1st International Workshop on Adaptive Service Ecosystems: Nature and Socially Inspired Solutions

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SASO 2012 Home Page:
 Emerging distributed computing scenarios (mobile, pervasive, and social) are characterised by intrinsic openness, decentralization, and dynamics. As a consequence, the effective deployment and execution of distributed services and applications calls for open service frameworks promoting situated and self-adaptive behaviours, and supporting diversity in services and long-term evolvability. This suggests adopting nature-inspired and/or socially-inspired approaches, in which services are modelled and deployed as autonomous individuals in an ecosystem of other services, data sources, and pervasive devices. Accordingly, the self-organizing interactions patterns among components and the resulting emerging dynamics of the system, as those of natural systems or of social systems, can inherently exhibit effective properties of self-adaptivity and evolvability.

Although many initiatives (like those named upon digital/business service ecosystems) recognise that the complexity of modern service systems is comparable to that of natural ecosystems, the idea that nature – other than a mean to metaphorically characterize their complexity – can become the source of inspiration for their actual modelling and implementation is only starting being metabolised.

The idea behind the ASENSIS workshop emerged in the context of the European Research Project “SAPERE: Self-aware Pervasive Service Ecosystems” (http://www.sapere-project.eu), with the goal of bringing together researchers and practitioners (from both inside and outside the project itself) interested in nature-inspired solutions for modern service systems. And, altogether, to spend a day involved in scientific and technological discussions about many challenges related to the modelling, design and implementation of adaptive service ecosystems in natural and social terms, and identifying promising approaches and solutions.

Based on the good response to the call for papers, and on the selection performed by the Program Committee, the workshop program includes 11 interesting presentations (and the corresponding papers that you find in this proceedings) that span over a variety of interesting topics, ranging from theoretical to more practical ones. In addition, the workshop program includes the necessary time for discussions, which we believe will be very lively and constructive.

The workshop organizers would like to thank the authors who submitted their contribution to the workshop, the members of the Program Committee for their hard work in revising the submitted papers, the SASO Technical Committee, and the workshop chair Jeremy Pitt in primis, for his support in the organization of the workshop.

Enjoy ASENSIS,

José, Sara, Andrea, Franco
ASENSIS Co-organizers

José Luis Fernandez Marquez - Institute for Service Sciences, Université de Genève
Sara Montagna - DISI, Università di Bologna
Andrea Omicini - DISI, Università di Bologna
Franco Zambonelli - DISMI, Università di Modena e Reggio Emilia

ASENSIS Program Committee

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Daniel Villatoro (Barcelona Digital Technology Centre)
Mirko Viroli (Università di Bologna, Italy)
Giuseppe Vizzari (Università di Milano-Bicocca, Italy)
Abstract—The formation of pervasive information and service systems is the next step towards the emergence of an implicitly interacting society. Applications for such a system benefit from guaranteed behavior and features such as self-organization or attention awareness. This paper presents a qualitative spatial interaction model for an “Ecosystem of Displays” to achieve such behavior. A portable sensor system based on infrared-depth technology to generate spatial relations between system components has been developed and was used in an experiment to evaluate the suitability of the presented technology and model. Using the system we were able to completely abstract complex movement patterns with precisions of 58.3% (sensor stationary), 64.4% (sensor moving straight) and 85.4% (sensor rotating). The results show that qualitative spatial abstractions can be effectively generated using infrared depth technology and support our hypothesis that these abstractions constitute a valid means to achieve self-organization and attention-recognition of artifacts in display ecosystems.

