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Enabling Integration across Heterogeneous Care Networks

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***Abstract*—The paper shows how the CASMAS modeling language, and its associated pervasive computing architecture, can be used to facilitate continuity of care by providing members of *patient-centered communities of care* with a support to cooperation and knowledge sharing through the usage of electronic documents and digital devices. We consider a scenario of clearly fragmented care to show how proper mechanisms can be defined to facilitate a better integration of practices and information across heterogeneous care networks. The scenario is declined in terms of architectural components and cooperation-oriented mechanisms that make the support reactive to the evolution of the context where these communities operate.

***Keywords*—Pervasive Computing, Communities of Care, Heterogeneous Care Networks, Multi-Agent System.

I. Introduction

The concept of integration of care is espoused by an ever-widening body of health providers, researchers, and policy makers to improve the continuity of care for individual patients and the quality of the entire care episode. That notwithstanding, its implementation remains a difficult task since to become effective continuity of care has to be considered along three main dimensions [10]: *management continuity*, i.e., the set of organizational interventions that guarantee an approach to the management of a health condition that is coherent and responsive to a patient's changing needs; *informational continuity* i.e., the possibility to fully exploit information on past events and personal circumstances in order to make current care appropriate for each individual; and *relational continuity* i.e., an ongoing therapeutic relationship between a patient and one or more care providers. These three types of continuous and seamless care is usually achieved by improving coordination, collaboration and knowledge sharing between heterogeneous networks of care-givers and healthcare professionals [17] across organizational and professional boundaries, and by involving patients and relatives as active participants in the process [12]. Using Andriessen's terminology [2], these networks have to become a *community of strategic communities* since they are both recognized as unavoidable entities in the care process and supported by an adequate socio-technical system that takes into account the very nature of each community. In this respect, the approaches mainly based on the spread of sensors and devices in different locations to facilitate opportunistic interactions through which stakeholders collaborate and achieve coordination, either in hospitals [4] or where patient are located (e.g., in the CareNet project, [9] or in the Aware Home Reseach Initiative [16]) can not be fully satisfactory. We are aligned with another stream of research aiming at building *pervasive spaces* [11] that enable users, designers and programmers to collaborate in the development of applications by using a more abstract representation of the physical world of sensors, actuators, and devices and concentrate on the logic that combines the information they gather with the one characterizing the application domain (e.g., EPRs in the healthcare domain). To this aim designers need to make use of frameworks characterized by higher level primitives to construct pervasive applications: in the healthcare domain different key concepts characterize these design frameworks. Among the others, the Mushroom project [13] focuses on the specific knowledge which has to be shared among clinicians in the care of diabetic patients; in [3] the focus is on activities along which professionals of hospitals staff can organize their handling of devices, services, and sharing and production of data, by switching computational context depending on the device at hand. ERHMAN [18] takes a services oriented approach to provide health operators, patients' relatives and social community members with supports to the care network. Although not explicitly applied to healthcare, WearCom [14] discusses how wearable devices can be used to foster social communities in an opportunistic way. CASMAS, the model characterizing our approach, takes the community of strategic communities as first class object. It allows their members to define mechanisms that foster communities sustainability and integration in terms of effective collaboration and knowledge sharing (i.e., the above mentioned kinds of continuity) by focusing on the requirements of dynamicity and adaptivity. CASMAS is shortly described in the next section and then applied to solve care fragmentation problems characterizing a reference scenario.

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II. The CASMAS architecture

CASMAS is a model supporting the design of systems that enable and foster cooperation in a pervasive computing perspective [5]. CASMAS is centered on the notion of community (inspired by the notion of strategic community [2]) whose members collaborate within a pervasive-computing environment involving both persons and devices. The model is an abstraction of a multi-agents system architecture where different types of agents are defined [5] and whose agents behavior is defined by a rule-based declarative approach.

In CASMAS actors (both persons and devices) are modeled as *entities* (see e.g. P and FD in Figure 1 which stand for a Patient and a Family Doctor, respectively) [15] that can be linked to both community *fulcra* and community *spaces*, where coordination and awareness information are exchanged, respectively. A specialized entity called *community assistant* is in charge to support the community as a whole when behaviors regard community-based policies that no particular entity should manage on its own.

