DISCOVERY OF THE CAUSES OF SCURVY: Could Artificial Intelligence have saved a few centuries?

Vincent Corruble **Jean-Gabriel Ganascia**

LAFORIA-IBP,
Université Paris VI
4, Place Jussieu - Boite 169
F-75252 PARIS Cedex 05
FRANCE
Tel. (33-1) 44.27.37.27
Fax. (33-1) 44.27.70.00
email: corruble@laforia.ibp.fr email: ganascia@laforia.ibp.fr

ABSTRACT:

Historical observations of cases of scurvy have been collected in the medical literature and given as inputs to the symbolic induction system CHARADE. The rules which were produced by the system simulate well the explanation given to scurvy in the 17th and 18th centuries. However, the results tend to show the importance of the implicit knowledge of the scientists, or their induction bias, to explain the problems they had to perceive the real cause of scurvy.

Introduction

Machine discovery is a growing field of Artificial Intelligence. Depending on the authors, it aims at replacing the researcher in a specific scientific field, usually well-defined and formalized, like mathematics, physics and chemistry [ZYTKOW, 1990], or at simulating the discovery process in order to get a better understanding of its mechanism [THAGART and NOWAK, 1989]. An important community has developed, which is interested in applying machine discovery to databases [PIATESTKY-SHAPIRO, G. and FRAWLEY W. J., 1991]

In the work presented here, inductive learning is used as an exploration tool in medicine. The field of medicine has been the subject of a great deal of AI work in the past twenty years, producing numerous expert systems, like MYCIN [SHORTLIFFE, E.H. 1976]. On the other hand, to our knowledge, the area of medical *research* has been relatively ignored by the machine discovery community, which by itself makes our contribution an original one. However, our main concern is more related to the role of induction in scientific discovery in general, rather than just in the applications to medicine.

The main turning point in the history of medicine [FOUCAULT, 1963] is indeed its development as a clinical science, i.e., a science favoring direct observations, and inductive reasoning. We think that the lack of good inductive tools to simulate this kind of reasoning provides an explanation for the absence of work in medical machine discovery. The new induction tool that we have used is particularly adapted to symbolic or qualitative induction, and has therefore been of great help to overcome this difficulty.

Also, the research in AI and machine learning tells us that, to be efficient, inductive reasoning must be guided by some domain knowledge when the search space becomes too large. In a field like medicine, it appears that a large part of this knowledge is implicit, and can therefore lead to wrong conclusions and hide the truth. The work presented here illustrates this kind of phenomenon, and this constitutes the main result of our research.

A brief history of the discovery of the causes of scurvy is first given in part A. Then, part B presents an attempt to simulate the inductive reasoning done by 17th and 18th century physicians, using modern inductive techniques of Artificial Intelligence. Historical observations of cases of scurvy have been collected in the medical literature and given as inputs to the symbolic induction system CHARADE. The rules which were produced by the system are relatively similar to the possible explanations given to scurvy in the 17th and 18th centuries. However, physicians had strong difficulties to perceive and understand the real causes of scurvy. As seen in part C, our results tend to show the importance of the implicit knowledge of the scientists, or their induction bias, to explain these difficulties.

A/ A brief history of scurvy.

Scurvy has been the cause of over a million of deaths aboard commercial and navy ships, and also on land, though on a lesser extent [BARKER, 1992] [RODDIS, 1951]. The disease took an increased importance in the 15th century, with the development of long circumnavigations [CARPENTER, 1986], and also in the 17th and 18th century, with the development of long missions in the navies, with numerous seamen involved. It is particularly striking that scurvy is said to have caused more deaths in the French navy than the British and Spanish navies together.