Index Terms—Ecosystem of displays, Local interactions, Qualitative spatial abstractions

I. THE ECOSYSTEMS OF DISPLAYS

Modern urban environments are pervaded by information resources to such a degree that people are constantly surrounded by digital and analog sources of data which aim to provide useful contextual information or have the goal of influencing our behavior. The sheer amount of information and the multitude of channels that it is presented over (e.g. billboards, fliers, digital signs, auditory signals, monitor screens...) necessarily lead to a situation where most of the offered data is missed, ignored or dismissed by the consumers. The solve this problem, the formation of “Pervasive Service Systems” has been proposed – i.e. an approach where information and services are no longer pushed at the user without regard to their domain and the user’s current context, but rather pulled to the front via spontaneous ad-hoc communication in reference to the user’s preferences and current interest. Devices in the system interact locally using established technologies and protocols to collaboratively achieve (system-wide) tasks such as providing desired content or steering users to arbitrary points in the system. Preferences and interests can be maintained on any personal, communication-capable device that can spontaneously interact with neighboring system components. The broad availability of public, programmable service technologies in urban environments are an enabling factor for the large-scale deployment of such a system. Each of these potential system nodes may contain arbitrary content that can be matched to the user’s current needs and displayed if a match is found.

It is conceivable to model such service infrastructures as “digital ecosystems” – locally communicating devices and services whose interaction dynamics are governed by a set of fundamental “natural” laws [1]. All components of this ecosystem can be understood as individuals that interact and combine to serve their own and the system’s needs. Each individual is part of a “species” that is made up of contextually related system components (e.g. location sensors, visualization agents, mobile devices...). We envision the formation of an “ecosystem of displays” - a pervasive service ecosystem made up of spatially related display nodes that offer services or information to arbitrary system components – be it a person or another digital entity – whereby each node acts based on its own spatial context. The devices and services of the ecosystem communicate over spontaneously formed directional links along which data can travel from one node to the next. This leads to the establishment of ecosystem subgroups (comparable to ecological niches) that share the same content and use the same services. However services may evolve and diffuse further along the links of the network. The creation of these links depends on the spatial properties of the environment of each system component and therefore relies on sensing technologies to determine these properties (i.e. detecting nodes for potential local interactions that are in range). We distinguish between:

- **Private displays**, which are mobile devices (e.g. smartphones, PDAs, tablets ...) that are privately owned and either worn or carried by a user, and
- **Public displays**, which are usually large-scale, static displays or even entire display walls. So far, such screens are generally used as static information platforms, however in the ecosystem of displays they act as adaptable, dynamic information service stations that sense passers-by and interested parties and offer location- and user-specific content.

A. Exemplary Interaction in an Ecosystem of Displays

We describe an exemplary interaction schemata between public and private components of the “Ecosystem of Displays” and discuss system behavior to enable/facilitate implementation.
User steering: Public display technology can be found at most points of interest in modern urban environments. As such it is possible to direct a person towards arbitrary locations in a deployed ecosystem if a (multi-hop) connection between the position of the user and the target exists. After an initial route finding phase the user will be continually supplied with directions to his goal. If such a service is simultaneously used by a large number of devices, congestions might occur. Implementing flow control through self-organizing behavior of locally interacting artifacts allows efficient scaling of this functionality. This paper deals with the emergence of such behavior through the use of qualitative spatial relations between neighboring artifacts.

B. Qualitative Spatiality

To enable spontaneous interactions between neighboring devices, a concept of space must be established. Neighborhoods may be defined based on communication hops between artifacts [1] but in the application domain of an “Ecosystem of Displays” it is more meaningful to base them on real-world spatial proximity. Apart from the general enrichment of each node’s knowledge of its spatial context, this approach also benefits the exemplary interaction scenario presented in Section I-A In the past, such spatial relations were usually represented quantitatively, however in systems with low resources that involve human interactions, the use of qualitative abstractions of quantitative values has been shown to be advantageous [2], [3]. While it has been shown that quantitative spatial relations between neighbors can be used to implement system-wide self-organizing behavior and to compute approximations for attention, this paper investigates the emergence and computation of these patterns based purely on qualitative abstractions of space. We further develop and evaluate a qualitative spatial interaction model (SIM) that utilizes representations of space in three granularities as introduced in [4] to compute such relations between colocated devices in an “Ecosystem of Displays”:

- Static spatial relations represent an object’s static location at a specific point in time.
- Dynamic spatial relations model the way in which the state of an object is changing at a specific point in time.
- Spatiotemporal relations represent the development of the state of an object over a series of time steps.

