Neuantrag auf Sachbeihilfe

ALMANAC: Argumentation Logics Manager & Argument Context Graph

Acronym: ALMANAC

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Contents

0 General Information (for the ELAN system only)

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0.2 Topic (Thema)

Argumentation Logics Manager and Argument Context Graph

0.3 Research area and field of work (Fachgebiet und Arbeitsrichtung)

Scientific discipline: Computer Science
Fields of work: Knowledge Management

0.4 Anticipated total duration (Voraussichtliche Gesamtdauer)

3 years; initial proposal

0.5 Application period (Antragszeitraum)

36 Months starting 1. May. 2017

0.6 Summary

Decision situations require individuals and organizations to choose between a multitude of options based on facts, opinions, and arguments about the situation at hand or similar ones. Current support systems are mostly fact-based and fail to take into account arguments found on the web or in the literature.

The SPP brings together a community of researchers who develop robust and scalable models for argumentations in human communication in all their complexity and imprecision. The proposed ALMANAC project aims to support the logic-based pillar of this enterprise. There is already a large set of prior work on the representation of knowledge, inference, and argumentations and the SPP will no doubt develop more.

The first objective of the proposed ALMANAC project is to provide a unifying infrastructure so that the SPP projects and wider community can interoperate, compare results, and create joint logic resources. Concretely we propose to

a) bring order into the zoo of proposed formalisms,
b) categorize their inter-relations, and
c) benchmark them on real-world corpora

For this the ALMANAC project proposes to utilize the OMDoc/MMT framework developed by the proposer's research group. The framework uses theory graphs for the modular representation of domain knowledge in logical languages and for logical formalisms themselves in meta-logics. Inter-logic relations can be modelled as theory-morphisms: truth-preserving mappings between theories. The ALMANAC project wants to provide the SPP with a "logic atlas" as a resource of explicitly represented formalisms and frameworks that can serve as a basis for integration of methods.

The second objective of the proposed ALMANAC project is to utilize the theory graph structure as a model for the contexts in multi-agent argumentations: theory graphs naturally provide "little ontologies" (the theories) that can be mutually exclusive and are interconnected by inclusions and views (in OMDoc/MMT). To augment them to full argumentation context graphs we want to add argumentation relations like attack, rebut, support, and undercut and study their ontological properties.

OMDoc/MMT is implemented by the MMT system, which serves as a (meta)-knowledge base and offers logical services like type/proof checking, inter-logic translation, and human-oriented browsing of corpora. MMT is integrated into the MathHub system which additionally offers user- and logic-corpus management facilities and can serve as the basis for logic-based challenges (Joint Tasks; the third objective of ALMANAC) that induce synergies between projects in the SPP and thus contribute to the coherence of the overall endeavor.

0.7 Zusammenfassung

In Entscheidungssituationen müssen Individuen und Organisationen zwischen einer Vielzahl von Optionen wählen. Sie stützen sich dabei auf Fakten, Meinungen und Argumente über diese oder ähnliche Situationen; Softwaresysteme, die bei der Entscheidung helfen könnten, beschränken sich dagegen auf die Faktenebene und ziehen Argumentationen nicht in Betracht.

Das Schwerpunktprogramm bringt Forscher zusammen, die robuste und skalierbare Modelle für Argumentationen in menschlicher Kommunikation untersuchen. Das ALMANAC Projekt soll den Logik-Pfeiler dieses Unterfangens unterstützen. Es gibt bereits eine große Menge an Arbeiten zur Wissensrepräsentation, zum Schlussfolgern und zur Modellierung von Argumentationen, und das SPP wird ohne Zweifel weitere entwickeln.

Das erste Ziel des ALMANAC Projekts is es, eine einheitliche Infrastruktur bereitzustellen, die die Zusammenarbeit zwischen den Projekten des SPP und der Argumentations-Community erleichtert, Resultate vergleichbar macht, und die Entwicklung gemeinsamer, logik-basierter Ressourcen unterstützt. Konkret wollen wir

a) Ordnung in den Zoo der Logik-Formalismen bringen,
b) ihre Zusammenhänge katalogisieren und
c) sie auf realen Korpora testen (Benchmarking).

Dafür wollen wir das in der AG Kohlhase entwickelte OMDoc/MMT Format nutzen. Dieses verwendet Theoriegraphen sowohl für die modulare Repräsentation von Domänenwissen in logischen Sprachen als auch der Logiken selbst in Meta-Logiken. Zwischenlogische Beziehungen können als Theoriemorphismen – also wahrheitserhaltende Abbildungen zwischen Theorien – dargestellt werden. Das ALMANAC-Projekt strebt an hierfür einen „Logikatlas“ zu erstellen, also eine offene Sammlung explizit repräsentierter Formalismen und Frameworks, der als Basis für die Methodenintegration im SPP dienen kann.

Das zweite Ziel des ALMANAC Projekts is es, die Theoriegraphenstruktur zu nutzen um Kontexte in Multi-Agenten-Argumentationen zu modellieren: Theoriegraphen erlauben bereits auf natürliche Weise durch Inklusionen und Interprätationen verbundene „kleine Ontologien“ (die Theorien), die intern konsistent sind, aber untereinander widersprüchlich sein können. Um Theoriegraphen zu vollgültigen Arugmentationskontextgraphen zu erweitern wollen wir die Argumentrelationen wie z.B. Attacke, Zurückweisung oder Schwächung hinzufügen und ihre ontologischen Eigenschaften untersuchen.

OMDoc/MMT ist im MMT System implementiert. Dieses fungiert als eine (Meta)-Wissensbank und bietet logische Dienste wie Typ/Beweisprüfung, Logik-Übersetzungen und Browsen von Logik-Korpora. Das System ist eingebettet in das MathHub System das zusätzlich Nutzer- und Korpus-Verwaltungsdienste anbietet und als eine Infrastruktur für Logik-Benchmarks dienen kann (Joint Tasks, das dritte Ziel von ALMANAC). Letztere sollen Synergien zwischen den Projekten des SPP induzieren und so zur Kohärenz des Gesamtunternhemens beitragen.

1 State of the Art and Preliminary Work

A focus in the SPP 1999 is to develop robust and scalable models for argumentations in human communication in all their complexity and imprecision. The proposed ALMANAC project aims to support the logic-based aspects of this enterprise.

There is a large set of prior work on the representation of knowledge, inference and computational models for argumentations. We will survey *i*) logical models for individual reasoning (arguments) and *ii*) models for the interaction of arguments brought forth by multiple agents (argumentation systems) in the next two sections (1.1 and 1.2). We observe that these two aspects are independent of each other, which opens the way to mixing and matching to get adequate target systems for representing real-world argumentations. To evaluate our options on this, the proposed ALMANAC project aims to

a) bring order into the zoo of proposed formalisms, (see objective **O1** in Section 2)
b) categorize their relations, and (**O2**)
c) benchmark them on real-world corpora (**O3**).

