Chronicle Based Alarm Management in startup and shutdown stages

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ISA-18.2 defines an alarm as: "An audible and/or visible means of indicating to the operator an equipment malfunction, process deviation, or abnormal condition requiring a response"
Alarm management

Alarm management → Determining, documenting, designing, operating, monitoring, and maintaining alarm systems.

Poor alarm management in startup/shutdown stages increase the accident probabilities.

- Startup/shutdown → Alarm saturation → Alarms ignored
- Alarm management ≠ Alarm reduction
Motivation

DIAGNOSIS BY SITUATION RECOGNITION DURING STARTUP/SHUTDOWN STAGE

OFF-LINE

Procedural actions

- Alarm flood
  - Expertise knowledge
  - Data from the process simulation

[Diagram showing a network of nodes and arrows representing process events and diagnosis]

CRS

- Chronicle recognized
  - $C_{ij}$: Normal
  - $C_{i}$: Abnormal

ON-LINE

Process

Event flow

Chronicle recognition system

How generate the chronicle database?

Help to the operator
Chronicle learning proposal

Hybrid causal model

Representative event sequences

Event abstractions

Expertise

Sequence generation for learning

HCDAM Heuristic Chronicle Discovery Algorithm Modified

Chronicle database

Reduce the conservation of the chronicles obtained

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CBAM in startup and shutdown stages
Objectives

- Alarm management based on a diagnosis process during startup and shutdown stages
- Diagnosis based on situation recognition
- Normal and abnormal situations captured by chronicles
- Chronicle database generated automatically.
- Apply the methodology in the petrochemical sector
Alarm historian visualization and analysis

- Recognizing alarm chattering, I. Izadi et al, 2009
- Grouping many alarms in a graphical representation, F. Higuchi et al, 2009
- Estimation of the alarm limits in transition stages, Z. Ge and Z Song, 2010
Process data-based alarm system analysis

- Alarm system evaluation using virtual subjects, X. Liu et al, 2010
- Alarm database for improve process safety, A Pariyani et al, 2012
- Correlation analysis for alarm visualization, F. Yang et al, 2011
Process variable causality analysis (causal methods)

- Using hybrid model based framework for alarm anticipation, S. Xu et al, 2013
- Event expert framework for managing process transitions, R. Srinivasan et al, 2005
- Diagnosis based on standard operating procedures, Z. Jing et al, 2013
Related work

Formalization of the proposal

- A. Subias et al, 2014: Chronicle learning using HCDAM.
Outline

- Chronicle Based Alarm Management (CBAM)
- Case study
- Formal framework
- Hybrid causal model
STEP 1, *event type identification*: From the standard operating procedures and from the evolution of the continuous variables, determine the set of event types in startup and shutdown stages.

STEP 2, *event sequences determination*: From the hybrid causal model, the event abstractions and the expertise, determine the date of occurrence to each event type and construct the representative event sequences.

STEP 3, *chronicle database construction*: From the representative event sequences in each scenario, determine the chronicle database using the algorithm *HCDAM*. 
Case study - HTG (Hydrostatic Tank Gauging)
Event types and sequences

- **Definition 1:** We define $E$ as the set of event types $\{ \sigma_i \}$.

- **Definition 2:** An event is defined as a pair $(e_i, t_i)$, where $e_i \in E$ is an event type and $t_i$ is a variable of integer type called the event date.

- **Definition 3:** A temporal sequence on $E$ is an ordered set of events denoted $S = \langle (e_i, t_i) \rangle$. 
Definition 4: A chronicle is a triplet $C = (\xi, T, G)$ such that:

- $\xi \subseteq E$. $\xi$ is called the typology of the chronicle.
- $T$ is the set of temporal constraints of the chronicle.
- $G = (V, A)$ is a directed graph where:
  - $V$ represents the event types of $\xi$
  - The arcs $A$ represents the time constraints between event dates.
Definition 5: A chronicle $C = (\xi, T, G)$ is recognized when occurs a temporal sequence $S$ of event types $\xi'$, such that $\xi \subseteq \xi'$ and it satisfies all temporal constraints $T$.