C. The SAPERE Approach

We believe the SAPERE project [5], that implements pervasive service ecosystems using locally interacting semantic annotations (“LSAs”) of devices, services and global laws to govern interactions (“Eco-Laws”), is well suited for the implementation of an ecosystem of displays.

Research Hypotheses

We hypothesize that,

(H.i) Using local interaction rules and qualitative abstractions of spatial relations between the entities of a distributed system and their neighbors allows implementation of system-wide spatial self-organization.

(H.ii) Spatial interaction models based on qualitative abstractions of dynamic focus regions can be used to implement attention awareness.

In the past, metric measurements of these properties were most commonly employed, however we propose the use of semantic, qualitative abstractions of space. We present a set of such relations for the domain of ecosystems of displays and argue their design and nomenclature as well as perform an early evaluation of a domain-relevant system to generate such abstractions efficiently.

Outline

The rest of the paper is structured as follows: Section II describes our approach to achieve self-organization and attention awareness in an ecosystem of displays and describes the qualitative spatial abstractions that were developed to implement self-organizing behavior in distributed, heterogeneous systems. Section III gives an overview over the design of an experiment that evaluates the precision of creating qualitative abstractions from camera streams of infrared depth (IRD) sensors and tests their real life performance in the application domain of an ecosystem of displays. Section IV describes the results of the experiment and discusses their relevance to the original research goal. Section V concludes the paper.

II. SELF-ORGANIZATION & ATTENTION AWARENESS USING QUALITATIVE SPATIAL INTERACTION MODELS

Spatial interaction models formally describe the way how artifacts (i.e. components) of a distributed system interact with their neighbors. They have been established for use in various applications domains (e.g. gravity models, swarm-motion analysis, activity awareness systems...) and are regularly used to implement/analyze the behavior of distributed system components by constructing sets of local interaction rules to match desired/observed properties. SIMs based on qualitative spatial abstractions enable us to implement self-organizing behavior in cases where large crowds of humans are steered towards a single goal, they can be used to approximate a single user’s interest in interacting with a display and allow us to compute the system structure of an ecosystem based on real-world spatial properties.

A. Self-organization

In the research domain of swarm-motion analysis, researchers analyzed the way how individuals in a flock behave and constructed three rules to model their interactions [6].

- Collision Avoidance: Avoid collisions with neighbors.
- Speed: Remain close to neighbors (i.e. match velocity).
- Orientation: Move in the same direction as neighbors.

It has been shown that self-organization in respect to movement emerges if all individuals follow only these three rules. Since qualitative abstractions of such relations are naturally used by animals and humans (e.g. we think of two people being “close” rather than 30cm apart), we propose that use...
of equivalent qualitative spatial abstractions will still lead to emergence of self-organizing behavior when steering crowds of people to a goal (e.g. when evacuating an area).

B. Attention Awareness

By tracking the development of the spatial relations between displays, we are able to generate a measure for the level of attention that a user is directing at another system component. As such, display components can communicate with especially those entities that are most likely interested in participating in an interaction. The developed measure of attention is based on the focus/nimbus model established in [7]. We adapt the proposed methodology, apply the ideologic construct to public and private displays and use it to predict their interest to interact. The “nimbus” of the various displays is defined as their “Zone of Influence” [8] – an efficient way to encapsulate the relative location and extension of a display – with radius equals the display’s effective communication range. We define the “focus” of a private display as its current projected movement path (i.e. a front-facing cone of variable length). This path is computed by utilizing spatial abstractions of the movement manner, orientation and speed of the private displays. Since a public display is generally static, it does not have a “focus” as such. However, its focus can be modeled as the effective sensor range of a public display. Given these definitions, we compute the level of attention as the match between the “focus” of a (private) display and the “nimbus” of another display.

C. Qualitative Relations for Abstracting Space

We developed a set of qualitative abstractions of space that are easily understandable by humans and meaningful in the context of pervasive service ecosystems to implement self-organization and attention awareness. We focus on representing the spatial properties of displays in a qualitative way due to the advantages of these representations over quantitative ones. To ensure ecosystem-wide applicability of the generated abstractions, they should be distributed in a uniform, easily processable format.

