

The Event Bush as a Potential Complex Methodology of Conceptual Modelling in the Geosciences

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Abstract: The event bush is a new method of artificial intelligence proposed specially to meet the needs of geosciences, from basic research to communication with non-professionals. First results of its application as well as combination of event bush with mathematical and logical formalisms are encouraging, and the method has shown some advantages to existing approaches, as well as an ability to unite them and become a complex integrated methodology. However, since the very first steps, it turned out that the way of thinking that underlies event bush differs from virtually all existing pathways of thought perceived in the Earth sciences. This paper aims to provide the practical guidelines for building event bushes. For this, it describes the method through an example, chosen to be clear to any geoscientist and even non-scientist. The procedure of inference in the event bush is considered in positional (graphic) and semantic aspects. Interrelations of event bush with existing formalisms and ways of thinking are discussed. Recommendations are formulated to make the best use of event bushes in practical reasoning.

Keywords: Event bush; Conceptual; Artificial intelligence; Geoscience; Knowledge; Reasoning.

1. INTRODUCTION

A new method of artificial intelligence, the event bush, was proposed specially to meet the needs of geosciences, from basic research to communication with non-professionals (Pshenichny and Khrabrykh, 2002). It aims to act as an intermediary between hardly formalized, loose, and largely intuitive knowledge, from one side, and strict methods of mathematics and logic providing quantitative computation and logical inference, from the other. It also intends to bring our knowledge into an intuitively clear framework to make it better understood by students and non-professionals.

First results of its application to various geoscientific tasks (Pshenichny and Fedukov, 2007; Behncke and Pshenichny, submitted) as well as combination of event bush with mathematical and logical formalisms (Nikolenko and Pshenichny, 2007; Pshenichny et al., 2008) are encouraging. However, since the very first steps, it turned out that the way of thinking that underlies event bush differs from virtually all existing pathways of thought perceived in the Earth sciences, be it essentially inductive and non-strict traditional geological consideration (for example, reconstruction of geological history), modelling in terms of physical parameters, building of a single-root event/probability tree (Newhall and Hoblitt, 2002), or compilation of a Bayesian belief network (BBN; Jensen, 2001; Aspinall et al., 2003) based on the expert's knowledge and intuition.

The purpose of this paper is to provide some guidelines to allow one to build an event bush. For this, the principles and application of the method are viewed through an example, which is deliberately taken far from the geosciences. We hope that this will make the procedure clear even to a non-scientist and prove the wide scope of the presented method.

The event bush itself is a firmly defined formalism based on the graph theory (e.g., Tutte, 1998). It is linked to some other formalisms like BBN and allows highly formal management of terms. Still, formalization of geoscientific and alike contents is a complex and still unresolved problem. Therefore, the construction of an efficient event bush for a particular domain of knowledge until now is largely a matter of intuition and may need repetitive tries, redefinition of entities, shifting their positions and interrelations to reach the "best fit" to the modeled domain. Therefore, the example of application is, in fact, an experience of our reasoning at solving a problem with an event bush, not necessarily straightforward from the very beginning and still not sufficiently formalized. Some of the results described below should be considered working guesses awaiting their strict formulation. Nevertheless, we believe that the reasoning we follow is efficient, and would like to share our experience.

2. PRINCIPLES OF CONSTRUCTION OF THE EVENT BUSH

2.1 Getting Started

Informally speaking, the method of event bush can be compared to creating a script for a cartoon, or, yet more precisely, for a computer game. One specifies characters and background, makes assumptions stating what these characters principally may and may not do, and how the background, or environment, may affect their action. Based on this, the imagination of scriptwriter creates a family, or a cluster, of alternative scenarios plausible from the point of view of the assumptions made. These scenarios have definite beginning and end, and are put in uniform and uniformly understood, though not necessarily well-defined, terms ("gun", "monster", "labyrinth", etc.). We believe that in such a way one may adequately describe various domains of geoscientific knowledge of virtually any contents (e.g., action of pollutants in subsurface, eruptive activity of a volcano, seismic hazard, urbanization in a river valley, ore formation and extraction at the seafloor).

However, the example we are going to consider here is equally far from all the abovementioned. Suppose that you are a father of a boy who asks you to let him go for a walk in a wood near your home for a couple of hours in the afternoon. You know that a fog may occur. What would your reasoning be to make a decision?

