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Foundations of Event-Based Information Flows and Management v0.1

Hayes-Roth, F

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Foundations of Event-Based Information Flows and Management (v0.1)
Rick Hayes-Roth[1]
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VIRT shows benefits of flow-by-value.
Valuable information reduces uncertainty (Shannon) and improves expected outcomes.
In any given context, the operator has some beliefs. In fact the total context for each actor is the set of beliefs held by that actor.
Uncertainty is reduced when beliefs are altered to be more certain.
Data that reduces uncertainty corresponds to bits of information, or simply information.
Bits that don't reduce uncertainty aren't information.

For any given context, information arises from events that reduce uncertainty. Perfectly predictable (certain) and predicted (believed) events don't reduce uncertainty when they occur. Events whose occurrence eliminates some possibilities in the operator's world model constitute information for that operator. Events correspond to instances of *conditions of interest*.

The simplest form of expression that defines an informative event corresponding to some condition of interest C is:

$$P(\mathbf{X}, \mathbf{ST}) =_C v, \qquad (1)$$

where

- **ST** is a region of space-time,
- **X** is a set of entities or variables,
- P is a proposition or function or measurement of X at ST,
- *v* is a target or criterial value,
- and $=_C$ is an equivalence or equality between P(X,ST) and *v* considered definitional for the condition of interest C.

More generally, events can be established by the outcomes of various comparison operators, especially including =, ~=, <, >, and similar operations on sets, when P and *v* are set-valued.

All variables and entities are dynamic in the sense that they can be indexed by space-time. We can simplify events by collapsing over time (ignoring time) or space (ignoring space).

To describe the state of any dynamic system, the minimum number of bits required results from describing the series of changes over time. (There may be ways to compress this encoding, but every bit in the series of changes is informative. Because every bit is informative, we consider the description minimalist)

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Let $P^{\boldsymbol{S}}(\mathbf{X},\mathbf{T})(s)$ be the total function that gives the value of $P(\mathbf{X},\mathbf{ST})$ for spatial region s at time **T**. For a specific fixed spatial region s, we can have $P_s^{\boldsymbol{S}}(\mathbf{X},\mathbf{T})$, which measures values in the system **X** over time.

All changes in a system **X** can be described by one or more measurements such as $P(\mathbf{X},\mathbf{ST})$, or when fixing the region of space, $P_s^{\boldsymbol{S}}(\mathbf{X},\mathbf{T})$.

If $P_s^{\boldsymbol{S}}(\mathbf{X},\mathbf{T})$ changes discretely rather than continuously, changes will occur at specific points T_1, T_2, … Exactly at those moments, corresponding events occur, when the new value of $P_s^{\boldsymbol{S}}(\mathbf{X},T_{j+1}) \sim= P_s^{\boldsymbol{S}}(\mathbf{X},T_j)$. (We've omitted the event type corresponding to condition of interest C from the equation.)

If $P_s^{\boldsymbol{S}}(\mathbf{X},T_{j+1}) = \boldsymbol{v}_{j+1}$ and $\boldsymbol{v}$ is a vector or set, only some elements of $\boldsymbol{v}$ need to have changed. We'll call that subset Δ_{j+1}. So, the series of deltas, $\boldsymbol{D} = \{\Delta_{j+1} : j = 1, 2, \ldots\}$ constitutes a terse description of the system (changes) over time, given some initial conditions $\mathbf{X}_0$.

Events might be based on constancy or change.
If events reflect unpredicted (surprising) constancy, uncertainty is reduced when no change is observed for some time interval. Whenever the interval ends, a timer is reset to 0, and an event occurs when the timer reaches the end of the interval. So constant value events are triggered when the value of a timer becomes just equal to the full interval. In this way, detection of informative constant events is the product of applying a comparison triggered by a change-detecting event (the time interval completing).

Events based on change need only examine the series ***D.***
Events based on constancies, need only examine the relevant values when the interval completes, which is one of the elements indicated in ***D.*** To make things simple, the value of still unchanged measures in constant events should be added to ***D*** as well. In that case, all events need examine only ***D.***

D is called the delta-description of system **X.**

D is a terse description of **X**. It contains no redundant bits.

A complete description $P_s^{\boldsymbol{S}}(\mathbf{X},\boldsymbol{T})$ can be constructed from ***D*** for all values of time T if $P_s^{\boldsymbol{S}}(X,T)$ is known for any time T'.

When system changes are predictable, as when the system is controlled by known dynamic laws with computable state changes, those dynamics can be built into the entities and state variables so that $\mathbf{X}(t+\delta) = \mathbf{X}(t) + \nabla(\mathbf{X}(t), \delta)$ or $\mathbf{X}(t+\delta) = M(\mathbf{X}(t), \delta)$. ∇ is an incremental gradient function. M is a model that can update a system from initial time t through a subsequent increment of time δ. In such cases, the **expected** state for **X** at any time t might be written as $E_M(\mathbf{X}(t))$. When we want to indicate the expected states of **X** over a space-time region, we write just $E_M(\mathbf{X}_{ST})$. The basic idea is that many systems can be simulated and their values computed or dead-reckoned by use of a system model M. In this case, most conditions of interest define differences between actual values and expected values, so that the events are often written as:

$$| P(\mathbf{X}, \mathbf{ST}) – P(E_M (\mathbf{X}_{ST}), \mathbf{ST}) | >_C \; v \quad (2)$$

