Paolo Diviacco[1,3], Cyril Pshenichny[3*], Roberto Carniel[2,3], Zinaida Khrabrykh[3], Victoria Shterkhun[3], Dmitry Mouromtsev[3], Silvina Guzmán[4] and Paolo Pascolo[2]

Organization of a geophysical information space by using an event-bush-based collaborative tool

1. Istituto Nazionale di Oceanografia e di Geofisica Sperimentale, IRI section, Borgo grotta Gigante, 34010, Sgonico, Trieste, Italy
2. Dipartimento di Ingegneria Civile e Architettura, Università di Udine, Via delle Scienze 206, 33100 Udine, Italia
3. Geognosis Project, ITMO University, Kronverksky Prospect, 49, St. Petersburg 197101, Russia
4. IBIGEO - (CONICET-UNSa) Museo de Ciencias Naturales, Universidad Nacional de Salta, Mendoza 2, 4400, Salta, Argentina.
* corresponding author, email: cpshenichny@yandex.ru; phone: +79213175686; fax: +78122322307

Abstract

Development of knowledge engineering makes it possible to bring an information space relating to an entire domain of knowledge within the field of geoscience into a strict form, which is both computer-tractable and convenient for collaborative research work. Nevertheless, there are issues that seriously hamper this process – the problem of defining key terms, which is often not shared by the colleagueship, and interrelation of concepts developed by different schools within the colleagueship focused on different aspects of this domain. Another issue is the export of results to a wider community unfamiliar with the specificity of local studies. All these issues can be successfully addressed by a novel technique of knowledge engineering, the event bush, brought into the COLLA environment for geoscientific collaborative studies. This paper demonstrates how the said issues can be resolved by the example of one of the most important information domains in the field of seismology, the site effects. Text, graphics, tabular data and a physical model coming from different sources and different contexts are united in one context keeping all the specificity of original understanding and allowing the researchers keep on following their own context and terminology.

Key words

Collaborative tool, geophysics, knowledge engineering, COLLA, event bush, site effect, model

1. Introduction

Geophysics possesses the most strict and formal language in geoscience. Nevertheless, projected on individual visions and different datasets, this language interacts with the researchers' intuition and non-formalized, tacit knowledge. From one side, alternative models can be developed for similar phenomena, and this is definitely positive. However, from the other, the relation of these models to each other and to nature as perceived by the scientists is much less transparent and bias-free than the models themselves. In addition, strict and sophisticated geophysical models are often hard-to-understand to the rest of the geoscientific community.

Therefore, a tool is needed to let geophysicists communicate, exchange opinions and facts and, generally speaking, *collaborate* (formally or informally) while (i) building the models, (ii) discussing the models, (iii) communicating them to the rest of the community. This need is especially urgent in cross-disciplinary collaborative research projects. Very often such projects refer to the knowledge that underlies geophysical models.

In the information age, naturally, such a tool must be computer-based. Broadly speaking, collaborative software *sensu lato* is a class of information technologies that spans from multiplayer online games to groupware or social networks, from ordinary e-mail agents to corporate-size systems, and from commercial to open-source products.

In computer-supported collaborative research (CSCR), each partner contributes not only with his work but also with his way of thinking, his background and traditions (Kuhn, 1962, Lakatos, 1970). Hence, not only sharing the information must be supported, but, likewise, there must be a space where various backgrounds can meet, be put into a similar framework, interact in it and, hopefully, produce common understanding – or at least a means to avoid colouring of one perspective by another. This can be done only with an account of epistemological and sociological issues peculiar to science and unlikely to any other human activity (Diviacco and Pshenichny, 2010, Diviacco, 2012).

For geophysics, this means to clarify the way the models are being built, strive for common understanding, however basic and general, relate the information, be it verbal descriptions, numerical data or model equations, to this understanding, track and explicate the assumptions that arise when doing this, and compare different models. This largely falls into the field of *knowledge engineering* (e.g., Feigenbaum and McCorduck, 1983) that still remains rather exotic for the geoscience. Notwithstanding, among the methods of knowledge engineering developed recently at least one was created ad hoc for the Earth Sciences, the *event bush* method (Pshenichny et al., 2008; 2009; Pshenichny and Kanzheleva, 2012). It looks quite natural to inquire whether it can meet the aforementioned claims.

Therefore, the computer-supported collaborative tool chosen for optimization of geophysical modeling must be integrated with an appropriate knowledge engineering tool, among which the event bush seems quite promising.

The purpose of this paper is to explore an opportunity of using an event-bush-based collaborative application to explicate the reasoning that underlies physical modeling of geologic phenomena. As an example, the phenomenon of site effects is considered, for this is known as one of the most troublesome at earthquakes. These effects are responsible for dramatic changes of local earthquake intensity and therefore cause a lot of unexpected damage and life loss.

In this paper, we will

1. introduce the collaborative tool we use,
2. give an outline of the event bush method,

3. inquire whether and how an information domain (the site effects) within a wider field of geophysics can be represented by means of the event bush,
4. try “parsing” a particular site effect model by the event bush method and
5. discuss the results.

2. Description of collaborative research tool

Most of the existing commercial, open-source or free collaborative tools were made for business purposes. These tools usually do not take into consideration that multiple and concurrent cognitive models can address the same issue. When people discuss, e.g., sales, project planning or financial reporting with synchronous tools like Webex or ShowDocument, or asynchronous ones (Zimbra, Google Docs) or just by email, it is assumed that they all know exactly what they sell, or plan, or report. They have the same representation of their common subject, and share the same *meaning* of it.

As mentioned above, such luxury rarely is the case of scientific research, and therefore within a CSCR system the information should be organized in a way that a researcher could understand it “with its full story” and paradigmatic projection.

Automated reasoning technologies based on structured collections of information and sets of inference rules are being progressively used to organize information even in our everyday life, in ticket booking for example. These are mainly targeted at computer-to-computer interoperability and therefore miss the intricacies of human-to-human collaboration.

To address these problems, we will adopt a different vision. It is based on graphic representation of the event bush approach to organization of the information. This resembles a “road map” of shared knowledge with strict semantic governance. Such an approach could help researchers to organize information locating and retrieving it from within the nodes (“events”) of the bush. The “full stories” of each node can be imagined as “hanging down” from it, so that if the bush is a two-dimensional object we can deem the collaborative system as “three-dimensional”.

Obviously, any model (or, putting it broadly, theory) must rest on two interrelated grounds – experiments and acceptance. The former ground produces data, which could support or refute the model, and the latter claims for discussion in the community that could lead to some shared vision (common theory or at least “more or less” common language, in which conflicting theories can be expressed).

As is shown by the practice, such discussion can be efficiently conducted based on a formal diagram that represents model (Pshenichny, submitted). Ideally, this may also help to link relevant data to particular parts of the model. This can be done in the way shown in **Fig. 1**. Such vision has been implemented in a web-based asynchronous system called COLLA (Diviacco, 2012).

