Countess	8	4
Quiz	14	6
Lost boyfriend	17	7
Tablet	18	10
Arsen L.	15	11
Bomb	18	6

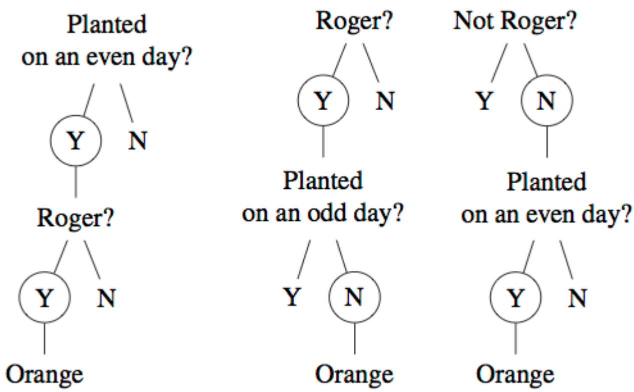
Disproportion observed between correct and correct and normative solutions provides a good basis for studying different strategies of solving QuestGen stories. We provide such a detailed analysis for the *Bomb* story below.

What is also visible is the tendency to learn how to solve QuestGen stories. Tables 1 and 2 present this stories in the order in which they were presented to our players. It may be noticed that with each story, players were getting better and more accurate in solving them.

On the basis of the all gathered data two other general tendencies may be derived. It seems that our players tend to process one premise after another in the order in which they appear in a given story. We often observe that the questions asked and their order reflect the order of premises. What is more, it is often the case that premises are paraphrased by players, mostly by reformulating negative sentences into affirmative ones.

Last but not least, it is also worth to mention that QuestGen players comprised themselves to the game rules (which is important, as QestGen is simply an on-line game and the process of data collection is not supervised). All questions asked in the game were (exactly as required) yes/no questions, and forbidden questions (i.e. asking directly for the solution) were rare. The low number of games without a solution being provided by the Detective suggests also that the difficulty level of stories and time constraints were chosen adequately.

Let us now focus on the story presented in details in the previous section, i.e. the *Bomb*. For this story 20 solutions were gathered. Out of these 19 ended with the solution given by the Detective, 18 solutions were correct and 1 was not correct (the Detective pointed out to the pink cable – see scheme D1 below). 1 game ended without a solution being delivered by the Detective. In this case the Detective asked a forbidden question ("Purple one?") and then the game ended. Let us now take a closer look on correct solutions. From the normative point of view only one auxiliary question was needed to reach the solution – see Figures 4 and 5. Only six out of eighteen correct solutions were reached exactly in the way predicted by the normative model. However more complex solutions were also recorded. Players asked more than one question usually referring to premises about the day the bomb has been planted. Below we present them in a schematic form.

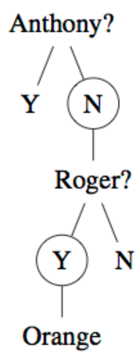


(B1) (B2) (B3)

Solution (B1) starts by asking an auxiliary question concerning the day the bomb was planted. Information retrieved by the Detective is not enough (from the normative point of view) to reach the answer to the initial question, thus the second auxiliary question is asked. This time the answer might be reached. Solutions (B2) and (B3) are even more interesting. Form the normative point of view, the Detective is able to solve the initial problem after obtaining the answer to first auxiliary question asked. Why players decided to ask yet another auxiliary question in these cases is an open question. At this point we should mention one of the main drawbacks of our method of using the game to collect data as compared with the Erotetic Reasoning Test presented in Urbański et al. (2016). The Test is designed in such a way, that it requires an answer associated with its explanations. This allows for better understanding of certain choices made by subjects. QuestGen provides a flexible environment collecting data, but the cost is that gathered solutions are not enriched with additional explanations.

It is worth stressing that QuestGen players often reformulate premises (as we have mentioned, such a behaviour is observed for all stories in the game). This is visible in the discussed schemata (B1), (B2) and (B3). Detectives sometimes ask about whether the bomb has been planted on odd day, and sometimes they decide to ask whether it was an even day (compare with the fifth premise "If the bomb *has not been planted* on an even day of the month, the culprit is Anthony"). We can even observe rather unexpected questions with negation as in (B3). Despite this variety of formulation of auxiliary questions by Detectives it may be observed that Informers (in vast majority of cases) are able to provide the correct answers with respect of their version of a given story. This may be interpreted in favour of the cooperative game design, where Detective and Informer play together against the game rules and the time limit.[11]

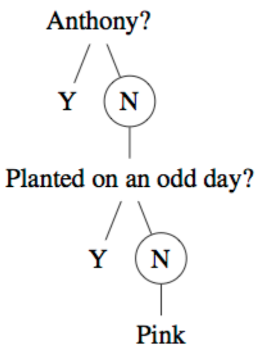
We also observed two solutions of the type presented in scheme (C). Here we may hypothesize that Detectives use a kind of heuristics addressing culprits mentioned in the premises. Observe that the order in which their names appear as questions is the same as the order in which they appear in premises (first Anthony, then Roger). This suggests a simple strategy of testing one option after another (we may hypothesize that it is done without a deeper analysis of available premises).



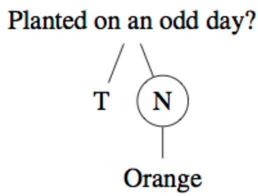
(C)

[11] An interested reader may find the discussion concerning competitive scenario for QuestGen implementation in Łupkowski & Wietrzycka (2015).

