Journal of Object Technology
Published by AITO — Association Internationale pour les Technologies Objets,
Online at http://www.jot.fm.

Natural Modelling

Zoe Zarwin[a] Marija Bjeković[cde] Jean-Marie Favre[b]
Jean-Sébastien Sottet[ce] Henderik A. Proper[cde]

a. University of Zimbabwe, Zimbabwe
b. University of Grenoble, Grenoble, France
c. Public Research Centre Henri Tudor, Luxembourg, Luxembourg
d. Radboud University Nijmegen, Nijmegen, the Netherlands
e. EE-Team*, Luxembourg, Luxembourg

Abstract
While modelling research typically concentrates on its more technical and formal aspects, this paper provides a case for what we coin *natural modelling*. Modelling has always been and will always remain a human-intensive activity. To be adopted at large, modelling technologies should be perceived as *natural* as possible. In order to characterise what natural means, this paper briefly provides an anthropological and historical perspective on modelling. Constituting per se a first contribution, this retrospective allows to exhibit fundamental modelling concepts, spanning across ages. By looking backwards to understand what was natural (in) modelling in the past, this paper aims to define some elements for what could what *computer-assisted natural modelling* could be in the future. More specifically, it is argued that (1) the need for compromises between flexibility and formality is rather natural than extreme, (2) languages are emergent by their very nature and continuously evolve, and (3) natural interaction with modelling technology should be provided to all stakeholders, as it strongly promotes stakeholders participation. Although these aspects took different forms in historical developments of technology, we argue that the principles are still relevant today, and that these should be considered in the future research. The paper ends with some simple illustrations, which help provide the insight on how computer-assisted natural modelling could look like in a possible future.

Keywords natural modelling, modelling, languages, history, infomation technologies, natural interfaces

*The Enterprise Engineering Team (EE-Team) is a collaboration between Public Research Centre Henri Tudor, Radboud University Nijmegen and HAN University of Applied Sciences (www.ee-team.eu).

Zoe Zarwin, Marija Bjeković, Jean-Marie Favre, Jean-Sébastien Sottet, Henderik A. Proper. *Natural Modelling*. In Journal of Object Technology, vol. 13, no. 3, 2014, pages 4:1–36.
doi:10.5381/jot.2014.13.3.a4

1 INTRODUCTION

In the last decades, the focus of mainstream modelling research has shifted from *modelling methodologies* (e.g. SA/SD, SADT, or Merise in the 70's and 80's; OMT, OOA/D, OOSA, OSE in the 90's) to *modelling languages*, *modelling standards*, (e.g. UML in mid 90's), and finally *modelling technologies* (e.g. EMF, GMF, ATL). Thanks to these recent dedicated efforts, models can now be produced, edited, transformed and managed by computerised modelling technologies in a rather systematic way.

The Model Driven Architecture (MDA) initiative by the OMG [Obj03], and more generally speaking, the area of Model Driven Engineering (MDE) had a rather significant impact: most papers published in the context of MoDELS[1] or ICMT[2] conference deal largely with MDE-related technological developments, associated techniques and standards. This rather techno-centric perspective on modelling is further reinforced by the development of standards such as XMI, MOF and QVT, leading to discussions on how to implement, formalise, integrate, improve, supersede or complement these technologies.

1.1 Two Complementary Perspectives on Modelling

The extensive body of knowledge mentioned above largely concentrates on *the automation of model processing* and associated issues: tool interoperability, standardisation, formal description of modelling languages, model management, etc. In the context of this paper, we will refer to such a focus in the research on modelling as *systematic modelling* or *formal modelling*[3]. It is depicted on the right of the Figure 1.

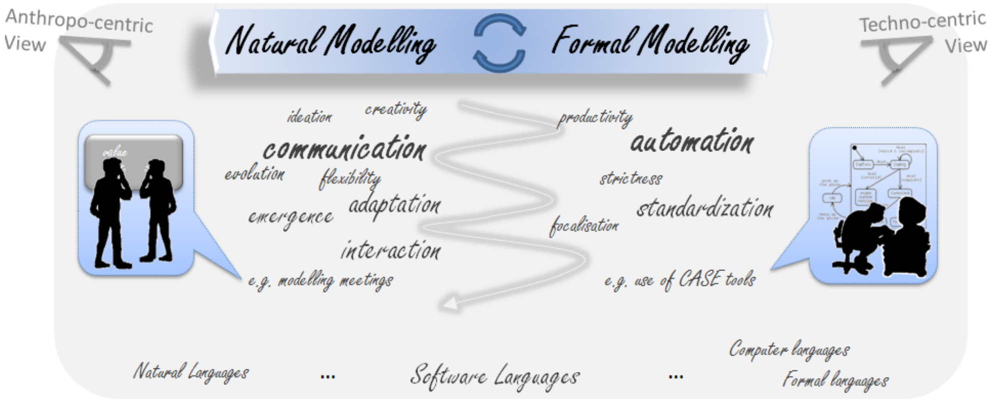


Figure 1 – Modelling and Linguistic Continuum

On the other hand, the actual practice of modelling and rather scarce empirical research on the practise/use of modelling, e.g. [DGR$^+$06, ATAF$^+$10, MLM$^+$13, PS01, SPS07] clearly put forward the utility of models and modelling languages for communication, collaboration and knowledge sharing between the stakeholders. This can be characterised as a rather anthropological perspective on modelling. In this paper, such a perspective is adopted and referred to as *natural modelling* (on the left side of the Figure 1). The paper has the ambition to raise the awareness on the human

[1]International Conference on Model Driven Engineering Languages and Systems
[2]International Conferences on Model Transformation
[3]Note that the term *formal* used here refers to the fact the syntactic-semantic restrictions are enforced on the modelling language, with the ambition to make models amenable to mechanical/-computer manipulation

dimensions immanent to modelling, and to underline the need for their better support by modelling technologies.

At this point, it is important to underline that formal modelling and natural modelling are *not* to be opposed: they are two different yet complementary perspectives on the same modelling world. Although opposing quality attributes are used in the Figure 1 to characterise each perspective, the clear-cut boundary between the two can hardly be drawn in practice. Indeed, natural and formal modelling rather take place in combination and/or alternation. This rather constant interaction between formal modelling and natural modelling is represented by an arrow in the centre of the Figure 1. We suggest that the two perspectives can best be considered within the context of a *modelling and linguistic continuum.*

1.2 Goals of the Paper

As already indicated, the paper draws attention to the need to recognise and better support human aspects of modelling.

The first goal of this paper is to exhibit and ***characterise the very notion of natural modelling****.* In its most general sense, modelling has always been and will always remain a human-intensive activity. While this capability is pervasive and intuitively performed by humans, we are far from fundamentally understanding what actually happens when people model. This paper aims to contribute to a systematic study of the modelling phenomena, by offering a historical and anthropological view of how (natural) modelling came about. We will present the historical evolution of modelling practices, and draw from it some principal characteristics of natural modelling.

The second goal of this paper is to identify the promising ***research directions for computer-assisted natural modelling****.* While formal modelling is well supported with dedicated modelling tools, natural modelling is usually done with the help of paper and eventually (Office-based) drawing tools. This necessitates a lot of redundant work when more informal models transit to more formal tasks (as they have to be 're-entered' in tools) and vice versa (more formal models have to be distilled into 'boxology' to be communicated back to stakeholders). We argue that the modelling continuum should be ensured, and that it is valuable to consider and combine all the technologies able to contribute to it. In addition, inspired by Weiser's vision of "disappearing computer" [Wei91], it is underlined that successful modelling technologies should be as transparent as possible and perceived as *natural* as possible by stakeholders. We hope that such a vision could inspire some fruitful research in modelling technologies.

1.3 Natural Modelling in a Nutshell

The choice of adjective *natural* in natural modelling is meant to refer to (the *two* meanings of *natural* in English):

- *Natural as reference to nature.* Homo sapiens is known as the *symbolic species*, according to the biological anthropologist Deacon [Dea97]. Models are indeed complex symbolic systems, and the *ability* to interpret such systems is bound to the very *nature* of humans and their linguistic abilities. This point is illustrated in the historical retrospective on modelling, showing that modelling was practised already during the Stone Age, in other words, that it is an inherent human capacity.

- *Natural as reference to culture.* According to WordNet, the adjective natural could also mean *"functioning in a normal way ... according to a social norm"*[4]. Hence, what is considered *normal* or *natural* is highly relative and depends a lot on the epoch considered, that is, on a particular *socio-cultural* and *technological setting.* For instance, writing on a piece of paper is considered as a natural activity. While this is true in our modern culture, it was not the case in e.g. medieval times, as writing was not accessible to a wider population. Likewise, at present times, many would consider interaction with HCI of a tablet as a natural way of interacting with machines, while until recently this technology was not widely used, and hence, not considered as natural.

The position of *natural* modelling can thus be condensed in one sentence: the entire cycle of creating and using models should be (instrumented to remain) as intuitive and non-intrusive as possible, with respect to the goals and stakeholders of modelling. More precisely, natural modelling incorporates the following key principles:

- **Collaborative modelling -** Modelling act is a *social act*[5] in which knowledge about the observed phenomena gradually becomes shared between stakeholders (by means of language), and "collective" model becomes a media to drive collective intelligence. Thus, as suggested on the left side of the Figure 1, the key for *natural* modelling consists in facilitating *participation* and enabling *communication* between modelling stakeholders.

- **Natural (symbol) interaction -** Humans intuitively create and interact with modelling (i.e. language) symbols in modelling situations. As most of modelling stakeholders are not experts in modelling techniques, the *interaction with symbols should be as intuitive as possible.*

- **Language flexibility -** While formal modelling assumes that the modelling language used is stable, well-defined and often standardised, in practice in many modelling situations modellers and users invent their own notations, decide to break the rules, introduce new conventions, converge to new modes of modelling, and all this on the fly. In the context of *natural* modelling, we should recognise that *modelling languages emerge, converge, diverge, and evolve naturally.*

These principal characteristics are derived based on our understanding of the evolution of modelling throughout the history. We suggest that these are also the primary dimensions of computer-assisted natural modelling, which will be discussed later in the paper.

1.4 A First Taste of Natural Modelling

Let us give a rough idea of how computer-assisted natural modelling could look like. The example draws on "MIT Sketching" video[6]. The application domain in this

[4] http://http://wordnet.princeton.edu/

[5] From this perspective, the case of an individual modeller, who creates a model for e.g. helping his/her own understanding of some phenomena, is also considered as a social act, though it does not comprise social interaction with other people. It is a social act as it is embedded in the particular socio-cultural setting, which conditions what is e.g. relevant knowledge of the phenomena, the way of representing the knowledge for the goals of modelling, the use of language etc.

[6] http://www.youtube.com/watch?v=NZNTgglPbUA

example is mechanics, but similar demonstrators were built for domains like molecular chemistry or electronics [Dav07]. Two snapshots from the video are presented in the Figure 2.

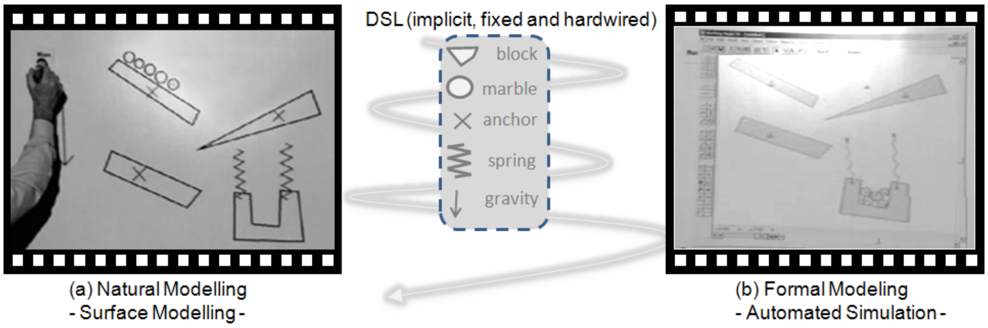


Figure 2 – Surface modelling applied in mechanics

In the first snapshot (a), an initial visual model of a particular physical configuration of blocks, marbles, and springs, has been drawn on a white board. In the background, the drawing is recognised and interpreted in terms of a (domain-specific) modelling language. The model is then further coupled with an existing simulator (or modelling environment dedicated to the domain). Pressing a "Run" button launches a simulation (Figure 2 (b)). According to physical laws, all marbles end in the U bloc attached with springs.

