Information quality and uncertainty

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Abstract. The quality of a piece of information depends, among others, on the certainty that can be attached to it, which relates to the degree of confidence that can be put in it. This paper discusses various components to be considered when assessing this certainty level. It shows that they cover a wide range of different types of uncertainty and provide a highly relevant application domain for theoretical questioning about uncertainty modelling. It also describes several frameworks that have been considered for this task.

Keywords: information scoring, information processing, uncertainty type, competence, reliability, plausibility, credibility, linguistic uncertainty

1 Introduction

Information quality (see e.g. [1]) and its implementation in the domain of information evaluation (see e.g. [2]) aim at providing guidance and help to users in the drowning quantity of information they are nowadays overwhelmed with, in particular due to the dramatic increase of Web usage, e.g. through blogs and social networks, such as Facebook and Twitter. One specificity of these new media is that everyone can participate in the information spread and be a source of information, making the question of a relevance measure of the available information crucial. As a consequence, it is necessary to dispose of tools for automatically assessing their quality: there is an acute need for automatic methods to identify the "best", e.g. understood as the most useful, pieces of information.

Numerous criteria and properties have been proposed and considered to to that aim [1, 2]. This paper[1] focuses on the certainty dimension, numerically evaluated as a degree of certainty that can be attached to any piece of information. In a schematic view, it exploits the argument according to which a certain piece of information is worthier than a doubtful one. Insofar, it is related to the task that aims at assessing the trust that can be put in a piece of information. It can be underlined that such a degree of trust can mean either evaluating the reality of the fact the piece of information reports [3–5] or the extent to which the rater

[1] This paper is based on part of the panel which has been organised by Prof. Kovalerchuk at IPMU2012 on the general topic "Uncertainty Modelling"

is convinced, based on the process with which he forms an opinion about this piece of information [6–8].

Even if uncertainty is only one of its components, information quality appears as a highly relevant application framework for the theoretical domain of uncertainty modelling. Indeed, it turns out to be a very challenging one, raising critical requirements that lead to question existing models and possibly to develop new ones. As discussed in this paper, information processing involves several types of uncertainty that must be distinguished, appropriately modelled and possibly combined: information-related uncertainty covers a wide spread spanning over several dimensions. As detailed in the following, one can mention distinctions between objective and subjective uncertainty, as well as between general vs contextual uncertainty.

This paper first discusses various kinds of uncertainty that can be attached to a piece of information in Section 2, organising them according to their cause, i.e. the characteristic of the considered piece of information that triggers them. Section 3 discusses the two axes objective-subjective and general-contextual. Section 4 briefly describes some theoretical frameworks that have been proposed to model uncertainty for information evaluation.

2 Sources of uncertainty in the information processing framework

This section discusses 5 sources of uncertainty that can be considered in the framework of information processing, structuring them according to their cause: it distinguishes the uncertainties respectively triggered by the content of a piece of information, its source, its context, its formulation and its automatic extraction.

In order to illustrate these types, it considers the following fictitious piece of information together with two basic meta-data, namely author and publication date:

On February 15th 2015, the International Olympic Committee declared
"In 2048, the Summer Olympic Games will probably take place in November"

2.1 Content-related uncertainty: what is said?

The degree of uncertainty attached to a piece of information obviously depends on its content, i.e. the answer to the question "what does it say?": for the running example, it for instance relates to the assertion that can be schematically written as "2048 Summer Olympic Games dates = November".

More precisely, the piece of knowledge provided by the considered information can trigger a surprise effect that influences its uncertainty level: an unexpected fact can, at least at first, appear as more uncertain than a known one. The surprise effect can be measured with respect to two types of background, leading to distinguish between the notions of plausibility and credibility.

Knowledge context: plausibility Surprise can be defined as compared to the personal background of the information rater, i.e. as the compatibility of the considered piece of information with his/her knowledge, which is defined as *plausibility* [8].

For instance for the running example, the asserted date may appear highly atypical, in particular to people living in the North hemisphere, who usually do not associate November with summer. As a consequence, they may receive the information with more caution and consider it as more uncertain than people living in the South hemisphere. Along the same lines, for someone with knowledge about the history of the Olympic Games, for instance knowing that the situation where the summer games take place in November already occurred (in 1956, for the Melbourne Games), the fact may appear as less uncertain.

Plausibility can be considered as the first component in the conviction establishing process [8], that determines an *a priori* confidence level attached to a considered piece of information.

Other information context: credibility Surprise can also be defined with respect to other available pieces of information, e.g. other assertions provided in the same period regarding the location and dates of the Olympic Games: in this case, the considered piece of information is compared to other statements, building the *credibility* component [3, 8].

