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Chris Reed
University of Dundee

Marcin Koszowy
University of Białystok

THE DEVELOPMENT OF ARGUMENT AND COMPUTATION AND ITS ROOTS IN THE LVOV-WARSAW SCHOOL

Abstract: The paper discusses the relation between computational models of argument and the study of reasoning carried out within the tradition of the Lvov-Warsaw School (LWS). Section 1 presents the origins and the recent strands of inquiry into the overlap between argumentation theory and computer science. Section 2 refers to the legacy of the study of reasoning in the Lvov-Warsaw School. Some research areas of the School which correspond to the contemporary study of argument and computation are indicated. Reasons for applying methods of automated reasoning (esp. the MIZAR system) in argument analysis are given.

Keywords: argument, computation, Lvov-Warsaw School (LWS), computer-assisted reasoning, MIZAR

1. Argument & Computation

1.1. The domain and community

Over the past ten years or so, a new interdisciplinary field has emerged in the ground between, on the one hand, computer science – and artificial intelligence in particular – and, on the other, the area of philosophy concentrating on the language and structure of argument. There are now hundreds of researchers worldwide who would consider themselves a part of this nascent community. Various terms have been proposed for the area, including "Computational Dialectics", "Argumentation Technology" and "Argument-based Computing", but the term that has stuck is simply Argument and Computation. It encompasses several specific strands of research:

- the use of theories of argument, and of dialectic in particular, in the design and implementation of protocols for multi-agent communication;
- the application of theories of argument and rhetoric in natural language processing and affective computing;

- the use of argument-based structures for autonomous reasoning in artificial intelligence, and in particular, for defeasible reasoning;
- computer supported collaborative argumentation – the implementation of software tools for enabling online argument in domains such as education and e-government.

These strands come together to form the core of a research field that covers parts of AI, philosophy, linguistics and cognitive science, but, increasingly is building an identity of its own. The diversity of research conducted in Argument and Computation reflects the different disciplinary points of origin, including:

- formal models of argumentation systems, originating in the nonmonotonic reasoning community;
- argumentation in legal reasoning, originating in the AI and Law community;
- the language of argument, originating in the discourse analysis and corpus linguistics communities;
- argument in multi-agent systems, originating in the distributed AI community;
- computer supported collaborative argumentation and argument visualisation, originating in the computer supported collaborative work community;
- argumentation-based pedadogy, originating in the AI and Education community;
- probabilistic argumentation, originating in the Bayesian reasoning community;

and covers many different specific themes, including:

- Argumentation and cognitive architectures;
- Argumentation and computational game theory;
- Argumentation and defeasible reasoning;
- Argumentation and nonmonotonic logics;
- Argumentation and Decision Theory;
- Argumentation and Logic Programming;
- Argumentation and game semantics;
- Software for teaching argumentation skills;
- Argumentation-based interaction protocols;
- Argumentation-based semantics of programs;
- Argumentation in natural language processing;
- Argumentation in human computer interaction;
- Argumentation in multi-agent systems;
- Computational models of natural argument;

- Dialogue games and conversation policies;
- Dispute resolution and mediation systems;
- Electronic democracy and public deliberation;
- Legal and medical applications;
- Models of bargaining and economic interaction;
- Reasoning about action through argumentation;
- Computational tools for argumentation support.

The diversity of contributing backgrounds is also reflected in the geographical distribution of the work. Though catalysed largely in Western Europe, there is a broad distribution of research across the world, of which the largest groups are based:

- in Argentina at Universidad Nacional del Sur, Argentina;
- in France at the Institut de Recherche en Informatique de Toulouse;
- in Germany at Fraunhofer FOKUS Berlin;
- in Italy at Universita Degli Studi di Brescia;
- in Luxembourg at the University of Luxembourg;
- in the Netherlands at Universiteits van Amsterdam and Utrecht and Rijksuniversiteit Groningen;
- in Thailand at the Asian Institute for Technology;
- in the UAE at the Masdar Institute;
- in the UK at the Universities of Aberdeen, Dundee, Liverpool, Southampton and Imperial College London;
- in the US at the City University of New York;

but in addition to these centres – which often serve to catalyse or connect research communities nationwide – there are also vibrant argument and computation communities in Austria, Australia, Belgium, Canada, Poland, Spain, Sweden, Switzerland amongst others.