This video indeed constitutes a masterly illustration of a modelling continuum i.e. computer-assisted natural modelling. However, in the concrete scenario, we were only able to observe the single dimension of natural modelling, namely surface modelling. As shown later in the paper, other modes of (natural) interaction with the modelling environment may also be envisioned. Furthermore, collaborative and language flexibility aspects (e.g. viewpoints synchronisation) are not tackled within this example. The scenario uses a fixed domain-specific language, which remains both implicit and hard-wired, and additionally, it does not demonstrate collaborative support for modelling. In order to give a big picture of what natural modelling could look like in a possible future, an extended scenario will be presented further in the paper.

1.5 Outline

The remainder of the paper is structured as follows. The list of relevant modelling fundamentals is given in Section 2, to clarify our position and guide the further reading. Sections 3 and 4 provide the historical retrospective of modelling, elaborating on the rise of rather natural modelling and rather systematic/formal modelling, respectively. Section 5 briefly discusses the challenges and needs of modelling in our current Information Age. Section 6 deals with the characterisation of key natural modelling principles, based on the historical insight, and devises the vision of computer-assisted natural modelling together with its promising research directions. Before concluding the paper, several short examples are provided in Section 7 to give a flavour of computer-assisted natural modelling in the future, and to discuss the challenges of realising such a vision.

2 MODELLING FUNDAMENTALS

In this section, we introduce some fundamental modelling concepts reused throughout the paper. The concepts presented are thus *neither* bound to particular technologies *nor* to particular incarnations in a period of time. They are presented as belonging to three groups (roughly arranged from left to right in the Figure 3): modelling, linguistics and technology fundamentals.

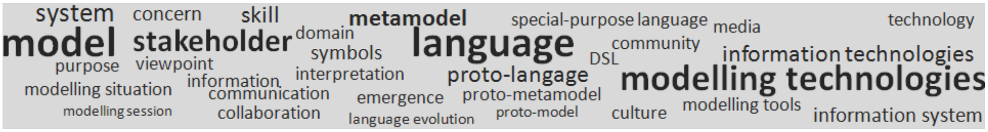


Figure 3 – Fundamental concepts necessary to understand modelling

2.1 Modelling Fundamentals

(A1) A **model** is a (partial) **representation** of a *system* elaborated with a **purpose** in mind. This commonly accepted definition assumes the existence of a relation "RepresentationOf" between the model and the system modelled [7].
(A2) By using models, different **stakeholders** with different **skills** and **concerns** are **collaborating** and sharing **information** in the production, description, exploitation, management of a (typically complex) **system**.
(A3) A model can be produced by one stakeholder and consumed by another stakeholder leading to synchronous or asynchronous **communication** between stakeholders.
(A4) A **modelling situation** is a situation in which one or more stakeholders are engaged in modelling.
(A5) A model is itself a *symbolic system*. The **symbols** that constitute a model can be **interpreted** by the stakeholders according to their ability to understand such symbolic information.

2.2 Linguistic Fundamentals

Modelling is intrinsically bound to the notion of language. Linguistics may indeed be of great use in understanding modelling. Traditionally, in computer science, languages were considered from the perspective of their formal organisation, i.e. mathematical point of view [8]. However, in the context of modelling, it may also be appropriate to seek to understand how languages function and how they are used by people. This is the position embraced in natural modelling.
(A6) According to the formal language theory and traditional computer science, a **language** is seen as set of sentences over a set of symbols.
(A7) From a rather anthropo-centric point of view, and according to e.g. functional and cognitive linguistics, a language is considered as a **social phenomena** involving a **community** of actors. By virtue of the existence of a common language, stakeholders have the ability to communicate, to engage in interactions, to share information, and ultimately to build a common **culture**.
(A8) A language can always be seen as a **system of symbols** governed by some **linguistic rules**. The difference between the two above-mentioned perspectives on

[7] See [Fav04, Fav06] for further discussions on this topic
[8] Consider for instance the body of work related to generative grammars or formal semantics.

language is essentially in their view on how the linguistic rules originate, what they serve for, how they are defined, shared, learned, and/or changed.
(A9) Natural languages do **not** need to be defined or represented explicitly. People in a **community** learn it from each other.
(A10) Languages are dynamic systems. **Language emergence** and **language evolution** are intrinsic properties of languages [Bic92, Dea97, Deu05, Lig06]. This contrasts the popular belief in computer science that (computer) languages do not evolve. Computer languages do evolve too [Fav05].
(A11) Just like languages, **proto-languages** are systems of symbols, characterised by low level of structural sophistication [Cry04], no established linguistic rules, and flexibility and the fluctuation of usage [Lig06].
(A12) Some proto-languages are potentially **emergent languages** that, under certain conditions, could convert over time to full-blown languages within their respective **communities of practice** [Des06, Lig06].
(A13) **Special-purpose languages (SPL)** are languages dedicated to specific concerns, (modelling) situations, communities, stakeholders, or domains of discourse [Cry04].
(A14) SPLs can take different forms including: (1) a sub-language of a general-purpose language (GPL) with potentially a domain-specific vocabulary and particular structural rules (e.g. the language of law), (2) a derivation of an existing language (e.g. the language of SMS, or sea speak for naval communication), (3) a new system of symbols dedicated to a profession (e.g. electronic diagrams or molecular diagrams) or another human activity, etc. There are plenty of other reasons to *adapt* a language, such as: adaptation of the language to a person's skills (e.g. using simplified concepts), or adaptation of the (concrete and abstract) syntax to various media (e.g. adaptation of symbols whether they are displayed on a large screen as icons, or as a few strokes on a black board).
(A15) **Domain-specific languages (DSL)** are particular cases of SPL where the specialisation is due to the **domain** of discourse.

The concepts mentioned above come from the field of Linguistics [Cry04]. More recently, and in a largely independent way, the attention of the modelling community was drawn to the fact that languages have to be **modelled** explicitly. This lead to the (slippery[9]) notion of metamodel. This and related notions may be seen as belonging both to the modelling and linguistic fundamentals.
(A16) A **metamodel** is a **model** of a (modelling) language.[10] As such, a metamodel is a **representation of a modelling language**. To put it even more explicitly, a metamodel is a **(potentially partial) representation** (of potentially any aspect) of a modelling language.
(A17) **Flexibility** denotes the way a language can be used, manipulated or interpreted with a great degree of liberty. A flexible Language is thus adaptable to the concerns it has to address according to a particular modelling situation.
(A18) **Systematisation** characterises the systematic enforcement of linguistic (i.e. syntactic-semantic) rules for producing models, processing or managing them. Systematisation is a pre-requisite to mechanical manipulation of models.
(A19) A metamodel, being a model, is elaborated by one or various stakeholders with particular **concerns** in mind. For instance, to ensure that stakeholders share

[9]While the term *metamodel* was popularised MDE approaches, the etymology of this term and its possible meanings result in a potential confusion. This stems from the several different meanings that the term model has. See [Fav06] for further discussion on this topic.
[10]The fact that a meta-model is a model has a lot of implications.

some common understanding about a language, metamodels can be made explicit and therefore shared.

2.3 Technology Fundamentals

In the following, some key technology-related concepts are discussed in order to explicitly distinguish between the notion of information technology and its incarnations along the history. This is necessary to understand the history of modelling, as well as what (technology) is considered natural at a given point in time.

(A20) **Technology** can be defined most broadly as the entities created by the application of human mental and physical efforts in order to achieve some value. Technology comprises tools, skills, techniques and machines that may be used to solve some problems [11].

(A21) Just like languages, **technologies** are indeed **social constructs** in the sense that for a given technique to be developed, improved, transmitted and adopted at large, the involvement of a sustainable **community** is necessary.

(A22) **Information technology (IT)**, in the general sense, is the technology for producing, representing, storing, retrieving, manipulating and communicating information. Depending on the historical period, we may speak about clay-based information technology, paper-based information technology, and computer-based information technology.

(A23) **Modelling tool** is a tool that allows representing, storing, retrieving, analysing, manipulating and communicating models.

(A24) **Information system** (IS) is a sub-system of an organisational system, comprising the conception of how the communicational and informational aspects of an organisation are composed and how these operate [FHL+98].

(A25) **Computerised information (sub-)system** is a sub-system of an IS, whereby all actions are performed by one or several computers [FHL+98].

3 MODELLING FROM STONE AGE TO MIDDLE AGE

As pointed out by Churchill, "*the farther backward you can look, the farther forward you are likely to see*". Following this advice and in order to gain insights on the future of modelling, we review the history of modelling.

As we shall see, the practice of modelling can indeed be traced back to the Stone Age [Cry04, SB97, Fav06]. We shall illustrate that the very notions of *model* and *language* can be interpreted consistently all along the history of mankind, in particular in the context of successive IT revolutions [Hea00, Gar08]. We also seek to understand which modelling technologies were considered as *natural* enough to cross various epochs. If a concept or a principle has been stable for various millennia, it is likely that we should consider it seriously when planning further research on modelling.

For the sake of this paper, the history of modelling [12] is split in two parts. The current section covers the period going from the Stone Age to the Middle Ages, and, as we shall see, discusses how (natural) modelling emerged. Section 4 is dedicated

[11] `en.wikipeidia.org/wiki/Technology`

[12] Strictly speaking what is provided here is a retrospective in the sense that the events related are interpreted and described using modern concepts and terminology that could otherwise be considered as anachronisms. Just like histories, retrospectives are models of the past established with a given purpose in mind. Here we do not care about precise dates or periods, rather about global trends relevant from the modelling perspective.

to the period from the Modern Age to the Computer Age and illustrates the rise of systematic and formal modelling.

3.1 Modelling in the Palaeolithic

Early prehistory is characterised by (1) the domination of nature over homo sapiens, (2) the emergence of very primitive and multi-modal (proto-)languages, (3) a very limited list of concerns for "stakeholders", basically the survival (finding food and shelter, as well as reproducing).

Sharing information about a particular system, for instance a group of mammoths, was a matter of survival in prehistoric times. Hunting required the collaboration between different stakeholders, and various stakeholders had basically the same concern, finding food. As one could imagine, facing the system (the mammoths) without previous planning was not the best option, and it is likely that, at some point in the history of mankind, homo sapiens realised that exchanging information about the mammoths enabled to plan the attack safely [Dea97]. Although this notion is anachronistic, we can see these as the first *modelling situations*. The question is therefore how they represented the information (i.e. model) in such a context. The precise answer to this question would be speculation, but it is established that language abilities of homo sapiens provided some unique benefits to our species. The biologist and anthropologist Terrence Deacon describes homo sapiens as a "symbolic species" [Dea97], a biological feature that provides us indeed with modelling abilities. Homo sapiens could rely on various modalities of communication/representation to model information.

(a) Spoken Language (b) Body Language (c) Tangible Language (d) Visual Languages

Figure 4 – Modelling in the Stone Age

Spoken languages assign meaning to articulated sounds. Although information encoded with this modality is volatile (see Figure 4.a), "language is mankind's greatest invention - except, of course, that it was never invented" [Deu05]. The origin of language is subject to numerous debates [Dea97, Lig06, Deu05, Bic92, Des06], but in any case language enabled homo sapiens not only (1) to elaborate and discuss much more sophisticated hunting plans, but also (2) to accumulate and capitalise knowledge over generations, thanks to oral transmission, leading to oral cultures.

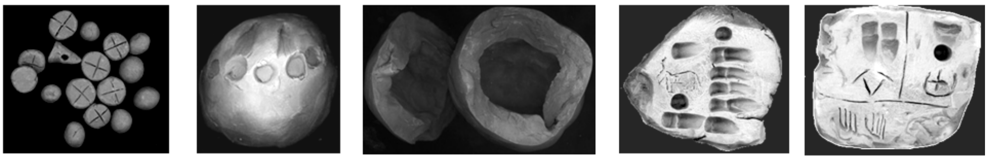
Body languages assign meaning to parts of the body or gestures [Cry04]. Although there is no evidence of that, counting on fingers might be one of the first computing techniques ever invented (see Figure 4.b). Similarly, information about the location of mammoths could have also been signalled in a hunting situation by means of gestures.

Tangible languages assign meaning to 3D objects. For instance, in planning or narrating hunts, a mammoth could have been represented by a leaf or a pebble, hunters by wood pieces or whatever objects at hand. Moving these objects allowed to simulate hypothetical hunting situation or to describe past situations (see Figure 4.c). Such absolutely primitive, yet very natural, modelling technology is a form of transient proto-languages.

Visual languages assign meaning to visual symbols represented typically on a 2D surface. Drawing a map on the floor with visual elements representing the location of animals, rivers, rocks or refuges was a modelling technique certainly in use during the Stone Age. When drawings were realised on the floor or perishable surfaces, no evidence remained. However, we inherited from our symbolic ancestors various examples of maps graved on stones, hand-prints or hunting scenes in the form of cave paintings, etc. The consistent reproduction of some symbols (e.g. male and female genital attributes) suggests some that common rules were probably in place when creating these proto-models on existing surfaces. Visual languages could either be figurative, like cave paintings, or much more abstract, like in the case of notched bones (see Figure 4.d).