A *community fulcrum* (see e.g. PCC, the Patient Community Fulcrum, in Figure 1) is the place where entities (as community members) share coordination information and community's conventions: the latter are expressed as behaviors characterizing the community and can be acquired by actors when they join the community if behaviors regard information that the actor-related entities should manage directly. Within the CASMAS model, the *WOAD* framework [8] provides the declarative linguistic constructs to model community conventions and mechanisms of awareness provision in those domains where documental artifacts play a central role in coordination. This is the case of the healthcare domain: indeed, locally defined and agreed patterns of coordination as well as conventions about how to manage data and interventions within a given care community are applied to the processing of documents content. This is done in combination with the information generated by devices spread in the different caring locations.

A *community space* (see Figure 1) is the space where entities perceive awareness information that is propagated in a modulated manner according to the topology of the space. In [6] we described how CASMAS manages the interactions with the devices by displaying awareness information: in this paper we concentrate only on the logic generating this kind of information.

Each community is identified by a single fulcrum while it can be linked to any number of spaces to propagate awareness information according to different topologies. Each topology models specific propagation policies. Each fulcrum and each space can be associated only to one community to preserve its identity. However, CASMAS allows the migration of both information and behaviors across fulcra so as to support the dynamic joining of entities to them and the adaptation of entities behavior according to information provided by different fulcra (this aspect will be exemplified in Section IV).

Details about all the functions and mechanisms provided by CASMAS, such as the assertion of information in a community fulcrum or the propagation of awareness information in a community space, are described in [7]; we recall here only the elements useful to understand how CASMAS is exemplified in Section IV.

Since each entity can dynamically take part to a community, a *join* (and *disjoin*) primitive function is defined, whose main parameter is the name of the community fulcrum to connect to. According to the community's policies, the entity docks to the fulcrum, interacts with the others entities by asserting (and retracting) information to (from) it, and finally, acquires the behaviors that are defined for this particular entity or for the *roles* it plays in the community. This is made possible by the fact that the following predefined rule is loaded into the entity by the join primitive function if the connection to the fulcrum ends successfully: *IF in the community fulcrum there is a behavior addressed to me or addressed to a role I play, THEN load this behavior.* This rule uses the *loadBehavior* primitive function to load into the entity a behavior and make

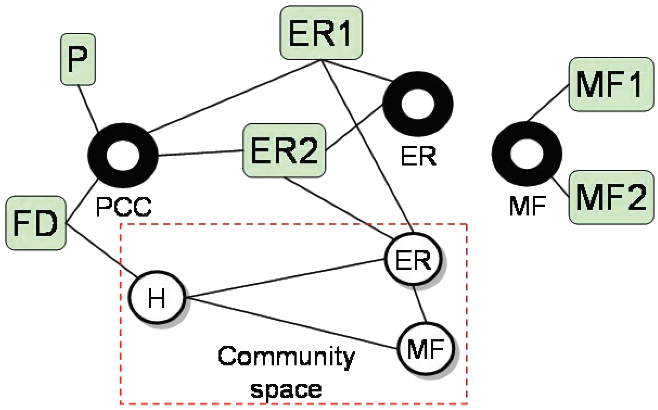

Figure 1. The involved entities in the scenario, linked to the communities' fulcra and located in the community space.

it executable. The same mechanism can be used to share and promote the adoption of local conventions across communities.

The next sections illustrate a scenario and the way in which CASMAS can be used to alleviate the problems the scenario sheds light on.

III. A Fragmented Care Scenario

In order to illustrate an example of how our architecture addresses the problem of care fragmentation and facilitates care providers to achieve care integration, we take inspiration from the case of Mrs. P., reported in [1] as paradigmatic of fragmented care, even beyond its anecdotal nature.

One day, Mrs. P., an independent elderly person suffering from high blood pressure, had a stroke at home. Two months after that she was discovered lying on the floor in her apartment, she had eight hospital admissions and spent a total of 42 days in the hospital. She had also eight medical assessments, three emergency room visits, and six nursing care plans. Fourteen physicians were involved in her care. Her charges totaled $140,000, with less than a third reimbursed.

