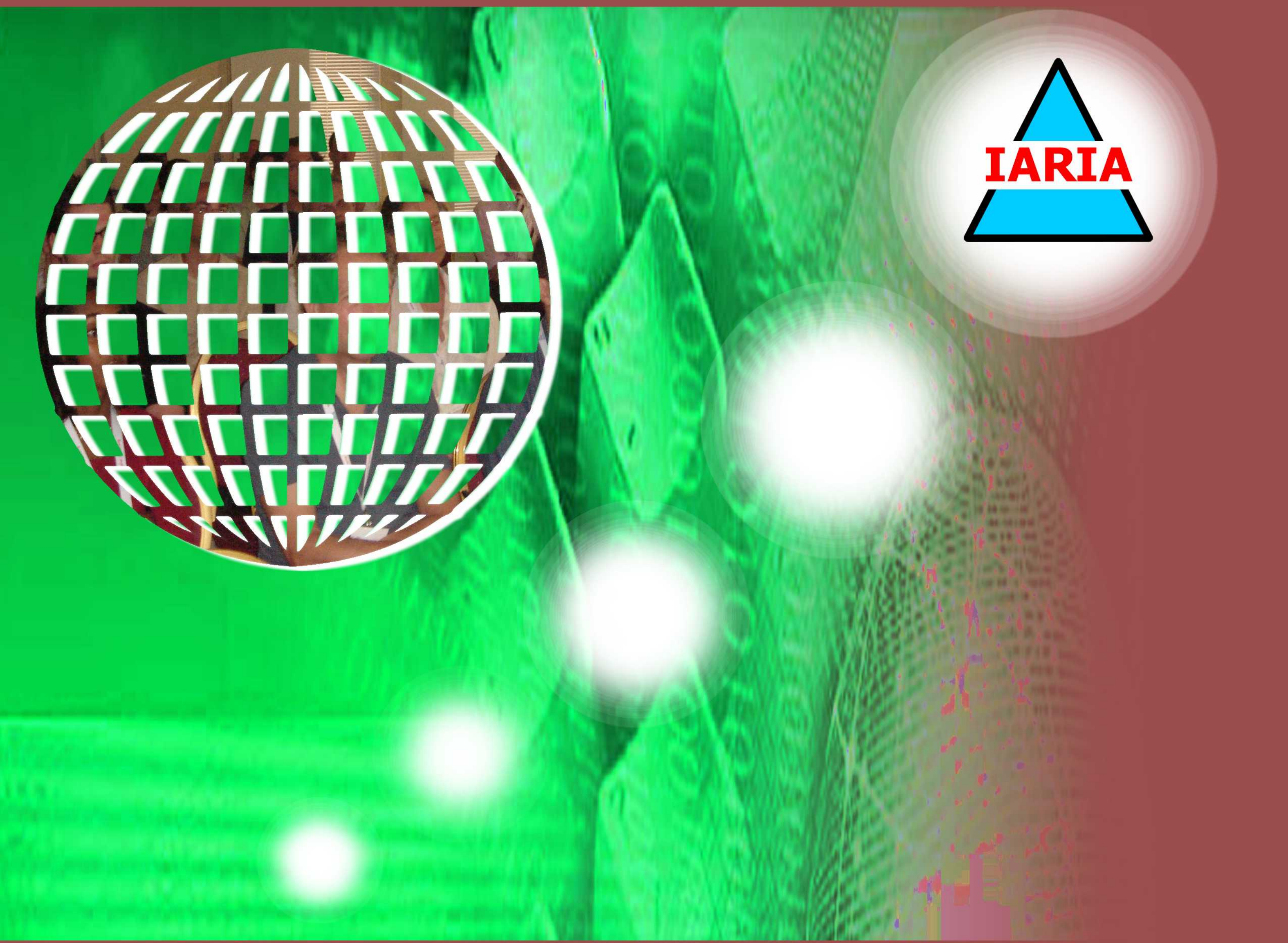
International Journal on Advances in Life Sciences



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Abstract— **This research study introduces, delivers, and evaluates the benefits of using web and mobile technology to provide consistent supportive health care to individuals living within London, Ontario and the surrounding area who have been diagnosed with a mental illness. This longitudinal, mixed method study consists of 400 (245 men and 155 women) individuals who have been diagnosed with either a mood or a psychotic disorder who are currently working with mental health care professionals (54 mental health care providers across 4 agencies). The participants will have access to the Lawson SMART record, a web-based application that provides individuals with a personal health record, and tools to help them manage their health. Participants will access the Lawson SMART record using an iPhone 4S. Based on preliminary findings, client participants are generally comfortable with the use of technology. Most indicated that they were either extremely comfortable (26.3%) or slightly comfortable (20.3%) with technology generally, while only a minority said that they were either slightly uncomfortable (4.0%) or extremely uncomfortable (5.8%). It is hypothesized that the use of smart technologies in the treatment of mood and psychotic disorders will improve quality of life while reducing health care costs through a decrease in hospitalizations and hospital room visits. The Mental Health Engagement Network: Connecting Clients with their Health Team project was presented at IARIA-Smart 2012 Conference by Dr. Cheryl Forchuk in May 2012 [1]. As a result of the presentation, this paper was developed.**

Keywords- SMART Technology; Mental Health Care; Personal Health Records; Quality of Life; Health Care Costs; Mood Monitor; Mobile Technology; Web-based Technology

I. INTRODUCTION

The economic cost of mental illness to Canada was recently estimated at $51 billion annually, and still the current "system" of care is fragmented and without sufficient resources (financial, human, and technological), per "The Healthcare Interview" Canadian Healthcare Network, December 2009 [2]. The 2009 cost estimates showed a dramatic increase from 2003, when it was estimated that the Canadian economic burden due to mental illness was ~ $34 billion ($1,056 per capita), which was a 3-fold increase from 1998 estimations of $12.3 billion. Twenty percent of Canadians will experience a mental illness in their lifetime and most others will experience mental illness indirectly through a family member, friend, or colleague. Mental illness affects people of all ages, regardless of education, income level, or culture [3]. With mental health services at a crisis point, even though billions of dollars are being invested to help, most people in need of care will not receive the care they require [4].

Commonly, mental health care is prioritized for individuals with the most severe symptoms, due to the lack of available services. This runs counter to the general health care system where prevention and intervention at less serious levels is the norm. The current way of treating psychiatric illness is unsustainable and only through developing new service models that provide support and early intervention, will the mental health care system be sustainable. A new and potentially more sustainable method of providing mental health care would be that of employing smart technologies to enhance the treatment of mental health clients.

The Mental Health Engagement Network (MHEN) is focused on putting technology in the hands of mental health clients and their mental health care providers to demonstrate a more effective and efficient mental health care service delivery model. In partnership with TELUS Health Solutions, this project will deploy TELUS health space™ consumer health platform along with a customized personal health record application, the Lawson SMART record, and interactive tools that support a novel way to provide clients with standardized health services, ongoing monitoring and regular communication with their mental health care providers. This innovative solution will help coordinate care across the continuum; ensuring that services are more accessible, patient-centered, and promote the empowerment of individuals so they can better manage their own health. From a population perspective, this proposed system re-design will have the capability to reduce or prevent acute episodes of mental illness and reduce the severe pressures on an already over burden health care system.

This document proceeds as follows. Section II provides an overview of existing literature and applications. Section III describes the methods employed by the MHEN project. The expected outcomes are outlined in Section IV and the conclusion is presented in Section V.

II. LITERATURE REVIEW

A. Existing Studies

In recent years there has been a growing body of research evaluating the benefits of using mobile and web based technology to help individuals better manage their health.

Studies evaluating the use of web-based interventions, including online learning programs, Personal Health Records (PHR), e-therapy, and online databases with access to mental health resources, have shown that these types of interventions have positive outcomes for mental health clients. For example, a study employing, Anxiety Online, an educational website which provides information about anxiety disorders, links to useful resources, psychological assessments and a referral system found e-mental health treatment increases accessibility to mental health care in a cost effective and efficient way. The authors also indicate that this type of technology may encourage individuals to access mental health treatment who would not otherwise access traditional forms of treatment due to stigma [5].

Another study, evaluated the use of an online cognitive behavioural therapy based treatment for depression, with a sample of 141 individuals diagnosed with major depressive disorder. The authors found that participants in the intervention group experienced a reduction in symptoms of depression and better clinical outcomes than the control group [6].

Other studies evaluating the use of mobile-based interventions, including text-messaging and mobile applications, have also shown that this type of intervention has positive outcomes for individuals with mental health issues. For example, one study in which 55 clients with schizophrenia or schizoaffective disorder received a cell phone and a text messaging based intervention found that medication adherence and social interactions increased significantly [7].

Another study with a similar population, of 154 participants diagnosed with schizophrenia, employing a text messaging based intervention found improvement in medication adherence among participants after 3 months, and improvement among negative, cognitive and global symptoms [8].

The MHEN project will contribute to the existing literature by providing an analysis to the effectiveness of a combination of web and mobile-based technologies in mental health care.

B. Applications

Several applications, both mobile and web based, have been developed employing smart technology to support health care. Examples include: My Mood Monitor [9] and MedHelp's Mood Tracker [10], which are both applications designed to monitor a user's mood; medication adherence assistance applications such as RxReminder [11]; the Mobile Assessment and Treatment for Schizophrenia (MATS) [7] which is an interactive text-messaging intervention; and the use of Personal Health Records/Electronic Health Records [12].

The MHEN project will contribute to the existing applications in that this web-based solution will employ all of these applications in one complete platform. Participants will have access to an electronic Personal Health Record, and to tools that will assist in the management of their health. Additionally, the MHEN project will contribute to the existing literature in that the effectiveness of these applications has not been extensively researched, particularly in mental health care.

III. METHODS

The following subsections describe the methods employed in the MHEN project.

A. Study Design

This research study began in September, 2011 and will conclude in November, 2013. It includes 54 community mental health providers and 400 clients who have been diagnosed with a mood disorder or a psychotic disorder. Client participants were randomized into Group 1 (early intervention) or Group 2 (later intervention) by care provider caseload, so that participating mental health care providers would have roughly 4 participants in Group 1 and Group 2.

Group 1 (200 participants) received an iPhone 4S, a TELUS health space™ account, and version 1.0 of the Lawson SMART record during Phase I (August 2012). The remaining 200 clients, Group 2, will initially act as a control group, and at Phase II (6 months later) will receive an iPhone 4S, a TELUS health space™ account, and version 2.0 of the Lawson SMART record. The participating mental health care providers will receive a Lawson SMART record account and an iPad during Phase I.

In addition to the tools deployed through the MHEN project, 12 month voice and data plans will be provided to client participants. Similarly, 18 month data plans will be provided to the mental health care provider participants.

B. Sample

The 400 client participants and 54 community mental health care provider participants were recruited from January, 2012 to August, 2012. Participants were recruited through community programs at London Health Sciences Centre and St. Joseph's Health Care, as well as through the Canadian Mental Health Association (London-Middlesex Branch) and WOTCH Community Mental Health Services.

London Health Sciences Centre Adult Mental Health Care Program offers a wide range of programs, including Prevention and Early Intervention Program for Psychoses, the First Episode Mood and Anxiety Program, and Geriatric Mental Health Program to support adults living in the community with mental illness. St. Joseph's Health Care governs Regional Mental Health Care- London and St. Thomas and both of these sites are participating in the MHEN project. Services offered include, Mood and Anxiety Programs, Transition to Primary Care Program, Forensic Outreach, a Schizophrenia Program, and Assertive Community Treatment teams. WOTCH Community Mental Health Services provides adults over 16 years of age who are managing serious mental illness many services including: one-on-one counseling, housing support, employment support, family support, and access to health services. The Canadian Mental Health Association (London-Middlesex) provides individuals living in the community with many services including, Court Support and Diversion programs, Housing Advocacy programs, the Justice-Community Support Program, Crisis Services, and peer support groups.

Mental health care provider participants were recruited through presentations at regularly held staff meetings at the participating agencies. Mental health care providers were eligible to participate if they had at least 8 clients on their caseload with mood or psychotic disorders, and if they were willing to employ the health information technology in addition to the regular care they provide. Of the 54 mental health care providers, 28 were recruited from St. Joseph's Health Care (12 community mental health care teams), 12 from London Health Sciences Centre (2 community mental health care teams), 7 from the Canadian Mental Health Association (London-Middlesex), and 7 from WOTCH Community Mental Health Services. The participating mental health care workers consists of 12 Registered Nurses, 12 Registered Social Workers, 7 Occupational Therapists, 7 Mental Health Care Managers, 4 Social Service Workers, 3 Rehabilitation Counselors, 2 Recreational Therapists, 2 Registered Practical Nurses, 2 Psychiatrists and 3 other (See Tables I and II).

TABLE I. DESCRIPTION OF COMMUNITY MENTAL HEALTH CARE PROVIDERS – AGENCY

Variable	Description of Community Mental Health Care Providers (N = 54)		
	Sub Variable	***Frequency***	***Percentage***
Agency			
	St. Joseph's Health Care London	29	53.7
	London Health Sciences Centre	11	20.4
	Canadian Mental Health Association	7	12.9
	WOTCH Community Mental Health Services	7	12.9

TABLE II. DESCRIPTION OF COMMUNITY MENTAL HEALTH CARE PROVIDERS – OCCUPATION

Variable	Description of Community Mental health Care Providers (N = 54)		
	Sub Variable	***Frequency***	***Percentage***
Occupation			
	Social Service Worker	12	22.2
	Registered Nurse	12	22.2
	Mental Health Case Manager	7	13
	Occupational Therapist	7	13
	Registered Social Worker	3	5.6
	Rehabilition Counselor	3	5.6
	Recreational Therapist	2	3.7
	Registered Practical Nurse	2	3.7
	Psychiatrist	2	3.7
	Other	4	7.4

Client participants were recruited from the caseloads of participating care providers. Eligible client participants had either a mood or a psychotic disorder and were between the ages of 18 and 80. Of the 400 client participants, 192 were recruited from St. Joseph's Health Care, 96 from London Health Sciences Centre, 48 from the Canadian Mental Health Association (London-Middlesex), and 62 from WOTCH Community Mental Health Services (See Table III).

TABLE III. CLIENTS PARTICIPANTS BY AGNECY

Variable	Client Participants (N = 410)		
	Sub Variable	***Frequency***	***Percentage***
Agency			
	St. Joseph's Health Care London	192	48
	London Health Sciences Centre	96	24
	Canadian Mental Health Association	48	12
	WOTCH Community Mental Health Services	62	15.5

C. The Lawson SMART record

The Lawson SMART record was developed in partnership with TELUS Health Solutions and an advisory group with community, clinical, consumer and technical representation. The solution employs TELUS health space™, a consumer platform powered by Microsoft® Health Vault™. TELUS health space™ is an electronic health care system, that allows individuals to store and manage health information and to share this information with their care providers. The Lawson SMART record is an application provided through TELUS health space™ to participants of the MHEN project.

The Lawson SMART record is a web-based application that provides individuals with an electronic personal health record. Through this record, individuals can store, maintain, and manage their personal health information (i.e. list of medications, family history, immunization records, allergies, care provider contact information, care plans and crisis plans). The Lawson SMART record also provides individuals with tools to help them in the management of their health. For example, as part of the MHEN project, a mood monitor was developed. This tool allows individuals to determine their mood at any given time and track it electronically. Through the Lawson SMART record client participants also have the ability to set prompts and reminders for themselves, where they can be reminded about upcoming appointments, when to take medications or when to exercise. Individuals can also electronically track physiological measures such as weight, blood glucose, blood pressure and cholesterol.

Through the MHEN project, the participating mental health care providers have electronic access to their participating client's Lawson SMART record. This access will allow the mental health care providers to view the information within their client's record, and to communicate directly with their clients through the Lawson SMART record's messaging tool.

D. Training

As a requirement of the MHEN project, participating clients and mental health care providers must complete one half-day training session to learn about the Lawson SMART record and their handheld device. A training committee with representation from the consumer, clinical, community and technical perspectives was created to guide the development of training content and materials. Each training session was structured to include Lawson SMART record and TELUS health space™ account creation, a live demonstration of the Lawson SMART record, during which the participants followed along using their handheld devices, instruction on the basic features of their respective handheld devices, and delivery of the guidelines associated with the use of their handheld devices and the Lawson SMART record. Participants also received a training manual which described the features and functions of the Lawson SMART record, outlined the guidelines for use of the Lawson SMART record and their handheld devices, and described the project support model.

Mental health care provider training sessions were held in June, 2012. Participants were trained in groups of up to 15 individuals. Each training session was approximately 3 hours in length and was facilitated by a member of the research team. Additional training sessions were held in September, 2012 to provide ongoing support as the Lawson SMART record and iPhones were deployed to their clients. The research team also developed a support model to manage hardware, software and application inquiries from the participating mental health care providers. After client training began and mental health care providers began to use the application and iPad, the research team did receive inquiries ranging from simple password resets to in depth support on the Lawson SMART record.

Client participant training began in July, 2012 and was completed in September, 2012. Clients from Group 1 were trained in groups of up to 15 participants per session. Each training session was approximately 3 hours in length and was facilitated by a member of the research team. Drop in sessions were held twice a week throughout the month of August and September, 2012 to provide additional support to client participants. Initial inquiries to the research team ranged from basic iPhone support, email support, phone calling support, text messaging support, and downloading of applications and music to inquiries about the specific features and functions of the Lawson SMART record.

Client participant training for Group 2 is scheduled to begin in February 2013. Findings obtained through Group 1 client feedback on training evaluations will be applied to the structure and content of Group 2 training sessions, as well as to the mental health technology.

E. Data Collection

Individual interviews with client participants were held during the baseline period and then every 6 months for 18 months (See Fig. 1).

The quantitative data collected during interviews will involve the following eight questionnaires: Demographic Form; Quality of Life – Brief Version (QoL-BV); Health, Social, Justice Service Use; Medical Outcomes Study 36-item Short Form Health Survey (SF-36); EQ-5D; Community Integration Questionnaire; Adult Consumer Empowerment Scale; and a Perception of Smart Technology Form.