FIG. 1 HERE

One terminological trap should be avoided in this consideration. In natural sciences, data are pieces of information gained from observation and/or analysis, which support models (principles, theories, laws) of science or claim to modify them. In computer science, “data” are usually understood as any information processed by software and opposed to “rules” embedded in the program. Then, from the programming point of view, not only the natural-scientific data but also the natural-scientific models, principles, theories and laws will be treated as “data” for a collaborative research-supporting software. However, below in this paper “data” will be understood in the natural-scientific way.

The internal diagram drawing facility offered by COLLA, upon creation of a new node, allocates a messaging and file management space that is made available and usable immediately by clicking on the node itself. Following the pragmatic (semiotic) approach, nodes are just labels for concepts, issues or activities, It is the population of this space with information that builds its contingent meaning. Upon entering the node, partners can upload files, documents or scientific data and refer to them within COLLA’s messaging system. The latter is a very simple e-mail-like tool that sends messages to all the partners enrolled in the project. Messages are stored in the database, listed on the web pages that correspond to each node, and at the same time forwarded to all partners via e-mail, with a specific format of the sender field that allows partners to easily sort out the received messages on their own mailing system, as they prefer. The message text contains a “magic link” (a Web link containing several parameters and keys to log in automatically) that allows the user to be driven inside the discussion thread directly from his mailing system, without the fuss of login and topic search.

Aside from the messaging facility, COLLA offers also uploading and versioning functionalities for documents, images, geophysical data or files in general within the nodes. Once these are uploaded, they can be easily linked (not attached) from within COLLA messages so that files remain on the central system and are not duplicated, enabling all partners to refer to the same entity and version during the discussion, and avoiding the problem of having local copies with inconsistent file naming (Diviacco, 2012).

Event bushes are presented in COLLA as Scalable Vector Graphics (SVG) files. SVG allows handling of vector graphics, server side, so that rendering is very fast. Objects being vectors do not show pixellation upon zooming, and, most importantly, each of them can behave independently of others and embed functionalities, e.g., hyperlinking.

Immediately all partners see the event bush and can interact with it to begin or follow a discussion or upload any kind of supporting/refuting/explaining data from their data files (documents, maps, snapshots, etc.) to the nodes of the bush.

Any time a partner interacts with the system writing a comment or uploading files, other partners are notified via e-mail. The e-mail notification embeds a simple web link that leads directly to the bush node where the information has been added. Following this link, a user can view not only the last modification made but all previous uploads to the same node and navigate away to other nodes if desired.

3. Outline of the event bush method

3.1 The Purpose

The method of event bush, suggested by Pshenichny and Khrabrykh (2002) and recently developed by Pshenichny et al. (2008; 2009) and Pshenichny and Kanzheleva (2011), intends to give a strict and finite but extendable display of an area of reality and corresponding domain of knowledge. Importantly, it does not intend to paint an objective and true picture of reality based solely on formal grounds. The purpose of the event bush is to impartially structure and give a shape to the subjective information coming from scientist's eyes to mind, and from scientists' minds to communication and, finally, to decisions. Like any other formalization, it does not decide what is true and what is false, or what is relevant and what is not, for an object in question. The event bush allows a scientist to formulate everything that can happen when given a list of premises. It imposes some requirements on these to ensure the most complete and objective inference, but the choice of premises is totally at a scientist's discretion. In a discourse or polemics, the tool of event bush may help us formally express and compare contrasting standpoints. Meanwhile, formalization itself often urges a scientist to revise knowledge, find gaps and strands of "wooly" reasoning, terminological and conceptual intricacy and the like. Such imperfections can be tackled, and to some degree cured, by the event bush. But like any other weapon, in principle it can be used alternatively, e.g., to produce a beautiful, formally perfect nonsense.

3.2 The Technique

The method of event bush rests on an assumption that a given area of reality (e.g. site effects on a loose sediment body overlying hard bedrock) can be represented as shown in **Fig. 2**. In the considered area of reality, the following events are identified.

FIG. 2 HERE

(ia) Primary internal events. These are primary, non-overlapping and non-unique inputs – e.g., bedrock, sedimentary bed on the earth surface unaffected by seismic motion. As we suppose to describe the latter in the spectral domain, we will talk about "seismic spectra". Such inputs, according to the concept of event bush, would determine any further course of events.
(ib) Primary external events. They indicate the way the environment may condition basic inputs or influence their further, indirect manifestations. For instance, seismic spectra would affect differently the bedrock, sedimentary bed, or the earth surface.
(ii) Secondary events (processes or objects) that result from primary inputs with or without the contribution of incoming circumstances – the "happenings" proper (bedrock/sedimentary bed/earth surface affected by seismic spectra and seismic spectra amplified by these) formulated in a strict concise way indicating their core features determined by the causes, following the principle "one more cause – one more property".
(iii) Tertiary events that denote end results, or products, generated either by primary internal or by secondary events, with or without primary external ones. Tertiary events document the completed "happenings". Describing site effects, it looks reasonable to consider as end results the textural features within hard rock bed, soft rock bed and earth surface that indicate if they were affected or not by incoming seismic spectra listed in (ib), and the seismic spectra resulting from amplification by rocks and surface.

In accordance with the syntax of event bush presented in **Fig. 2**, the relations between the (i) - (iii) can be set (for a given time):
Events (*ia*) and (*ib*) must not lead to other (*ia*) or (*ib*);
Event (*ib*) may lead to an event only together with (*ia*) or (*ii*);
Event (*ii*) must not lead to (*ia*) or (*ib*);
Event (*iii*) must not lead to (*ia*), (*ib*), (*ii*), and another (*iii*).

These relations are enforced by the connectives of the event bush, each having a graphic designation. Pshenichny and Kanzheleva (2011) define four connectives, flux, influx, conflux, and furcation, of which the first two, flux and influx, are mandatory for an event bush.

1. **Flux** connective (denoted by simple arrow; **Fig. 3a**) describes one event (E_i) producing another (E_j):
   E_i Flux E_j.
2. **Influx** connective (denoted by the rounded crossing – the "right turn" sign; **Fig. 3b**) describes two events (E_i, E_j) producing another (E_k), but playing different roles (this will be described below):
   E_i, E_j Influx E_k.
3. **Furcation** connective (denoted by the circle; **Fig. 3c**) describes production of multiple events (E_{i+1}, E_{i+2}, …, E_n) by one (E_i):
   E_i Furcation E_{i+1}, E_{i+2}, …, E_n.
4. **Conflux** connective (denoted by the coupled rounded crossing, "double turn" sign; **Fig. 3d**) describes production of one event (E_n) by multiple events (E_i, E_{i+1}, E_{i+2}, …, E_{n-1}):
   E_i, E_{i+1}, E_{i+2}, …, E_{n-1} Conflux E_n.

FIG 3 a-d HERE

The presence of flux and influx is mandatory for an event bush. Each triple of a set of events left of a given connective, the connective itself and the set of events right of the connective make up one *change* in event bush. A succession of changes from an (ia) event to a (iii) event is a *scenario*.

Subjects of primary events are grouped, with reasonable reduction, in a statement of the form "Subjects of primary internals" listed via "and" – "are affected by" – "subjects of primary externals". This statement forms the title of the bush and delineates the information domain covered by the bush (see below).

For more details on the methodology of event bush the reader is referred to Pshenichny and Kanzheleva (2011).