For this the ALMANAC project proposes to utilize the OMDoc/MMT framework developed by KWARC group of the proposer. The framework supports theory graphs for the modular representation of domain knowledge in logical languages (see Section 1.3) and for logical languages themselves in meta-logics (Section 1.4). We want to employ the latter for **O1**, the former for **O2**, and OMDoc/MMT infrastructure developed at KWARC (see Section 1.5) for **O3**.

The main motivation here is to provide a unifying infrastructure for the SPP so that participating projects can interoperate, compare results, and create joint logic resources.

1.1 Argumentation Systems

The field of argumentation systems (see e.g. [BH08] for a general overview) uses various approaches to representing arguments and their interaction with counter-arguments. The foundational work of Dung [Dun95] introduces *abstract argumentation systems (AAS)* as directed graphs, in which "arguments" are nodes and edges are "attack relations" between arguments. Dung's model treats arguments as atomic by abstracting from their inner structure.

Extending AASs with an additional *support* relation yields *bipolar argumentation frameworks*. AASs can also be extended by adding a *preference relation* on arguments (*preference-based argumentation frameworks*), which are further refined by *value-based argumentation frameworks*. [Jan+15] surveys these extensions.

Structured argumentation [BH08] gives arguments an internal e.g. deductive structure. This allows to study and catalogue argumentation schemata in texts [WRM08]. *Abstract Dialectical Frameworks* (ADF) are hybrids between abstract and structured argumentation (see [Bre+13]), they are currently the focus of study, as they generalize many of the existing formal models of argumentation. *Argument trees* can be used to formalize *undercuts* in an argumentation [BH06]. An edge in such a tree points from an argument concluding $\neg P$ to an argument using P as a premise.

Assumption-based argumentation, a form of structured argumentation extended by "defeasible axioms" (i.e. assumptions), lend themselves to being represented as more general graphs [CT16]. Closely related is Hunter's framework for approximate arguments [Hun07] based on *enthymemes*, where arguments can have *implicite* assumptions not necessarily shared between all participating agents.

Notably, (almost) all of these systems abstract away from a specific internal logic and only posit certain requirements, e.g. a classical negation, or an implication that satisfies the deduction theorem.

First-Order Argumentation Somewhat surprisingly, there are few systems that consider properties beyond simple propositional logical aspects; a notable exception is Besnard and Hunter's work on a "first-order argumentation framework" [BH05]. Here, the argument trees presented in [BH06] are extended by first-order quantifiers.

Argumentation Software Several software implementations of various argumentation systems have been proposed or actually implemented. [Bes+14] is an introduction into a representative sample of available services. For example, ASPIC+ [MP14] is a framework for generating Dung-style structured argumentation systems from a set of premises, inference rules and attack relations. Implementations of ASPIC+ exist e.g. in the form of the TOAST system [SR12].

Another system is DeLP (*defeasible logic programming*) – a logical programming language intended for argumentative reasoning [GS14].

The former suffers from a lack of predefined logics, inference rules etc. – the user needs to explicitly add every inference rule that they want to hold for the current context, and expressivity is necessarily limited. The latter is a logical programming language which by necessity is based on a fixed logic. Consequently, expressing tensed, vague or otherwise difficult natural language arguments is highly non-trivial. Just providing a library of predefined logics and their inference rules would make both of these systems a lot more convenient for handling "real world" arguments without sacrificing formality.

[Jan+15] surveys dozens of existing web-based argumentation support applications with various purposes (intended for eLearning, ontology-building, visualization, argumentative discussion, ...) and concludes – concerning logical argumentation – that (almost) all of them are dialogical and rely on user feedback to evaluate the validity and value of (exclusively informal) arguments.

Many such services can be found at the *Argument Web* [1], all of them utilizing the generic *argument interchange format (AIF)* [Che+06].

1.2 Robust Representation of individual Inference

In classical logic, the calculus of natural deduction [Gen35] serves as a foundation for single-agent argumenation. For the representation of real-world knowledge and inferences and such given in natural language, "robust" logics integrate inference with insecure knowledge (e.g. probabilistic and fuzzy logics), non-monotonic reasoning (e.g. default logics, abduction and induction) or linguistic phenomena (e.g. discourse logics and modal logics). These logics are usually classified as "philosophical logics" or "non-classical logics"[GG84]; for the purposes of this proposal – and the RATIO SPP overall – we prefer to think of them as logics that allow the *robust representation of human argumentations*.

Logics for robust representation of argumentation A plethora of logics have been devised to express various aspects of natural language or logical inference not covered by classical logic. To name only some examples, *(multi-)modal logics* extend classical logic by (potentially various different) notions of *possibility* and *necessity*. *Preference logic* allows for stating sentences of the form "A is better than / worse than B". *Relevance logic* restricts the classical (i.e. material) implication in such a way as to avoid valid implications between seemingly disconnected premises and conclusions, which seems false from a colloquial understanding of "If... then"-sentences. It is one example for *paraconsistent logics*, which try to deal with inconsistency in a non-fatal manner by systematically avoiding *ex falso quodlibet*. *Temporal logics* allow for reasoning about time (e.g. "X is true at time t_0"), *probabilistic logics* about probabilities.

Most of these logics come with some variant of a natural deduction style proof calculus. However, in their formal semantics, these logics can differ significantly from classical logic (and its standard set theoretic semantics). For example, the most common semantics for modal logics (see [BRV01]) makes use of different *worlds* and an *accessibility relation* between them (or several different ones). A statement can then be true in *some* world (and false in others), and its truth at a world A may depend on which other worlds are accessible (via which relations) from A.

Dynamic Logics Representations of arguments naturally arise from the interpretation/formalization of natural language documents. Therefore we need to include dynamic formalisms for natural language meaning representations. While we are mostly interested in those logics with linguistic applications, Pratt

[1] http://www.argumentinterchange.org

style programming languages and process calculi (such as dynamic propositional logic) are closely related. A paradigmatic language here is Discourse Representation Theory (DRT) [KR93] which introduces "discourse referents" to treat anaphoric references in statements like *"A student is sleeping. He is tired."*. In static logics, the first sentence would be modeled by a formula like $\varphi = \exists x.x \in \mathrm{Student} \wedge \mathrm{sleep}(x)$. However, the *"he"* in the second sentence refers to the student in the first sentence, so formalizing the first sentence as φ doesn't work, since the scope of the existential quantifier is restricted to that formula. Dynamic logics try to remedy these problems in various ways by changing the behaviour of variables or introducing non-standard quantifiers with "non-recursive" scoping behaviour. Discourse referents also account for many other linguistic phenomena including tense, propositional attitudes, dialogue, and – importantly for argumentation – presuppositions and propositional anaphora. Other dynamic logics include Dynamic Predicate Logic (DPL) [GS91], and their Montague-style higher-order versions [GS90; KKP96]. Dynamic logics have been combined with e.g. modal logics [Rij98] and can be seen as propositional modal logics themselves.

