A METHOD FOR INTERACTIVE SATELLITE FAILURE DIAGNOSIS: TOWARDS A CONNECTIONIST SOLUTION

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ABSTRACT

In this paper we briefly analyze the various kind of processes which allow one to make a diagnosis.Then we focus on one of these processes used for satellite failure diagnosis.This process consists of sending instructions to the satellite about system status alterations to make masked the effects of one possible component failure or to look for additional abnormal measures.

A formal modele of this process is given.This model is an extension of a previously defined connectionist model which allows computation of ratios between the likelihoods of observed manifestations according to various diagnostic hypoththeses.We show that we are able to compute in a similar way the expected mean value of these likelihood measures for each possible status of the satellite.Therefore,we are able to select the most appropriate status according to three different purposes:to confirm an hypothesis,to eliminate an hypothesis,or to choose between two hypotheses.

Finally a first connectionist schema of computation of these expected mean values is given

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I Introduction

There are a lot of human activities which involve diagnostic problem solution.This kind of problem solving typically calls to the mind the physician activity looking for the diseases which may be the cause of observed symptoms.However similar mental processes are involved when a detective looks for a murderer,various specialists try to repair a device and when a scientist tries to dtermine the composition of a given sample(proteins by electrophorese for a biologist,chemical composition by spectrum analysis in chemistry, etc...

1.1.1 Various diagnosis procedures

Everyone who makes a diagnosis does not uses exactly the same reasoning process.How one infers a diagnosis depends in part upon their way to get information.We can distinguish at least three main classes:1) All needed information is immediatly available

2) A part of the needed information is masked from the person trying to make a diagnosis

3) The cause of the observed symptoms may change during the gathering of information. This last case is the most difficult and we will only consider the first two kinds of diagnosis here.

1.1.2 The most general procedure

The basic information with which one can deal in a diagnostic process consists of propositions like:a given disorder may cause a given symptom or manifestation.Therefore,diagnostic inference cannot only be a deductive process:some symptoms of a disorder may be absent and symptoms can be the consequence of several disorders.The mathematical modelling of the cause has been the aim of several previously published papers:[PEAR86],[PEAR87],[BOUR87],[WALD89].For some of them "may cause" is represented by a probability,[PEAR86],[PEAR87],and for others there is a numerical "causal strength" between a disorder and its manifestations,[PENG87].In still another model,[BOUR87] the observed manifestations may also be caused by unknown disorders and a measure of likelihood of each manifestation is introduced in order to be able to neglect the lessprobable manifestations when the deductive process leads to contradictions

1.1.3 The stepwise procedures

Inpractice the diagnostic process consists of two alternate phases:

First seach for a set of plausible hypotheses which explain the set of obseved manifestations, and

Second,confirmation and/or elimination of selected hypotheses.

In order to confirm or to eliminate an hypothesie one can proceeds in two ways

a)New queries The simplest approach is to ask new queries the results of which would enable us to confirm or to eliminate an hypothesis.But such an approach implies that all needed information is available.This is not true in many cases.For instance in a satellite the measured information is chosen when designing the satellite and cannot be changed when the satellite is in space.

b)The indirect diagnosis procedure This second process is applied when a diagnosis is needed for a still working device (satellite,in flight aircraft,boats,etc...).This device has many possible working modes.Each working mode may mask the effects of some disorders.Therefore by change of working mode (within the limits of posible working mode at a given time),people doing diagnosis are able to confirm or to eliminate a given hypothesis.For instance, in a satellite failure diagnosis the operator may force the battery to supply power to various components in order to eliminate the assumption "solar cells failure",if the manifestations diapear with this new working mode.

