INTELLIGENT AGENT CONTROLLED SIMULATION WITH THE CASSANDRA SYSTEM

András Jávor, Attila Für

McLeod Institute of Simulation Sciences Hungarian Center
Budapest University of Technology and Economics
H-1111 Budapest, Sztoczek u. 4., Hungary

javor@eik.bme.hu (András Jávor)

Abstract

An alternative approach to the conventional ones is presented and its application for problem solving outlined. Usually a model is built, the dynamic simulation is executed and the results obtained are used. In case of ill defined or soft systems however the model of the system is only vaguely determined and first the model representing the system to be investigated adequately has to be determined. Such cases can be found in the fields of micro- and macro-economy. The development of regions and sustainable development taking also problems of environmental control into consideration poses similar problems. The solution proposed is to use the methodology of identification by reconstruction. As a first step a preliminary model is built and the simulation is undertaken using "historical" data as inputs. The performance of the model during the simulation run is monitored continuously by intelligent agents (demons) and the model is reconstructed by them to obtain a model the behavior of which represents adequately the system to be investigated by simulation. After having identified the model; its behavior under various conditions can be investigated by simulation in the conventional way. The approach described can be applied using the CASSANDRA simulation system developed at the McLeod Institute of Simulation Sciences Hungarian Center. This methodology has already been used with success in various fields. In the present paper after describing the method an application illustrating it is presented.

Keywords: intelligent agents, identification by reconstruction, Knowledge Attributed Petri Nets, sustainable development of regions, transdisciplinary models

Presenting Author's Biography

András Jávor holds the degrees MScEE, PhD and DSc in computer science. He is director of the McLeod Institute of Simulation Sciences (MISS) and also director of the MISS Hungarian Center. He is professor at the Budapest University of Technology and Economics. He is chairman of the Hungarian Simulation Society and of IMACS/Hungary, member of the Board of Directors of EUROSIM and the editorial boards of 4 international scientific journals. His publications exceed 170 items. He was visiting professor 3 times at the Aachen Technical University and invited lecturer several times at various universities in Austria, the Netherlands, Japan and China. In 2006 he was awarded the Gold Cross of Merit of the Hungarian Republic for his internationally acknowledged scientific results in simulation sciences.

ISBN 978-3-901608-32-2

1 Introduction

Although at the beginning 21st century the application of simulation to promote problem solving is already a widespread approach; usually it is used in a linear way. This means that a model of the system to be investigated is built, the simulation – under given boundary conditions and external effects – executed and the behavior of the system evaluated. However in a very wide range of fields there is a problem already at the beginning. Namely the model itself is hard to determine and there are only vague ideas about its structure and operation. Among many other cases this is true for social systems, environmental problems, micro- and macro-economy and various systems where in general human behavior has a significant influence, etc. In these cases – in order to obtain at least relatively useful and reliable information – the first step should be to determine a model corresponding to the system to be investigated with an acceptable fidelity. Consequently before executing the simulation; the determination of the appropriate model is essential. In the approach presented it is intended to solve the above mentioned problem by applying intelligent agents to do the job.

2 Principles of the Methodology

The approach proposed is the following:

- Initial model building based on the information obtained from the experts of the field.
- Run the model using historical data.
- Monitor the model behavior continuously during dynamic simulation and modify it according to the deviation of model behavior from that of the real system during the simulation run.
- After the model is determined by the above procedure of identification by reconstruction it can be used to forecast the system behavior in the future.

In order that the methodology described above should be applicable it is essential that the simulation model should be built in an object oriented way i.e. the model should be built as a network of interconnected and interacting objects.

To make this process feasible it is important that the procedure should be automated since if the model reconstruction should be undertaken with human efforts this would require enormous time and energy. Therefore the process – in our proposed solution – is undertaken by intelligent agents (demons) [1][2][3] monitoring the behavior of the simulation model continuously and modifying it [4].

The above mentioned approach is illustrated in Fig. 1.