1) Static Relations: We developed semantic abstractions of the

- **distance** from the sensing display to the tracked display.
- **intrinsic direction** from the sensing display to the tracked display and
- **orientation** of the tracked display in relation to the orientation of the sensing display.

These properties represent the static relation between a primary- and reference display at a distinct point in time. To describe the distance between displays in an intuitive, meaningful way, we adapted Hall’s concept of Proxemics [9], which describes how humans react in culturally defined areas of personal space. By separating the space around the sensing display into four distinct distance regions, we created an equal number of abstraction classes [10] that can be thought of as 3-dimensional “bubbles” (concentric circles in 2-dimensional euclidean space). Further, we measure the direction to the tracked private display intrinsically from the point of view of the sensor by using a cone-based representation of direction as described in [11].

2) Dynamic and Spatiotemporal Relations: By looking at sequences of such consecutive static abstractions, we gain the ability to reason about the dynamic relation of the sensing- and tracked display. Based on the past- and current static state, abstractions of the dynamic development of the tracked display’s spatial properties can be derived. By defining and using a dedicated set of abstraction rules we are further able to create high-level spatiotemporal abstractions from such dynamic relations. We identified useful dynamic spatial properties that semantically describe the movements of a system component, its direction of motion and its speed, and further developed qualitative representations of those properties. These three manifestations can be used as measurements to enable self-organization of movements according to the rules of swarm behavior introduced by [6] and described in Section II-A. The semantic descriptions are listed in Table I. On its first detection, a system component is assigned the “New” state. Apart from this unique state, all possible state combinations may occur.

3) Relation Generation Table: A set of abstraction rules that can be used for the generation of high-level spatiotemporal abstractions and only requires the previous and current dynamic state of a display as input was developed and is partly listed in Table II.

We omitted rules that are used to maintain the current system state if no change occurred.

### III. Experiment

To evaluate the potential of using qualitative spatial properties in the domain of ecosystems of displays, we designed an experiment using infrared-based depth (IRd) sensors. In [12] the authors state that the use of IRd motion tracking cameras has multiple advantages over more traditional approaches to generate this kind of spatial data, which are often based on marker-dependent sensor infrastructures. They show that IRd cameras are a viable way to unintrusively track the spatial properties of a person in relatively close distances. We developed a portable sensor system that can be easily...
mounted on a public display and that generates the mentioned qualitative abstractions using 2 Kinect devices - commercial RGB cameras with integrated IRd sensor technology. During the performed experiment, these devices were mounted on an experimenter’s belt facing both to the front and the back at an angle of 180° to allow for experimentation on abstraction precision in case of moving camera sensors. The system uses the Microsoft Kinect SDK [13] and its associated driver software to capture data from the depth sensor. As the Kinect SDK is only able to (i) perform skeletal tracking on the depth stream of one sensor device at a time and (ii) fully track the skeletal joints of a maximum of two people, we integrated face detection analysis using the “SHORE” [14], [15] face detection engine on the RGB camera stream of the back-facing sensor to abstract the location of additional people in the surroundings of the system.

A. Experiment Design

The evaluation was performed in a room of approximately 10 × 5m. It was lighted by 3 windows on one side and neon rods mounted on the ceiling. The experiment consisted of 21 test runs, each of which composed of 16 different movement scenarios. These scenarios describe the motion of 2 test subjects (i.e., private display components) and the experimenter that was equipped with the sensor system. The movement path of the first subject was situated in front of the experimenter, while the second was moving in his back. After completion of a movement scenario, the two subjects were advised to switch positions and the same movement scenario was executed again. For the given reasons, the data from the 8 movement sequences captured by the front-facing sensor was abstracted using the skeletal joint tracking algorithm from the Microsoft SDK, while the movement patterns of subjects situated behind the experimenter were abstracted using a face detection engine on the associated RGB stream.

B. Abstraction Class Design

Given the specifications\(^1\) of the Kinect sensor device, which show that the Kinect’s horizontal viewing angle only partly covers 3 of the 16 cardinal directions (see Figure 1), and using the static spatial relations established in Section II-C1, we get a total number of 12 possible location classes per sensor to abstract the position of a tracked display.