3.2 Modelling in the Neolithic

The **emergence and consolidation of proto-writings** [Hou08] is one of the characteristics of the Neolithic period. For instance, proto-writings were materialised by the early Sumerian clay tablets [SB97]. Retrospectively, this could probably be considered as one of the most important contributions in the history of modelling and IT [Hea00, Fav06]. It was indeed the first time that rather unambiguous and precise information representing a system was systematically recorded and stored explicitly on a persistent media [SB97, Jon99, Hou08].



(a) Clay Tokens (b) Token envelopples with external symbols (c) Early clay tablets

Figure 5 – Modelling in the Neolithic

The progressive transition **from tangible modelling to surface-based structured modelling** (depicted from left to right on the Figure 5) is indeed of great interest in the context of this paper. According to archaeological evidence [SB97], the emergence of proto-writings could have resulted from progressive transitions between following steps:

1. The first step corresponds most probably to the repeated use of tangible modelling techniques, relying on ("regular") *pebbles or seeds*. For instance, representing quantities by means of physical objects and making simple arithmetic operations was the basis of computation.

2. In a second step, *clay tokens* of with different shapes and marked with different symbols were created and used (Figure 5.a). It is believed, for instance, that the crosses on some of the clay tokens in Figure 5.a were the symbols of sheep. Indeed, in the Neolithic, the progressive adherence to some conventionalised rules in representing information can be observed.

3. A third step consists in the inclusion of tokens into *envelopes* (Figure 5.b) [Hou08] to ensure model security, and the impression of seals on envelopes to ensure model authenticity [SB97]. These non-functional properties were a major concern for modellers, as envelope's content represented transactions realised in the context of trade.

4. The next step was the transition **from tangible modelling** (e.g. using 3D objects as accounting device, and moving objects to realise operations) **to surface modelling**, i.e. the use of symbols on a surface. At some point, the idea to "flatten" envelops while keeping marks (i.e. symbols) on the surface led to early *clay tablets* (Figure 5.c). We can see a figurative representation of a goat on the left tablet of a Figure 5.c, while the right tablet allows us to observe again the symbol of sheep, as well as a head of cow. In both tablets, conic and circular marks represent numerical information.

5. The following step is due to the increasing complexity of the information to be modelled. It corresponds to the progressive *appearance of structural means* - in the form of e.g. visual compartments dividing available surfaces. While the tablet on the left of Figure 5 just represents a record of "33 goats", the tablet on the right of Figure 5 has three compartments. Two of them represent two records (respectively "4 cows" and "11 sheep"), and the third compartment (below) represents some meta-information about the transaction (the content is unknown for this particular tablet).

6. The need for *more sophisticated conventions both in terms of syntax and semantics* arose from the need to share and exchange models on a large scale and/or to represent more complex information. As a matter of fact, hundreds of records with elaborate structure can be found on the administrative tablets of later periods. Moreover, some basic business rules were added when necessary. For instance, in the area of "business", the sum of quantities recorded on the obverse side of clay tablets had to be written on their reverse [Hou08]).

While going further into the details of this evolution process would not be feasible in this paper, we hope that the short sketch presented above illustrates well (what history can teach us about) the **emergence of proto-languages**. We believe that such emergence processes are very important to understand natural modelling. Fortunately, the **emergence process of proto-writings** has been studied systematically in the recent years, constituting an important body of knowledge [Hou08] to be studied.

The **separation of concerns** and the notion of **stakeholder** can be also traced back to the Neolithic. The domestication of nature led to farming and culture. The possibility of surpluses in food production led in turn to the diversification of human activities (e.g., butcher, weaver, farmer, shoemaker, etc.) and corresponding domains of knowledge, and indeed to the separation of concerns among stakeholders. It is in this social context that IT emerges in the form of **domain-specific proto-writings** to support these various human activities (e.g. trade, work management).

3.3 Modelling in the Antiquity

The invention of written languages is considered as one of the mankind's greatest achievements, as it marks the shift from Prehistory to History [Hea00, HS00, Kra56]. Writing is indeed considered as the pillar of civilisation. In the Prehistory, the size of social groups was estimated to (1) a dozen in Palaeolithic (e.g.̃tribes of hunters-gatherers), and (2) a few hundreds in Neolithic (e.g.̃with settlements and villages). In early Antiquity, this number dramatically increased to (3) thousands and millions in antic cities, city states, kingdoms and empires. The number of participants in social groups matters: oral communication cannot scale up over a certain limit.

This increase in population prepared the context for **the emergence of written languages**.

Written languages arose from the generalisation of proto-writings [Hou08]. While proto-writings typically correspond to domain-specific proto-languages, written languages can be seen as general-purpose modelling languages that can be added to the multi-modal palette of languages.

(a) Roman Abacus (b) Annotated Map (c) Alphabet (d) Scribes recording food supplies

Figure 6 – Modelling in the Antiquity

Increasingly complex ecosystems of stakeholders and concerns characterised first civilisations. Just like in the context of nowadays global organisations, the number of professions and stakeholders increased significantly, with some people being not only affected to the primary and secondary sectors, but also to tertiary one with more and more stakeholders in the service of the state such as laymen, commanders of military forces, accountants, tax collectors, astronomers, land rulers, etc.

Proto-information systems and communication systems were needed to rule kingdoms or empires over time and space. Although not considered as (information) systems per se, states produced an increasing number of models of all kinds including texts of laws, maps, calendars, accounts of all sorts, etc., all these kind of artefacts being represented in a mixture of domain-specific languages and/or general-purpose writings.

Model-based governance was in some sense already practised during the Antiquity. Writing as a management technology was first developed in early civilisations in Egypt, or in the region of Sumer. Following the early use from Neolithic, but this time at the level of states, writing and more generally modelling were applied to new domains of activity, such as land management (for instance, the annotated map combining visual, textual and numerical information on Figure 6.b), food distribution, management of stocks and harvests (see Figure 6.d), laws, poperty management, tax collection, etc. With the appearance of cities and kingdoms, the societies get organised hierarchically. IT of that time became a central element for the management of society, and governing a state required the use of different kind of models.

Model management also appeared from the necessity to deal with the profusion of documents. Various techniques such as colophons or other storage and indexing mechanisms were invented to deal with an increasing numbers of models, but also to establish references between models.

Proto-metamodelling appeared during Antiquity. In order to share and transmit knowledge and rules governing written language, (partial) models of languages, that is metamodels, were realised in the form of glossaries or domain-specific vocabularies. For instance, some clay tablets list systematically the names of professions. Figure 6.c is a reproduction of a metamodel of the ougaritic language. It represents, in the form of a clay tablet, the alphabet of this language, that is the list of symbols that each ougaritic clay tablets should conform to. This example shows that metamodelling is *not* a new concern.

Proto-models of transformation made also their appearance, as transformation rules from one language to another were materialised by multi-language dictionaries, showing, for instance, the translation of words between Sumerian and Akkadian. In the domain of computing, mathematical transformations were also represented explicitly, but only as a catalogue of examples.

Proto-conformance or manual conformance checking was the rule during the Antiquity (this remains the only type of conformance available until the Paper Revolution and Computer Age because no automation was possible. Nowadays, the difference was introduced between manual conformance, tool-supported conformance, conformance by construction, formal conformance and automated conformance [FEB06]). Manual conformance between a model and a metamodel had to be ensured by the scribe producing the model. That was precisely the purpose of the acquisition of writing skills. A famous Sumerian text recalls how pupils' errors during conformance checking were signalled by the school master via a stick [Kra56]. As a matter of fact, if metamodels such as the one presented in Figure 6.c were produced, this was for teaching purposes. The absence of automation and formality could be perfectly compensated by dedicated effort to language acquisition or language transmission. This last aspect is important because proto-languages often characterise the natural modelling landscape.

Tangible modelling remained during the Antiquity a viable alternative to writing and other forms of modelling. This can be observed, for instance, in the field of computing. A roman abacus shown in Figure 6.a is roughly based on the same principles as clay tokens. One of the major differences however is that tokens on the abacus device can be moved only in some ordered manner (this is some form of constrained modelling). While all the tokens have the same shapes, their value changes with respect to their relative position from left to right. Interestingly enough, numerical symbols that were integral part of clay tokens during Neolithic, were written on the top of each column of abacus (as roman numerals). In fact, roman numerals were used to record numbers persistently (thanks to writing) while abacus was used to perform transient calculations. In other words, tangible modelling and writing/surface modelling were used in close combination to deal with the same activity, switching on the fly for one mode of representation to another to solve the problem at hand.

3.4 Modelling in the Middle Age

Various areas of knowledge emerged during the Antiquity and continued their development through the Middle Age. The reader can imagine how the histories of mathematics, cartography, architecture, accounting, or heraldry just to name a few, are full of examples describing the emergence and evolution of **domain-specific languages**.

(a) Heraldry (b) Tangible Computing (c) Written Computing (d) Rethorical Mathematics

Figure 7 – Modelling in the Middle Age

In all the cases, the tension between more formality and more flexibility can be found. In all the fields, the emerging and social nature of languages can be demonstrated (even in the field of Mathematics[13]). In all the cases, the evolution of languages can be linked to socio-technical reasons. Passionate debates between visual or textual languages, highly symbolic versus more concrete languages can be found in many periods in history and across many fields.

4 MODELLING FROM MODERN AGE TO COMPUTER AGE

In the period that roughly covers Modern Age and Computer Age, a progressive rise of systematic and formal modelling can be observed, relating to the progressive technological developments in these periods. We discuss these tendencies within the subsections spanning the Age of Reason (4.1), Paper Age (4.2) and Computer Age (4.3).

4.1 Modelling in the Age of Reason

As shown by Headrick, the period between 1700 and 1850 is characterised by the intellectual development of the "scientific" culture of information systems [Hea00].

Languages of sciences were developed during the Age of Reason. This includes, for instance, Lavoisier's nomenclature and Linnaeus's classification that revolutionised chemistry and biology, respectively, and that are still in use today. When a model is realised in one of these disciplines today, it conforms to the body of knowledge and rules established back then.

Scientific models made their appearance as well. For instance, cartography turned into a scientific activity. Statistics emerged as a way to provide numerical models summarising static or dynamic properties of complex systems. This period is characterised by the intellectual need of systematisation, formalisation and standardisation (Consider for instance the introduction of the metric system as a result of the French revolution.). In the absence of machines and technologies, the automation was not however a direct concern: inventions like the machine of Pascal never found their path to some actual usage.

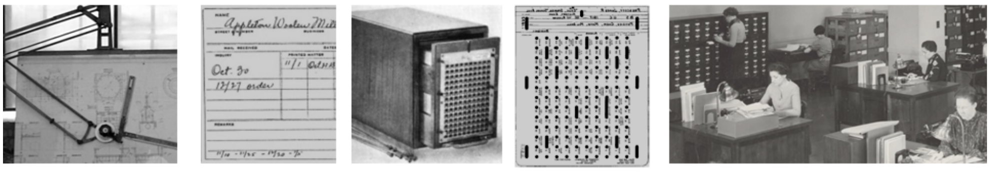
Model-based governance became a requirement for various nations. Ambitious projects involving cartographic and statistical models were developed at the national level and this in the context of international competition. Scientific models such as maps or population census became means of governance. Statistical indicators enabled governments to get better vision of what happened in their countries and take actions when necessary. Model played a central role in this context, because one cannot govern a country without having some representation of what's in it.

4.2 Modelling in the Paper Age

The period (1800-1940) is described by Gardey [Gar08] as the Paper Revolution. Although paper had been used since the 13th century in the Occident, its industrial manufacturing in the 19th century lowered its costs dramatically, increasing its availability and leading to its proliferation into all professional activities.

[13] A very common confusion consists in making no difference between the system denoted by mathematical languages, mathematical objects which are by definition formal, and mathematical languages which are social constructions and are often ambiguous

Paper-based technologies were developed for structuring and managing paper-based models: this includes records, structured forms (Figure 8.b), cards, templates, folders, indexed files with their retrieval mechanisms ((Figure 8.c), punched forms ((Figure 8.d), classification and reproduction techniques, and so on [Gar08].



(a) Technical Drawing (b) Paper Form (c) Indexed File (d) Indexed Form (e) Paper-based Workflow in Offices

Figure 8 – Information technologies during the Antiquity

Paper-based workflows were put in place during this period with a huge impact on information processes in organisations, leading ultimately to systematic processes where models had to transit between offices or departments and be interpreted, transformed and analysed by many stakeholders (see Figure 8.e).

