Using Smart Sensing and Digital Stigmergy for Agnostic Detection of Behavioral Pattern Shifts
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Ambient Assisted Living

• Ambient Assisted Living focuses on increasing the confidence of elderly people living autonomously, by building on the knowledge base of the most common disorders (and the most expensive for a national health system) and respective characteristic vital sign changes for this age group.

• The main point is the gathering of clinical data and the interpretation of these data.
Cognitivist approach

• The streams of data obtained by a continuous monitoring of the patients are supplied to a healthcare professional who is on line and able to recognize the first signs of an acute episode of a chronic disease

• Data are collected through smart sensors, computers, smartphones..
Problems of this approach

• Analyzing continuous streams of data from monitored patients and making relevant diagnosis can be an arduous task for the healthcare professionals.
  – It can also impact network traffic and scalability of the patient monitoring systems.
Moreover

• Intrusion in the normal activities of the patients
• Pervasive presence of computing/mobile communication resources, and sensing devices in everyday objects such as smart shirts
• Patient collaboration
Objective

- However, the cognitive load on the healthcare professional should be lowered by automating the analysis of the obtained medical information and involving the healthcare professionals only when required.
- Intelligent environment with the potential of learning and reacting to anomalous conditions.
But..

• Privacy entails the right of a user to control the collection and dissemination of personal information and security is the protection of user's information from unauthorized users.

• Privacy and security are one of the key challenges towards large scale adoption and diffusion of ubiquitous computing empowered by wearable devices.
Alternative approach: characteristics

• No need to know details of the data domain (characteristics of diseases)
• Data obfuscation
• Invisibility
Self-organizations

• Coordination emerges out of local interactions between agents of an initially disordered system (Heylighen, 2013).

• Animals rely on self-organization to increase their chances for survival of the group and the individual by sharing information immediately and responding collectively (Berdahl and Torney et al., 2013)

• Organisms can achieve critical, time-sensitive and complex tasks such as escaping predators or hunting prey.
Emergent approaches

• Emergent paradigms are based on the principle of the self-organization of the data, which means that a functional structure appears and stays spontaneous at runtime when local dynamism occurs.

• The purpose is to overcome explicit top-down domain-dependent representations of data, which are more efficient to be computed but more inefficient to be managed in the entire lifecycle.
  – For example, the collective properties or interactions between sensory data can be described with a domain-independent spatiotemporal logic.
Stigmergy

• This emergent paradigm is based on
  – data blurring: each input datum transforms into a structure, called mark, with spatio-temporal characteristics (the structure is «around the data» and «around the time» they are produced)
  – mark aggregation: marks aggregate and persist in time becoming tracks
  – track evaporation: marks evaporate during time
  – track similarity (similar tracks are recognized)
Markers-based stigmergy

- A marking subsystem takes as an input, for instance, the coordinates generated by an indoor localization system and leaves marks in a computer-simulated spatial environment, thus allowing the accumulation of marks.

- The marking process is transparent and not tied up to a specific localization system.
Accumulated Marks

(a) Single mark.
Marking sub-system behavior

• The levels of mark intensity are represented by different gray gradations: the darker the gradation, the higher is the intensity of the mark.

• The highest intensity of the mark is in the middle, which corresponds to the position of the person when the mark is left (Fig. (a)).

• Mark intensity decreases with the number of squares from the position of the person, of a percentage (called spatial decay) for each square. Further, mark intensity has a temporal decay. Hence, an isolated mark after a certain time tends to disappear.

• The time that a mark takes to disappear is longer than the period used by the marking subsystem to release a new mark. Hence, if the user is still in a specific position, new marks at the end of each period will superimpose on the old marks, thus increasing the intensity up to a stationary level.
Accumulated marks and Tracks

(b) Aggregation of two overlapping marks.

(c) Track left by a person who has stopped after a brief walk.
Accumulated marks and Tracks

- If the person moves to other locations, consecutive marks will be partially superimposed and intensities will decrease with the passage of time without being reinforced.
- While Fig. (b) shows two consecutive and overlapping marks, Fig. (c) shows the track left by a person who has stopped after a brief walk. The area with the highest intensity (on the right bottom) corresponds to the place where the person is still.
- The track with lower intensity is the area where the person was moving. Thus, when the person is still, the superimposition of marks causes their intensities sum up, and then the resulting intensities tend to be higher than in other places.
- The stigmergic track can then be considered as a short-term memory.
Pilot scenario

- As a real-world pilot scenario, Fig. (a) shows the layout of an apartment where an elderly has been monitored.
  - Here, a black or gray region represents non-walkable areas (e.g., wall, wardrobe, TV, etc.), whereas a white region represents an area where the person can walk or stay (e.g., floor, bed, armchair, etc.).
(a) Pilot scenario: layout of the apartment.
Different tracks

(b) Stigmergic track in a normal day.

(c) Stigmergic track in a day with disease progression.
• Fig.(b) shows the stigmergic track generated in the morning of a normal day. Here, a relevant intensity is located on two points of the apartment.