Interoperability of Logical Systems By and large, the robust logics surveyed above have usually been developed with a focus on the particular features and primitives they introduce to remedy a particular shortcoming of classical logics. Efforts for integration of features in more comprehensive logics exist, but are unsystematic and sparse. As a consequence the logics – and the domain developments in them – are insular, duplicate work, and make comparison and benchmarking difficult. In this sense, the logical systems – taken as a whole – lack the robustness required for the RATIO SPP.

On the other hand, there is a large body of literature on comparing the relative strength of classical and non-classical logics. These usually involve semantical arguments or come in the form of embeddings of one logic into another. This is an important *theoretical* endeavour, but does not solve the interoperability/robustness problem, since they cannot be used to build *practical* interoperability. Even the logic embeddings do not really help here, since they are usually "deep embeddings", which blow up formula sizes and do neither preserve domain invariants nor the structures systems use to achieve tractability.

What we would need for a robust representation of knowledge and argumentation is a system of "shallow embeddings" that make classical and non-classical logics practically interoperable and thus creates a **uniform meaning space** of logic-based representations. To do so, we need a uniform framework in which we can represent logics, their semantics, and their embeddings, so that we can systematically study – and engineer – combinations.

Homogenous vs. Heterogeneous Knowledge Representation Knowledge representation studies the formalization of knowledge for knowledge-based systems. The last decades have seen a focus on the development of decidable fragments of logic – in particular description logics [Baa+07] which form the basis of the *Web Ontology Language* (OWL) and thus of many of the existing large-scale domain ontologies. In such *homogenous* approaches it is difficult to represent the – often contradictory – argumentation contexts of different agents and their relations.

Heterogeneous ontologies like theory graphs [FGT92; RK13] (see Section 1.3 below) model multiple internally consistent ontologies (theories) and relate them by truth-preserving mappings (theory morphisms). In the semantic web context, these ideas and techniques have been established with the heterogeneous *Distributed Ontology Language* [Mos+15] and have even been ISO-standardized.

In the argumentation theories reviewed above, the context of argumentation is essentially reduced to a set of assumptions. This makes the "management" of (and reasoning about) contexts – which humans routinely do in argumentation – difficult to model. Heterogeneous ontologies can be used as a structured basis for "graphs of argumentation contexts" if additional relations are introduced for overlaps and mutual exclusions of theories to make assumptions and their consequences explicitly representable and thus mechanizable. It seems that the management of argumentation contexts should be independent of the base logic – a service an argumentation framework should offer "on top".

In the remainder of the section we will survey the prior work of the KWARC group we want to utilize for the ALMANAC project.

1.3 Theory Graphs for Modular Knowledge Representation

OMDoc [Koh06] is a wide-coverage representation language for mathematical knowledge (formal) and documents (informal/narrative). In the last decade development has focused on the formal aspect leading to the OMDoc/MMT instance (Meta-Meta-Theories [RK13; HKR12; Rab14]), which increases expressivity, clarifies the representational primitives and formally defines the semantics of this fragment.

OMDoc/MMT is designed to be foundation-independent and introduces several concepts to maximize modularity and to abstract from and mediate between different foundations, to reuse concepts, tools, and formalizations. The OMDoc/MMT language *integrates successful representational paradigms*

- the logics-as-theories representation from logical frameworks,
- theories and the reuse along theory morphisms from the heterogeneous method,
- the Curry-Howard correspondence from type theoretical foundations,
- URIs as globally unique logical identifiers from OpenMath,
- the standardized XML-based interchange syntax of OMDoc,

and makes them available in a single, coherent representational system for the first time. The combination of these features is based on a small set of carefully chosen, orthogonal primitives in order to obtain a simple and extensible language design.

OMDoc/MMT offers very few primitives, which have turned out to be sufficient for most practical settings. These are

1. *constants* with optional types and definitions,
2. types and definitions of constants are *objects*, which are syntax trees with binding, using previously defined constants as leaves,
3. *theories*, which are lists of constant declarations and
4. *theory morphisms*, that map declarations in a domain theory to expressions built up from declarations in a target theory.

Using these primitives, logical frameworks, logics and theories *within* some logic are all uniformly represented as OMDoc/MMT theories, rendering all of those equally accessible, reusable and extendable. Constants, functions, symbols, theorems, axioms, proof rules etc. are all represented as constant declarations, and all terms which are built up from those are represented as objects.

Theory morphisms represent truth-preserving maps between theories. Examples include theory inclusions, translations/isomorphisms between (sub)theories and models/instantiations (by mapping axioms to theorems that hold within a model), as well as a particular theory inclusion called *meta-theory*, that relates a theory on some meta level to a theory on a higher level on which it depends. This includes the relation between some low level theory (such as the theory of groups) to its underlying foundation (such as first-order logic), and the latter's relation to the logical framework used to define it – e.g. LF; see [Pfe01] for an overview.

All of this naturally gives us the notion of a *theory graph*, which relates theories (represented as nodes) via vertices representing theory morphisms (as in Figure 1), being right at the design core of the OMDoc/MMT language. It is a central advantage of the OMDoc/MMT system that theory morphisms "transport axioms, definitions, theorems, ..." to new contexts and thus induce knowledge that is not explicitly represented in the graph. Therefore it is a central design invariant of the system that we can name all induced objects with canonical URIs, the MMT URIs, which contain enough information to reconstruct the induced objects themselves – given the graph.

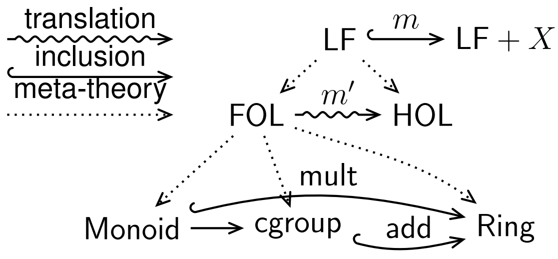

Figure 1: A Theory Graph with Meta-Theories

Flexiformal Content Recently, OMDoc/MMT has been extended to enable handling content of *flexible formality* [Koh13] in a bid to reach full OMDoc coverage. In a nutshell, *Informal* parts are modeled as opaque constants, objects or theories [Ian17]. While they can obviously not be formally analyzed with respect to their formal structure, they can still be used in (and be subject to) the various knowledge management services provided by MMT (see Section 1.5), in particular they can be connected to formal content via theory morphisms. As a result, we believe we can use OMDoc/MMT to represent all kinds of arguments in a unified manner, whether they can be fully formalized in some logic and/or argumentation system or need to be represented informally.