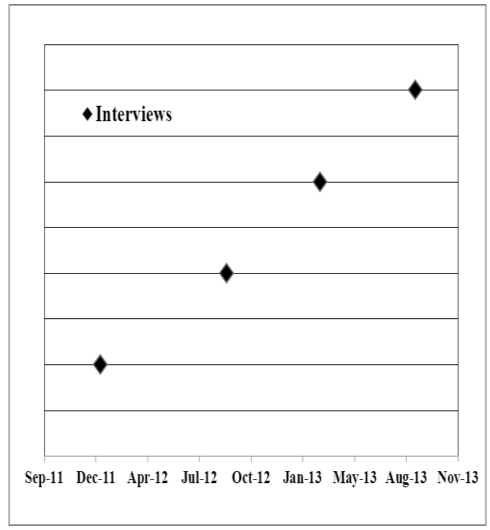

Figure 1. Interview Timeline

Focus group sessions will take place at multiple points during the study. Group 1 will have the option to participate in three focus group sessions: (1) approximately one month after receiving the handheld device and a TELUS health space™ account to discuss usability and adoption; (2) follow up focus group sessions will be held two months thereafter to discuss the benefits and pitfalls associated with the technology and to form base recommendations for the next phase of study (Group 2); and (3) 6 months later to discuss future recommendations. Group 2 will also have the opportunity to participate in 3 focus group sessions. They will meet in a similar timeframe: (1) approximately one month after receiving the handheld device and a TELUS health space™ account to discuss usability and adoption; (2) follow up focus group sessions will be held two months thereafter to discuss the benefits and pitfalls associated with the technology; and (3) 6 months later to discuss future recommendations. Focus group sessions with mental health care providers will also be held at similar time points so that issues can be identified and addressed quickly (See Fig. 2).

The knowledge learned through Group 1, over the initial 6 months will provide baseline and comparative data to understand the client's perceptions for designs and outcome purposes of the technology intervention. Improvements in the technology approaches made during the initial 6 month period will enhance the tools for Group 2. We are expecting different feedback from focus group sessions, one to guide development and one to improve what is developed.

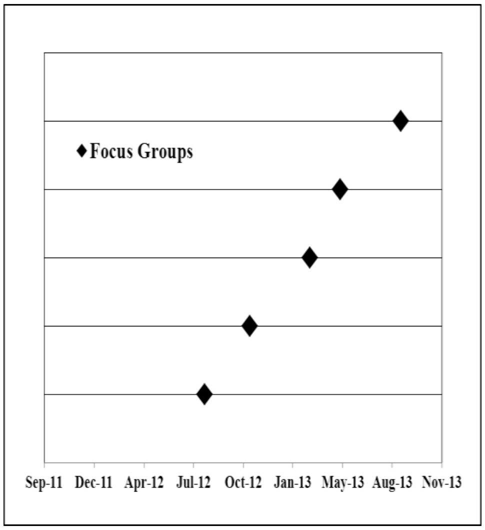

Figure 2. Focus Group Timeline

IV. BASELINE RESULTS

A. Baseline Interviews

Preliminary quantitative data analysis of 400 client participants (245 men and 155 women) indicates that the mean age of the population is 38.48 (SD = 13.792). A large population of client participants reported to be single and never married (69.5%), and to be living alone (41.5%). A majority of client participants completed high school (44.5%), or just grade school (31%). The most common psychiatric diagnoses in this sample population are mood disorders (59.25%), psychotic disorders (58.25%), anxiety disorders (32%), substance-related disorders (13.75%), personality disorders (6.25%), disorders of childhood/adolescence (5%) and developmental handicaps (0.75%). Most client participants indicated that they have been admitted to the psychiatric hospital at least once (85.75%) and of those individuals, most have been admitted a mean of 7.7 times (SD = 10.815) (See Table IV, V, and VI).

TABLE IV. DESCRIPTION OF CLIENT PARTICIPANTS – AGE

Variable	Description of Client Participants (N=410)		
	Mean	***Standard Deviation***	***Range***
Age	38.5 years	13.8	18-78
Age at first contact with mental health system	22 years	9	3-61
Estimated total number of hospitalization	7.7	10.8	1-100

TABLE V. DESCRIPTION OF CLIENT PARTICIPANTS – SEX, MARITAL STATUS, FAMILY, LIVING ARRANGEMENTS, EDUCATION LEVEL AND EMPLOYMENT

Variable	Description of Client Participants (N=410)		
	Sub Variable	***Frequency***	***Percentage***
Sex			
	Male	245	61.3
	Female	155	38.8
Marital Status			
	Married or Common Law	36	9
	Seperated Divorce	83	20.8
	Single-Never Married	278	69.5
	Widowed	3	0.8
Having Children			
	Yes	125	31.3
	No	275	68.8
Current Living Arrangement			
	Inpatients	11	2.8
	Lives alone	166	41.5
	Lives with other relative	20	5
	Lives with parent(s)	71	17.8
	Lives with spouse/partner	42	10.5
	Lives with unrelated person	88	22
	Other	2	0.5
Level of Education			
	Community College/ University	95	23.9
	High School	178	44.5
	Grade School	124	31
	Don’t Know	1	0.3
	Other	2	0.5
Currently Employed			
	Yes	102	22.5
	No	298	74.5

TABLE VI. DESCRIPTION OF CLIENT PARTICIPANTS – PSYCHIATRIC DIAGNOSIS AND HOSPITALIZATIONS

Variable	Description of Client Participants (N=410)		
	Sub Variable	*Frequency*	*Percentage*
Pscyhiatric Diagnosis			
	Developmental Handicap	3	0.75
	Anxiety Disorder	128	32
	Disorder of Childhood and Adolescence	20	5
	Organic Disorder	3	0.75
	Susbtance-related Disorder	55	13.75
	Personality Disorder	25	6.25
	Psychotic Disorder	233	58.25
	Mood Disorder	237	59.25
	Other	10	2.5
	Unknown	2	0.5
Ever had a psychiatric hospitalization			
	Yes	343	85.75
	No	56	14

Initial quantitative analysis shows that most client participants are generally comfortable with the use of technology. Most indicated that they were either extremely comfortable (26.3%) or slightly comfortable (20.3%) with technology generally, while only a minority said that they were either slightly uncomfortable (4.0%) or extremely uncomfortable (5.8%) with technology generally (See Fig. 3).

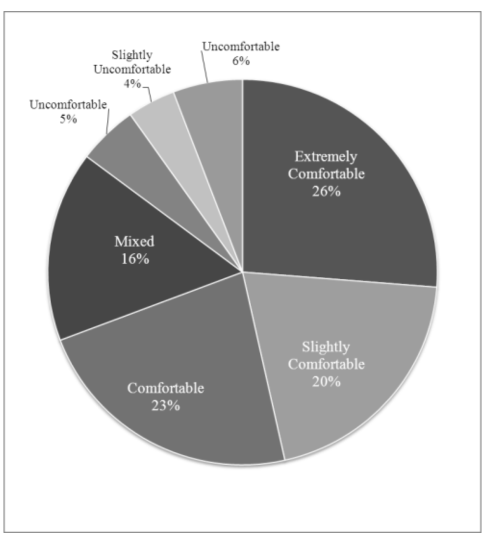

Figure 3. How comfortable are you with technology in general?

A number of individuals owned a phone (90.3%) however, less than half of the population (43.3%) owned a cell phone (See Fig. 4 and Fig. 5). Most participants indicated that they used a phone frequently (73.1%), (See Fig. 6).

Participants also indicated that they had regular access to a computer (77%) with a large percentage of the population (60.5%) reporting regular access at home (See Fig. 7 and 8). Additionally, participants indicated frequent use of computers (43.8%) (Fig. 9) and most stated that they were extremely comfortable (31.2%) or slightly comfortable (14.6%) with using a computer, while only a smaller percentage of the population indicated that they were either slightly uncomfortable (4.5%) or extremely uncomfortable (9.8%) with using a computer (See Fig. 10).

This indicates that since most client participants are familiar and comfortable with technology and suggests that they will be receptive to the interventions smart technology training.

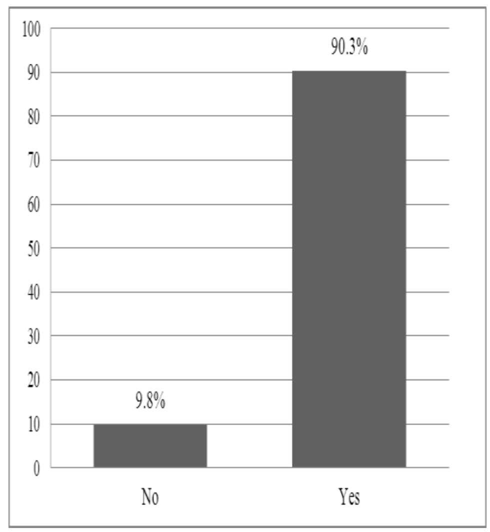

Figure 4. Do you own a phone?

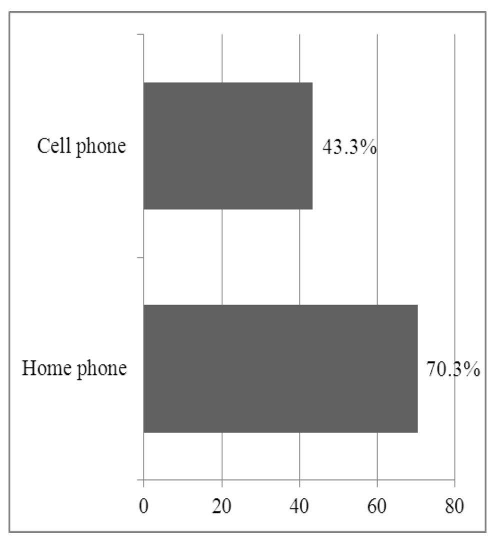

Figure 5. Type of phone owned?

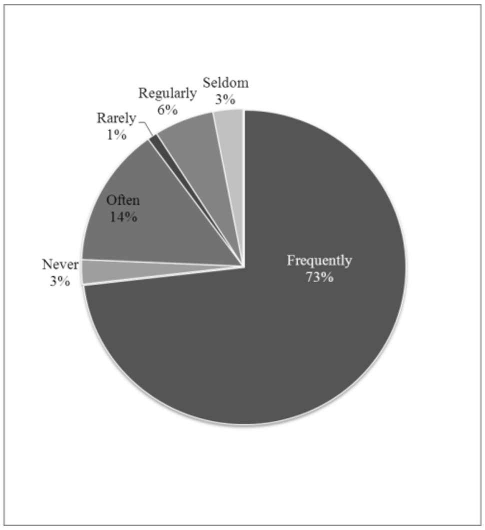

Figure 6. Use of phone?

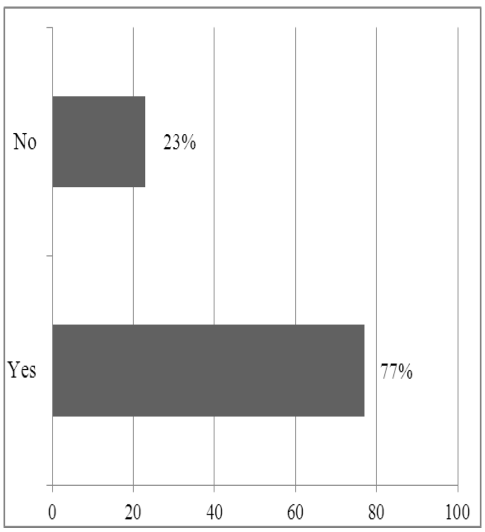

Figure 7. Do you currently hace access to a computer on a regular basis?

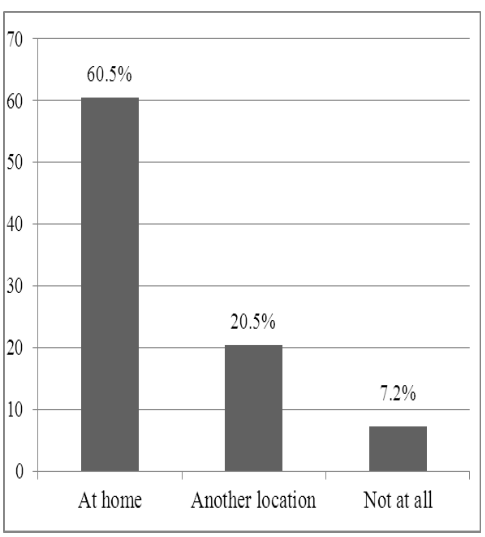

Figure 8. Location of access to a computer?

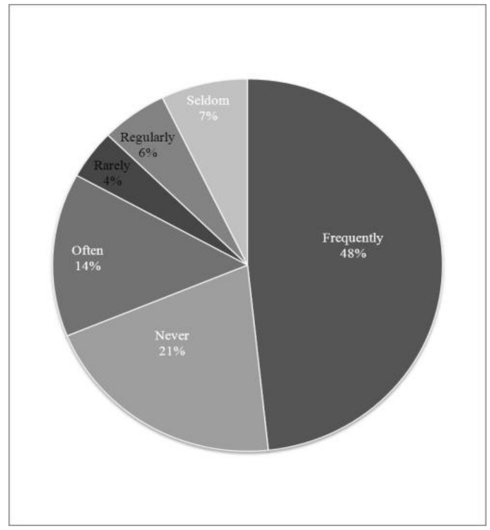

Figure 9. Use of computer?

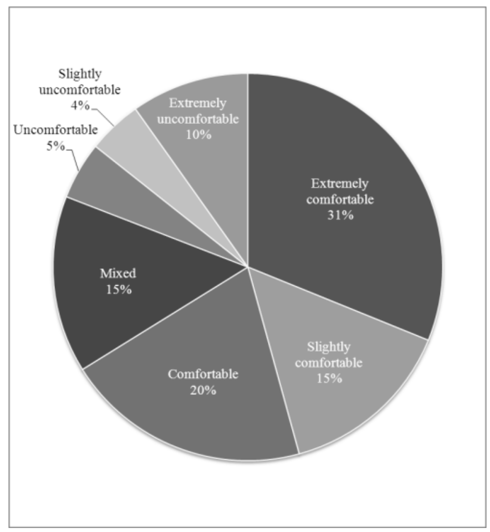

Figure 10. Comfort with computers?

B. *Initial Focus Group Sessions*

Focus group sessions have been completed for the early intervention group with both client participants and mental health care provider participants. In total there were 5 client focus group sessions with 21 participants, and 3 mental health care provider focus group sessions with 21 participants (See Table VII and VIII).

Overall the feedback was positive and participants gave many examples of how the technology improved health care and health status. For example, one mental health care provider stated that a client he had been seeing for 2 years made more progress in the meeting after receiving the technology than the 2 years prior. The mental health care provider indicated that this was because the client had a focus for discussion and was able to use the device to organize himself. Client participants gave examples of having a better understanding of the patterns of their moods, which provided them more sense of control. One client visited an emergency ward for a medical situation and was able to access his Lawson SMART record using his iPhone and show the emergency staff his list of medications.

During focus group sessions both clients and providers also identified ways the strategy could be further improved. Client participants focused on very pragmatic issues such as faster log-in, a calendar available on the homepage, and pictures of pills. Similarly mental health care providers wanted a notification mechanism for messages received from their clients and confirmation that clients had received messages they had sent. Follow up focus group sessions for both clients and mental health care provider participants will be held early 2013.

Phase II development of the Lawson SMART record began in December 2012. The project team has based this development on feedback from the initial focus group sessions. Enhancements to the Lawson SMART record are to be delivered early 2013. Once Phase II developments are complete client participants in Group 2, will receive the intervention.

TABLE VII. FOCUS GROUP SESSIONS: MENTAL HEALTH CARE PROVIDER PARTICIPANTS

Variable	Focus Group Sessions: Mental Health Care Provider Participants (N=21)		
	Sub Variable	***Frequency***	***Percentage***
Agency			
	St. Joseph's Health Care London	5	23.81
	London Health Sciences Centre	7	33.33
	Canadian Mental Health Association	4	19.05
	WOTCH Community Mental Health Services	5	23.81

TABLE VIII. FOCUS GROUP SESSIONS: CLIENT PARTICIPANTS

Variable	Focus Group Sessions: Client Participants (N=21)		
	Sub Variable	***Frequency***	***Percentage***
Agency			
	St. Joseph's Health Care London	9	42.86
	London Health Sciences Centre	7	33.33
	Canadian Mental Health Association	2	9.52
	WOTCH Community Mental Health Services	3	14.29

V. EXPECTED RESULTS

Baseline data was complete in August, 2012. Training and implementation of the first 200 participants began on July 30, 2012 and was completed September 2012. Additional data, including use of technology, will be available in January, 2013.

The overall hypothesis is that smart health information technology will improve quality of life and reduce health care system costs. To test this hypothesis we will use an evaluation framework that includes four levels of analysis: effectiveness, economic, ethical and policy. Development and testing of a more cost-effective means of addressing mental health issues will increase the ability to provide the best practice at an affordable cost which benefits consumers and taxpayers.

With the introduction of the Lawson SMART record several outcomes are expected. For example, with the introduction of medication prompts, scheduling, ongoing monitoring and regular communication, it is expected that clients will experience an improvement in mental health. Additionally, with the introduction of medication prompts, monitoring, and prescription renewal reminders, it is expected that there will be a resulting improvement in overall medication adherence.

The availability of personal health information to a client is foundational to empowerment and to the effective management of an individual's own health and wellness. The ability to store, maintain and manage one's personal health information as provided through the Lawson SMART record and is expected to increase individual empowerment.

The Lawson SMART record also provides a forum for communication between client participants and their mental health care providers. It is expected that with this increased communication, individuals will have greater access to the mental health care system. With this greater access, it is expected that mental health care providers will be able to intervene when clients are experiencing earlier stages of crisis. It is also expected that with greater access to community mental health care resources, there will be a decrease in the use of expensive emergency mental health care services.

Overall, it is expected that with the introduction of the Lawson SMART record, client participants will experience an improvement in their mental health and obtain greater access to the mental health care system.

VI. CONCLUSION

The MHEN project is focused on putting technology in the hands of clients of the mental health system and their mental health care providers to demonstrate how to more effectively and efficiently deliver mental health care services. Employing the Lawson SMART record, the MHEN project will evaluate the use of Smart technologies in mental health care on four levels: effectiveness, economic, ethical and policy. Smart technologies, have the potential to improve the quality of care for people who access mental health services. Continued evaluation of personalized health records and specific mental health applications will provide important information for mental health system re-design.