As a direct consequence, the research on the causes of scurvy attracted the brightest minds of the time. Among them, James Lind is famous for his remarkable Treatise of the Scurvy [LIND, 1753]. From the 17th to the 20th century (when the actual cause, i.e., the lack of vitamin C, was discovered), dozens of theories were elaborated on the origins of the disease. Many of these were totally disconnected from the real cause, like for example those referring to the psychological effect of being at sea, far away from home. Other theories were quite close from finding the real cause, especially the one that became widely accepted, which said that scurvy was the result of the conjunction of the humidity in the air and of the lack of fresh fruits and vegetables in the diet.

The lack of fresh fruits and vegetables was eventually accepted as the only cause of scurvy in the early 20th century. A first explanation for this late discovery is the lack of a concept necessary to a global understanding of the disease. The concept of vitamin, i.e., the idea of a small quantity of a chemical which has a great influence on the functioning of the human body, is a key to the comprehension of the mechanism leading to the scurvy. However, knowing that seamen were acquainted with the importance of fresh fruits and vegetables as early as the 15th century, it is surprising to realize that a practical cure was not widely accepted earlier. To put it into some more formal terms, though the lack of an *explanatory adequate theory* of the scurvy is easily understandable by the need for a new concept, the reason of the absence of a *descriptively adequate theory* (i.e., a theory establishing only the conditions of development of the disease) seems unclear.

This last question is a good motivation to try modern induction techniques coming from AI research on the kind of data that was used until the end of the 19th century. This attempt is described in the following sections.

B/ Automated induction on scurvy cases.

1) Data collection.

In order to give to our work a real simulation value, it has been necessary to use as training examples cases descriptions that were as close as possible to the description that were made before the discovery of the causes of scurvy. Therefore, the examples used all come from the 1880 *Dictionnaire des Sciences Médicales*, which provides relatively detailed descriptions of 25 cases of scurvy. During the unavoidable translation of these natural language descriptions into the description language of the machine, a main objective was to remain as close as possible to the original, without modifying the description using our own knowledge of the disease, or the desired results of the induction.

Ten features which constitute the description language given to the induction system were found in most cases. They are summarized in Figure 1. Beside the date and location of the case, they include the temperature, the humidity in the air, the hygiene level, the quantity of food, its variety, the use or absence of fresh fruits and vegetables, the type of location (at sea or on land), and finally the severity of the disease. Each of these attributes is defined by a type (set, hierarchy, ordered, integers, etc.) and domain, thus enabling the induction process to take full advantage of the structure of the data. Also, the induction system used does not require a value for each attribute in each case, so that missing values did not have to be filled with estimates. Examples of training cases will be given in the following sections but it is necessary to first give some details on the induction system which has been used.

Attribute	Type	Domain
year	integer	NA
location	string	NA
temperature	ordered set	severe-cold < cold < average < hot < very-hot
humidity	ordered set	low < high < very-high
food-quantity	ordered set	starvation < severe-restrictions < restrictions < OK
food-variety	ordered set	low < average < high
hygiene	ordered set	very-bad < bad < average < good < very-good
type-of-location	unordered set	land, sea
fresh_fruits/vegetables	boolean	yes, no
affection-severity	integer interval	[0,5]

Figure 1: List of attributes with their characteristics

2) The Induction System CHARADE

CHARADE [GANASCIA, 1987, 1991] is a symbolic induction system which extracts logical rules expressing empirical regularities between attributes in a set of examples. The aim of this paper is not to explain the theory of CHARADE. People interested are invited to refer to the previous papers to obtain more details. However, some interesting features of CHARADE are highlighted in this section.

One of the main advantages of this system is to have most of the induction bias explicit. CHARADE takes as inputs a language description which defines all attributes, their type (unordered set, ordered set, hierarchies, etc.), and their domain. Another input is the set of training examples. Also, a feature of particular interest here is the possibility of formalizing some domain knowledge using axioms. This knowledge (entered as IF-THEN rules), as well as some built-in general knowledge about the types of attributes, is taken into account during a first phase named saturation. This phase is used to enrich the description of each training case, as illustrated on Fig. 2 with example 6 from the database.