1.4 LATIN: an Atlas of (Classical) Logics

The LATIN project [Cod+11] was a DFG funded project running from 2009 to 2012 under the principal investigators Michael Kohlhase and Till Mossakowski. Its aim has been to build a heterogeneous, highly integrated library of formalizations of logics and related languages as well as translations between them. It uses OMDoc/MMT as a framework, with LF as a meta-theory for the individual logics.

True to the general OMDoc/MMT philosophy, all the integrated theories are built up in a modular way and include propositional, first-order, sorted first-order, common, higher-order, modal, description, and linear logics. Type theoretical features, which can be freely combined with logical features, include the λ-cube, product and union types, as well as base types like booleans or natural numbers. In many cases alternative formalizations are given (and related to each other via theory morphisms), e.g., Curry- and Church-style typing, or Andrews and Prawitz-style higher-order logic. The logic **morphisms** include the relativization translations from modal, description, and sorted first-order logic to unsorted first-order logic, the negative translation from classical to intuitionistic logic, and the translation from first to sorted first- and higher-order logic.

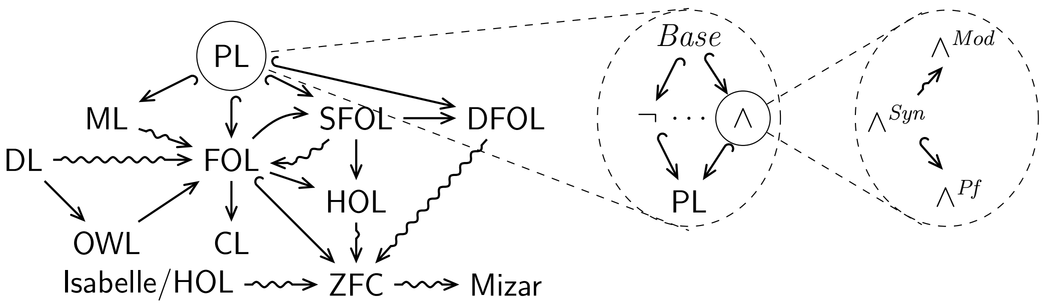

Figure 2: A Fragment of the LATIN Atlas (from [KR16])

The left side of Figure 2 shows a fragment of the LATIN atlas, focusing on first-order logic (FOL) being built on top of propositional logic (PL), its translation to HOL and ultimately resulting in the foundations of Mizar, Isabelle/HOL and ZFC, as well as translations between them. The formalization of propositional logic includes its syntax as well as its proof and model theory, as shown on the right of Figure 2. In a nutshell, the LATIN Logic Atlas provides the logic-interoperability framework and seed content (classical, description, and some modal logics) that we called for in Section 1.2 above. Crucially, domain theories can be aligned by theory morphisms, iff there are “meta-morphisms” for them (see Figure 1), therefore LATIN – and an extension for robust logics and argumentation frameworks – also provides an *uniform meaning space* for logical content and argumentations.

1.5 MathHub: A Portal for Logics, Libraries, and Active Documents

The OMDoc/MMT language is implemented by the **MMT system** (Meta-Meta-Tool [Rab13; MMT]), which provides a powerful API to work with documents and libraries in the OMDoc/MMT language, including a terminal to execute MMT specific commands, a web server to display information about OMDoc/MMT libraries (such as their theory graphs) and a plugin for the text editor jEdit, that can be used to create, type check and compile documents in the OMDoc/MMT language. The API is heavily customizable via plugins to e.g. add foundation specific type checking rules and import and translate documents from different formal systems. The MMT system can be used to give individual users access to a mathematical library and supports their knowledge management workflows.

But a full-scale infrastructure for logic-based integration in the RATIO SPP requires user/rights management, distributed revision control, and Web 3.0 features (e.g., discussions and user-generated annotations). For that purpose, we introduce the MathHub system [MH; Ian+14], which has four main components (see Figure 3):

i) a versioned *backend* holds the libraries,
ii) the MMT API as the kernel tool understands the libraries and provides semantic services for them,
iii) a web-based *frontend* makes the libraries and services available to users ,
iv) a Javascript *plugin architecture* [GLR09] enriches document presentations with localized semantic services.

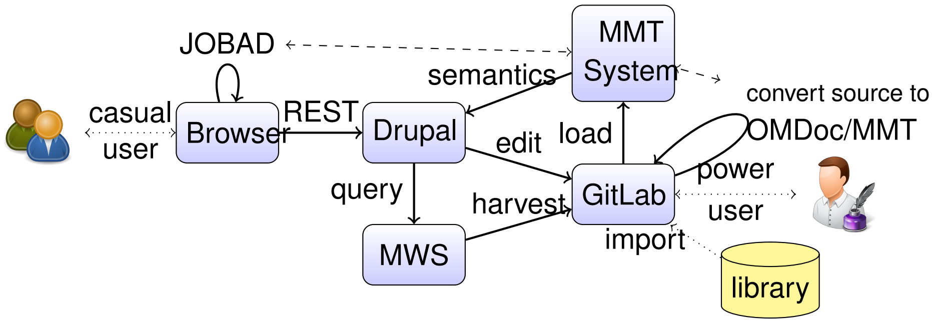

Figure 3: The modular MathHub Architecture

This componentized architecture has the advantage that we can combine two methods for accessing the contents of MathHub: *i*) an online, web-based workflow for the casual user, and *ii*) an offline authoring workflow based on git working copies for power users and bulk edits. Users can fork or pull the relevant repositories from GitLab, edit them, and submit them back to MathHub either via a pull request to the repository masters or a direct commit/push. As the content is often highly interlinked and distributed across multiple interdependent repositories, we have developed tool support for managing multiple working copies across repository borders. The interactive functionalities in MathHub are based on the OMDoc/MMT representation of the libraries, but authors and users have to interact with them in the respective source language of the library.

1.6 List of Project-Related Publications

1.6.1 Peer-Reviewed Articles

[Cod+11] M. Codescu, F. Horozal, M. Kohlhase, T. Mossakowski, and F. Rabe. "Project Abstract: Logic Atlas and Integrator (LATIN)." In: *Intelligent Computer Mathematics*. Ed. by J. Davenport, W. Farmer, F. Rabe, and J. Urban. LNAI 6824. Springer Verlag, 2011, pp. 289–291. ISBN: 978-3-642-22672-4. URL: https://kwarc.info/people/frabe/Research/CHKMR_latinabs_11.pdf.

[Koh+11] M. Kohlhase et al. "The Planetary System: Web 3.0 & Active Documents for STEM." In: *Procedia Computer Science* 4 (2011): *Special issue: Proceedings of the International Conference on Computational Science (ICCS)*. Ed. by M. Sato, S. Matsuoka, P. M. Sloot, G. D. van Albada, and J. Dongarra. Finalist at the Executable Paper Grand Challenge, pp. 598–607. DOI: 10.1016/j.procs.2011.04.063.