1. First of all, let us define the area of reality. To make a decision, one should reason on “what can happen if a boy goes for a walk”. This is a fair entitlement for the said area and, simultaneously, for the corresponding event bush. Note that it distinctly splits into two parts, “what can happen” and “boy goes for a walk”. (Though, formal ground for this division still needs to be defined.) Let us plot the former on the top, and the latter, on the left of the future graph (Fig. 1). General flow of scenarios will be from left to right; modifications will come from top. It is solely up to us what to put where. If our concern is *what can happen to a boy*, then we should put this phrase on the left; if we want to know *what can happen to a boy*, then “boy goes for a walk” goes to the left, and the other phrase, to the top. Right column and central field remain blank so far.

2. Below each phrase, we will add the appropriate details that we know and/or want to consider. Thus, at the left, we put the boy who goes for a walk and the father who stays at home (Fig. 2).

We may add other family members, neighbors, friends, accidental passers-by and whomever and whatever else we consider relevant (e.g., hungry wolf, dead tree longing to fall down onto somebody's head, and so forth). These will be the “type one entities” (Pshenichny et al., 2008) denoting

the primary, not overlapping and non-unique inputs (basic objects, processes or tendencies). These inputs would predetermine any further course of events (“happenings”) in the modeled area. Either we use a classification to define them, or simply take any entities we like, just making sure that we always mean different things by different words.

At the top, just to start with, we put the circumstances of the supposed walk that we know: in a wood, for a couple of hours, in the afternoon, with possible fog. These circumstances, after some revision, will become environmental entities of the event bush. They will indicate the way the environment may independently affect the primary inputs or influence their further, indirect manifestations, thus “shaping up” different

“happenings” – what if the boy walks in a wood, what if he gets in a fog, and so forth.

3. Now we should analyze the primary and environmental entities we selected and formulate simple statements describing them. Simple statements are those

that have one subject and one predicate (e.g., “Fog occurs”),

and hence, no logical connectives like AND, OR, etc. With these statements, we will begin to construct the bush. Editing them still relies on intuition and is determined by the context. Environmental entities are the circumstances that may happen or not in the environment. As we are interested only in the walk in a wood, the entity “in a wood” is unlikely to be

	What can happen	
Boy goes for a walk		

Fig. 1. Setting the task to compose an event bush

	What can happen	
	In a wood For a couple of hours In the afternoon With possible fog	
Boy goes for a walk Father stays at home		

Fig. 2. Adding entities (i) and (ii) to the bush draft

regarded as such. At present, we add it as a property to the boy's walk (the first-type entity). If nothing peculiar comes out of it, we may reject it all.

The circumstances “for a couple of hours” and “in the afternoon” seem to make sense together: the matter is obviously not a fixed duration of walk but coming back before dark. Then, these two circumstances can be fairly well expressed by one statement, “It is getting dark” (with the truth values “yes”/“no”).

Similarly, the possibility of fog can be expressed by a simple statement “Fog occurs” (yes/no).

The first-type entities are also transformed into simple statements with assumed truth value “yes”. The fact that father is at home can be expressed directly, “Father stays/is/remains/etc. at home”. Concerning the boy, we have to pick up the circumstance expelled from the top, “in a wood” (Fig. 2). Also, we may formulate the same idea in a number of ways, “Boy goes for a walk in a wood”, “Boy is walking in a wood”, “Boy follows his way in a wood”, etc. We may make final choice later. The statements (i) of the first-type entities may change their formulation (say, become compound) but unlikely be added or removed (that means, we will go ahead with the same two), while the environmental statements (ii), vice versa, must remain simple and may not change their formulation once added to the bush, but may be added anew, as well as moved from the top or removed from the bush at all.

2.2 Developing the Bush

Now we plot the statements, which we have had, in the form of nodes (Fig. 3) and begin the procedure of inference in the bush. The inference is assumed to be represented by an “IF... THEN...” relation and is graphically expressed by an arrow (directed arc). Making the inferences from statements (i) with or without participation of (ii), we obtain various “happenings”, which we term as secondary entities (being iii, after the primary, i, and environmental, ii), and tertiary end results (iv). Their location is shown in Fig. 3.

