PRODUCTION SYSTEMS AND (URBAN) HYDROLOGY

Introduction :

This article deals with the use of methods derived from researches in **Artificial Intelligence** to automatically perform the **control of a sewerage network** in urban hydrology.
First, we will introduce the concept of artificial intelligence, and try very schematically to describe the origin, the development and the aims of such a science.
Then, we will study the characteristics of the control problem in urban hydrology, and the reasons why new methods were proposed.
The last part, deals with the construction of an **expert-system** to automatically control the a network. The involved questions and possible solutions will be discussed

I) Some words about 'Artificial Intelligence':

In the early seventies, a new knowledge field developped at the intersection between mathematic, logic, and computer science, which was called 'Artificial Intelligence'.
The denomination may seem very pretentious. The concept of 'intelligence' is actually so strongly related to the human behaviour and identity, that it hardly can be understood how a machine could be assigned such a quality.

Nevertheless, the purpose of the new science is not to build a machine whose capabilities could be compared to the humain brain. This aim would assume a knowledge which is far beyond ours, in the present time.

More simply the task consists in building systems which are able to tackle special problems, in a way that be could qualified as intelligent if it had been solved by a man.

A important part of the theoretical basis was already elaborated in the beginning and middle of the twentieth century, by mathematicians and logicians, who made researches in 'axiomatic'.

At this time, some of the questions to be solved were :
Given a set of elements with some associated properties (written as axioms).

- Is the set of properties relevant ? (consistence, completness)
- Can we add other properties and under which conditions ?

- Can I derive other properties ? (inference process)
- Is a given property to be derived from the set ? (limit of the inference process)

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Such questions remained, for several decades, the exclusive preoccupations of a limited number of mathematicians and logicians, who wrote theories about logical systems and the elaboration of methods to prove (or refute) the validity of axioms or properties.

Of fundamental interest was the question whether and under which conditions, solutions could automatically be performed. This problem found a satisfying answer in Robinson's results, who proved that, with an adequat formalism, demonstrations can be automatically performed.
In the same time, computers increased rashly their performance, and made it possible to reach another step.
Mathematicians and computer specialists associated and tried first, to develop a computer system to solve any problem, a so called 'General Problem Solver '(Newell, Shaw, Simon in 1957).

The problem proved to be harder as originally thought, and must be decomposed .

a)

- On the one hand, one tried to build different systems to cope with specific problems. This means a limitation of the validity range of the system in its solving capabilities.

As a result, a number of 'expert-systems' were proposed to solve technical problems such as
- 'the definition of the chimical composition of something'
- 'the diagnosis of special diseases' in medicine.
- 'the solving of integral equations'
...

b)

- On the other hand, researchers tried to develop computer languages, which could directly perform inference processes (set of the processes that compose a logical demonstration), without writing specific algorithms.
R. Kowalski (London) as first, analysed which should be the properties , specifications and requirements of such a language.
In the same time, A. Colmerauer (Marseille) realised a first prototype interpreter of a language which he called PROLOG (for 'PROgramming in LOGic').
These were the first steps towards conceiving a computer language which can <u>directly</u> describe an object, by means of logical propositions.
Directly means here that the built-in interpreter treat the axioms and perform demonstrations, without receiving any further informations about the way it σhoul be done (algorithms).
It shall be noted here, that there are some restrictions to be aware of (particularly about the order of the logic in which the objects shall be described).
Nevertheless, the present versions of PROLOG can be considered as an important progress in direction of '<u>a logical computer language</u>', that could directly deal with any kind of axiomatic.

Both parts of the research field influence each other.
For example, the developpement of logical languages, will greatly facilitate the writing of expert-systems.
More precisely, logical languages allowed the dissociation of the knowledge levels.
Classically, in an expert-system, a separation will be done between :

- a general induction knowledge (that composes **the inference engine**)
- the knowledge related to the given application field, where the expert-system should be utilized (that composes **the knowledge base**).

Nowadays, concepts or methods derived from the research in 'Artificial Intelligence' are applied for solving very different problems.
In urban hydrology as well, it is investigated whether these methods can be of use, particularly for the **automatic control of sewerage networks.**

II) Use of AI methods in the context of urban hydrology

One of the great problem in urban hydrology is to avoid upsets within sewerage networks specially, when a strong rainfall event occurres.

Traditionally, the dimensionning of the canalisation in the sewerage networks, are calculated on the basis of a 'design event'
This means that the network actually will be optimally utilized in case the design rainfall occurres, otherwise not. It can then happen that, in weak points of the system, overflows are registred, whereas elsewhere, storage capacity in canalisations or basins, still remains unused.

This was not a critical issue, as long as relatively small quantities of water were transported into the networks and it was relatively easy to enlarge canalisations or add news ones.