The induction in itself takes advantage of the lattice structure of the search space to produce all the logical IF-THEN rules that can be expressed with some conjunctions of elements of the descriptions. The default option is to only produce the rules that do not have any exceptions: a rule does not need to cover[1] all the examples to be produced, but if at least

[1]We say that a rule covers an example when all the premises of the rule are matched by the description of the example. An example contradicts the rule if and only if the previous is true *and* the conclusion of the rule is not matched by the description of the example.

one of the examples contradicts the rule, it will not be produced. There is also a "statistical" option which produces rules that have exceptions, but it has not been used in this study. Globally, the induction process has some similarities with more classical ones like ID3. They can all be classified as top-down Induction Systems, since they search for more and more specific rules (by generating new nodes in ID3, and by exploring new layers in CHARADE). The main difference is that CHARADE does not restrict its exploration to a tree structure. Even if a training case has been successfully classified by a previous rule, it will continue searching for other rules for this example. The "classify-and-forget" aspect of the induction done by ID3 is therefore avoided, at the cost of a greater complexity for the exploration. But this makes CHARADE's induction more open, and openness is exactly the kind of feature we are interested in to discover new knowledge.

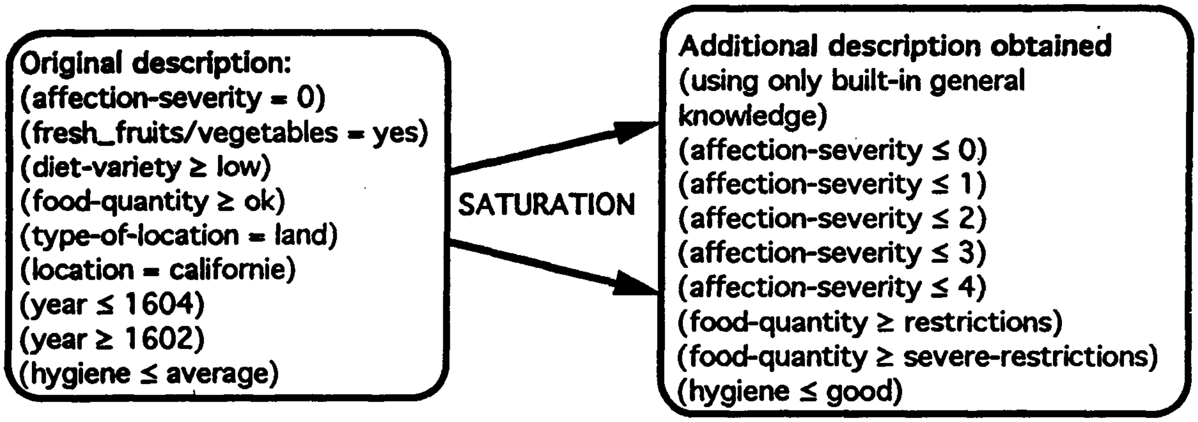

Figure 2: An example of saturation on one training case

The last type of bias which can optionally be defined by the user is the desired structure of the output rules. It is possible to define some levels of attributes, and to restrict the search to all the potential rules that conclude on one class of attributes. In the case of scurvy, it is quite obvious that the most interesting rules are the ones that conclude on the severity of the disease, because this is what we want to predict or explain. So it appears that the only induction bias which is not semantically justified is the restriction to conjunctive concepts, the choice of a noise parameter (rules that do not cover at least a defined number of cases are rejected), and the maximal number of rules that should cover an example.

3) Induction on scurvy cases

The 25 cases given to the system cover examples of sea and land scurvy from 1602 to 1810. They are summarized in the appendices. Some cases of remission were particularly useful to provide "negative" examples of the disease to the system, which are necessary to any supervised learning. Also, by providing two cases relatively close except for a few attributes, these cases of remission help greatly the induction process.

4) First induction results.

Our first experiment has be done without giving any domain knowledge to the system. This "pure" induction produced 12 logical rules which are given in Figure 3 with some analysis.