If we focus on the first month from the stroke, Mrs. P. was first admitted into an Emergency Room (ER), then to a Medical Floor (MF), a Rehabilitation Unit (RU), and to a Nursing Home (NH) (see Figure 2). In this month of care, several problems and coordinative breakdowns occurred, resulting in an example of fragmented and less than effective care.

Mrs. P. was admitted to the ER with delay due to the fact that she was not attending a hypertension monitoring programme: she was found completely unresponsive by her apartment manager by chance. In this case, we can detect a defect in *management continuity*, since the community of care established to address the health problems of Mrs. P failed to be responsive to Mrs. P's needs: more in particular, the family doctor was not put in the position to understand the critical conditions of his patient, and her niece was not put in the position to be notified that her aunt needed urgent help. With reference to Figure 2, this problem occurred in the place denoted by the letter H (Home).

At the emergency room, no information about medical history, family contacts or even her physician was immedi-

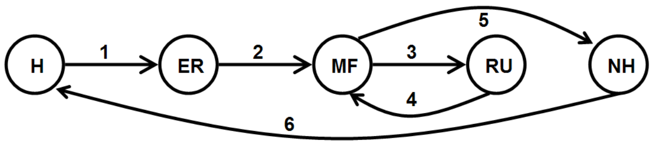

Figure 2. The involved places and transfers mentioned in the scenario. Numbers indicate chronological order of transfers.

ately available and it was difficult to track down her closest relative, i.e., her niece. In this case, we can detect a defect in *informational continuity* since not even elementary data could have been accessed to put care providers in the position to either make informed decisions and become included members of Mrs. P.'s community of care: e.g., to know what Mrs. P.'s will is on reanimation, who her closest attendant is and what doctor to call to get up-to-dated anamnestic indications. This problem occurred in the transfer between the H and ER (for Emergency Room) places (arc 1 in Figure 2).

At the medical floor, Mrs. P. was placed on physical and occupational therapy with two days of delay, for a misunderstanding occurring in the handover between the ER and the MF staff. In this case, we can detect a defect in *relational continuity* and in sharing patient-specific information. Indeed, although the ER produced a detailed account to work on, no one triggered any member of the MF staff in timely considering a particular part of that account and begin a course of interventions consequently. This problem has its causes in the transfer between the ER and MF (for Medical Floor) places (arc 2 in Figure 2).

By the sixth day of her stay, Mrs. P developed pneumonia due to aspiration of her food mainly because a proper swallowing evaluation had not been conducted as part of the stroke workup. In this case, we detect a problem in aptly applying medical knowledge, complying to both local best practices and international guidelines for the stroke management. The same occurred when Mrs. P. had to be readmitted to the medical floor, after two weeks in the rehabilitation unit, for high fever. This fever was attributed to a urinary tract infection due to an indwelling catheter that was not removed in a timely manner. These two problems occurred within the MF and RU (for Rehabilitation Unit) places, respectively (see Figure 2).

Then, two days after that Mrs. P. was admitted in a nursing home, the niece took Mrs. P. home with her, mainly because the nursing service was too expensive. In this case, the niece ignored that her national health insurance program would have paid for the first three months of nursing home care. Premature discharge from any secondary care facility and lack of information lead to loose attending and inadequate care: this compromised her recovery till further hospitalizations. This problem occurred in the NH (Nursing Home), or better yet, in the transfer between NH and H (arc 6 in Figure 2), since this transfer was anticipated for a lack of proper information at due time.

IV. Towards an Integrated Application Scenario

The number of problems that occurred in the very first month of care we illustrated above are mainly due to the

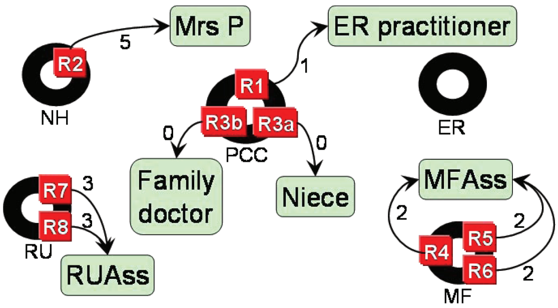

Figure 3. How rules are acquired from fulcra by entities. Numbers on arcs refer to Figure 2. 0 indicates rules acquired before the stroke.

fact that (a) relevant stakeholders were poorly coordinated, like in the case of the initial relationship between Mrs. P. and her niece and family doctor (in H in Figure 2) and like in the case of the handover between the ER and MF (arc 2 in Figure 2); and (b) providers and carers lacked relevant information provided at the point of care and at due time, as in the case of the missed compliance to guidelines and best practices with respect to the complications occurred at ER and MF (in MF and RU in Figure 2) and the missed opportunities and inadequate training occurred when the niece decided to host Mrs. P. in her home (arc 6 in Figure 2).