$\xi = \{a, b, c, d\}$, $T_{ab} = [3, 4]$, $T_{ac} = [1, 2]$, $T_{cb} = [2, 3]$, $T_{bd} = [1, 2]$
The hybrid system is represented by an extended transition system:

$$\Gamma = (\vartheta, D, E, Tr, Init, CSD, COMP, DMC)$$ (1)

- $\vartheta$ is a finite set of continuous process variables $\vartheta = \{v_i\}$
- $D$ is a finite set of discrete variables $D = Q \cup K \cup V_Q$
  - $Q$ is a set of states $q_i$ of the transition system which represent the system operation modes.
  - $K$ is the set of auxiliary discrete variables that represents the system configuration in each mode $q_i$.
  - $V_Q$ is a set of qualitative variables whose values are obtained from the behavior of each continuous variable $v_i$. 
$E = \Sigma_o \cup \Sigma_{uo}$ is a finite set of observable ($\Sigma_o$) and unobservable ($\Sigma_{uo}$) event types, noted $\sigma$, where:

- $\Sigma$ is the set of event type associated to the procedural actions in the startup or shutdown stages.
- $\Sigma^c$ is the set of event type associated to the behavior of the continuous process variables.

$Tr : Q \times \Sigma \rightarrow Q$ is the transition function.

$Init$ Represents the initial conditions of the hybrid system.
Causal System Description (CSD)

- \( CSD \supseteq \bigcup_i CSD_i \) is the Causal System Description
  
  - Every \( CSD_i \) associated to a mode \( q_i \), is given by a graph \( G_c = (\emptyset \cup K, I) \).
  
  - The set of influences is noted \( I \) and the set of process components is \( COMP \)

Diagram:

- A graph \( G_c = (\emptyset \cup K, I) \) with nodes \( v_i \) and \( v_j \) connected by an edge from \( v_i \) to \( v_j \).
Dynamic model of control (DMC)

\[ K(\text{Comp.}) \]

\[ v_j \rightarrow v_i \]

Procedure action \( \sigma_i \in \Sigma \)

Set point

Controller

Comp. model

Procedure action \( \sigma_i \in \Sigma U \sigma \)

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Steps of the Chronicle Based Alarm Management

**Step 1:** Event types identification
- Procedural actions
- Evolution continuous variables

**Step 2:** Event sequences generation
- Hybrid causal model
- Event abstraction
- Expertise

**Step 3:** Chronicle database construction
- Representative event sequences
Step 1: Procedural actions

- Set of event types $\Sigma$ for the system HTG:
  \[
  \Sigma = \{ V_{1,c,o}, V_{2,c,o}, P_{u_f-n}, V_{1,o,c}, V_{2,o,c}, P_{u_n-f} \} \in \Sigma_o
  \]  
  \]

- Assumption: $\Sigma_{uo} = \{ e_{M/A} \}$
  Event type $e_{M/A}$ corresponds to the transition from manual to automatic operation.
For each continuous variable $L$, $Po$ and $Q_{oV2}$, the following event types, correspond to the indications of that the continuous variable has passed its alarm limits of low ($l$) or high ($h$).

$$
\Sigma^c = \left\{ l^+_L, l^-_L, h^+_L, h^-_L, \\
l^+_Po, l^-_Po, h^+_Po, h^-_Po, \\
l^+_QoV2, l^-_QoV2, h^+_QoV2, h^-_QoV2 \right\}
$$

(3)
Notation for the event types:

\( a: \ V_1^{c,o}, \ b: \ V_2^{c,o}, \ c: \ Pu_{f-n}, \ d: \ V_1^{o,c}, \ f: \ V_2^{o,c}, \ g: \ Pu_{n-f}, \)

\( h: \ l^+_{(L)}, \ i: \ h^+_{(L)}, \ j: \ l^-_{(L)}, \ k: \ h^-_{(L)}, \)

\( l: \ l^+_{(Po)}, \ m: \ h^+_{(Po)}, \ n: \ l^-_{(Po)}, \ o: \ h^-_{(Po)}, \)

