

Cultures of Formalization

Towards an encounter between humanities and computing

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1. Introduction

The past three decades have seen several waves of interest in developing cross-overs between academic research and computing; molecular biology is often cited as the prime exemplar of 'what computation can do for a field'. The humanities and social sciences have also been the terrain of such interactions, at times through bottom-up collaborations, and at times through concerted policy-driven efforts (Wouters and Beaulieu, 2006). The main developments vary across national contexts and disciplines. In our local context (in the Netherlands), we can roughly identify the following waves: the 'history and computing' and 'literature and computing' efforts of the 70s and 80s; the collaboratory and infrastructure discussions of the last decade; the current efforts at developing computational humanities, and recent emphasis on virtual research environments (VREs) of which Alfalab¹ can be regarded as an example.

Efforts to introduce computational method typically involve collaborative work between scholars and engineers and the combination of their complementary skills and expertise. Along the lines of Traweek (1988) and Knorr-Cetina (1999), we consider such collaborations as encounters between 'epistemic cultures', that is to say, particular combinations of meanings, material arrangements and practices that organize an area of scholarly work. In this paper we focus specifically on formalization, and we use an analytic metaphor, 'cultures of formalization', as a means to highlight the epistemic variety underpinning formalization practices in different epistemic cultures. We argue that critical reflection on formalization practices is important for any computational program to succeed, and that this is of particularly importance in the humanities domain--foremost because experience tells that rigid prescriptive heuristics and mandatory explicit formalizations, if uncritically imposed from a computational paradigm, generally do not 'land well' in different humanities research communities. While both computational sciences and humanities can be intrinsically characterized by their epistemological and methodological openness to complexity and uncertainty, their sensibility as to what is acceptable in terms of heterogeneity of method and approaches often does not overlap. By conceptualizing and describing cultures of formalization in the humanities, we can also identify aspects of research that could be better supported, if suitable and compatible computing approaches are developed. An approach that stresses cultures of formalization can therefore also enrich the computing research agenda, and contribute to more symmetrical and constructive interactions between various stakeholders in computational humanities.

From these initial observations, our exploration takes on three forms. First, we propose to look more closely at formalization and to question whether it is a singular concept. Second, we ask whether formalization is also an aspect of research in the humanities, even without (necessarily) thinking of it as driven by computation, and we present four case studies that help us explore that question. Finally, we consider how our analysis enriches what can be understood by formalization, and what kind of light it throws on the encounter between computing and humanities.

1 Several institutes of the The Royal Netherlands Academy of Arts and Science (KNAW) have joined forces in a cross-institute project named Alfalab (see <http://alfalablog.huygensinstituut.nl/>). All authors of this paper are members of the Alfalab team. The KNAW has also set up a committee to develop a programme of research on Computational Humanities; Beaulieu and van Zundert are members of the programme committee.

2. What is formalization in humanities computing?

Formalization is highly recognizable as a basic principle underpinning the logic of computation. Apparently, this has led to the perception that any computational approach in the humanities should be rooted in formalization as well. Subsequently repeated failed attempts at deploying computational approach in the humanities have been attributed to the lack of formalization, and, in the worst cases, even the lack of apprehension of formalization by humanities scholars. Indeed, at first blush it may seem evident that formalization of humanities research heuristics and hermeneutics is closely tied to the rise in computational efforts. But it is a fallacy to posit that formalization is a new development in humanities, driven solely by computation. In music theory, for instance, a trend toward formalization has been present since the 1960's, prompting an increased interest of computer scientists and psychologists in musicology rather than the other way round (Honing 2006). Such examples support our argument that formalization is not a newly emerging element in humanities research and, moreover, that methods of formalization can facilitate interdisciplinary scholarship. Rather than simply a necessary and straightforward condition for computation, formalization is a rich and productive aspect to think about the computation, the humanities, and their encounters.

Yet, if formalization is a foundation of humanities computing, what form does it take? As noted above, there is a strong tendency in computing to emphasize the importance of formalization in order to deploy computing – that is to say, to point to the need to explicitly define properties of research objects. Yet, we also find formalization in other aspects of computing in humanities research. Data-sharing also demands formalization: of notions of authorship and ownership of data, the formalization of research methods, and the formalization of annotations (see: Arzberger et al. 2004; Beaulieu, 2003). Formalization is therefore far from a homogeneous standard of quality— a hard to reach status of epistemic purity to be attained by research objects before they can be 'computed'. So why does formalization seem to come to the forefront so prominently in the context of interactions between humanities and computing?