2000 represents one good point at which to mark the rise of the interdisciplinary area between computing (specifically, artificial intelligence) and argumentation. Before that, there were occasional conferences such as *Formal and Applied Practical Reasoning* (Gabbay & Ohlbach, 1996) and workshops, such as those on Computational Dialectics in the mid 90's organised by Loui, Gordon et. al. But otherwise little else.

In 2000, the Symposium on Argument and Computation brought together philosophers, AI researchers, linguistics, psychologists, lawyers and rhetoricians in a structured way to collaborate on a book project which turned out very successfully as the *Argumentation Machines* book published in Kluwer's Argumentation Library. Independently, the CSCW community was developing links with practical reasoning philosophers and educators in developing visualisation and group-working systems (see, e.g. The CSCA workshops organised by Buckingham-Shum, which resulted in (Kirschner et al., 2003)). Philosophers of argument were also starting to interact with AI independently (e.g. Walton with multi-agent systems, Hitchcock with defeasible reasoning, and Jackson with AI and education, amongst many others).

Over the following few years, there has been steady growth. The CMNA workshops, for example, organised by Grasso, Reed and latterly, Green have helped to nurture that growth since 2001 (2001, ICCS, San Francisco was a small meeting; then 2002, ECAI, Lyon was a full workshop; 2003, with IJCAI in Acapulco; 2004, with ECAI in Valencia; 2005, with IJCAI in Edinburgh; 2006 with ECAI in Riva del Garda was the first time the workshop was a 2-day event; 2007 with IJCAI in Hyderabad; 2008 with ECAI in Patras; 2009 with IJCAI in Pasadena; 2010 with ECAI in Lisbon and in 2011, with AAAI in San Francisco). Grasso and Reed produced a special issue of the International Journal on Intelligent Systems with resubmitted and re-reviewed material from the first three CMNA workshops, for which the introductory editorial provides a thorough overview of the field at that time (Reed & Grasso, 2007).

2004 also witnessed the introduction of another relevant workshop series focusing on argumentation in multi-agent systems, ArgMAS run with the AAMAS conference in New York. This workshop is co-organised each year by a subset of the steering committee comprising Kakas (Cyprus), Maude (Paris, France) McBurney (Liverpool, UK), Moraitis (Paris, France), Parsons (New York, US), Rahwan (Masdar, UAE) and Reed (Dundee, UK). It has a healthily selective acceptance rate and publishes proceedings with Springer. It is held with AAMAS every year, after New York in 2004 it was held at Utrecht in 2005, Hakodate in 2006, Hawaii in 2007, Estoril in 2008, Budapest in 2009, Toronto in 2010 and Taipei in 2011.

2006 saw the inauguration of the new international conference series on Computational Models of Argument, COMMA. The second COMMA conference was held in Toulouse in 2008, and the third in Brescia in 2010. In 2012, it will be in Vienna. The third COMMA conference saw the formal launch of the new journal dedicated to the area, the *Journal of Argument and Computation*, and this journal has been recognised by its publisher, Taylor & Francis (who use the Routledge imprint in philosophy) for its high rate of both selectivity and citations in its first few years.

The first decade of the century also saw an increasing number of journal special issues dedicated to various computational aspects of argument, covering some of the most high profile journals in the field including:

- *Computational Intelligence* (Blackwell, 2001);
- *Journal of Logic and Computation* (OUP, 2003);

- *Autonomous Agents and Multi-Agent Systems* (Springer, 2005);
- *Artificial Intelligence and Law* (2005);
- *Argumentation* (Springer, 2006);
- *International Journal of Intelligent Systems* (World Scientific, 2006);
- *Artificial Intelligence* (Elsevier, 2007);
- *IEEE Intelligent Systems* (IEEE, 2007).

Following on from the success of its special issue, the *Journal of Logic and Computation* also in 2009 introduced a special track of 'corner' on argument and computation.