A first striking observation is the strong link between the rules produced by CHARADE and the explanations proposed for the disease until the end of the 19th century. All the rules produced correspond to an explanation from the medical literature. The three main factors are, after CHARADE (and some post-analysis), the presence of fresh fruits and vegetables in the diet, the variety of the diet (very linked to the previous factor), and the hygiene level.

A second striking observation is obtained by looking at the number of examples covered by the rules. The lack of fresh fruits and vegetables covers 13 + 5 = 18 examples, i.e., more than two thirds of the total. So, THE main factor according to CHARADE (and with this kind of ordering), is the real cause of scurvy. It is important to remember here that these results have been obtained without any domain knowledge. However, in some way, it seems to perform better than the scientists of the past centuries.

Note the number between brackets at the right of each rule stating how many examples it covers (i.e., the number of examples that match the premises of the rule). The affection-severity is a ranking from 0 (no disease at all) to 5 (most severe).

DIET:

It was J.F. Bachström (1734) who first expressed the opinion that, "Abstinence of vegetables is the only, the true, the first cause of scurvy."[DICTIONNAIRE DES SCIENCES MÉDICALES, 1880]

`Set I: Rules 3,4,7,8,10 use in their premises the variety of the diet and the presence (or absence) of fresh fruits and vegetables in the diet.`

R3:	IF diet-variety ≥ high	THEN affection-severity ≤ 0.	[5]
R4:	IF diet-variety ≤ average	THEN affection-severity ≥ 3.	[4]
R7:	IF fresh_fruits/vegetables = no	THEN affection-severity ≥ 2.	[5]
R8:	IF diet-variety ≥ average	THEN affection-severity ≤ 2.	[11]
R10:	IF fresh_fruits/vegetables = yes	THEN affection-severity ≤ 2.	[13]

We are lead to conclude that a decrease in quantity of food, or to speak clearly, starvation, can occasionally serve the cause of scurvy, but it cannot produce it by itself. [DICTIONNAIRE DES SCIENCES MÉDICALES, 1880]

`Set IV: Rule 2 uses in its premises the quantity of food available.`

R2:	IF food-quantity ≥ ok	THEN affection-severity ≤ 0.	[4]

HYGIENE:

If Cook's crews were entirely spared from scurvy, in a relatively large extent considering the times, it is thought that these great results were precisely the happy consequence of the care given to the cleanliness and drying of the ships. [DICTIONNAIRE DES SCIENCES MÉDICALES, 1880]

`Set II: Rules 5,6,9,12 use in their premises the level of hygiene.`

R5:	IF hygiene ≤ bad	THEN affection-severity ≥ 3.	[3]
R6:	IF hygiene ≤ average	THEN affection-severity ≥ 2.	[4]
R9 :	IF hygiene ≥ average	THEN affection-severity ≤ 2.	[7]
R12:	IF hygiene ≥ good	THEN affection-severity ≤ 1.	[6]

CLIMATE:

Spring and winter are obviously the seasons of predominance for scurvy. [Dictionnaire des sciences médicales, 1880]

`Set III: Rules 1, 11 use in their premises the temperature.`

R1:	IF location = land, temperature ≥ hot	THEN affection-severity ≤ 0.	[4]
R11:	IF temperature ≤ severe-cold	THEN affection-severity ≥ 1.	[5]

Figure 3: Excerpts from the 1880 medical encyclopedia followed by the corresponding rules proposed by CHARADE.

Though all the rules proposed by CHARADE correspond to some explanations of the scurvy found in the medical literature, there are some explanations from the literature which are not produced by CHARADE. Among these, the most important one is undoubtedly the explanation referring to the humidity of the air as the main predisposing cause to scurvy. This theory has been defended by people like Lind, beside the role of fresh vegetables and fruits. It is also the theory which seems accepted by the authors of the medical encyclopedia from which the examples are extracted. So, it is very surprising that it does not appear, at least marginally, in the rules produced by CHARADE. The next section will attempt to answer to this question.