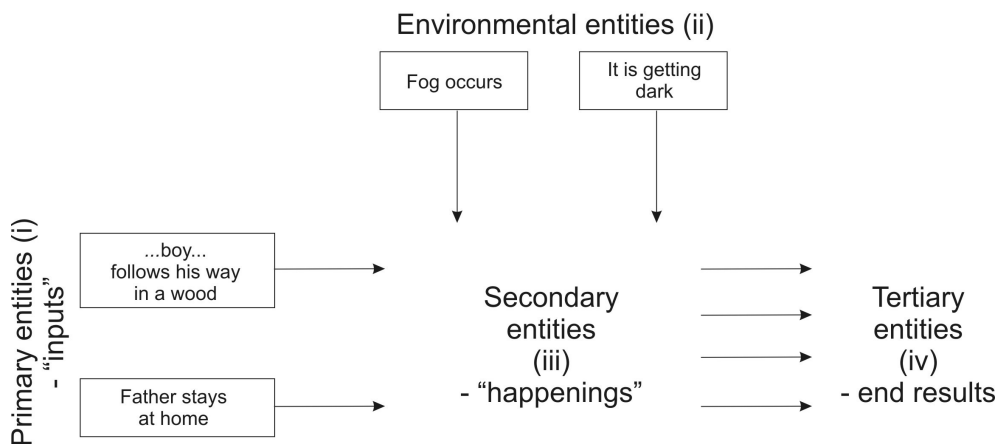


Fig. 3. Architecture of the event bush

In general,

1. statements (i) and (ii) must not lead to other (i) or (ii);
2. statement (ii) may lead to a statement only together with (i) or (iii);
3. statement (iii) must not lead to (i) or (ii);
4. statement (iv) must not lead to (i), (ii), (iii), and another (iv) (Pshenichny et al., 2008).

Inference in the event bush is determined graphically and semantically.

Graphically, the simplest inference is that of one statement from another, e.g., “IF Father stays at home THEN Father stays at home”. Another example could be, IF “... boy gets wet” THEN “Boy... becomes sick”. The nature of omission dots will be explained below.

This kind of inference implies four positional options itself,

- IF (i) THEN (iii),
- IF (iii) THEN (iii),
- IF (iii) THEN (iv),
- IF (i) THEN (iv).

Also, two statements may lead to one. This operation is called *combination* of premises (Pshenichny et al., 2008) and attributed the connective AND. An example of combination is IF (“... boy... follows his way in a wood...” AND “Fog occurs”) THEN “... boy... follows his way in a wood in a fog” (Fig. 4). Only pair combination is adopted in the event bush. Aiming to combine three or more statements, one should ensure that a combination of at least two of them makes sense in the considered domain, and its result makes sense in combination with at least one of the remaining statements, and so forth, otherwise combination is not permitted (see example in Pshenichny et al., 2008). Moreover, in each combination, we distinguish the main and the modifying premises – e.g., “Boy follows his way in a wood” (or whatever formulation we choose) is the main member, and “Fog occurs”, the modifying one. On a graph, combination is marked by a rounded crossing (“right turn”) from the main premise to the conclusion. As is seen from the above, there is notable difference between combination and logical conjunction.

Besides, one statement may lead to a number of statements. This is the operation of *division* of corollaries, which is marked by a circle in Fig. 5. The circle implies that the resulting statement is compound and includes alternatives listed via OR (IF “... boy... follows his way in a wood in a fog” THEN (“... boy... loses his way in a wood in a fog” OR “... boy... walks slower in a wood in a fog” OR “... boy... admires the fog following his way in a wood”). Each alternative represents a separate node of the bush. Like in the probability theory (and unlike the disjunction in logic), the statements resulting from division must comply with additivity condition, i.e., be mutually incompatible and exhaust the whole variety of possible outcomes seen by an expert.

Wishing to express a case that the options are compatible, one may put several arcs going out of one node (in Fig. 5, another arc leads from “... boy... follows his way in a wood in a fog” to “... boy... gets wet following his way in a wood”). This means that a statement can lead to any number of others, in combination with another statements or itself. However, drawing each next arc from a node, one should make sure that the newly introduced statement denotes a consequence really compatible with those denoted by the statements already derived from this node. Otherwise a new arc must begin not from the node but from the division mark (circle).

Two operations one after the other are not permitted in the event bush; a node must be in between. In other words, each result of each operation must be named. Thus the graphic issue comes to intersection with the semantic one.

Semantically, the event bush does not require strict definition of terms, nor does it insist on exhausting enumeration of all possible entities (i) and (ii). Still, to make maximum use of the event bush, one should very accurately manage each word introduced in any node. Strict and formal semantic rules are expected to be developed for the event bush method in the language of predicate logic. However, semi-intuitive guidelines, which notably increase the representative power of the event bush, can be introduced right now.