More precisely, the assessment of credibility relies on the identification of corroboration or invalidation of the considered piece of information, defining another type of background for the evaluation of its attached uncertainty. This dimension both depends on the content of the information and the context of its assertion, it is more detailed in the section discussing the latter (Section 2.3).

2.2 Source-related uncertainty: who says it?

The uncertainty attached to an assertion also depends on its source, i.e. the answer to the question "who says it?": for the running example, it for instance relates to the fact that the International Olympic Committee provides it, who can be considered as a qualified source. The question is then to define the characteristics that make a source "qualified", this section discusses some of them, a more complete discussion can be found in [9] for instance.

It must be underlined that, altogether, the qualification of a source is contextual: it may not be the same for all pieces of information and may for instance depend on their topics, i.e. on their contents. However, some of its components remain topic-independent and general.

Source trustworthiness: reliability The reliability of the source corresponds to an *a priori* assessment of its quality, independently of the considered piece of information: it indicates whether, in general, the assertions it provides can be trusted or should be considered with caution.

In the seminal model for information evaluation [3], reliability plays a major role: this model represents the information score as a bi-gram defined as the concatenation of two symbols measured on two discrete graded scales associated to linguistic labels. The first one is called reliability, although it may depend on several distinct dimensions [10]: its explicit and direct presence in the final score underlines its crucial role.

This subjective dimension, that may take different values for different raters, is difficult to define formally and thus to measure. It can be related to the concept of source reputation although the latter may be as difficult to model and quantify. In the case of Twitter sources, it has for instance been proposed to establish it from measurable quantities such as the number of followers or the source social status [11].

Reliability can also be assessed by comparing previous source assertions with the ground truth when the occurrence of events has make it possible to establish whether the source was right or wrong [12, 13]. This approach highlights the fact that reliability is a dynamic concept whose measure should evolve with time. It also relates this dimension to validity [4], according to which if the source produces a piece of information, then the latter is true[2].

Another component of reliability can be derived from the formulation used by the source: the number of citations that are contained in its publications allows to evaluate the extent to which it cites its own sources [14, 15, 9]. Now, offering a possibility to track back the origin of the provided information contributes to its reliability. Another indication can be derived from the amount of grammatical and spelling errors [14, 15, 9]: it is argued that a grammatically mistake-free text advocates for analysis capacity and critical way of thinking, which are desirable qualities for reliable sources. Although these quantities are related to the question "how is it said", discussed in Section 2.4, they capture an uncertainty originated from the source, allowing to infer some of the source characteristics, whereas the components described in Section 2.4 measure uncertainty originated from the expression itself.

Source expertise level: competence A distinct component of source-related uncertainty comes from its competence, that measures the extent to which it is entitled to provide the information, i.e. whether it is legitimated to give it [7, 9]. In the considered example, it can for instance be considered that the IOC is much more competent than a taxi driver would be, leading to a lower uncertainty regarding the date of the 2048 Olympic Games than would occur if the latter provided the information.

Competence relates to the source expertise and appears to be a topic-dependent component: the IOC would be significantly less competent to provide information about the World Football Champions' cup; likewise, the taxi driver would

[2] Conversely, a source is said to be *complete* if, when a piece of information is true, the source provides it [4]. This useful characterisation, related both to the source omniscience and "sharing communication type", is however less central for the assessment of the information uncertainty.

be a legitimate source about efficient routes or traffic jams for instance, leading to less uncertain pieces of information regarding these topics.

It is worth noticing that two types of competence can be distinguished, an essential one and a more accidental one, that respectively apply to experts and witnesses [9]. Indeed, an essential competence can be established from the source fields of study and possibly diplomas, or from official roles: they provide a theoretical expertise and indeed entitle a source to make assertions about a given topic. On the other hand, a geographical or temporal proximity to an event provides an empical competence, granting witnesses a local expertise level.

Source intention The assessment of the certainty degree attached to a piece of information, or the degree of trust put in it, can also depend on source characteristics even more difficult to establish, related to its *intention*: indeed, a source may for instance pursue an aim of desinformation, with the intention to lure the information rater. The certainty degree should obviously be reduced in such a communication paradigm, if it can be recognised as such.

This dimension is related to a *sincerity* feature, which captures the tendency of the source to tell the truth or not (see also [4]): it can be considered that sincerity is a general characteristic of the source, describing its global tendency, whereas its intention is more contextual and varies for each piece of information. Sincerity can be considered as being related to the source reliability, as they both depend on the truth of the source assertions. The notion of sincerity may be seen as integrating a judgment component, that takes into account the source intention when interpreting the reason why it is wrong.