One of the probable reasons is that encounters between different fields tend to throw difference into relief. The need to explain, to make explicit what one does and how, will tend to highlight processes of articulation, which are related to formalization. We stress that formalization has been implicitly around in humanities research; however, making certain kinds of formalization explicit through the use of computational methods, appears as an almost hostile act within some of the humanities domains. We posit that this is because the kind of formalization that is put at the forefront as a necessary condition for computing is only one kind of formalization, currently dominant in computing but far from universal across research domains. By paying attention to this mismatch in kinds of formalization, we can see the underlying reasons for resistance or, as is more often the case, indifference of scholars to computational tools that are proposed.

In order to illustrate these points, we now turn to four examples of formalization in different humanities domains. These case studies show the distinct different approaches, modes and realizations of formalizations that exist and emerge in various humanities projects taking a computational turn.

3. Case studies

Our case studies are pursued in the framework of Alfalab and in various institutions inside and outside the Royal Netherlands Academy of Arts and Sciences, including the Virtual Knowledge Studio for the Humanities and Social Sciences and Oxford University. Alfalab functions as a meeting point of these various endeavors, enabling encounters that, in turn, can foster critical reflection on our respective projects.

3.1 Hypothesizing history

In the preparatory phase of research Joris van Zundert and Tara L. Andrews are carrying through, the objective is to explore the possibilities of computationally inferring and visualizing the hypotheses dependency structure underlying argumentation in historical interpretation.

Historical reconstruction, particularly for medieval periods, rests on scraps of evidence, surmises about its quality and biases, and attempts to fit it into a framework of what we think we know. Elaborate hypotheses must be built to explain our evidence, many of which require intricate argumentation that depends on other hypotheses. These feats of historical analysis can be deeply impressive and thorough (Dédéyan 2003) but at the same time very dangerous. How can historians assess the full extent of the impact of a new piece of evidence, such as evidence of a market economy found in an area 'known' to have suffered a 'dark age', when it challenges assumptions that have been part of the basis for our understanding of the entire period (cf. Auzépy 2007)? As 'generations' of interpretation build layer upon layer of hypotheses, the complete supportive structure of hypotheses becomes too complex to fully 'compute', even for the finest minds. Problems of contradictory interpretation due to conflicting hypotheses structures within one and the

same synthesis are a demonstrable result of this complexity.

Our work is therefore a supportive analytical task. It seeks to infer explicitly the relations between hypotheses and to evaluate how (self-) supporting the hypotheses dependency trees are. This task could be a very valuable addition to the method of aggregative argumentation and interpretation, which is at the core of research heuristics in historical studies. It is also a task that could be highly facilitated through a computational approach. For instance, analysis techniques like topic maps (cf. Bock, 2009) and/or rhetorical structure theory (cf. Man, 1986) can readily be applied to describe or visualize argument dependency trees. However, to be able to apply these techniques, we need specific forms of hypothesis and argument formalization, both of which can be viewed as complex tasks of data curation. We need to be able to capture the hypothetical argumentation in a way that is both simple to apply and unambiguous to a dependency computing algorithm. Unfortunately, such means of expressing argumentative structure are still a rather abstract form. Rather than taking the form of the original text, the argumentative structure is represented in the form of a series of symbols capturing the argumentative statements and the formalized relations between those statements.

