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Temporal Modeling by means of an Event Bush

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Bayesian belief networks (BBNs) have become one of the most often used mathematical tools to model dangerous phenomena on the Earth and support decision-making. Geological data are commonly related to time. To know *when* is no less important than to know *what*. BBNs have several known approaches to time handling. These can be divided into two main classes: discrete time (where it usually comes down to copying the nodes of the network several times corresponding to the time slices) and continuous time.

Event bush is a qualitative tool of organization of a domain of knowledge. Together with the BBN formalism it forms a powerful tool for geohazard assessment. However, so far it did not account for time in any way.

We describe here the simplest approach to handling time-related information in an event bush and transforming such event bushes into BBNs and back. We take the most common (and sufficient for most practical purposes) approach of discrete time handling. Thus, we divide the time scale into discrete periods with lengths known in advance. Each primary or secondary event in an event bush may have a *time interval* when it occurs (e.g. "magma ascent takes place from hour 2 to hour 5", where time is measured from some arbitrary point when the modeled processes begin). If it is not specified, we take that the event occurs throughout the whole time scale (e.g. it is a landscape peculiarity).

Apart from the time interval, there are two other questions that should be answered about each of the nodes of the event bush in order to incorporate time properly. First, how fast does this event influence its successors? E.g. if magma ascent leads to lava doming, does it occur immediately, in an hour, or in two hours? There is room for intermediate options here: magma ascent may lead to lava dome in one hour with probability 0.4 and in two hours with probability 0.6. This can also be easily accounted for in the corresponding BBN.

Second, for some events it may be impossible to say when they end (we detect that magma ascent has begun, but it has not yet ended). In these cases it should be noted how an event occurring now influences the probability of the same event occurring in the next time interval. E.g. if magma is ascending, how probable is it that it will be ascending in the next hour? Usually answers to these questions depend also on the duration of an event; this can also be taken into consideration.

Therefore, in the proposed framework a user may now input the duration of an event if it occurs or the time of its beginning and how probable it is for it to continue for different durations.

The event bush "loaded" with time values is translated then into a BBN (where the actual propagation will take place). We are given the value of a discrete time step (e.g. an hour) and information described above about the nodes of the event bush. In order to build a time-specific BBN, we first build a regular BBN on this event bush, discarding for the moment all time-related information (note that we also discard cause-and-effect relationships that do not take place immediately). Afterwards, we copy this BBN n times, where n is the number of time periods under consideration (if it is undefined, we may take the maximum of all possible durations or just set a reasonable upper bound for our modeling).

In the resulting BBN, we keep the structure of the initial BBN but add edges corresponding to time-related relationships. Specifically, we add directed edges between time-related causes and effects. Of course, the edges should be directed from the earlier event to the later. The additional edges may connect similar events with different time ("if magma ascends at time x, it will with probability 80% ascend at time $x+1$") or different time-separated events ("if magma ascends at time x, with probability 80% there will be a lava dome or a lava flow at time $x + 1$"). The BBN in which actual computation proceeds is transformed back into an event bush to display results to the user.

Time-specific event bushes will allow to adequately capture monitoring data, fully incorporate abundant physical models of eruptive scenarios, seismic unrest, flow propagation, and others, and will be tested on a number of various hazardous objects (volcanoes first of all), for which good time-series exist.