Regarding any statement (node) that is already present in the bush, we may specify, at least informally, what corollaries it may, or must, have. For instance, let us put that statements “Father/son... gets into a fog” must have two independent groups of corollaries – one, consisting at least of two statements describing whether the person is lost (these corollaries are listed via OR), and the other, consisting of one statement telling quite a different thing – that the person has got wet. Also, we may agree on that the statement “It is getting dark” may be combined in our bush (and hence, have corollaries) only with those statements describing the boy, which are, in turn, the corollaries of “(Something else) AND Fog occurs”. This is reasonable if we consider a case that the fog, if happens, does in the

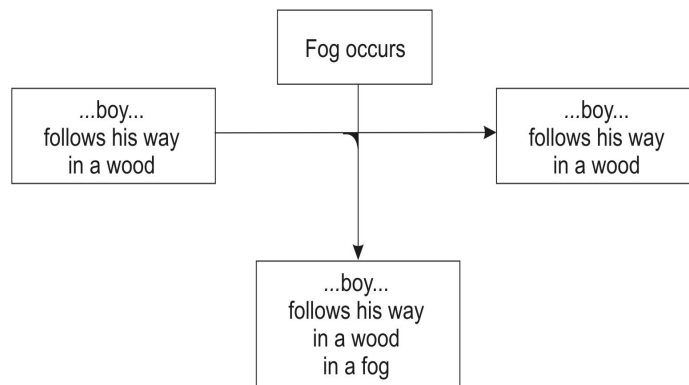


Fig. 4. Operation of combination in the event bush

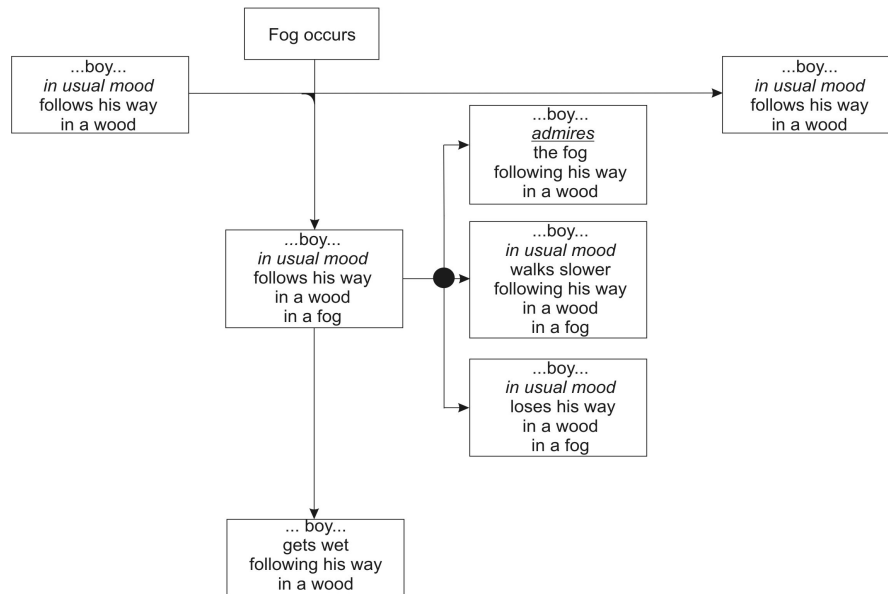


Fig. 5. Operation of division and multiple compatible corollaries in the event bush.

afternoon, well before it begins to darken, and the boy, whose intention was to go for a walk to return before dark, is disciplined enough not to be late without a reason. Meanwhile, statements describing the father are not subject to this rule, because father may leave home and seek for the boy precisely because it has already become dark – certainly, if we believe that fog is the only circumstance that may impede the boy's return before dark. It is noteworthy that we have made quite a few of additional remarks, or assumptions, at a pretty small step. These are,

- fog happens in the afternoon but well before dark,
- boy wanted to be back before dark,
- boy is disciplined and honest,
- fog is the only circumstance that may impede the boy's return before dark.

Such additional preconditions may arise at every step of construction of an event bush. Naturally, once arose, they remain at the following steps if are not refuted by new premises. We recommend to put these preconditions down in explicit form and store them with the bush. One should keep track of them at least not to loose them making new steps of inference and to avoid a contradiction between such assumptions introduced at different steps. Moreover, such assumptions can retrospectively refine the definition of the field of reality/knowledge the bush describes.

