USING CAUSE-AND-EFFECT KNOWLEDGE TO SOLVE COMPLEX PROBLEMS

Donald V Steward
steward@problematics.com

ABSTRACT

People are good at collecting the dots to describe complex problems, but atrocious at doing the logic to connect the dots to see what they imply. It is shown here how a computer program can help us by doing the logic to connect the dots.

Cause-and-effect statements are used to describe the knowledge of the situation from which a behavior can arise. Given an effect to be explained that could arise from that situation, the Explainer program uses abduction to find all the plausible explanations for that effect.

Then for each explanation, it finds by deduction all the effects that that explanation would predict. A valid explanation should predict behaviors that are observed to be true and not predict behaviors that are observed not to be true. The user conducts tests to determine which predictions are true and eliminates explanations that predict behaviors that are not true.

Globalization and the power of the computer have unleashed great powers to do substantial things with worldwide consequences that we may not understand, making our social problems more intertwined, much more complex, and potentially more momentous. Now we need greater problem solving abilities to deal with the consequences of these actions.

This technique can be used to resolve many different types of complex problems, including social problems that our government apparently has not been able to resolve. When these problems remain unsolved, our politicians and media tend to direct their energies to oversimplifications that lead to frustration, myths, emotions, arguments and gridlock.

1.0 What is the Explainer?

The Explainer is a method implemented as a computer program that finds explanations for what causes behaviors. Many types of problems fall into this category.

Given knowledge of a situation and given a behavior that could arise from that situation, the Explainer will find all the plausible explanations for that behavior within the scope of that knowledge. Knowledge of the situation is described by a collection of cause-and-effect statements. The behavior to be explained is an effect or set of effects. The explanation is a function of assumptions that would predict that behavior. A fact is treated as a type of assumption.

The Explainer first helps the users to collect the cause-and-effect statements that describe the situation. They may also use and possibly modify available knowledge developed by others. Over time there will develop a library of such knowledge bases.

Once it has the knowledge, it uses logical abduction [4,7] to find all the plausible explanations that would predict the behavior to be explained. Some of these explanations may predict behaviors that can be observed not to occur, and those explanations must be ruled out. It may also predict behaviors that had not yet been observed, leaving to further research to determine whether these other predictions also occur.

The Explainer uses logical deduction for each explanation to determine all the behaviors that that explanation would predict.

But this does not come right out of the box. It depends on the quality of the knowledge of the situation that is developed by the collaboration of knowledgeable people. Therefore, it is necessary to have a critical learning process to develop that knowledge. So given an explanation, the Explainer will produce a scenario showing the logical steps by which it developed that explanation. This scenario needs to be looked at carefully to see what can be learned from it and how the knowledge can be improved. This should be an ongoing process.

2.0 What are some of the types of problems the Explainer can deal with?

Many types of problems can be stated in terms of what causes behaviors, and thus can be addressed using the Explainer, such as:.

- Medical diagnosis
- Finding the causes of the failures of machines or processes to behave as intended.
- Gaining an understanding of what might have happened in the past such as understanding history or the culture that left certain artifacts found in archeological digs.
- Understanding what may have happened in the course of committing a crime in order to identify the culprit.

The Explainer method can also be turned around to find what would cause a desired behavior by first explaining the desired behavior and then

turning the assumptions that would explain it into actions to produce it.

This approach can be used to make plans by explaining the goal of the plan and finding the steps that would realize that goal.

Or it can be used to design something by describing its likely components with cause-and-effect statements and asking the Explainer how to use these component descriptions to explain the requirement specifications of the design.

The various uses of the Explainer are very broad and limited primarily by the imagination.

3.0 The Brainer – A Speculation

One conceivable application that would be very interesting, but has not yet been adequately studied is to use the Explainer to produce a device that can learn to understand and work with its environment. This would extend the concepts presented in [1]. I call this device a Brainer. It would use its sensors to monitor its environment, looking for pairs of events that occur frequently within a reasonable interval of time, and always in the same order. These would be candidates for cause-and-effect relations and would be provisionally added to its cause-and-effect library.

By using its sensors and actuators, it could experiment on its environment to test what it observed as apparent cause-and-effects, improve its knowledge, and try to achieve its needs and desires.

Philosophical questions about epistemology and ontology might be seen in a new light in reference to such a model.