Relevant to the subject of this paper is the preliminary observation that the process of formalization and the knowledge of logic involved seem to be non-tangible and actually rather inhospitable to history researchers. Formalizing both argumentative structure and the 'surface structure', i.e. the very personal idiolect and style of the argumentative text, evoke feelings of 'meddling' in with the core capacity, competence, method and techniques of the researchers. But, from the computational perspective, these formalizations are merely descriptive, and they serve no other purpose than to compute and visualize argument dependency on former hypotheses, empowering the research to self-evaluate and infer the soundness of argument. However, it needs little argument that the process of transcribing an argument structure from painstakingly stylized idiolect into a computable form is an alienating process for the researcher, idiolect arguably being one of the strongest identifiers of 'self' around. This is why formalization in this case creates the risk of resistance and distrust within the targeted research community (historians in general and Byzantinists in the prototype phase of the research in particular). Furthermore, in order to make formalization a useful activity, historians need to trust formalization and not perceive it as an alienating research practice. This will only be achieved if formalization does not appear as an intrusive process and daunting activity for those researchers. This could be accomplished, for example, by utilizing -or even creating- much higher order computing languages than usually applied. However, this requires computational engineers to recognize form and representation as important factors in establishing trust and enabling unobtrusive formalization.

3.2. The onymic landscape

Names are so common in our daily lives that we tend to overlook them. Still, names are often a cause for laughter, teasing, and – worse – discrimination. Expecting parents take an enormous amount of time and energy in deciding how to call their child. Persons sometimes change their own names. And, occasionally, names of cities or streets are changed. Such examples show that names are more than just tools for discriminating or referencing entities. Their very characteristics make names a subtle stylistic tool in literary texts too. Often, an author can create an idea or certain expectations of a character in a story just by mentioning a name. Tension can be created by mistakes in names, or by the introduction of aliases, which are only solved at the appropriate time (from the story teller's point of view). Names can imply a geographical and/or social background of characters. In the case described here, Karina van Dalen-Oskam aims to analyze the usage and functions of names in literary texts from a comparatistic point of view, i.e., between texts, oeuvres, genres, time periods, and even languages (Van Dalen-Oskam 2005). The first results of the research will become available in 2011.

The study of names in literature is a subdiscipline of Onomastics (name studies). Until recently, research in literary onomastics was very eclectic, only pointing out 'significant' names in a literary work and describing their role in the text(s). About a decade ago, scholars have started to emphasize the need to look at all the names in a text (oeuvre, genre, etc.) and to analyze the so-called onymic landscape. Only with such an analysis we can be sure which names are really significant and have an extra role in the plot of the story, as motive or theme bearing stylistic elements.

This, however, is easier said than done. It takes too much time for one researcher to reconnoiter a large onymic landscape. This has to be done by many scholars, and they should approach their data in a comparable way in order to make their 'mapping' useful for each other. There are no useful software tools yet for this type of work, which is why creating such tools is part of the Alfabab endeavor. It may seem that names are easy to find in texts, and that usage of tools such as those for named entity recognition and classification (NERC) could make such research very easy. But this is not the case. Tools for NERC usually focus on one language only, and for that language on just a few text types, mainly texts from specific topic areas or from newspapers. Even then the maximum success rate only occasionally exceeds 80 % (Sekine and Ranchhod 2009). Literary texts contain sorts of name types, so several NERC tools would

have to be applied before getting a result that still needs a lot of manual cleaning up.

The comparative literary onomastic research Van Dalen-Oskam conducts will look into the frequency and function of names occurring in literary texts. It will also observe the ratio of types of names (e.g. personal first and family names, place names etc.). To enable comparative analysis, scholars working on different texts will have to follow the same rules. This of course constitutes a form of formalization. A deceptively simple challenge, the formalization of identifiable properties of names and their uses, is in fact a cumbersome task. For example, the most common names in literary texts are personal names. These can be divided in first names, bynames, and surnames. Scholars will usually agree on what category a name belongs to, but what to do with classical names such as Julius Caesar? Julius was not a first name and Caesar not a family name. We can agree about 'Jesus' being a name, but what about 'God'? The second most frequent name type, place names, is also relatively easy to agree on, but is Niagara Falls a location (so a place name) or an object? Several other categories are denoted as being names in theory, e.g. currencies and time indications, or as names in one usage while not in another (Van Langendonck 2007). But such categories are probably not very relevant to a literary analysis of the texts. And on top of that, scholars would need extensive training before being able to spot these correctly. So these will be excluded from the comparative literary onomastic research. Part of this project therefore involves finding the right degree of formalization, to do justice to the research goals at hand, to make use of the potential of tools to support comparative analysis, and to maintain the feasibility of the endeavor.