[Koh06] M. Kohlhase. *OMDoc – An open markup format for mathematical documents [Version 1.2]*. LNAI 4180. Springer Verlag, Aug. 2006. URL: http://omdoc.org/pubs/omdoc1.2.pdf.

[KR16] M. Kohlhase and F. Rabe. "QED Reloaded: Towards a Pluralistic Formal Library of Mathematical Knowledge." In: *Journal of Formalized Reasoning* 9.1 (2016), pp. 201–234. URL: http://jfr.unibo.it/article/download/4570/5733.

[RK13] F. Rabe and M. Kohlhase. "A Scalable Module System." In: *Information & Computation* 0.230 (2013), pp. 1–54. URL: http://kwarc.info/frabe/Research/mmt.pdf.

[Sta+10] H. Stamerjohanns, M. Kohlhase, D. Ginev, C. David, and B. Miller. "Transforming large collections of scientific publications to XML." In: *Mathematics in Computer Science* 3.3 (2010): *Special Issue on Authoring, Digitalization and Management of Mathematical Knowledge*. Ed. by S. Autexier, P. Sojka, and M. Suzuki, pp. 299–307. URL: http://kwarc.info/kohlhase/papers/mcs10.pdf.

1.6.2 Other Articles None.

1.6.3 Patents None.

2 Objectives and Work Schedule

The general goal of the RATIO SPP is to develop methods to capture, represent, aggregate, and contextualize arguments in human communication and it sets the following four scenarios as reference applications of the captured argumentation structures:

- **S1 Deliberation**: for a given topic, initiative, or thesis extract all pro- and contra arguments from relevant sources and aggregate them.
- **S2 Validation**: examine the internal coherence, consistency, or plausibility of a given argument.
- **S3 Reconstruction**: extract and systematize the reasons and exchanged arguments for a decision taken to make decision processes more transparent.
- **S4 Synthesis**: for decision support in a given context present the user with multiple options and alternatives justified by systematically synthesized arguments.

All of these have in common that they rely on a detailed representation of argumentation structures and the structure of the knowledge behind them. The underlying knowledge representation and reasoning problems will be attacked by a variety of logic-based techniques in the RATIO SPP.

2.1 Anticipated total duration of the project

The total project duration is anticipated to be six years; *the current proposal requests DFG funds for the initial project phase of three years (36 Months)*, which will develop a uniform representation format, an interchange infrastructure, and a general resource collection for the logic aspects (multiple foundations) in the SPP (see next section).

In the subsequent, second project phase we will expand on the results – using the ALMANAC infrastruture to combine foundations based on the findings of the first project phase and to offer foundation-independent algorithms addressing the four scenarios **S1**-**S4** above.

2.2 Objectives

The aim of the proposed ALMANAC project is to support logic-based approaches to argumentations. In the previous section we have identified three shortcomings in the state of the art: *i*) a zoo of logical formalisms and frameworks that address various aspects of human inference and argumentation, but are usually incomparable and often even incompatible. *ii*) the management of argumentation contexts, and *iii*) the lack of tools for corpus-based evaluation of logic-based approaches to argumentation – this is a major problem for scaling up logic-based methods to real-world applications. Concretely, the proposed ALMANAC project sets the following objectives.

O1: An Atlas of Argumentation Logics We need to bring order into the zoo of argumentation logics and frameworks. We propose to build an "atlas" that identifies the representational and inferential primitives, a modular development in a (meta)-theory graph, and relates the systems via theory morphisms in the OMDoc/MMT format.

O2: Context Graphs for Argumentation We want to develop a logic-independent framework for context management in argumentations based on (domain-level) OMDoc/MMT theory graphs.

O3: Supporting Evaluation of Logics We want to support the empirical evaluation of logic-based approaches to argumentation by developing an infrastructure that hosts the logical representations developed by the RATIO projects in the uniform meaning space given by O1, browse, compare, and reuse them across systems.

A note on transdisciplinarity: The SPP calls for "transdisciplinary" projects to prevent projects from becoming methodically insular and ensure that methods are "robust", i.e. grounded in real-world data. The ALMANAC project pursues the same ultimate goals, but chooses a "meta-orientation-logical" and an explicit resource construction component. We see this as a good complement to transdisciplinary projects for ensuring cohesion of the SPP.

2.3 Work Schedule

The project is organized around ten work packages, which we summarize in Table 1. The three work areas correspond to the three objectives stated above. Figure 8 shows a rough time plan that takes the work package dependencies into account.

WA/P	Title	page	RM	RAM
WA1	**Atlas of Argumentation Logics**	**8**	**14**	**0**
WP1.1	Identifying useful logics for structured argumentation	8	1	0
WP1.2	Logics for robust representation of arguments	9	8	0
WP1.3	Linguistic Logics	9	5	0
WA2	**Context Graphs for Argumentation**	**10**	**13**	**18**
WP2.1	Annotated Corpus of Technical Documents	10	4	12
WP2.2	Context Graph via Argumentation Relations	11	3	0
WP2.3	Extending the MMT system with Context Graph Relations	11	3	6
WP2.4	Framing in Arguments	12	3	0
WA3	**Archive and Manager for Logic Argumentations**	**13**	**9**	**18**
WP3.1	Management System	13	3	6
WP3.2	Import/Export Facilities	13	3	6
WP3.3	Joint Task	14	3	6
	totals		36	36

R(A)M $\widehat{=}$ Researcher (Assistant) Months

Table 1: Work Areas and Work Packages

Work Area 1: Atlas of Argumentation Logics

We propose building an "atlas" of various formal logics and frameworks used in argumentation theory. The LATIN project described in Section 1.4 already covers the syntax, proof theories and semantics for many common logics and thus demonstrates the feasibility of such a project; however, the logics contained in LATIN are usually insufficient when analysing argumentation. Here, paraconsistent, probabilistic and other multi-valued logics are much more useful. Furthermore, argumentation theory comes with its own set of frameworks and semantics for analyzing statements in these logics, as well as relating them in various ways (arguments can support, attack and contradict other arguments etc.).

When modeling and relating the argumentation logics in OMDoc/MMT, we will give precedence to the paradigmatic logics from the literature and the logics used in the RATIO SPP to enable collaboration on resources and results, competition on services for the four scenarios **S1**-**S4** above, and generally synergies in the SPP. Once that is achieved, we will proceed with logics from the literature to extend these virtues to the wider argumentation community. The virtue of the proof-theoretic approach is that we can model non-atomic deductions in the argument of one agent.

Work Package 1.1: Identifying useful logics for structured argumentation (1 RM+0 RAM)

To serve the projects in RATIO – obviously not determined yet at the time of writing the ALMANAC proposal – we will have to survey the logics under investigation in the accepted projects. We will dedicate a session in the RATIO kickoff workshop for this.