4.0 A Big Surprise! It's more complex than we ever thought

I expect that most people without the aid of a computer might be able to handle perhaps five interrelated issues and maybe two levels of logical reasoning at most. However, the analysis of the economic crisis and wealth gap using the computer required considering over thirty interrelated issues and nearly twenty levels of logical reasoning. I suggest that this could not have been done without a computer. It tells us why many of our complex social problems have not been adequately solved.

5.0 Why do we need an Explainer?

Search engines can retrieve information or reveal how someone has already solved a problem.

However, to solve new problems requires both information and relations between aspects of that information. Such a problem may be: 'What is the cause of the economic crisis and widening wealth gap?'

As the world has become more interconnected, the social problems we face have become more complex, and the consequences of decisions are less understood yet more momentous. Failure to solve our complex social problems is causing chaos and is leading us to our ruin.

When problems cannot be solved, people resort to oversimplifications, myths, and fallacious reasoning. This leads to ambiguities that result in constant bickering, power plays, threats, and hostilities. Congressional gridlock and its simplistic focusing on quick deficit reduction with no consideration of the future is just one illustration of oversimplification.

People try to live by a consistent model of their world. But they are limited by how consistent they can make their model, in great part because they are unable to use logic.

Various people develop different models with different deficiencies. Then they argue over whose model is correct. But it is likely that neither of their models may be correct.

People tend to become upset when they are presented with deficiencies in their models. This often occurs when one person's model conflicts with another's. The more defects in the models, the greater likelihood discussions will end in arguments.

The premise of this article is that using the computer to help them do the logic will minimize these deficiencies and should reduce the conflicts between people.

People tend to group with others who do not reveal deficiencies in their models, and become hostile to other groups that do reveal their inconsistencies. This leads them to become frustrated, causing them to resort to oversimplifications, myths, and useless arguments.

The premise of this article is that by using a computer to help do the logic, these different groups can produce better models and reduced the conflicts between them.

The Explainer is an aid that allows people with different knowledges to collaborate to develop more compatible and less conflicting models of their worlds. This will help them solve problems rather than engage in eternal conflict.

6.0 A closed-finite non-classical logic

A non-classical logic based on a closed finite system is used here. This differs from the classical logic in [2, 3, & 5].

It is assumed that no effect outside the system being studied can cause any effect within the system. It is also assumed that the system is finite so that if no effect within the system causes something to be true, it is assumed to be false.

Two forms of implication or cause and effect are assumed. 1. A implies/causes B, and 2. A implies/causes NOT B. If A is false, it is assumed that it has no consequence on B.

In working with graphs later, the arc for A implies/causes B will be given a positive label, while the arc for A implies/causes NOT B will be given a negative label.

7.0 How does the Explainer work?

7.1 Elimination by substitution

To find the behavior as a function of the assumptions that would explain it, we need to eliminate the intermediate effects in the cause-and-effects that stand between the behavior to be explained and the assumptions that would explain it.

To see how this works, let us first see how the analogous process works when solving systems of simultaneous linear algebraic equations by using substitution to eliminate intermediate variables. Consider the following example:

X_1
$2*X_1 + X_2 = 4$
$3*X_1 + X_2 + X_3 = 6$
Substituting X_1 into the second equation , we get:
$X_2 = 4 – 2*X_1$
And by substituting X_1 and X_2 into the third equation, we get:
$X_3 = 6 – 3*X_1 - (4 - 2*X_1)$
So that
$X_3 = 2 – X_1$

So now X_3 is a function of only X_1 after elimination of the intermediate variable X_2 .

In the logic analogy, X_1 plays the role of an assumption, X_2 plays the role of an intermediate effect to be eliminated, X_3 plays the role of the effect to be explained. There can be multiple assumptions, multiple effects to be explained, and multiple intermediate effects to be eliminated.

Note that all the X's here are on or below the diagonal in what is called lower triangular form. We can also eliminate intermediate effects in cause-and-effect expressions by an analogous elimination by substitution process provided we could order the expressions so they are in lower triangular form. But if we cannot, this implies that there is a circuit in the cause-and-effects, which must be handled differently than we could in dealing with algebraic equations.

7.2 Some computational considerations

When doing elimination by substitution with logical expressions, redundancies such as A OR (A AND B) that can be replaced by the shorter A may occur. Such redundancies can cause further redundancies until the process overwhelms the computational capacity of the computer. Thus, these redundancies must be eliminated as quickly as they occur.