Model systematisation was the condition *sine qua non* for the instrumentation and automation of information processing tasks. Filling forms (Figure 8.b) with a predefined set of fields became the predominant way of representing domain-specific information. The templates governing the structure of these forms played indeed the role of metamodels, whereas the filled forms themselves were structured models. This gave rise to systematic or formal languages.

Semi-structured modelling is one of the characteristics of this period. Interestingly enough, hand writing techniques (with some access to natural languages) were combined with predefined and/or pre-printed techniques. Consider for instance the indexed form depicted in Figure 8.d. The actual content of information is written on the top of the card in textual hand-written form. This is the most *natural* part of the model, while the predefined field represent the *more structured* part of the model. Finally, the holes in the cards just encode some aspects of the information stored in the card, those aspects considered as necessary to automatically retrieve the card. This is the *formal* part of the model that allows the mechanical retrieval of selected forms.

As we can see, the paper revolution truly engenders an IT revolution. The notion of semi-structured information/model, and the need for instrumentation and automation of information management precedes the Computer Age. This instrumentation started with copying machines, address printing machines, automatic cards retrieval, and so on [Gar08], but however "blossomed" with the invention of computer.

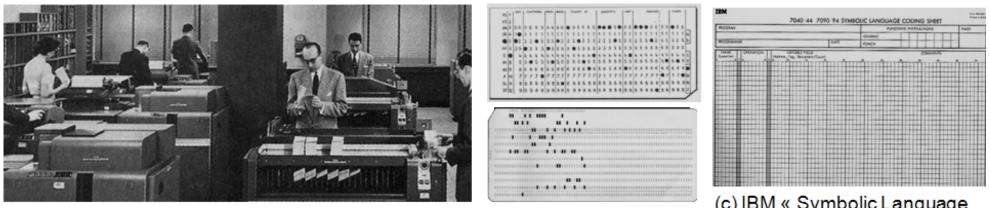
4.3 Modelling in the Computer Age

The Computer Age is characterised by the focus on computerisation, i.e. partial or total automation of human activities, including modelling. This epoch consequently corresponds to the culmination of a rather techno-centric orientation on modelling[14].

One way to delineate the Computer Age is to consider that it starts with the appearance of so-called tabulating machines (Figure 9.a) and the punched cards,

[14]Note that we make an explicit distinction between the Computer Age and the Information Age, discussed independently in the Section 5. The latter is rather characterised by the orientation on information and their value to human actors. As we shall see later, The Information Age demonstrates the emerging need to reconsider the human role with regards to computers, given such an orientation.

which were used to "communicate" with these machines.



(a) Punch-card flow in a typical IBM installation (b) Punch cards (c) IBM « Symbolic Language Coding Sheet »

Figure 9 – Information technologies in the Computer Age

Tabulating machines implemented highly specialised operations, as testified by their names (e.g. adders or sorters). The human operators had the role of bringing the set of cards from one machine to another, so that the operations are realised in the right order.

The information necessary for the realisation of operations was represented in a **highly-structured form** on **punched cards**. This mode of representation corresponds indeed to an extremely restricted and controlled form of surface modelling [15]. Two example punched cards are given in Figure 9.b. At first sight, it seems that there is no difference between these two cards. However, they can be observed at a closer look. The card on the top has some vertical compartments with printed labels that indicate the meaning of the compartments (to humans). Conversely, the card below is an alphanumeric card representing a line of 80 characters. The critical point here is that the textual content that made the most important part of indexed forms (Figure 8.d) from the Paper Age totally vanished on punched cards, due to the focus on automated manipulation of the model. Indeed, on the punched card from the bottom of Figure 9.b, the holes used by the machine are the sole vehicle of information. This is undoubtedly the culminating point of the techno-centric view in the whole history of IT.

Given the **rather narrow focus on computerisation and automation** in this period, we can also see it as a significant shift backward, in the sense that people (aka "operators") and human aspects are backgrounded and put at the "service of machines". For instance, Figure 9.a shows a typical tabulating machine installation, where operators had to go from one machine to another to "feed" these machines and indeed to make the information flow.

Punched cards remained the standard way of representing information, and later computer programs, for a number decades. They were still in use with mainframes in the early eighties. However, in order to make the machine *language* more understandable to humans, and simplify human control over machine programs, **computer languages** were introduced. Contrary to what the literal translation of the term might suggest, these languages are not languages dedicated to computers, but to humans (e.g. programmers). They essentially abstract away from the highly-structured form of machine languages to make them easier to use and understand by humans. However, computer languages remain constrained by the machine capabilities. Consequently, these languages come with a number of *structural and linguistic restrictions*, such as a limited "vocabulary" of predefined machine commands, required use of non-ambiguous sentences, highly structured information, etc.

In addition, the use of a first of such computer languages - *symbolic* language by

[15] As a matter of fact, the term *mécanographie* (mechanical writing) is used in French to designate this technology.

IBM - required that the programs are written on a sheet of paper with a predefined structure called a "symbolic language coding sheet" (Figure 9.c). This can be seen as the pinnacle of the system of forms where all symbols had to be put in an independent cell in order to encode all the information for computers. While the sheet was populated with commands (of a program) by programmers using pens (indeed highly structured surface modelling example), its content (i.e. the program) was then translated into the (holes on the) punched cards, which were used by computers to execute the programs.

With such historical background, it is rather straightforward to understand why computer scientists were focusing on a techno-centric view, where all the constraints come from the needs of mechanical manipulation of information/models.

5 MODELLING IN THE INFORMATION AGE

Our epoch is often referred to as Information Age[16], as it can be characterised by the focus on *information* and its *value* for *all* the *stakeholders* in all the areas of human activity. It roughly started with the widespread use of internet technologies in the economy, which radically transformed the way of doing business, and led to the global information economy. The information became the critical resource in doing business, while the capacities of (effective and efficient) creation, use, and integration of information became crucial for competitiveness of organisations.

Model-based governance of organisations is becoming critical to cope with and master the continuously increasing complexity of modern organisations, and their supporting information systems. Modern-day organisations need to negotiate many challenges, such as the financial crisis, innovations, novel technologies, new business models, global competition, de-monopolisation of markets, deregulation of international trade, etc. Mastering such a complexity of information and business is impossible without models. The developing fields of enterprise architecture [OPW$^+$08], enterprise modelling [Ver96] and enterprise engineering [Die06] all strongly promote the use of models to support transformation and governance of enterprises. In this context, models are used for a wide range of purposes, such as: the analysis of the current situation of the enterprise (Figure 10.c), problems and challenges with regard to the current situation, developing strategy and vision, (re)design of future states of the organisation (and its information systems), knowledge management, stakeholder communication, activity-based costing, [DGR$^+$06, BPS10, ATAF$^+$10] etc.

The increasing system complexity and consequent **growing number of stakeholders** whose stakes and concerns have to be taken into account in organisational governance and informations systems design led to the need for *multi-perspective system specifications* (see Figure 10.b). In traditional information systems development, the need for different perspectives/viewpoints was acknowledged quite early on, for example, in terms of the Multiview [WAA85] approach. In the mid-eighties of the twentieth century, the CRIS Task Group of the IFIP Working Group 8.1 developed similar notions, where stakeholders' *views* were reconciled via appropriate *representations* [OSV82]. These notions also found their way to software engineering [Kru95], information systems architecture, e.g. [Sch86, Zac87], and enterprise

[16]While Computer Age and Information Age are often used to refer to the current period in human history, the latter term is, in our opinion, more suitable and more representative of our times, in particular because it relates to the so-called *information economy*, which is fundamental to understand our modern society.

engineering [Fra02, PHV05, WF07].

The viewpoint coordination [FKN+92] problem raises from the need to relate the models representing system from different perspectives, pretty much like in data and application integration. Historically, the approach to viewpoint coordination was dealt with the assumption that viewpoints of different stakeholders (perspectives) can be predefined and be a priori integrated within a single and *unified* representation of an integrated model (i.e. metamodel) of an information system [OMG03], or the enterprise [LVP+05, Ver02]. From the techno-centric point of view, this is indeed the most effective way to ensure the (semi-)automated manipulation of properties such as inconsistency, integrity, and cross-model analyses. While various techniques and strategies are developed for (technically) dealing with the challenge of model integration, the initial problem of viewpoint coordination is still not fundamentally understood. Indeed, the viewpoints coordination cannot to be reduced to just a technical challenge. What makes this problem even more challenging to deal with in a traditional way is that the *relevant* perspectives of stakeholders for the given organisation are very hard to identify a priori. First of all, the perspectives are highly context-specific [WPW12]. In addition, with the continuously changing environments and challenges for modern organisations, new concerns and therefore new perspectives arise dynamically, and these also have to be taken into account within the (model-based) governance. In our belief, the road to this understanding is paved if we stop equating viewpoints to *just* metamodels. Viewpoints are inherently related to the knowledge and languages of stakeholders, such as practised in their community of practice (see Section 2.), and used to communicate on their view/concern relative to some phenomena. In other words, widening the scope of the viewpoint-related research to the more anthropo-centric perspective and topics may be promising.

(a) Post-it Modelling (b) Multiplicity of viewpoints (c) Modelling Workshop (d) Model-based Governance

Figure 10 – Modelling in the Information Age

This **gradual re-emergence of the more anthropo-centric perspective in modelling research** can indeed be observed. A part of scientific community was working since the 1980-ties on the FRISCO report [FHL+98]. The FRISCO Task Group of the IFIP Working group 8.1 called, in this report, for the different foundations of research on information systems and modelling, stressing their primarily purpose of supporting communication within the organisations. On the continuum of such initiatives, a different understanding of e.g, the act of modelling (e.g., [PVH05, HPW05]), the role of modelling languages (e.g., [Hop03, HW10, BP13]), model and language quality (e.g., [Kro12, BHPW07]), started being developed in the research. What is common to these efforts is that the communication, its processes and effects are put at the centre of interest, and that the utility of models is examined from such a perspective.

On the same line of argument, **domain-specific modelling languages** became very popular both in software engineering [Kle08] and in the area of IS and enterprise modelling [Fra11], as they are adapted to the languages of relevant stakeholders and thus facilitate their understanding of models. While domain-specific languages essentially tune the conceptual basis of the modelling language to the particular domain, it is also argued that the intended audience and usage of models influence the adjusting of syntactical, semantic and notational restrictions of the language/-model [MLM+13, BPS10, BPS12]. From the communication-focused view on modelling, this tuning of the language/model to the modelling purpose at hand is explained as the need to adapt to different goals of (model-based)communication situations [HW10]. For instance, on Figure 5.a and Figure 5.c the stakeholders use specific (non-computerised) models to communicate and share ideas: post-it and white board.

Essentially, this *adaptation* (would)result(s) in purpose-specific variations of original (general-purpose) modelling languages, i.e., in **purpose-specific modelling languages** [BPS12, BSFP13]. For instance, the empirical research in enterprise modelling practice elaborates in detail the need to adapt the model/language to the particular purpose of model(ling), e.g., [BPS10, SP12, ATAF+10]. Within this field, it is not uncommon for researchers to underline that the modelling language is just an instrument and not an end in itself [Fra02, PS01], and that as such it should be flexible to provide for an efficient means of communication.

Hence, while historically modelling languages defined in IS and enterprise engineering were mostly used within the narrow group of modelling techniques experts, and in particular, for the "communication" of models to the (computerised) modelling tools, we observe in this epoch, the inclusion of a much wider and diverse group of stakeholders in modelling. While the modelling experts may be used to the machine-oriented languages and their inherent "way of thinking", it is not reasonable to expect that most stakeholders can easily adapt to such a language.

Given the diversity of purposes and stakeholders of modelling in the context of the transformation and governance of modern organisations, the role of modelling languages and, in general, modelling technologies may need to be reconsidered. As suggested earlier, modelling technologies should be as non-intrusive and intuitive as possible to be successfully used in this context.

6 COMPUTER-ASSISTED NATURAL MODELLING

The previous sections of the paper followed the transformation of modelling practices and associated technologies throughout the history of mankind. Building on the fundamental understanding of the needs underlying this transformation, we identify three basic principles that characterise *natural modelling*.

Collaborative modelling - Modelling is a social act in which knowledge about the observed phenomena gradually becomes shared between stakeholders, and "collective" model becomes a media to drive collective intelligence. The collaborative aspect here implies that these stakeholders, possibly with different skills and concerns, work together in order to define and reach some common goal. Collaboration and constant feedback/evaluation by different parties is necessary to ensure that decisions taken while modelling are agreed to and committed to by all the stakeholders. In this context, it is key to facilitate the *participation* and *communication* between the stakeholders. Models should therefore act as communication enablers, i.e. allow the information to be exchanged and understood between the many stakeholders. The modelling 'system' should be helpful rather than create burdens in expressing and communicating stakeholders' views and concerns.