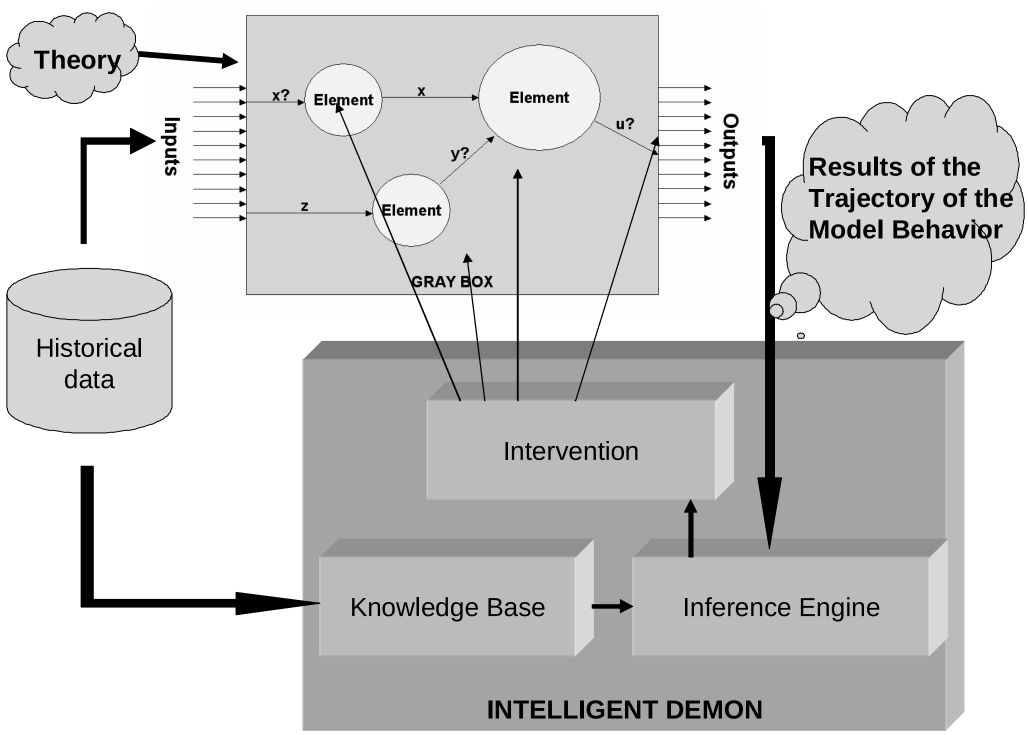

Fig. 1 Model identification by reconstruction

The intelligent demons have knowledge bases where the historical data of the model behavior in the past is stored. The anticipated model operates driven by the historical data provided to its inputs. It delivers its outputs representing the model behavior and the inference engines of the demons compare it with the behavioral information in their knowledge bases, intervene into the model structure and modify it to improve its resemblance to the real system to be investigated. This procedure continues until the initial model is modified to reveal the real system with acceptable fidelity.

The demons can evaluate the information about the model operation after preprocessing it (as e.g. average values, correlation, standard deviation, etc.). The modification of the model can be different as e.g.

- Modification of model element parameters
- Modification of model structure (i.e. changing the structure of the model element network constituting the model as a whole)
- Effects of the interconnected model elements on each other in the simulation model as a whole

3 The Applied Tool System

The tool applied is the CASSANDRA (Cognizant Adaptive Simulation System for Applications in Numerous Different Relevant Areas) simulation system. [5][6][7] The classical process of simulation consists usually of a series of simulation runs. After each experiment with the model, the results are evaluated and following the necessary modifications of the model structures and/or parameters or the experimental conditions respectively the simulation run is repeated. This iterative process is continued until the optimal or acceptable model is obtained. The CASSANDRA system aims at the automation of this process (see Fig. 2.) a number of demons possessing knowledge bases and inference engines are monitoring the trajectory of the simulation experiment continuously and modify the model structure, parameters or the experimental conditions during dynamic simulation according the goals set by the investigator of the system simulated.

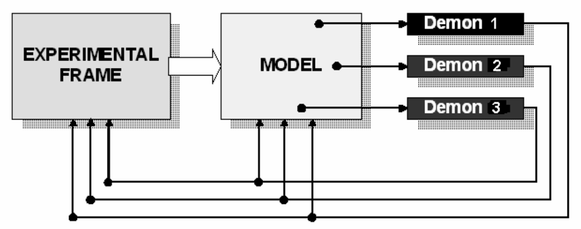

Fig. 2 Control of the simulation experiment using intelligent demons

The possibility of applying distributed AI for experimental control by utilizing more demons for monitoring and intervention in different places may contribute to the efficiency of the simulation experiment.