We may define the wording of the corollaries given the premise. For instance, we postulate that any corollary of statement “Fog occurs” must include “...gets into a fog”, and if we obtain a statement that includes “to be lost” (or “loose one's way”, or the like), at least one of its corollaries must include the property “get depressed spirits”. Moreover, rules can be suggested for a statement in a bush depending on whether it leads to a corollary alone or in combination, whether it is the main or modifying member in the combination, what the character of some preceding or neighboring statements is, and so forth. Importantly, the wording can be predetermined not only for direct corollaries but also for some farther consequences, up to the very end of a succession of inferred statements. Along with stored assumptions, this is often very helpful in retaining all the necessary information throughout the bush. Thus, concerning the property “in a wood” that we moved from top to left, we decide to keep it in all statements that describe only the behaviour of the boy, from primary (first-type) to the end results (tertiary statements) – to allow the case that this circumstance appears relevant at some step of inference. However, even if not, we may wish to have it explicitly pronounced throughout the bush. The same time, keeping such properties with the nodes means that simple statements describing the entities (i, iii, and iv) and associated with the corresponding nodes accumulate new properties and therefore become compound: “...boy is walking/follows his way/etc. in a wood” actually consists of the following

statements, "...boy is walking/follows his way/etc." AND "Walk takes place in the wood"/"the way lies in the wood"/etc.

Similarly, once we infer that "...father/boy... becomes sick", as we do not admit any immediate remedy in the wood, the said person would remain sick till the end of the story, and the sickness itself remains relevant, for it may lead to corollaries like "get depressed spirits" at any time. Therefore, all the concomitant consequences from the statement "...father/boy... becomes sick" till the end results of the bush will include the property "sick": "Sick father/boy ... (does something, feels something, becomes something, etc.)" can be rewritten as "Father/boy is sick" AND "Father/boy ... (does something, feels something, becomes something, etc.)". The connective AND here seems to be quite compliant with logical conjunction, in contrast to the AND we use in the operation of combination. However, "dragging" the words throughout the bush is not mandatory. On the contrary, the property "gets wet" can be mentioned only once in our bush relating each of the primary entities of the bush (I.e., boy and father), because, despite that the wet state may last long in a wood, it is relevant actually once (to our mind) – namely, in making a person sick. "Once" is not necessarily "instantly", we do not consider quantitative measures like duration here; this is a subject of other investigations (Nikolenko and Pshenichny, 2007; Yakovlev and Nikolenko, 2008). Speaking qualitatively, "once" means at one step of inference, whatever time it takes, seconds or ages.

An important feature of the event bush semantics is backward redefinition – an opportunity to change the formulation of statements introduced earlier (and thus to redefine the nodes) depending on new corollaries. For instance, as discussed above, a statement "... gets wet" implies "... becomes sick". Once someone became sick, our common sense implies that he/she was not sick before. Moreover, saying that he/she became sick under some condition and only thus, we mean that the property "to be sick" would not be attributed to those cases which have not met this condition, unless stated otherwise. Then, if there is no property, there must be its negation. Hence, we may automatically ascribe the negation of this property to all nodes of the bush that describe the same primary entities (for example, "son" and "father" but not "hungry wolf") and have no word "sick" in their formulation.

Furthermore, negation of a property is a property itself. For the sake of simplicity, we put "healthy" as the negation of "sick", though, generally speaking, one could define the physical states of a person as "healthy, wounded, sick, sick and wounded", and formulate the negation of "sick" per se as "healthy OR wounded OR sick and wounded", and multiply the nodes of an event bush, correspondingly. Phrases added by backward redefinition of nodes are given in italics in Figs. 5 and 6. In the example in Fig. 5, in addition, the added property ("admires") that made us redefine other nodes is italicized and underlined. The backward redefinition is the reason for numerous omission marks in the statements quoted above. Indeed, until the bush is completed, we cannot give a full formulation of any statement except an environmental one (put on the top) – but concerning the latter we are not sure it will "survive" at all. This implies that, with inferring new corollaries, the premises become more and more compound a posteriori.