The extension of such a display was modeled by its “Zone of Influence” (Zoi) [8] and implemented as the effective dynamic area that a user of a private display may physically influence.

C. Movement Pattern Design

In this subsection, we describe the developed movement patterns and discuss their design rationale in reference to the interactions between components of an ecosystem of displays. Movement sequences are visualized in Figure 2.

1) **Stationary Sensors:** In test cases 1–3 the sensors were static (i.e. mounted on a public display). The grids model the field of view of the cameras, the experimenter is represented by a black dot and the blue colored dots and arrows represent the owners of the private displays and their movement path. These movement sequences were designed to model approach vectors of persons (i.e. private displays) that are interested in using a public display. They either directly converge to the display (sequence 1), switch between approaching/distancing themselves (sequence 2) or approach/distance themselves on a curved trajectory (sequence 3).

2) **Linear Movement of Sensors:** Throughout the remaining test cases both the test subjects and the experimenter moved (i.e. sensors are mounted on a private display’s user), whereby in test cases 4–6 the experimenter always moved on a linear trajectory. The movement sequences in test cases 4–6 modeled walking users of private displays that are passing each other by (sequence 4, front), overtaking each other (sequence 4, back), moving orthogonally to each other, whereby either the experimenter moved in a sideways fashion (sequence 5) or the observed private displays (sequence 6, back). Lastly, we model a private display that crosses the experimenter’s path.

\(^1\)Kinect depth sensor: Range = 1.2~4m; Opening angle= 43° vertical by 57° horizontal.
on a curved trajectory until they pass each other by (sequence 6, front).

3) Rotational Movement of Sensors: The movement sequences of test cases 7 and 8 feature rotational motion of the experimenter. The observed private displays are either stationary (sequence 7) or close in on the sensors in a linear fashion (sequence 8). Since the system abstracts the orientation of artifacts in reference to an intrinsic frame of reference, the rotational motion of the experimenter changes the directional relation between his private display’s orientation and the observed test subjects’.

D. Expected Abstraction Sequences

The different walking paths were designed to model realistic, domain-relevant movement scenarios to allow inferences from the experiment results about the applicability of qualitative spatial relations to implement enabling behavior for interaction scenarios in ecosystems of displays. The trajectories were indicated by start and finish markers on the floor and verbal description of how to move between them. The path itself was not strictly specified – allowing test subjects to move in a natural way – thus increases the likelihood that the final results are applicable to the real world. Since the system uses respectively larger spatial abstraction regions, this does not have a significant detrimental effect on the evaluation results. Further, the movement patterns can be mapped to sequences of the semantic abstractions that have been introduced in Section II-C2. The sequences generated from the front-facing camera stream are listed in Table III with the number of abstractions in each sequence as the value of “L”.

IV. Evaluation

The developed system was evaluated in a controlled, indoor setting with 21 volunteers (11 females, age range 17 to 88 years, $\mu = 38.36$, $\sigma = 21.08$; 10 males, age range 14 to 67 years, $\mu = 33.10$, $\sigma = 16.45$). No vital information about the nature of the project, the aim of the studies, the operation principle of the system, etc. was given to them prior to their service. The process and interactions were recorded with two “GoPro HD HERO 2” cameras attached to the ceiling. Further, the sensor module of the system was set up to create and save bitmap files of every processed video frame delivered by the cameras (depth, RGB) on the Kinects utilized. The videos and images were used to verify the generated abstractions. The presented evaluation focuses purely on those movement patterns and abstraction results that were generated by the front-facing sensor using the skeletal tracking algorithm since we believe this sensing technology is well suited for practical use in an ecosystem of displays.

A. Evaluation results

The computed abstractions were stored as text representation and manually processed afterwards (results can be seen in Table IV). If, during a test run, a subject was not detected at all, the data point was counted as “No person detected”. Otherwise the data points were labeled as “Correct abstraction” if we detected not a single incorrect state, or “Wrong abstraction” in case of one or more unexpected labels. If a sequence contained all expected, but also additional, unexpected values, it was counted as “Wrong abstraction”. In these cases the table lists the ratios of the various error causes that are introduced and described in IV-B.