When there are many cause-and-effects included in the knowledge base that are not pertinent to a particular problem, some of the eliminations by substitution may be avoided by using an inverted list to pick out just those expressions that are pertinent to the problem. Expressions that do not need to be considered can arise as for example in a medical knowledge base where the knowledge base contains knowledge about many aspects of the body, but the current problem concerns only what affects the circulatory system.

Done incorrectly, generating an inverted list can consume an immense amount of computing time by processing the whole original list for each element to be stored in the inverted list. So to do this efficiently, one should process the original list once just to count the number of occurrences of each element to be stored in the inverted list so that in a second pass of the original list, each element can be put directly into its proper place in the inverted list.

8.0 Handling cause-and-effect circuits

To handle circuits in cause-and-effects, we must first find the circuits. For this, we use graph theory. We convert the effects into nodes and the cause-and-effect relations into labeled directed arcs. If A causes B, the arc from node A to node B in the graph is labeled 'positive'. If A causes NOT B, the arc from node A to node B is labeled 'negative'.

Now that we are working with a graph, we can partition the graph into blocks. For this partitioning operation, we ignore the signs of the arcs and ignore the distinction between ANDs and ORs. We are only interested in what is connected to what.

A block is a subset of nodes and arcs such that there is a path from every node in the block to every other node within the same block but this would no longer be true if any other node were added to the block [6]. Now each circuit is confined to be within a block.

When we return to considering logical expressions rather than just arcs, we must take into account the ANDs and ORs. If a block contains ORs, the ORs must first be converted to ANDs and NOTs by De Morgan's rule, A OR B = NOT(NOT A AND NOT B), before the elimination process begins.

If we consider each block by itself and ignore any arcs entering or exiting the block, it can be shown that the labeling of the nodes within the block as true or false consistent with the arcs will have

precisely two what are called homogeneous solutions, or else no solution if there is an inconsistency..

Now the role of the circuit is replaced by two structures. The first is what we call jump-over arcs that replace the circuit during the elimination of intermediate variables. The second is not involved in the elimination of intermediate variables process. It labels the nodes in the homogeneous solution as true or false depending on which homogeneous solution is pertinent. The pertinent homogeneous solution is the one where the truth-value of the incoming node matches the same truth-value of that node in the appropriate homogeneous solution. Multiple input variables may also match the truth-values of the same homogeneous solution. If not, then both homogeneous solutions occur.

The truth-values of the nodes in the homogeneous solution are set by introducing an artificial node labeled 'true'. Then the truth-values of the nodes in the homogeneous solution are established by being joined to the artificial truth node either by a positive or negative arc.

The labeling of the nodes in a block to obtain one homogeneous solution begins with choosing one node, labeling it true and then labeling the other nodes to be consistent with the arcs. The second homogeneous solution is found by labeling the same initial node false and labeling the other nodes consistent with the arcs.

The true or false labeling in one of the homogeneous solutions will be the opposite of the labeling in the other homogeneous solution, i.e. a true in one will be a false in the other and vice versa.

If the block contains any circuit in which there is an odd number of negates, no consistent labeling is possible. This implies that if a node in that circuit were labeled true, the arcs would then imply that that same node must be false; a contradiction. This indicaes an error in the formulation of the problem that should be reported back to the user for reconsideration, i.e. the error is in the semantics.

An input node is an external node that has a direct effect on a node inside the block. An output node is an external node that is directly affected by a node within the block.

Consider an input node A_o outside the block that directly causes an effect A_i within the block, and a node B_i inside the block that directly causes an effect B_o outside the block. Then there is a jump-over arc from A_o to B_o for every combination of input node A_o and output node B_o.

If in the relevant homogeneous solution, A_i and B_i are labeled with the same truth-value, then the replacement arc from A_o to B_o has a positive label meaning that A_o implies or causes B_o. If in the same homogeneous solution A_o and B_o have opposite truth-values, then the replacement arc from A_o to B_o has a negative label.

In this way we find a jump-over arc for every combination of an input node and output node for that block.–These jump-over arcs replace the circuit so that their consequences are the same as the circuits so they can be used during the elimination of intermediate effects.