Another problem usually encountered in using simulation tools is the contradiction between generality and user friendliness.

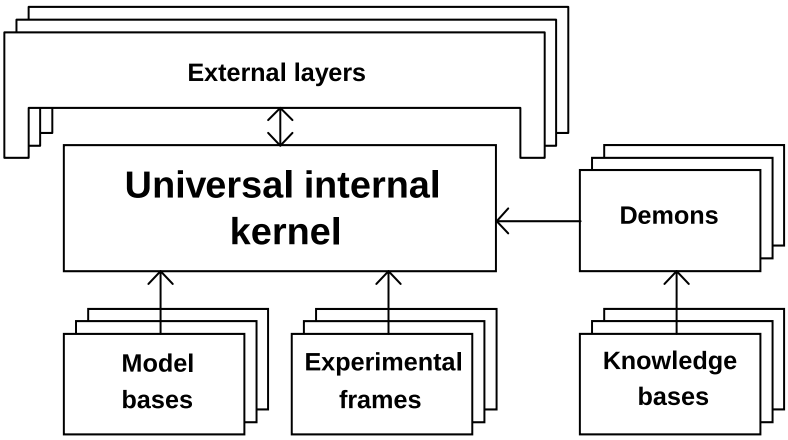

Fig. 3 Architecture of the CASSANDRA system using a universal kernel with different external layers

This means that user friendly objects can be used externally which are mapped into Knowledge Attributed Petri Net (KAPN) [8] networks of the kernel.

The architecture of CASSANDRA resolves this contradiction by using a universal internal kernel that can easily be adapted to the demands of the users of various fields of application

[9][10][11][12][13] (see Fig. 3.). The models in the internal kernel have an object oriented structure forming a network of interconnected elements. So the models represent the real systems revealing their structure.

For the internal model representation KAPN are used, and the mobile entities are represented by knowledge attributed tokens carrying knowledge bases as attributes during their movement within the model (see Fig. 4.). This enables the assignment of appropriate knowledge determining the individual trajectories of the mobile entities.

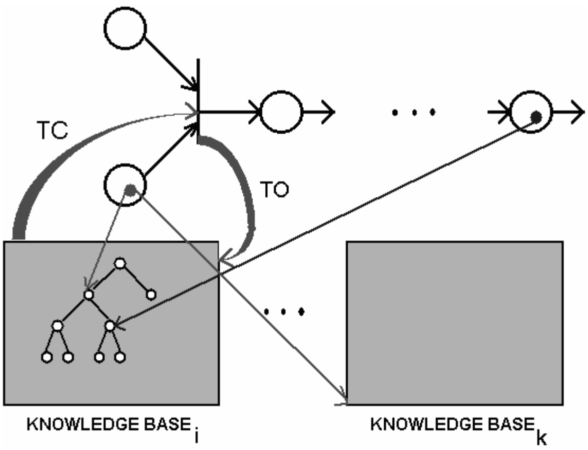

Fig. 4 Structure of the Knowledge Attributed Petri Nets

Finally the building block structure of the models can be used hierarchically enabling that multilevel models can be built with various degree of aggregation.

4 Environmental Assessment Using Identification by Reconstruction

As well known, questions of ecological economics and sustainability, regional environmental policy, protection of nature and identifying the processes of the whole biosphere are the most complicated fields of future environmental strategy that should be investigated by alternative methodologies such as model identification by reconstruction. One of the major areas of the above mentioned is the environmental assessment, that is integrated into all processes of economics and should be taken into consideration not only in the case of feasibility studies for local projects, but also for regional policy and planning sustainable development [16][18].

Environmental assessment as qualifying, quantifying, clustering, measuring of unknown or fuzzy defined quantities is a typical problem of identification of soft systems. Assessment – as a feedback phenomena for the closed loop control of nature and economy based processes – should be carried out with high precision because of the caused consequences by the interventions.

To highlight the main problem of the classical approach of environmental assessment the notional word has to be analyzed. The first part contains the word "environment". What is meant by that composition? The local physical area of living beings? Regional artificial and natural environment? The whole biosphere? It is obvious that each concept is acceptable under given conditions, but using of hybrid aspects are very dangerous, because their model scalability is limited and accuracy of measuring the environmental state will be reduced. Each real system should be approximated by the most adequate model description.