3.3 Microtoponymy

Microtoponym is a term used for names of small to very small entities in both natural and human-made landscape. Imagine for example a small field called 'the Gallows'. It may very well be that the name is not even formally designated in any land registry but is only known and used by the local population. It is such microtoponyms that are part of the object of research and formalization in yet another pilot of the Alfalab project, called GISLab. This specific exploratory research is interested in applications of Geographical Information Systems (GIS) as a suitable platform for humanities research.

Within the broad spectrum of the humanities, the study of onomastic variation, and in particular the study of place names, or toponymy, may come across as a very specialized niche. But microtoponyms are actually of interest for, amongst others, historians, historical geographers and archaeologists. In the Netherlands, researchers from different disciplines agree that having the Meertens Institute collection, which contains more than 200.000 microtoponyms and their geospatial parameters digitally available, would facilitate and open up new avenues of research in various subjects.

Regarding the subject of this paper, it is useful to point out that in the process of digitizing and utilizing a legacy consisting of 200.000 physical index cards, systematically recording toponyms and their metadata, formalization indeed does play a role on several levels: determining functional requirements of the GIS by interviews and studying prior work, development and implementation, etc. However the microtoponym case study is less about formalization and the possibility of making heuristics explicit. It is more about formalization at the level of the objects of research, which, through being formalized and situated in a digital context, can offer new research possibilities.

The following example may serve to clarify the previous statement. For Dutch onomasticians concerned with the microtoponyms, Schönfeld's book *Veldnamen in Nederland*, or 'Microtoponyms in the Netherlands' (Schönfeld 1950), provides a usable starting point. However, although Schönfeld's work is still a standard in its field, it was written in 1949, long before anyone envisioned a field called Computational Humanities. The computational approach and interdisciplinary character of the microtoponym virtual research environment (VRE) that will be established through Alfalab seeks to evolve the present onomastic community and create an interdisciplinary new one. Therefore, an a priori focus on descriptive or prescriptive formalization based on recognized yet superseded theory would potentially hinder the exploration of new and cross-disciplinary possibilities. Explicit generic formalization would also be hard to achieve. For example: since the visual aspects of a GIS specifically allow researchers to make their own interpretations of certain maps *separately* from other researchers' interpretations, their actual method of interpretation may and must remain fully implicit. The advantages of formalization in this case have to do with opening up the possibilities for interacting with microtoponyms as digital objects in a VRE.

3.4 The empirical image

This case study concerns the use of Flickr as used by researchers who explore graffiti and street art.² The case study

2 The material presented here is part of an ongoing ethnographic project, Network Realism, pursued at the Virtual Knowledge Studio for the Humanities and Social Sciences, Amsterdam by Sarah de Rijcke and Anne Beaulieu. See the project blog: <http://networkrealism.wordpress.com/>.

focuses on the constitution of Flickr as a resource and means of interaction between researchers and empirical material. In every field, there is an accepted way of constituting one's object of research, and this aspect of research is a key dimension of epistemic cultures.

Best known as a photo-sharing platform, Flickr can also be used to build a personal archive of photos, to browse material uploaded by (un)known others, or to engage in a wide variety of activities around photos. Flickr has several features of "ongoing sociability" (Fuller, 2003) typically associated with social networking sites. It enables users to represent themselves and to articulate links to other users and the content they upload. Furthermore, Flickr, like other social networking platforms, makes use of traces generated by use of the system and its content, a defining feature of Web 2.0 applications.

The researchers studied in this case are mostly (visual) sociologists or anthropologists, who focus on urban and/or material culture. Amongst the huge variety of photos on Flickr, urban photography and the documentation of urban life is a prevalent theme (Petersen 2009). All of the researchers use photography as part of their research practices, which they define as "fieldwork". Through interviews, email exchanges, analysis of articles and other output, and the researchers' use (or, in one case, vehement non-use) of Flickr, this case study is able to characterize how Flickr is used in relation to empirical material in the researchers' work.

Researchers use Flickr as a source to throw further light on material they have gathered in their fieldwork, by connecting different bits of empirical material. This use resembles searching, browsing and 'googling' on the web, but more specifically in relation to visual material and to street culture, for which Flickr is an especially good source. Visual material is also notoriously under served by search engines, which are oriented to textual, (and even ascii) material.