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Object-aware Process Support in Healthcare Information Systems: Requirements, Conceptual Framework and Examples

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***Abstract*—The business processes to be supported by healthcare information systems are highly complex, producing and consuming a large amount of data. Besides, the execution of these processes requires a high degree of flexibility. Despite their widespread adoption in industry, however, traditional process management systems (PrMS) have not been broadly used in healthcare environments so far. One major reason for this drawback is the missing integration of business processes and business data in existing PrMS; i.e., business objects (e.g., medical orders, medical reports) are usually maintained in specific application systems, and are hence outside the control of the PrMS. As a consequence, most existing PrMS are unable to provide integrated access to business processes and business objects in case of unexpected events, which is crucial in the healthcare domain. In this context, the PHILharmonicFlows framework offers an innovative object-aware process management approach, which tightly integrates business objects, functions, and processes. In this paper, we apply this framework to model and control the processes in the context of a breast cancer diagnosis scenario. First, we present the modeling components of PHILharmonicFlows framework applied to this scenario. Second, we give insights into the operational semantics that governs the process execution in PHILharmonicFlows. Third, we discuss the lessons learned in this case study as well as requirements from the healthcare domain that can be effectively handled when using an object-aware process management system like PHILharmonicFlows. Overall, object-aware process support will allow for a new generation of healthcare information systems treating both data and processes as first class citizens.**

***Keywords-Process Management*, *Object-aware Process Management*, *Data-driven Process Execution*.**

I. Introduction

Healthcare processes are characterized by their high complexity and the large amount of data they have to manage [22], [33], [20]. The latter is usually represented in terms of business objects like, for example, medical orders, medical reports, laboratory reports, and discharge letters. Since healthcare processes require the cooperation among different organizational units and medical disciplines [19], cross-departmental process support becomes crucial.

A. Problem Statement

In this context, process management systems (PrMS) are typically the first choice for implementing and maintaining process-aware information systems. However, despite their widespread adoption in industry, existing PrMS have not been broadly used in healthcare environments so far [8]. One major reason for this deficiency is the fact that contemporary PrMS are *activity-driven*; i.e., the processes are modeled in terms of "black-box" activities and their control-flow defines the order and constraints for executing these activities. However, activity-centric process modeling approaches like BPMN [29] or BPEL [18] present numerous limitations [14]: business data is typically treated as second-class citizen [4], [7]. Moreover, most PrMS only cover atomic data elements, which are needed for control flow routing and for supplying the input parameters of activities with respective values [31]. In turn, business objects are usually maintained and stored in external databases and are outside the control of the PrMS. Hence, integrated access to processes and data, which is crucial for any healthcare process support, is missing. Particularly, contemporary PrMS are unable to provide immediate access to important process and business information in case of unexpected events [11].

Regarding the execution of activity-driven PrMS, a process requires a number of activities to be processed in a certain order and be completed to terminate successfully. In turn, healthcare processes and their steps depend on the availability of certain information [19]. For example, if the temperature of a patient is above 38°C, the doctor may have to prescribe a medicine to contain the fever. Consequently, the activation of an activity does not directly depend on the completion of other activities, but rather on changes of business object attributes.

Typically, it is also not possible to squeeze healthcare processes into one monolithic process model [22]. In healthcare environments, there exists numerous processes depending on each other. For example, the distribution of a medicine in the hospital pharmacy may depend on the patient's treatment process which, in turn, may depend on his diagnosis process. The latter comprises diagnostic procedures like blood tests and image examinations (or imaging encounters). To be applicable in a healthcare context, therefore, a PrMS must provide mechanisms for coordinating the interactions between interdependent processes. Thereby, respective coordination mechanisms must take the role of business objects into account.

Another challenge arises from the fact that activities are not only executed in the context of single process instances. Instead, they may be invoked at different levels of granularity comprising several process instances (of the same and of different type). A medical doctor, for instance, may examine one patient at a time, while a nurse prepares medications for several patients in one go, that means, different kinds of working styles need to be supported.

Finally, healthcare processes highly depend on medical knowledge as well as on case-specific decisions [19], [9]. Thus, the type and order of invoked activities may vary from process instance to process instance. In particular, healthcare processes cannot be "straight-jacketed" into a set of pre-defined activities [4], [38].

B. Contribution

Generally, the described limitations of existing PrMS can be traced back to the missing integration of processes and data [13], [14]. To overcome these limitations, several approaches have pioneered certain concepts for enabling data-driven process execution [4], [26], [10], [23], [24], [39], data-driven exception handling and process adaptation [24], [35], process coordination [2], [23], integrated access to data [4], and process definition based on data behavior [5], [39]. However, none of these approaches considers all identified limitations in a comprehensive and integrated way. Furthermore, many existing approaches solely focus on process modeling or do not make a difference between the modeling and execution of a process; i.e., they provide rich capabilities for process modeling, but do not explicitly take runtime issues into account.

Opposed to these approaches, PHILharmonicFlows targets at a comprehensive framework addressing all described limitations (and many others) [13], [17]. In addition, PHILharmonicFlows enforces a well defined modeling methodology governing the object-centric specification of processes based on a precise and formal operational semantics [15], [17]. In this paper, we evaluate the applicability of PHILharmonicFlows framework to healthcare processes. For this purpose, we present a breast cancer diagnosis procedure as performed at a Women's hospital. This paper significantly extends the work we presented in [1]. In particular, besides the modeling issues of the framework, we present the operational semantics governing process execution during runtime as well as some screenshots of our prototype, built as proof-of-concept.

Section II describes the medical scenario we consider and elaborate the fundamental requirements that any PrMS supporting corresponding healthcare processes must meet. In Section III, we model this scenario using the components provided by the PHILharmonicFlows framework. The operational semantics for executing processes in PHILharmonicFlows is presented in Section IV. Following this, Section V discusses how the identified requirements are met by the framework. Related work is discussed in Section VI. Finally, Section VII concludes with a summary and an outlook.

II. Healthcare Scenario

The healthcare scenario we consider is a breast cancer diagnosis process we obtained from a process handbook of a Women's hospital [36], [37]. As illustrated in Figure 1, this process comprises an anamnesis, a physical examination (including the collection and confirmation of symptoms), a set of medical examinations (e.g., MRI, mammography, and blood analysis), and a tumor biopsy. Some of these procedures are illustrated in Figure 2. We describe the different procedures using state charts, which are considered as an intuitive modeling paradigm providing a natural view for end users [21].

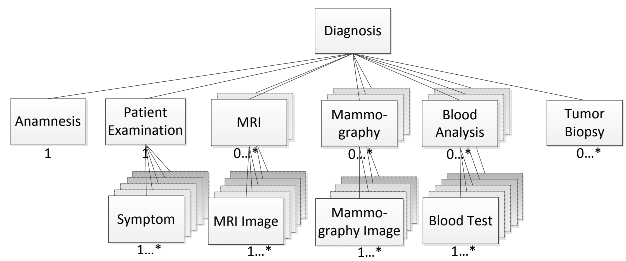

Figure 1. Objects involved in the breast cancer diagnosis process

During anamnesis (see Figure 2b) the doctor asks the patient specific questions (e.g., about her history of diseases, family diseases, or current medication). In the meanwhile, the doctor examines the patient and interviews her about the presence of any symptom (see Figure 2d). The doctor also asks the patient about breast nodules and he performs a physical examination in order to confirm or exclude the symptoms (see Figure 2c). If the symptoms brought up by the patient are not confirmed during the physical examination, the presence of the tumor will be denied (see Figure 2a). In this case, the diagnosis process is finished. Otherwise, the doctor decides about a battery of examinations based on the symptoms confirmed.

One of the examinations, required to detect the presence of a breast tumor or to exclude it, is mammography (see Figure 2e). To perform this examination, the secretary of the radiology department must schedule it. At the day of the appointment, the procedure is performed and the resulting images are stored in a database (see Figure 2f). The MRI examination requires a similar process as shown in Figure 2g. The images from both examinations are then analyzed by a specialized doctor of the radiology department and are added to the respective medical reports. As opposed to the mammography examination, for which the equipment does not cause claustrophobia, during the MRI examination (see Figure 2h) the patient may have a case of elevated anxiety due to the enclosure of the MRI equipment. In such cases,

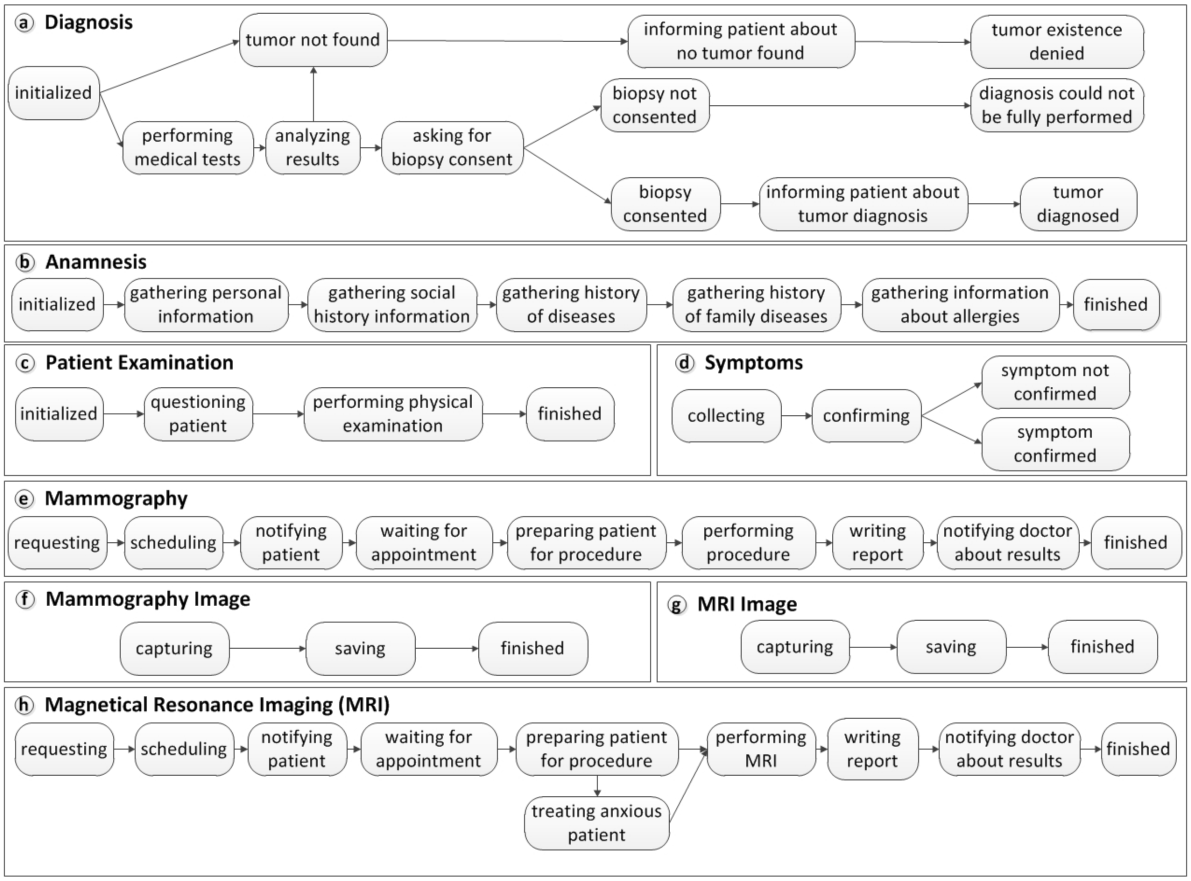

Figure 2. State diagrams for diagnosis, anamnesis, patient examination, symptom, mammography, and breast MRI examinations

the radiology specialist responsible for the examination must decide whether or not the patient shall be sedated before continuing with the procedure.

In the meanwhile, the doctor may request further examinations like, for example, another MRI examination or additional blood tests. Otherwise, if the existence of a tumor is confirmed, the doctor may want to biopsy this mass in order to confirm the malignancy of the tumor (see Figure 2a). In this case, however, the consent of the patient is required. The biopsy report is returned to the doctor who will then inform the patient about the malignancy status of the tumor. Finally, the diagnosis process is finished as positive, confirming the presence of a breast tumor.

Although this diagnosis scenario seems to be rather simple, it already indicates a number of requirements to be supported by the PrMS in order to be applicable to this healthcare environment:

Requirement R1 (Data and process integration): Our scenario is composed of many procedures, including an anamnesis, search for symptoms, mammography, and MRI. The product of each of these procedures is data related to the patient's diagnosis; e.g., the data obtained when interviewing the patient during the anamnesis. Respective data is not only important for keeping the patient's history updated or for registering all events for the purpose of auditing, they are also vital in respect to process execution. In particular, the milestones reached during process execution do less depend on the execution of specific activities, but more on the availability of certain data. For example, a mammography medical report may only be written after having captured and stored the respective images. In addition, user decisions, which are typically based on available data, are fundamental for process execution. For example, a radiology specialist may decide whether or not to sedate a patient during an MRI examination.

Requirement R2 (Intense use of forms): Like for other healthcare scenarios, the sketched procedure comprises a large number of medical forms to be filled by authorized medical staff (e.g., doctors, nurses, laboratory staff) with any information being relevant for patient treatment. For example, consider the information obtained when interviewing the patient during the anamnesis.

Requirement R3 (Interacting processes): The breast cancer diagnosis process needs to interact with other processes (e.g., MRI); i.e., there are points in the diagnosis process at which data from the MRI process is required. In particular, these processes have *synchronization points*, at which the further execution of a particular process instance depends on the data produced during the execution of one or several related process instances. Such synchronization points do not only correspond to one-to-one relationships. Additionally, the execution of a particular process instance may depend on the execution of multiple instances of another process type as well. Regarding our example, the execution of the diagnosis process depends on the results of various examinations.

Requirement R4 (Flexibility regarding process instantiation): Figure 1 indicates different cardinalities for the various procedures of the diagnosis process. These cardinalities indicate whether or not the execution of the respective procedures is mandatory and whether they may be executed more than once. Mandatory procedures (e.g., *Anamnesis*, *Patient Examination*) have cardinality *1*, while optional ones (e.g., *MRI*, *Mammography*, *Blood Analysis*, *Tumor Biopsy*) have cardinality *0...**. The latter indicates that there are no restrictions regarding the number of the instances of respective optional procedures. Depending on the concrete case of a patient, doctors may decide which of these optional procedures shall be ordered and which not. Finally, note that it is possible to order them more than once.

Requirement R5 (Authorized user access): To meet security constraints and ensure privacy, only authorized users are allowed to access patient data. In our scenario, for example, the secretary of the radiology department must not access information about the patient obtained during the anamnesis and she must not register symptoms of the patient. However, she may access the data related to the medical order or the scheduling of a mammography or an MRI examination. Besides, the permission to access data may depend on the progress of the process, which means that certain data shall be only accessible at certain points during process execution. For example, the medical report of a mammography may be accessible for the doctor who placed the order solely when the procedure has been completed and the report been approved by the radiologist.

Requirement R6 (Flexible data access): Any healthcare information system must provide the flexibility to its users to access and modify business data at arbitrary points during process execution. Amongst others, this is extremely important in order to be able to properly react to unexpected events [34]. For example, in case of an emergency, the system must allow the doctor to access examination data before the medical report becomes available.

III. Case Study: Modeling Healthcare Processes with PHILharmonicFlows

In the previous section, we introduced fundamental requirements for adequately supporting healthcare processes. In particular, the requirements imposed by healthcare processes can be easily linked to the major characteristics of *object-aware processes* [16], [34]:

1) *Object behavior:* This first characteristic covers the processing of individual object instances. More precisely, for each object type a separate process definition must be provided. At runtime, the latter is then used for coordinating the processing of individual object instances among different users. In addition, it must be specified in which order and by whom the attributes of a particular object instance shall be (mandatorily) written, and what valid attribute settings (i.e., attribute values) are. At runtime, the creation of an *object instance* is directly coupled with the creation of its corresponding *process instance*. In this context, it is important to ensure that mandatory data is provided during process execution; i.e., during the processing of the object instances. For this reason, object behavior should be defined in terms of *data conditions* rather than based on black-box activities.
2) *Object interactions:* The behavior of a particular object must be coordinated with the one of other related objects. The related object instances may be created or deleted at arbitrary point in time, emerging a *complex data structure*. The latter dynamically evolves during runtime, depending on the types and numbers of created object instances. Furthermore, individual object instances of the same type may be in different processing states at a certain point in time. More precisely, it must be possible to execute individual process instances (of which each corresponds to the processing of a particular object instance) in a loosely coupled manner; i.e., concurrently to each other and synchronizing their execution where needed, taking semantic object relations and cardinality constraints into account.
3) *Data-driven execution:* To proceed with the processing of a particular object instance, in a given state, certain attribute values are mandatorily required. Hence, object attribute values reflect the progress of the corresponding process instance. More precisely, the setting of certain object attribute values is enforced in order to progress with the process through the use of *mandatory activities*. However, if required data is already available (e.g., it may be optionally provided by authorized users before the respective mandatory activity becomes enabled), these activities will be automatically skipped when becoming activated. Furthermore, users shall be able to *re-execute* a particular activity, even if all mandatory object attributes have been already set. For this purpose, data-driven execution must be combined with *explicit user commitments*. Finally, the execution of a mandatory activity may depend on attribute values of related object instances. Thus, the coordination of multiple process instances should be supported in a data-driven way as well.
4) *Flexible activity execution:* For creating object instances and changing object attribute values, *form-*

based activities can be used. Respective user forms comprise *input fields* (e.g., text fields or check-boxes) for writing selected attributes and *data fields* for reading attributes of object instances. In this context, however, different users may prefer different work practices. Therefore, activities should be executable at different levels of granularity; e.g., it should be possible that an activity may relate to one or to multiple object process instances.

5) *Integrated access:* Authorized users should be able to access and manage process-related data objects at any point of time. More precisely, *permissions* for creating and deleting object instances, as well as for reading and writing their attributes need to be defined. However, attribute changes contradicting specified object behavior must be prevented. Which attributes may be written or read by a particular (form-based) activity not only depends on the user invoking this activity, but also on the progress of the corresponding process instance. While certain users must execute an activity mandatorily in the context of a particular object instance, others might be authorized to optionally execute this activity; i.e., a distinction is made between mandatory and optional permissions. Furthermore, for object-aware processes, the selection of actors usually not only depends on the activity to be performed, but also on the object instances processed by this activity. In this context, the relationships between users and object instances must be taken into account.

PHILharmonicFlows has recognized the need to offer flexible support for this kind of processes [13]. More precisely, it provides a comprehensive and well-grounded framework with components for modeling, executing, and monitoring object-aware processes (see Figure 3). To be able to define these processes in tight integration with data, PHILharmonicFlows enforces a well-defined modeling methodology that governs the definition of processes at different levels of granularity. In this context, PHILharmonicFlows differentiates between *micro processes* and *macro processes* capturing either the *behavior* of single objects or the *interactions* among multiple objects.

First of all, the behavior of a single object may be expressed in terms of a number of possible *states*. Furthermore, whether or not a particular state will be reached at certain time depends on the values of object attributes. The interactions among objects, in turn, are enabled when involved objects reach certain states. Hence, object states serve as interface between micro and macro processes as well.

Data Model (Figure 3a): As prerequisite for providing integrated access to data and processes, a *data model* must be provided. The latter must comprise object types (including object attributes) and object type relationships (including cardinalities) [15]. For example, data model depicted in Figure 1 gives an overview of the object types relevant in the context of our diagnosis process; i.e., there is one object type for each of the phases of the diagnosis process. Furthermore, Figure 6 illustrates the attributes of object type *Mammography*.