1.2 The Satellite Failures Diagnosis Procedure

The indirect diagnosis procedure has already been studied[BOUR86].It can be summarized as follows.When an alarm is on in a satellite control room,contollers first apply the emergency procedure related to this alarm.They,then,try to analyse the latest information which has been sent by the satellite to determine if there is a failure and, if so, what kind of failure is it.Because the emegency procedure always protect the satellite,sevral hours can be used to make an accurate diagnosis.In the case of low level satellites,it is not possible to try several working modes within a revolution because the satellite can only received one command and send information back during the short period in which it is visible from antennae.Minimizing the number of needed working modes to complete the diagnosis is thus of prime importance in this case. The deduction process is the following:controllers have at their disposal schemas with various levels of details.They start from the measured point of the sschema which has caused the alarm and follow the functional links starting from one component that arrive at this point.Then they make the assumption that there is a breakdown in this component.After that they try to eliminate this assumption by looking for information,among that most recently received,which contradicts their assumption.If they one they follow back the functional links until they identify a new component.This process seems so simple that one might think that advanced information systems are not required. But, in fact the process is made more difficult by two things.First,in every satellite there are a lot of automatic reconfigurations that occur in order to avoid hazardous effects of a failure.Thus the controller has at his/her disposal only a few pieces of information about what has really happened.More often he/she only knows that an automatic reconfiguration has happened on a given device.He/she must look through long sequences of measurements in order to detect what part of the device has broken.Second,in most cases information is gathered on board the satellite and periodically sent to the control center without information on the time at which each has been gathered.Only the order in which each piece of information is gathered is known.So it is sometime very difficult to exactly know when the failure which caused the alarm happened,and thus which information is related to the period before the failure and which one is related to the period after the failure. We can also say that the failures are rare on board a satellite,so controllers are not well trained to face this kind of event.Morover,failures usually occur more frquently at the end of the satellite life (typically 7 years).By this time, the designers of the satellite,who are the most qualify to find the failure,are either no longer available or have forgotten a large part of their knowledge about the satellite.Therefore an intelligent decision aid for controllers is absolutely needed.

1.3 The study purposes

In a previous study[BOUR86], an expert system was prototyped to make diagnosis automatically.But the solution had two main drawbacks:it was time consuming (a first list of possible failures needed up to tweenty minutes on a SUN/50) and it did not give any advice for selecting a working mode that would be the most appropriate to confirm or eliminate an hypothesis on the list.Another previous study has shown that making the list of most probable hypothesis can be done using a connectionist model[PENG89].We have wanted to go further and to compute, in a similar way, which working mode of the satellite would give the most information in order to reduce the hypotheses list.

II General Mathematical Model

2.1 Notations and basic assumptions

Let $D=\{d_1,...,d_n\}$ be the set of possible disorders,

$M=\{m_1,...,m_k\}$ the set of manifestations,

$p_i, i=1,...n$ the apriori probabilities of d_i, and

c_{il} the frequencies with wich d_i *causes* m_l ($c_{il}=0$ if there is no causal relation between d_i *and* m_l)

Note that $c_{il}=P(m_l \mid d_i)$.For detailled explanations of this point see[PENG88]

Let $C=\{c_{il}\}$ and let $e(d_i)=(m_l : c_{il} \neq 0)$ Let be M^+ the set of observed manifestations in the current working mode W_0 and $M^-=M-M^+$ Let $D_I \subset$ D be an assumption representing a set of possible disordres which can explain all observed manifestations M^+ The following three assumptions are made:

1)Disorders are independent of each other

2)Causal strength (c_{il}) are invariant :whenever d_i occurs it always causes m_l with the same strength.

3)No manifestations can be present without being caused by some disorder.

Define the **Relative Likelihood** measure of $D_I \subseteq$ D,given M^+, to be $L(D_I \mid M^+)=P(M^+ \mid D_I)\prod_{d_i \in D_I}\frac{p_i}{1-p_i}$

Where $P(M^+ \mid D_I)$ stands for the probabilitybof the observed set of manifestations, given the set of disorders D_I.