Work Package 1.2: Logics for robust representation of arguments (8 RM+0 RAM)

Naturally, many logics that might be useful for structured argumentation frameworks, such as probabilistic logics, tense logics or paraconsistent logics are not as well studied in a computational setting as more common logics. A particular challenge is posed by logics, where the space of truth values is infinite or possibly even continuous. Still, logical frameworks such as LF are well-suited to represent any kind of logic that admits a natural deduction style proof calculus, which most of these do. Infinite truth value spaces can be handled by using (e.g. real valued) *generic literals* [Rab], natural deduction style proof calculi can be formalized using the judgments-as-types paradigm (as the LATIN project demonstrated). For logics (with or) without a suitable proof theory, we believe OMDoc/MMT can adequately represent the semantics of these logics. Here, too, LATIN serves as a proof-of-concept.

- **T1 Specifying logics in OMDoc/MMT** We want to formalize the syntax, proof theories (if possible) and semantics of the logics identified in WP1.1 in a unifying atlas of logics (similar to LATIN) using OMDoc/MMT.
- **T2 Specifying (multi-)modal logics in a logical framework** Since we want these specifications to be as shallow as possible, it might be useful to extend existing logical frameworks (such as LF) by new features specifically to represent modal operators primitively.
- **T3 Building a formal framework to specify their coalgebraic semantics** Many logics such as probabilistic logics or description logics can furthermore be represented as (multi-)modal logics. While LATIN already contains the classic modal logics K, D, T, S4 and S5, less well-known (and in particular multi-)modal logics are so far missing. However, the modal logical representations of (at least some of) these logics give us a unifying language to represent these.
  In particular, these modal logics admit a coalgebraic semantic, which allows for stating, proving and analyzing common properties such as completeness or compactness on a more general level [Cir+09]. Expressing these semantics using theory graphs and OMDoc/MMT could help in stating and analyzing the most important properties of these logics formally.
- **T4 Combination of Robust Logic Features** We will use the modular development of logic features above to try to combine them into a joint robust logic. It has been our experience from the LATIN project that the MMT/MathHub support makes the development of logics more efficient and that investments in modular modeling pay off handsomely. Thus we anticipate that a combination – at least of orthogonal features – is feasible. This combination may benefit from the coalgebraic framework in the previous task.

Work Package 1.3: Linguistic Logics (5 RM+0 RAM)

Dynamic logics (such as discourse representation theory DRT [KR93]) differ from “static” logics in various ways. Most prominently, these logics usually handle variables and their scoping quite differently - variable scopes are e.g. “linear” as opposed to recursively defined, resulting in non-standard quantifiers with “non-recursive” scoping behaviour. As a result, the usual logical frameworks (such as LF, which was used in LATIN) and related systems are insufficient to specify their behaviour accurately.

- **T1 LF with Imperative Variables** To solve this problem, a new framework will need to be designed that can specify this behaviour properly while still being integrable into and compatible with our proposed and current system.
  The key missing piece in LF is the handling state in discourse referents (or equivalently imperative program variables), and in particular an assignment operator. The main problem to solve here is

the interaction between the classical (recursive) λ-bound variables, and the discourse referents. We want to investigate whether ideas from [KK97] or [Gro06] can serve as a basis.

T2 Modeling concrete Dynamic Logics Once the meta-logical primitives have been established, using these to model the particular domain-level constants becomes a routine task of stating the (well-described in the literature) respective properties of the dynamic connectives – e.g. that dynamic negation closes off dynamic scope and that dynamic implication allows anaphora from the succedent to the antecedent only.

T3 Combination with Robust Logics We will use the modular development of logic features from WP1.2 to combine the respective features with the dynamic logics modeled in this work package.

Work Area 2: Context Graphs for Argumentation

In this work area, we will develop the ideas for adding multi-agent context models alluded to in O2: WP2.1 prepares a document corpus that will a) contribute new facts to the RATIO project and b) need the precision of logic-based methods for argument modeling: scientific/technical corpora are much less redundant, more structured, and less emotionally charged than the usual web corpora. WP2.2 develops the intended theory-graph based models of argumentation context by extending OMDoc/MMT, and WP2.3 implements it in the MMT system. Finally, WP2.4 tries to extend coverage of these models by taking advantage of the theory-graph structure.

Work Package 2.1: Annotated Corpus of Technical Documents (4 RM+12 RAM)

To ground the development of context graphs, we will generate and annotate a corpus of scientific/technical documents. Unless another project in the SPP proposes cooperation on a more interesting corpus, we will make use of our arXMLiv corpus [Sta+10; ARX], which contains almost 1.1 million scientific papers from the Cornell ePrint arXiv translated into XML (XHTML5 with MathML) for ease of parsing. The corpus contains pre-prints from physics, mathematics, statistics, computer science, quantitative biology and finance. We believe that scientific/technical documents add an interesting facet to the RATIO corpora as we expect that the arguments put forth in the papers are more carefully reasoned and more explicitly justified. Moreover, the citation practices in publications give us a valuable graph structure for the documents – if you attack, undercut, or strengthen an argument in another scientific article, you have to cite it.

A striking example is a paper of the arXiv corpus by Coffey and Sondow [CS12], which rebuts several aspects of a proof by Kowalenko [Kow10] for the irrationality of Euler's constant γ and challenges the novelty of his rational series for γ (see Figure 4 for an excerpt). Their rebuttal of the proof is based on identifying false assumptions made by the original author and on giving counter-examples to refute the validity of his methods. Additionally they disprove the novelty of the series by giving concrete reference to a former publication, which mentions this series already. The structure of the rebuttal closely follows the original argumentation and gives detailed references to the original paper in the form of page and equation numbers. The reference between the initial arguments and their counter-arguments can thus be extracted easily.

T1 Subcorpus Identification M0-M3@.3First samplings of the arXMLiv corpus suggest that only a subset are argumentative in the strong sense that they argue *against* other positions, but most argue *for* their own positions. Therefore the first task in this work package is to single out a collection of subcorpora with interesting argumentation structures by corpus-linguistic methods. We intend to collaborate with Prof. Stefan Evert from FAU Erlangen on this topic.

T2 Argumentation/Context Annotation M3-M6@.3The next step is to annotate the argumentation structures and contexts in the articles. The crucial task here is to identify the modeling assumptions that contribute to the context. As the articles are XML-based and the non-textual modalities in the text (mathematical formulae, quantity expressions, tables, and diagrams) carry crucial parts of the

> The irrationality of Eulers constant γ *[...]* has long been conjectured. *[...]* In 2010 Kowalenko claimed that simple arguments suffice to settle this matter [4]. *[...]* we *[...]* describe the flaws in his very limited approach.
> *[...]*
> Kowalenko derives the following formula for Eulers constant in equation (65) of [4, p. 428]: *[...]*
> *[...]*
> Here he claims that the sum of a series of positive rational numbers cannot be equal to $C - \pi^2/6$. But, for example, decimal expansion does give such a series: *[...]*

Figure 4: Short excerpt of Coffey's and Sondow's rebuttal [CS12] of Kowalenko's paper [Kow10].

meaning, text annotation tools like BRAT [BR] or Hypothes.is [HYP] are unsuitable for the task. We will adapt our KAT Web annotator [Gin+15; KG] for the task by extending existing argumentation ontology for scientific/technical documents and a suitable KAT binding.