Micro Process (Figure 3b): In PHILharmonicFlows, for each *object type* of the data model, a particular *micro process type* must be defined. At runtime, object instances of the same and of different object types can be created at different points in time. In this context, the creation of a new object instance is directly coupled with the one of a corresponding micro process instance. In general, a *micro process type* expresses the behavior of the respective object type (e.g., *Mammography*); i.e., it coordinates the processing of an object among different user roles (e.g., nurse or doctor) and specifies what valid attribute settings are. Additionally, the cardinality of an object type in relation to other object types defines restrictions regarding the instantiation of micro process types and object types respectively. For example, in our case the cardinality of object type *Anamnesis* in relation to object type *Diagnosis* is *1*; i.e., for each *Diagnosis* instance, there must be exactly one instance of object type *Anamnesis*. By contrast, it is not mandatory that there exists an instance of object type *Mammography* for each *Diagnosis* instance. However, it is up to the respective doctor to create several instances of this examination as long as cardinality constraints are met. To meet requirement R4 (see Section II), PHILharmonicFlows provides the flexibility to handle a varying number of instances of interrelated examinations. More precisely, it is up to the doctor to decide when and which examinations are required. We will show later, that so-called macro processes enable a coordinated execution of dependent micro process instances.

Each micro process type comprises a number of *micro step types*, which describe elementary actions for reading and writing object attribute values. More precisely, each micro step type is associated with one particular attribute of the respective object type. In turn, micro step types may be connected with each other using *micro transition types*. To coordinate the processing of individual object instances among different users, several micro step types can be grouped into *state types*. The latter are then associated with one or more user roles responsible for assigning values to the required attributes. At runtime, a micro step can be reached if for the corresponding attribute a value is set. In turn, a state may only be left if, for all attributes associated with its micro steps of this state, respective values are set. Whether or not the subsequent state of the micro process is then immediately activated may depend on user decisions. In this context, micro transition types, which connect micro step types belonging to different state types, are either categorized as *implicit* or *explicit*. Regarding *implicit micro transitions*, the target state will be automatically activated as soon as all attribute values required by the previous state

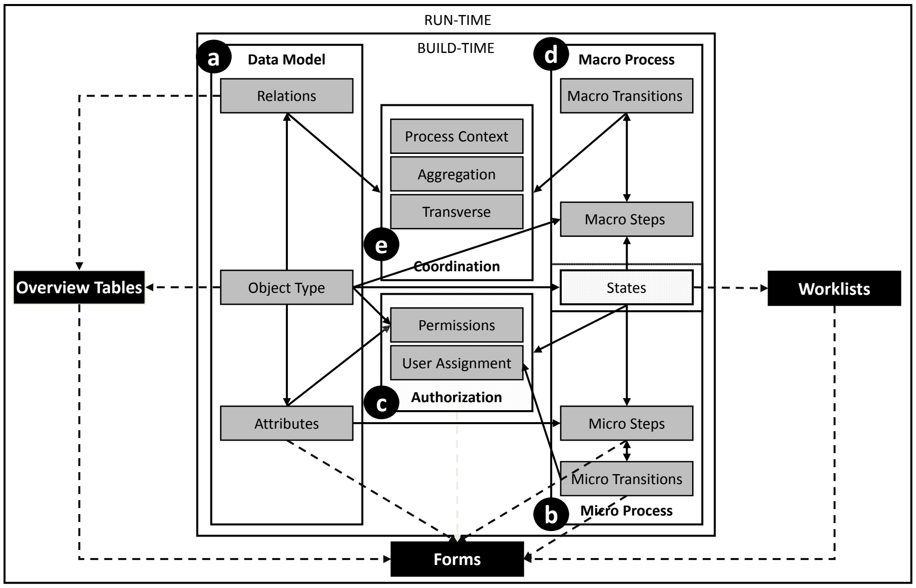

Figure 3. Overview of the PHILharmonicFlows Framework

are available. In turn, *explicit micro transitions* additionally require a user commitment; i.e., users may decide when the subsequent state shall be activated. This way, users still may change attributes even if all attribute values required to leave the state have been already set.

An example of a micro process type is depicted in Figure 5. Object type *Mammography* and its respective micro process type are instantiated when the doctor requests a new *mammography* examination. For *requesting* a *mammography*, the (authorized) user must set the *request date*; i.e., to complete micro step *request_date* a value needs to be assigned to the corresponding attribute. In our example, the micro transition type between state types *requesting* and *scheduling* is explicit (dotted line). This ensures that the doctor may still review the examination request before sending it to the secretary of the radiology department. In turn, in state *scheduling*, the *Secretary* must fill attributes *scheduled_date*, *scheduled_doctor*, and *scheduled_room*. She further must decide when to notify the patient about the scheduled appointment; i.e., the subsequent state *notifying patient* will not be activated before explicitly confirmed by the *Secretary*.

In turn, a user decision is required if a micro step type has more than one outgoing micro transition types. For this purpose, each micro step type may comprise a set of corresponding *value step types*. Each value step type represents a particular constraint to the micro step type; i.e., specific value constraints to the attribute associated to the micro step type. In our scenario, the responsible user must decide which of the subsequent states shall be activated. Figure 4 shows a fragment of the *MRI* micro process type; here, the radiology specialist must decide in case of a patient's anxiety scenario (state type *treating anxious patient*) whether or not to sedate the patient (attribute *sedation*). If the doctor decides not to sedate the patient (value step type *no*), at runtime the next activated micro step will be *reason_no_sedation*; i.e., the doctor must provide a reason for his decision. If he decides that sedation is required (value step type *yes*), micro step types *sedative* and *sedation_time* will be activated at runtime.

User authorization (Figure 3c): To coordinate the processing of an object, user roles have to be assigned to the different states of its micro process type. Based on these role assignments, a corresponding *authorization table* is automatically generated for each object type. More precisely, PHILharmonicFlows grants different permissions for reading and writing attribute values as well as for creating and deleting object instances to different user roles. In this context, the different states are considered as well; i.e., users may have different permissions in different states allowing for a fine-grained access control policy. The right to write an attribute may either be *mandatory* or *optional*. When initially generating the authorization table, the user role associated to a state type automatically receives mandatory write authorization for all attributes related to any micro step type of the respective state type. Optional data access may be additionally granted to user roles not associated with the state type. This way, users currently not involved in process execution may access process relevant data if required.

Based on the authorization table of a micro process type, PHILharmonicFlows automatically generates user forms. Which input fields are displayed to the respective user depends on the permissions he has in the currently activated state. If he only has the permission to read a particular attribute in a certain state, the respective form field will

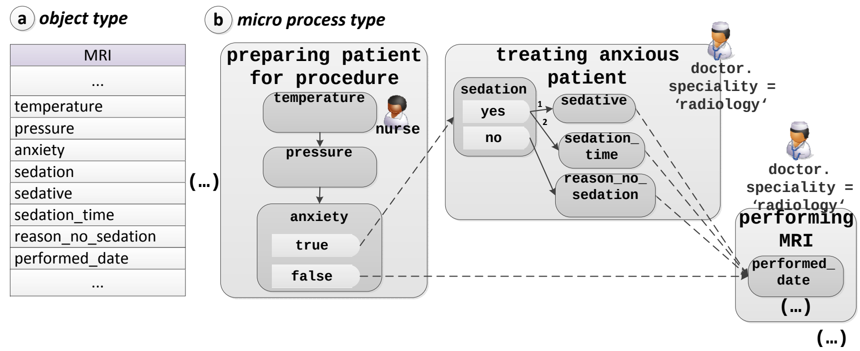

Figure 4. Partial view of the MRI micro process type

not be editable and marked as read-only. A mandatory or optional attribute, in turn, is associated with an editable field. In particular, mandatory fields are highlighted in the respective user form.

The concepts provided by PHILharmonicFlows to enable proper authorization for micro process execution are exemplified in Figure 6. It illustrates the authorization table of micro process type *Mammography*. In this example, state type *requesting* has only one mandatory attribute *request_date* (marked as *MW* in the authorization table). This attribute must be set by the doctor requesting the examination. In addition, attributes *request_desired_date* and *request_observations* are optional (marked as *OW*); i.e., they may be written by the doctor in the respective state. However, this state may be also left as soon as mandatory attribute *request_date* is written. In state *scheduling*, the same doctor may change the values of the aforementioned optional attributes as opposed to the secretary of the radiology department. The latter may only read the values of these attributes (marked as *R*). However, she is allowed to write attributes *scheduled_date*, *scheduled_doctor*, and *scheduled_room*, which, in turn, may only be read by the doctor.

Macro Process (Figure 3d): Whether or not subsequent object states can be reached may not only depend on object attributes, but also on the states of other micro process instances. At runtime, for each object instance, a corresponding micro process instance exists. As a consequence, a healthcare scenario may comprise dozens or hundreds of micro process instances. Taking their various interdependencies into account, we obtain a complex, dynamically evolving *process structure*. In order to enable a proper interaction between these micro process instances, a *coordination mechanism* is required to realize the interaction points of the micro processes involved. For this purpose, PHILharmonicFlows automatically derives a state-based (i.e., abstracted) view for each micro process type. This view is then used for modeling macro process types.

A *macro process type* refers to parts of the data structure (i.e., to particular object types) and consists of both *macro step types* and *macro transitions types* connecting the former. As opposed to traditional process modeling approaches, which define process steps in terms of black-box activities, a macro step type always refers to an object type with a corresponding state type. The macro process type depicted in Figure 8 illustrates this. The process begins with the instantiation of object type *Diagnosis*, which triggers the creation of a corresponding micro process instance. Then, object type *Anamnesis* is instantiated (i.e., the responsible doctor receives a corresponding item in his worklist) and its micro process instance is created. During *Patient Examination*, the *symptoms* may be collected, which are confirmed after the *physical examination* has taken place. If the symptoms are not confirmed, the diagnosis will be finished as negative, indicating that no tumor was found. Otherwise, the diagnosis process continues with requesting imaging encounters. It is noteworthy that for one primary examination, more than one symptom may be collected.

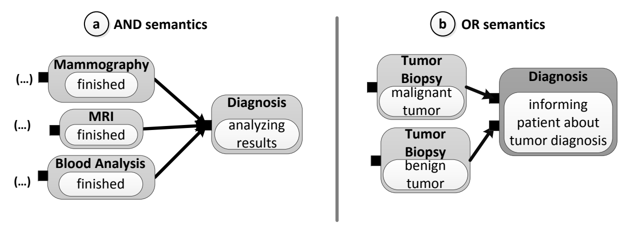

Figure 7. Example of macro input types representing different semantics

Since the activation of a particular state may depend on instances of different micro process types, macro input types are assigned to macro step types. Such input types can then be associated with several macro transitions. At runtime, a macro step is enabled if at least one of its macro inputs becomes activated. In turn, a macro input is enabled if all incoming macro transitions are triggered. In PHILharmonicFlows, it is possible to differentiate between AND and OR semantics. For representing the semantics of

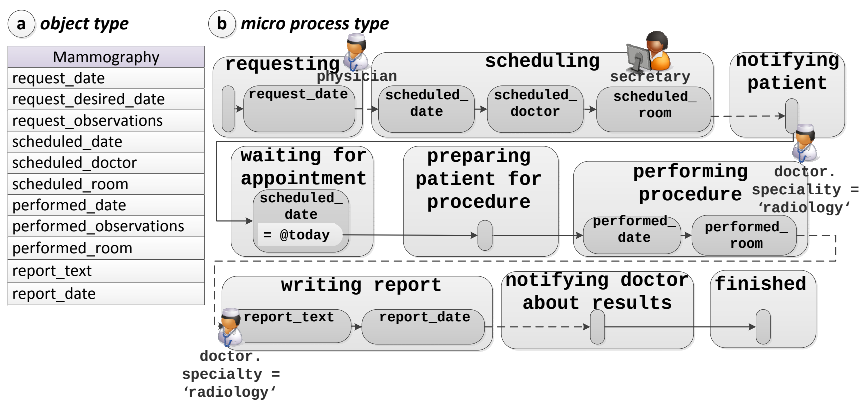

Figure 5. Mammography micro process type

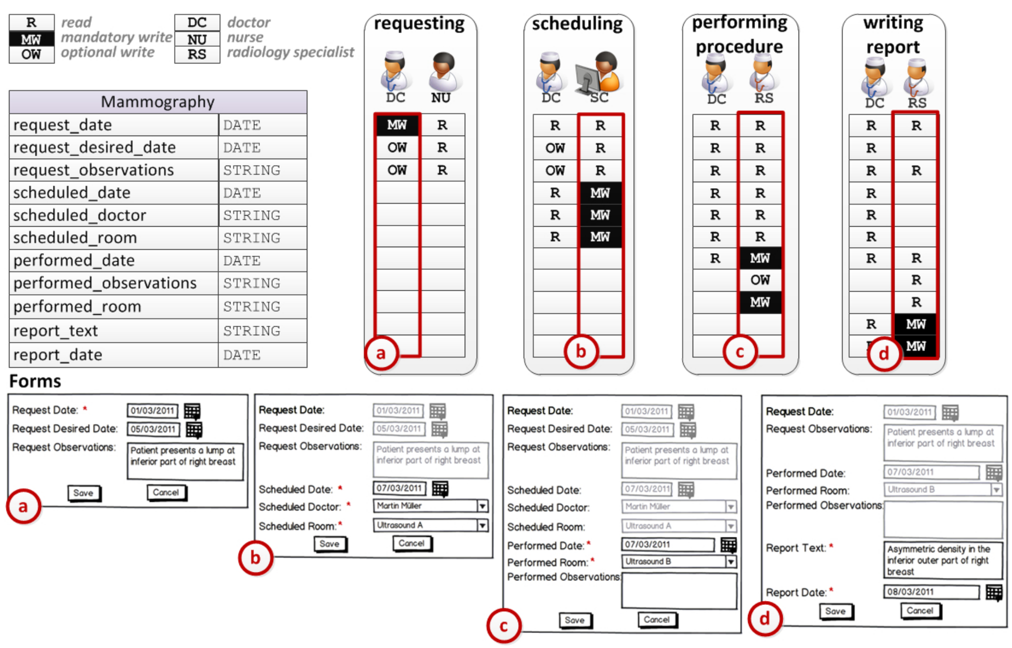

Figure 6. Authorization table and forms of the Mammography micro process type

an AND-join in the macro process, several incoming macro transitions target a single macro input type (see Figure 7a). For representing the OR-join semantics, a macro step type must have more than one macro input type associated (see Figure 7b). In this case, to enable the targeting macro step at least one of its macro inputs must be activated.

Coordination (Figure 3e): To take the dynamically evolving number of object instances as well as the asynchronous execution of corresponding micro process instances into account, for each macro transition a corresponding *coordination component* needs to be defined. For this purpose, PHILharmonicFlows takes the relationship between the object type of the source macro step type and the one of the target macro step type into account, making our approach fundamentally different compared to conventional PrMS.

To enable this, the framework automatically structures the data model into different *data levels*. All object types not referring to any other object type are placed on the top level (Level #1). Generally, any other object type is always assigned to a lower data level as the object types it references. As illustrated in Figure 9, in our case study, object type *Diagnosis* is at the top level, while all examinations are placed at a lower level. For example, images refer to respective examinations (i.e., imaging encounters). Hence, they are placed at Level #3. In this paper, we do not discuss self-references and cyclic relations, but they are considered by PHILharmonicFlows framework [17].

By organizing the object types of the data model into different levels, PHILharmonicFlows automatically categorizes macro transitions either as *top-down* or as *bottom-up* (see

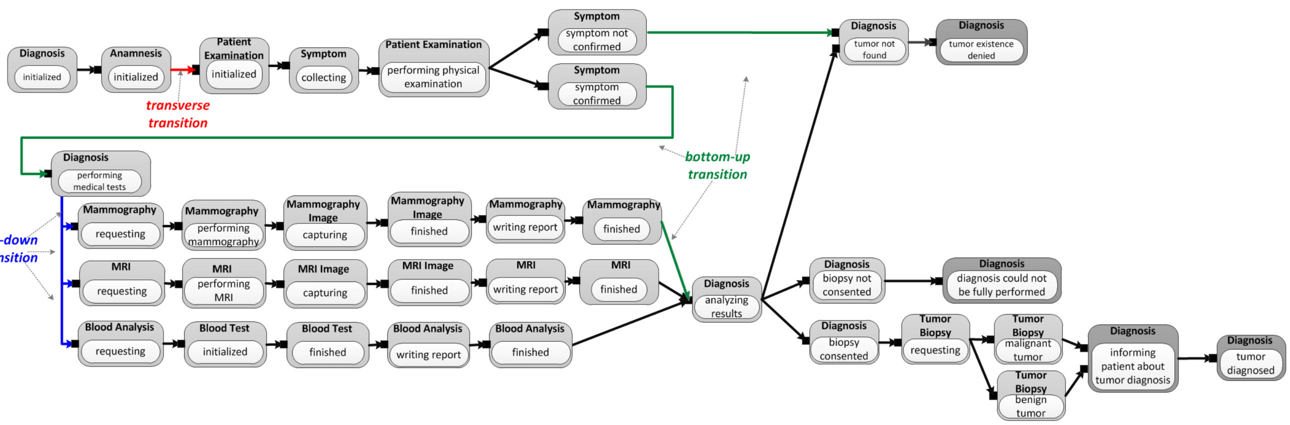

Figure 8. A macro process type coordinating the interactions among the different micro process types

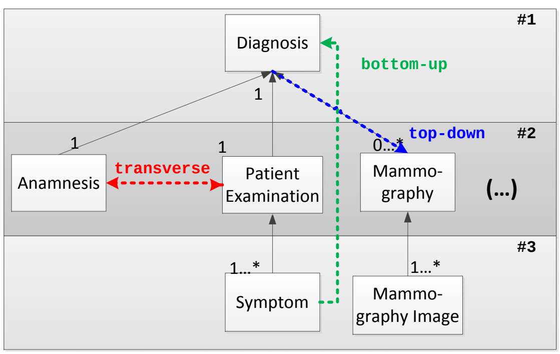

Figure 9. Different kinds of relationships between object types

Figure 9). Furthermore, if the object types of the source and sink macro state refer to a common higher-level object type, the macro transition is categorized as *transverse*. For macro transitions types connecting macro step types, which refer to the same object type, no coordination component is needed. These transitions are denoted as *self-transitions*. For all other ones, the required coordination component depends on the type of the respective macro transition. A *top-down transition* characterizes the interaction from an upper-level object type to a lower-level one. Here, the execution of a varying number of micro process instances depends on one higher-level micro process instance. In this context, a so-called *process context type* must be assigned to the respective macro transition type. Due to lack of space, we omit further details. We do also not discuss transverse macro transition types. In turn, a *bottom-up transition* characterizes an interaction from a lower-level object type to an upper-level one. In this case, the execution of a higher-level micro process instance depends on the one of several lower-level micro process instances of same type. For this reason, each bottom-up transition requires an *aggregation component* for co-ordination. For this purpose, PHILharmonicFlows provides *counters* managing the total number of lower-level micro process instances and the number of micro process instances for which the state corresponding to the source macro step type is currently activated. To enable asynchronous micro process execution, additional counters for reflecting the number of micro process instances currently being before or after the respective state or being skipped are provided. These counters can be used for defining aggregation conditions, which establish constraints regarding the lower-level micro process instances in order to activate a particular state of a higher-level micro process instance. As illustrated in Figure 10, the *Diagnosis* process activates state *tumor not found* if all the micro process instances related to instances of object type *Symptom* reach state *symptom not confirmed*. The aggregation condition for this case (`#IN=#ALL`) indicates this constraint. This example illustrates how such counters work. As illustrated in Figure 10, there are three micro process instances of *Symptom* related to one micro process instance of *Diagnosis*. In this example, the counter indicates that two of the running instances of *symptom* have already reached state *symptom not confirmed* (`#IN=2`), while one instance has not yet reached this state (`#BEFORE=1`). When all three instances reach this state (i.e., the condition defined in the aggregation is met), state *tumor not found* is activated for the respective *Diagnosis* instance.