Among other applications, event bush can be used as an organizer, or a "skeleton", of an information domain. Information that is not preserved in the bush itself can be related to any part of it (subjects, predicates, events in general, individual changes of one event to another and scenarios) or to the bush in general. This will be shown in detail below.

4. A geophysical information domain: site effects of earthquakes

Many earthquakes have indicated in particular that the presence of deposits of soft soil, sediments or (e.g. more fragmented or looser) rocks over an underlying hard rock can increase dramatically and/or concentrate locally damages and life losses. Soft soils, sediments or rocks amplify shear waves and, thus, amplify ground shaking. This amplification of motion over soft sediments or rocks is mainly due to the trapping of seismic waves associated to the impedance contrast between the more superficial sediments and the underlying and/or adjacent hard bedrock. Also, landforms and topography are known to modify seismic waves and, as a consequence, the possible damage they make on the Earth's surface. In general, these variations of wave properties due to local geological and geomorphological conditions are known as *site effects* (Field et al. 2000; Luzon et al., 2002, and others). Naturally, they have gained the attention of scientists that has resulted in a sufficient volume of publications including the textual descriptions, quantitative data on particular earthquakes, general conceptualizations, physical models and other pieces of information.

Site effects are commonly considered in the classical seismological context of source, path and site (see **Fig. 4**).

FIG. 4 HERE

Despite all the discrepancies in meaning and commonly observed absence of distinct margins, such three-part division (source-path-site; see comment to **Fig. 4**) is simple, self-describing and obvious enough to be generally adopted and shared by nearly all the seismologists. It is readily represented in the form of event bush "How propagating source seismic waves are affected by path and site" (**Fig. 5**). Usage of simple and self-describing words is in general a virtue of the event bush semantics that allows one to avoid terminological traps and build conceptual structures that can be shared by the majority of a community.

FIG. 5 HERE

We do not ascertain that this bush is the only possible one describing the transformation of seismic signals in heterogeneous geological environment. It would be interesting to try to build other bushes in a different semantics and look at their interrelation. Moreover, a "vice versa" bush can be created describing the way the geologic bodies (bedrock, sedimentary bed and, finally, the earth surface) are being affected by seismic spectra and, in turn, transform the latter. Nonetheless, in this paper we are going to explore this path.

Although basic, even this event bush may serve to organize the information domain of site effect studies. For this purpose, it was imported into the COLLA environment. The event bush originally plotted in the Corel Draw software was uploaded then as an SVG file to COLLA, thus giving start to a new COLLA project currently available online after registration at http://colla.ogs.trieste.it. **Fig. 6** shows how textual evidence, graphic and tabular data can be linked to it. Note that different pieces of information can be related to different parts of the bush. These can be: (i) particular subject or predicate occurring in a number of events throughout the bush (not shown here), (ii) one event, (iii) several events linked by connectives (arcs), once change from event to event (not shown here), (iv) particular scenario or scenarios, (v) the bush in general. Also, it is noteworthy that information in different formats (textual, tabular or graphic) and in different natural languages (English and Spanish) is related to the same bush.

FIG. 6 HERE

At the current level of the COLLA technique, this can be achieved only partially as shown in **Fig. 7a-c**. The event bush is plotted in the COLLA environment highlighting the scenarios in question (**Fig. 7a**), and then each part of the bush (any node, connective, scenario and so forth) can be taken as a *task*, with which either files (**Fig. 7b**), or messages (**Fig. 7c**), or both can be associated. The thread of messages associated with the node (event, task) "Source seismic wave propagates affected by source, unaffected by site" is given below. Note that it constitutes an example of a scientific discussion with a well-defined topic and links to external sources of information.

FIG. 7 HERE

2013-12-21 22:41:07
Cpshenichny
Subject
Unaffected by site?
Text
Assuming that a portion of the wave is reflected downward from the boundary between the hard and soft rock, how can one say that the source seismic wave is unaffected by site?

2013-12-22 13:33:48
Rcarniel
Subject
Re:Unaffected by site?
Text
I see your point. Actually, every model has some assumptions. For instance, you can always modify the model in order to take into account the effect of reflection downwards too, regardless of how small this effect is. As you know, this would have to be handled by plotting another event bush based on this one.

2013-12-22 17:13:12
Cpshenichny
Subject
Re:Re:Unaffected by site?
Text
OK, as it always happens in modeling - making a model more and more accurate makes it more and more complicated...

2013-12-22 17:20:43
Diviak
Subject
Re:Re:Re:Re:Unaffected by site?
Text
Interesting discussion, Have a look at this link
Link 1 (http://data-informed.com/why-more-data-and-simple-algorithms-beat-complex-analytics-models/?utm_source=LinkedIn+Groups&utm_medium=WIS+group+post&utm_campaign=algorithms+article)
Controversial maybe but can be relevant
Cheers
P

2013-12-22 21:56:37
Cpshenichny

Subject
Re:Re:Re:Re:Re:Unaffected by site?
Text
A very interesting point indeed! The article at the quoted link raises, in our context, a general issue of possible application of the event bush to processing of big datasets. Statistically proven relationships within a dataset perhaps can be interpreted by the scenarios of an event bush. Then, the bigger is the dataset, the more complicated event bush must be at hand to interpret those latent relationships captured by increasing amount of data. Moreover, perhaps to build a more detailed event bush may appear less costly in some cases than to acquire "big data", and hence, "additional" scenarios exhibited in the bush may somehow "predict" statistical relationships within the dataset. However, I guess this should be discussed separately, as it brings us away from site effects.
Cyril

Still, a conceptualization like that discussed above is often too general and therefore not enough to encapsulate most of the existing scientific knowledge. At a closer look, the phenomenon of site effects has appeared much more complicated than that supposed by the classical tripartite vision, and even to define the subjects and predicates necessary to describe it becomes a tricky business. Field et al. (2000, p. S3) state, “For example, one might logically define a site as the extent of a sedimentary deposit; but this leads to problems when such deposits are several kilometers deep and bounded by earthquake-generating faults. For example, how should one distinguish between path and site effects for a fault that ruptures along the edge of the Los Angeles basin? Such ambiguities inevitably lead to arbitrary distinctions, such as the 30-m-depth cutoff used to characterize site conditions.” Later, quoting Dobry et al., 2000, Field et al. (2000) add that exactly this 30-m-depth cutoff distinction was adopted in current building codes via the Vs30 parameter, a choice that is now often debated (e.g. Gallipoli and Mucciarelli, 2009).

A common problem that might arise is the presence of interbedding of meter-sized layers of soft and hard sediments/rocks, a phenomenon fairly common in nature. Another important factor may be the dimension and shape of the soft material confined by the hard rocks and the relative frequency of these bodies of soft material; consider for example an intricated paleotopography made mostly of diagenized sandstones covered by a lacustrine sediments, the resulting morphology will probably be one of small bodies of soft materials bounded by hard material. Moreover, the presence of soft sediments may not always lead to amplification of seismic waves; lateral facies changes are common features of sedimentary and pyroclastic rocks, which can lead to a gradual variation of impedance that at last would not produce such wave amplification. Controls on these features for a given study area can help identify substrate characteristics and their geophysical properties, but often many of the areas studied for site effects have the geophysical information but lack the geological interpretation of the configuration of the buried rocks.