Nowadays, renovating a network has become less attractive because of financial constraints.
It was found that actually a lot of time and money could be saved, if instead of transforming the network, a way could be found to optimally control it, by using control gages (pumps,weirs,gates).

- Anyway, these control gages must often be installed because of some other independent constraints.
For example, in Bremen, the whole water which flows to the network, must be pumped to the treatment plant or to the Weser (when the treatment capacity is exceeded), because of the flatness of the catchment area. -

The issue is classicaly referred as **'research of an 'optimal' real time control strategy '**.

The criteria which allow a evaluation of a given strategy, are:

- occurrence of overflows or even floodings at given points.
- occurrence of pollution discharges into the environnemnt.-
- security constraints, in case some organ should become out of order.
- financial constraints - the energy costs should be as small as possible -.

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All these criteria (either considered as constraints or goals) must be evaluated when determining a strategy, for the next time steps. This requires that :

- the system contains <u>a strategy research module</u> which is able to analyse,at any time, the network state.

- a simulation module which simulates the behaviour of the network. The latter depends on
  - the values of the disturbance variables (rainfall intensities)
  - the values of the control variables (regulations of the control gages).

The separation of both modules is more or less emphasized, depending on the chosen method.

III) **Optimisation methods to find out the relevant strategy**

Classically, a mathematical optimisation method is proposed to find out the strategy.

Formally, the problem is considered as equivalent to the research of the optimum of a function F which depends on :

- the state (present and future) of the network Xi
- the regulation (present and futur) of the control organs Ui
- the values (present and future) of the disturbance variables Yi

This function **F(Yi,Xi,Ui)** is called the **cost function.**

The future state of the network, depends on
- the values of the present state,
- the values of the disturbances in the given time interval,
- the values of the control variables in the given time interval.

This requires the existence of a simulation model which therefore can not be separated from the cost function (The simulation model is part of the cost funktion).

<u>Difficulties and restrictions of the optimisation methods</u>

Is the best solution really found out ?

- Depending on the characteristics of the cost function, several methods are available to find out the minimum.
More general methods (which do not require any assumptions about the cost function) need much more time. They can hardly be used in real time.
This is the reason why, very often **'linear optimisation programs'** are utilized, which, on the other hand, require that the relationships between the state variables are linear too. In other words, the simulation model of the network should be linear.
Of course, this can only be a crude approximation of the processes and therefore one can not pretend anymore that the proposed solution is the best of all. The proposed solution may utmost be a good one (if the linear simulation is not too far from reality).

b) - The construction of the cost function imposes to put on the same level, very heterogeneous criteria, whose costs shall be ponderated and added.
There are seldom, enough information to decide which ponderation the different costs should be allocated.

- What is the cost of a m^3 overflow ?
It depends probably on the location.
In a very heavy populated area, people may be injured.
In a residential area, the financial costs may be higher, let alone the possibility that politically influent persons could clame.

- How can we compare the cost of a m^3 overflow and the cost of a m^3 of polluted water rejected in the environnement without being treated ?

It is often very difficult to recognise how the ponderation may influence the choice of a given strategy.

IV) A expert-system to find out the relevant strategy

People always confronted strategy research problems (whichever application field it may be). Very often, they could solve them in a satisfying way, although they did not dispose of optimisation programs.
To this purpose, they had developped some kinds of reasonning, which may be called **'an expert-knowledge in the given field'.**

This expert-knowledge is most of time, the result of years of practical experience and gives satisfying solutions.
One the other hand, it is a 'fuzzy' knowledge that can hardly be incorporated in the classical decision research algorithms and is very difficult to transmit.

In the beginning of the seventies, one became interested in constructing computer systems which store this expert-knowledge and are able to treat it : the 'expert-systems'.

A basic feature of an expert-system (in opposition with an optimisation model) is a structural separation between :

- the specifical expert-knowlege, called knowledge base.
- the treatment of this knowledge (all called meta-knowledge).

It will be here distinguished into :

- **the inference engine**
- **the explanation component**
- **the knowledge acquisition component.**

- The inference engine determines the general inference processes.

- The explanation component, traces which part of the expert-knowledge, has been used in finding the solution.
It allows the user or expert, to judge the solution (relevant or not relevant).
Such a facility is very important, specially in the developpement phase.

- The knowledge acquisition component, looks after the storage of new informations, in the long time memory (part of the knowledge base).

It decomposes into :

- a dialog interface expert - machine, if the expert can directly store new informations, in the long time memory.
- a learning module, if the system is able without any human intervention, to modify the knowledge base.
It is then assumed differentiated knowledge levels in the knowledge base.
One knowlegde level, to solve the strategy problem, and another one, to analyse how successful the solution is.