Natural interaction. This dimension refers to the way of interacting with the modelling environment, and in particular, with the symbols used for representing model. From the natural modelling perspective, the modelling environment as well as modelling symbols (i.e language) would ideally be adapted to the stakeholders and goals of modelling. As most of the modelling stakeholders lack expertise in modelling techniques, the interaction with modelling symbols should be as intuitive as possible. As shown throughout the historical overview, humans were already in the Prehistory using many of such *natural* techniques of interaction. Nowadays, these are studied in the area of Human Computer Interaction (HCI), and mimicked in *natural user interfaces* [Val08]. Introducing natural interfaces in modelling and, specifically, combining them with conventional modelling tools could significantly improve the use and utility of such tools.

Language flexibility. While formal modelling assumes that the modelling language used is stable, well-defined and often standardised, in practice in many modelling situations modellers and users invent their own notations, decide to break the rules, introduce new conventions, converge to new modes of modelling, and all this on the fly. In the first place, we should recognise that modelling languages also emerge and evolve naturally. In the modelling retrospective, it is possible to observe the natural emergence of (modelling) languages, which got established in a lengthy (modelling) process (from proto-language to a full-blown language). It started by intuitive creation of model(s), whose structure got stabilised due to repetitive use in alike modelling situations, remaining however flexible in the use. Interestingly enough, the same pattern of stabilisation of the modelling language through the repetitive use of intuitively created drawings has been observed in modelling experts' practice in [ATAF+10]. Secondly, the need for compromises between natural and formal modelling is rather natural. These views are just the extremes on the modelling continuum, and depending on the modelling situation and purpose. The modelling stakeholders tend to intuitively adapt the language, i.e. choose the right level of linguistic restrictions to be used. This means not only that the flexibility should be incorporated within modelling tools, but more importantly, that the underlying linguistic processes should be studied.

It is obvious that the three defined principles are interrelated. We believe they should be considered in synergy rather than in an isolated way, in order to develop effective and non-intrusive modelling environments. The illustrations given in Section 3 could be considered as examples of such environments, embedded in a particular socio-cultural context, and thus less sophisticated than they can nowadays be. By contrast, the Section 4 illustrates gradual shifting away from the above-mentioned principles, following the predominant focus on systematisation and subsequent (semi-) automation of mechanical manipulation of models.

Having defined these principles, we reflect on how (natural) modelling practices could better be instrumented in the future, using modern technologies. The vast majority of currently existing modelling environments is designed from the technocentric perspective on modelling. As already discussed in the introduction, natural and formal modelling practice are rather complementary and take place in alternation and/or combination. So, a successful modelling technology of the future would need to (do its best to) ensure the modelling continuum (see Figure 1). We indeed believe that the principles of natural modelling indicate the main dimensions of improvement of existing modelling technologies.

This is where the vision of **computer-assisted natural modelling** comes in place. It is inspired by Weiser's vision of "disappearing computers" as "The Computer for the Twenty-First Century" [Wei91]. Weiser suggests that interactive systems should be "hidden" so that stakeholders can interact freely with them. Along these lines, *computer-assisted natural modelling* calls for improving current modelling technologies in two principal directions [17]:

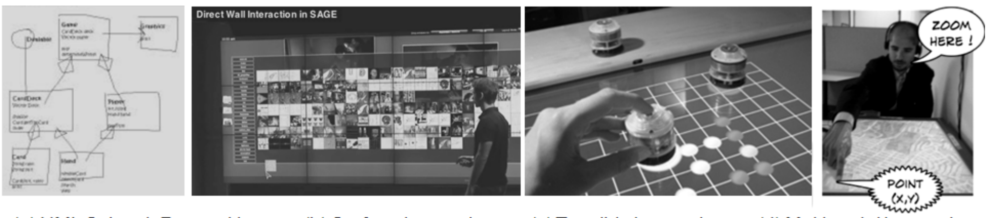
- In terms of support for intuitive (non-intrusive) interaction, communication and knowledge creation in modelling, specifically within stakeholder-intensive modelling tasks.
- in terms of inferring (metamodel), maintaining and manipulating links between models of different levels of formality and completeness.

Clearly, the improvement called for here goes far beyond a mere evolution of modelling tools like EMF or UML. Indeed, the technologies necessary to make this vision a reality are quite sophisticated. As we shall see in the remainder of this section, such technologies are indeed emerging, along with the growing research interest into their application in modelling.

6.1 Natural Interaction in Modelling

If we want to achieve computer-assisted natural modelling, one of the first possibilities is probably to improve the way we interact with models. The *naturalness* of natural modelling consists in assuming that any technology used for modelling should ideally be transparent, i.e. it supports the natural way people interact in modelling situations. The point here consists in "augmenting" (with computer technology) the technology commonly used in modelling situations, such as papers or white boards. This way, we are able to support the most intuitive and the least intrusive way of using modelling technology.

The above-mentioned Weiser's vision has led to development of natural interfaces[18] [Val08]. A wide range of these emerging technologies is currently available, and most of them could be fruitfully used in the context of natural modelling. In this regard, some promising research directions to follow include (but are not limited to):



(a) UML Scketch Recognition (b) Surface interaction (c) Tangible Interaction (d) Multimodal Interaction

Figure 11 – Natural Interfaces for Interactive Modelling

Surface modelling (see Figure 6.1.b) - Looking back in history, modelling using a clay tablet or a piece of paper was one of the classical way to create models. Nowadays, Intelligent Paper techniques [DC98] enable to recognise handmade writings and shapes. Diagram recognition technologies [Lan03], including UML model recognition [LTC00] (see Figure 6.1.a), are also being developed for modelling activities.

[17] We recognise that for realising computer-assisted natural modelling vision, it also required to fundamentally understand the processes underlying human creation and use of languages and models. The present paper discusses however the research directions tackling mostly the technological aspect of this vision, while the previously indicated aspects are subject of another research line in our group, e.g. [LHLM12, WBHH12, BP13].

[18] See http://naturalinteraction.org/ for examples.

Pen-based interfaces can be complemented with direct surface interaction using hands and fingers recognition [LBS85]. On the other side, different modes of interaction on a 2D surface may be complemented with technologies such as Magic Paper [Dav07], which allows models to be used and modified dynamically after recognition. In addition, natural/controlled language processing technologies could be used to enhance natural interaction (e.g. natural MDA [LPCD06]).

Tangible modelling - Just like for homo sapiens of prehistoric times, tangible modelling is a natural act in everyday life: we use objects available at hand during coffee breaks or informal meetings to indicate geographical positions or to narrate more complex modelling stories. Tangible user interfaces [IU97] are based on using a physical(i.e. tangible) object as a representation of the system under study (see Figure 6.1.c). Tangible programming introduced in [Smi09] is an example of tangible modelling. Within modelling, and in particular, business process modelling, this vision has been already explored: tangible modelling contributed to a better embodiment of stakeholders into the modelling activity [LW11].

Multimodal modelling - is inherent in human interaction (see Figure 6.1.d). For instance, describing something consists in pointing at the element (gesture) and providing some oral narration. Our proposition of multimodal modelling takes its root in multimodal user interfaces defined in [Bol80]. This work combines different kinds of interaction such as tactile, vocal or haptic. There are various examples of applying the multi-modality aspect in the modelling research, such as [LN04] for enhancing flexibility or for annotating models [SJNE06].

Multimedia modelling is based on combining the media dimension (which can be either photo, video, audio, etc.) with the time dimension as a complement graphical representation of model. The time dimension is used to depict models as a stream, which can be persisted using multiple means, i.e. video, audio records, etc. For instance, a related research work advocates the use of different media (e.g. video [COB06]) for recording the rationales behind some models.

6.2 Flexible Metamodelling

The techno-centric approaches to modelling rely on a well-defined but also fixed metamodels. However, for non-expert stakeholders, the distance between machine-dedicated languages (strict and fixed metamodels) and natural language is huge. This often causes the burden in stakeholder involvement and model communication, where rather informal models and descriptions are needed [MLM$^+$13]. Furthermore, different modelling situations and goals require different levels of restrictions on models/languages [BPS10, SP12].

The **the lack of flexibility** of the existing modelling languages with this regard is a frequently evoked problem by the modelling practitioners [MLM$^+$13, BPS10, ATAF$^+$10]. For instance, studies [DGR$^+$06, OBA$^+$09] conclude that Visio was far more used than any other modelling tool, since it catered for the needed flexibility in modelling.

Flexibility of modelling languages, as in natural languages, can be discussed at two levels: 1) language emergence, and 2) adaptation of an already existing language.

Emergent metamodels are inferred from the previously (freely) constructed models, in other words, inferring the language structure from examples. This implies the inferring process to be iterative, due to the multiple adaptations (i.e. re-factoring) that could occur in the use. Related idea can be found in [CSGW11], where metamodel is inferred from annotations given on the model; this notion is related to the concept of programming by examples. The inference mechanism can also be doubled by annotations made by the modelling infrastructure experts [SLG12].

Metamodels emergence raises issues (especially when models are collaboratively built) such as incompleteness, uncertainty or conflicts. The conflict resolution problems are notably addressed for EMF in [KNHH10]. Within an metamodel emergence process, some portion may be not clearly or not defined at all. In order to manage this problem, the analysis of the many usages of multiple models constructed by stakeholders is necessary [HRK11]. To remain adapted to a specific use (i.e. not encompassing all the modifications), this approach should also identify in which modelling situation the metamodel is used. Just like ontologies produced independently have to be aligned, metamodel reconciliation and convergence are important topics.

According to [GGLS11], the definition of modelling editors is an important step to achieve flexibility in modelling. While the current state of practice, the creation of full-blown editors may seem too heavy for most stakeholders, the **emergent modelling editors** could allow the reuse of a model syntax (and emerged metamodel) between modelling sessions, without too much initial work.

The **adaptability of the modelling language** refers to the adaptation of an *existing* modelling language to the modelling purpose at hand. In practical modelling situations, general-purpose modelling language is used in different ways with regard to the discipline with which the syntax and semantics of the language are obeyed to [MLM+13]. In our view, this essentially leads to a purpose-specific variation of the same original generic modelling language. The need for purpose-specific tuning of the language for a given communication situation is a rather natural principle, and indeed corresponding to the way humans normally use natural language. In order to support such adaptations, the modelling languages might have to be constructed in a more flexible way.

Finally, all elements (models, metamodels, editors, traceability among models, stakeholders concerns, modelling purpose, language boundaries etc.) that emerge in a modelling ecosystem may be taken into account in the context of an **emergent megamodel**. Through this megamodel, the cartography of languages in their context of use may be represented. Indeed, this (mega)model can also be considered as a *natural model*: all its elements can be manipulated by (natural) interfaces [SCFC09]. To realise this, a number of instruments for modelling language design and integration may be extended and combined. For instance, the instruments may involve: megamodel [BSFP13], viewpoints, metamodel hierarchies [FHL+98], model weaving [BBD+06], etc.

6.3 Collaborative Modelling

Collaborative modelling is a research field on its own. It addresses the complex issue of sharing a common (understanding of a) model where an extensive process of negotiation and gradual model construction is needed. It is of particular interest in situations where stakeholders come from different communities and typically speak different languages, since reaching the agreement on the domain being modelled might be quite challenging [HBP05]. Various tools and methods exists to promote some form of collaborative modelling, notably in the UML community [BMI07] or in language learning [Bas10].

This research field has impact on many different research communities, e.g. in enterprise modelling projects where collaborative and participative modelling is commonly pursued [SPS07, BPS10, Bar09]. Such an approach is considered advantageous for facilitating negotiation and shared understanding, and is also argued key for acceptance and commitment to the decisions taken [BPS10]. In this context, more intuitive interfaces, such as interactive tables and plastic walls [BPS10] are used to encourage sharing of the modelling space amongst stakeholders and to foster interaction and stakeholder involvement. It can thus be easily assumed that natural user interfaces could bring further advantage in such modelling efforts in terms of stakeholder involvement, as some example applications confirm,e.g. [LHN+04, LW11, SSF13].

Collaboration may also be enhanced with the support for language flexibility (Section 6.2). Indeed, this provides more freedom regarding the language to be constructed/adopted, and therefore may more naturally accommodate for the concepts negotiation between stakeholders. Following the idea developed in [KH11], we believe that the flexibility introduced by natural modelling should lower the adoption barrier of modelling.