The event bush method may cope with such complications. This becomes possible because the event bush does not directly use any definition; rather, it fixes the usage of the terms given the context. Thus, in the considered case, based on the information presented in **Fig. 4** and the fact that, as stated by **Fig. 6**, this information has been related to the entire event bush presented in **Fig. 5**, the latter can be reformulated using the following equivalence of meanings: “Source” is equivalent to “Earthquake-generating fault”, “Path” is equivalent to “Hard rock bed” (later we will have to put another equivalence, to “Bedrock”), “Site” is equivalent to “Soft rock bed or Earth surface landforms”, “or” being a non-exclusive disjunction. Then, taking a part of the meaning of the latter, namely the “soft rock”, and adding one more equivalence, “Soft rock” is equivalent to “Sedimentary rock bed”, we can proceed further, adding one more scenario emphasized by Field et al. (2000), that sedimentary rock body can be bordered directly by earthquake-generating faults (**Fig. 8**). Though, of course, terminological correctness of such equivalences is arguable (for “hard” and “soft” denote the mechanical properties of rocks, and “sedimentary”, their genesis. So, sedimentary rock (and sedimentary rock bed) can be quite hard and we can have soft rocks with different genesis, such as pyroclastic deposits (e.g. Nunziata et al., 1999) or can have their mechanical characteristics modified by external processes, as is the case for seismites (Ettensohn et al., 2011) or as post-emplacement changes due to diagenesis, cementation and physical and/or chemical alteration. Also, “bedrock” does not necessarily imply “hard rock”. Moreover the usage of surface landforms as synonyms of soft sediments are not true in all cases, consider a volcanic edifice (landform), that usually has a hard core or their hard products (e.g. lavas).. We are interested in capturing actual meaning of terms, including also the cases of misuse.

One common source of problems in the interaction between geophysicists and geologists is the different (often implicit) definition or understanding of terms like “soil”, “bedrock”, “sediment”, etc.. Geophysicists are usually mainly concerned with their mechanical characteristics, while geologists are more concerned with their genesis.

Perhaps another solution could be to plot a singular bush with “neutral” terms (“fault”, “hard rock bed” and “soft rock bed”), then relate all the involved terms (including “source, “path” and “site”) to relevant subjects and draw equivalences within the information attached to one subject, but this at present seems more complicated both methodologically (as we have not suggested formal rules to manage the information linked to similar part of the bush) and technically (one should put arrows from each linked term, e.g., “site”, to every occurrence of “soft rock bed” throughout the bush).

It is important to note that this is not the only complication related to the classical context. Another implicit assumption is that soft rock, if present, is bedded above the hard rock; this is common, but not necessarily so. The event bush can depict alternative scenarios as well, and this will be reported elsewhere.

FIG. 8 HERE

The event bush conceptualization appears formal and flexible enough to be extensible and specifiable to any reasonable extent, and this offers the opportunity to organize and structure information domains in this way. However, a question crucial for geophysics remains unresolved, whether, along with tabular and graphic data and verbally expressed standpoints, this method can represent physical models.

This issue will be addressed below – using, as a first try, one of the most simple site effect models known to the authors. We are not going to discuss its pros and cons here; instead, our interest now is to examine how "digestible" it may be for the event bush method, whether the latter can treat this model correctly and in what way it should be extended to correctly incorporate *any* physical model.

5. The HVSR approach to estimation of site effects and Nogoshi-Igarashi-Nakamura model

The horizontal-to-vertical spectral ratio (HVSR) approach will be described below based on the work of Carniel et al. (2006).

Consider a typical 1D model, i.e. a sedimentary bed upon a bedrock body (**Fig. 9**). This is in the first place just one of many possible geometrical configurations. We are not considering at all possible lateral variations of the mechanical characteristics, and we exclude the situation in which the softer sediment is below a harder deposit, or that "relatively hard" deposits such as sandstones could be interbedded with "relatively soft" deposits such as limestones . But, although it is definitely a simplification, this is indeed a common case, if not the most common. Another almost obvious observation is that in the hard rock the seismic velocities are much higher than those in the soft bed. This configuration behaves like a filter, amplifying some wave frequencies and attenuating others. The frequencies for which the maximum amplifications are observed are said resonance frequencies, and the knowledge of such frequencies can provide important information about the sedimentary bed. If its material is linear elastic, an hypothesis which is generally acceptable for small deformations, and homogeneous, the resonance frequencies are given by the so-called quarter wave law, which links such frequencies to the propagation velocity of the S waves in the superficial layer and to its thickness.

FIG. 9 HERE

Although the spectrum is conceptually only a property of the seismic waves, it is its essential property with respect to the site effect issue. We may therefore take even forward the reasoning and declare that in our information domain the concept of "wave" is represented by its "spectrum", i.e. the two terms can be considered semantically equivalent. Also, it should be noted that in most of seismological monitoring techniques any wave (or spectrum) is regarded either as "signal" or "noise", depending on purpose. However, the HVSR approach "digests" any signal; therefore it has been accepted in description of this method to use "noise" as a synonym of "wave" and, hence, "spectrum" and consider "noise spectrum" and "spectrum" the same.

The HVSR approach, i.e. the study of the ratio between the amplitude spectra of the horizontal and the vertical component of seismic noise), was first introduced by Nogoshi and Igarashi (1971) but became widely known only with the work of Nakamura (1989). The same Nakamura then clarified his method in a more recent paper (Nakamura, 2000). The widely accepted result of these authors is the existence of a correlation between the peak frequency of the H/V ratio and the fundamental resonance frequency of the site. The determination of the H/V ratio then becomes a logistically simple methodology to obtain information about the local buried structure, because it requires the installation of a single three-component seismometer (Nakamura, 2000), without the need of any other reference site. However, the spectral peaks are still not always easily determined in practice and sometimes some preprocessing is required for the recorded time series in order to exploit the similarity of the two horizontal components (Carniel et al., 2006; 2008), to separate isotropic and anisotropic amplifications (Barazza et al., 2009) or simply to choose the best time windows on which to compute the spectral ratios (Carniel et al., 2009).

If the practical applicability of the method is widely accepted by the scientific community, the same cannot be said about the theoretical assumptions, described below, on which Nakamura (1989, 2000) bases the methodology, in particular the negligible contribution of surface waves with respect to that of body waves. This hypothesis has been contradicted by several papers that highlight the relationship between the H/V and the ellipticity of fundamental Rayleigh-wave mode and suggest further investigations of the real relative contribution of body and surface waves in the composition of the seismic noise wave field (see e.g. Bonnefoy-Claudet et al., 2008 and references therein).

It is important to note that, as we will clarify later, in this paper we are not concerned about the correctness of Nakamura's hypothesis but focus on its formal "parsing", i.e., understanding of assumed interrelationship of entities that are meant by its variables and thus reconstructing the way it was built (more or less similar to parsing a sentence of natural language).

