Dichotomy – a forgotten ancient principle

György SURJÁN
National Institute for Strategic Health Research Budapest, Hungary

Abstract Dichotomy is an ancient principle of categorisation, where a class is divided into two jointly exhaustive and mutually disjoint categories. The principle as a general requirement was abandoned during the middle. The recent inquiry shows that studying this principle is still worthwhile and in some cases it can be used as a quality assessment tool. The paper presents algorithms that can transform any kind of categorial structures into dichotomy. The resulting representation sometimes can make apparent the problematic parts of the source. Problems often result from stating Is_a relations without differentiating criteria. A simple experiment of dichotomous transformation of the high level categories of the first chapter of ICD was carried out. The problem of "other" and "not elsewhere classified" categories is discussed. Conclusion: we should not strive to build dichotomous structures but sometimes a dichotomous transformation of an existing structure can be helpful to detect critical parts of a system of categories.

Keywords: Dichotomy, categorisation, ontology, quality assessment

Introduction

The principles of classification and formal ontologies first were discussed in detail by ancient philosophers, Plato and Aristotle. At their time one subject of debate was the dichotomy principle. In a strictly dichotomous classification each node has exactly two subclasses that are discriminated by the presence or absence of one definite property. The most famous ancient example of dichotomy is the so called Tree of Porphyry, an example of a strictly dichotomous top down hierarchy. [1] Aristotle himself was not very much in favour of dichotomy. He gave several arguments against dichotomy as a strict rule in one of his work 'De partibus animalium' [2]. In the 16th century Pierre de la Ramée (alias Petrus Ramus) provided a dichotomous system of logics (also called dialectics) [3].

Later on the dichotomy principle was abandoned and the author is not aware of any recent publication in the bio-medical informatics literature that supports this principle. It was recognised that strange structures can result from unreasonable enforcing of dichotomy. However, the aim of this paper is to show that it is still worthwhile to study and can play some role in modern bio-medical terminological systems, at least as a quality assurance tool. We definitely do not propose that current bio-medical terminologies or classifications should be dichotomous.

1 Correspondence: György Surján ESKI Arany J u 6-8 Budapest Hungary 1051 e-mail: surjan.gyorgy@eski.hu
1. Definition of dichotomy and the dichotomous transformation

Dichotomy is splitting up a class into two jointly exhaustive and mutually exclusive subclasses. This means that if B and C are direct subclasses of A, than it is a dichotomous subdivision if

\[ \forall x \text{ instance } (x, A) \iff \text{ instance } (x, B) \lor \text{ instance } (x, C) \]

\[ \forall x \text{ instance } (x, A) \implies \neg(\text{ instance } (x, B) \land \text{ instance } (x, C)) \]

Now we would like to show, that once we represent a hierarchical system of categories in a computer there is no need to decide in advance whether or not the system is dichotomous. This is because any hierarchical system that satisfies the criteria of a directed acyclic graph can be rewritten into a dichotomous form, although a number of new "auxiliary" categories have to be introduced.

Let say we have a tree structure, that has a node \( a \) with a series of subcategories \( a_1, \ldots, a_n \). If \( n > 2 \) the following procedure transforms this graph into a dichotomous structure:

Let us define an auxiliary category, \( a_{1,k} \) that is defined as the union of \( a \) and \( \neg a_1 \).

This will be a subcategory of \( a \) and a super-category of \( a_2 \) to \( a_n \). In this new arrangement \( a \) has two direct subclasses, \( a_1 \) and \( a_{1,k} \). If \( a_1 \) has a differentiating criterion, then the presence or absence of that criterion makes the difference between the two subcategories of \( a \). If \( a_{1,k} \) has more than two subcategories then the same procedure should be repeated iteratively, until the whole structure is transformed to a dichotomous tree. This procedure can be applied to all nodes in a tree, so the whole graph can be transformed into a dichotomous structure. This procedure can be carried out algorithmically and a relatively simple computer program can do it within a predictable time. Therefore whenever there is a need for dichotomy, this can be established 'on the run'.

Let us call the procedure described above dichotomous transformation. Such a transformation preserves all categories and relations of the original structure but creates a number of new categories (what we called auxiliary categories) together with their relations.

Let we take granulocyte as an example. This is a kind of white blood cells that has three types, the so called basophil, eosinophil and neutrophil granulocytes according to staining property of the granules in the cytoplasm. This serves as a clear differentiating criterion for each type of granulocytes.

The transformation can be carried out in three different ways depending on which type we take first (Figure 1). This shows two important drawbacks of dichotomous structures. One is that it is quite accidental that a category appears at a higher or a lower level of the system. The other is that it is also accidental which auxiliary categories appear.
A blind, algorithmic dichotomous transformation of a system however might lead to false dichotomy. Let us take a system as an example that consists of the following categories: 'human', 'male', 'female', 'black' and 'white' (where black and white means human races), 'black male', 'black female', 'white male' and 'white female'. For sake of simplicity not other races are included.