This use of Flickr depends on the presence of material from huge numbers of contributors, and, significantly, on the use of recognizable tags or labels. Tagging and labeling subtend formalization of content, meaning or significance of aspects of images. While often done without much conscious effort, these seemingly banal gestures are important practices that facilitate the constitution of Flickr material as empirical sources. Consider that most of these researchers have very strong feelings about the use of captions for their photos, and condemn these as parasitic textual practices that undermine the narrative power of the visual material. Yet, all of them assign titles and tags to their photos on Flickr. These are usually summary, but nevertheless label the photo with a transcription of the tag text (i.e. the 'name' of the writer of a graffiti or artist. Locations are also often used as tags.) This labor in turn enables Flickr to function as a searchable source. Tagging is a recursive practice in these settings (i.e. popular tags can be used to generate 'views') that shapes the constitution of categories and modes of organization of material.

This case study illustrates how visual material is made usable through formalizations that involve textual labels, which are useful to some extent—and certainly interesting as an emergent phenomenon. But this reliance on textuality is far from desirable for some researchers. Visual formalizations that do not rely on text would highlight different aspects of this empirical material for researchers. This is a case that suggests how computational approaches might be developed to better serve researchers' needs in relation to their empirical material. Possibilities to formalize image data in ways other than textual labeling, and to make them empirically useful to humanities researchers, would be a valuable contribution of a computational approach.

4. Conclusion

If any computational humanities program is to succeed, the policy makers, organizers and implementers of such programs should take into account how formalization is put forth and what is understood by formalization. We have presented four cases that show the highly varied modes and realizations of formalization in humanities research. The case of Van Zundert and Andrews (3.1) predominantly focuses on technical and cultural aspects in formalizing properties of a research object. The research of Van Dalen (3.2) draws our attention to the formalization of the heuristics of a specific research domain. Zeldenrust (3.3) demonstrates that formalization can lead to more freedom, not less. Finally, the case of Beaulieu (3.4) calls our attention to emergent formalization as a driver for the development of computational approach rather than the other way round (as is often suggested to be the primary dynamic.) These different modes of formalization are connected to, but not singularly driven by current computational practices. Formalization manifests itself as a multi-faceted, multi-directional and multi-motivated complex of activities, not as a simple, unitary principle underlying computational approach.

The case studies presented in this paper also illustrate that formalization can be supported by computation, if we recognize formalization as an integral part of humanities practice and not as a feature driven by computation only. Such understanding can be used to better align technology and tool development efforts to the needs and ambitions

of researchers. Furthermore, by recognizing and articulating different modes of formalization, computational science can enrich its own research agenda, further expanding its ambitions in terms of what computation can mean.

Also, if we identify and describe the 'cultures' of formalization, researchers will have a more explicit means to recognize practices of formalization in their own and other humanities domains. Put differently, researchers will be able to look over the walls and identify both implicit and explicit formalization practices in different humanities domains. Such recognition of different modes of formalization would enable researchers to interact with each other's modes of formalization and start networking and cross-fertilizing different knowledge domains. From there, a community or network of researchers furthering and fostering formalization as a value-added means for humanities analytics could develop.

Finally, in examining promises and challenges of computational methods in general and formalization in particular, two points should be taken into account. First of all the ongoing computational 'waves' and 'turns' should not turn the research community away from maintaining and promoting humanities tradition in contemporary scholarship. Put differently, computational humanities should be unequivocally recognized as only one stream of contemporary humanities research. Perpetuating claims about potency and ubiquity of computational methods, while regarding non-computational scholarship as conservative, evokes resistance toward methodological and epistemological innovation. Such claims also obscure the fact that not all questions in humanities research can and should be approached by the way of some unified computational analysis. The variety of cultures of formalization illustrated in this paper highlights that there is no single golden road to computation.