II.2 Mains results Let $\alpha_i = \prod_{m_l \in e(d_i)-M^+} (1-c_{il} \frac{)p_i}{(1-p_i)}$ [1]

Let $L_1(D_I, M^+) = \prod_{m_l \in M^+} (1- \prod_{d_i \in D_I} (1-c_{il}))$ [2]

Then $L(D_I, M^+) = L_1(D_I, M^+) \prod_{d_i \in D_I} \alpha_i$ [3]

$= L_1(D_I, M^{+)UB(D_I}, m^+)$ where $UB(D_I, M^+) = \prod_{d_i \in D^I} \alpha_i$

Defition of a "confort measure" CM

CM is a real number btween 0 and 1 which represents how certain we wish to be that a collection of diagnosis hypotheses $(D_1, D_2, \ldots, D_k)$ includes the actual set of causitives disorders that are present.

Definition of a minimal solution of a diagnosis problem

Let D,M,C,M^+ be a diagnosis problem that we wish to solve given a confort measure CM $(0 \leq CM \leq 1)$.S=$\{D_1, D_2, \ldots, D_k\} \subseteq$ "subsets of D" is said to be a minimal solution the problem iff

1)$P(D_1 \bigcup D_2 \ldots \bigcup d_k \mid M^+) = \sum_{i=1}^{k} P(D_i \mid M^+) \geq CM$

2) for all $D_j \in S$ $\sum_{i=1, i \neq j}^{k} P(D_i \mid M^+) \leq CM$

Let $A_{D_I} = \sum_{d_i \in D \ D_I} \alpha_i$

Theorem 1 [Peng88]

For any hypothesis $D_I \subseteq$ D: $\sum_{D_J \supseteq D_I} L(D_J \mid M^+) \leq UB(D_I, M^+)(e^{A_{D_I}}-1)$ There is an algoritm [PENG88] which allows to determine the k most probable hypothesis among all members of subsets of D and to order them by decreasing probabilities. An hypothesis is said to cover a problem if this hypothesis canexplain all observed manifestations M^+.

Theorem 2 [Peng88]

Let $D_1, D_2, \ldots, D_k$ be the k most probale covers of a problem PB=D,M,C,M^+ where D_k is the least probable among the k covers.Let CM be a given confort measure.Then S=$(D_1, D_2, \ldots, D_k)$ is a solution for problem PB if:

$$\sum_{i=1}^{k} inf \ (D_I) \geq CM \geq \sum_{i=1}^{k-1} sup \ (D_I)$$

where $\inf(D_I) = \frac{L(D_I \mid M^+)}{\sum_{D_J D_I} L(D_J \mid M^+)} = \frac{L(D_i \mid M^+)}{UB(D_I, M^+)(e^{A_{D_I}} \ 1)}$ [4]

and $\sup(L(D_I, M^+)) = \frac{L(D_I \mid M^+)}{\sum_{D_J \, cover of \, M^+} L(D_J \mid M^+)}$ [5]

II.3 A Connectionist Approach of the General Diagnosis Problem Solving [PENG89]

Let x_i be binary variables.x_i =1 if $d_i \in D_I$;x_i =0 otherwise.

Thus to maximize $L(D_I \mid M^+)$ amounts to maximize:

$$Q(X) = \prod_{m_j \in M^+} (1 - \prod_{i=1}^{m} (1-c_{ij} x_i)) \prod_{m_j \in M - M^+} \prod_{i=1}^{n} (1-c_{ij} x_i) \prod_{i=1}^{n} \frac{1-x_i(1-p_i)}{1-p_i x_i}$$ [6]

This maximization can be get by the use of a two layers neural network.

The units of the first layer represent the manifestations and the units of the second layer represent the disorders.

x_i becomes the activation level of units which represent the disorders. The activation rule of the manifestation nodes is the following:

$$m_j(t)=1-\prod_{i=1}^{n}(1-c_{ij}\,x_i(t))=1-\prod_{d_i \in causes(m_j)}(1-c_{ij}\,x_i(t)) \quad [7]$$

Thus this activation rule is a local computation since it only depends on current activation levels of m_j 's causative disorders which are directly connected to m_j in the causal network.