C/ The problem of the humidity.

The influence of a cold and humid atmosphere has been said to be the key factor for the apparition of scurvy. "Air humidity is the main predisposing cause of this disease," according to Lind. [DICTIONNAIRE DES SCIENCES MÉDICALES, 1880]

CHARADE does not seem to consider that the humidity in the air has any impact on the presence or absence of the disease. There is no inductive element that leads to this kind of conclusion. Therefore, it seems that, to reach this conclusion, the scientists had an induction bias. They had some *a priori* knowledge on the subject which biased their judgment on the origin of the disease.

A good way to test this hypothesis would be to have the induction system reproduce the "wrong" induction of the scientists by formalizing the implicit knowledge they used while working on the subject. This is greatly helped by the work of historians of medicine which have tried to reconstitute the conceptual and reasoning framework of physicians like Lind. In [CARPENTER, 1986] for instance, it appears that the system of *Blocked Perspiration* was very widely accepted by the medical community at Lind's time.

<u>The "Blocked Perspiration" theory</u>

In this system, the body is made mainly of solid tissues and fluids. The fluids naturally tend to become corrupted. So, the role of all the excretions, and especially of perspiration, is to evacuate these corrupted fluids from the body to keep only some healthy fluids inside. If perspiration is blocked, the corrupted fluids act as a poison and produce some diseases. One can fight against the poisonous effect of the corrupted fluids by eating fruits whose acidity acts as a "detergent". This being accepted as a reasoning framework, the explanation of the role of humidity becomes clearer: humidity tends to block the pores of the skin; therefore it prevents a good perspiration, and is the main cause of scurvy.

The major steps of the reasoning framework which derives from the blocked perspiration theory have been formalized into a set of axioms presented in Figure 4a. As seen in the figure, two new concepts (the perspiration level, and the fluids quality) had to be added in the description language. Indeed, these two concepts, presented in Figure 4b are pure abstractions and are not linked to any direct observations. The axioms state how the two abstract concepts are logically linked to the observable features according to the theory.

Also, we want to point out that these axioms do not constitute a global theory of scurvy, since they do not express how the disease severity is logically linked to the observable features by a series of implications. They introduce only the abstract concepts proposed by the blocked perspiration theory.

We have iterated the previous experiment giving this set of axioms to CHARADE. The aim is to observe the behavior of the system within the conceptual framework of the blocked perspiration theory given as domain knowledge to the system. To illustrate how CHARADE practically uses the domain knowledge, Figure 5 shows how the saturation is done in this experiment on example 6. It can be compared to Figure 2 when only general built-in knowledge on the types of attributes was used.

IF (humidity = high)	THEN (perspiration ≥ hard)
IF (hygiene ≥ good) (humidity ≤ high)	THEN (perspiration ≤ hard)
IF (humidity ≥ very-high)	THEN (perspiration ≥ blocked)
IF (perspiration ≤ hard)	THEN (fluids ≤ healthy)
IF (fresh_fruits/vegetables = yes)	THEN (fluids ≤ healthy)
IF (fresh_fruits/vegetables <> yes) (perspiration ≥ blocked)	THEN (fluids ≥ corrupted)
IF (hygiene ≤ average)(location = sea)	THEN (humidity ≥ very-high)
IF (hygiene ≥ good)	THEN (humidity ≤ high)

Figure 4a: Axiom set describing the "blocked perspiration" theory

Attribute	Type	Domain
perspiration	Ordered set	normal < hard < blocked
fluids	Ordered set	healthy < corrupted

Figure 4b: Definitions of the two new concepts:

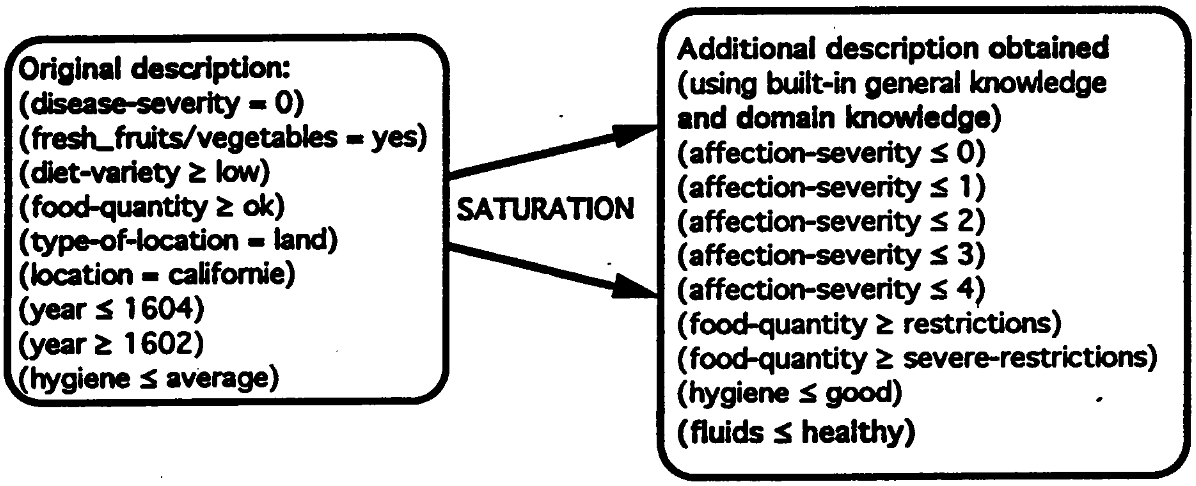

Figure 5: Saturation on one example with some domain knowledge

The results confirm our hypothesis about the importance of implicit knowledge. The rules produced (cf. Figure 6) correspond very well to the explanations given by 18th century physicians. Moreover, considering the number of examples covered, the rules using the fluid quality in their premises override the simpler (and true) rule found in the previous experiment condemning the lack of fresh fruits and vegetables. They indeed cover 14 + 9 = 23 examples out of 25 instead of 13 + 5 = 18 for the true explanation.

This phenomenon has been analyzed using a machine learning approach. It can also be explained from a pure scientific discovery point of view. In other words, the induction bias constituted by the domain knowledge can be seen as a hypothesis about the effect of the environment on some internal functions of the human body. The induction itself is then an attempt to induce some rules from examples using this hypothesis. Therefore, the rules produced can be seen as a test of the explanatory or descriptive power of the hypothesis. In our case, the fact that the rules which use the abstract concepts cover a larger number of example than the ones that we found in our first experiment is a sign of their greater explanatory power. We think that this might provide a good explanation of the importance given to the humidity over the lack of fresh fruits and vegetables until the end of the nineteenth century. This analysis meets the point of view expressed in [THAGART and NOWAK, 1989] about the role of the explanatory power of a theory to explain its acceptation by the scientific community at a given time, given a conceptual framework.

IF	humidity ≥ high fresh_fruits/vegetables = unknown,	THEN affection-severity ≥ 2. [4]
IF	humidity ≤ high, hygiene ≥ average	THEN affection-severity ≤ 1. [6]
IF	perspiration ≤ hard	THEN affection-severity ≤ 1. [6]
IF	fluids ≥ corrupted	THEN affection-severity ≥ 2. [9]
IF	fluids ≤ healthy	THEN affection-severity ≤ 2. [14]

Figure 6: New rules produced when the domain knowledge is given to the system

Conclusions

There are two axes to the work presented here. The first one is purely the use of induction for discovery. In the example we have treated here, pure induction on 25 scurvy cases gave surprisingly good results. However, the pure induction did not produce some of the explanations of 18th century physicians. The idea of reproducing these explanations expresses what we pursue in a second axis of research: the simulation of actual discoveries as they took place in history. A second experiment in which some domain knowledge has been given to the system produced eventually the missing explanations. This shows the importance of taking into account the conceptual framework of a scientist, even in a science reputedly relying only on induction, to understand its reasoning.