Another semantically peculiar case is the «one from one» inference. This can be of two types, «IF A THEN A», e.g., "IF Father stays at home THEN Father stays at home", or «IF A THEN B», e.g., IF "... boy gets wet" THEN "Boy... becomes sick". The former case is trivial yet important. It reflects the situation when nothing happens. The latter one represents the option of "self-generation" of a consequence: it looks as "getting wet" produces "becoming sick" without any other premises. However, this can be the case if, and only if, we have assumed as a general rule for the whole bush that IF "... gets wet" THEN "... becomes sick". This is another semantic assumption that determines the wording of the corollary and, possibly, ultimate consequences. Moreover, like any other semantic assumption, it may be made not only for one, but also for some or even all entities "eligible" to take the place of omission dots in corresponding statements. Indeed, for the father, if he gets wet (in a fog or somehow else) the effect will be the same as for the boy – he will become sick. As was stated above, structurally, there are four opportunities for such inference, IF (i) THEN (iii), IF (iii) THEN (iii), IF (iii) THEN (iv), and IF (i) THEN (iv). Concerning the latter, it is very convenient to begin the inference in an event bush by drawing horizontal arcs across the entire plot from each primary statement to the right column, thus setting up a "skeleton" of the future graph (though these arcs may then disappear in the process of construction). In our experience, the inference «IF A THEN A» makes sense for a domain of knowledge only in this case, IF (i) THEN (iv). First, this provides a good semantic guidance for the process of event bush construction. Also, if we

come up with the same as that what we started with, this implies a beautiful, though still unexplored, opportunity of building semi-cyclic bushes. Although, to keep on the point better accepted by our common sense, we may slightly modify the formulation of the tertiary statement to make it merely grammatically different from its cause, e.g., IF “Father stays at home” THEN “Father at home”. However, in the present case we would like not to do this and will formulate the primary statements, as well as and their corollaries, as follows.

Primary statement One: taking into the account that the first environmental statement “Fog occurs” is combined with it and implies at least one of the corollaries of this combination be “... loses his way”, the primary statement must explicitly include the negation, that is “... follows his way”. Then, at present, we put this statement as “...boy follows his way in the wood...”. However, we do keep in mind that other properties will be added to it in the process of construction of the bush.

Primary statement Two is formulated yet simpler, “Father stays at home” - but with the same reservation.

Armed with these guidelines, we can go ahead composing the event bush to answer the question, what can happen if the father says “yes” and boy goes for a walk.

3. DISCUSSION

General answer to this question is given in Fig. 6. The graph represents only the part of the event bush that describes what can happen to a boy. It does not include the part describing scenarios of the father's and joint father and boy's destiny. Statements in that part may look like

“Healthy father, who left home searching for healthy boy
being late following his way in a wood in high spirits,
gets into a dark”,

or

“Sick boy in depressed spirits, being late following his way in a wood,
and sick father, who left home searching for sick boy
being late following his way in a wood in depressed spirits,
get into a dark”.

Full version of the bush does not fit the publication format and will be reported elsewhere. However, the link between the two parts of the bush can be easily seen in Fig. 6. In the considered area of reality, this link is determined by paternal love and anxiety. In the domain of knowledge, it is expressed by the statement “Love exists” added as environmental (ii) to the bush. It produces, in combination with those statements telling that the boy is late or lost, an array of nodes (“Love urges to take care of...”) that are, in turn, all combined with “Father stays at home” and thus lead to statements describing father's potential responses to the situation, e.g.,

IF (“Father stays at home” AND “Love urges to take care of healthy boy
being late following his way in a wood in high spirits”)
THEN “Father leaves home in search for healthy boy
being late following his way in a wood in high spirits”;

then,

IF (“Healthy father leaves home in search for healthy boy being late
following his way in a wood in high spirits” AND “It is getting dark”)
THEN “Healthy father, who left home searching for healthy boy
being late following his way in a wood in high spirits, gets into a dark”.

Naturally, other additions are also possible to the bush. For instance, we may suggest another node, “... boy gets wounded”, and drop an arrow to it from virtually every node of the bush describing the boy, including the primary one, “Healthy boy in usual mood follows his way in a wood not going to be late”. This is so because the very property “in a wood” may be assumed leading to “... gets wounded”, for it is much easier to get a trauma walking in a wood than on a meadow or in a town. Similar inference (by “one from one” inference) could be made from “...gets in a fog” and “... gets into a dark”, for both fog and dark notably favor wounding anywhere.

However, one may argue that not only fog and dark, but wood itself can also favor losing the way. Hence, this may happen to a boy yet before the fog. To express this opportunity,

above such tools are redundant indeed. But mind that billion-dollar decisions often answer very simple questions too and require just saying “yes” or “no”. However, we see that even in this quite ordinary case the cost of decision could be boy's health and safety. Provided the father had a user-friendly decision-support software making recommendations based on an event bush, he may have used it – especially as the decision is actually more extended than just yes or no. If the father is wise enough, his most likely decision would consist of two parts, one, actually said (e.g., “yes, you may go”), and the other, unsaid (“but if fog occurs and he is not back, I will go seek for him, and take his dry clothes with me, and must do this before dark, because otherwise he may feel despair and become unpredictable”). To formulate this second, the most important, part, tools of decision support are highly welcome.