Since $x_i(0)=p_i \quad m_j(0)=1-\prod_{i=1}^{n}(1-c_{ij}\,p_i)$

The activation rule of x_i is a bit more sophisticated.

Firstly Q(X), which is to maximize is decomposed in $Q(X)=Q'(X-x_i)q_i(x_i(t))$.

Then the activation rule of the node x_i is chosen in order to optimize $q_i(x_i(t))$.

Since $q_i(x_i(t))$ is only function of $x_i(t)$, the use of local optimization for each x_i yields to the optimization of Q(X).

Let $M_i^+=M^+\cap e(d_i)$ and $M_i^-=(M-M^+)\cap e(d_i)$

$$\text{Let } q_i(t)=\prod_{m_l \in M_i^+}\left(1-\prod_{k=1}^{n}(1-c_{kl}\,x_k(t))\right)\prod_{m_l \in M_i^-}\prod_{k=1}^{n}(1-c_{kl}\,x_k(t))\prod_{k=1}^{n}\frac{1-x_k(t)(1-p_k)}{1-x_k(t)p_k} \quad [8]$$

in which all $x_k(t)$ are considered to be parameters and $x_i(t)$ the only argument of the function $q_i(x_i(t))$.

Note that the first two products in Equation [8] which are local to x_i not over M^+ and $M-M^-$ as in Equation [6].In this sense Equation [8] is a patially localized version of Equation [6] (partially because the parameter $x_k(t)$ for $k \neq i$ are still present.

Viewing $q_i(x_i(t))$ as an objective function and $x_i(t)$ as being constraint to $\{0,1\}$ we decompose the global optimization problem of $D_j(t)$ into local optimization problems of its elements $x_i(t)$:derive whichever of $x_i(t)=1$ or $x_i(t)=0$ will maximize q_i , i.e whichever of $q_i(1)$ or $q_i(0)$ is greater,if all other $x_k(t)$ are fixed.If $q_i(1)>q_i(0)$ $x_i(t)$ should decrease in order to get local optimization.Thus we define the ratio $r_i(t)=\frac{q_i(1)}{q_i(0)}$. It can be proven [PENG89] that:

$$r_i(t)=\prod_{m_l \in M_i^+}\left(1+c_{il}\,\frac{1-m_l(t)}{m_l(t)-c_{il}(t)x_i(t)}\right)\prod_{m_l \in M_i^-}(1-c_{il})\left(\frac{p_i}{1-p_i}\right)$$

$r_i(t)$ can rewritten as:

$$r_i(t)=\prod_{m_l \in M_i^+}\left(1+c_{il}\,\frac{1-m_l(t)}{m_l(t)-c_{il}\,x_i(t)}\right)K_i \quad [9]$$

The activation rule of the "disorders nodes" can easily be deduced from Equation [9]

Let f(x) be defined as follows:

=1 if x>1
f(x)=-1 if x<-1
=x otherwise

The activation rule for $x_i(t)$ is the following: $\frac{dx_i(t)}{dt}=f\,(r_i(t)-1)(1-x_i(t))$

This differential equation is approximated by the following differences equation: $x_i(t+\Delta)=x_i(t)+f\,(r_i(t)-1)(1-x_i(t))*\Delta$

But if $x_i(t+\Delta)$ is less than 0.0 it is set to 0.0.Thus,as desired $x_i(t)$ is guaranteed to be in [0,1] at any·

time t.
Experimental studies of this model[PENG89] show that it fits well with its purposes and allows to find out the most probables hypotheses which may explain the obseved manifetations.