As a *proof-of-concept*, we developed a prototype that implements the concepts of the PHILharmonicFlows framework, enabling the modeling and enactment of object-aware processes. Figure 11 shows a screenshot of the data model from our healthcare scenario being modeled in the tool. Figure 12 shows the micro process type regarding object type *Mammography*. In this screenshot, the upper part of the screen presents the object types with their relations and lets the user select for which object type he wants to model the micro process type. The lower part of the screen lets the user model the corresponding micro process type.

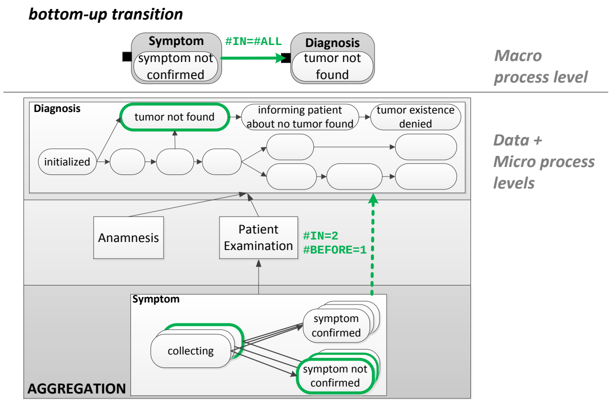

Figure 10. Aggregation example

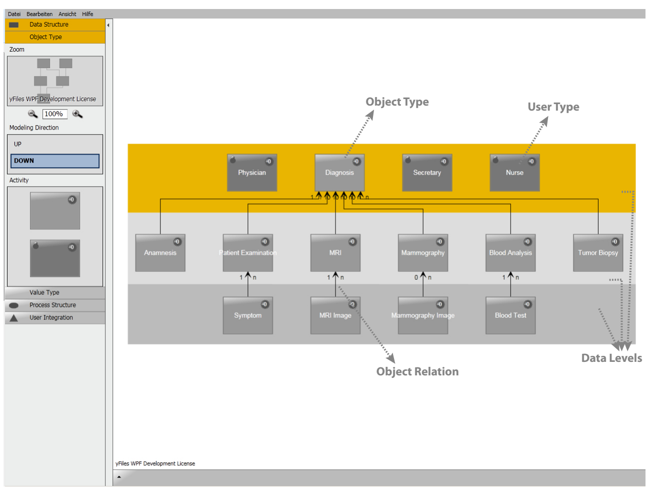

Figure 11. Screenshot of a Data Model

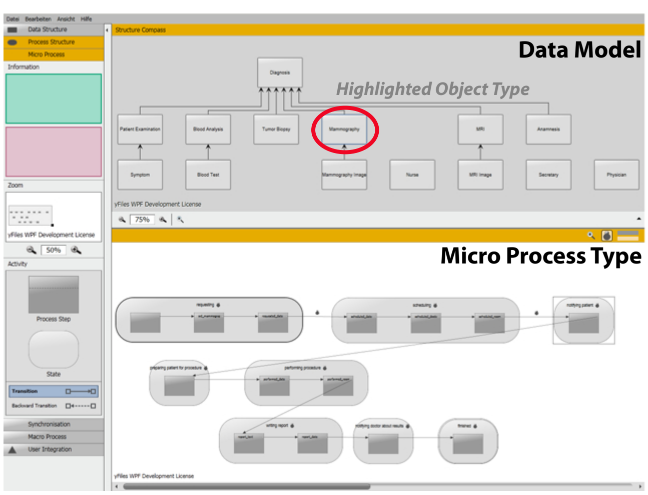

Figure 12. Screenshot of a Micro Process Type

IV. RUNTIME ENVIRONMENT OF PHILHARMONICFLOWS

The *runtime environment* of PHILharmonicFlows provides data- as well as process-oriented views to end-users. In particular, authorized users may invoke activities for accessing data at any point in time as well as activities needed in order to proceed with the execution of micro process instances. In this context, the operational semantics defined by PHILharmonicFlows enables sound process execution. Additionally, it provides the basis for automatically generating end-user components of the runtime environment (e.g., tables giving an aggregated overview of all processed object instances, user worklists, and form-based activities).

At runtime, the execution of individual micro process instances is based on well-defined *markings* [15]. More precisely, these markings indicate which components of a micro process instance are activated at a certain point of time; i.e., the *processing state* of a micro process instance is defined by the current marking of its states, micro steps, and micro transitions. Based on these markings (see Figure 13), it becomes possible to not only specify which components are activated at a certain point in time, but also the components that may be activated later on and the ones that cannot be activated anymore (since they belong to a *skipped execution path*).

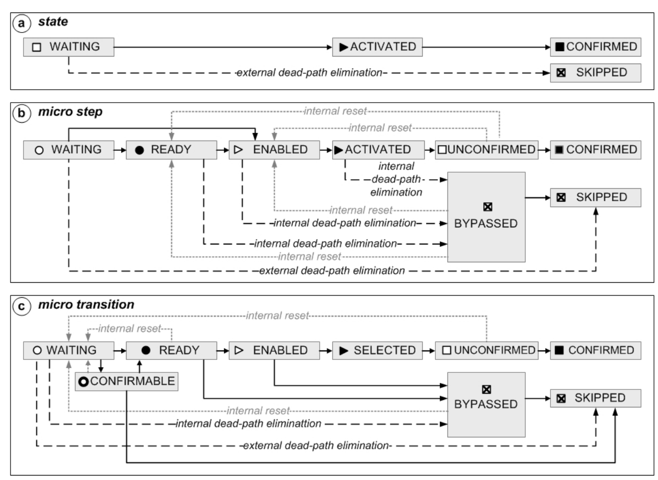

Figure 13. Operational semantics for states, micro steps, and micro transitions

To illustrate how a micro process instance is created, executed, and terminated, we refer to our example. In particular, to illustrate how the operational semantics of PHILharmonicFlows looks like, we refer to the micro process type related to object type *MRI* (see Figure 4).

Creation of a Micro Process Instance: When creating an instance of object type *MRI*, a corresponding micro process instance is automatically generated and initialized as well. According to Figure 14, the start micro step is then marked as CONFIRMED and the state to which it belongs (i.e., state *requesting*) is marked as ACTIVATED. In turn, all other states are initially set to WAITING. Further, the outgoing micro transition of the start step is marked as READY, while all other micro transitions are initially marked as WAITING. In our example, this micro transition corresponds to the incoming micro transition of micro step *request_date*, which is marked as ENABLED. All other micro steps not belonging to the state *requesting* are marked as WAITING.

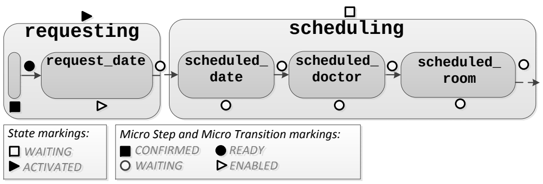

Figure 14. Initiating an instance of a micro process

Execution of a Micro Process Instance: Consider Figure 15a. When state *treating anxious patient* is reached, it is marked as ACTIVATED. The first micro step (i.e., *sedation*) is then marked as ENABLED. This means that a value must be provided for the corresponding attribute. In particular, this micro step refers to a decision to be made by the medical doctor on whether or not sedate the patient. Note that the execution path of the micro process depends on this decision; i.e., if the doctor chooses to sedate the patient, he must fill the values on the form about the *sedative* used and the sedation time chosen. In the micro process, this decision point is represented as a value-specific micro step. Thereby, not only the micro step, but its value steps *yes* and *no* are marked as ENABLED. If the user sets a value corresponding to one of these value steps (see Figure 15b), the selected value step is set to ACTIVATED as well as the corresponding micro step. However, if the user sets a value that does not correspond to any value step type (see Figure 15c), the micro step is marked as BLOCKED. In turn, this blocks the execution of the micro process instance as whole. The latter is indicated to the user by highlighting the input field in the form with an exclamation point. To unblock a blocked micro process execution, the user must set a valid value for the attribute referred by the BLOCKED micro step.

When a valid value is set for the attribute referred by micro step *sedation* (i.e., this micro step is marked as ACTIVATED), the incoming micro transition of this micro step changes its marking to ACTIVATED. In turn, this enables micro step *sedation* to change its marking from ACTIVATED to UNCONFIRMED. However, the corresponding value steps of this micro step must be handled as well. In our example (see Figure 16), the value step marked as ACTIVATED (i.e., *yes*) changes its marking to UNCONFIRMED, while the one still marked as ENABLED is now marked as BYPASSED.

After setting a value for the attribute corresponding to micro step *sedation*, micro steps *sedative* and *sedation_time* become marked as ENABLED (see Figure16a). In the user form, this is visualized by highlighting both input fields, which means that the user must provide a value for at least one of the two attributes; i.e., if for one of these attributes (e.g., *sedation_time*) a value is set, the corresponding micro step will be marked as ACTIVATED (see Figure 16b). Additionally, the incoming micro transition is marked as ENABLED. Since no value for attribute *sedative* is provided, the priorities of the micro transitions (i.e., signalized on the respective micro transitions outgoing from micro step *sedation*) are not relevant for this case. Thereby, the incoming micro transition may be marked as ACTIVATED as well (see Figure 16c). In order to omit the alternative execution path, in this case an *internal dead path elimination* is performed (see Figure 16d). Based on it, all micro transitions and steps belonging to the non-selected path are marked as BYPASSED; i.e., a micro step is marked as BYPASSED if all incoming micro transitions are marked as BYPASSED.

As long as the change of state *treating anxious patient* has not been confirmed (i.e., the transition to the next state is not confirmed by the user), the doctor still may set a value for attribute *sedation*. To accomplish this, an *internal reset* of the currently activated state is performed (see Figure 16e). Normally, the micro steps and transitions will be reset if an attribute value corresponding to a micro step marked as UNCONFIRMED or BYPASSED is changed. However, if values for both attributes *sedation* and *sedation_time* are assigned (see Figure 16f), more than one micro transition becomes ENABLED. Since only one micro step (and one micro state) can be reached, it must be ensured that only one of the execution paths is in fact executed (i.e., only one of the micro transitions is fired). For this purpose, only the micro transition with the highest priority is marked as ACTIVATED (see Figure 16g); i.e., only the one that reaches micro step *sedation* is ACTIVATED. The other micro transition is marked as BYPASSED using an internal dead path elimination. If a state is marked as CONFIRMED afterwards, micro steps and transitions marked as BYPASSED are finally marked as SKIPPED.

When marking a micro step as UNCONFIRMED, outgoing micro transitions are either marked as READY or CONFIRMABLE. More precisely, external micro transitions, for which an explicit user commitment is required, are marked as CONFIRMABLE. Consequently, a mandatory activity enabling this commitment is automatically assigned to the worklist of the responsible user. Regarding our example, after deciding to sedate the patient and filling out in the form which sedative was given to the patient, the outgoing explicit micro transition is marked as CONFIRMABLE. In turn, this requires for the assigned user (e.g., radiologist) to confirm the values of the corresponding attributes. In this case, the explicit micro transition then changes its marking to READY. Opposed to this, implicit micro transitions are immediately marked as READY. If an external

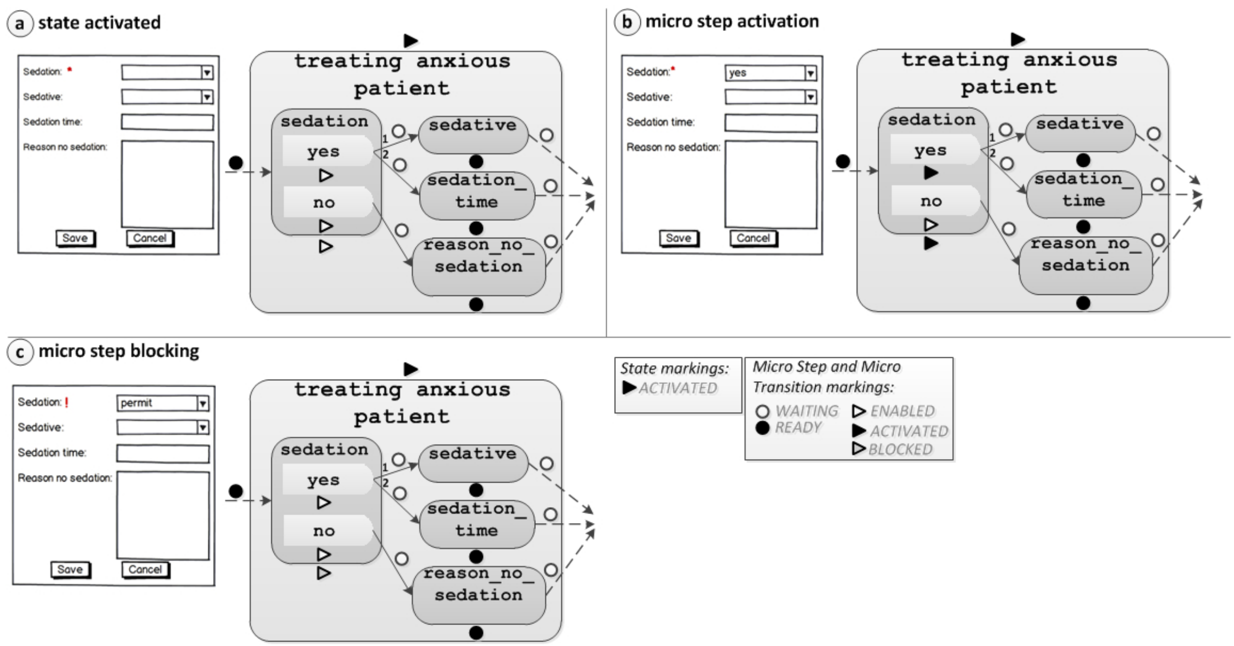

Figure 15. Execution markings for value-specific micro step

micro transition is marked as READY, the currently activated state will be marked as CONFIRMED. Additionally, all corresponding micro steps as well as internal micro transitions (currently marked as UNCONFIRMED) are remarked as CONFIRMED. Following this, the subsequent state (i.e., state *performing MRI* in our example) is marked as ACTIVATED and its micro steps as READY. The target micro step of the external transition (i.e., in our example *performed_date*) is marked as ENABLED. For this micro step, a value must be set for the corresponding attribute. Moreover, PHILharmonicFlows performs an *external dead-path elimination* in order to mark micro steps, micro transitions, and states, which can no longer be activated, as SKIPPED.

Despite any predefined sequence of micro steps, users may freely choose their preferred execution order; i.e., the order in which attribute values are set within a processed form does not have to coincide to the one of the corresponding micro steps. Particularly, at runtime a micro step may be completed as soon as a value is assigned to the corresponding object attribute.

Termination of a Micro Process Instance: The execution of a micro process instance terminates when a state containing an *end micro step* becomes marked as SELECTED. Using the introduced internal and external dead-path elimination, all other states, micro steps and micro transitions are then either marked as CONFIRMED or SKIPPED.

V. Discussion

In Section II, we have introduced a realistic healthcare scenario, which we modeled in Section III using the PHILharmonicFlows framework. In Section IV, we presented the operational semantics of the execution environment of PHILharmonicFlows framework to indicate how data-driven process execution works in PHILharmonicFlows. In this section, we discuss how the requirements posed by the healthcare scenario are met.

Requirement R1 (Data and process integration): The well-defined modeling methodology provided by PHILharmonicFlows ensures that each procedure (e.g., anamnesis, physical examination, or mammography) is modeled from a data-oriented perspective (i.e., by using object types) as well as from a process-oriented one (i.e., by using micro process types). Hence, all the data produced by respective procedures is stored and managed without need to access external databases during the execution of activities. In particular, this enables users to access and manage process-related data (i.e., object instances) at any point in time (assuming proper authorization) and not only when working on assigned mandatory activities.