Finally, there has also been a concommitant increase in funders' recognition of the importance of the area with a variety of projects across Europe and worldwide, representing, between them, over €20m of support for research into argument and computation, including:

- ASPIC (EU funded, 2004–7);
- ArgueGRID (EU funded, 2006–8);
- AMI and AMIDA (EU funded, 2004–9);
- I-Exchange (EPSRC funded, 2004–6);
- Dialectical Argumentation Machines (EPSRC funded, 2009–12);
- Argumentation Factory (EPSRC funded, 2006–9);
- ITA (DARPA funded, 2006–16).

Of course, many more national and international projects have touched upon themes in the argument and computation space as well.

1.2. The research of the field

It is convenient to summarise the major landmarks in the field to give an introduction to, and orientation within, the domain of argument and computation. Fuller introductions can be found in (Reed & Grasso, 2007) and (Reed & Norman, 2003b) amongst others: the aim here is simply to sketch the main advances.

An early paper outlining the role that argumentation plays in unifying particular types of logic – and in particular, nonmonotonic logics – was (Lin & Shoham, 1987), which shows how many of the major approaches (both then and now) to understanding and modelling reasoning in AI can be seen as instances of argumentation. Circumscription, default logic, nonmonotonic logic and defeasible logic were all demonstrated to be special cases of a more general argumentation-based logic, showing not only that there are strong connections between these system (which was to have been expected, but had not previously been shown formally) but also that argumentation is a powerful notion for understanding and interpreting formal computational systems.

In 1995, two major landmark papers appeared which are now considered to be foundational works. (Krause et al., 1995) describes the 'logic of argumentation', LA, which laid the foundation for a rich seam of theoretical and applied work by the British cognitive and computer scientist, John Fox and colleagues – one which continues today. (Dung, 1995) described a formal notion of 'acceptability' which allows for the development of various types of semantics of argumentation. The approach has subsequently been described elqouently (by Prakken) as a 'calculus of opposition', and has driven a small industry of research into the development of various variations, extensions and applications which again is still growing today. The same year a major landmark in the domain-specific segment of argument and computation dedicated to legal argument also appeared: (Gordon, 1995).

2000 to 2002 saw publication of several important review articles, to which the interested reader is referred for a more comprehensive treatment of particular facets of argument and computation. (Carbogim et al., 2000) review techniques for representing and reasoning with knowledge using argumentation structures; (Chesñevar & Maguitman, 2000) review logical approaches to argumentation, and (Prakken & Vreeswijk, 2002) to defeasible argumentation in particular. (McBurney & Parsons, 2002) review the area of dialogue games in multi-agent systems.

The two significant monographs in 2003, (Reed & Norman, 2003a) and (Kirschner et al., 2003) already mentioned, coincide with the rapid growth in the number of people working in the area and the related increase in recognition and citation of the work. More recently, monographs primarily within the field of philosophy have also started to appear as a result of sustained interdisciplinary collaborations (such as Walton et al., 2008).

Finally, work on the Argument Interchange Format, started in 2006 (Chesñevar et al., 2006), has begun to bring together many of the disparate techniques and approaches into a framework that supports interchange, evaluation, and resource re-use across tools and theories and represents an exciting new potential hub around which future research might be conducted.

In the context of this collection, it is also worth highlighting the recent establishment of a nascent community of scholars working on argument and computation in Poland, an effort spearheaded by Budzyńska (UKSW) and Kacprzak (Białystok) in collaboration with colleagues at PAN, and the Universities of Poznań and Warsaw, amongst others (see, for example, publications such as (Budzyńska et al., 2009; Budzyńska & Dębowska, 2010)), and the ArgDiaP series of workshops (http://www.argdiap.pl). As this national community develops its own coherence, it has started to collaborate with those internationally, resulting in publications such as (Kacprzak et al., 2007; Bex & Budzyńska, 2010; Dębowska et al., 2009).

With the research area of argument and computation now established in both the computational and philosophical communities (appearing as special tracks, themes, or sections of major conferences such as IJCAI and APA and major journals such as the Journal of Logic and Computation and Synthese), and developing an identity of its own with the COMMA conference and the Journal of Argument and Computation, the field looks set to grow in breadth and maturity, a growth to which this special issue is aimed at supporting and encouraging. The articles of the volume discuss key topics presented in this section, as well as some new lines of inqiury. Among the addressed issues there are: applications of the Carneades Argumentation System (Walton, 2011; Łoziński, 2011), formal tools for evaluating persuasion dialogues (Amgoud & Dupin de Saint Cyr, 2011; Budzyńska & Kacprzak, 2011), applications of the AIF in representing schemes of inference, conflict, and preference (Bex & Reed, 2011), argument diagrams (Trzęsicki, 2011), the implementation of epistemic logics in argument analysis and evaluation (Bryniarski, Bonikowski, Waldmajer, and Wybraniec-Skardowska, 2011), the connections between the study of argument and computation and the Pragma-Dialectical Discussion Model (Visser, Bex, Reed, & Garssen, 2011; Lewiński, 2011), and the impact of information technologies on the social discourse (Stefanowicz, 2011).