III Modelling The Indirect Procedure

III.1 Notations

Let W_i i=1,...p be the possible working modes of the satellite

$H(W_i)=(d_{j1}, d_{j2}, d_{jk})$ the set of "hiden" disorders in the working mode W_i .(the hiden desorders in a given working mode are the disorders the effects of which are masked in this working mode.For exampme a "solar cell failure " is masked in the working mode "power supplied by battery"

Let $C(m_j)$ be the set of disorders which may be the cause of the manifestation m_j

$M^*(W_i)= \bigcup_{d_j \in D - H(W_i)} M(d_j)$ be the set of manifestations which can be observed in the working mode W_i

III.2 Various Strategies Models

We have studied three possible strategies in the choice of the best working mode in an indirect diagnosis procedure.First we can want to confirm the most likeky explanation of the first phase diagnosis.In this case we have to choose the working mode such that the mean value of this explanation likelihood will be maximum.Thus we have to maximize,with respect to W_j

$E(L(D \mid W_j))= \sum_{M_i^+ \subset M(W_j)} L(D \mid M_i^+)p(M_i^+)$ where M_i^+ stands for all possible set of manifestations and p(M_i^+) stands for the probability of this set of manifestations to be observed with the working mode W_j .Second we can want to eliminate one of the explanations which has been selected in the first phase.For this purpose we have to minimize the mean value of the expected likelihood of this explanation, which amount to minimize $E(L(D \mid W_j))$ .Last, the likelihood of the two most likely explanations may be very close and we can want to maximize the ratio of their mean values of their expected likelihood.In this case we have to look for W_j which maximizes $\frac{E(L(D \mid W_j))}{E(L(D' \mid W_j))}$ if D and D' are the two most likely explanations of the first phase.

III.3 Mathematical Approach

In order to achieve these objectives we may use the analytical expression of the relative likelihood and compute it for each possile set of manifestations and make the wheigthed summation of these results for everyworking mode.Because such a way becomes quicklyuntractable when the number of disorders, manifestations and working mode grows, we will show in the next section how the complexity of the computation may be reduced.But before this, we need two easy to compute results:$L(D \mid M^+ - \{m_l\})$ and $L(D \mid M^+ \cup \{m_l\})$ which stand respectively for the relative likelihood of the hypothesis D when the set of maifestation is respectively M^+ and not m_l and M^+ and m_l A characteristic of satellite failure diagnosis is that we can assume that there is only one failure at a time.Therefore D=$\{d_i\}$ According to Equation [2] we get:

$$L_1(\{d_i\}|M^+ = \prod_{m_j \in M^+} (1 - \prod_{d_i \in D} (1-c_{ij}))$$

$$L_1(\{d_i\})|M^+) = \prod_{m_j \in M^+} (1-(1-c_{ij})) = \prod_{m_j \in M^+} c_{ij}$$

which yelds to:

$$L_1(\{d_i\})|M^+ \cup m_l) = \prod_{m_j \in M^+ \cup m_l} c_{ij}$$

$$L_1(\{d_i\})|M^+ - m_l) = \prod_{m_j \in M^+ - m_l} c_{ij}$$

So:

$$L(\{d_i\})|M^+\cup m_l)=L_1(\{d_i\})c_{il}\alpha_i$$
$$=L(\{d_i\})c_{il} * \frac{1-p_i}{p_i(1-c_{il})} \quad \text{if } m_l \in e(d_i)-M^+$$
$$=L(\{d_i\})c_{il} \quad \text{otherwise} \quad [11]$$

$$L(\{d_i\})|M^+-m_l)=\frac{L(d_i \mid M^+}{c_{il}} \quad \text{if } m_l \in M^+$$
$$=L(\{d_i\})|M^+) \quad \text{if } m_l \in e(d_i)-M^+$$
$$=L(\{d_i\})|M^+)(1-c_{il})\frac{p_i}{1-p_i} \quad \text{otherwise. } [12]$$