The left side of Figure 2 illustrates a possible arrangement of these categories into a system, where the arrows represent 'Is-a' relations. A blind transformation of this system would lead to a rather fallacious system that is shown on the right side of Figure 2. The auxiliary categories are presented in boxes and the new relations by dotted lines. The fallacy in this arrangement is that 'male' and 'female' are kind of a 'not black' and 'not white' human; and this contradicts with the fact that e.g. 'black male' is a kind of 'black'. So 'black' and 'not black' have common subsumees, and the same holds for 'white' and 'not white'. This fallacy shows that something must be wrong in the original structure. Of course the mistake is that we used more than one differentiating criterion when we divided humans into 'male', 'female', 'black' and 'white' without any notice. We have to put either gender or race on the first level, so we get a consistent classification as shown in Figure 3. Both versions shown in this Figure are accidentally dichotomous, since we have two kinds of gender and also to kinds of race. A soon as we would include a third race, the structure would not be dichotomous any more, but still would be consistent, and each division would be jointly exhaustive and mutually exclusive. It is easy to see, that regardless the number of branches, a dichotomous transformation on such consistent structure always leads to a consistent dichotomy that is free from the fallacies that were shown above.

But if we put gender on the first level, we have to miss 'black' and 'white'; and if we put race first, we lose 'male' and 'female'. So the price of consistency is that we are not able to represent multiple inheritance any more.

2. Dichotomy and multiple inheritance

Multiple inheritance is an evergreen problem. In the age of paper based systems there was a technical constraint: there is no convenient way to represent multiple inheritance in large classifications (large here means that the whole system can not be drawn up on one single sheet). This technical limitation disappeared in the computer age, but later on it was recognised that manual building up poly-hierarchical structures is an error prone practice. Therefore it is often recommended today that ontology engineers should
build mono-hierarchies manually and the missing relations should be computed automatically based on formal definitions of the entities.

Figure 3

The only problem is that the nature of reality does not support this approach: I am male and white at the same time, and there are no obvious rules which of these relations should be asserted manually and which should be computed. But there are also no rules to choose from the options illustrated in Figure 3. More generally speaking: if we try to avoid poly-hierarchy by using strictly one differentiating criterion at each level, then there will be a number of equally justified solutions and we have to make an accidental decision by which some sensible categories (either male-female or black-white) will be lost.

The fallacy of the dichotomous transformation of the structure shown in Figure 2 makes clear that the assertion of Is a relations without specifying the differentiating criterion is risky. That means that if we state that A subsumes B then we always have to tell, what makes B different from A. Doing so, it becomes clear in our example that e.g. 'black human' is different from 'human' due to the restriction on race, while 'female' is different from 'human' due to the restriction on gender. The conclusion is that instead of forcing a taxonomy structure, categories should be defined (e.g. a white male should be defined as a human who has male gender and white race). Building up the taxonomy is then a task that could be left to automated reasoning. Summing up this section, we propose to rephrase the above mentioned recommendation: Assertion of an Is a relation without specifying the differentiating criterion should be avoided. The differentiating criterion, of course, consists of a restricted property and a restriction value. We can not claim that all divisions should be disjoint, because, as we saw, restrictions on different properties often lead to overlapping categories. We can not claim even that categories defined by restrictions on the same property should be disjoint. In case of gender, 'male' and 'female' are apparently disjoint; but there are many other properties for which an entity can have more than one value. E.g. scientific papers can be classified according to their authors. Since several papers are co-authored, a restriction on the 'has_author' property will not lead to disjoint categories.

If the proposed recommendation is followed, the dichotomous transformation is always possible without resulting fallacious structures. Instead of the described blind method, we can transform such systems into a decision tree forming a YES/NO question from each property (E.g. "Is this human a female?" or "Is this paper authored by Surján?"). Each possible value of each restricted property should be transformed to such a question. The series of all questions forms a dichotomous tree. Since categorial structures rarely contain all possible combinations, some of the questions could be skipped depending on the answer to previous questions.
3. Dichotomy principle as a quality assessment tool, an experiment with ICD

The above described method of dichotomous transformation can be used as a quality assessment tool, since if a system contains ill-defined categories, the transformation fails or result in inconsistency. We tested this on the upper level categories of the first chapter of ICD 10 (Certain infectious and parasitic diseases). Some parts of the chapter that are not infections were intentionally omitted. The result of this manual transformation is shown in Figure 4. If one goes through the questions, sooner or later one arrives at a code range or section (e.g. A80-A89) that can be considered as a root of another tree recursively; by moving along the branches of such a sub-tree one can finally arrive at a definite three digit category of ICD. (Again in turn the three digit code can be seen as the root of a third level tree that leads to four-digit codes). Wherever there is a (!) mark in the figure, there is some serious problem with the approach.