2. Reasoning and computation – the legacy of the Lvov-Warsaw School

2.1. Main research areas

The Lvov-Warsaw School (LWS) was established by Kazimierz Twardowski at the end of the 19th century in Lvov. Along with the development of logic there were systematically carried out studies in ontology, epistemology, ethics, aesthetics, methodology of science, philosophy of science, semiotics, and philosophy of language (see Woleński, 1989, Ch. 1–2; Jadacki, 2006). Among other achievements in various branches of philosophy, the school is famous for its achievements in mathematical logic (see e.g. Woleński 1989, Ch. 1, part 2). In 'the golden age of Polish logic', which lasted for two decades (1918–1939), formal logic became a kind of an 'international visiting card' of the LWS (Jadacki 2009, p. 91; see also Falkenberg 1996).[1]

[1] The key role in popularizing logical ideas of the LWS was played by Heinrich Scholz

The keystone for the developments in formal logic was laid, among many others, by Jan Łukasiewicz, Stanisław Leśniewski, Alfred Tarski, Kazimierz Ajdukiewicz, Tadeusz Czeżowski, Bolesław Sobociński, Andrzej Mostowski, Adolf Lindenbaum, Stanisław Jaśkowski, Mordechaj Wajsberg, Mojżesz Presburger, Jerzy Słupecki, and Bolesław Sobociński (see e.g. Woleński, 1995, pp. 369–378; Jadacki, 2009, pp. 11–20; Wybraniec-Skardowska, 2009, pp. 6–8).

This section is based on works of few representatives of the LWS, and on works of successors of the LWS. It aims at sketching an answer to the question: which logical ideas of the LWS may be employed in the area of building computational models of argument? Among many issues discussed within the logical studies carried out in the LWS, there are two topics which may be of interest in the context of investigating the issues on the boundary between argumentation theory and computer science:

1. the concepts of logic and reasoning – for these concepts illustrate the tendency to combine formal analysis of arguments with the pragmatic characteristics of the context of argument use;
2. the impact of some logical ideas of the LWS on computer science – for it indicates possibility of applying further the language and methods of logic to building computational models of reasoning; among these ideas there are (see Trzęsicki, 2007, pp. 19–29):
   - Polish notation (parenthesis-free notation) invented by Jan Łukasiewicz;
   - multi-valued logics also created by Łukasiewicz;
   - the system of natural deduction invented by Stanisław Jaśkowski (independently of Gerhard Gentzen);
   - discursive logic developed by Stanisław Jaśkowski;
   - impact of some ideas of Jerzy Łoś on the invention of temporal logic by Arthur Norman Prior;
   - categorial grammar developed by Kazimierz Ajdukiewicz;
   - the theory of recursive functions elaborated by Andrzej Grzegorczyk.

Since one of the goals of designing computational models of argument is developing computer-aided procedures of argument analysis, in what follows, a possible application of a system of automated reasoning in representing arguments will be given. A key idea applied in designing systems of

(1930), who is claimed to be the first modern historian of logic (Woleński, 1995, p. 363) For the discussion on Scholz's role in propagating the LWS see Jadacki, 2009 (Ch. 8: *Heinrich Scholz and the Lvov-Warsaw School*, pp. 155–171).

computer-aided reasoning is Stanisław Jaśkowski's system of natural deduction. For it constituted a theoretical inspiration for designing MIZAR – the system of a computer-aided representation and verification of mathematical knowledge.[2] Therefore some applications of MIZAR in argument representation will be suggested.