Requirement R2 (Intense use of forms): Based on authorization tables, PHILharmonicFlows automatically generates user forms during runtime. For this purpose, it takes the currently activated state of a micro process instance as well as the user and his data access permissions into account. Each user form comprises fields corresponding to read and write permissions for respective object attributes. Moreover, in PHILharmonicFlows, object instances and activities are

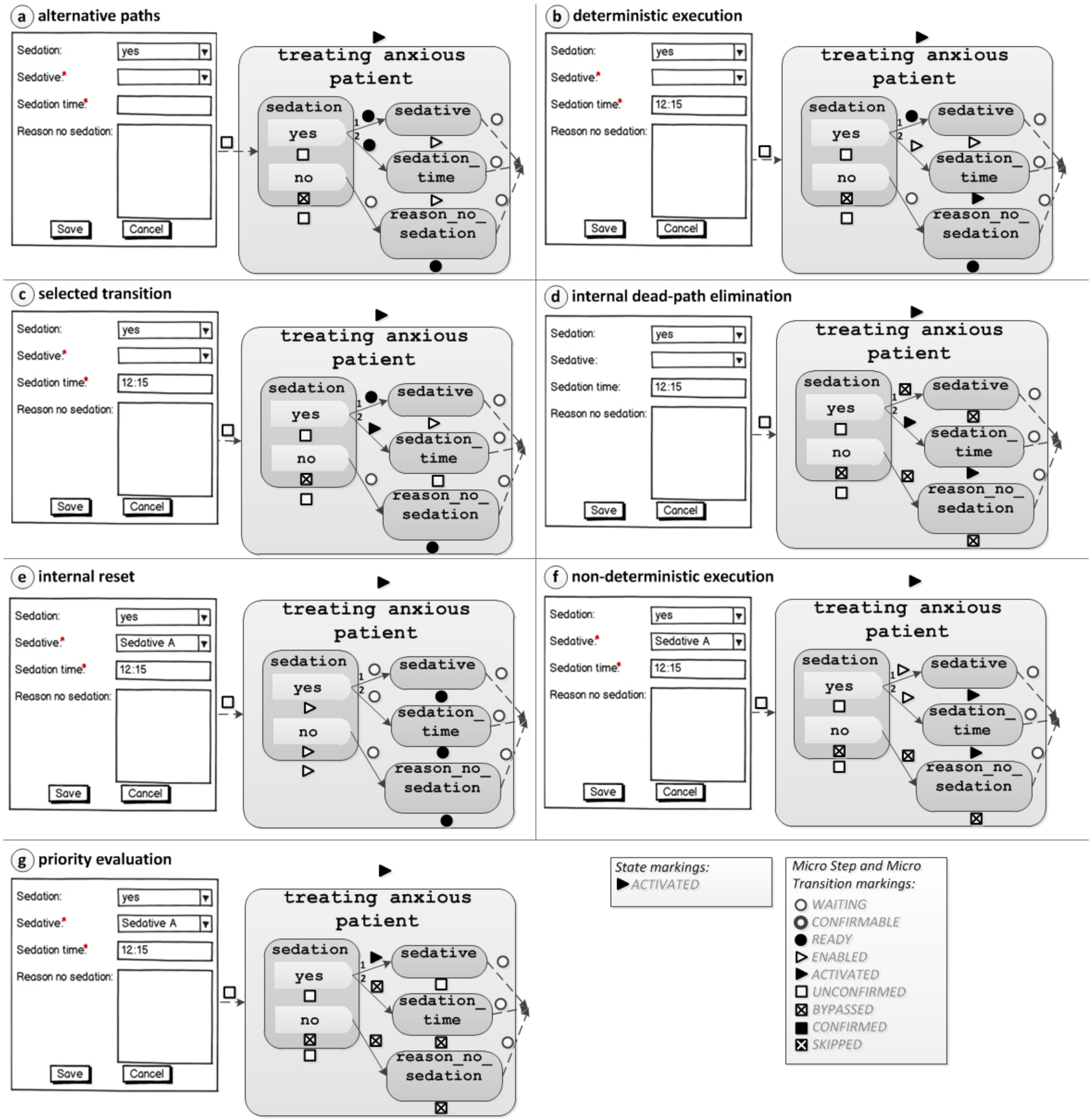

Figure 16. Execution of state *treating anxious patient*

not strictly linked with each other. For example, it is also possible to execute a particular form in relation to a collection of object instances of the same object type. In this scenario, entered attribute values are assigned to all selected object instances in one go. In addition, a user may invoke additional object instances of different (related) types. When generating corresponding forms, the currently activated states of these instances as well as the permissions assigned to the respective user in these states are taken into account as well.

Requirement R3 (Interacting processes): As discussed in Section III, this requirement is met by PHILharmonicFlows by the support of macro processes that coordinate the execution of related micro process instances. Using macro step types it becomes possible to define the required synchronization points. At runtime, it is possible to execute the individual micro process instances asynchronously to each other as well as asynchronously to the instances of other micro processes. In addition, it is possible to instantiate them at different points in time. Consequently, the resulting process structure comprises a varying number of interrelated micro process instances being in different execution states. For this purpose, each macro transition type can be specialized using different coordination components. The choice of the latter depends on the relation existing between the corresponding object types within the overall data structure. This way, not only the asynchronous execution, but also the different cardinalities between different sets of dependent micro process instances are considered.

Requirement R4 (Flexibility regarding process instantiation): Using PHILharmonicFlows it becomes possible to consider a dynamically evolving number of inter-related micro process instances. Taking the defined cardinality constraints into account, users may autonomously decide which and how many micro process instances shall be created. If the minimum cardinality is not met, PHILharmonicFlows automatically assigns a corresponding mandatory activity to the worklists of responsible users asking for the creation of new instances of the respective micro process type. Opposed to this, if the maximum cardinality is reached, PHILharmonicFlows prohibits the creation of additional micro process instances. By specifying the cardinality of each object type, it is possible to define which of them must be instantiated (cardinality *1*) and which ones are optional (cardinality *0...*). This enables qualified staff members to request examinations at arbitrary points during the diagnosis process and to react on unexpected events (e.g., drug prescription in case of intense fever).

Requirement R5 (Authorized user access): The *authorization table* enables the level of data privacy required by healthcare processes. For each micro process type, it is possible to define which attributes may be written or read by a particular user role in the currently activated micro process state. PHILharmonicFlows ensures that no data is written or read by unauthorized users. Since each state type has an associated user role, the authorization table automatically ensures that this role owns the required data permissions; i.e., the role has mandatory write permission regarding the attributes associated with the micro step types in the state type.

Requirement R6 (Flexible data access): As opposed to traditional PrMS, PHILharmonicFlows presents two different views to the end-users: a process-oriented view (i.e., worklists) and a data-oriented one (i.e., overview tables listing selected object instances together with their attribute values). The latter enables the access to data at any point in time by authorized users. Thus, data access does not depend on the activation of an upcoming activity; i.e., the data can be accessed beyond the context of a particular mandatory activity.

VI. Related Work

Healthcare is a challenging domain for process support, since it comprises structured and unstructured processes. The enactment of such processes requires a high degree of flexibility [19], [20], [34]. In particular, due to their tighter integration of data and processes, data-centric approaches support process flexibility.

One prominent approach is the Case Handling paradigm [4]. It aims at data and process integration by managing the data inside the "case" scope. It also enables form-based activities. If further targets at increasing the degree of flexibility by providing access to information outside the scope of an activity. However, data is provided in terms of atomic elements and may be completely read by any user involved in the case; i.e., no fine-grained access control can be realized. Furthermore, there is no full support regarding interactions among different cases. In [4], the authors mention case studies realized in the healthcare area. However, they focus on administrative processes (e.g., patient registration and administrative processing).

In COREPRO [23], [24], the process structures are generated accordingly to the data structure and the interaction among different process instances is enabled. However, it does not offer the same execution flexibility as PHILharmonicFlows and Case Handling, since the process execution is not directly coupled with the activity of data. The Product-driven Workflow Design approach [39] targets at the precise derivation of a process execution sequence according to the product structure following three design criteria (quality, costs, and time). However, it does not aim at flexible execution of processes driven by data. The Proclets approach [2], [22] enables interactions among process fragments. However, data is managed outside the scope of the process management system and can only be accessed when an activity is being executed.

The document-based workflow approach α-flow [27], [28] incorporates workflow semantics into the documents involved. Such documents are edited and viewed taking the separation of responsibilities and inter-institutional collaboration into account.

For more details about existing data-aware process management approaches, we refer interested readers to [16].

VII. Summary & Outlook

We analyzed a breast cancer diagnosis scenario. By modeling it with PHILharmonicFlows we studied how effectively this framework covers the semantics of healthcare processes. First, we elicited a list of requirements not adequately met by traditional process management systems in this context. Following this, we modeled the considered scenario by using components of the PHILharmonicFlows framework and we explained how the runtime environment of PHILharmonicFlows works. Finally, we discussed the effectiveness of this approach and showed how it covers the requirements of healthcare processes.

Healthcare processes are knowledge-intensive and need a high level of flexibility in order to allow qualified staff members to flexibly react to unexpected events. Compared to other data-oriented approaches, in a very effective way, PHILharmonicFlows covers the requirements posed by healthcare processes. By tightly integrating data and processes, our approach enables an environment in which data drives process execution and coordination. In turn, this allows for a higher degree of flexibility enabling data access outside the context of black-box activities.

Like in activity-centered approaches [32], [34], schema evolution is a complex and error-prone task to be accomplished for object-aware processes as well. Therefore, we are working on an extension of the framework to enable controlled schema evolution; i.e., a mechanism to manage and apply changes to object-aware process models as well as their running instances. Since all components of the framework are tightly integrated, the mechanism must take into account that each change (e.g., deleting an object attribute) might affect other components (e.g., a micro step type in a micro process type that must be deleted when the corresponding object attribute is deleted). Thus, the mechanism must be able to detect such interdependencies between components and to assist the user to apply the changes in the process without affecting process correctness. A preliminary work defining the challenges existing in this context is presented in [6].

Concerning healthcare processes, another potential future work is the integration of the PHILharmonicFlows framework with medical information systems. One particular challenge is dealing with complex attribute types (e.g., image data) and making the processes compliant with the DICOM [40] standard.

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Using Expert and Empirical Knowledge for Context-aware Recommendation of Visualization Components

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***Abstract*—Although many valuable visualizations have been developed to gain insights from large datasets, selecting an appropriate visualization for a specific dataset and goal remains challenging for non-experts. In this article, we propose a novel approach for knowledge-assisted, context-aware visualization recommendation. Therefore, both semantic web data and visualization components are annotated with formalized visualization knowledge from an ontology. We present a recommendation algorithm that leverages those annotations to provide visualization components that support the users' data and task. Since new visualization knowledge is generated while working with a visual analytics system due to users insights, particularly a component is suitable or not for a selected dataset, we track these findings by means of users explicit and implicit ratings. This empirical visualization knowledge is reused in subsequent recommendations to better adapt the ranking of components to users needs. We successfully proved the practicability of our approach by integrating it into a mashup-based research prototypes called VizBoard.**

***Keywords*-visualization, recommendation, ontology, knowledge, collaborative filtering, mashup**

I. Introduction

Through this article we detail, update, and extend our approach for a context-aware recommendation of visualization components [1] presented at the eKNOW 2012[1].

Visualization is a powerful way of gaining insight into large datasets. Therefore, a myriad of visualizations have been developed in recent decades. To bridge the gap between data and an appropriate visual representation, models like the visualization pipeline [2] have been established in numerous tools. As one part of this process, the mapping of data to a graphic representation is critical because only small subsets of existing visualization techniques are expressive and effective for the selected data in a specific context. Generally, domain-specific data can be visualized either using tools which were developed specifically for that domain and use case, or using generic visualization systems. The development of the former requires extensive knowledge by visualization and domain experts, and is usually costly and time-consuming. Thus, in many cases generic visualization

[1] http://www.iaria.org/conferences2012/eKNOW12.html

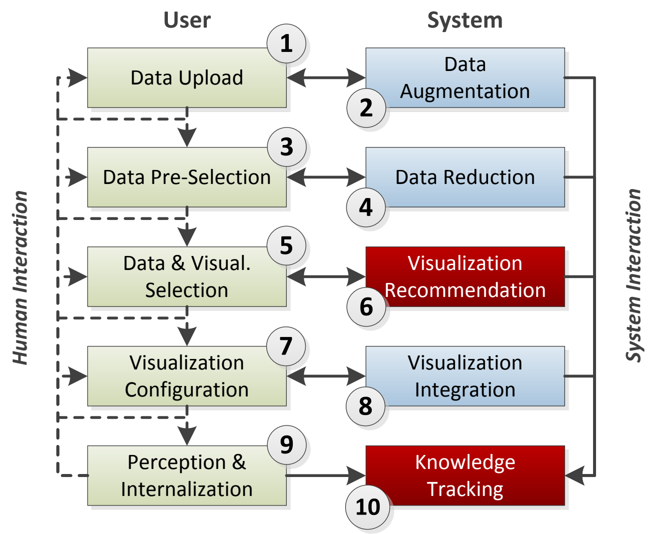

Figure 1. Overview of the complete semantics-based information visualization workflow. The highlighted Visualization Recommendation and Knowledge Tracking are presented in this article in detail.

tools are preferable, because they are quickly available and reusable in different contexts. Using such tools, domain experts can directly get the information they need out of their data. However, these tools typically require them to select the visualization type and to specify the visual mappings, which can be difficult because they often lack the necessary visualization knowledge [3]. Knowledge-assisted visualization can address this problem by representing and leveraging formalized visualization knowledge to support the user [4]. Suggesting automatically generated visualizations to the user is one promising approach to aid domain experts in constructing visualizations [3], [5].

The concepts defined within this article are essential parts of a semantics-based information visualization workflow for end-users tailored to semantic web dataset [6]. Fig. 1 gives an overview. It consists of five stages users needs to pass: choosing or uploading a dataset 1, getting an overview of the data and choosing a subset 3, selecting relevant data

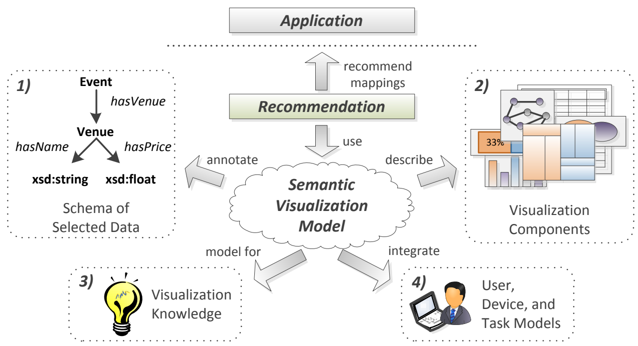

Figure 2. Overview of our goal to recommend mappings of a data source (1) to a visualization component (2) based on a semantic model utilizing visualization knowledge (3) and context information (4).

variables and suitable visualization components 5, configuring them 7 and, finally, interacting with the rendered data to gain the desired insights 9. Due to the interactive nature of the visualization process, users can sequentially pass through, but may also move backwards. For instance, the configuration step can be skipped by using default mappings. Furthermore, users may choose to search and integrate multiple, alternative visualizations to benefit from multiple coordinated views of their data after completing the workflow. This user-driven process is supported by five system-side functionalities (the right rectangles in Fig. 1) where the concepts for the visualization recommendation 6 and the knowledge externalization 10 are proposed within this article.

We employ a simple example to get our approach across (Fig. 2). It considers a semantic web dataset comprising a list of events hosted at different venues with varying fees. A business user with less visualization experience wants to get an overview of how expensive the events are using his laptop. Thus, he selects a subgraph from a semantic dataset as shown in 1 containing two classes (EVENT, VENUE) linked by a Property (*hasVenue*) and two Data Properties (*hasName*, *hasPrice*). To map this data to a compatible visualization component 2, a user needs visualization knowledge 3. Context information 4 about the user (knowledge, skills), his device (hard- /software capabilities) and his task (get overview) must also be considered to create a successful mapping. We strive for a generic recommendation approach utilizing and understanding these different ingredients based on a common semantic knowledge model to facilitate the automated visualization process for different tools.

Our goal of creating a knowledge-assisted, context-aware system which recommends visualization components involves basically five challenges, which are addressed by this article. Firstly, a **formalized vocabulary** for the interdisciplinary visualization domain is required. To this end, we have developed a modular visualization ontology called VISO. Secondly, means to **semantically describe visualization characteristics** of both data sources and visualization components must be provided. Therefore, we propose the linking and annotation of semantic web data and component descriptors with concepts of VISO. Thirdly, appropriate visualization components must be **discovered** for a certain set of data. Thus, we present a matching algorithm which takes the aforementioned formalized visualization knowledge and given user requirements into account to search for compatible visualization components. Fourthly, component candidates need to be **ranked** with regard to the user, usage and device context. Hence, we have developed a corresponding ranking algorithm for the mappings, i. e., component candidates resulting from the discovery. Fifthly, internal visualization knowledge created by the user during the visualization workflow needs to be externalized and **reused**. Accordingly, we defined an architecture and algorithms to externalize, consolidate, store, and reuse this knowledge.

The remainder of this article is structured as follows. First, we discuss related work in the fields of automated or knowledge-assisted visualization, semantic models for visualization, and semantics-based component recommendation in Section II. Then, Section III introduces our visualization ontology VISO in detail and clarifies how it is applied to describe visualization components and data sources. Afterwards, we present the corresponding recommendation algorithm separated into matching and ranking in Section IV. We detailed the gathering and the reuse of empirical visualization knowledge in Section V. Section VI gives an overview of the architecture and its corresponding prototypical implementation. Finally, we conclude the article and outline future work in Section VII.

II. Related Work

The recommendation algorithm presented in this article builds on previous research in the four different research areas: (1) automated visualization, (2) semantic visualization models, (3) mechanisms for semantics-based component discovery and ranking, and (4) collaborative filtering. We will now discuss the state of the art in those four areas.

A. Automated, Knowledge-assisted, and Component-based Visualization

Several automatic visualization systems have been developed to help users to create visualizations. They produce visualization specifications based on user-selected data and implicitly or explicitly represented visualization knowledge. We distinguish between data-driven, task-driven, and interaction-driven approaches. Furthermore, we differentiate into two orthogonal facets: knowledge-assisted and component-based visualization. The firsts objective is to overcome the burden of learning complex visualization techniques by formalizing and sharing domain and visualization knowledge [7]. We narrow the definition so that these systems need to build on current semantic web technologies, e. g., RDF or OWL, to formalize, use, and maybe share this knowledge in a standardized and widely-adopted way. Component-based visualization means that the single visualization techniques are encapsulated in components or even (user interface) services. It allows for their flexible, context-aware reuse in different scenarios.

Data-driven approaches analyze the meta-model of the data and potentially instance data to generate visualization specifications. Mackinlay addressed the problem of how to automatically generate static 2D visualizations of relational information in his APT system [8]. It searches the design space of all possible visualizations using expressiveness criteria and then ranks them using effectiveness criteria. The more recent visualization mosaics approach from MacNeil and Elmqvist [9] works the same way. Gilson et al. developed an algorithm that maps data represented in a domain ontology to visual representation ontologies [10]. Their visual representation ontologies describe single visualization components, e. g., tree maps. A semantic bridging ontology is used to specify the appropriateness of the different mappings. Our automated visualization approach is similar to the one by Gilson et al. in that both data and visualization components are described using ontologies. The main limitation of data-driven approaches is that they do not take other information such as the user's task, preferences or device into account. Task-driven and interaction-driven approaches usually build on the data analysis ideas present in data-driven approaches, but go beyond them.

The effectiveness of a visualization depends on how well it supports the user's task by making it easy to perceive important information. This is addressed by **task-driven approaches**. Casner's BOZ system analyzes task descriptions to generate corresponding visualizations [11]. However, BOZ requires detailed task descriptions formulated in a structured language and is limited to relational data. The SAGE system by Roth and Mattis extends APT to consider the user's goals [12]. It first selects visual techniques based on their expressiveness, then ranks them according to their effectiveness, refines them by adding additional layout constraints (e.g., sorting), and finally integrates multiple visualization techniques if necessary. In constrast to SAGE and BOZ, our algorithm is ontology-based to allow for reasoning and it leverages device and user preference information.