Let $\Delta(m_l, d_i, M^+, x)=x$ if $m_l \in e(d_i)-M_+$
$=1$ otherwise

Let $r_{ij}=\frac{L(d_i \mid M^+)}{L(d_j \mid M^+}$

$$\frac{L(d_i \mid M^+\cup m_l)}{L(d_j \mid M^+\cup m_l}=r_{ij} * \frac{c_{il}}{c_{jl}} * \Delta(m_l, d_i, M^+, \frac{1-p_i}{p_i(1-c_{il})}) * \Delta(m_l, d_j, M^+, \frac{p_j(1-c_{jl})}{1-p_j}) \quad [13]$$

$$\frac{L(d_i \mid M^+-m_l)}{L(d_j \mid M^+-m_l)}=r_{ij} * \frac{c_{jl}}{c_{il}} \quad \text{if } m_l \in M^+$$
$$=r_{ij} \quad \text{if } m_l \in e(d_i)\cap e(d_j)-M^+$$
$$=r_{ij}(1-c_{il})\frac{p_i}{1-p_i} \quad \text{if } m_l \in e(d_i)-e(d_j)$$
$$=r_{ij}(1-c_{jl})\frac{p_j}{1-p_j} \quad \text{if } m_l \in e(d_j)-e(d_i) \quad [14]$$

We also need the a priori probability of a given set of manifestations M_s in a given working mode W_i

$$P(M_s \mid W_i)=\prod_{m_j \in M_s} p(m_j) \prod_{m_k \in M^*(W_i)-M_s} (1-p(m_k)) \quad [15]$$

$p(m_j)=N_j \sum_{d_i \subset H(W_i)} p_i c_{ij}$ (remember that $c_{ij}=0$ if $m_j \neg\in M(d_i)$)

N_j is a constant such that $\sum_{M_s \in M^*(W_i)} P(M_s \mid W_i)=1$

From [15] we easily get:

$$P(M_s \cup m_l \mid W_i)=\frac{P(M_s \mid W_i)p(m_l)}{1-p(m_l)} \quad [16]$$

$$P(M_s - m_l \mid W_i)=\frac{P(M_s \mid W_i)(1-p(m_l)}{p(m_l)} \quad [17]$$

We are now able to compute:

$E(L(d_1) \mid M_1^+ \mid W_i)=\sum_{M_s \subset M^*(W_i)} L(d_1 \mid M_s)P(M_s \mid W_i)$ by computing $L(d_1 \mid M_s)$ from $L(d_1 \mid M_1^+)$ by succesives use of formulae [2] and [3]

But we have to compute $2^{|M^*(W_i)|+1}$ values and we are going to show in the next section that formulae [11],[12],[13],[14],[16],[17] allow us to minimize the cost of the computation of one value.In the last section we give a theoretical neural ntework which enables us to get the expected mean value of $E(L(d_1) \mid W_i)$ and therefore its maximum or minimum among the avilable W_i

III.4 Complexity analysis and computational cost minimization

If we want to compute $L(d_i \mid M_s)$ we need $1 + \mid e(d_i) \mid + \mid M_s \mid$ operations and $P(M_s \mid W_i)$ needs $\mid M_s \mid$ operations.

Thus the computation of one of the term of $E(L(d_1 \mid W_i))$ needs $2 \mid M_s \mid + \mid e(d_1) \mid +1$ operations.Because the mean value of $\mid M_s \mid$ is $\frac{\mid M^*(W_i) \mid}{2}$ the total computation cost of $E(L(d_1 \mid W_i))$ is $(1 + \mid e(d_1 \mid + \mid M^*(W_i) \mid)2^{\mid M^*(W_i) \mid +1}$ But,using formulae [11],[12],[13],[14],[16],[17] the computation cost of $P(M_s \mid W_i)$ is only three operations,the computation of $L(d_i \mid M_s)$ is only one operation and the total cost of computation is reduced to $3 * 2^{\mid M^*(W_i) \mid +1}$.