\( p: \ l^+_{(Q_{oV2})}, \ q: \ h^+_{(Q_{oV2})}, \ r: \ l^-_{(Q_{oV2})}, \ s: \ h^-_{(Q_{oV2})}. \)
Step 2: Underlying DES of the HTG system
Step 2: Qualitative variables $V_Q$

\[
f(V_i)_{qual} = \begin{cases} 
  V_i^H & \text{if } v_i \geq H_{vi} \\
  V_i^M & \text{if } L_{vi} < v_i < H_{vi} \\
  V_i^L & \text{if } v_i \leq L_{vi}
\end{cases}
\]
Step 2: Event abstraction

**Abstraction function** \( f_{V_Q \rightarrow \sigma} \)

\[
f_{V_Q \rightarrow \sigma} : V_Q \times \gamma(V_Q, \Sigma^c) \rightarrow \Sigma^c
\]

\[
\forall v_i \in V_Q, (V_i^n, V_i^m) \rightarrow \begin{cases} 
  l^+(v_i) & \text{if } V_i^L \rightarrow V_i^M \\
  l^-(v_i) & \text{if } V_i^M \rightarrow V_i^L \\
  h^+(v_i) & \text{if } V_i^M \rightarrow V_i^H \\
  h^-(v_i) & \text{if } V_i^H \rightarrow V_i^M 
\end{cases}
\]

\[
V_i^n, V_i^m \in \{V_i^L, V_i^M, V_i^H\}
\]

\[
\Sigma^c = \bigcup_{v_i \in \gamma} \{l^+(v_i), l^-(v_i), h^+(v_i), h^-(v_i)\}
\]
Step 2: Event type dates

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### Step 3: Chronicle database

In the set of chronicles \( \{ C_{ij} \} \), the rows represent the operating modes (i.e. \( O_1 : \text{Startup} \), \( O_2 : \text{Shutdown} \), etc) and the columns the normal and abnormal situations.

\[
C_{Ar_k} = \begin{bmatrix}
C^k_{01} & C^k_{11} & \cdots & \cdots & C^k_{1j} \\
C^k_{02} & C^k_{12} & \cdots & \cdots & C^k_{2j} \\
\vdots & \vdots & \ddots & \vdots & \vdots \\
C^k_{0j} & C^k_{1j} & \cdots & \cdots & C^k_{ij} 
\end{bmatrix}
\]

- Use of the \textit{HCDAM} to find all the chronicles for each scenario.
It learns the chronicles, whose instances occur in all temporal sequences represented exhibiting the same situation. Phases:

1. Filtering operation
2. Building a constraint database from the temporal sequences.
3. Generating a set of candidate chronicles
**PHASE 1:** The *filtering operation* is a preliminary treatment on sequences and it can be summarized in two possible actions:

- Filtering the event types those do not be present in all sequences $S$. If $\exists S_k \in S$ such as $\exists e_i \not\in S_k$, then $e_i$ will be removed of all other sequences.

- Filtering on a given set of event types $\mathcal{E} = \{e_i, e_j, \ldots e_k\}$ if we are interested only those event types during processing.
PHASE 2: From the temporal sequences, it stores for each pair of event types its temporal constraints in a constraint graph structure.

In this constraint tree, time constraints are nodes of an acyclic oriented graph whose arcs represent the relationship between constraints.
PHASE 3: The generation of a set of candidate chronicles initializes with a set of chronicles that were proved to be frequent and it uses the constraint database to explore the chronicle space.

- The set of candidates initiates with the set of root trees
- Use the operator "add $\varepsilon$". This operator, checks at the constraint graphs in order to find the restrictions of $\varepsilon$ with all elements of $E$.
- Determinate the minimal number of occurrences of the candidate in $S$
RESULTS ON THE SCENARIOS

1. Scenario 1: Normal startup
2. Scenario 2: Abnormal startup, possible fail in V2
3. Scenario 3: Normal shutdown
4. Scenario 4: Abnormal shutdown
Scenario 1: Normal startup

Normal startup simulation

Signal of color blue: Level ($L$) in the tank $TK$

Signal of color green: Outlet pressure ($Po$) in the pump $Pu$

Signal of color red: Outletflow ($Q_{oV2}$)
Representative event sequences in the *Scenario 1* 1/2