Practical provisions of the *H/V* method require measuring only the seismic noise at one three-component seismometer at the surface. The recorded seismic noise is considered composed by two parts, i.e. body waves and surface waves (Rayleigh waves). Horizontal and vertical spectra on the surface ground of the sedimentary basin (H_f, V_f) can then be written as follows:

$$H_f=A_hH_b+H_s \text{ and } V_f=A_VV_b+V_s,$$

where A_h and A_v are the spectral amplification factors of the horizontal and vertical motion of vertically incident body waves, correspondingly, while H_b and V_b are the spectra of horizontal and vertical motion as they would be acquired in the bedrock under the basin. H_s and V_s are the spectra of horizontal and vertical components respectively of surface waves traveling along the earth surface. Thus two types of seismic signals are involved in producing the final site effect, called by us for simplicity "interior spectrum" (i.e. a seismic signal with given – horizontal or vertical – spectrum, originating in the earth's interior) and "exterior spectrum" (i.e. a seismic signal with given – horizontal or vertical – spectrum, coming to the surface from anywhere on or above it).

So the entire model of site effect on seismic spectra as suggested by Nogoshi and Igarashi (1971) can be represented as $H_f/V_f=(H_b/V_b)*((A_h+H_s/H_b)/(A_v+V_s/V_b))$ – which is a purely mathematical derivation from two equations, $H_f=A_hH_b+H_s$ and $V_f=A_VV_b+V_s$, which are actually the model. Exactly these two equations will be addressed by the event bush.

An event bush was composed to describe how the propagating seismic spectra are transformed by heterogeneous geologic substrate up to the earth surface (**Fig. 10**) based on the qualitative understanding of this phenomenon presented in Section 4. For this, two of the three semantic equivalences assumed above were extended (the extension is marked bold): "Path" is equivalent to "Hard rock bed" and to **"***Bedrock*", "Site" is equivalent to "Soft rock bed" and to **"***Sedimentary bed***"**. Also, some more equivalences are added to address the particular model: "Affect" is equivalent to "Amplify", It is worthwhile to note that for a given frequency, amplification factor can well be less than unity, a situation which a layman would more easily define "Reduction", thus using the verb "Reduce". In terms of frequency transfer function of the filter, however, the verb "Amplify" is simple and powerful enough and we will be content with that.

The model says that the sedimentary bed *amplifies* spectra (and this is its influence on the latter, mathematically representable with a linear filter transfer function). However, this is again a verbal simplification, because we know that what really amplifies spectra is the full "geometrical" configuration of "sedimentary soft rock bed over the hard rock bed bedrock", due to their impedance contrast. There would be almost no amplification if there were a transitional variation of the mechanical characteristics from a "hard" end member "bedrock" to a "soft" end member "sedimentary bed". This is why the *Vs* sometimes fail to correctly characterize the site effect (Gallipoli and Mucciarelli, 2009). Moreover, we may not exclude that other two primary external "players", bedrock and surface, also may *affect* (or not) somehow. Still, these options should be considered in another bush (see **Fig. 10**).

FIG. 10 HERE

The title of the bush implies that its main "players" should be the interior and exterior couples of horizontal and vertical seismic spectra (initially placed on the left, i.e., being classified as primary internal events) and geologic substrate (bedrock and sedimentary bed) plus the Earth surface, which are put on top of the bush as primary external ones.

As could be concluded from the Nogoshi – Igarashi – Nakamura model, the interior couple is considered to come to the bedrock (the "path") but not be generated in it (see **Fig. 4**). Still, it should be noted that the discussed model, in fact, considers only "path" and "site" parts of the classical context, as it does not account for any properties of the source. This is why neither "source", nor "earthquake-generating fault" are mentioned in the title of the bush, and the spectra are said to be just "propagating". Instead, the bush includes propagation of exterior spectra, which may well have quite a different source, e.g., on the Earth surface or even in the atmosphere, by (partial) conversion of a pressure wave into ground velocity (Ichihara et al., 2012).

In principle, interior spectra may never meet the bedrock *meant in the model* (say, traveling yet deeper than, or far away from, this bedrock body all along). Exactly this is what the same-formulated tertiary event caused by this primary internal one is introduced for. Hence, the encounter of *that* bedrock by the spectra is another, secondary event "Interior horizontal spectrum and vertical spectrum go affected by bedrock, unamplified by sedimentary bed and unaffected by Earth surface". Naturally, this secondary event is caused by the said primary internal and a primary external one, "Bedrock exists".

From this point, other possible events involving interior spectra develop. These spectra can either travel in the considered area within the bedrock and not leave it (this is expressed by a tertiary statement formulated the same way as the above secondary one), or come to sedimentary bed, or come to the surface. Two latter options, shown in **Fig. 4**, are secondary events that result from a combination of the secondary event "Interior horizontal spectrum and vertical spectrum go affected by bedrock, unamplified by sedimentary bed and unaffected by Earth surface" with a primary external, "Sedimentary bed exists and amplifies", in one case, and "Earth surface exists", in the other. Exactly these two secondary events represent the contrasting cases analyzed by Nakamura. Each of them can be clearly documented, i.e., represent some end results of propagation of the spectra, and this is reflected in the bush by corresponding tertiary events.

Now, another independent "actor" comes to play. This is a purely superficial, atmospheric or possibly anthropogenic, event that may also generate vertical and horizontal seismic spectra, henceforth denoted as "exterior". This is another primary internal event of the bush. In principle, it may pass unrelated to the interior spectra, just "meaning itself" and resulting in a tertiary event. Nevertheless, if a portion of it comes to the Earth surface (i.e., a combination of this primary internal event with the primary external one "Earth surface exists" takes place), this results in a couple of superficial spectra spreading close to the ground and being somehow affected by the latter. This is expressed by the secondary event, "Exterior horizontal spectrum and vertical spectrum go affected by Earth surface", and the end result of this, by the same-named tertiary event.

If two different couples of spectra, one coming from the interior, the other purely exterior, meet at the Earth surface, this naturally leads to two interior-exterior "couples from couples", one interior-exterior horizontal and one interior-exterior vertical. These "couples from couples" will be denoted composite spectra. Their Interior components bear the history of previous transformations ("affected by bedrock, amplified or not by sedimentary bed and affected by Earth surface"), while exterior ones may only be affected by Earth surface. In the event bush, this is expressed as confluence of the event into two events – one of these in both cases is in one case, "Exterior horizontal spectrum and vertical spectrum go affected by Earth surface", and the other, depending on what kind of interior spectra are involved (or, in other words, where the seismometer is located – see marks H_b, V_b and H_f, V_f in **Fig. 11**, either "Interior horizontal spectrum and vertical spectrum go affected by bedrock, unamplified by sedimentary bed and affected by Earth surface", or "Interior horizontal spectrum and vertical spectrum go affected by bedrock, amplified by sedimentary bed and affected by Earth surface". Both events describing the composite spectra lead to tertiary events, which document the two scenarios captured by the Nogoshi – Igarashi – Nakamura model.

Remarkably, this 6 paragraph-long piece of text of nearly 750 words (from the beginning of this section on to this point) has been required to explain what is shown in a simple and concise graph (**Fig. 10**). This itself may serve as a convincing argument to think about an event bush as a relatively compact means of presentation of knowledge.

Some important notes can be made on the overall structure of the event bush.

Its primary internal events include two different types of spectra couples, interior and exterior (see above). In the model examined, no other seismic signals are considered.