Secondly, an interplay among computation, formalization and humanities should not be light-heartedly considered as yet another way of doing humanities research. Such an interplay is rather more about cognition than about method; cf. Brey (2005): "when the computer functions as an enhancement of human cognition ... human and computer are best regarded as a single cognitive unit, a hybrid cognitive system that is part human, part artificial, in which two semi-autonomous information-processing systems cooperate in performing cognitive tasks" (p. 392). Understanding the cognitive interplay of computational systems and human users is important for analysis of formalization in humanities research: the 'computational turn' does not involve 'just' a specific formalization of research hermeneutics; it possibly also involves a specific formalization of the research thought process. However, the community of computational humanists seems to shy away from such a view, and instead seems to specifically highlight methodological and epistemological aspects of formalization. Yet, recognizing the cognitive and affective aspects of scholarship could help understand some of the reasons for the still prevalent resistance toward computational methods. Such an understanding would also help acknowledging scholars' right to not compute, i.e. to decide which turn to take.

References

- Arzberger, Peter, Peter Schroeder, Anne Beaulieu, Geof Bowker, Kathleen Casey, Leif Laaksonen, David Moorman, Paul Uhlir, and Paul Wouters. 2004. SCIENCE AND GOVERNMENT: An International Framework to Promote Access to Data. *Science* 303, no. 5665: 1777-1778.
- Auzépy, M. 2007. 'State of Emergency (700-850)', in Shepard (ed.), *The Cambridge History of the Byzantine Empire c.500-1492*. Cambridge.
- Beaulieu, Anne. 2003. *Annex1, Case study of data sharing at the fMRI Data Center, Dartmouth College, USA, in Promoting Access to Public Research Data for Scientific, Economic, and Social Development, Final Report, OECD Follow Up Group on Issues of Access to Publicly Funded Research Data*.
- Benjamin Bock, Lutz Maicher, Marco Büchler, Frederik Baumgardt. 2009. *Automatic Extraction of Topic Maps based Argumentation Trails*. Leipzig, at http://www.topicmapslab.de/publications/automatic_extraction_of_topic_maps_based_argumentation_trails?locale=en .
- Brey, Philip. 2005. The Epistemology and Ontology of Human-Computer Interaction. *Minds and Machines* 15: 383-398.
- Dedeyan, Gerard. 2003 *Les Arméniens entre Grecs, Musulmans et Croisés: étude sur les pouvoirs arméniens dans le Proche-Orient méditerranéen (1068-1150)*. Lisbon: Fundação Calouste Gulbenkian.

- Fuller, Matthew. 2003. *Behind the blip: Essays on the culture of software*. Brooklyn, USA: Autonomedia.
- Honing, Henkjan. 2006. On the Growing Role of Observation, Formalization and Experimental Method in Musicology. *Empirical Musicology Review* 1: 2-6
- Knorr-Cetina, Karin. 1999. *Epistemic Cultures: How the Sciences Make Knowledge*. Cambridge, Massachusetts: Harvard University Press.
- Mann, William C. and Sandra A. Thompson. 1986. *Rhetorical Structure Theory: description and construction of text structures*, Nijmegen: Information Sciences Institute.
- Petersen, Søren Møren. 2009. *Common Banality: the Affective Character of Photo Sharing, Everyday Life and Producers Cultures*. PhD, IT University of Copenhagen.
- Schönfeld, M. 1950. *Veldnamen in Nederland*. Amsterdam: Noord Hollandsche Uitg. Mij.
- Sekine, Satoshi, Elisabete Ranchhod. 2009. *Named entities. Recognition, classification and use*. Amsterdam / Philadelphia: John Benjamins.
- Traweek, Sharon 1988. *Beamtimes and lifetimes: the world of high energy physics*. London: Harvard University Press.
- Van Dalen-Oskam, Karina. 2005. 'Vergleichende literarische Onomastik'. In: Brendler, A. und S. Brendler (Hrsg.). *Namenforschung morgen: Ideen, Perspektiven, Visionen*. Hamburg: Baar, 2005, p. 183-191. English translation, 'Comparative Literary Onomastics', at <http://www.huygensinstituut.knaw.nl/vandalen>
- Van Langendonck, Willy. 2007. *Theory and typology of proper names*. Berlin / New York: Mouton de Gruyter, 2007 (Trends in linguistics; Studies and monographs 168).
- Wouters, Paul and Anne Beaulieu. 2006. Imagining e-science beyond computation. In *New Infrastructures for Knowledge Production: Understanding e-Science*, edited by Christine Hine, 48-70. London: Idea Group.