2.2. Concepts of logic and reasoning

The very concepts of logic and reasoning present in the works of the LWS representatives illustrate the tendency to combine formal analyses of reasoning with some pragmatic account of the context of reasoning. The concept of logic present in the works of some thinkers of the LWS (see e.g. Ajdukiewicz, 1974, pp. 2–4) embraces not only formal logic, but also semiotics and methodology of science. Within this broader account of logic the tendency to treat formal logic as an indispensable, but not exclusive tool of the study of reasoning has been developed. Hence, the study of reasoning in the LWS is surely not tailored for applying the formal-logical tools in analyzing and evaluating reasoning.[3]

A possible point of departure of the logical studies of argument within the tradition of the LWS[4] is conceiving an argument as a pair of nonempty sets of propositions. For example, arguments are structures $\langle \Sigma, \Gamma \rangle$, where Σ is the set of premisses and Γ is the set of conclusions. Among the relations between Σ and Γ there are: direction of argumentation, direction of entailment, and direction of justification (see Trzęsicki 2011, this issue). An example of a tendency to include pragmatic concepts (such as justification within a given context) into symbolic representations of arguments is the 'pragmatic concept of inference' which was introduced by another representative of the LWS, Seweryna Łuszczewska-Romahnowa (1962). According to this approach, the proposition p_k follows pragmatically (given the theoretical context) from the sequence of propositions $p_1, \ldots, p_n$ if and only if the implication $p_1, \ldots, p_n \rightarrow p_k$ has been justified within this context. A similar approach is present in Kazimierz Ajdukiewicz's analyses of subjectively uncertain inference (1974, Ch. 4, pp. 120–181). The pragmatic account of arguments may also manifest itself through introducing prag-

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[2] http://mizar.org.

[3] Due to the fact that reasoning was carefully investigated in the LWS (see e.g. Jadacki, 2009, pp. 98-99), classifications of reasonings were designed by the major representatives of the LWS, for example by Łukasiewicz, Czeżowski, and Ajdukiewicz (see Woleński, 1988; Kwiatkowski, 1993).

[4] It is not claimed, however, that this point of departure is specific exclusively for the logical studies carried out in the LWS.

matic predicates (such as 'assume that', 'allow that', and 'assert that') and the pragmatic concept of subjective (psychological) probability (Budzyńska, 2004, pp. 128–129).[5]

Another illustration of accepting a broader account of arguments within the legacy of the LWS is a general argumentation framework presented by Jan Woleński (2008, p. 105). Argumentation is examined as a sequence of moves $\alpha_1, \alpha_2, \ldots, \alpha_n \rightsquigarrow \beta$, where β is a thesis (claim, view, standpoint), $\alpha_1, \alpha_2, \ldots, \alpha_n$ is a finite sequence of argumentative moves made in order to convince an audience to accept β, and $\rightsquigarrow$ denotes the relation of acceptance of the thesis. This general argumentation framework may be treated as a point of departure for characterizing argumentative moves from the point of view of (a) formal logic and (b) pragmatics. The main question raised from the point of view of logic is: does β follow logically from $\alpha_1, \alpha_2, \ldots, \alpha_n$? The pragmatic approach to a given sequence of moves is based on treating them as persuasive moves of the proponent.

The next example of the pragmatic account of reasoning is Witold Marciszewski's definition of argument as reasoning whose aim is to influence an audience:

> A reasoning is said to be an argument if its author, when making use of logical laws and factual knowledge, also takes advantage of what he knows or presumes about his audience's possible reactions (Marciszewski, 1991, p. 45).

The remark that the knowledge about the audience's reactions plays a key role in any successful persuasion is a point of departure for seeking theoretical foundations for the art of argument not only in formal logic, but also in accounts of human cognition and the mind-body relations, as present in philosophy and in cognitive science.[6] In what follows the basic features of this approach will be discussed.

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[5] For the analysis of Ajdukiewicz's account of the subjectively uncertain inference see (Koszowy 2010).

[6] An example of employing this broader approach is the research project *Undecidability and Algorithmic Intractability in the Social Sciences*, which was realized from 2003 to 2006 at the University of Białystok. The research was supported by the Polish Committee for R&D Ministry of Science (Grant No. 2 H01A 030 25). The project was coordinated by Witold Marciszewski. Amongst other goals, the research focused on identifying some problems that are (algorithmically) undecidable or intractable (Marciszewski, 2003, pp. 79–80; 2006a, p. 9; 2006b, pp. 145–157).