Thus, when state changes can be predicted through model-based expectations, we can compute expected states of entities and variables, and then ask about their properties and measurements. If actual values differ from expected values by more than some value *v* appropriate for condition of interest C, that's an event of interest. Noting that the selected values of **X** needed for condition of interest C might be denoted $\mathbf{X}_C$, that **ST** can be elided, and that expected values of $\mathbf{X}_C$ can be written simply as $E(\mathbf{X}_C)$, a shorthand expression for the typical condition of interest C is:

$$| \mathbf{X}_C – E(\mathbf{X}_C) | >_C \; v. \quad (3)$$

Putting this all together, we can imagine a continuous monitoring system that simultaneously updates memory with evolving and expected state variable values as in ***D*** above. So in addition to a delta-description ***D*** of the observed state values**,** we can also store the significant changes in expected values of variables participating in conditions of interest, designated $\boldsymbol{D^E}$. The actual variables that need to be monitored and recorded over time are those $\mathbf{X}_C$ and $E(\mathbf{X}_C)$ participating in any conditions of interest C.

Comparisons of Dynamic Variables in Conditions of Interest

Many conditions of interest describe events where dynamic entities interact in space and time, as when they first get within range of one another or when the distance between them falls below some acceptable threshold. The values of interest are the actual or predicted distances, so the general type event equation is:

$$| \langle lat_1, long_1, alt_1, t \rangle - \langle lat_2, long_2, alt_2, t \rangle | <_C \; v . \quad (4)$$

Eqn. 4 describes a condition where the distance between two locations at time t are closer than *v*. The variables might be either actual state variables or expected variables. Usually, we are interested in adapting to closures before they occur, so that the system model M is constantly being updated and calibrated so that it can continually improve the accuracy of its current predictions.

Note that the distance in (4) being computed for the condition of interest C defines one type of system measurement that could be in **X** or P(**X**) as described at the outset.

The delta description ***D*** could record a series of significant changes in such distances, as suggested above for variables that participate in conditions of interest.

Post Hoc Comparisons

One risk in recording only minimal changes of variables that participate in conditions of interest is that one might fail to record data that others would find useful in reviewing outcomes later. After the fact evaluations, or *post hoc comparisons,* might need to look at raw data that had been used in determining values but not actually recorded. For example, locations of two entities 1 and 2 in (4) would not necessarily be recorded, but merely distances and times when their separating distance changed significantly. Obviously there's a tradeoff between maximum efficiency for monitoring conditions of interest and maximum recorded state for after action reviews and post hoc investigations.

Fields of Entities, Interactions and Measures

The example of distance between two entities in (4) is a typical type of concern in dynamic environments. In these environments, however, the conditions of interest are usually expressed in terms of interactions between any element of one set with any element of another set. For example, no Blue vehicle should come within a certain distance of any Red vehicle, or no civilian aircraft should ever be too close to another, or no aircraft should ever be less than 200' above local terrain obstacles. In all of these cases, the interactions that matter are between pairs of entities determined dynamically, according to their relative proximity. We call spatiotemporal regions occupied by interacting sets of this sort *fields.*

Many of our conditions of interest apply to all entities or pairs of entities in a field. For computational purposes, we can associate with each entity a set of potential interacting entities of interest. For example, each Blue vehicle is associated with all Red vehicles that it might potentially interact with. We need to continuously monitor the condition of interest between the Blue vehicle and all of the associated potentially interacting Red ones. More generally, we want to monitor the values of key variables (such as distance) across all such pairs, and not evaluate it continuously for other pairs.

Some conditions will concern aggregate measures on all pairs associated with one entity. An example might be the total number of Red vehicles within 10 miles of a Blue vehicle.

Some conditions will concern aggregate measures over all interacting pairs in a field. An example might be the number of pairs of civilian aircraft that violated minimum separation requirements during a 24 hr period over the entire US. In many operations, we might want to aggregate risks associated with an expected set of interactions. For example, we might want to associate a risk measure to every close interaction between Red and Blue vehicles or between civilian aircraft. If we have expected positions for each in the next 10 minutes, for example, we can aggregate the risk measure for the entire field. When the aggregate risk exceeds an acceptable threshold, we can intervene and change plans.

There are many types of measures that apply over fields and which can be usefully aggregated. These are valuable either for actual or expected values.

Scenarios and examples from the "VIRT Technical Architecture Specification"

For convenience, the examples from that document are repeated here:

1.4 Events, computations and conditions of interest:

(a) Intersection of route of H with trajectory of F's detection wedge at some time t
(b) Expected positions of F and its detection wedge at future times t
(c) Expected positions of H at future times t
(d) Possible positions, though not expected, of F and its detection wedge at future times t
(e) Possible positions, though not expected of H at future times t (through deviations, emergencies, etc.)
(f) Detection of F by A
(g) Time limits for route continuations (fuel exhaustion)
(h) Estimated landing times for aircraft (routes completed)
(i) Time intervals for relevant operations (H, A, F airborne)
(j) [same as (8) above] H wishes to know that F's likely to detect it when the chance is considered more than unlikely (when F is expected eventually to get H in its detection envelope)
(k) [same as (9) above] H wishes to get a higher level of alert than in (8) when F is expected to eventually get H in its detection envelope and H is already within 50 nm of F and that separation is expected to be further reduced.
(l) [same as (10) above] H wishes to get the highest level of alert when F has apparently begun to pursue H (changed its flight pattern from expected and closing on H)