These three components are essential parts of what is called **'the shell'** of a expert-system.
If the separation between shell and knowledge basis is correctly done and if the shell uses sufficiently general inference processes, then this one shell can be used and reused, each time along with the associated knowledge base, to solve very different problems.

V) **Construction of an ES, in a practical case**

For a few years, a cooperation has been started between the institute and the city of Bremen, for the partial control of the sewerage network, on the left side of the Weser.

The network decomposes into :
- statical installations : canalisations, collectors, outlets, retention basins, a treatment plant
- control organs : pumps, weirs, gates (In the functional description of the network (simulation model), weirs and gates are modelised as pumps).

The problem is the following. One must so regulate the control organs that the minimal damage is produced.

Hierarchically ordered are the objectives :
- to avoid overflows
- to avoid pollution discharges
- to minimise the energy costs.

The control is done, by following directives or rules.
These strategy rules decompose into 2 parts :
- the condition part
- the action part

If the condition part is satisfied then the action part must be performed.
The condition part refers to the state of the network. (How high is the water level in the critical points or in the retention basins ? How much does it rain ? ...)
The action part refers to how the each control gage should be regulate.

The set of rules which constitutes in this case the expert--knowledge, is called, in the AI terminology, a **'productions base'**.
The rules in the productions base, are called, production rules

or productions.
Even facts that describe the state of the network, can formally be entered in the knowledge base (short-time memory), as rules whose condition part validity is 'true'.

The basic idea of the project, was to elaborate a computer system which stores the productions base and can automatically use it, in real time, to support the people, at the control centre.

<u>The construction of an inference engine :</u>

Assuming that the productions base exists already and can easily be written in a production rules file, the remaining task is to build the inference engine.

Formally, the inference engine, in a production system, works like a theorems demonstrator, that assumes properties (facts) and relations between the properties (rules) and tries to demonstrate the validity or invalidity of other (derived) properties (facts).
There are three several points involved.

1) How should an inference process be performed ?

2) Is it possible that contradictions occurre within a resolution process ? (consistency of the set of rules)

3) Is it possible to give an answer to all the questions I could ask in relation to the problem ? (completeness of the set of rules).

The inference Process:

There are, in principle, two ways to perform an inference process :

- the forward chaining
- the backward chaining

- In the forward chaining, every convenient rule will, in the row, be started, till the answer is found out.

A convenient rule is a rule, whose condition part, is full-filled.
To start a convenient rule, means that its action part, will be considered as proved and added to the knowledge base as a new fact (a dynamic fact).

The research is obviously not oriented. The order in which the rules are started, doesn't depend on the fact whose validity is to be proved.
This can be a very great handicap, if a lot of possibly convenient rules exist. In this case, it may happen that a lot of rules be started, which have nothing to do with the goal we want to check.

- Such disadvantages don't exist in the backward chaining. All the rules, whose conclusion (action) part corresponds to the fact to prove, will be in the row, treated. Its conveniency will be checked up.
Shall the rule be convenient, then the fact to be proved is considered proved.
Shall the rule not be convenient (some of its validity conditions can not be verified), then another rule, from the to be started ones, will be treated (such a process is named **'back tracking'**).
The 'expert-system' prototype which was realised, at the institute, implements a forward chaining.
The structure of the productions system ensures, that for each

question the number of convenient rules is limited.

A production system, directly written in Prolog, would assume a backward chaining. Of course, it is possible to write, on its own, in Prolog, a forward chaining interpreter.

The problem of consistency and completness of a production base is very difficult to tackle in a general.
For each production base, a number of tests should be performed to assure that, for every configurations, the system gives a correct result.

In Prolog, a very important point is the 'close world assumption'. It means that the validity of a fact is either true or false.
Is considered true every fact whose validity is provable.
Is considered false every fact whose validity is not provable.
Of course, in the 'real world', it is not so that a fact is false because it is not provable.

In the expert-system, that is used for the control of the network in Bremen, general checking processes are not available.

- On the one hand, the knowledge base is organised in such a way that the decision process, is basically a one step process . One rule for one decision.
The consistency can therefore easily be checked up.

- On the other hand, the world in which the inference process is performed is not a pure logical world. It means :
Instead of considering the 'validity' of facts, the system decides according to the 'probability of a validity'.
A fact is not anymore 'true' or 'false', it will be rather told that the probability it is valid, is x percent.
In this respect, several autors have spoken of a **'fuzzy logic'**.
In a fuzzy logic, the completness of the production base, is assured, since there is always a 'convenient' rule that can be started, - whose condition part has the highest probability of

validity -.
An strategy will consequently always be proposed by the system.
Whether it is relevant, is another question.