After the object to be investigated has been defined, right indicators have to be selected, that give relevant information on the change of the environmental state. At environmental model synthesis indicators reflect significance, relevant information that is selected and ranked by members of economical and natural aspects considering their points of view on the specific indicators. The same indicator can have very different meaning for different environmental elements: e.g. biodiversity is an irrelevant indicator for the artificial (built) environment directly, but it is very important from the point of view of living beings. Nevertheless air pollution has nearly the same importance for both elements: e.g. acid rains cause erosion on buildings and destroy forests as well.

As delineated it is not enough to choose the right indicators, but it is also needed to find and set the importance values (weights) for all possible elements. The following methodologies give the starting point for environmental assessment:

- A matrix $\overline{\overline{L}}$ has to be constructed, where columns (indexed with "j") give the environmental elements and rows (indexed with "i") give the indicators themselves. Its elements L_{ij} determine a kind of correlation value, importance between rows and columns. (The matrix is analogous with modified Leopold Matrix well known from the field of environmental impact assessment [14].)
- The matrix has to be normalized to one
- The relative values of matrix elements can be determined by AI controlled simulation
- Matrix elements should express importance deduced from direct influences on specific environmental element not considering secondary effects, these are viz. part of the dynamic simulation model symbolized by connections of Knowledge Attributed Petri Nets [8].

Tab. 1 Importance of indicators (Modified Leopold Matrix)

Environmental elements → Indicators↓	Flora	Fauna	Men	Artifical (built) environment	Non-living natural environment	Etc…	Sum (j)
Biodiversity	L_{11}	L_{12}	L_{13}	L_{14}	L_{15}	L_{1J}	$\sum_j L_{1j}$
Air pollution	L_{21}	L_{22}	L_{23}	L_{24}	L_{25}	L_{2J}	$\sum_j L_{2j}$
Water pollution	L_{31}	L_{32}	L_{33}	L_{34}	L_{35}	L_{3J}	$\sum_j L_{3j}$
Soil pollution	L_{41}	L_{42}	L_{43}	L_{44}	L_{45}	L_{4J}	$\sum_j L_{4j}$
Needed area	L_{51}	L_{52}	L_{53}	L_{54}	L_{55}	L_{5J}	$\sum_j L_{5j}$
State of buildings	L_{61}	L_{62}	L_{63}	L_{64}	L_{65}	L_{6J}	$\sum_j L_{6j}$
Etc…	L_{I1}	L_{I2}	L_{I3}	L_{I4}	L_{I5}	L_{IJ}	$\sum_j L_{ij}$
Sum (i)	$\sum_i L_{i1}$	$\sum_i L_{i2}$	$\sum_i L_{i3}$	$\sum_i L_{i4}$	$\sum_i L_{i5}$	$\sum_i L_{ij}$	$\sum_j \sum_i L_{ij}$

The main problem of importance of the indicators is how to determine the values for non-human beings, when even human beings cannot determine their relation to several indicators. Therefore we suggest to separate three types of importance:

- Known
- Anticipated
- Impacted (unknown)

Known type of importance is based on knowledge and real necessities. Anticipated importance is a self-determined thought qualifying that can have real and fake grounds. Impacted type importance is not directly known and can only be exposed by the methodology of model identification by reconstruction. The real importance value is compounded as the sum of the above mentioned importance.

After importance matrix had been defined it is possible to begin the evaluation of causes and effects. That can be carried out by AI controlled simulation (adequate simulation system is the CASSANDRA [2]). In that case causes and effects are mapped into an other matrix $\overline{\overline{K}}$ that is based on the Leopold Matrix and considers the following properties:

- Importance, cause and effect correlation (not equal to importance of indicators for environmental elements)
- Benefit
- Time of occurrence
- Duration
- Remedial measures
- Probability

The mentioned properties (table entries) define a FUZZY like system. The sets can have the following names e.g. in case of Importance: MAJOR, MODERATE, MINOR, in case of Benefit: POSITIVE or NEGATIVE, or in case of Duration TRANSIENT, SHORT, PERMANENT, etc.