<table>
<thead>
<tr>
<th>Events</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>V1_c-o</td>
<td>a</td>
<td>Press_h+</td>
</tr>
<tr>
<td>V2_c-o</td>
<td>b</td>
<td>Press_l-</td>
</tr>
<tr>
<td>Pu_f-n</td>
<td>c</td>
<td>Press_h-</td>
</tr>
<tr>
<td>V1_o-c</td>
<td>d</td>
<td>Qo_l+</td>
</tr>
<tr>
<td>V2_o-c</td>
<td>f</td>
<td>Qo_h+</td>
</tr>
<tr>
<td>Pu_n-f</td>
<td>g</td>
<td>Qo_l-</td>
</tr>
<tr>
<td>Level_h+</td>
<td>i</td>
<td></td>
</tr>
<tr>
<td>Level_l+</td>
<td>j</td>
<td></td>
</tr>
<tr>
<td>Level_h-</td>
<td>k</td>
<td></td>
</tr>
<tr>
<td>Press_l+</td>
<td>l</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sequences</th>
<th>REPRESENTATIVE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal startup</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>a h j c b p l m q k o s</td>
</tr>
<tr>
<td>2</td>
<td>h i b c p l q m k s</td>
</tr>
<tr>
<td>3</td>
<td>h i b c p l q m k s</td>
</tr>
</tbody>
</table>

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Chronicle $C_{01}$, Scenario 1

Chronicle generated using the algorithm $HCDAM$
Scenario 2: Abnormal startup with a fail in V2

Abnormal startup simulation

Signal of color blue: Level ($L$) in the tank $TK$
Signal of color green: Outlet pressure ($Po$) in the pump $Pu$
Signal of color red: Outletflow ($Q_{oV2}$)
### Representative event sequences in the Scenario 2

<table>
<thead>
<tr>
<th>Events</th>
<th></th>
<th>Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>V1 c-o</td>
<td>a</td>
<td>Press h+</td>
</tr>
<tr>
<td>V2 c-o</td>
<td>b</td>
<td>Press l-</td>
</tr>
<tr>
<td>Pu f-n</td>
<td>c</td>
<td>Press h-</td>
</tr>
<tr>
<td>V1 o-c</td>
<td>d</td>
<td>Qo h+</td>
</tr>
<tr>
<td>V2 o-c</td>
<td>f</td>
<td>Qo l-</td>
</tr>
<tr>
<td>Pu n-f</td>
<td>g</td>
<td>Qo h-</td>
</tr>
<tr>
<td>Level l+</td>
<td>h</td>
<td></td>
</tr>
<tr>
<td>Level h+</td>
<td>i</td>
<td></td>
</tr>
<tr>
<td>Level l-</td>
<td>j</td>
<td></td>
</tr>
<tr>
<td>Level h-</td>
<td>k</td>
<td></td>
</tr>
<tr>
<td>Press l+</td>
<td>l</td>
<td></td>
</tr>
</tbody>
</table>

#### Sequences

<table>
<thead>
<tr>
<th>Abnormal startup</th>
</tr>
</thead>
</table>

1. | a | h | i | c | b | l | m | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |

2a | h | i | b | c | l | m | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |

3a | h | i | b | c | l | m | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
HCDAM in the Scenario 2

Step 1: Event types identification
Step 2: Representative event sequences
Step 3: Chronicle database construction
Results

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CBAM in startup and shutdown stages
Scenario 3: Normal shutdown

Simulation of a normal shutdown when the V2 fail in the startup stage.