B. Discussion

From data analysis applied to the recorded trajectories we identified four distinct reasons given below why a certain movement pattern was misinterpreted. In some of the test cases not only a single error, but a combination of two or more of these errors occurred in a sequence – these cases were classified as “Multiple errors”. The ratios of identified error causes are listed in Table IV.

- **Late discovery**: The framework was only able to correctly capture the second part of the movement pattern, thus generating an incomplete abstraction sequence.
- **Lost and found**: If the position of the tracked artifact in two consecutive camera frames varied strongly and the
TABLE IV: Evaluation results of movement patterns gathered from the front-facing sensor. The values represent the percentages of the respective characteristics over all 21 test subjects. Entries indicate the proportion of successfully detected or missed artifacts as well as correctly or incorrectly abstracted movement patterns. In case of erroneous sequences the table lists the percentages of the five different reasons for errors.

<table>
<thead>
<tr>
<th>Test case 1</th>
<th>Test case 2</th>
<th>Test case 3</th>
<th>Test case 4</th>
<th>Test case 5</th>
<th>Test case 6</th>
<th>Test case 7</th>
<th>Test case 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>No person detected</td>
<td>0</td>
<td>4.76</td>
<td>95.24</td>
<td>4.76</td>
<td>14.28</td>
<td>0</td>
<td>4.76</td>
</tr>
<tr>
<td>Person detected</td>
<td>100</td>
<td>95.24</td>
<td>90.48</td>
<td>95.24</td>
<td>85.71</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Correct abstraction</td>
<td>100</td>
<td>55</td>
<td>15.79</td>
<td>30</td>
<td>66.67</td>
<td>57.14</td>
<td>80.95</td>
</tr>
<tr>
<td>Wrong abstraction</td>
<td>0</td>
<td>45</td>
<td>84.21</td>
<td>30</td>
<td>33.33</td>
<td>42.86</td>
<td>19.09</td>
</tr>
<tr>
<td>Late discovery</td>
<td>0</td>
<td>88.89</td>
<td>87.5</td>
<td>33.33</td>
<td>50</td>
<td>22.22</td>
<td>0</td>
</tr>
<tr>
<td>Lost and found</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>50</td>
<td>35.33</td>
<td>44.44</td>
<td>75</td>
</tr>
<tr>
<td>Lost person</td>
<td>0</td>
<td>0</td>
<td>12.5</td>
<td>0</td>
<td>0</td>
<td>11.11</td>
<td>0</td>
</tr>
<tr>
<td>Pathing</td>
<td>0</td>
<td>11.11</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>25</td>
<td>50</td>
</tr>
<tr>
<td>Multiple errors</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>16.67</td>
<td>16.67</td>
<td>22.22</td>
<td>0</td>
</tr>
</tbody>
</table>

V. CONCLUSION

This paper demonstrated that sequences of qualitative spatial relations between neighbors can be computed using IRd imaging technology. We presented a model to enable self-organization and attention awareness in display ecosystems using qualitative representations of spatial relations between neighbors. We developed a spatial abstraction framework and a display sensor system using two IRd cameras and tested the validity of our approach in an experiment that modeled realistic interaction scenarios of components in an ecosystem of displays. An evaluation revealed that the system reaches precisions of 58.3% (stationary), 64.4% (linear movement) and 85.4% (rotational movement). When accepting a single wrong abstraction per sequence, overall abstraction precision is significantly higher (81% (stationary), 67% (linear movement), 95% (rotational movement)). These results demonstrate that, using IRd cameras and skeletal joint tracking algorithms, we are able to robustly detect the presence of a person and can completely abstract complex movement patterns with acceptable reliability. Future work includes research into effective algorithms to implement self-organizing behavior, attention recognition and user steering with the presented spatial interaction model given a deployed display ecosystem testbed consisting of IRd sensor-equipped public displays that communicate with mobile private displays moving through the system.

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