2.3. Logical ideas of the LWS and the computational models of argument

An example of developing an account of argument from the point of view of computing is Witold Marciszewski's approach to an argument (1991). This account is rooted in a conception of reasoning as computing, which is the most briefly expressed with Gottfried Wilhelm Leibniz's call: *Calculemus*![7] Within Marciszewski's approach, the concept of information processing constitutes a theoretical foundation of the art of argument. Information is treated as a theoretical entity recorded in a material vehicle. Two kinds of records of information are distinguished: *external* (information is not part of a communicating system) and *internal* (information is part of a communicating system). Next, two ways of information processing are distinguished: *direct processing* (performed without recording), and *indirect processing* (performed with producing records).

Those two distinctions allow answering the question: what is the place of arguments on the map of information-processing phenomena? Arguments are located in the area of indirect processing of consciousness with external records, and then in processing internal records by the corresponding acts of consciousness (Marciszewski, 1991, p. 46).

The next theoretical tool for dealing with the structure of arguments is the framework of transforming a sequence through appending new elements. Within this framework one may distinguish a sequence which belongs to a definite (1) domain. Items in that sequence are created by applying a definite (2) operation (a many-one or one-one transformation). The sequence tends to (3) a bound either in virtue of that operation itself or by our decision as to the point to stop. When generating a next element of the sequence by employing a definite operation, a trait of preceding elements is preserved – this trait is called (4) an invariant. Within this framework, arguments ruled by formal logic are characterized as follows:

1. a domain consists of propositions;
2. operations are defined by inference rules;
3. a bound is a conclusion one seeks for;
4. a preserved trait (invariant) is a logical value called truth.

[7] Leibniz's legacy is stressed by Witold Marciszewski, who is an administrator of the WWW domain "Calculemus" (www.calculemus.org). The goal of this domain is, among other tasks, to expose the impact of Leibniz's logical and philosophical ideas on the origins and development of computer science (see Marciszewski, 1997; Trzęsicki, 2007). For some results of a research project *Logical Systems and Algorithms for Automatic Testing of Reasoning* (1986-1990) concerning mechanization of reasoning see (Marciszewski & Murawski, 1995).

Propositions from the proof (i.e. premisses and conclusions) may be treated as pieces of information:

> It is difficult to articulate an adequate definition of information processing, however the practice of proving theorems provides us with a partial, at least, operational definition. It is so, because anybody who proves a proposition on the basis of other ones, thereby displays an intuitive understanding of what a proposition is, and it does represent, indeed, a typical piece of what we call information (Marciszewski, 1991, p. 47).

Hence, transforming premisses into a conclusion is treated as a paradigmatic example of information processing:

> [...] the rules of inference deal solely with graphical transformations of formulas, i.e. with changing their shapes, and at the same time abstract entities, viz. propositions, are attached to those external records. Thus the processing of the record gets matched with the processing of information corresponding to that record (likewise, operations on numbers as abstract entities correspond to the processing of digits) (ibid.).

Taking into account the explanatory power of this example of information processing, Marciszewski treats it as a heuristic model of human reasoning:

> Human thoughts (in a psychological sense), as phenomena occurring in time, together with their records in the internal language of a (biological machine) are to be construed as spatio-temporal instantiations of abstract entities being propositions (ibid).

Hence, this framework may serve as a useful heuristic model in analyzing logical fallacies by comparing deductively invalid inference schemes with this model. Since the universal laws of information processing are common to all information-processing systems (both to human beings and to computers), this model is claimed to be applicable in analyzing various information processing phenomena, despite the fundamental differences between human beings and cipher machines (p. 48). However, the discussed model is not claimed to be a unique legitimate tool for analyzing arguments, for it does not deal with defeasible inference schemes.

The main features of the proposed approach to arguments may constitute a point of departure for research projects which mainly aim at:

- placing arguments in the framework of information processing;
- analyzing arguments in terms of external records, especially of formalized proofs as a paradigm of information processing.