In order to only use this set of formulae we have to use an algorithm which generates the $2^{\mid M^*(W_i) \mid}$ parts of $M^*(W_i)$ in an order such that we can transform each part in the following part only by adding or suppressing an element.This can easily be done by the following recursive algoritm.Let us assume that we want to generate the 2^N parts of a set of N elements $\{a_1, a_2, \ldots, a_N\}$ with respect to the property that two successives parts only differ by one element.Let us assume that we have genrate the 2^{N-1}parts of the subset $\{a_1, a_2, \ldots, a_{N-1}\}$ with respect to the previous property on the order of the parts.Let us assume that the empty set is the first part and that the last part consists of a single element.Let us also assume that the first non empty part is also a single element.Therefore we have $2^{N-1}-1$ non empty parts.In order to get the 2^N parts with respect to the four previously assumed properties we only need to repeat in the reverse order the $2^{N-1}-1$ non empty pars with adding the N^{th} element a_N; in such a way we get $2^{N-1}-1$ parts with a_n begining and ending by a two elements part ;$\{a_i, a_N\}$ and $\{a_j, a_N\}$.This last element can give the part $\{a_N\}$ by suppressing a_j

By concatenation of the two lists of $2^{N-1}-1$ parts and $\{a_N\}$ we get 2^N-1 parts.Therefore with the empty set we have 2^N parts and these parts are ordered with respect to the four previously enouced properties.

Example $\{\emptyset\} \rightarrow [\{a_1\} \rightarrow \{a_1, a_2\} \rightarrow \{a_2\}] \rightarrow [\{a_2, a_3\} \rightarrow \{a_1, a_2, a_3\} \rightarrow \{a_1, a_3\} \rightarrow \{a_3\}]$
$\rightarrow [\{a_3, a_4\} \rightarrow \{a_1, a_3, a_4\} \rightarrow \{a_1, a_2, a_3, a_4\} \rightarrow \{a_2, a_3, a_4\} \rightarrow \{a_2, a_4\} \rightarrow \{a_1, a_2, a_4\} \rightarrow \{a_1, a_4\} \rightarrow a_4\}]$

Remark The expected mean value of the likelihood needs a maximum of computation $2^{\mid M^*(W_i) \mid}$ terms because those related to $m_j \in M^*(W_i) \cap M^{+1}$ are already known.The exact number of terms whic have to be computed is $2^{\mid M^*(W_i) - M_1^+ \mid}$ and the strarting value is in this case $L(d_i \mid M_1^+ - M^*(W_i))$

IV Towards a full connectionist solution

It is obvious that for large $\mid M^*(W_i) \mid$ the proposed solution in the previous section becomes intractable.Because the maximum of $L(d_i \mid M_1^+)$ can be found by the means of a connectionnist network the way of a full connectionist solution must be taken into account.The exact computation of a mean value only seems to be done by an Hopfield model network in which each unit represents a part of $M^*(W_i) - M_1^+$ and is linked to the two parts which differ by only one element as it is shown in the previous section.The weight of the link is the factor by which the activity level of a unit must be multiplied in order to get the activity level of the following.But,since this introduces an order for the computation of units activity levels,there is no parallelism in the method.Moreover ,because such a machine with a large number of units is not available nowadays we have not search an algorithm which allows us the use of parllelism,but it must be noticed that the optimum computation cost should be $\mid M^*(W_i) \mid - \mid M_1^+ \mid$ cycles (one for all parts of size 1, one for all parts of size 2 and so on).