In our work, the induction bias seems to have a harmful effect, since it tends to hide the real cause of scurvy to the physician. However, it is not our goal to convince the reader that the induction bias is harmful by nature. We know that in most cases of induction, especially cases of human induction, a bias is necessary to constraint the search space. However, a definite lesson from this research is that it is capital to take into account one's induction bias to understand one's reasoning. In order to do so, it seems important to render this bias explicit since it is often the result of implicit knowledge, especially in medicine. It is our belief that computer simulation can be of a great help for this task.

Acknowledgments

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ANNEXES: Database composed of 25 cases of scurvy.

***** ex1 *****
(affection-severity = 0)
(fresh_fruits/vegetables = yes)
(food-quantity ≥ restrictions)
(humidity ≥ high)
(temperature ≥ hot)
(type-of-location = sea)
(location = inde)
(year = 1609)
(hygiene ≤ average)

***** ex2 *****
(food-quantity ≥ very-low)
(fresh_fruits/vegetables = no)
(affection-severity = 3)
(humidity ≥ high)
(temperature ≥ hot)
(type-of-location = sea)
(location = inde)
(year = 1609)
(hygiene ≤ average)

***** ex3 *****
(affection-severity = 4)
(type-of-location = sea)
(hygiene ≤ bad)
(humidity ≥ high)
(year = 1806)
(fresh_fruits/vegetables = unknown)

***** ex4 *****
(affection-severity = 5)
(temperature ≤ severe-cold)
(food-quantity ≥ restrictions)
(type-of-location = land)
(location = groenland)
(year = 1633)
(fresh_fruits/vegetables = unknown)
(hygiene ≤ average)

***** ex5 *****
(affection-severity ≥ 3)
(fresh_fruits/vegetables = no)
(diet-variety ≤ average)
(food-quantity ≤ restrictions)
(type-of-location = sea)
(location = californie)
(year ≤ 1604)
(year ≥ 1602)
(hygiene ≤ average)

***** ex6 *****
(affection-severity = 0)
(fresh_fruits/vegetables = yes)
(diet-variety ≥ average)
(food-quantity ≥ ok)

(type-of-location = land)
(location = californie)
(year ≤ 1604)
(year ≥ 1602)
(hygiene ≤ average)

***** ex7 *****
(affection-severity ≤ 3)
(affection-severity ≥ 2)
(fresh_fruits/vegetables = no)
(type-of-location = sea)
(location = baltique)
(year ≤ 1730)
(year ≥ 1720)
(hygiene ≤ average)

***** ex8 *****
(affection-severity = 0)
(fresh_fruits/vegetables = yes)
(type-of-location = sea)
(location = baltique)
(year ≤ 1730)
(year ≥ 1720)
(hygiene ≤ average)

***** ex9 *****
(affection-severity ≥ 3)
(fresh_fruits/vegetables = no)
(diet-variety ≤ average)
(humidity ≥ high)
(temperature ≥ hot)
(type-of-location = sea)
(location = pacifique)
(year = 1740)
(hygiene ≤ average)

***** ex10 *****
(affection-severity = 0)
(fresh_fruits/vegetables = yes)
(diet-variety ≥ high)
(food-quantity ≥ ok)
(humidity ≥ high)
(temperature ≥ hot)
(type-of-location = land)
(location = pacifique)
(year = 1740)
(hygiene ≤ average)

***** ex11 *****
(affection-severity ≥ 3)
(fresh_fruits/vegetables = no)
(hygiene ≤ very-bad)
(temperature ≥ hot)
(type-of-location = sea)
(location = guinee)
(year = 1783)