7 ILLUSTRATION & CHALLENGES

We have seen in the previous section, the requirements for natural modelling: natural user interfaces, flexible modelling and collaborative modelling. The last dimension emphasises the integration of both natural user interfaces and flexibility in modelling. We indeed think that the collaboration is central, which is notably illustrated in augmented meeting rooms [Lah05]. They that capture the collaboratively establish meeting artefacts (such as models, discussions, etc.). In this section, we propose to discuss some of the requirements and challenges for the implementation of computer assisted natural modelling in this context.

7.1 Collaborative, Tangible and Multi-modal Modelling

We want to illustrate, through a simple implementation, the two following questions: How tangible modelling can be implemented to increase stakeholder involvement? Consequently, how can this improve collaboration and communication? To do so, our demonstrator should be able to capture the presence of tangible objects on a table, as well as simple drawings (i.e. basic shapes such as arrows, circles, etc.). A parallel can be made between such tangible modelling environment and tangible language used in Palaeolithic.

Let us assume that this modelling environment is used for support in an augmented meeting room scenario. The meeting environment is, for this purpose, composed of a short table with a video-camera and microphone. In addition, the demonstrator is currently limited to the recognition of simple shapes. Simple shapes (even drawn ones) may not convey, a priori any information about what they should represent, on the contrary to figurines for instance. In the Figure 12 we show, thanks to computer vision technologies [19] the capacity to identify the basic shapes (i.e. tangible objects) present on the "filmed" portion of a meeting table.

The infrastructure allows, during the modelling process, to select [20] a tangible object and associate it with some meaning, i.e. *type semantics*. This association with a specific label (pointing to a type) can be made using either dialogue box (keyboard entry) or voice, thus in a multi-modal way. For instance, on the left side of the

[19] The computer-vision libraries used here are OpenCV (opencv.org) and its Java wrapper JavaCv (/code.google.com/p/javacv/).

[20] Currently this selection is done thanks to a pointing device which is not an optimal solution.

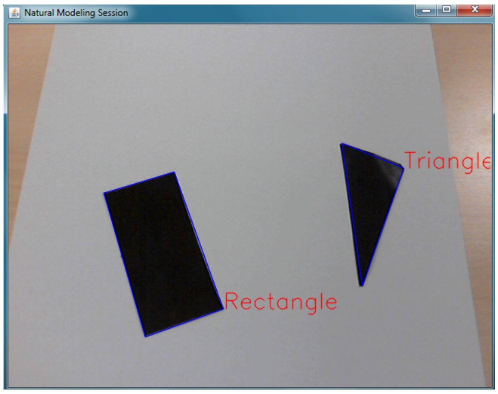


Figure 12 – Simple object (shape) recognition

Figure 13, a stakeholder has pointed the triangle shape to denote a part (saying "part"). For instance, he may want to represent the part of the current component being discussed. In the same way, if the modelling element need multiple parts, anyone (same or another stakeholder) in the meeting is able to take another triangle shape and put in on the table, and this will be automatically be recognised as adding another part to the current model (see Figure 13 on the right side).

7.2 Flexible Modelling Language

7.2.1 Assigning Concepts to Shapes

As a result of the preceding action, the triangular shape is bound to the modelling element called "Part". In other words, an abstract syntax (meta)model element "Part" is attached to the concrete syntax (tangible) model element "Triangle" in the emerging metamodel. In this case, the emergence is reflected in the association of a *symbol* (triangle) with a *type* (part), which have only be introduced within the modelling situation. Emergence processes are by nature very highly dynamic.

Moreover, by assigning the concrete to the abstract syntax element (of a metamodel), the process of emergence, on the fly, of a model editor, as suggested in the Section 6.2. Let us remind of the Figure 13 on the right side, where a stakeholder uses the previously defined (rudimentary) semantics for triangle shapes: the pile of tangible triangles are a kind of model editor "palette". The action of specifying a particular semantic/concept for a given shape is a semiotic action. However, this semiotic association and underlying metamodel is not fixed nor a priori, neither after the association step, since users can always change the type associated to the triangle shape.

The next step may consist in establishing relationships between modelling elements. In order to do so, a stakeholder can use a large pen to draw an arrow on the white paper (see Figure 14).

Assuming that the concepts of "Part" and "Component" ware previously assigned to triangle and rectangle shapes, respectively, the demonstrator recognises the drawing of the arrows and thus, stakeholders can specify on the fly a relation name: "isPartOf" that links up a "Part" and a "Component". Note that at this level, from the user perspective, the objects are clearly linked together by the arrow, but, for the system, the notion of arrow as a link between elements is not *yet* defined. That is, arrows

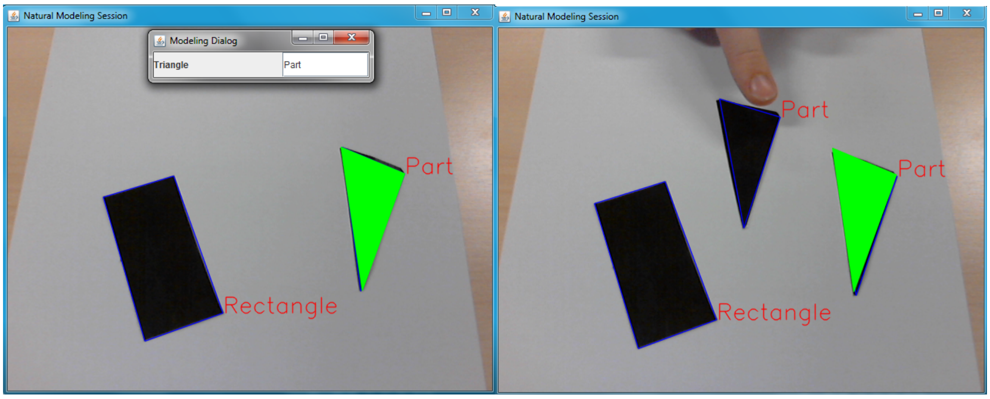


Figure 13 – Dynamically assigning semantic and using factual objects during a meeting: left assigning abstract syntax to triangle. Right using the newly created syntax to construct model

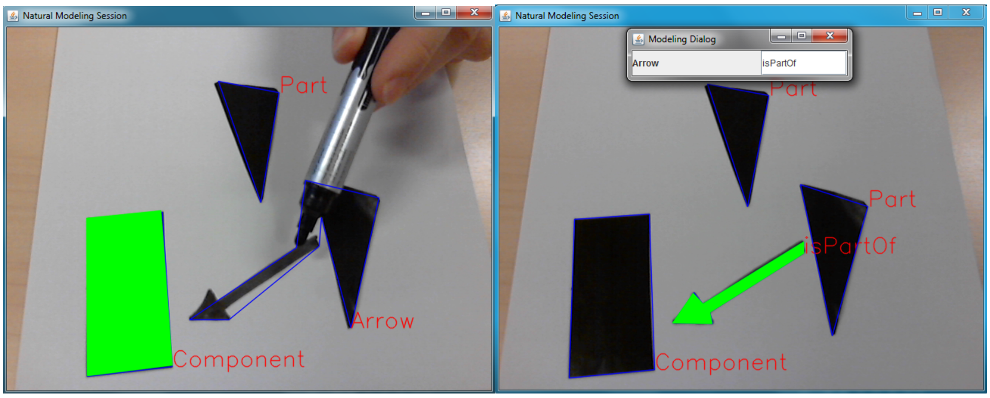


Figure 14 – Using arrow shape to specify relationships

could be just seen as an isolated elements alike rectangle or triangles. There are many solutions to ensure that an arrow recognised as link between elements:

- Fix the behaviour of “arrows” as a binary relationship between elements. This solution will be fixing a priori a behaviour for particular modelling elements (such as the arrow).
- Compute proximity of shapes and propose to the modelling stakeholder to take the middle one as a relationship. For instance with the pattern “arrows” in the middle of a triangle and a rectangle.
- Ask the user or a modelling expert (as expert annotation in [SLG12]) about the possibility of making a particular shape for relation.

The first solution will certainly impose a particular interaction pattern to the modeller. This will certainly reduce the expected flexibility of the provided environment. Similar to the palette used in traditional models editors, it fixes some syntactical constructs. Nevertheless, it gives a better guidance to modellers. Conversely, the two other solutions would leave more control over the emergence process to the stakeholders. Technically, the last one is the most easy to implement and avoids ambiguity (e.g., "proximity" definition of shapes), but assumes the existence of a modelling expert in the modelling session.

7.2.2 Structuring the Concepts

Following the previous example, we here zoom in to illustrate how meta-elements are created and linked together. At the very beginning, there is no (meta)model, only shapes that the system is able to recognise. The "user interface" part of the implemented modelling environment is *not* that flexible, since the set of recognisable shapes are a priori fixed. During the meeting, shapes are linked to a semantic structure (abstract syntax of the modelling language). The stakeholders are thus creating an emergent metamodel with the dialogue-box assignation: linking shapes to concept, or more precisely linking shape to metamodel entities. However, users may also want to start by referencing the name of an instance of the objects. Allowing this option is like addressing the bottom-up metamodel inference as in [CSGW11, SLG12].

In the current demonstrator, we illustrate a mix of both: *flexible metamodel definition* and *emerging structure*. Indeed, we assume that a first modelling step would be to **naturally propose a general meaning to object we manipulate**: i.e. this object/shape represents that concept. Then a particular name can be given to the concept instances, e.g. "this is the left part of the engine". This pre-assignation is like building a metamodel first and then a model later, i.e. a standard MDE approach. The subtle difference is that the metamodel is flexible and allows for inconsistencies between metamodel and models.

In Figure 14 on the right side, all the syntactical elements (the shapes) are assigned to a particular concept. This is reflected in Figure 15, where triangles are assigned to "Part", rectangle to "Component" and arrow to "isPartOf". Let us consider the particular case of the arrow. As discussed previously, one of the solutions to resolve the arrow "isPartOf" as an association is using the proximity of shapes on the table. In that particular case, we use the proximity on the table of the three shapes, two by two: triangle-arrow and arrow-rectangle as shown in Figure 15. However, the current information does not allow to compute the cardinalities. In fact, we need instances to know exactly if one or many (or a predefined number) elements can be linked together, this would emerge later in the process.

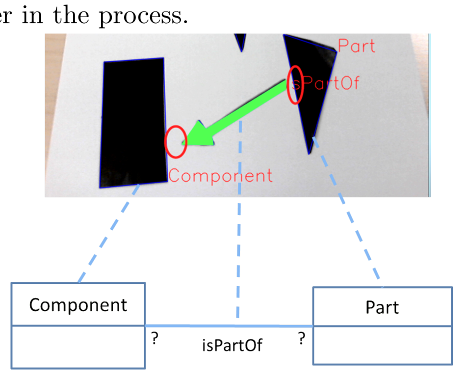


Figure 15 – Dynamic metamodel construction obtained from situation of Figure14

7.3 Discussion

This illustrates a concrete step in the direction of natural modelling, in particular: **tangible**, **multimodal** and **surface** interactions, as well as **metamodel emergence** for dynamic creation (and adaptation/evoloution) of a modelling language. Indeed, such a language composed of simple shapes and drawings (arrows) could be easily shared amongst stakeholders. This implementation does not enforce the complete specification of metamodel, e.g. see the incomplete cardinalities in Figure 15. The complete structure of the metamodel can be established later on in its use, if it is needed (e.g. for computation purpose). As we have seen, when implementing such an environment, all the dimension of natural modelling come together making, namely, the aspect of natural interaction with symbols, intuitiveness of symbols themselves, at the same time with the concept associated with the symbol. This makes it obviously difficult to deal with only a portion of the problem. For instance, the implementation of the recognition mechanism for shapes, limits *de facto* the concrete syntax (in variety) and as a consequence limits the number of concepts (abstract syntax) to be defined. As pointed out by the demonstrator, some specific solutions can be implemented (e.g. to infer the relationships) that may correspond (or not) to different modelling situations (collaborative modelling with or without domain expert, restricting the concrete syntax, etc.). As a result, it is crucial to identify the situation in which the modelling effort is being done and adapt accordingly the computer assistance of natural modelling.