Another way is to use a competitive activation model in which the units which compete represent a working mode which is associated with a given disorder the likelihood of which has the required property (i.e to be maximum,or to be the second,or to be minimum in a given set).By similar activation rules (even for minimization for which only the ratio $r_i(t)$ is changed in $\frac{1}{r_i(t)}$) we can determine which working mode has the maximium likelihood with respect to the set of manifestations units.These manifestations units have an activation level equal to the mean value of the binary random variable related to the presence of the manifestation.(See Figure 1)

In this case ,which can easily be implemented on an actual machine with a few thousands of units,we do not compute the expected mean value of the likelihood but the likelihood of the mean values of the manifestations which can be observed during a given working mode.This is different of our initial purpose but can be a good criterion for the selection of the working mode

We have seen that with a very sligthly modification we can define a network which determines the working mode which has the smallest likelihood of the manifestations mean values for a given disorder.Therefore we can help a controller for the choice of the best working mode which would enable him to confirm (respectively eliminate) an explanation.But for the working mode which should maximize $\frac{L(d_i \mid M^*(W_k)-M_1^+)}{L(d_j \mid M^*(W_k)-M_1^+)}$ (i.e for which the two explanations d_i and d_j should have likelihoods the most different) we must define another net work.(See Figure 2) This network consists of the both networks previously defined and a set of units which represent each possible working mode.Their activation levels are the ratio between the activation level of the working mode related to an explanation and the activation level of the same working mode related to the other explanation.The unit with the maximum activity level showes the best wor king mode for the choice between the two explanations.

V Conclusion

The framework of a method which allows one to minimizes the number of successives working modes which can be needed for an accurate diagnosis of a satellite failure is established.This method will become tractable when large enough actual neural network become available.Like it can be seen in the previous sections some problems are not yet entirely solved and can only be solved when the characteristics of specific networks will be known.But we also want to outline that this method can be used in a lot of others area;for instance the set size of biological experiments which are needed to type the histocompatibility of cells can be significantly reduced by a stepwise building of experiments plan which is based on the presented method.

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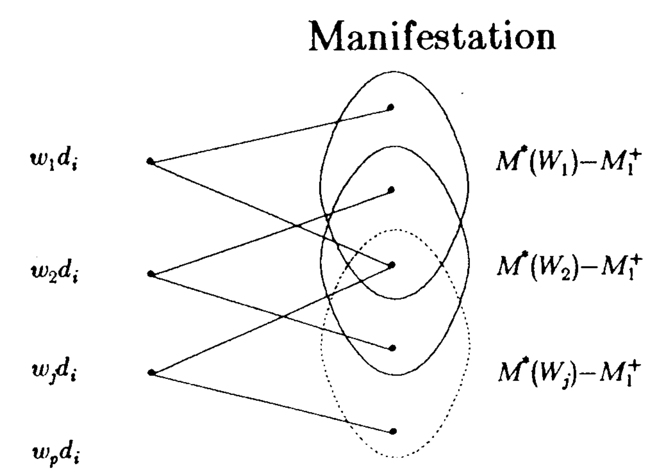

Figure 1

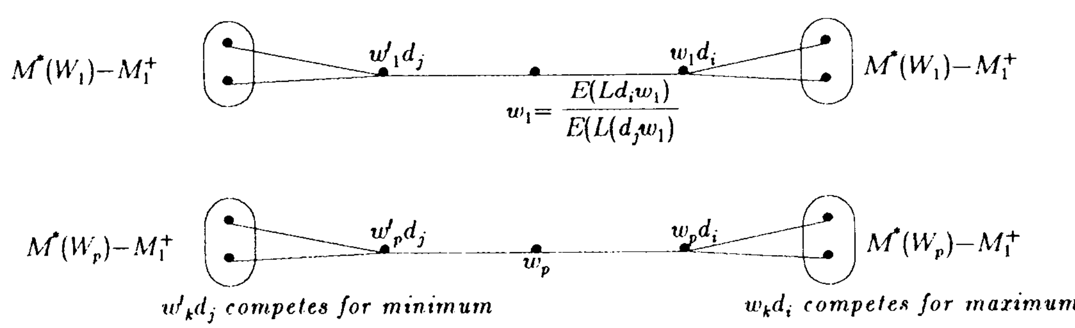

Figure 2