Though, one could argue that the decisions based on this event bush could be fairly well told by bare intuition and do not require such an intellectual effort. This might be true, but the weakness of intuition is its subjectivity, while event bush is a knowledge engineering tool that makes knowledge much more impartial. A domain of knowledge may start looking more simple or more complicated after using it, but in any case this tool provides a verification of intuitively made decisions.

Still, commonly the domains of knowledge in geoscience addressed by the event bush method appear far from simple, and the approach described in this paper allows one to handle this complicated and ambiguous knowledge and organize it to extract complete, well-substantiated, quite reasonably biased, and valuable conclusions.

“Traditional” domains of knowledge can be put in the event bush framework, as was demonstrated by Behncke and Pshenichny (submitted) by the example of description of volcanic eruptions of Etna, Sicily. The event bush suggested by these authors helped to better understand unusual eruptive activity that took place recently on this volcano, infer eruptive scenarios that were observed but had not been predicted, and foresee other possible scenarios to beware in the future. Consideration of physical models of geologic phenomena in the event bush framework will be discussed elsewhere (Pshenichny et al., in preparation). This is a perspective avenue for future research.

As for the relation of event bush to the most popular knowledge engineering and probability assessment tool in the geoscience, the event/probability tree, it can be concluded from Fig. 6 that a bush with several primary entities can be, with the loss of some valuable information, split into smaller bushes, each having only one such entity, and these, in turn, can be converted into event trees by ignoring all modifying members in combinations (and hence, omission of environmental statements), that means yet greater loss of relevant information. Naturally, a reverse operation (“assemblage” of event bush from event trees) is not possible.

Conversion of event and probability bushes into BBN and back was performed by Pshenichny et al. (2008) and Yakovlev and Nikolenko (2008). However, there existed problems in automatic conversion of statements of the bush into variables and states of BBN, which now seem to have been overcome even by those relatively loose semantic guidelines introduced in this paper.

Further perfection of these guidelines would lead, together with the structural rules introduced earlier, to thorough logical formalization of the event bush. This, in turn, must allow the construction of strict formal theories from event bushes and application of calculi of classical logic to prove or refute standpoints in given domain of knowledge like theorems in mathematics. This is seen as one of the main directions of ongoing research.

This research is fueled not only by academic interest, but also by an expected application to processing expert judgments. Any bush expresses, in fact, someone's opinion, or set of concepts someone has in mind in the given domain of knowledge. As has been shown in this section by the example of bush rebuilding (see Fig. 7), the same semantics can be used to generate a family of bushes expressing alternative opinions (or expert judgments) in similar terms. This opens a new opportunity for elicitation and reconciliation of expert judgments and computation of their logical probabilities seen as alternative to subjective probabilities used now (Pshenichny, 2004). Thus the conceptual modelling by means of event bush may lead to improvement of numerical assessment of expert judgments. However, to be able to quickly build and edit a number of bushes, a software is needed, which is being written now.

Other directions of development of event bush include quantitative applications of probability bush, particularly incorporation of geodata into the nodes and building the event bush-based geoinformation systems (GIS), development of temporal models and creation of

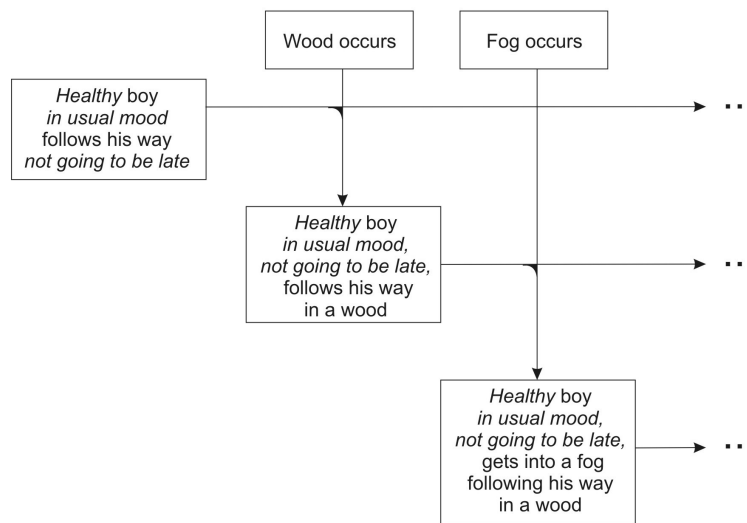


Fig. 7. Further transformation of the event bush to cope with new standpoints

learning algorithms for definition of temporal intervals associated with each node of the bush (Nikolenko et al., 2008).