Primary external events include the members of the geological sequence (bedrock and sedimentary bed) and the earth surface. Again, in the considered case this is surely the full set of opportunities.

Secondary events (*ii*) fall into four classes:

1. those formed by a combination of *ia* and *ib*;
2. those formed by a combination of the 1st class type (*ii*) events and one event *ib* (namely, "Earth surface exists");
3. those formed by the confluence of the 2nd class type (*ii*) events and one of the 1st class type (*ii*) events (namely, "Exterior horizontal spectrum and vertical spectrum go affected by Earth surface");
4. those formed by a simple cause-effect relation from the 3rd class type (*ii*) events.

Tertiary events, as supposed by the rules of event bush composition, were generated by primary internal ones and secondary events except those of the 3rd class. Their formulation repeats that of the events they originate from.

This event bush provides a verbally-defined context of the Nogoshi – Igarashi – Nakamura model. Yet, it does not address directly and explicitly the model parameters and equations. We deem this to be done in three principal steps (see **Fig. 11**).

FIG. 11 HERE

1. Relevant subjects and predicates of events are denoted by symbols. In our case, interior horizontal spectrum becomes H_0, interior vertical spectrum becomes V_0, exterior horizontal spectrum, H_{s0}, exterior vertical spectrum, V_{s0}, and amplification by sedimentary bed, A_h (horizontal) and A_v (vertical), and so forth. We tried to follow as much as possible the notation used by Carniel et al. (2006). Words could not be omitted and denotation could not be done from the very beginning, at construction of the event bush, because symbols, contrary to words, do not imply semantically clear negation, which is essential for the event bush. For instance, putting "amplified by sedimentary bed" we imply that the negation of this predicate would be "unamplified by sedimentary bed", but putting "amplified with A_h, A_v", we have no clue whether the negation is absence of amplification or amplification with, say, some other A_b, A_c. Thus, denotation may go only above the wording, not instead of it.

2. More predicates can be added to primary internal events and to their corollaries. For instance, we added a predicate "to be equal" to interior vertical and horizontal spectra (H_0=V_0).

3. Each operation of the event bush except the simple cause-effect relation is attributed a computational sense, either an equation, or an assumption, as is shown in **Fig. 11**. As one can see, the assumptions include all those which were explicitly put by the scientists (Nakamura, 1989; 2000) and also those which were not. The former, "hidden" assumptions include "No amplification in the bedrock" and "No amplification at Earth surface". The latter, representing the main cognitive interest, include the presence of notable spectrum differences on Earth surface in the case the sedimentary bed crops out, and in the case, when the sedimentary bed is absent, bedrock crops out. This

clearly and doubtlessly shows the use of the event bush in untangling the reasoning that underlies geophysical modeling.

In general, **Fig. 11** shows how we pass from assumptions on top to the model of Nogoshi – Igarashi – Nakamura at the bottom. Of course, different event bushes could be built for other models aiming to describe or explain the same phenomena. What we clearly see is that every connective of the bush (simple arrow, "right turn", "double right turn" except those leading to tertiary events) appears related to one assumption or one computation step, and vice versa.

The event bush method makes geophysical models quite transparent to eye and mind – one can see all the assumptions, track all the computation, and realize what natural processes and objects these are related to. For instance, computation of horizontal and vertical spectra in sedimentary bed (H_{sd}, V_{sd}) is possible when two events co-occur, "Interior horizontal spectrum H_0 and vertical spectrum V_0 being equal (H_0=V_0) go affected by bedrock, unamplified by sedimentary bed with A_h, A_v and unaffected by Earth surface" and "Sedimentary bed exists and amplifies spectra with A_h, A_v" (see **Fig. 5**).

One can also compare the models in this way by any of the criteria: number of assumptions and their generality, mathematical formalisms used to express the same relations between natural objects, succession of computation and, possibly, others. Moreover, one could add any piece of relevant information as quaternary event (Pshenichny et al., 2009) to any of the nodes (e.g., lithologic properties, genetic interpretation – to the primary external events) and track how they relate to the model assumptions or computations. Another opportunity is to add time intervals (an extension of the formalism that is being developed theoretically) or space areas to the events. In general, this brings geophysical modeling into the context of geoinformatics, which opens wide opportunities for comparison of models with real data (Sinha et al., 2008).

Such a tool could be helpful not only for geologists willing to understand and evaluate geophysical models, but for the geophysicists themselves, and exactly for the same purpose: to clarify reasoning and compare the results with strands of evidence from different fields.

6. Discussion: theoretical and implementation issues

The information domain of site effects can be represented by a succession of interrelated event bushes (see figs. 5, 7 and 9). These bushes can, in principle, be infinite in number, being focused to best represent particular standpoints and peculiarities of meaning. Some of these bushes can be derived from others by using accepted semantic equivalences or "class-subclass" relations, e.g., "hard rock bed" (class) – "granite" (subclass) or "seismic waves from earthquake-generating fault" (class) – "seismic waves from strike-slip earthquake-generating fault" (subclass). A new event bush would be obtained automatically by substituting a subject to its equivalent or subclass. Others are being constructed independently but are related to others by semantic relations.

Considering event bushes as directed hypergraphs as suggested by Pshenichny and Mouromtsev (2013), one may say that event bush is a pair $G= (E,A)$, where $E=\{E_1, E_2,..., E_n\}$ is the set of vertices (or events) and $A=\{A_1, A_2,..., A_m\}$, with $A_i \subseteq V$ for $i=1,..., m$, is the set of non-empty subsets of A called arcs, or changes, in the event bush terminology. Then, comparing the bushes in **Fig. 5** and **Fig. 8**, we shall put forth,

$$G_{Fig.5}= (E_{Fig.5},A_{Fig.5});\ G_{Fig.7}= (E_{Fig.7},A_{Fig.7}).$$

Now, based on the semantic equivalences, we can say that such events as "Path affects" and "Hard rock bed affects" are the same, but there is one event in **Fig. 8** bush ("Seismic wave propagates from earthquake-generating fault unaffected by hard rock bed, affected by sedimentary rock bed") that is absent in the **Fig. 5** bush, and a few related changes, correspondingly (namely, those that form the scenario emphasized by Field et al., 2000 – see above). This means that the set of events of the **Fig. 5** bush is a subset of those of the **Fig. 8** one:

$$E_{Fig.5} \subset E_{Fig.7},$$

and the same for the arcs:

$$A_{Fig.5} \subset A_{Fig.7}.$$

Then we consider possible to say that the entire event bush in **Fig. 5**, "How propagating source seismic waves are affected at path and site", is a part of the bush in **Fig. 8**, "How propagating seismic waves from earthquake-generating fault are affected by hard rock beds and sedimentary rock beds". Similarly, based on that the event bush in **Fig. 11** includes at least a primary internal event relating the exterior spectrum that is in no way accounted for in the previous bushes, we have to say that the event bush in **Fig. 8** is a part of that in **Fig. 11**, "How the propagating seismic spectra are amplified by bedrock, sedimentary bed and earth surface". This is shown on a simple scheme in **Fig. 12**.