Visual data analysis is an iterative and interactive process in which many visualizations are created, modified and analyzed [3]. **Interaction-driven approaches** consider either the user interaction history or the current visualization state to generate visualizations that support this process. Mackinlay et al. have developed heuristics that use the current visualization state and the data attribute selection to update the current visualization or to show alternative visualizations [13]. Behavior-driven visualization recommendation monitors users' interactions with visualizations, detects patterns in the interaction sequences, and infers visual tasks based on repeated patterns [14]. The current visualization state and the inferred visual task are then used to recommend more suitable visualizations. Interaction-driven approaches leverage implicit state information, but they consider neither task information that is explicitly expressed by the user, nor user preferences or device constraints.

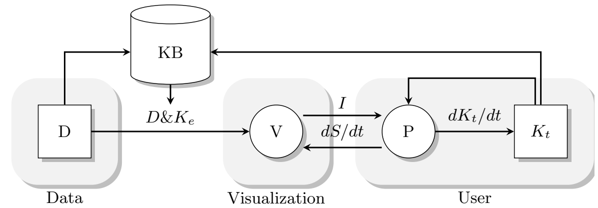

Figure 3. Knowledg-assisted Visualization, based on [15], [16].

As mentioned before, **knowledge-assisted visualization** is a more orthogonal aspect of a visualization approach. It means, that the single process steps, e. g., filtering, automated mapping, and configuration, are underpinned by semantic models, i. e., ontologies, which allow for reasoning but also for sharing and, thus, enhancing the knowledge in a collaborative manner. Chen et al. [4] give a good but only a theoretical impression how such a visualization workflow could be designed.

Furthermore, Wang et al. [15] propose a knowledge conversion process in visual analytics system. Fig. 3 sketches this workflow for the identification of the applicable visualization for the chosen data (D). The visualization component (V) represents its (interactive) image I to the user. With its perception (P), the user gets internal knowledge about this visualization over time dK_t/dt (*internalization*) and an insight whether this visualization is applicable or not. If it is not suitable, the user can adapt the representation by changing the specification of the visualization over time (dS/dt). In the end, the internal knowledge (K_t) can be *externalized* to a (global) knowledge base (KB). In case of choosing the same or equivalent data next time, the externalized knowledge is fetched and the suitable visualization presented. Since this theoretical process is valuable for our work, their prototype do not rely on visualization-specific knowledge and, hence, does not cover the recommendation and automated mapping of graphic representations.

Also, the already sketched data-driven approach from Gilson et al. [10] is a knowledge-assisted one since it makes extensive use of ontologies to identify suitable mappings from data to visualization techniques. Its greatest drawback is the manual definition of effective mappings from data items to visual variables within the semantic bridging ontology. In [17], Shu et al. present an ontology (cf. Sect. II-B) and a simple discovery approach for visualization service which regrettably neglects an automated mapping.

Using encapsulated **components** or widgets is a common concept to reuse generic visualization techniques in different contexts or applications. In particular, web-based applications like sgvizler [18] or dashboards [19] employ visualization libraries, e. g., Google Chart Tools[2] or Highcharts JS[3], to present the data. Their biggest disadvantage is that the user has to manually define the mappings. Further, dashboards are mostly static. In contrast, mashup environments like DashMash [20] take the user by the hand to specify mappings or to interconnect the widgets without high cognitive efforts. But all in all, they are not tailored to the needs of automated information visualization since their components are often data-dependent and do not explicitly support the steps of a visualization process. In the visualization domain, some approaches, e. g., [3], [9], are component-based and allow for a flexible combination of visualization widgets. Although they support visualization-specific features like automated mapping or linking and brushing, their components are not loosely coupled like in mashup platforms nor consider context parameters.

In summary, while our work builds on many ideas from automated and knowledge-assisted visualization approaches, in particular the work by Gilson et al. [10] and Wang et al. [15], it is extensible in terms of visualization components, and it considers task, user preferences and device capabilities. In contrast to generative approaches [8], [11]–[13], the strength of using visualization components is that they are optimized for the visual metaphor they represent.

B. Formalizations of Visualization Knowledge

As shown in the previous section, automated visualization requires one or more models to bridge the gap between data and suitable graphic representations. In this regard, prevalent approaches use different concepts, such as rules [12], heuristics [13], and semantic models [10]. We share the view of Gilson et al. [10] that semantic technologies are the methods of choice today. They allow for capturing and formalizing expert knowledge in a readable and understandable manner for humans as well as machines. Therefore, they provide an effective solution for automated recommendation. Further, the current technologies facilitate an easy and dynamic reuse of existing semantic models in new scenarios.

Actually, only few academic works have explored semantic web technologies as means to capture visualization knowledge for describing and recommending resources. Duke et al. [21] were the first proposing the need for a visualization ontology. Their promising approach captures an initial set of concepts and relations of the domain comprising data, visualization techniques, and tasks. Potter and Wright [22] combine formal taxonomies for hard- and software capabilities, sensory experience as well as human actions to characterize a visualization resource. Similarly, Shu et al. [17] use a visualization ontology to annotate and query for visualization web services, with regard to their (1) underlying data model and (2) visualization technique. While the former is a taxonomy comprising various kinds of multidimensional datasets, the latter builds on the data module to classify the graphic representations. For our work, their data taxonomy is not flexible enough as we need to support graph-based data structures for example. Gilson et al. [10] employ three dedicated ontologies to allow for automatic visualization: the first one captures domain semantics and instance data to visualize; the second one describes a particular graphic representation; the final ontology contains expert knowledge to foster the mapping from domain to visualization concepts. In contrast, we allow for a more flexible and generic linking of both sides by annotating each with VISO concepts instead of the explicit, manual creation of an additional ontology. But we reuse this concept of a mapping ontology in a particular way. The adapted concept gives the possibility for an automated insertation of user-generated knowledge by storing mappings of chosen data with the applied visualizations. Rhodes et al. [23] aimed to categorize, store and query information about software visualization systems using a visualization ontology as the underlying model. Their approach facilitates methods for specifying data, graphic representation, or the skill of users.

All in all, we share the goal of the works presented above: defining a formalized vocabulary to describe and recommend visualization resources. However, as we strive for a context-aware recommendation we need a more comprehensive and detailed model that covers not only data and graphical aspects, but also represent the user, his activity, and device.

C. Semantics-Based Component Discovery and Ranking

When it comes to finding and binding adequate services for a desired goal, such as visualizing semantic data as we are, *Semantic Web Services* (SWS) tackle a very similar problem. SWS research provides solutions for finding a service or service composition that fulfills a goal or user task based on certain instance data. Therefore, they employ a formal representation of the services' functional and non-function semantics – usually based on description logics – to facilitate reasoning. Based on this, they strive for the automation of the service life-cycle including the discovery, ranking, composition, and execution of services through proper composition environments.

The discovery of suitable semantic services employs either complete semantic service models, e. g., in OWL-S [24] and WSMO [25], or semantic extensions to existing description formats, as proposed by SAWSDL [26] and WSMO-Lite [27]. The former *top-down* approaches are usually very expressive, but descriptions are complex and time-consuming to build. The latter *bottom-up* approaches add semantic annotations, i. e., references to concepts in external

[2]https://developers.google.com/chart/
[3]http://www.highcharts.com/

ontologies, to WSDL. Even though the above-mentioned solutions cannot be directly applied to our problems, e. g., due to their limitation to web services formats and design principles (stateless), we follow the idea by extending a mashup component description language with semantic references. Thereby, visualization components can be described regarding their data, functional and non-functional semantics, including references to formalized visualization knowledge.

In SWS discovery, suitable services are searched based on a formalized goal or task definition, which is usually a template of an SWS description. Thus, the desired data and functional interface is matched with actual service models. The corresponding algorithms either use measures like text and graph similarities, which restricts the applicability to design-time, or determine the matching degree of services, operations, etc., using logic relationships between annotated concepts as in [28]. In contrast to SWS, we follow a data-driven approach, in which semantically annotated data forms the input for the discovery of suitable candidates. The direct generation of SWS goals from a selected dataset is not feasible. Therefore, we individually match data types, functional interface and hard-/software requirements with and between data and visualization components based on shared conceptualizations. Based on this measure, compatible visualization components can be found.

Ranking of service candidates in SWS bears a number of similarities with ranking visualization components for a certain dataset. It is usually based on non-functional properties, such as QoS and context information (user profile, device capabilities). To this end, a number of sophisticated concepts exist, e. g., for multi-criteria ranking based on semantic descriptions of non-functional service properties [25] and for context sensitive ranking [29]. Since these algorithms are rather generic and work on a semantic, non-functional level, they likewise apply to our concept space.

In summary, the discovery and ranking of candidate services for a predefined goal in SWS research follows a similar principle as our work. Yet, its solutions can not be directly applied to our problems. For one, there is a difference in component models, e. g., with regard to statefulness of visualization components. Furthermore, the discovery of visualization components can not be based on predefined, formalized goal descriptions, as it basically depends on semantic data which is annotated with visualization knowledge. For the annotation of visualization components with semantic concepts though, we can apply the ideas of SAWSDL and WSMO-Lite to the component descriptions. To *link* semantic data with visualization components, a shared conceptualization of visualization knowledge is needed. Therefore, the next section presents VISO.

D. Collaborative Filtering Mechanisms

One approach to share and track user-generated knowledge are Collaborative Filtering Recommender Systems (CFRS) [30]. In contrast to the content-based recommendation, which employs the structure of the items, these systems investigate the similarity of ratings for items given by users. Hence, no content analysis or tagging by experts is required. All knowledge is generated due to ratings from end-users while using the system.

The ratings can be distinguished into implicit and explicit ones [31]. Implicit ratings are acquired by tracking the user interactions within the application, by reaching predefined time slices or a number of iteration steps. Nichols et. al [32] specify an extensive list of possible kinds implicit ratings and their corresponding recognition. The most suitable ones for us are *Repeated Use*, *Glimpse* and *Associate Ratings*. In contrast to the implicit ratings, the explicit ones are concretely expressed by the user by a concrete interaction, e. g., by pressing a button. The only requirement is that the user knows what is the effect of the interaction or rating. Unfortunately, it is challenging to identify suitable methods and scales since it is usually a trade-off between getting a detailed opinion from the user by not overburden or scaring him. For example, ebay gathers feedback on four distinct 5-star scales. On the other hand, facebook just eases the interaction by just *liking* content.

The algorithm used for the CFRS is the *Neighborhood-based Recommendation Method*, which can be calculated in two different ways [33]–[35]. The user-based approach looks for similar users in the system, by finding akin ratings according to the actual user. This approach lacks mainly in the possibility to justify the calculated prediction to the user [35]. The system has only the ability to present similar users not items, which is not appropriate for a mainly item-oriented system like ours. The item-based approach searches for similar items to make a prediction of interesting ones for the specific user.

Unfortunately, the recommender systems compete with the cold-start problems, which are based on the non-existence of ratings. According [36], they can be classified into three categories: (1) *new users* or (2) *new items* have no ratings in the system, hence, it is impossible to find similar items or users; (3) a *new community*, which comprises new users and items, is applied. For these problems, the CFRS community has identified different strategies, e. g., un-personalized results, automatically generated ratings, or closed beta phases, which should be considered and carefully balanced during the system design.

To the best of our knowledge, CFRS are not used within automated visualization systems so far. In our opinion, the main reason is that they may identify suitable graphical representations based on users ratings but do not allow for an automated mapping of data structures and values to visual

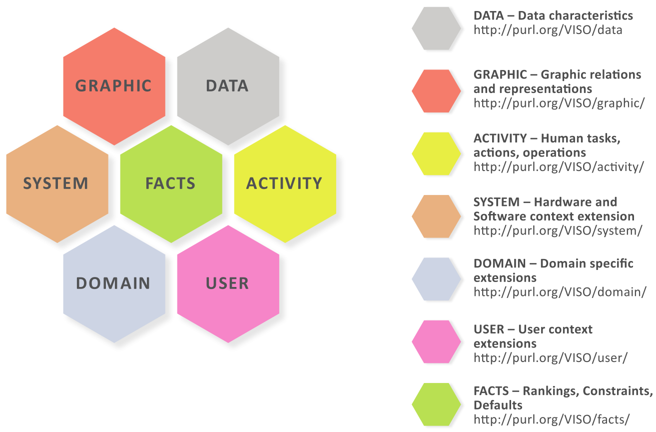

Figure 4. Overview of the VISO.

structures and attributes. However, if this mapping is already provided by the visualization system, collaborative filtering introduces a new facet for recommending visualization techniques: users conclusion if a mapping is suitable in the current context. Thus, it allows for tracking and storing user knowledge – the so-called externalization (cf. Sect. II-A) – and enables the adaption of the visualization process due to this evolving knowledge.

III. VISO: A Modular Visualization Ontology

The foundation of our visualization recommendation approach is a formalized, modular visualization ontology called VISO [37], [38]. It provides a RDF-S/OWL vocabulary for annotating data sources and visualization components, contains factual knowledge of the visualization domain, and serves as a semantic framework for storing contextual information. Altogether, it serves as a *bridging ontology* between semantic data and visualization components by offering shared conceptualizations for all four mapping ingredients shown in Fig. 2. Details of VISO and its development are described in [37], [38]. Furthermore, it can be downloaded and browsed under http://purl.org/viso/. The seven VISO modules (data, graphic, activity, user, system, domain, and facts) represent different facets of data visualization domain. They refer to each other and to other existing ontologies as needed. In the following, we discuss essential parts of the ontology, which are used for the recommendation of visualization components, in detail.

Data: Fig. 5 shows parts of the data module which contains concepts for describing data variables and structures for visualization purposes. While all concepts are employed to describe visualization components, those with dotted lines are also used to annotate semantic data. The vocabulary is especially needed at component-side to describe possible input data in a generic manner as the most visualizations allow for representing domain independent data. For example, a simple table may visualize data about hotels,

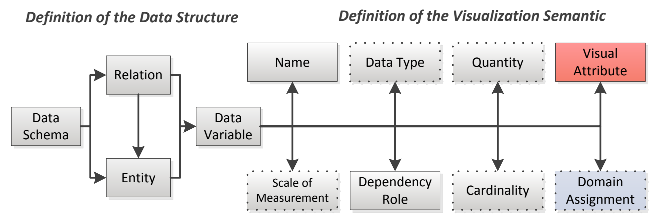

Figure 5. Overview of the VISO data module.

cars, or humans. Using this vocabulary, we specify only the data structure and characteristics. As can be seen, a DATA SCHEMA consists of ENTITY and RELATION concepts. The latter represent links between ENTITY concepts like an OWL Object Property. Both ENTITIES and RELATIONS can contain DATA VARIABLE concepts, whose equivalent in OWL space is a Data Property. For example, the semantic data model of a table visualization component would be represented as one ENTITY concept with several DATA VARIABLES for every column. Further semantics, e. g., the SCALE OF MEASUREMENT and CARDINALITIES – specified using built-in OWL constraints – can be defined on the DATA VARIABLE concepts (Fig. 5) to constrain its scale etc. By linking the concepts from the data module to the VISUAL ATTRIBUTE concepts from the graphic module, we bridge the gap between data attributes and visual elements.

Graphics: The graphics module conceptualizes the semantics of GRAPHICAL REPRESENTATIONS and their parts, e. g., their VISUAL ATTRIBUTES. Concrete graphical representations, e. g., *scatter plot* and *treemaps*, and concrete visual attributes such as *hue* or *shape* are contained as instance data. The concepts from the graphics module are used to semantically annotate visualization components and to define visualization knowledge in the facts module.

Activity: The activity module models user activity in a visualization context. It builds on the ontology-based task model by Tietz et al. [39], which distinguishes betweens high-level, domain specific TASKS and low-level, generic ACTIONS, similar to the distinction made by Gotz and Zhou [40]. We have extended the action taxonomy of Tietz's task model by separating data- and UI-driven ACTIONS, and by formalizing ACTIONS from the visualization literature such as *zoom* and *filter*. This enables the fine-grained annotation of interaction functionality in visualization components.

User: The user module formalizes user PREFERENCES and KNOWLEDGE. Users can, for example, have PREFERENCES for different GRAPHICAL REPRESENTATIONS, and their *visual literacy* can differ. As manifold context models for users, their characteristics and preferences, already exist those can be seamlessly integrated and used here.

System: The system module facilitates the description of the device context, e. g., installed PLUG-INS or SCREEN SIZE. It also allows us to annotate a visualization component with its system requirements. Again, sophisticated models for device characteristics and context exist, which were reused or integrated in this module. As an example, we borrow concepts from the *CroCo* ontology [41], which combines user, usage, system, and situational context from different existing works developed by academia.

Domain: Many visualizations are domain-specific, and thus it is important to consider the domain context during visualization recommendation. However, it is not feasible to model all possible visualization domains. Instead, we support linking to existing domain ontologies. A DOMAIN ASSIGNMENT links VISO concepts, e. g., a DATA VARIABLE (Fig. 5), to concepts from specific domain ontologies. As this assignment is usually created automatically during data analysis, it can be qualified with a probability value reflecting its accuracy. Thus, the analysis of a data source with ambiguous Properties, such as *typeOfJaguar* and *typeofApple*, will result in multiple domain assignments with probabilities below 1. In contrast, a Data Property *hasPrice* from our motivating example could be annotated with *price* and a probability of 1. A visualization component supporting DATA VARIABLE annotated with the more general concept *value* could be inferred as a possible mapping.

Facts: The visualization recommendation also depends on factual visualization knowledge to select suitable visualizations. Thus, we formalized knowledge from the information visualization community, e. g., verified statements such as “position is more accurate to visualize quantitative data than color” [42], to make it machine-processable. These rankings and constraints are formalized in rules in the Facts module. These rules use of the vocabulary of the other VISO modules in their conditions part, e. g., SCALE OF MEASUREMENT (*quantitative*) and the VISUAL ATTRIBUTE (*position, color*) for the mentioned example. If the conditions are matched, a rating is assigned to the corresponding visualization component description.

To give a more practical insight, the following example explains how a *treemap* visualization is described using VISO (Fig. 6). First, the hierarchical data structure of the *treemap* is specified. At the top level, a *Node* ENTITY represents the whole *treemap*. It can contain *Leaf* ENTITIES and *Node* ENTITIES. The label and size variables of *Leafs* can be configured. They are annotated with visualization semantics, e. g., the SCALE OF MEASUREMENT for the label variable is *nominal* and the ROLE of the size variable is *dependent*. Further domain semantics could be added to the variables, e. g., WordNet (http://wordnet.princeton.edu/) concepts such as *value*. In addition to the data structure and the variables, more general semantics such as the kind of GRAPHIC REPRESENTATION (*treemap*), the LEVEL OF DETAIL (*overview*) and possible ACTIONS (*select*, *brush*) are defined for the entire visualization component.