T3 Distribution We will distribute the annotated subcorpora first to the RATIO project partners and if the licensing permit – we are currently negotiating with the arXiv project – to the research community under an open license.

Work Package 2.2: Context Graph via Argumentation Relations (3 RM+0 RAM)

Argumentation frameworks such as Dung-style frameworks [Dun95], abstract dialectical frameworks [Bre+13] or the first-order argumentation framework by Besnard and Hunter [BH05] introduce their own relations between arguments, such as support, refutation or undercut.

Modelling arguments and their prerequisite knowledge and assumptions as theories, we can in turn model these relations as arrows between theories, giving rise to theory graphs as described in Section 1.3 and thus using existing and new tools for theory graphs for applying these frameworks in a formal setting. Figure 5 shows a typical situation for agents P and C, which agree on a common ground, expressed as the theory graph CG, but differ on some assumption A, which P accepts and C rejects (see also Figure 6 for a real-world example). Essentially, if P and C are "internally consistent", then they accept only the material below the respective dashed line, but any argument that involves A will essentially play out in the top quadrant, which is contested by both – hence the argument. We have marked the tension between A and ¬A via the dotted "antithesis" line in Figure 5. Context graphs are particularly interesting in the context of approximate arguments and enthymemes [Mai16].

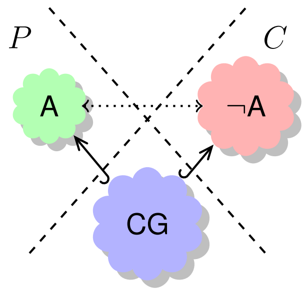

Figure 5: Context Graph

This simple example already shows that theory graphs can serve as knowledge-based context models, where many interesting properties can be read off the graph struture. We conjecture that we can model the attack-like relations in argumentation frameworks (e.g. refute and undercut) as paths in suitably granular theory graph which contain a single "antithesis"-like relation and the support-like relations as paths without.

Work Package 2.3: Extending the MMT system with Context Graph Relations (3 RM+6 RAM)

Modelling context graphs as theory graphs naturally implies that the relations in these graphs (support, refutation, attack, undercut etc.) become different arrows in a theory graph. The theory graphs used by OMDoc/MMT currently (mostly) assume, that the arrows are various kinds of theory morphisms, meaning they are supposed to map declarations in one theory to corresponding declarations in another theory in a truth-preserving manner, and most of the existing services offered by OMDoc/MMT are based on this assumption.

While framings (see WP2.4 and possibly support relations) should be easily representable as theory morphisms, the same is not true for attacks, undercuts and related “negative” relations. We want to extend the OMDoc/MMT format and the MMT system by new kinds of arrows in a theory graph, that can correctly specify the behaviour of these relations. Since OMDoc/MMT is highly extensible by design, we believe that we can handle these negational relations in a similar manner as the already present theory morphisms.

In particular, *structural features* have recently been added to the OMDoc/MMT system (see e.g. [Ian17]), which allow for adding new syntactical constructs that can be *elaborated* automatically into the symbols used by the abstract OMDoc/MMT language. In particular, these could induce arrows in a theory graph that do not correspond to the currently implemented theory morphism. Consequently, we can probably represent all the relations between arguments and argumentation contexts as structural features in OMDoc/MMT.

Representing argumentations as theory graphs has the additional advantage, that we can use theory graph operations, such as theory intersections (see [MK15]) or “theory difference” to identify the common ground and refactoring the corresponding theories yielding a theory graph as in Figure 5.

Work Package 2.4: Framing in Arguments (3 RM+0 RAM)

Often, agents do not pick up on arguments of others directly, but via “framing” (see e.g. [Sno+86] for a discussion). In a nutshell, framing means that a *concept mapping* between *argumentation/knowledge contexts* (a **frame**) is established and the facts and assumptions underlying the argument are mapped along the frame. This happens often in counter-arguments by framing the original argument in terms of an obviously wrong argument, as in the following example[2]:

- The 1973 Roe vs. Wade decision denied fetus’ rights on the basis of personhood.
- The 1857 Dred Scott decision denied Black Americans rights on the basis of personhood.
- Personhood for Black Americans has been denied purely on the basis of cultural consensus.
- Therefore the denial of personhood for fetuses could also be purely on the basis of cultural consensus.

Here, the argument that abortion should be legal because of a court decision is reframed in terms of a similar court decision regarding African Americans, and the invalidity of the latter case is used to infer the invalidity of the former. We could express this in terms of a views by the (pseudo-)formalization in Figure 6. Building on a common ground CG that persons do not have rights, the invalidity of Arg2 can be transfered to $\varphi(\text{Arg2}) = \text{Arg1}$.

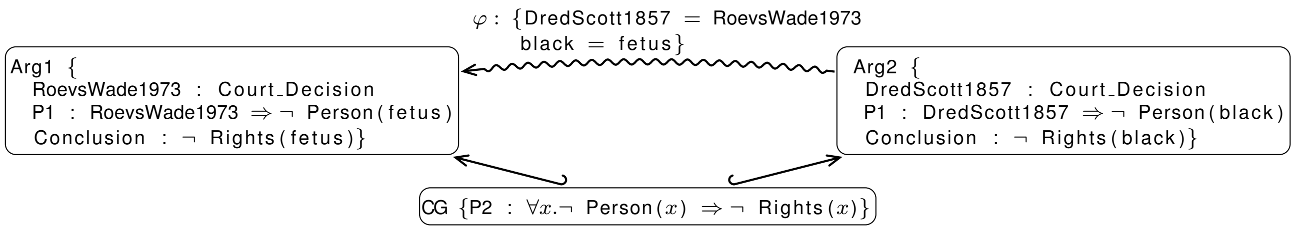

Figure 6: A Theory Graph with a view that encodes the framing of an argument

We have studied framings in spreadsheets [KK09], for “recaps” in mathematical articles [IK15], and as the motor of application of mathematical models in serious games [RKM16]. In all cases, we have been able to model frames as views in the theory graph.

T1 Empirics: Annotating Frames We will annotate framings, first in the corpus from WP2.1, and once corpora from the RATIO partners become available in these as well.

[2] Adapted from www.truthmapping.com/map/647/

T2 Modelling For all cases, where we have context graph annotations, we will (try to) model the framings as views in the context graph. We expect to find many examples as the one on Figure 6 (**T4.1**) that will guide the modeling in this task. We conjecture that admitting frames will make many more arguments accessible to logic-based representation. It will be interesting to see whether the logics from WP1.2 will allow for less strict views, which could further enhance the reach of framing in argumentations.