***** ex12 *****
(affection-severity = 0)
(fresh_fruits/vegetables = yes)
(diet-variety ≥ high)
(food-quantity ≥ ok)
(temperature ≥ hot)
(type-of-location = land)
(year = 1783)
(hygiene ≤ average)

***** ex13 *****
(affection-severity = 0)
(diet-variety ≥ high)
(fresh_fruits/vegetables = yes)
(hygiene ≥ good)
(type-of-location = land)
(year = 1806)

***** ex14 *****
(affection-severity = 0)
(temperature ≥ hot)
(type-of-location = land)
(location = pacifique)
(year = 1767)
(hygiene ≤ average)

***** ex15 *****
(affection-severity = 0)
(fresh_fruits/vegetables = yes)
(diet-variety ≥ average)
(food-quantity ≥ restrictions)
(temperature ≤ cold)
(humidity ≥ high)
(type-of-location = sea)
(hygiene ≥ good)
(location = bonne-esperance)
(year = 1772)

***** ex16 *****
(temperature ≤ severe-cold)
(affection-severity = 1)
(fresh_fruits/vegetables = yes)
(diet-variety ≥ average)
(food-quantity ≥ restrictions)
(humidity ≥ high)
(type-of-location = sea)
(hygiene ≥ good)
(location = bonne-esperance)
(year = 1772)

***** ex17 *****
(affection-severity = 2)
(fresh_fruits/vegetables = yes)
(diet-variety ≥ average)
(food-quantity ≥ restrictions)
(temperature ≤ severe-cold)
(humidity ≥ high)
(type-of-location = sea)
(hygiene ≤ average)

(hygiene ≥ average)
(location = bonne-esperance)
(year = 1772)

***** ex18 *****
(affection-severity ≥ 2)
(temperature ≤ severe-cold)
(type-of-location = sea)
(location = 71*latsud)
(year ≤ 1774)
(year ≥ 1774)
(fresh_fruits/vegetables = unknown)
(hygiene ≤ average)

***** ex19 *****
(affection-severity = 0)
(food-quantity ≥ ok)
(diet-variety ≥ high)
(fresh_fruits/vegetables = yes)
(type-of-location = land)
(location = 71*latsud)
(year = 1774)
(hygiene ≤ average)

***** ex20 *****
(affection-severity = 0)
(fresh_fruits/vegetables = yes)
(diet-variety ≥ average)
(food-quantity ≥ restrictions)
(humidity ≥ very-high)
(hygiene ≥ good)
(type-of-location = sea)
(location = kamschatka)
(year = 1787)

***** ex21 *****
(affection-severity = 1)
(fresh_fruits/vegetables = yes)
(food-quantity ≥ restrictions)
(diet-variety ≥ average)
(temperature ≤ severe-cold)
(humidity ≥ high)
(type-of-location = sea)
(hygiene ≥ good)
(location = vancouver)
(year = 1791)

***** ex22 *****
(type-of-location = sea)
(affection-severity ≥ 3)
(diet-variety ≤ low)
(hygiene ≤ bad)
(humidity ≤ high)
(temperature ≤ cold)
(location = bonne-esperance)
(year = 1788)
(fresh_fruits/vegetables = unknown)

***** ex23 *****
(affection-severity ≤ 0)
(hygiene ≥ good)
(type-of-location = sea)
(location = etats-unis)
(fresh_fruits/vegetables = unknown)
(year = 1792)

***** ex24 *****
(diet-variety ≤ average)
(type-of-location = sea)
(affection-severity = 3)
(year ≤ 1810)
(year ≥ 1802)
(fresh_fruits/vegetables = unknown)
(hygiene ≤ average)

***** ex25 *****
(fresh_fruits/vegetables = yes)
(affection-severity = 0)
(humidity ≤ high)
(temperature ≥ hot)
(diet-variety ≥ high)
(type-of-location = land)
(year ≤ 1810)
(year ≥ 1802)
(hygiene ≤ average)