FIG. 12 HERE

Obviously, there may be other relations between the bushes that describe the same information domain – identity (with account of semantic equivalences), structural distinction (when similar events are grouped in different changes) and incompatibility. In addition to the purely academic interest, this may have an important, though yet unexplored, practical consequence for using the event bushes in collaborative research support systems, e.g., COLLA. If an information resource is linked to a part of or entire event bush, and the bush itself appears to have some relationship to another bush, doesn't this mean that the information resource from the first bush appears to be somehow linked to (and therefore, accessible from) the second bush? This can be illustrated by **Fig. 13**, in which the information previously linked to the event bush "How propagating source seismic waves are affected at path and site" (see **Fig. 6**) is re-linked to the event bush "How the propagating seismic spectra are amplified by bedrock, sedimentary bed and earth surface". With further development of COLLA, we believe this could be automated, so that a scientist building an event bush suiting his concept or model would immediately relate the information he links to "his" bush to a number of other bushes describing the same information domain, and vice versa, remaining within "his" bush, he would receive updates from others. This actually means that, while retaining his own language, terminology and modeling approach, a researcher will be able to successfully communicate and collaborate with others.

FIG. 13 HERE

However, in its present form, the collaborative tool based on the event bush embedded in COLLA may show, inter alia, how well this or that fact, concept or idea (expressed as any part of the bush) is supported by data – for instance, in **Fig. 6** one can see that there is evidence that supports the entire bush, evidence that supports one particular scenario (marked red) and, finally, some events involved in this scenario (*ib* events in this case). This obviously means that in the entire domain the facts expressed by these events are best substantiated by the data involved. The same may refer to the physical models – ideally, a model should "cover" the entire bush, offering a variable for each subject and an operation for each connective of the bush. If the "coverage" of the bush is equal for two models, they can be evaluated by other criteria (e.g., theoretical reasonableness or abundance of observation data and expert judgments linked to the bush that favor the model in question). Such approach may be used to formalize the assessment of conceptual (epistemic) and aleatory uncertainties (Bond et al., 2007; 2008; Woo, 1999, and references therein). Moreover, this approach in the COLLA interface may provide a computational aid for series of experiments aiming to elicit and calibrate expert opinions being carried out for decades (see Bond et al., 2007; 2008, Morgani and Henrion, 1990, or Aspinall and Cooke, 1998).

The experience gained in representation of geoscientific domains can be extended toward political science and history, where the event-bush-based conceptualizations have been already applied (Solomin and Mandrik, in press; Rogalchuk et al., submitted).

Finally, the event bush has given rise to development of a unified grammar of dynamic knowledge (Pshenichny and Mouromtsev, in press), which would bring to implementation in COLLA numerous methods used to model dynamic environments – such as Petri nets (Rogalchuk and Solomin, in press), sequence diagrams, activity diagrams, influence diagrams and many others, already tested in descriptive domains of knowledge including geosciences (Pshenichny, in press). The road to their computer-based application for the purposes of collaborative studies has been paved by the event bush method.

Organization of a domain into a system of dynamic environments principally opens new opportunities for querying and searching information on the Internet and transforms the value of the COLLA tool, making it a tool to create a specific "Internet" for researchers studying similar domain.

7. Concluding Remarks

As was shown above, the event bush method gives ground to a tool in the COLLA environment which is quite capable of explicating the reasoning that underlies the physical modeling of geological phenomena. Therefore, event-bush-based applications can be used as a collaborative tool for projects in the field of geophysics. To each fragment of the bush, from a subject or predicate of any of its event to a scenario or the bush in general, files and messages can be attached. Moreover, relevant physical parameters may emerge from its events, and each connective can (and should) be associated with an assumption of a model or a step of a computation. This allows physical models to be placed in the event bush framework within the COLLA tool and, with regard to files and messages uploaded to the same COLLA project, make the models understandable and easily operable for the geoscientific community.

Implementation of the event bush-based COLLA software for asynchronous support of collaborative research is not only promising per se, but opens an opportunity of building an "Internet inside the Internet", a worldwide information system for support of the scientists working in particular information domain.

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References

Aspinall, W., and Cooke, R. M. 1998. Expert judgement and the Montserrat Volcano eruption. In: Mosleh, A. and Baris, R. A. (eds). *Proceedings of the 4th International Conference on Probabilistic Safety Assessment and Management (PSAM4)*, 13–18 September 1998, New York City, 3, 2113–2118.

Barazza F., Malisan P. and Carniel R. 2009. Improvement of H/V technique by rotation of the coordinate system, Communications in Nonlinear Science and Numerical Simulation, 14,182-193.

Behncke B. and Pshenichny, C. A., 2009. Modeling unusual eruptive behavior of Mt. Etna, Italy, by means of event bush, Journal of Volcanology and Geothermal Research, 185, 3, 157-171.

Bond, C.E., Gibbs, A.D., Zhipton, Z.K., and Jones, S. 2007. What do you think this is? “Conceptual uncertainty” in geoscience interpretation. GSA Today, 17, 4-10.

Bond, C.E., Zhipton, Z.K., Gibbs, A.D., and Jones, S. 2008. Structural models: optimizing risk analysis by understanding conceptual uncertainty. First Break, 26, 65-71.

Bonnefoy-Claudet S., Köhler A., Cornou C., Wathelet M and P.-Y. Bard, 2008. Effects of Love Waves on Microtremor H/V Ratio, Bulletin of the Seismological Society of America, 98, 288 – 300

Carniel R, Malisan P, Barazza F and Grimaz S. 2008. Improvement of HVSR technique by wavelet analysis. Soil Dyn Earthquake Eng 28, 321-327.

Carniel R., Barazza F. and Pascolo P. 2006. Improvement of Nakamura technique by singular spectrum analysis, Soil Dyn Earthquake Eng 26, 55–63.

Carniel R., Barbui L. and Malisan P. 2009. Improvement of HVSR technique by self-organizing map (SOM) analysis, Soil Dyn Earthquake Eng 29, 1097-1101.

Diviacco, P., & Pshenichny, C. A. 2010. Concept-referenced spaces in computer-supported collaborative work . In *Geophysical Research Abstracts* (*Vol. 12*). Vienna, Austria: EGU

Diviacco, P., 2012 “Addressing Conflicting Cognitive Models in Collaborative E-Research: A Case Study in Exploration Geophysics” in Collaborative and Distributed E-Research: Innovations in Technologies, Strategies and Applications, IGI Global press, DOI: 10.4018/978-1-4666-0125-3.ch012

Ettensohn F.R, Zhang C., Gao L., Lierman R.T., 2011. Soft-sediment deformation in epicontinental carbonates as evidence of paleoseismicity with evidence for a possible new seismogenic indicator: Accordion folds. Sedimentary Geology, 235, 3–4, 222–233
http://dx.doi.org/10.1016/j.sedgeo.2010.09.022

Feigenbaum, E. and McCorduck, P. 1983. The fifth generation: artificial intelligence and Japan's computer challenge to the world. Boston, MA, USA : Addison-Wesley Longman Publishing Co., Inc.

Field, E.H., and SCEC Phase III Working Group, 2000. Accounting for Site Effects in Probabilistic Seismic Hazard Analyses of Southern California: Overview of the SCEC Phase III Report. Bulletin of the Seismological Society of America, 90, 6B, pp. S1–S31.