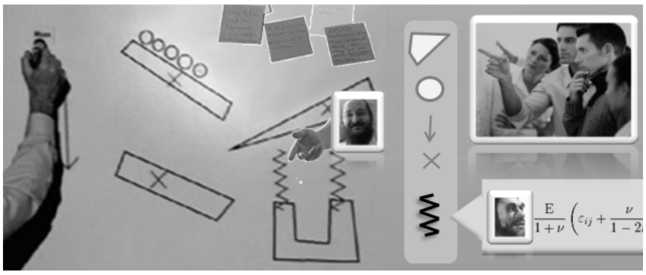


Figure 16 – Ad-hoc Natural Modelling vs. Computer-Assisted Natural Modelling

As an inspiration for the scenario, we propose here an extension of the illustrating scenario discussed in the paper's introduction (see Figure 2). The advanced scenario (Figure 16 on the left) brings together aspects of natural modelling discussed throughout the paper. Consider, for example, that the model is drawn collaboratively on the magic paper [Dav07]. In the modelling session, there are several stakeholders participating remotely. During the session, a remote participant suggests to add the spring to the model. The remote participant draws the symbol of the spring (remotely) to the existing model, which is immediately added to the language (as not yet completed element) and appears on the legend. In order to characterise the spring behaviour, another participant enters the corresponding physical equations of the (elements of the type) spring. On the other side, the group of remote participants (on the right side of the photo) discusses the validity of this model, possibly working on a different, tangible, interface to move the objects and adjust the model accordingly. Theses adjustments are also visible to the other participants. The picture displays the instant where the model is about to be finalised (agreed on), and a local participant leading the session is about to bring life to the model by pressing a "Run" button. As one can expect, the balls will ride down the slope, then fall eventually end their way into the basket. This fictional scenario illustrated some of the possibility of natural modelling and ensuring the modelling continuum using: 1) mix of interactions techniques and remote participation; 2) dynamic and flexible (mega)modelling (including models, metamodels and participants in one visualisation); 3) weaving formal aspect (spring equations) in a natural model.

8 CONCLUSION

Mainstream research in the area of modelling focuses rather on its technical and formal aspects, i.e. on more formal modelling. In this paper, we propose that it is time to consider not only instrumentation and automation of modelling, but also its generalisation and adoption. We should not forget that modelling has always been and will always remain a human-intensive activity. To be adopted at large, modelling technologies should be perceived as *natural* as possible.

In order to characterise what *natural* in this context means, we provided a historical and anthropological perspective on the transformation of modelling practices and related technologies. Relying on this, we characterised the essence of what we coined *natural modelling*. This essence is devised in terms of the following principles: 1) Modelling is mainly a social act, where stakeholders collaboratively create and share knowledge about some observed phenomena using models as a vehicle of communication; 2) People intuitively create and interact with symbols used for representing models, and 3) Languages (systems of symbols) emerge and evolve, in modelling situations, to be adapted at best to the needs of modelling.

Relying on these principles, we discussed how human aspects of modelling could be better instrumented in the future, using modern technologies. In this regard, we underlined that natural and formal modelling (practice) should be fundamentally understood as the two polarities on the same modelling and linguistic continuum. In line with this consideration, we believe that the success of future modelling technologies resides on how well they will be able to support such a continuum. Heavily inspired by the vision of "disappearing computer" [Wei91], we indicated a number of promising research directions in this respect.

The scenarios discussed indicate some of the challenges for fully realising the idea of "disappearing", i.e. fully transparent, technologies in modelling. What is especially challenging in this context is not the very nature of modelling activities that one can envision in the future, but the number of scientific disciplines and techniques that have to be brought together to make modelling technologies appear natural, just as they should be. Indeed, scientific and technical obstacles exist when supporting the linguistic continuum. Notably, natural models should be carefully manipulated since they can be incomplete, inconsistent and may provide an incorrect idea of the problem at hand. When processing such models, (e.g. passing from natural to more formal model) one should be aware of the potential uncertainties resulting from above mentioned issues. We can make the parallel with a situation where formal models are build on top of incorrect specifications: issues remain at the borderline between the humans and the models. Yet, we believe that natural modelling is a promising future. Since the characteristics of homo sapiens have not considerably changed in this regard, and will not change soon, we must adapt computers to our human practices, not the other way around.

References

[ATAF+10] A. Anaby-Tavor, D. Amid, A. Fisher, A. Bercovici, H. Ossher, M. Callery, M. Desmond, S. Krasikov, and I. Simmonds. Insights into Enterprise Conceptual Modeling. *Data Knowl. Eng.*, 69(12):1302–1318, 2010. URL: http://dx.doi.org/10.1016/j.datak.2010.10.003.

[Bar09] J. Barjis. Collaborative, Participative and Interactive Enterprise Modeling. In *ICEIS*, pages 651–662. Springer, 2009. URL: http://dx.doi.org/10.1007/978-3-642-01347-8_54.

[Bas10] M. Basheri. Collaborative Learning of UML-State Diagrams using Multi-Touch Technology. *Durham University*, TR-TEL-10-05, 2010.

[BBD+06] J. Bézivin, S. Bouzitouna, M.D. Del Fabro , M.P. Gervais, F. Jouault, D .S. Kolovos, I. Kurtev, and R.F. Paige. A Canonical Scheme for Model Composition. In *ECMDA-FA*, pages 346–360. Springer, 2006. URL: http://dx.doi.org/10.1007/11787044_26.

[BHPW07] P. van Bommel, S.J.B.A. Hoppenbrouwers, H.A. Proper, and Th.P. van der Weide. QoMo: A Modelling Process Quality Framework based on SEQUAL. In *Proceedings of the EMMSAD'07, held in conjunction with CAiSE'07*, pages 118–127. CEUR Workshop Proceedings, 2007. doi:10.1.1.97.8728.

[Bic92] D. Bickerton. *Language and Species*. University of Chicago Press, 1992.

[BMI07] N. Baghaei, A. Mitrovic, and W. Irwin. Supporting collaborative learning and problem-solving in a constraint-based CSCL environment for UML class diagrams. *International Journal of Computer-Supported Collaborative Learning*, 2(2):159–190, 2007. URL: http://dx.doi.org/10.1007/s11412-007-9018-0.

[Bol80] R. A. Bolt. Put-that-there: Voice and gesture at the graphics interface. In *Proceedings of the 7th annual conference on Computer graphics and interactive techniques*, SIGGRAPH '80, pages 262–270. ACM, 1980. URL: http://doi.acm.org/10.1145/800250.807503, doi:10.1145/800250.807503.

[BP13] M. Bjeković and H.A. Proper. Challenges of modelling landscapes: Pragmatics swept under the carpet? In *Proceedings of the 3rd Int. Symposium on Business Modelling and Software Design*, pages 11–22, 2013. URL: http://www.is-bmsd.org/Documents/ProceedingsOfThirdBMSD.pdf.

[BPS10] J. A. jr. Bubenko, A. Persson, and J. Stirna. An Intentional Perspective on Enterprise Modeling. In Salinesi C., Nurcan S., Souveyet C., and Ralyté J., editors, *An Intentional Perspective on Information Systems Engineering*, pages 215–237. Springer, 2010. doi:10.1007/978-3-642-12544-7_12.

[BPS12] M. Bjeković, H.A. Proper, and J-S. Sottet. Towards a Coherent Enterprise Modelling Landscape. In *PoEM (Short Papers)*, volume 933 of *CEUR Workshop Proceedings*. CEUR-WS.org, 2012. URL: http://ceur-ws.org/Vol-933/pap3.pdf.

[BSFP13] M. Bjeković, J.S. Sottet, J.M. Favre, and H. A. Proper. A framework for natural enterprise modelling. In *Proceeding of the 15th IEEE Conference on Business Informatics*, 2013. `doi:http://dx.doi.org/10.1109/CBI.2013.20`.

[COB06] O. Creighton, M. Ott, and B. Bruegge. Software Cinema-Video-based Requirements Engineering. In *RE*, pages 106–115. IEEE Computer Society, 2006. URL: `http://doi.ieeecomputersociety.org/10.1109/RE.2006.59`.

[Cry04] D. Crystal. *The Cambridge Encyclopedia of the English Language*. Ernst Klett Sprachen, 2004.

[CSGW11] H. Cho, Y. Sun, J. Gray, and J. White. Key challenges for modeling language creation by demonstration. In *ICSE 2011 Workshop on Flexible Modeling Tools, FLEXITOOLS*, 2011.

[Dav07] R. Davis. Magic paper: Sketch-understanding research. *Computer*, 40(9):34–41, 2007. URL: `http://dx.doi.org/10.1109/MC.2007.324`.

[DC98] M. Dymetman and M. Copperman. Intelligent Paper. In *Proceedings of the 7th International Conference on Electronic Publishing*, EP '98/RIDT '98, pages 392–406. Springer, 1998. URL: `http://dl.acm.org/citation.cfm?id=647506.725889`.

[Dea97] T.W. Deacon. *The Symbolic Species: The Co-evolution of Language and the Brain*. W.W. Norton & Company, 1997.

[Des06] J-L. Dessalles. From protolanguage to language: Model of a transition. *Marges linguistiques*, 11:142–152, 2006.

[Deu05] G. Deutscher. *The Unfolding of Language: An Evolutionary Tour of Mankind's Greatest Invention*. Metropolitan Books, 2005.

[DGR+06] I. Davies, P.F. Green, M. Rosemann, M. Indulska, and S. Gallo. How do practitioners use conceptual modeling in practice? *Data Knowl. Eng.*, 58(3):358–380, 2006. URL: `http://dx.doi.org/10.1016/j.datak.2005.07.007`.

[Die06] J.L.G. Dietz. *Enterprise Ontology – Theory and Methodology*. Springer, Berlin, Germany, 2006. `doi:dx.doi.org/10.1007/3-540-33149-2`.

[Fav04] J-M. Favre. Foundations of Meta-Pyramids: Languages vs. Metamodels - Episode II: Story of Thotus the Baboon. In *Language Engineering for Model-Driven Software Development*, Dagstuhl Seminar Proceedings, 2004.

[Fav05] J-M. Favre. Languages evolve too! changing the software time scale. In *IWPSE*, pages 33–44. IEEE Computer Society, 2005. `doi:http://dx.doi.org/10.1109/IWPSE.2005.22`.

[Fav06] J.M. Favre. Megamodelling and Etymology – A Story of Words: From MED to MDE via MODEL in five milleniums. In *Transformation Techniques in Software Engineering*. Schloss Dagstuhl, Germany, 2006.

[FEB06] J.M. Favre, J. Estublier, and M. Blay. Beyond MDA: Model Driven Engineering (L'Ingénierie Dirigée par les Modèles: au-délà du MDA). Technical report, Edition Hermes-Lavoisier, 2006.

[FHL+98] E.D. Falkenberg, W. Hesse, P. Lindgreen, B.E. Nilsson, J.L.H. Oei, C. Rolland, R.K. Stamper, F.J.M. Van Assche, A.A. Verrijn-Stuart, and K. Voss. FRISCO - A Framework of Information System Concepts - The FRISCO Report. Technical report, IFIP WG 8.1 Task Group FRISCO, 1998.

[FKN+92] A. Finkelstein, J. Kramer, B. Nuseibeh, L. Finkelstein, and M. Goedicke. Viewpoints: A Framework for Integrating Multiple Perspectives in System Development. *International Journal of Software Engineering and Knowledge Engineering*, 2(1):31–57, 1992. URL: `http://dx.doi.org/10.1142/S0218194092000038`.

[Fra02] U. Frank. Multi-perspective Enterprise Modeling (MEMO) - Conceptual Framework and Modeling Languages. In *Proceedings of HICSS'02*, volume 3. IEEE, 2002. URL: `http://doi.ieeecomputersociety.org/10.1109/HICSS.2002.993989`.

[Fra11] U. Frank. Some Guidelines for the Conception of Domain-Specific Modelling Languages. In *EMISA Proceedings*, pages 93–106, 2011. URL: `http://subs.emis.de/LNI/Proceedings/Proceedings190/article6461.html`.

[Gar08] D. Gardey. *Ecrire, Calculer, Classer. Comment une révolution de papier a transformé les sociétés contemporaines.1800-1940 2008.* 2008.

[GGLS11] G. Gabrysiak, H. Giese, A. Lüders, and A. Seibel. How Can Metamodels Be Used Flexibly. In *Proceedings of ICSE 2011 Workshop on Flexible Modeling Tools, FLEXITOOLS*, volume 22, 2011.

[HBP05] S.J.B.A. Hoppenbrouwers, A.I. Bleeker, and H.A. Proper. Facing the Conceptual Complexities in Business Domain Modeling. *Computing Letters*, 1(2):59–68, 2005. `doi:10.1163/1574040054861258`.

[Hea00] D.R. Headrick. *When Information Came of Age. Technologies of Knowledge in the Age of Reason and Revolution. 1700-1850.* Oxford University Press, 2000.

[Hop03] S.J.B.A. Hoppenbrouwers. *Freezing Language; Conceptualisation processes in ICT supported organisations.* PhD thesis, University of Nijmegen, Nijmegen, The Netherlands, 2003.

[Hou08] S.D. Houston. *The First Writing: Script Invention as History and Process.* Cambridge University Press, 2008.