Source implication Another source characteristic is captured by its *commitment degree*, i.e. the extent to which it is involved in the propagation of the information it produces. Commitment depends on what the source may loose if it produces erroneous information, and, insofar, can be seen as related to its reputation.

It has for instance been proposed, in the case of Twitter sources, to measure the commitment degree as a function of the energy they put in their accounts [15, 9], in turn quantified by the richness of their profile, e.g. the number of filled fields or the presence of a picture, or the number of publications.

The source commitment also influences the uncertainty that can be attached to its assertions, under the interpretation that a highly committed source should be less prone to produce erroneous content and may be trusted.

Successive sources: hearsay A specific case for the evaluation of the source of an information occurs when the piece of information is not directly obtained, i.e. when it results from a series of successive sources, following a scheme of the form "S_1 says that S_2 says that ... S_n says that F" where F is the fact and S_i, $i = 1..n$ the sources. Dedicated models have been proposed to process such cases, see e.g. [16, 17].

Indeed, for such pieces of information, all previous source-uncertainty related components are measured not with respect to F (except for S_n) but, for S_i, with respect to "S_{i+1} says that... S_n says that F": competence then for instance measures whether S_i is entitled to report the assertions of S_{i+1}.

2.3 Context-related uncertainty: when is it said?

Another meta-data that influences the certainty attached to a considered piece of information relates to the context of its assertion, undestood as the global answer to the question "when is it said?". Different components can be considered, a purely temporal one as well as a more global one that depends on other available assertions.

Temporal context The date associated to an assertion contributes to the certainty level that can be attached to it, both in comparison with the date of the reported event and with the current date.

Indeed, the gap between the reported event and the assertion influences the uncertainty: information provided too much in advance may be considered with caution, decreasing their certainty level. For instance for the running example, if the assertion is about the Olympic Games in 2084, it may be interpreted as less certain.

On the other hand, a comparison with the current date can influence the importance that should be granted to a considered piece of information: when faced with an information stream, it can be useful to take into account older, and possibly out-of-date, pieces of information to a lesser degree than the more recent ones. It has for instance been proposed to associate each assertion with a currentness score [5], so as to weight down the pieces of information according to their possible obsolescence. It can be underlined that such a model makes the evaluation sensitive to the information order, possibly leading to different results if a piece of information I_1 is published before I_2 or reciprocally. Such a behaviour can be considered as a realistic approach to model the uncertainty evolution when faced with an information stream.

It can be noted that beside these relative date comparisons, with respect to the information content and the current date, an absolute effect can be considered: some dates do bear meaning and influence the evaluation of their content. This component depends on a cultural dimension that makes difficult its general implementation. For instance, one can consider that information produced on April 1st os less certain than others; announcements contained election campaigns may also require a specific processing.

Other assertion context: credibility The evaluation of the uncertainty attached to a piece of information classicaly includes a cross-checking step, aiming at identifying complementary information backing up or undermining it: confirmations and invalidations respectively increase and decrease its certainty level.

The *credibility* dimension can be understood as a degree of confirmation resulting from comparison of the piece of information to be rated with the available information [3, 5, 7, 18].

In the seminal model [3], the second symbol of the bigram measures this confirmation degre, as indicated by the description it are accompanied by. It can be underlined that its inguistic labels mainly describe the information certainty, across the scale *improbable, doubtful, possibly true, probably true, confirmed by other sources*, showing the relation with this underlying essential component.

The principle of credibility evaluation [5, 7] consists in aggregating several assertions, said to be homologous, that refer to the same content. It thus depends on the choice of a similarity measure that measures the degree of confirmation by assessing the extent to which an homologous piece of information corroborates the information to be rated (see e.g. [5] for a discussion on such eligible measures and their components).

The aggregation step can take into account various dimensions, among which the previous degree of confirmation, the individual uncertainty attached to the homologous information [5, 7, 18], but also the relations between the sources [5]: one can consider a refined notion of confirmation and invalidation, weighting them according to affinity or hostility relations between sources. Indeed, a confirmation provided by sources known to be in affinity relation should have a lower influence than a confirmation by independent, not to say hostile, sources: friendly sources are expected to be in agreement and to produce somehow redundant information.

As the temporal component, the credibility dimension makes uncertainty evaluation sensitive to the order of the pieces of information in a stream, taking into account more subtle relations than their publication dates only. This dynamical behaviour, source of many a theory of argumentation, considers that two confirmations followed by an invalidation may lead to a different level of uncertainty than a confirmation followed by a contradiction and another confirmation might [18].