Omitting the technicalities, the results of these studies show that the method of event bush is compatible with all the mentioned approaches and techniques. However, some of them lack congruity with one another. For instance, despite some interesting attempts (e.g., Gitis and Ermakov, 2004), formal theories per se are unlikely implementable in GIS. However, a formal theory can be recorded, with some theoretical development of the method, as an event bush. Based on the bush, a GIS can be built, where each node of the bush represents a layer or a theme. Thus a formal theory will become correctly exportable into a GIS. The same can be said about the combination of a formal theory and BBN. Another expected result is involvement of equations of multiple, competing or complementary, physical models into a BBN through the event bush. At present, to the authors' knowledge, these models are actually treated the same way as expert guesses in Bayesian computations in geoscience.

Generally speaking, nodes of an event bush can be attributed not only time and space coordinates but also synonymic terms, bibliography, comments, graphic and video information and so forth. This means that nodes may represent a kind of metadata, and the event bush can act as an ontology of the domain of knowledge/reality it describes. In contrast to most of ontologies, the event bush shows the ways of generation of specified classes of instances, which are precisely the steps of inference in the bush.

Many other promising interrelations of qualitative and quantitative approaches, and among the latter, the deterministic, probabilistic, fuzzy and, possibly, other ways of computation, are expected from the event bush.

The applications and extensions of this method discussed above must make it possible to express virtually any feature of an entity of the world addressed by our reasoning, be it a name of an entity, its explicit or implicit definition, consideration of what entities it resembles and what it looks like, what properties it has, what its sub/superclass and part-whole relations are, when and where it takes place, how it acts and what it is affected by, how this can be expressed in terms of quantitative (say, physical) models, what probability has its occurrence and what this probability is conditional on, and so forth. Moreover, suggesting a simple and intuitively clear language, the event bush is able to express different standpoints in similar terms and bring them in one framework. Moreover, the event bush suggests a unique approach to reconciliation of opinions – every step of its construction, from definition of the domain of knowledge/reality to making inference and attributing the pieces of additional information to the nodes, can be used to compare views and reveal discrepancies. Herewith, each possible disagreement can be appropriately placed. Scientists, decision-makers and other debating parties can query and figure out whether their misunderstanding sits in choice of primary/environmental entities, or in drawing a particular line of inference, or in formulation of the outcomes, or in considering

different time and space values, or in linking synonyms, etc. Not only the scientists but laymen able to reason in terms of event bush as demonstrated in Fig. 6 can pin down the contradictions and decide how they would like to cope with them. This makes the event bush highly amenable to decision-makers and gives us ground to consider it as a potential core methodology of organization and processing of information in the Earth sciences.

An important and intriguing issue is whether the event bush can be combined not only with BBNs but also with a large kit of existing knowledge engineering techniques – conceptual/existential graphs, semantic networks, Boolean networks, entity-relationship diagrams, causal loop diagrams, cognitive maps, qualitative probabilistic networks, influence diagrams, stock and flow diagrams, reasoning maps and others. Developed mainly by mathematicians and computer scientists with little or no account of the complexity of geoscientific information and wording, these techniques, however powerful, have found very limited application in the geosciences. Their interrelation with event bush needs to be explored, and we hope that a joint approach can be created incorporating the advantages of many methods.

4. CONCLUSIONS

Compared to other existing tools of knowledge engineering used in the geosciences (e.g., event trees, belief networks), the event bush provides a more detailed, structured, and accurate record of information. The principles of composition of event bush are simple enough to allow a geoscientist, who is not necessarily a specialist in knowledge engineering and artificial intelligence, to build and use event bushes for his own research needs as well as for everyday issues. Nevertheless, a bush is not as simple in composition as an event tree or BBN, and building and editing it requires some effort from a geoscientist. To make the best use of event bush, one should follow not only its graphic rules of composition and inference, but also the semantic guidelines that determine the formulation of statements. As a result, the language of event bush may differ from the language accepted in a modeled domain of knowledge and look somewhat clumsy and artificial; nevertheless, it provides much higher degree of objectivity and formalization.

The event bush has proved its principal compatibility with a wide range of methods and approaches used in the Earth sciences to organize information and compute values. This gives us ground to hope that this method may evolve into a complex methodology of treatment of geoscientific information.

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