[HPW05] S.J.B.A. Hoppenbrouwers, H.A. Proper, and Th.P. van der Weide. A Fundamental View on the Process of Conceptual Modeling. In *ER 2005 Proceedings*, pages 128–143. Springer, 2005. `doi:10.1007/11568322_9`.

[HRK11] M. Herrmannsdoerfer, D. Ratiu, and M. Koegel. Metamodel usage analysis for identifying metamodel improvements. In *Proceedings of the Third international conference on Software language engineering*, SLE'10, pages 62–81, Berlin, Heidelberg, 2011. Springer-Verlag. URL: `http://dl.acm.org/citation.cfm?id=1964571.1964579`.

[HS00] M.E. Hobart and Z.S. Schiffman. *Information ages: Literacy, numeracy, and the computer revolution.* John Hopkins University Press, 2000.

[HW10] S.J.B.A Hoppenbrouwers and I. Wilmont. Focused Conceptualisation: Framing Questioning and Answering in Model-Oriented Dialogue Games. In *PoEM*, pages 190–204. Springer, 2010. URL: http://dx.doi.org/10.1007/978-3-642-16782-9_14.

[IU97] H.U. Ishii and B. Ulmer. Tangible Bits: Towards Seamless Interfaces between People, Bits and Atoms. In *Proceedings of CHI 97 Conference on Human Factors in Computing systems*, pages 22–27, 1997. URL: http://doi.acm.org/10.1145/258549.258715.

[Jon99] C. Jonscher. *The evolution of wired life: From the alphabet to the soul-catcher chip–how information technologies change our world.* Wiley, 1999.

[KH11] D. Kimelman and K. Hirschman. A Spectrum of Flexibility-Lowering Barriers to Modeling Tool Adoption. In *ICSE 2011 Workshop on Flexible Modeling Tools*, 2011.

[Kle08] Anneke Kleppe. *Software Langauge Engineering: Creating Domain-Specific Languages Using Metamodels.* Addison-Wesley, 2008. doi:http://dl.acm.org/citation.cfm?id=1496375.

[KNHH10] M. Koegel, H. Naughton, J. Helming, and M. Herrmannsdoerfer. Collaborative model merging. In *Proceedings of the ACM international conference companion on Object oriented programming systems languages and applications companion*, SPLASH '10, pages 27–34. ACM, 2010. URL: http://doi.acm.org/10.1145/1869542.1869547.

[Kra56] S.N. Kramer. *History begins at Sumer: Thirty-nine firsts in recorded history.* University of Pennsylvania press, 1956.

[Kro12] J. Krogstie. *Model-Based Development and Evolution of Information Systems - A Quality Approach.* Springer, 2012. URL: http://dx.doi.org/10.1007/978-1-4471-2936-3.

[Kru95] P. Kruchten. The 4+1 View Model of Architecture. *IEEE Software*, 12(6):42–50, November 1995. doi:10.1109/52.469759.

[Lah05] S. Lahlou. Cognitive attractors and activity-based design: augmented meeting rooms. In *Proceedings of Human Computer Interaction International*, volume 5, 2005.

[Lan03] E.H. Lank. A Retargetable Framework for Interactive Diagram Recognition. In *Proceedings of the Seventh International Conference on Document Analysis and Recognition*, ICDAR '03, pages 185–189. IEEE, 2003. URL: http://dl.acm.org/citation.cfm?id=938979.939282.

[Lan05] M.M. Lankhorst, editor. *Enterprise Architecture at Work: Modelling, Communication and Analysis.* Springer, Berlin, Germany, 2005.

[LBS85] S.K. Lee, W. Buxton, and K.C. Smith. A multi-touch three dimensional touch-sensitive tablet. In *ACM SIGCHI Bulletin*, volume 16, pages 21–25. ACM, 1985. URL: http://doi.acm.org/10.1145/1165385.317461.

[LHLM12] D. J. T. van der Linden, S.J.B.A. Hoppenbrouwers, A. Lartseva, and W. Molnar. Using Psychometrics to Explicate Personal Ontologies in Enterprise Modeling. *Applied Ontology*, 7:1–15, 2012. URL: http://dx.doi.org/10.3233/AO-2012-0115, doi:10.3233/AO-2012-0115.

[LHN+04] P. Luff, C. Heath, M. Norrie, B. Signer, and P. Herdman. Only touching the surface: creating affinities between digital content and paper. In *Proceedings of the 2004 ACM conference on Computer supported cooperative work*, pages 523–532. ACM, 2004. URL: http://doi.acm.org/10.1145/1031607.1031695.

[Lig06] D. Lightfoot. *How New Languages Emerge.* Cambridge University Press, 2006.

[LN04] K. Lyon and P.J. Nürnberg. Multimodal Modelling Languages to Reduce Visual Overload in UML Diagrams. In *Third Prrogram Visualization Workshop*, 2004. URL: http://www.dcs.warwick.ac.uk/pvw04/p06.pdf.

[LPCD06] L. N. Leal, P. F. Pires, M.L.M. Campos, and F. C. Delicato. Natural MDA: Controlled Natural Language for Action Specifications on Model Driven Development. In *OTM Conferences (1)*, pages 551–568. Springer, 2006. URL: http://dx.doi.org/10.1007/11914853_33.

[LTC00] E. Lank, J.S. Thorley, and S.J.S. Chen. An interactive system for recognizing hand drawn UML diagrams. In *Proceedings of the 2000 conference of the Centre for Advanced Studies on Collaborative research*, pages 7–. IBM Press, 2000. URL: http://dl.acm.org/citation.cfm?id=782034.782041.

[LVP+05] M.M. Lankhorst, L. Van der Torre, H.A. Proper, F. Arbab, F.S. De Boer, and M. Bonsangue. Foundations (of ArchiMate). In Lankhorst [Lan05], pages 47–66.

[LW11] A. Luebbe and M. Weske. Tangible Media in Process Modeling - A Controlled Experiment. In *CAiSE*, pages 283–298, 2011. URL: http://dx.doi.org/10.1007/978-3-642-21640-4_22.

[MLM+13] I. Malavolta, P. Lago, H. Muccini, P. Pelliccione, and A. Tang. What Industry Needs from Architectural Languages: A Survey. *IEEE Trans. Software Eng.*, 39(6):869–891, 2013. URL: http://dx.doi.org/10.1109/TSE.2012.74.

[OBA+09] H. Ossher, R.K.E. Bellamy, D. Amid, A. Anaby-Tavor, M. Callery, M. Desmond, J. de Vries, A. Fisher, T. Frauenhofer, S. Krasikov, I. Simmonds, and C. Swart. Business Insight Toolkit: Flexible Prerequirements Modeling. In *ICSE Companion*, pages 423–424. IEEE, 2009. URL: http://dx.doi.org/10.1109/ICSE-COMPANION.2009.5071043.

[Obj03] Object Management Group. MDA Guide v1.0.1. Technical Report omg/2003-06-01, Object Management Group, June 2003.

[OMG03] OMG. UML 2.0 Superstructure Specification – Final Adopted Specification. Technical Report ptc/03–08–02, August 2003.

[OPW+08] M. Op 't Land, H.A. Proper, M. Waage, J. Cloo, and C. Steghuis. *Enterprise Architecture – Creating Value by Informed Governance.* Enterprise Engineering Series. Springer, 2008.

[OSV82] T.W. Olle, H.G. Sol, and A.A. Verrijn–Stuart, editors. *Information Systems Design Methodologies: A Comparative Review.* North–Holland/IFIP WG8.1, Amsterdam, The Netherlands, 1982.

[PHV05] H.A. Proper, S.J.B.A. Hoppenbrouwers, and G.E. Veldhuijzen van Zanten. Communication of Enterprise Architectures. In Lankhorst [Lan05], pages 67–82.

[PS01] A. Persson and J. Stirna. Why Enterprise Modelling? An Explorative Study into Current Practice. In *CAiSE*, pages 465–468, 2001. URL: `http://dx.doi.org/10.1007/3-540-45341-5_31`.

[PVH05] H.A. Proper, A.A. Verrijn–Stuart, and S.J.B.A. Hoppenbrouwers. Towards Utility–based Selection of Architecture–Modelling Concepts. In *Proceedings of the Second Asia–Pacific Conference on Conceptual Modelling (APCCM2005)*, pages 25–36. Australian Computer Society, 2005. `doi:10.1.1.1.1634`.

[SB97] D. Schmandt-Besserat. *How writing came about.* University of Texas Press, 1997.

[SCFC09] J.S. Sottet, G. Calvary, J.M. Favre, and J. Coutaz. Megamodeling and Metamodel-Driven Engineering for Plastic User Interfaces: MEGA-UI. pages 173–200, 2009. URL: `http://dx.doi.org/10.1007/978-1-84800-907-3_8`.

[Sch86] A.-W. Scheer. *Neue Architektur für EDV-Systeme zur Produktionsplanung und -steuerung.* Institut für Wirtschaftsinformatik im Institut für Empirische Wirtschaftsforschung an der Universität des Saarlandes, Saarbrücken, Germany, 1986. In German.

[SJNE06] W. Scacchi, C. Jensen, J. Noll, and M. Elliott. Multimodal Modeling, Analysis, and Validation of Open Source Software Development Processes. *International Journal of Information Technology and Web Engineering (IJITWE)*, 1(3):49–63, 2006. `doi:10.4018/jitwe.2006070104`.

[SLG12] J. Sánchez-Cuadrado, J. de Lara, and E. Guerra. Bottom-Up Meta-Modelling: An Interactive Approach. In *Model Driven Engineering Languages and Systems, MODELS 2012, Proceedings*, pages 3–19. Springer, 2012. URL: `http://dx.doi.org/10.1007/978-3-642-33666-9_2`.

[Smi09] A.C. Smith. Simple tangible language elements for young children. In *Proceedings of the 8th International Conference on Interaction Design and Children*, pages 288–289. ACM, 2009. URL: `http://doi.acm.org/10.1145/1551788.1551860`.

[SP12] J. Stirna and A. Persson. Purpose Driven Competency Planning for Enterprise Modeling Projects. In *CAiSE*, pages 662–677, 2012. URL: `http://dx.doi.org/10.1007/978-3-642-31095-9_43`.

[SPS07] J. Stirna, A. Persson, and K. Sandkuhl. Participative Enterprise Modeling: Experiences and Recommendations. In *Advanced Information Systems Engineering, 19th International Conference, CAiSE 2007, Proceedings*, pages 546–560. Springer, 2007. `doi:10.1007/978-3-540-72988-4_38`.

[SSF13] C. Stary, W. Schmidt, and A. Fleischmann. Agility based on stakeholder interaction - blending organizational learning with interactive bpm. In *HCI (3)*, pages 456–465, 2013. URL: `http://dx.doi.org/10.1007/978-3-642-39265-8_51`.

[Val08] A. Valli. The design of natural interaction. *Multimedia Tools and Applications*, 38(3):295–305, 2008. URL: `http://dx.doi.org/10.1007/s11042-007-0190-z`.

[Ver96] F.B. Vernadat. *Enterprise Modeling and Integration, Principles and Applications*. Chapman & Hall, London, 1996.

[Ver02] F. Vernadat. UEML: Towards a Unified Enterprise Modelling Language. *International Journal of Production Research*, 40(17):4309–4321, 2002. `doi:10.1080/00207540210159626`.

[WAA85] A.T. Wood–Harper, L. Antill, and D.E. Avison. *Information Systems Definition: The Multiview Approach*. Blackwell, Oxford, United Kingdom, 1985.

[WBHH12] I. Wilmont, E. Barendsen, S.J.B.A Hoppenbrouwers, and S. Hengeveld. Abstract reasoning in collaborative modeling. In *HICSS*, pages 170–179, 2012. URL: `http://dx.doi.org/10.1109/HICSS.2012.88`.

[Wei91] M. Weiser. The computer for the twenty-first century. *Scientific American, September Issue*, pages 94–100, 1991. URL: `http://www.stanford.edu/class/cs344a/papers/computer-for-21-century.pdf`.

[WF07] R. Winter and R. Fischer. Essential Layers, Artifacts, and Dependencies of Enterprise Architecture. *Journal Of Enterprise Architecture*, 3(2):7–18, 2007. `doi:10.1109/EDOCW.2006.33`.

[WPW12] R. Wagter, H.A. Proper, and D. Witte. A Practice-Based Framework for Enterprise Coherence. In *PRET*, pages 77–95, 2012. `doi:http://dx.doi.org/10.1007/978-3-642-31134-5_4`.

[Zac87] J.A. Zachman. A framework for information systems architecture. *IBM Systems Journal*, 26(3), 1987. URL: `http://dx.doi.org/10.1147/sj.263.0276`.