Signal of color blue: Level (L) in the tank TK
Signal of color green: Outlet pressure (Po) in the pump Pu
Signal of color red: Outletflow (QoV2)
Representative event sequences in the *Scenario 3* 1/2

<table>
<thead>
<tr>
<th>Event</th>
<th>Sequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>V1_c-o</td>
<td>a</td>
</tr>
<tr>
<td>V2_c-o</td>
<td>b</td>
</tr>
<tr>
<td>Pu_f-n</td>
<td>c</td>
</tr>
<tr>
<td>V1_o-c</td>
<td>d</td>
</tr>
<tr>
<td>V2_o-c</td>
<td>f</td>
</tr>
<tr>
<td>Pu_n-f</td>
<td>g</td>
</tr>
<tr>
<td>Level_l+</td>
<td>h</td>
</tr>
<tr>
<td>Level_h+</td>
<td>i</td>
</tr>
<tr>
<td>Level_l-</td>
<td>j</td>
</tr>
<tr>
<td>Level_h-</td>
<td>k</td>
</tr>
<tr>
<td>Press_l+</td>
<td>l</td>
</tr>
<tr>
<td>Press_h+</td>
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</tr>
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<tr>
<td>Press_h-</td>
<td>o</td>
</tr>
<tr>
<td>Qo_l+</td>
<td>p</td>
</tr>
<tr>
<td>Qo_h+</td>
<td>q</td>
</tr>
<tr>
<td>Qo_l-</td>
<td>r</td>
</tr>
<tr>
<td>Qo_h-</td>
<td>s</td>
</tr>
</tbody>
</table>

Sequences

1. Normal shutdown

2. a h i c b l m d f g o

3. a h i b c l m g f d o
HCDAM in the Scenario 3

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**Scenario 4: Abnormal shutdown**

Simulation of an abnormal shutdown when the $V2$ fail in the startup stage.

![Graph showing signal levels](graph.png)

Signal of color blue: Level ($L$) in the tank $TK$
Signal of color green: Outlet pressure ($Po$) in the pump $Pu$
Signal of color red: Outletflow ($Q_{oV2}$)
Representative event sequences in the *Scenario 4* 1/2

<table>
<thead>
<tr>
<th>Events</th>
<th>Press_h+</th>
<th>Press_l+</th>
<th>Press_h-</th>
<th>Press_l-</th>
</tr>
</thead>
<tbody>
<tr>
<td>V1_c-o</td>
<td>a</td>
<td>m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>V2_c-o</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Pu_f-n</td>
<td>c</td>
<td></td>
<td>o</td>
<td></td>
</tr>
<tr>
<td>V1_o-c</td>
<td>d</td>
<td></td>
<td>p</td>
<td></td>
</tr>
<tr>
<td>V2_o-c</td>
<td>f</td>
<td></td>
<td>q</td>
<td></td>
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<tr>
<td>Pu_n-f</td>
<td>g</td>
<td></td>
<td>r</td>
<td></td>
</tr>
<tr>
<td>Level_h+</td>
<td>h</td>
<td></td>
<td>s</td>
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<tr>
<td>Level_h+</td>
<td>i</td>
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<tr>
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<td>j</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level_h-</td>
<td>k</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Press_l+</td>
<td>l</td>
<td></td>
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</tr>
</tbody>
</table>

Sequences: Representative

Abnormal shutdown

1 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30

2

3

The second occurrence of event type “m”
**HCDAM in the Scenario 4**

1. **Step 1: Event types identification**
2. **Step 2: Representative event sequences**
3. **Step 3: Chronicle database construction**

Results

HCDAM in the **Scenario 4**

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CBAM in startup and shutdown stages
Conclusion

- A preliminary method for an alarm management based on a diagnosis process has been proposed.
- The proposal is based on a hybrid causal model of the system and a chronicle based approach for diagnosis.
- An illustrative example of an hydrostatic tank gauging has been considered to introduce the main concepts of the approach.
- The algorithm *HCDAM* is a tool for obtain the chronicles from the representative event sequences of a determined scenario.
Future work

- Analyze the use of *prohibition constraints* in the algorithm for reduce the quantity of constraints in the chronicle resulted from the event sequences representatives.

- Analyze the use of temporal runs as input to the algorithm for the automatic generation of chronicles. These temporal runs can represent the expertise knowledge of the process.