Gallipoli M.R. and Mucciarelli M. 2009. Comparison of site classification from Vs30, Vs10 and HSVR in Italy. Bulletin of the Seismological Society of America, 99(1):340-351

Ichihara, M., Takeo, M., Yokoo, A., Oikawa, J., and Ohminato, T. 2012. Monitoring volcanic activity using correlation patterns between infrasound and ground motion, Geophys. Res. Lett., 39, L04304, doi:10.1029/2011GL050542

Kuhn, T. S. (1962). *The structure of scientific revolutions*. Chicago, IL: University of Chicago Press.

Lakatos, I. (1970). Falsification and the methodology of scientific research programmes. In Lakatos & Musgrave (Eds.), *Criticism and the Growth of Knowledge*. Cambridge, UK: Cambridge University Press.

Luzón, F.,, Palencia, V. J., Morales, J., Sánchez-Sesma, F. J., and García, J. M., 2002. Evaluation of Site effects in sedimentary basins. *Fisica de la Tierra*, v. 14, pp. 183-214.

Morgan, M. G., and Henrion, M. 1990. Uncertainty: A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis. Cambridge University Press, New York. [Reprinted 1998].

Nakamura Y., 1989. A Method for Dynamic Characteristic Estimation of SubSurface using Microtremor on the Ground Surface, Q Rep Railway Tech Res Inst 30, 1, 25–33

Nakamura Y., 2000, Clear identification of fundamental idea of Nakamura's technique and its application, Proceedings of the 12th World Conference of Earthquake Engineering. Auckland, New Zealand.

Nogoshi and Igarashi, 1971. On the amplitude characteristics of microtremor (Part 2), J. Seismol. Soc. Jpn. 24, 26–40.

Nunziata, C., Mele, R., and Natale, M. 1999. Shear wave velocities and primary influencing factors of Campi Flegrei–Neapolitan deposits. Engineering Geology, 54, 3–4, 299–312
http://dx.doi.org/10.1016/S0013-7952(99)00044-7

Pshenichny C.A., Nikolenko S. I., Carniel R., Vaganov P.A., Khrabrykh Z.V., Moukhachov V.P., Akimova-Shterkhun V.L., Rezyapkin A.A. 2009. The event bush as a semantic-based numerical approach to natural hazard assessment (exemplified by volcanology), Computers & Geosciences, 35, 5, 1017-1034.

Pshenichny, C.A., Nikolenko, S.I., Carniel, R., Sobissevitch, A. L., Vaganov, P. A., Khrabrykh, Z. V., Moukhachov, V. P., Shterkhun, V. L., Rezyapkin, A. A., Yakovlev, A. V., Fedukov, R. A., and Gusev, E. A. 2008. The event bush as a potential complex methodology of conceptual modelling in the geosciences, in: Proceedings, iEMSs - International Congress on Environmental Modelling and Software (Sanchez-Marre, Bejar, J., Comas, J., Rizzoli, A., and Guariso, G., Eds.), Barcelona, July 2008; vol. 2, pp 900-912.

Pshenichny, C.A., and Khrabrykh, Z.V., 2002. Knowledge base of formation of subaerial eruption unit, Environmental Catastrophes and Recovery in the Holocene (Abstracts), Brunel University, London: http://atlas-conferences.com/cgi-bin/abstract/caiq-22

Pshenichny, C.A., and Kanzheleva, O.M., 2011, Theoretical foundations of the event bush method. Societal Challenges and Geoinformatics, GSA Special Paper 482, Sinha, K, Gundersen, L., Jackson, J., and Arctur, D. (Eds.), pp. 139-165.

Pshenichny, C.A., and Mouromtsev, D.I. 2013. Representation of the Event Bush Approach in Terms of Directed Hypergraphs. H.D. Pfeiffer et al. (Eds.): ICCS 2013, LNAI 7735, pp. 287–298, 2013. Springer-Verlag Berlin Heidelberg 2013.

Pshenichny, C.A., and Mouromtsev, D.I. Grammar of Dynamic Knowledge for Collaborative Knowledge Engineering and Representation. In Diviacco, P. Fox, P., Pshenichny, C., and Leadbetter, A. (Eds), Collaborative Knowledge in Scientific Research Networks, IGI Global: chapter 16 (to appear in 2015).

Pshenichny C.A. Knowledge engineering in volcanology: practical claims and general approach. In press in Journal of Volcanology and Geothermal Research.

Rogalchuk, V., and Solomin, K. Perspectives of Use of Petri Nets in Collaborative Research. In Diviacco, P. Fox, P., Pshenichny, C., and Leadbetter, A. (Eds), Collaborative Knowledge in Scientific Research Networks, IGI Global: chapter 18 (to appear in 2015).

Roten D., Fäh D., Cornou C. and Giardini D., 2006. Two-dimensional resonances in Alpine valleys identified from ambient vibration wavefields, Geophysical Journal International, 165, 3, 889-905.

Sinha, K., Malik, Z., Raskin, R., Barnes, C., Fox, P., McGuinness, D., Lin, K., 2008, Semantics-based Interoperability Framework for Geosciences. AGU Fall Meeting Abstracts.

Solomin, K., and Mandrik, M. Constructing historical knowledge through graphic boundary objects. In Diviacco, P. Fox, P., Pshenichny, C., and Leadbetter, A. (Eds), Collaborative Knowledge in Scientific Research Networks, IGI Global: chapter 17 (to appear in 2015).

Figure captions

Fig. 1. A “flat” conceptual diagram depicting the field of knowledge and the messaging and storage facility together create a three-dimensional space where information becomes the third dimension. Users follow the diagram to find the issue they are interested in and then by entering the corresponding node they can access the corresponding messages and files (from: Diviacco, 2012).

Fig. 2. Basic syntax of the event bush (from Pshenichny and Kanzheleva, 2011)

Fig. 3. Graphic notation for the connectives of the event bush: (a), flux, (b), influx, (c), furcation, (d), conflux,; E_1, E_2, …, E_n are connected events..

Fig. 4. Classical tripartite context of seismology (Figure 1 from Luzon et al., 2002): fuente (Spanish) – source, camino (Spanish) – path, Geologia local (Spanish) – site.

Fig. 5. An event bush describing the source-path-site understanding of seismic motion.

Fig. 6. Strands of information added to the event bush from Fig. 5 in the COLLA environment. Red is the scenario to which one piece of information is linked.

Fig. 8. An event bush accounting for the scenario suggested by Field et al. (2000) – see comments in the text. This scenario is marked red.

Fig. 9. Sketch of the typical geological structure of sedimentary basin as comprehended by the followers of the HVSR approach. Modified from Carniel et al. (2006)

Fig. 10. An event bush that verbally fits Nogoshi – Igarashi – Nakamura model.

Fig. 11. An event bush that entirely formalizes the Nogoshi – Igarashi – Nakamura model..

Fig. 12. “Subset – set” interrelation between several event bushes addressing the same information domain.

Fig. 13. Re-linking of information to the sub-bush that formalizes the Nogoshi – Igarashi – Nakamura model.