These goals are realized by systems for automated reasoning, automated deduction, and automated proof checking. MIZAR[8] is an example of such a system. The MIZAR project started in 1973, on the initiative of Andrzej Trybulec. MIZAR is (1) a formal language for writing formalized mathematical definitions and proofs, (2) a computer program used for verifying mathematical proofs (see Trybulec 1993, Matuszewski & Rudnicki 2005; Grabowski et al., 2010). Since 1989 the focus of the project has been also to develop a database for mathematics (*Mizar Mathematical Library* – MML). Marciszewski (1994) describes MIZAR as:

> (i) a natural deduction system of (ii) Multi-Sorted predicate logic with Equality, for short MSE, (iii) that simulates the language of proofs, esp. that used by mathematicians, in a simplified and standardized form, adjusted to computer processing, and (iv) that is combined with a proof checker, i.e. a program checking proof validity (Marciszewski, 1994).

In order to make the connections between the methods of analyzing reasoning in the legacy of the LWS and the methods of building computational models of argument more explicit, we shall discuss two main theses concerning possible applications of MIZAR in proposing a kind of a computational model of argument. The theses hold that:

- the MIZAR language is a useful tool of representing the structure of arguments;
- the MIZAR methods of automated proof-checking are applicable in identifying formal logical fallacies.

In order to present applicability of the methods, first some basic features of the MIZAR language shall be briefly discussed. Since MIZAR is based on the first order predicate logic (Grabowski et al., 2010, p. 155; Wiedijk, 2011, p. 1, 50), statements are composed of atomic (predicative) formulas combined with connectives and quantifiers of classical logic. The main logical connectives and quantifiers are expressed as follows (ibid.):

$\neg\alpha$	not α
$\alpha \wedge \beta$	α and β
$\alpha \vee \beta$	α or β
$\alpha \rightarrow \beta$	α implies β

[8] When referring to the origins of the name of system, Marciszewski (1994) states: *Don't try to guess what the name "*MIZAR*" means. It was the author's fancy to take a star's name (...) [to stand for it].*

$\alpha \Leftrightarrow \beta$	α iff β
$\exists_x \alpha$	ex x st α
$\forall_x \alpha$	for x holds α
$\forall_{x:\alpha} \beta$	for x st α holds β

Since a type of each quantified variable has to be given, the form of quantifiers may be as follows (ibid.):

```
for x being set holds...
```

or

```
ex y being real number st...
```

In order to present a possibility of representing arguments in the MIZAR language we shall consider an example of a fallacy of affirming the consequent (AC). Let us take the following reasoning: *if one is able to make a cipher machine intelligent, then one may understand intelligence. One understands intelligence, therefore one is able to make a cipher machine intelligent.* This reasoning falls under the invalid inference scheme:

$$\frac{\begin{array}{l} p \rightarrow q \\ q \end{array}}{p}$$

The representation of the fallacy in the MIZAR style is as follows:

```
environ
begin
:: p[]
:: q[]
scheme Invalid Rule {p[],q[]}:
p[]
provided
A1:p[] implies q[]
and
A2:q[]
proof
  thus p[] by A1,A2;
::>        *4
end;
```

The system identifies the logical invalidity of this reasoning by showing the error '*4'.

This inference scheme may be contrasted with a valid inference scheme such as Modus Ponens (if p then q, and p, therefore q), which is expressed in the MIZAR style as follows:

```
environ
begin
:: p[]
:: q[]
scheme ModusPonens {p[],q[]}:
q[]
provided
A1:p[] implies q[]
and
A2:p[]
proof
  thus q[] by A1,A2;
end;
```

This time, directly after drawing the conclusion (q) from the premisses ($A1$, $A2$), no error occurs, because of the fact we have the logically valid inference scheme.

In order to show how predicates are expressed in MIZAR, let us consider the second example, which alludes to an imitation game upon which the Turing Test was designed. Let us imagine someone trying to guess whether his or her interlocutor is a human being or a machine. Let us now consider the following line of reasoning: *every interlocutor is either a human being or a computer, therefore either every interlocutor is a human being or every interlocutor is a computer.* This reasoning has a following deductively invalid inference scheme:

$$\frac{\forall x[P(x) \vee Q(x)]}{\forall x P(x) \vee \forall x Q(x)}$$

The reasoning may be expressed in the MIZAR style as follows. Instead of the letters 'P' and 'Q' we can also use names such as 'Human Being' and 'Computer':

```
environ
begin
reserve x for set;
scheme Ex1{HumanBeing[set],Computer[set]}:
```

```
(for x holds HumanBeing[x]) or (for x holds Computer[x])
provided
A1: for x holds HumanBeing[x] or Computer[x]
proof
  thus (for x holds HumanBeing[x])
       or (for x holds Computer[x]) by A1;
::>                                *4
end;
```