• Fig. (c) shows the stigmergic track generated in the same day of the week for the same timetable
  – top-right track is larger and the bottom-left track is smaller than the corresponding track in the normal day.
Track analysis

• It is clear that a stigmergic track provides comprehensive information that can be handled to automatically detect behavioral changes without explicit activity modeling, with simple processing, and preserving privacy.
• An in-depth (cognitivist) investigation reveals that the above-mentioned disease’s symptoms are sleep changes and loss of energy, causing more sleep and late breakfast, with a shift of about 20 min with respect to the normal day.
• Indeed, the two major tracks are placed on the bed (top-right) and on the living room (bottom-left).
<table>
<thead>
<tr>
<th>Id</th>
<th>Day</th>
<th>Start-end (ticks)</th>
<th>Duration (ticks)</th>
<th>Description of the observed behavioral deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Tue</td>
<td>185–204</td>
<td>20</td>
<td>He had a shorter lunch</td>
</tr>
<tr>
<td>2</td>
<td>Wen</td>
<td>096–100</td>
<td>5</td>
<td>He woke up later in the morning</td>
</tr>
<tr>
<td>3</td>
<td>Wen</td>
<td>150–158</td>
<td>9</td>
<td>He had a shorter lunch</td>
</tr>
<tr>
<td>4</td>
<td>Wen</td>
<td>181–230</td>
<td>50</td>
<td>He had a longer nap and shorter tasks in the afternoon</td>
</tr>
<tr>
<td>5</td>
<td>Thu</td>
<td>098–107</td>
<td>10</td>
<td>He woke up later in the morning</td>
</tr>
<tr>
<td>6</td>
<td>Thu</td>
<td>150–153</td>
<td>4</td>
<td>He had a shorter lunch</td>
</tr>
<tr>
<td>7</td>
<td>Thu</td>
<td>195–240</td>
<td>46</td>
<td>He had a longer nap and shorter tasks in the afternoon</td>
</tr>
<tr>
<td>8</td>
<td>Fri</td>
<td>092–095</td>
<td>4</td>
<td>He woke up later in the morning</td>
</tr>
<tr>
<td>9</td>
<td>Fri</td>
<td>108–119</td>
<td>12</td>
<td>He carried out less housekeeping tasks</td>
</tr>
<tr>
<td>10</td>
<td>Fri</td>
<td>170–173</td>
<td>4</td>
<td>He had a longer nap in the afternoon</td>
</tr>
<tr>
<td>11</td>
<td>Fri</td>
<td>190–216</td>
<td>27</td>
<td>He carried out less tasks in the afternoon</td>
</tr>
<tr>
<td>12</td>
<td>Fri</td>
<td>246–250</td>
<td>5</td>
<td>He had a shorter dinner</td>
</tr>
<tr>
<td>13</td>
<td>Sat</td>
<td>103–107</td>
<td>5</td>
<td>He woke up later in the morning</td>
</tr>
<tr>
<td>14</td>
<td>Sat</td>
<td>158–164</td>
<td>7</td>
<td>He had a shorter lunch</td>
</tr>
<tr>
<td>15</td>
<td>Sat</td>
<td>188–242</td>
<td>55</td>
<td>He had a longer nap and shorter tasks in the afternoon</td>
</tr>
<tr>
<td>16</td>
<td>Sun</td>
<td>109–113</td>
<td>5</td>
<td>He woke up later in the morning</td>
</tr>
<tr>
<td>17</td>
<td>Sun</td>
<td>119–122</td>
<td>4</td>
<td>He did not carry out self-care tasks</td>
</tr>
<tr>
<td>18</td>
<td>Sun</td>
<td>153–156</td>
<td>4</td>
<td>He did not carry out self-care tasks</td>
</tr>
<tr>
<td>19</td>
<td>Sun</td>
<td>241–246</td>
<td>6</td>
<td>He had a shorter dinner</td>
</tr>
</tbody>
</table>
System levels

• Level 1
  – Marking sub-system: from the position coordinates to marks and tracks

• Level 2
  – Perception sub-system: comparison (similarity between marks $X$ and $Y$ is $S=|X \cup Y|/|X \cap Y|$) is performed between the current track and a reference track taken as prototype

• Level 3
  – Detection sub-system: an activation function is applied to similarity to obtain an output showing the progression of the disease
An illustrative example of similarity between two consecutive marks, $S = |X \cap Y| / |X \cup Y| = 4/16 = 0.25$. 

(a) $|X| = 1 \times 8 + 1 \times 2 = 10$. 

(b) $|Y| = 1 \times 8 + 1 \times 2 = 10$. 

(c) $|X \cup Y| = ||\max(X, Y)|| = 16$. 

(d) $|X \cap Y| = ||\min(X, Y)|| = 1 \times 4 = 4$. 

X \cup Y \quad \text{X \cap Y}
An illustrative example of similarity between tracks, $S = \frac{|X \cup Y|}{|X \cup Y|} = \frac{54}{254} = 0.21$. 
Activation function

• To clarify the behavior of the similarity function we apply to it a smoothed activation function.
  – The term “activation function” is taken from the neural sciences and it is related to the requirement that a signal must reach a certain level before a processing layer fires to the next layer.

• A smooth activation function allows achieving a better distinction of the critical phenomena during unfolding deviation events, with a better detection of progressing levels of the anomaly. For this purpose we employ the s-shaped activation function to the similarity output.
Behavior of an activation function

\[ f(x) = \begin{cases} 
0, & \text{if } x \leq \alpha \\
\frac{(x - \alpha)^2}{(\beta - \alpha)^2}, & \text{if } \alpha \leq x \leq \frac{\alpha + \beta}{2} \\
1 - 2 \times \frac{(x - \alpha)^2}{(\beta - \alpha)^2}, & \text{if } \frac{\alpha + \beta}{2} \leq x \leq \beta \\
1, & \text{if } x \geq \beta.
\end{cases} \]

S-shape activation function with \( \alpha = 0.7 \) and \( \beta = 0.8 \).

S-shaped similarity.
Actual 1-level architecture
Future work

• To analyze several concurrent temporal series and/or to compare each one against different reference series.
  • Multichannel and multilevel architectures
  • We are investigating sleep pattern shifts through a smart watch that produces different data types