The truth-values of the effects in the relevant homogeneous solution are fixed by the selection of the appropriate homogeneous solution, which in turn is established by the inputs to the bock. They affect the outputs of the circuit. But they are not involved in the elimination by substitution process. However, the replacement arcs from the inputs to the outputs of the block are involved in the elimination by substitution process.

The truth-values of the effects within the block must be forced by creating an artificial new node labeled 'True'. The truth-value of each effect in the homogeneous solution is forced by being caused either by a positive or negative arc between this artificial 'True' node and this node.

It is possible that one input to a block may select one homogeneous solution, and another input to that same block will select the other homogeneous solution. Then both homogeneous solutions will occur as two sets of solutions separated by ORs.

9.0 If Expert Systems or something else can already solve the problems that the Explainer solves, then why have these other methods not already solved these problems?

- The Explainer is the only method I know that can handle circuits in cause-and-effects.
- Unlike Rule Based Systems, the Explainer does not suffer ambiguity due to the order in which the rules are applied.
- The Explainer can in addition to proposing causes for behavior to be explained, can also suggest to the problem solver what tests are needed to rule-out those explanations that predict behaviors that do not occur.
- The rules for expert systems are usually intended to be entered by those who have some experience in programing. The Explainer is intended for use directly by the domain expert.

10.0 A simple case of medical diagnosis with no cause-and-effect circuits

10.1 Cause-and-effect representation

EFFECT A
CAUSED BY
B
C
OR CAUSED BY
D

Means A is caused by (B AND C) OR D

10.2 The pertinent medical knowledge

EFFECT Headache
CAUSED BY Migraine
OR
CAUSED BY Sinus Headache
EFFECT Migraine
CAUSED BY Dilation of Blood Vessels
EFFECT Sinus Headache
CAUSED BY Sinus Pressure
EFFECT Sinus Pressure
CAUSED BY NOT Drain Sinuses
EFFECT Drain Sinuses
CAUSED BY Constricted Blood Vessels
EFFECT Dilation of Blood Vessels
CAUSED BY Reaction to constricted blood vessels
EFFECT Reaction to Constricted Blood Vessels
CAUSED BY Constricted Blood Vessels
EFFECT Constricted Blood Vessels

CAUSED BY Taking Vasoconstrictor
EFFECT To be explained
CAUSED BY Headache

Then we ask this knowledge what could cause a headache. The response is:

EFFECT Headache
CAUSED BY NOT Taking Vasoconstrictor
OR CAUSED BY Taking Vasoconstrictor

So taking a vasoconstrictor under different circumstances can either cause or prevent a headache. To distinguish the two possibilities, we chose the initial state as 'Headache' AND 'Taking Vasoconstrictor' and look at a scenario to tell what would be the consequences.

10.3 Rules for developing scenarios

A term is a conjunction of variables. A scenario uses the following rules:

- A term is True if all its variables are True
- A term is False if any of its variables are False
- A term is Unknown if at least one of its variables is unknown and none of its variables are False
- An explanation is True if any term is True
- An explanation is False if any term in its explanations is False and no term is True
- An explanation is Unknown if no term is either True or False

The scenario showing the consequences if the patient has a headache and is taking a vasoconstrictor is shown below. Each effect is true unless shown otherwise.

10.4 Then the consequences are:

EFFECT Headache
EFFECT Taking vasoconstrictor
EFFECT Constricted Blood Vessels
CAUSED BY: Taking Vasoconstrictor
EFFECT Drain Sinuses
CAUSED BY: Constricted Blood Vessels
EFFECT Reaction to Constricted Blood Vessels
CAUSED BY: Constricted Blood Vessels
EFFECT Sinus Pressure IS FALSE
CAUSED BY: Drain Sinuses
EFFECT Dilation of Blood Vessels
CAUSED BY: Reaction to Constricted Blood Vessels
EFFECT Migraine
CAUSED BY: Dilation of Blood Vessels

Thus:
EFFECT Headache
CAUSED BY: Migraine

There are also other apparently different mechanisms for causing migraines, such as hormone imbalances. These may be added to the knowledge. It may also be worth investigating whether these are totally different mechanisms, or whether they also work though the same mechanism of dilating blood vessels.

11.0 Transition from discrete logical model to continuous model

A discrete logical model can provide the structure on which continuous calculations may be hung. But this requires the development of an intermediate transitional model. Each arc in the

transitional model represents a computation to be made in the continuous model.

Where the logic model only shows whether an effect is true or false, the transitional model shows different mechanisms where magnitudes to be calculated and added together.