- Apply the methodology to the furnace sector of the refinery.
Definition 9: In a chronicle $C = (\xi, \mathcal{T}, \mathcal{G})$, a prohibition constraint is a quintuplet $\langle i, j, \varepsilon, t^-, t^+ \rangle$ with $1 \leq i < j \leq |C|$, $\varepsilon \in E$ and $t^-, t^+ \in \mathbb{N}$. The prohibition means that an occurrence of $C$ in $S$ only is validate, if there is no occurrence of $\varepsilon$ between $t^-$ time units after $\xi_i$ and $t^+$ time units after $\xi_j$. Then, the prohibition $\langle \varepsilon, t^-, t^+ \rangle$ is attached to the constraint $\xi_i, \tau_{ij}, \xi_j$. 
Definition 10: A chronicle extended (or a chronicle with prohibitions) is $C_e = (\xi, T, G, I)$, where $I$ is set of prohibitions $I = \{(t^-, t^+)_{i,j,\varepsilon}, 1 \leq i < j \leq |C|, \varepsilon \in E\}$. The absence of prohibition in one interval is noted as $(t^-, t^+) = (+\infty, -\infty)$. 
Temporal run

We denote a temporal run as the tuple $\langle R, C_T, T \rangle$ where:
- $R$ is the interleaved sequence of events type $R = \{\alpha_1, \alpha_2, \ldots, \alpha_n\}$.
- $C_T$ is the set of time constraints $[l^{-}, \ l^{+}]$ for each pair of time points. Lower $l^{-}$ and upper $l^{+}$ limits.
- $T = \langle T_p, \lambda \rangle$ is a directed graph denoted as a time constraint graph where:
  - The nodes are a set of time points $T_p = \{t_p\}$
  - $\lambda$ represent the relationships between each pair of time points $(t_p, t'_p)$

The equation (1) represents the integration of two time graphs.

$$\forall (t_p, t'_p) \in T_p^2, \ C_T(t_p, \ t'_p) = C_{T'}(t_p, \ t'_p) \cap C_{T''}(t_p, \ t'_p) \quad (4)$$
From the *temporal runs* to a *chronicle*

Construct a chronicle is possible by means of a unique equivalent time constraint graph resulting from the integration of the temporal runs that represent the possible behaviors in a specific scenario. Example:

**TEMPORAL RUNS**

<table>
<thead>
<tr>
<th>Event</th>
<th>Temporal Constraint</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t_{p(a)}$</td>
<td>$[0, +\infty]$</td>
</tr>
<tr>
<td>$t_{p(b)}$</td>
<td>$[0, 1]$</td>
</tr>
<tr>
<td>$t_{p(c)}$</td>
<td>$[1, 3]$</td>
</tr>
<tr>
<td>$t_{p(d)}$</td>
<td>$[1, 3]$</td>
</tr>
<tr>
<td>$t_{p(e)}$</td>
<td>$[0, +\infty]$</td>
</tr>
<tr>
<td>$t_{p(f)}$</td>
<td>$[0, 1]$</td>
</tr>
<tr>
<td>$t_{p(g)}$</td>
<td>$[2, 4]$</td>
</tr>
</tbody>
</table>

**CHRONICLE**

- $a$ connected to $b$, $c$, $d$, $g$ with constraints $[0, +\infty]$ for $b$, $c$, $d$, $g$
- $b$: $[-1, 1]$
- $c$: $[0, +\infty]$
- $d$: $[2, 3]$
- $g$: $[2, 3]$
I. Izadi, et all, "A framework for optimal design of alarm systems.". *7th IFAC Symposium on fault detection, supervision and safety of technical processes, Barcelona, Spain* 2009

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F. Yang et al. "Improved Correlation Analysis and Visualization of Industrial Alarm Data". *18th IFAC World Congress Milano, Italy 2011*
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A. Subias, L. Travé-Massuyès, E. LeCorronc. "Learning Chronicles signing Multiple Scenario Instances". *25th International Workshop on Principles of Diagnosis (DX-14), Graz (Austria)* (2014)

2016-1: Course IPD2, 2 Courses 4 credits (c/u). Prepare article journal. Analyze furnace area.
2016-19: Visit Toulouse, Prepare presentation and assistance conference ICONS. Advance algorithm
2017-2: Sept. Final thesis presentation
THANK YOU