Let us now take a look at solutions presented in (D1) and (D2). In (D1) the Detective arrives to a wrong solution to the initial question. In his case auxiliary question required by the normative solution does not appear during the process. It seems that the player in this case is not able (or willing) to use given premises to decompose the initial question. In favour of this interpretation is that after obtaining clear information that it was not Anthony who planted the bomb, the player uses the premise related to Anthony as the culprit. What is more the second premise stating clearly that only purple or orange wires should be taken into account for disarming the bomb is ignored here – Detecitve points at pink wire as the one to be cut. This solution is far from the normative one, and may be a result of pure guessing (possibly enforced by the time constraints of the game). As such, solution (D2) is also interesting. The Detective asks here whether the bomb has been planted on an odd day. The information given by the Informer is correct, however (given the premises) it is certainly not enough to reach the solution to the initial question.

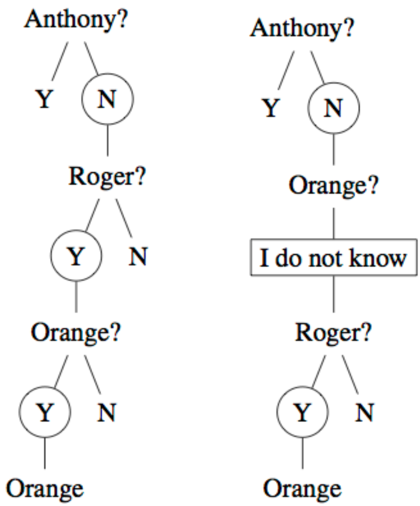


(D1)



(D2)

What is also interesting, there were cases when QuestGen design allowed to cope with certain more complex Detective moves. These are solutions depicted as (E1) and (E2).



(E1) (E2)

Let us remind that in QuestGen a direct question for a solution is forbidden. Thus we allow the Informer to react with "I do not know" in situations when the Detective asks for such an information – which is in line with the version of a story for the Detective. (The Informer may also use this response in a situation when she/he cannot resolve a question form Detective, i.e. there is not enough information in her/his version of the story). What we find puzzling with (E1) and (E2) is that they start with question about one of the culprits. It is not simply the case that the first question appearing is the forbidden one. What is more puzzling is that (E1) and (E2) differ with respect to Informer's reaction to a forbidden question. In (E1) we see "Yes" answer, while in (E2) we observe behaviour with accordance to the game rules – i.e. "I do not know" response. A closer look on the way questions are formulated here sheds some light on these cases.

In (E1) we are dealing with well-formed questions. (Original spelling is preserved in following dialogues.)

DETECTIVE: Czy Arkadiusz ma coś wspólnego z bombą? [*Is it the case that Anthony has something to do with de bomb?*]

INFORMER: No.

DETECTIVE: A więc to Roman jest winny?! [*So it is the case that Roger is guilty?!*]

INFORMER: Yes.

DETECTIVE: **Czyżby** pomarańczowy? [*Orange,* **isn't it***?*]

INFORMER: Yes.

DETECTIVE: Pomarańczowy. [*Orange.*]

In our opinion the question about the orange wire should be interpreted here as a tag question in this context. Its formulation suggests that Detective already knows the answer. Informer seems to correctly interpret this move and thus does not use "I do not know" response, and simply confirms the answer given by Detective. In the case of (E2) we observe – more typical for QuestGen – extremely simply formulated questions.

DETECTIVE: arek? [*Anthony?*]

INFORMER: No.

DETECTIVE: fioletowy? [*purple?*]

INFORMER: I do not know.

DETECTIVE: roman?

INFORMER: Yes.

DETECTIVE: Pomarańczowy. [*Orange.*]

Here the Informer's response is well justified. For such a formulation of a question about the wire, there is no way (without actually hearing the question) to decide whether it is a proper question or whether the Detective knows the answer and just wants to make sure. What is interesting, after "I do not know" response, the Detective seems to use the heuristics observed in (C) and reaches the correct answer to the initial question.

4. Summary and discussion

In this paper we present and discuss data gathered with the use of the on-line game QuestGen. The data consists of solutions of detective-like stories, which are formulated accordingly to erotetic search scenarios. This allows us to compare normative point of view on these solutions with the solutions delivered by players. There are at least two conclusions from the presented analysis which point out the future research areas. First of all, we may conclude that QuestGen offers a convenient platform for gathering the valuable language data. Of course there is still a room for the improvements. As we have mentioned above, there are no additional explanations collected in QuestGen. This somehow restricts interpretation of certain solutions. However, we may reach for the results presented in Urbański et al. (2016). The *Bomb* puzzle in QuestGen is analogous to the Bomb task used in Erotetic Reasoning Test. The key difference is in structure of the task. In both cases we have detective-like story with initial problem and gathered evidence presented, but in the Erotetic Reasoning Test the task of a subject is to pick a question (one out of four listed below the story), each answer to which will lead to some solution to the initial problem. The subjects are also asked to justify their choices. On the basis of the analysis of these justifications Urbański et al. (2016) propose the notion of a weak erotetic implication in order to tackle the rationality behind using questions about the day of the month or about Anthony. These are still useful for the solution, however they do not meet requirements of e-implication (they are not cognitively useful). For the weak erotetic implication the second condition is restricted for some (not all – see Definition 6) direct answers to the implied question (cf. Urbański et al. 2016, 42). This illustrates how empirical perspective concerning normative models may enrich the formal tools used as a point of departure. As we may read in (Urbański et al. 2016, 45), “modelling the solutions by means of weak e-implication introduces an important descriptive factor into the formal framework of IEL”. In our future research we plan to analyse the gathered solutions using this notion. What is especially interesting here are these solutions that are correct but cannot be counted as normative, when we think about regular e-implication. As for the second conclusion, the analysis performed for the needs of this paper show

how complicated and demanding is the task we are dealing with here. We are convinced that including the collected data into the Erotetic Reasoning Corpus project will simplify the future processing and analysis of the discussed data type.

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