Again, the fallacy is identified with '*4'. In order to show how valid inference may be expressed by MIZAR, let us consider the inference scheme:

$$\frac{\forall x P(x) \vee \forall x Q(x)}{\forall x [P(x) \vee Q(x)]}$$

The reasoning which is in accordance with its scheme may be expressed in MIZAR as follows:

```
environ
begin
reserve x for set;
scheme Ex2{HumanBeing[set],Computer[set]}:
for x holds HumanBeing[x] or Computer[x]
provided
A1: (for x holds HumanBeing[x]) or (for x holds Computer[x])
proof
  thus for x holds HumanBeing[x] or Computer[x] by A1;
end;
```

After the conclusion (`for x holds HumanBeing[x] or Computer[x]`) is drawn, no error occurs.

The above examples[9] illustrate the possibility of applying systems of computer-aided mathematical reasoning both in argument representation and in identification of formal fallacies. Some future inquiry into applications of MIZAR in analyzing fallacies may consist in detecting some formal logical fallacies on the basis of analyzing the structure of reasoning. This task is in accord with deductivism – the view which holds that fallacies may be identified as deductively invalid inferences (see e.g. Jacquette, 2007;

[9] We are grateful to Mariusz Giero and Karol Pąk for discussion of examples. For nontrivial examples of natural deduction proofs see (Pąk, 2010, pp. 100–105).

Jacquette, 2009). Those possible applications are also in line with some initial attempts to propose computational methods of detecting formal logical fallacies in an argumentative discourse, such as those made by Gibson, Rowe, and Reed (2007, pp. 27–29), in which an example of the fallacy of affirming the consequent is represented in the XML and in the AML (*Argument Markup Language*, based on the XML). However, this general idea of computer-aided detection of formal logical fallacies needs to be further systematically developed. Examples given in the paper show how the essential features of the MIZAR language may be instructive in an inquiry into this field.

Hence, possible applications of systems of automated reasoning may be justified by indicating those twofold profits:

1. representation of argument schemes by means of a computer-aided knowledge representation enriches the palette of devices of mathematical knowledge representation;
2. expressing the structure of arguments in MIZAR may be instrumental in exposing the key similarities between the project of automated reasoning and the study of computational models of natural argument.

Moreover, some key features of the MIZAR language, such as clarity in natural language representation of formal texts (see e.g. Matuszewski, 1999a; 1999b; 2006), allow to use it as a tool for teaching argumentation theory for those students who are familiar with methods of computer-aided proof checking, applied for example in academic teaching at the faculties of computer science.

However, some applications of MIZAR, as discussed in this section, focus exclusively on deductive inference rules and deductive invalidities of reasoning. In order to combine this formal approach with the broader pragmatic account of arguments (as presented in section 2.2), further research on the applications of MIZAR is necessary. One of the main goals of such an inquiry would be to analyze, by means of the MIZAR language, a set of those tools of argumentation theory which are (at least to some extent) formalizable, and which take into account the context of argument use. Among the tools of argumentation theory which fit to those requirements there are argumentation schemes. The research on representing the main argument schemes in MIZAR would be in accord with the attempts at formalizing some argumentation schemes, such as the ad hominem argumentation scheme (Walton, 2010). The fact that some argumentation schemes are generalized rules of inference (Prakken, 2010; see also Bex & Reed, 2011, this issue) constitutes an additional justification for such an inquiry, because, as discussed examples show, representing inference rules is also possible in Mizar. Hence, the task for further inquiry would consist in expressing in the Mizar language those schemes which have the form of generalized inference rules.

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Chris Reed
Argumentation Research Group
School of Computing
University of Dundee
Dundee DD1 4HN Scotland, UK
chris@computing.dundee.ac.uk

Marcin Koszowy
Chair of Logic, Informatics and Philosophy of Science
University of Białystok, Poland
koszowy@uwb.edu.pl