T3 Automation We will experiment with recent work on the KWARC view-finder [MK15] – a theory-graph-based algorithm that finds partial views automatically – to see whether framings can be automated.

Work Area 3: Archive and Manager for Logic Argumentations

To satisfy objective O3 we propose to develop a software infrastructure that facilitates the cooperation, competition, and evaluation of logic-based activities in RATIO. The work here is divided into three work packages: WP3.1 concerns a general trans-logic management system for document/logic corpora, WP3.2 develops import/export facilities to the various logical representation languages to ensure that we can collect a meaningful set of corpora, and WP3.3 facilitates the development of a set of challenge problems to be given as a "joint task" to the community. As in WA1 we will first serve the RATIO projects and then extend participation to the wider argumentation community for dissemination.

Work Package 3.1: Management System (3 RM+6 RAM)

We will build an instance of the MathHub system that is dedicated to managing the logical corpora of the RATIO SPP.

While linguistic annotations to corpora mainly consist of classifications of and relations between natural language phrases, logical annotations relate phrases to logic-based representations, and context annotations (as e.g. provided by work area WP2.1) refer to context representations and possibly update them with new assumptions and facts. Figure 7 shows a schematic view on the situation. On the left we have a traditional document corpus, and on the right a theory graph as it can already be hosted in the MathHub system. The dashed arrows between the two corpora depict the logical annotations to the documents.

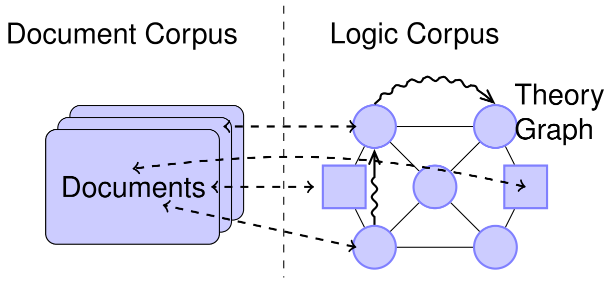

Figure 7: A linked logic/document corpus

Assuming that these are in – or can be converted to – RDF[3], we can extend the MathHub system by an API that allows to manage these and supply logic suitable computations. We will also build on the existing MathHub presentation front-end and specialize it for browsing the joint linguistic/logic corpus.

Work Package 3.2: Import/Export Facilities (3 RM+6 RAM)

In this work package we will build translators for the concrete logical syntax formats of the RATIO project partners as well as other existing representation languages; for example the argument interchange format AIF. These allow to interface their systems and annotations with MathHub. The KWARC group works on similar integration interfaces in two current research projects ([OAF] and [ODK]); the former on various libraries of formal mathematics (in particular from interactive theorem provers), the latter with respect to various mathematical software systems (such as computer algebra systems) and databases. The methodology consists of the following tasks for each system:

[3] RDF annotations are based on URI triples, for tokenized XML documents, the phrases can be identified as RDF subjects by XPath URIs, and the logical annotations (the objects of the RDF triples) have canonical OMDoc/MMT URIs as well

T1 A Meta-Theory Writing an OMDoc/MMT theory that specifies the logical language, inference systems, and possibly the semantics of the system under consideration. This should mostly be already taken care of in WP1.2.

T2 An Import/Export Plugin for the respecitve system that generates a system-near representation of the native content in a parseable (ideally XML) format.

T3 An MMT Plugin that takes the system-near representations and translates these into OMDoc/MMT theories, using the specification theory from the former task as a meta-theory.

The necessary infrastructure for these tasks already exists in the OMDoc/MMT system and has been extensively used in – and improved upon during – the projects mentioned above. This suggests the feasibility of this work package, if the authors of the external system come up and maintain the system-near Import/Export plugin.

Work Package 3.3: Joint Task (3 RM+6 RAM)

Building on the system from WP3.1 and WP3.2, we will lead the infrastructure development for a *logic-based joint task* for the RATIO SPP. The proposer has been a co-organizer of the NTCIR Math Information retrieval tasks [AKO13; Aiz+14; Aiz+16], and even though the joint task proposed here is different, we propose that the experience gained at NTCIR carries over.

T1 Joint Corpus this is a direct consequence of the logic formalization effort in WA1, and the import/-export facilities in WP3.2. We believe that the prospect of a joint task corpus will strengthen the motivation of the SPP partners to participate in those.

T2 Tasks & Challenges The exact form of the shared task will be a matter of coordination with the other RATIO projects that use logic. We expect that we will base the challenges – i.e. the tasks to be performed on the joint corpus – on the four scenarios **S1** - **S4** introduced by the RATIO SPP proposal (see the introduction to Section 2).

T3 Evaluation We will need to develop an evaluation methodology for the results of the challenges specified in **T3.3.2** above. We cannot directly use the standard Information Retrievel challenge measures like “Mean Average Precision” (MAP) or “Precision at 5/10”, etc. here: the relevance of the results to the challenge is no simple hit selection task, so it does not carry over to other results.

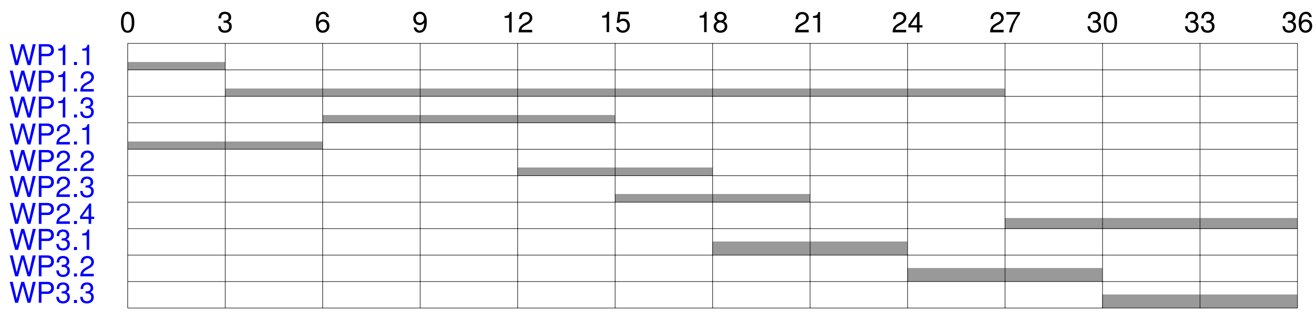

Figure 8: Gantt Chart: Overview Work Package Activities

2.4 Data Handling

The ALMANAC project will not systematically produce research data.

[3]Bars shown at reduced height (e.g. 50%) indicate reduced intensity during that work phase (e.g. to 50%).

2.5 Other Information n/a

2.6 Explanations on the Proposed Investigations n/a

2.7 Information on Scientific and Financial Involvement of International Cooperation Partners n/a

3 Bibliography concerning the state of the art, the research objectives, and the work programme

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