2.4 Formulation-related uncertainty: how is it said?

The words used in a piece of information play a major role on the attached uncertainty level, both because of the imprecision they convey and the uncertainty they intrinsically convey. The additional role of linguistic quality, that influences the assesment of the source reliability, has been discussed in Section 2.2.

Natural language is often imprecise (see e.g. [19]), allowing for fuzziness of the conveyed message, which can lead to uncertainty: if, for instance, the IOC asserts that the 2048 Games will take place "around the end of the year", some uncertainty is attached to the fact that the games will take place in November. In this case, uncertainty arises from the approximate compatibility between the rated piece of information and the query (e.g. regarding the Games date): only a partial answer is available. Such imprecision also plays a role in the identification of homologous information involved in the cross-checking step of credibility assessment discussed in Section 2.3.

Beside imprecision, the used words also convey uncertainty: they give indication regarding the source own level of uncertainty and influence the overall evaluation of the uncertainty [20]. In the case of the considered example for instance, the linguistic expression contains the adverb "probably" whose presence increases the uncertainty of the final evaluation.

Linguistic works (see e.g. [21, 22]) propose classification of uncertainty bearing terms, making it possible to assess the global expressed uncertainty. Such terms include adjectives (such as certain, likely or improbable), modal verbs (e.g. may, might, could, should), adverbs (such as certainly, possibly or undeniably) or complex idiomatic structures. Modifiers such as "very" can be used to reinforce or weaken the previous linguistic tags.

2.5 Automatic processing-related uncertainty: how is it extracted?

A fifth level of uncertainty comes from the fact that the available pieces of information are automatically processed, which can introduce errors in the content identification and thus for many of the components mentioned in the previous sections.

Indeed, the evaluation of the uncertainty attached to a piece of information according to the previously cited dimensions for instance include the use of tools for named entity detection, event and relationship identification and date extraction [22]. They also require to solve difficult linguistic tasks, as negation handling and anaphora resolution, that still are challenges for automatic text processing systems. These uncertainties can be measured automatically, for instance through performance rates of the corresponding methods, i.e. using recognition rate, recall or precision.

Among the examples of the encountered difficulties, one can for instance mention possible errors in the text topic identification, possibly leading to erroneous assessment of the source competence (see Section 2.2). Similarly, the identification of the date in the processed document may result in mistakes in the evaluation of the temporal content (see Section 2.3). The most impacted dimension is probably credibility (Section 2.3), that relies on the extraction of homologous pieces of information, and therefore both on all the documents processing and the computation of their similarities. It can be noticed that this task is sometimes performed semi-automatically, in order to guarantee its quality, crucial for the whole system [5].

3 Uncertainty types for information

Form a formal point of view, the various uncertainty types discussed in the previous section can be classified according to two axes, opposing objective s subjective uncertainties as well as general vs contextual ones.

It can be underlined that the considered uncertainties also differ in their very nature: for instance, some express structural doubts about the phenomena, as content plausibility or recognition rate for instance, whereas the linguistically triggered uncertainty on the other hand captures an imprecision level.

Objective vs subjective uncertainty A first axis discriminating the listed uncertainty types refers to the position of the rater and his/her implication in the evaluation: some of them actually do not depend on the rater and constitutes objective dimensions, whereas others are subjective.

Indeed, the evaluation of the uncertainty triggerend by the automatic processing step for instance is objective and can be automatically measured. Similarly, the evaluation of the degree of confirmation between two pieces of information, i.e. the credibility dimension, does not depend on the rater and is identical for all users.

On the other hand, the plausibility dimension is subjective: it is measured by comparison to the rater's background knowledge and therefore varies from one rater to another. Likewise, most source evaluation criteria can be considered as subjective: for instance, not all users may agree on the competence fields of a given source, nor on its intention.

General vs contextual uncertainty Another discriminating axis refers to the dependence of the dimension to the rated piece of information: some criteria are evaluated generally, *a priori*, i.e. independently of any information, whereas other characterise the considered one.

As an example, the source reliability does not depend on the rated piece of information and similarly applies to all the source assertions. The category of general criteria also involve the evaluation of the uncertainty triggered by automatic processing step, which is measured globally, for all types of information. Similarly, the measure of the formulation-related uncertainty relies on a linguistic modelling of uncertainty expression: the latter is built generally, not for a specific piece of information.