After all the matrix elements are functions, inference engines that have the above mentioned parameters. As known the prime Sugeno-type FUZZY relation has the following form [15][17].

$$R_i : if\ x_1\ is\ A_1^i\ and\ \ldots and\ x_n\ is\ A_n^i\ then\ y\ is\ c_{i1}x_1 + \cdots c_{in}x_n + c_{i0},$$
$$i = 1, \ldots, m.$$

According to the Leopold matrix relation between causes and effects can easily be expressed by their linear combination. Elements listed at causes can also be mentioned as effects and the other way round.

Therefore two matrices have to be constructed that are transposed in their headings, but have different elements.

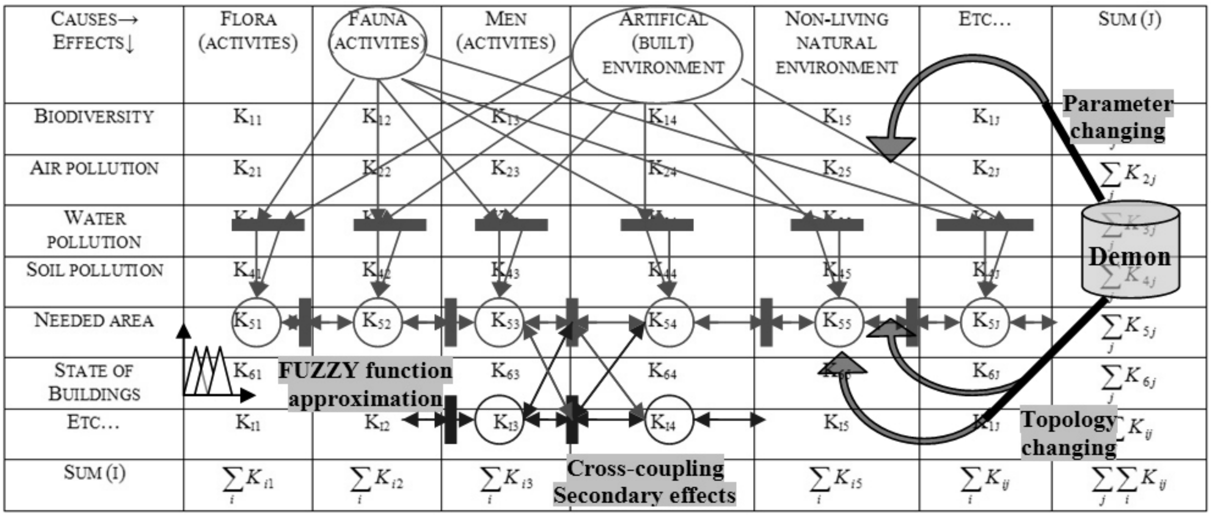

Fig. 5 Importance of indicators (Modified Leopold Matrix)

As in Fig. 5. delineated elements of $\overline{\overline{K}}$ matrix contain Wang-type FUZZY function approximations [17]; inference engines as linear combination of causes and effects. The entries are intelligent: they have influence on each other through parametric and topological connections. That concept can be mapped directly into Knowledge Attributed Petri Nets (KAPN)[8]. Global structural modification is possible through dynamic interventions of demons (intelligent agents) that execute model identification by reconstruction.

The methodology is detailed in the following:

- At start initializing the matrix elements (FUZZY decision systems) K_{ij} are needed
- The known parameters have to be built into the inference engines of entries
- Each cell has a state (FUZZY function parameters) and an output (normalized number between 0 and 1 to give appropriate numeric input to further model layers)
- The FUZZY model network as the state mentioned before (similar to Neuro-FUZZY systems[17]) have to be mapped into KAPN, where the places contain the K_{ij} FUZZY coupling between cause and effect as knowledge attributes of the tokens
- Places of effects have coupling between each other according to secondary effects
- Tokens carry the information form one entry to the other
- Effects from incoming connections are additively taken into consideration
- Moving of tokens (mobile entities) change the marking of KAPN through the firing process, so transitions will dynamically determine which parameters in which combination will give the relevant impact on the FUZZY systems on the output side
- List of secondary or unsure effects have to be listed in the knowledge bases of demons to ensure model changeability and reconstruction
- After model had been initialized measuring of matrix output elements have to be carried out.
- Model identification by reconstruction have to be carried out to recognize the right system of couplings between environmental processes
- If the trajectory of model the behavior is not stable – as in most cases of environmental analysis – dynamic interventions have to be carried out, so impacted type of importance, detailed before, have to be raised or reduced.
- When Modified Leopold Matrix (see Table 1.) will change, importance of indicators will cause change in parameters of the environmental process (quality and quantity)
- In optimal case through demon controlled modification of entries of the two mentioned matrices and topology of KAPN based model can be reached a balanced stable state of the system

This methodology is appropriate to recognize unknown processes or to find secondary effects in environmental cross-coupled systems and is able to highlight the main problem of environmental indicators in out time, namely the anthropocentric approach. Using model identification by reconstruction it is possible to find new indicators that are more sensitive and can express better the need on intervention.