New rules are used in this transitional model. If the arc is positive, false at the tail of an arc will produce false at the head of the arc. If the arc is negative, false at the tail will produce true at the head. However, when magnitudes are computed, the signs of the arc are instructive, but less relevant and can be ignored.

The following example shows the use of mechanisms and the new rules as well as being an example of how circuits are handled.

The exits from different mechanisms are shown as different nodes. In the corresponding continuous model, the magnitude of each effect is computed and added to determine the net effect.

The following is part of a larger model used in finding the cause and proposing a resolution of the economic crisis and widening wealth gap.

Figure 1 shows the labeling of the nodes in the diagrams of Figures 4, 5, and 6. A bar across an arc means that the arc is labeled negative. Figure 2 shows the *from-to* of the arcs and their sign in Figure 4. Figure 3 shows the two homogeneous solutions, A and B.

Figure 5 shows the replacement for the circuit by an arc that jumps over the circuit so the elimination of intermediate effects/nodes can proceed.

Figure 6 shows the true-false labeling of the nodes in the homogeneous solution. Since the input arc would cause 1 to be false, and the homogeneous solution A also has 1 as false, solution A represents the labeling of the nodes within the circuit.

1	Increase in automation
2	Increased payments for jobs
3	People able to afford products and services
4	Businesses able to sell products and services
5	Businesses able to hire
6	Increase in money available to invest
7a	Production of Goods and Services-Mech. a
7b	Production of Goods and Services-Mech. b
7c	Production of Goods and Services-Mech. c

Figure 1 - Labels for nodes

1	2	-
2	3	+
3	4	+
4	5	+
5	2	+
2	6	-
1	7a	+
6	7b	+
4	7c	+

Figure 2 - Arcs from node in column 1 to node in column 2 with sign of arc in column 3.

	A	B
2	False	True
3	False	True
4	False	True
5	False	True

Figure 3 - Homogeneous solutions A and B

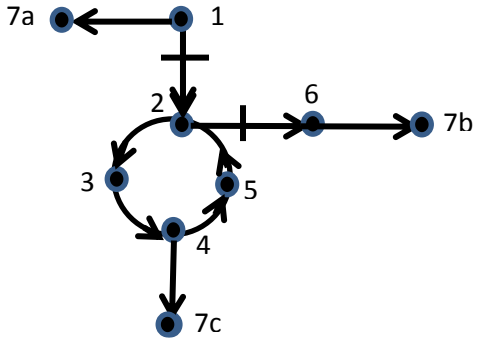

Figure 4 – Diagram of cause and effects

A path with an even number of negatives can be replaced by a positive arc, while a path with an odd number of negatives can be replaced by a negative arc.

Figure 5 –Jump-over arc for circuit

This shows that an 'Increase in automation' can cause an 'Increase in money available to invest', but a decrease in 'Jobs'.

The question today is will the 'Increase in money available to invest' actually be invested, or will it be held out of the economy.

Another cause found in the more complete model is that a lender can gain an advantage over the borrower by hiding from the borrower the

information the borrower needs to understand his self-interests, as was done in sub-prime mortgages.

11.0 BIBLIOGRAPHY

[1] Gopnik, Alison, (2009) *The Philosophical Baby*, (Farrar, Straus and Giroux)

[2] King, Ross D., Oliver Ray, Amanda Clare, Maria Liakata, Larisa Soldatova, Ken Whelan "Towards the automation of scientific method" *21st International Joint Conference on Artificial Intelligence IJCAI'09*

[3] Pearl, Judea, (2000) *Causality: Models, Reasoning, and Inference* (Cambridge University Press)

[4] Peng, Yun & James A. Reggia, *Abductive Inference Models for Diagnostic Problem-Solving* (1990) (Springer; 1st edition)

[5] Russell, Stuart. & Peter Norvig, (2003) 2nd ed., *Artificial Intelligence: A Modern Approach*, (Prentice-Hall of India)

[6] Steward, Donald V, (1981) *Systems Analysis and Management: Structure, Strategy and Design*, (Petrocelli Books, Inc., now McGraw-Hill)

[7] Walton, Douglas (2004) *Abductive Reasoning* (The University of Alabama Press)

[8] http://problematics.com/readings.asp/ APPLICATIONS-E shows demonstrations of Explainer applications to several problems.