On the other hand, the source competence for instance is topic-dependent and thus varies from one piece of information to the other. In that sense, it is considered to be contextual. Obviously, the content credibility, as well as the temporal dimension, are contextual too.

4 Formal frameworks for information scoring

As discussed in the previous sections, the uncertainty to be considered in the domain of information quality covers different types. As a consequence, distinct formal frameworks have been considered to represent it or some of its components. A central issue is to dispose of aggregation operators to combine the individual uncertainty scores obtained for each considered component. It can be observed that some propositions focus on this aggregation issue, in a multi-criteria aggregation approach, using for instance Choquet integrals [9].

This section briefly discusses the main existing uncertainty modelling frameworks applied to the case of information evaluation, distinguishing them depending on whether they model symbolic, ordered or numerical uncertainties.

Symbolic framework Symbolic approaches in the domain of information evaluation include logical representation, in particular in the framework of modal logics [4, 23–25], that allow to perform logical inferences to characterise the sources and the pieces of information. However, they usually do not model the attached uncertainty.

The first formal framework for information evaluation considering uncertainty has been proposed in the seminal model [3]: it represents the information score as a bi-gram defined as the concatenation of two symbols measured on two discrete graded scales associated to linguistic labels: according to the descriptions they are accompanied by, the first one captures the source reliability and the second one the information credibility. However it has been shown [26, 6, 10] that this symbolic approach raises some difficulties, among others regarding the manipulation and comparison of the obtained scores.

Ordered framework: extended multivalued logic In order to ease the manipulation of uncertainty scores, it has been proposed to exploit an extended multivalued logic framework [27, 8] to model the process of trust building: trust can be defined on a single discrete graded scale, clarified with linguistic labels, improving the legibility of a unique degree with a semantic interpretation. Moreover, this framework is equipped with formal tools to combine the truth degrees through logical operations that generalise conjunction, disjunction or implication, as well as arithmetical ones [28].

The extension [27, 8] of classical multivalued logic consists in introducing an additional degree that allows to distinguish between facts that are 'neither true nor false', i.e. that have a neutral truth value, and facts whose truth values cannot be evaluated: it makes it possible to distinguish between ignorance and neutral knowledge, which is for instance required to distinguish between a source whose reliability is unknown from a source with intermediate reliability.

Numerical frameworks: probability, possibility and evidence Probability theory is one of the most frequent framework used to model uncertainties. In the case of information evaluation, it can for instance naturally be used to quantify the uncertainty related to the extraction process, e.g. to measure error recognition rates of the applied automatic tools. However, many components of information evaluation uncertainty cannot be considered as having a probabilistic nature. Moreover, they need to distinguish between ignorance and uniform distribution, as sketched above, which cannot be implemented in the probabilistic framework. Furthermore, probabilities impose strong axiomatic constraints, restricting the choice of aggregation operators. Finally, probability theory often requires to set *a priori* distributions, which may be a difficult task in the case of information evaluation.

Possibility theory [29] allows to represent the ignorance case separately from the neutral one and offers a wide variety of aggregation operators allowing to model many different behaviours for the combination of the considered uncertainty dimensions. It has for instance be applied to assess the uncertainty that can be attached to an event e, to answer the question “did e take place?”, based on a set of pieces of information, enriching the binary answer yes/no with a confidence level [5].

The theory of belief functions [30] generalises the probability and the possibility theories, offering a very rich expression power. It has been applied to information evaluation in particular to the issues of reported information [26, 16] and source reliability measures[31, 25].

5 Conclusion

This chapter considered the issue of uncertainty in the domain of information evaluation, discussing the various types of uncertainty that can be attached to a piece of information, describing either the event it reports or its intrinsically attached trust. Many components can be distinguished, whose combination build to a complex notion for which several theoretical frameworks have been considered, so as to capture its diverse facets.

Among other topics related to uncertainty in the context of information evaluation, dynamics and validation offer challenging issues opening the way to research directions. The need for modelling the temporal evolution of uncertainty comes from the availability of information streams, beyond the individual pieces of information, as briefly mentioned previously. It also comes from the possible evolution of the general components of the source characteristics: if, for instance, the reliability of a source proves to change over time, it may require to re-evaluate the uncertainty attached to previously assessed pieces of information this source had provided, and, consequently, also to the information they are analogous to.

The issue of validation aims at assessing the quality of the proposed uncertainty models, both regarding the considered components and the chosen formal framework. Now its difficulty comes from the lack of data allowing to perform empirical studies: in the case of real data, it is difficult to dispose of expected scores to which the computed ones can be compared. The use of artificial data raises the challenge of their realistic generation controlling their relevance.

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