The solution enabled by the CASMAS architecture addresses both the lack of common access to relevant situational information and domain knowledge and the lack of coordination between actors. In regards to the former point, the patient community fulcrum (PCC in Figure 3) contains all the relevant information regarding Mrs. P., i.e., the so called *health personal record*: this is a data structure where identification, anamnestic and current health status information is stored, as well as current health programmes and who the attendants and care providers in charge are. In regards to the latter point, the ER and MF fulcrums contain both a copy of the information managed by their *electronic patient records*, where information about current interventions, diagnosis, prognosis and therapy in each department of the same health facility is stored. In order to make these two repositories of factual information active and ready-to-use whenever necessary, the fulcra of the care communities involved in the scenario are also endowed with *reactive knowledge*. This is expressed in terms of running and context-aware "clinical algorithms" and rules, such as proactive reminders, reactive alerts, and customized data monitors that are sensitive to factual information (in their IF-parts) and that create coordination information (by means of their THEN parts) in order to make the members of the community of care of Mrs. P. aware of relevant information about her case. These reactive behaviors are local to their fulcra, but they can be shared across different communities (as described in Section II) to become sensitive to local factual information and represent a support in sharing practices and useful information. This mechanism can solve the problems occurred in the H-ER transfer and in the NH-H transfer. In the first case, rules local to the community of Mrs. P. (the PCC community in Figure 3) are shared with ER community and acquired by the members of this community. Specifically, the rule R1 is executed by the ER practitioner entity that docks to the PCC fulcrum when Mrs. P. enters the ER. R1 states: *IF a stroke hits Mrs. P., THEN alert to call her niece.* This is rendered according to the CASMAS model in the following way:

```
if stroke in ER with patient equals ''Mrs.P.''
then assert alert set content=''call patient's
   niece at phone number: 0345678''.
```

In the second case, a rule local to the NH community is shared with the community of Mrs. P., so that an apt reminder can inform her niece of the applicable reimbursement policies. R2 is executed by the Mrs. P. entity linked to the NH fulcrum and states: *IF a post-stroke elderly patient is admitted in the NH, THEN remind within her community that she has right to full reimbursement for the first three months.* In CASMAS terms:

```
if patient in NH with name equals ''Mrs.P.''
  and diagnosis equals ''post−stroke''
then assert reminder in PCC set content=''
  reimbursement for the first three months''.
```

To solve the problem occurred in the H place, the community of Mrs. P. is endowed with rules by which specific members, either referred by name or role, can be notified of any relevant change in the patient conditions. R3a is executed by the Niece entity linked to the PCC fulcrum and states: *IF Mrs. P. does not take her blood pressure or her medicine at the right time, even once, THEN notifiy it to her niece AND remind her to urge her aunt to comply to the monitoring programme better.* The rule is expressed as:

```
if takenBloodPressure in PCC with atRightTime
  equals ''no''
    and takenMedicine in PCC with atRightTime
      equals ''no''
then assert notify set content=''Mrs.P. does
  not comply to the monitoring programme'';
     assert reminder in PCC set content=''Mrs.P
      . should comply to the monitoring
      programme better''.
```

R3b is executed by the Family Doctor entity linked to the PCC fulcrum; it states: *IF Mrs. P. does not take blood pressure for a number of time, OR she is not losing weight, OR she is not taking her medicine with regularity, THEN remind her family doctor to intervene and contact her.* This is rendered as:

```
if irregularlyTakenBloodPressure in PCC
    or not losingWeight in PCC
    or irregularlyTakenMedicine in PCC
then assert reminder set content=''contact
  Mrs.P. because she does not comply to the
  monitoring programme''.
```