As main consequence it is delineated, that environmental assessment should not only be a static examination, but it is necessary to investigate the problem as a section at time t_n of dynamic model behavior.

Finally it is revealed that according to methodology, model synthesis is suggested to carry out from the fine structure to a robust one, therefore it is suited to plan local sustainability of regions.

5 References

[1] A. Jávor. Demons in Simulation: A Novel Approach. *Systems Analysis, Modelling, Simulation* 7(1990)5. 331-338.

[2] A. Jávor. Demon Controlled Simulation. *Mathematics and Computers in Simulation* 34(1992)283-296.

[3] A. Jávor. Demons as Forerunners of Software Agents in Simulation – Invited paper. 2006 SCS International Conference on Modeling and Simulation - Methodology, Tools, Software Applications (M&S-MTSA'06), Calgary, Canada, July 31- August 2. 151-155.

[4] A. Jávor. Simulation of Soft Systems – Keynote lecture. Informatics 2005, Bratislava, Slovak Republic, June 20-21, 2005, 13-17.

[5] A. Jávor, M. Benkõ, A. Leitereg and G. Moré. AI Controlled Simulation of Complex Systems. *Computing & Control Engineering Journal* 5(1994)2, 79-82

[6] A. Jávor. Distributed Intelligence in the Control of Simulation. IMACS Symposium on Systems Analysis and Simulation, 26-30 June, 1995, Berlin, Germany, 417- 420.

[7] A. Jávor. Simulation Model Structures with Mobile and Static Intelligent Entities. EUROSIM '95 Simulation Congress, 11-15 September, 1995, Vienna, Austria, 1175-1180.

[8] A. Jávor. Knowledge Attributed Petri Nets. *Systems Analysis, Modelling, Simulation,* 13(1993)1/2, 5-12.

[9] A. Jávor. Problem Solving by the CASSANDRA Simulation System Controlled by Combined Mobile and Static AI. Summer Computer Simulation Conference, Arlington, Virginia, July 13-17, 1997. 723-728.

[10] A. Jávor and G. Szűcs. Simulation and Optimization of Urban Traffic using AI. *Mathematics and Computers in Simulation* 46 (1998) 13-21.

[11] A. Jávor and G. Szűcs. AI Controlled Simulation of the Complex Development of Regions. Summer Computer Simulation Conference, Chicago, Illinois, July 11-15, 1999. 385-390.

[12] A. Jávor and G. Mészáros-Komáromy. Investigation of the Influence of the Road Traffic Network Conditions on the Development of Regions by Means of AI Controlled Simulation. AIS'2002, Lisbon, Portugal, April 7-10, 2002. 86-90.

[13] A. Jávor and G. Mészáros-Komáromy, Simulation using Intelligent Mobile Agents. Summer Computer Simulation Conference, Montreal, Canada, July 20-24, 2003. 19-23.

[14] C.A. Barlow, J.M. Raisbeck, M. Lieberstein and R.N. Varney. *Water, Air, & Soil Pollution* Springer Netherlands, 2004.

[15] S.J. Russel and P. Norvig. Artificial Intelligence: A Modern Approach. Prentice Hall, (2002)

[16] E. Boulding Kenneth. The Economics of the Coming Spaceship Earth, Valuing the Earth. The MIT Press Cambridge, Massechusetts, London, England,1993.

[17] B. Lantos. Fuzzy Systems and Genetic Algorithms. Műegyetemi Kiadó 2002 Budapest

[18] R. Constanza, R. d'Arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R.V. O'Neill, J. Paruelo, R.G. Raskin,, P. Sutton and M. van den Belt. The Value of the World's Ecosystem Services and Natural Capital. *Nature* Vol. 387, 15 May 1997, 253-260.