At the first line the problem is that the title of the 1st chapter in ICD is not "Infectious diseases" but 'Certain infectious and parasitic diseases', revealing the fact, that there are infections in other chapters also. See also A20-A28: certain zoonotic diseases. In case of spirochete and Chlamydia infections the word 'other' refers to the fact that again some of these infections belong to other parts of the system.

<table>
<thead>
<tr>
<th>Question</th>
<th>Code Range</th>
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<tbody>
<tr>
<td>Is infectious (?): (N) go to the next chapter</td>
<td></td>
</tr>
<tr>
<td>(1) Is intema? (Y) go to A00-A09</td>
<td></td>
</tr>
<tr>
<td>(2) Is tubercle? (Y) go to A15-A19</td>
<td></td>
</tr>
<tr>
<td>(3) Is zoontic? (Y) go to A20-A22</td>
<td></td>
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<tr>
<td>(4) Is bacterial? (Y) go to A30-A39</td>
<td></td>
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<tr>
<td>(5) Is venereal? (Y) go to A50-A54</td>
<td></td>
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<tr>
<td>(6) Is (other) spirochetal disease? (Y) go to A65-A69</td>
<td></td>
</tr>
<tr>
<td>(7) Is (other) disease caused by chlamydia? (Y) go to A70-A74</td>
<td></td>
</tr>
<tr>
<td>(8) Is caused by loddmata? (Y) go to A75-A79</td>
<td></td>
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<tr>
<td>(9) Is viral?</td>
<td></td>
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<tr>
<td>(10) Is infection of the central nervor system? (Y) go to A80-A89</td>
<td></td>
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<tr>
<td>(11) Is arthropod-borne or haemotogic fever? (Y) go to A90-A99</td>
<td></td>
</tr>
<tr>
<td>(12) Is characterized by skin, mucous membrane lesions? (Y) go to B00-B09</td>
<td></td>
</tr>
<tr>
<td>(13) Is hepatitis? (Y) go to B15-B19</td>
<td></td>
</tr>
<tr>
<td>(14) Is HIV infections? (Y) go to B20-24</td>
<td></td>
</tr>
<tr>
<td>(15) go to B25-B34</td>
<td></td>
</tr>
<tr>
<td>(16) Is mycotic? (Y) go to B35-B49</td>
<td></td>
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<tr>
<td>(17) Is caused by protozoa? (Y) go to B50-B64</td>
<td></td>
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<tr>
<td>(18) Is caused by helminths? (Y) go to B65-B68</td>
<td></td>
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<tr>
<td>(19) Is it an infectin? (Y) go to B85-B88</td>
<td></td>
</tr>
<tr>
<td>(20) Is it parasitic disease? (Y) B99</td>
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</tbody>
</table>

There is an implicit rule here that should be followed. Once we arrive to a section and go through the corresponding sub-tree, it may happen that none of the questions in the sub-tree is answered positively. Then we ought to return to the first level, and continue. But in case of the sexually transmitted diseases, before we could return to the upper level, we find A48 'Other bacterial diseases not elsewhere classified'. This means, that if we got a YES to the question 'Is bacterial' and arrive to A48, this branch should be first skipped, all other possibilities have to be investigated and only if all other
questions get NO, can we return and use A48. Similar problem would rise in many of
“not elsewhere classified” categories since they have no definite semantics: not being
classified elsewhere is not an intrinsic property of an entity, rather a feature of a given
classification. What we can add to this based on the above described experience with
dichotomous transformation, that these categories can make any decision algorithm
rather difficult.

4. Conclusions

The dichotomy principle was an idea of some ancient philosophers, and there was no
reason to maintain it over centuries. In the computer era there is no reason to follow the
dichotomy principle when designing a terminological system, since it would be not
convenient in many cases. Whenever it is needed it is possible to convert any tree
structure into a dichotomous tree. Even lattice structures – if all entities have well
defined differentiating criteria – can be transformed into dichotomous decision trees.
However the dichotomy principle is something that is still worthwhile to keep in mind,
as something that can be useful in testing and improving quality of classifications and
ontologies. Quality management is a hot issue in this field even today [6] and in respect
of newly developed systems [7], [8]. This is what gives still relevance to the dichotomy
principle even today. This study of dichotomy has shown that stating Is_a relations
between categories without defining the restricted property of the subsumed category is
something that should be avoided, because mixing up restrictions on different
properties might lead to errors.

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