In order to solve the problem that occurred when Mrs. P. was transferred to the MF from the ER (arc 3 in Figure 2), a rule could be activated in the MF community that is sensitive to particular data, which are highlighted by ER members, and that reminds MF practitioners of them during and after the scheduled handovers for a number of next shifts. R4 is executed by the MF Community Assistant linked both to the PCC and the MF fulcra; it states: *IF an information is highlighted in any point of the patient record, THEN remind practitioners to consider this information in the next shifts.* Accordingly, R4 is expressed as:

```
if patientRecord in PCC with info.highlighted
  equals TRUE
then assert reminder in MF set content=''
  consider''+patientRecord.info+''from Mrs.P.
  record in the next shift''.
```

In order to solve the problems of low compliance to standards of quality of care, which are set either locally or at nation level, occurred at the MF and RU, the ER and MF fulcra are endowed with declarative representations of care pathways and clinical guidelines. In this way, apt reminders can be triggered whenever, from the official data reported in the patient record, MF and RU members seem to have neglected their useful indications: to prevent problems like that occurred in MF, we designed a rule stating that: *IF a post-stroke patient is admitted in the MF, THEN remind that a thorough swallowing evaluation must be performed in the first n hours.* R5 is executed by the MF Community Assistant entity and is expressed in these terms:

```
if patient in MF with diagnosis equals ''post−
  stroke''
    and maxTime in MF with type=''post−stroke
      ''
then assert reminder in MF set content=''a
  thorough swallowing evaluation must be
  performed in the first''+maxTime.hours+''
  hours to patient ''+patient.name.
```

The maxTime.hours (or **n**) parameter is usually set according to the local protocols used within the MF, but it can be overwritten according to explicit statements from the ER and its triage (by asserting a sharedMaxTime in the PCC fulcrum), i.e., according to the very conditions in which the patient has been transferred from the ER to the MF. In particular this adaptability to change dynamically the value of the maxTime parameter is made possible by a rule such as R6:

```
if sharedMaxTime in PCC with type=''post−
  stroke''
    and maxTime in MF with type=''post−stroke
      ''
then modify maxTime set hours=sharedMaxTime.
  hours.
```

In order to prevent problems like that occurred in RU, we designed a rule stating that: *IF a post-stroke patient is attended in the RU, THEN remind that her indwelling catheter must be removed every m hours.* R7 is executed by the RU Community Assistant linked both to the PCC and RU fulcra:

```
if patient in RU with diagnosis equals ''post−
  stroke''
    and maxTime in RU with type=''post−stroke,
      catheter''
```

```
then assert reminder in RU set content=patient
  .name+''s indwelling catheter must be
  removed every''+maxTime.hours+''hours''.
```

Also in this case, the maxTime.hours (or **m**) parameter is usually set according to the local protocols used within the RU, but it can be overwritten according to explicit statements from either the MF or any other medical member of the PCC according to the anamnestic profile of the patient (e.g., her predisposition to get urinary infections). Again, this adaptability to contextual modifications of the maxTime.hours parameter is made possible by means of rules like R8:

```
if sharedMaxTime in PCC with type=''post-
  stroke,catheter''
     and maxTime in RU with type=''post-stroke,
       catheter''
then modify maxTime set hours=sharedMaxTime.
  hours.
```


V. Conclusions

In this paper, we presented how CASMAS, a language to model applications that support collaboration among members of communities in Pervasive Computing environments, can be applied in order to support communities of professionals and relatives involved in the care of a long-term patient. More specifically, our aim is to show how CASMAS can be used to overcome the care fragmentation that results from lack of mutual awareness and difficulty in sharing knowledge. The technological capabilities of Pervasive Computing are combined with the notion of community in order to endow the modeling language with abstractions that are suitable to achieve this goal. In order to illustrate our approach, we used CASMAS to model mechanisms that could support the communities of people that are involved in the care of an elderly person who had a stroke. Future developments concern the improvement of the CASMAS-WOAD framework (modeling language and architecture) to make its usage easier to design and deploy cooperative applications, and to continue its testing in the healthcare domain as well as in other domains characterized by high demand of support to cooperation and knowledge sharing in Pervasive Computing environments.

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