In order to facilitate the construction of visual mappings,

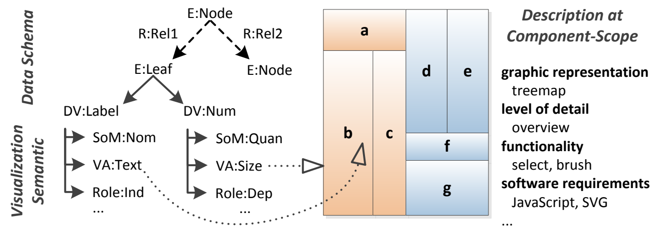

Figure 6. Description of a treemap visualization in VISO.

VISO is used to annotate visualization components and semantic web data. In the latter case, we annotate only RDF Properties on a schema level. RDF Properties hold the data that will be visualized, e. g., literals and relations, whereas RDF classes assemble such properties and do not provide additional information that would be relevant for visualization. Similarly, annotations are made on the schema level, because instance data annotation would be redundant. Consider our motivating example (Fig. 2-1), comprising the Property *hasPrice*. Because the Property has the RDFS Range *xsd:float*, the required DATA TYPE is already defined and the SCALE OF MEASUREMENT is *quantitative*. The number of distinct values (CARDINALITY) and the overall number of values (QUANTITY) can be extracted from the instance data. While a DOMAIN ASSIGNMENT is not mandatory, it could be applied, e. g., to *price* from the WordNet vocabulary.

In summary, VISO models the concepts required for data visualization. It is used to annotate data, to describe visualization components, to represent context and factual knowledge. Together, these different pieces are the foundation of our visualization recommendation algorithm.

IV. VISUALIZATION RECOMMENDATION ALGORITHM

The visualization recommendation algorithm creates an ordered list of mappings of visualizations components for the selected data (Fig. 2-1). It considers contextual information (e.g., device, user model) as well as knowledge about the full data source. While the user model and device are mandatory inputs, visualization specific information like the required LEVEL OF DETAIL or the requested kind of GRAPHICAL REPRESENTATION are optional constraints.

The algorithm consists of two separate steps: matching and ranking (Fig. 7). Both steps leverage semantic knowledge formulated as VISO concepts (cf. Sect. III). In the matching step, potential mappings between data and widgets are generated based on functional requirements. The resulting visualization set is then sorted in the ranking step using the formalized visualization knowledge, domain concepts, and contextual information.

A. *Discovery of Mappings*

The matching algorithm generates a set of mappings from the selected data to visualization components (Fig. 7).

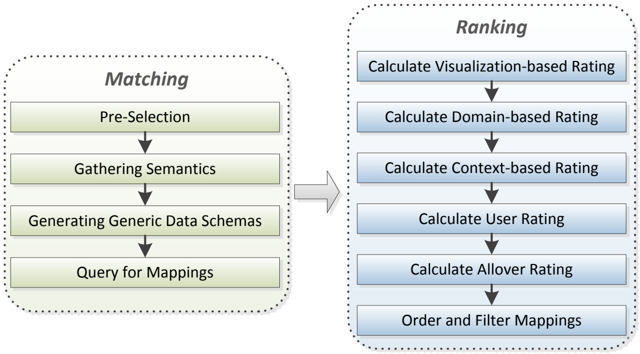

Figure 7. Overview of the recommendation algorithm.

First, potentially applicable widgets are identified and non-applicable components are ruled out (**pre-selection**), since limiting the set of available visualization components early improves the overall algorithm performance. To be applicable, a widget has to (1) be compatible with the target device (e. g., required PLUGINS must be available), (2) support the number of selected Data Properties, and (3) support visualization and task specific requirements (e. g., showing an *overview*), if specified by the user. As can be seen, these constraints do not relate to data structure or semantics of the data variables, yet. Semantic matching is carried out with the resulting component candidates in the following step.

Second, semantics, e. g., the SCALE OF MEASUREMENT, DATA TYPE, and QUANTITY (Fig. 5) of the selected Properties are fetched (**gathering semantics**). For example, the DATA TYPE *xsd:float* or the SCALE OF MEASUREMENT *quantitative* of the property *hasPrice* (Fig. 8-3)) would get retrieved. This semantic information about the Properties is used in the next steps.

Third, we **generate generic data schemas**, which are then used to query for mappings. We distinguish between tabular and graph-based DATA SCHEMAS. TABULAR DATA SCHEMAS contain one ENTITY with several DATA VARIABLES (Fig. 8-1). GRAPH-BASED DATA SCHEMAS contain two or more linked ENTITIES, each containing zero or more variables (Fig. 8-2).

If a **single class** has been selected, a TABULAR DATA SCHEMA is chosen and an ENTITY is created for that class. For every selected Data Property of this class, a DATA VARIABLE with the semantic information (that was retrieved in the previous step) is attached to the ENTITY.

If **several classes** have been selected, we generate both a tabular and a graph-based DATA SCHEMA. For the TABULAR DATA SCHEMA, a single ENTITY gets created. For any selected Data Property from those classes, a DATA VARIABLE with the semantic information is attached to the single ENTITY. This reduces the graph-based data structure to a tabular structure. For example, consider the data shown in Fig. 8-3. The algorithm would create one ENTITY with two DATA VARIABLES. The first DATA VARIABLE would represent the semantics of *hasName*, e. g., the *nominal* SCALE OF MEASUREMENT, and the second DATA VARIABLE would represent *hasPrice*. A GRAPH-BASED DATA SCHEMA gets generated as follows. Beginning with a class from the input data, e. g., *Event* in Fig. 8-3, an ENTITY is created. Similar to the other cases, DATA VARIABLES and their semantics are attached to this ENTITY for the selected Data Properties linked to the class. Next, for each Object Property connected with the class, a RELATION gets generated. If the target class for that RELATION has not been processed yet, it is created and processed in a similar way. This depth-first processing continues until the current part of the input graph is completely traversed. If there are multiple unconnected classes in the input, the algorithm continues with those until all graph components are processed, e. g., the algorithm would generate the DATA SCHEMA illustrated in Fig. 8-4 by processing the input data structure shown in Fig. 8-3.

Fourth, the mappings are generated by querying the semantic representations of the pre-selected components with the generic DATA SCHEMAS that were computed in the previous step (**query for mappings**). The mappings include permutations of DATA VARIABLES with similar semantics, and thus the number of mappings may be higher than the number of existing components. Using the data structure generated by the algorithm for the example shown in Fig. 8-4, both the *scatter plot* (Fig. 8-1) and the *treemap* (Fig. 8-2) would fit on the level of data structure. However, only the *treemap* is a suitable mapping due to the annotated semantics which are also employed by querying. The *scatter plot* is not suitable because it has two *quantitative* DATA VARIABLES, where both a *nominal* and a *quantitative* DATA VARIABLE are required. The generated set of mappings from the selected data to the visualization components is ranked in the next part of the algorithm.

B. *Ranking of Mappings*

The ranking step of the algorithm sorts the visual mappings that were generated by the previous matching step. While this step identifies valid mappings and visualization components that satisfy functional criteria, it does not take their effectiveness into account. To sort the mappings by their effectiveness, the ranking step applies factual visualization knowledge, domain assignments, contextual user and device information, and a user rating.

The four different kinds of rating are combined using an arithmetic mean. The overall rating has a range between 0 and 1. We weight all three, receptively four, rating types equivalently for two reasons. First, the assignment of a (quantitative) rating is often subjective. Second, a profound user study is needed to evaluate the impact of each knowledge base in users visualization selection process what will be future work. As x, y, z, and r_u are the number of each kinds of rating, the overall rating R for each mapping is

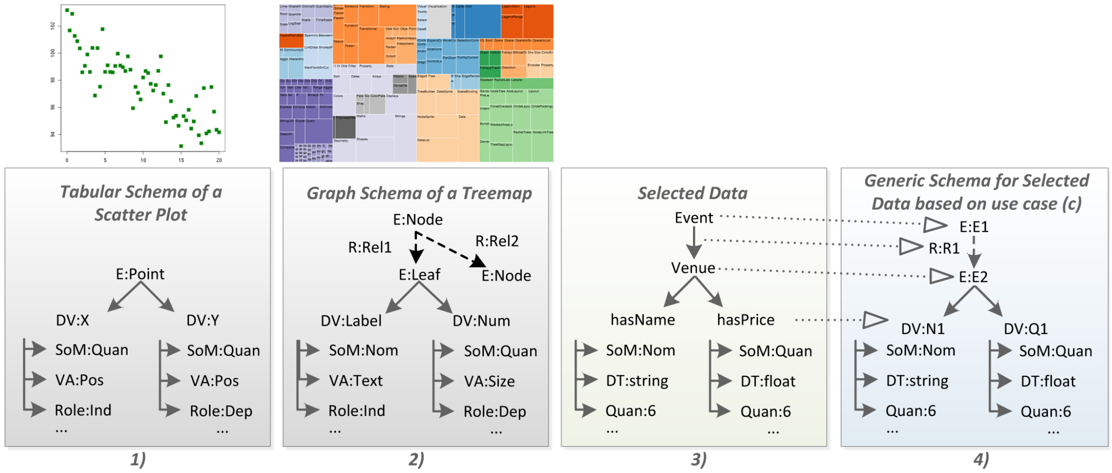

Figure 8. Comparison of the data structure and the annotation between 1) a scatter plot, 2) a treemap, 3) user's selected data, and 4) a generic equivalent of the selected data.

calculated in terms of eq. 1. The meaning factor $1/n$ is therefore assigned with $1/3$, if neither an user rating can be found, nor can be calculated. In all other cases, it is assigned with $1/4$ to keep the equivalently rating of all factors.

1) Factual Visualization Knowledge: The factual visualization knowledge (see Section III) is defined by a set of rules that consists of a condition and a rating. The conditions are specified using the VISO vocabulary for the visualization components. For each widget, the ratings of all rules that are met are added to its specification. During runtime, the arithmetic mean of all ratings r_v is calculated for the discovered component of each visual mapping. For example, we formalized rules to rate the appropriateness of visual encodings for quantitative data [42]. The *quantitative* DATA VARIABLE of the *treemap* (Fig. 8-2) is rated with 0.5 as it employs "only" *size* and not *position*.

2) Domain Assignments: Domain concepts from various ontologies are assigned to both the data input and the visualization components with a certainty value (see Section III). For each pair of input Property and DATA VARIABLE of the visualization component, we calculate a semantic similarity rating between 0 and 1 (e. g., using [43]), if they both have a domain concept assigned with a certainty greater than 0. The final rating r_d is the product of the semantic similarity and the arithmetic mean of both certainties. In our example (see Sect. III), we used *value* and *price* from WordNet to annotate the *quantitative* DATA VARIABLE of the *treemap* and the Property *hasPrice* from our dataset, each with a certainty of *1*. Using [43], we get a rating r_d=0.9094.

3) User and Device Information: The rules for the context-based rating r_c are part of the knowledge base and use the VISO vocabulary, similar to the factual visualization knowledge. The rules are executed during runtime and employ the above mentioned identifiers of users' and their device. For example, we construct a SPARQL-based rule that counts the use of different GRAPHIC REPRESENTATIONS, like *treemaps* or *scatter plots*. This rule assigns a rating r_c between 0 and 1 to the visual mappings.

4) User-shared knowledge: The factor r_u is associated to our concept of employing the user-generated visualization knowledge [15] by using collaborative filtering, see Section V. Since the user has not rated the visualization component in the specific combination with a selected dataset, the algorithm tries to foresee a possible rating. This calculated rating r_u assigns a factor between 0 and 1.

Finally, the complete list of mapping is ordered based on the combined ratings R for each mappings. This ranking could be used to automatically display the most suitable visualization component to the user, or, as in our approach, to let the user pick one of the top n ranked visualizations.

V. Reuse of Empirical Visualization Knowledge

As identified in Sect. II-A, the idea of *knowledge-assisted visualization* is mostly presented in a theoretical way and lacks of concrete descriptions of data structure or applied algorithms. Hence, in the latter sections we propose the VISO as well as a concrete recommendation and mapping algorithm, which employs the ontological knowledge base, to enhance the so-called internalization process [15]. Unfortunately, we only use the a priori knowledge formalized by experts so far. Users insights, particularly a component is suitable or not for a selected dataset, are neglected. Thus, in the following subsections we provide concepts to externalize and reuse also this empirical knowledge which is lost otherwise.

A. Externalization of Empirical Knowledge

The *externalization* process describes the storage of user's internal knowledge within the system. This process can be distinguished in acquiring *implicit* and *explicit* insights. The

$$R = \frac{1}{n := \{3,4\}} \left(\frac{1}{x} \sum_{i=1}^{x} r_{v_i} + \frac{1}{y} \sum_{j=1}^{y} r_{d_j} + \frac{1}{z} \sum_{k=1}^{z} r_{c_k} \; (+ \, r_u) \right) \tag{1}$$

tracking and interpretation of interactions as knowledge is called *implicit rating* and is used for gathering knowledge, before the user indicates the end of the adaption loop by an *explicit rating*. In our concept, a rating is always saved for a combination of a generic data schema (cf. Sect. IV-A) and concrete visualization component.

For the storage of ratings, we developed a rating ontology similar to the Semantic Bridging Ontology of Gilson et al. [10]. It maps all ratings of one generic data schema with one visualization component, see Fig. 9. The ratings are saved in a flat table beside these combinations. The flattened table is necessary to apply the collaborative filtering algorithm on ontologies without the conversion of the data types. However, the use of an ontology allows for a simple reuse of other concepts within the VISO without duplicating information. Thus, we are able to query for instance “only good rated components that are able to visualize trends”. To harvest implicit rating, we rely on the following three actions from [32].

- **Repeated Use:** A visualization component is *used* more than three times by the same user. The usage of the component is recognized by counting interactions within a defined time interval. Since the repeated use is a sign that the user favors a component, it is added to a so-called white list.
- **Glimpse:** If the chosen visualization component is discarded without reaching a defined time interval or a count of interactions for recognizing the *Repeated Use*, it is downgraded by adding it to a black list.
- **Related Rate:** The visualization component was explicit rated by the user, but in a different data combination. Since the user knows its characteristics, it is possible that he likes it for other data selections, which are distinct from the generic data schema, as well. In case of a good rating, the component is added to the white list, otherwise to the black list.

Beside this implicit knowledge tracking, we gather *explicit* ratings. Thus, the user can explicitly decide whether the visualization is applicable for its purpose or not. Since we like to stimulate the user to rating, we employ a simple scale of *applicable* (1) or *not applicable* (0). Thereby, we fulfill the requirement to give the user an adequate possibility to rate, without an excessive demand.

B. Collaboration

The *collaboration* process describes a direct collaboration of two or more users [15], such as chat, telephone, or co-browsing. We broaden this scope by including indirect sharing of knowledge as collaboration. For this purpose, we use algorithms for the collaborative filtering, what allows for predicting a rating based on similar users and ratings. After an evaluation on accuracy, efficiency, stability, justification, and serendipity [35], we decide to employ the item-based approach for our use-case. It calculates the similarity between the ratings of visualization components, given by different users. With this information, the algorithm can predict the rating for the current visualization. An example is given in Fig. 10. It has to calculate the prediction r_{rs} for user B_3 and visualization component K_2. In this exemplary setting, the prediction is assessed based on the rating distances between K_2 and all other visualization components (K_1 - K_5). The algorithm chooses K_4 and K_5 as *nearest neighbours* and forecasts a rating of $r_{rs} = 1$ for this setting. The formal calculation can be considered in detail in the work from Sarwar et. al [34] and could be used without adaption, concerning the flattened structure of the rating storage.

The quality of the CFRS can be measured by calculating the *mean absolute error*. This technique involves the distance between the predicted and the encountered rating. All distances are saved within the system and are normalized by their count. This comparative simple method can be applied

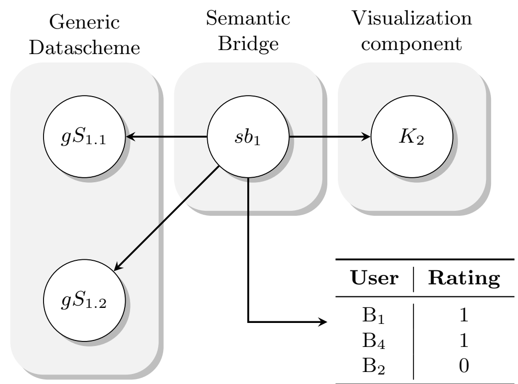

Figure 9. Overview of the rating ontology.

	$\mathbf{K}_1$	$\mathbf{K}_2$	$\mathbf{K}_3$	$\mathbf{K}_4$	$\mathbf{K}_5$
B_1	1	0	-	0	0
B_2	0	1	0	1	1
B_3	0	r_{rs}	1	1	1
B_4	1	1	1	1	-

Figure 10. Example set for CFRS prediction.

in recommender systems, that scales the rating on a base of 0 and 1 [44]. If the measured error is near 1, the CFRS will predict the wrong values and, therefore, sharing *wrong knowledge*. In this case, we deactivate the prediction in the ranking algorithm, acquire more ratings and activate it if a given threshold is reached.

If no rating exists and also no one could be predicted due to missing information, our approach tries to employ the implicit ratings stored in the white and black list as mentioned in the foregoing subsection. The problem of their application is the missing expressiveness as it is always vague if the implicit rating is true or not. We decide to assign the weight of 0.25 if a component is on the black list and 0.75 if it is on the white list. Their appropriateness needs to be analyzed and maybe aligned in a broader evaluation scenario.

C. Using Empirical Knowledge for Evaluation

The empirical knowledge, especially the explicit rating is an interesting foundation for the evaluation of our ranking algorithm presented in Sect. IV-B. We can calculate the distance between the mean of *factual visualization knowledge*, *domain assignment* and *user and device information* to the given explicit rating. As it is also normalized to a scale between 0 and 1, it is possible to apply the method of the *mean absolute error*. In case the measured error converges to 0, we can verify that the calculated elements of the ranking algorithm are significantly correct. In contrast, if the measured error converges to 1, the ranking algorithm and the users needs shows a big gap, which can disprove its correctness.

VI. Architecture and its Implementation

After presenting the conceptual foundations of our approach, in this section, we show how they are integrated into a knowledge-based and mashup-based architecture. Furthermore, we outline some implementation-specific details.

A. Knowledge-based Architecture

To realize the concepts discussed above, we specified a reference architecture shown in Fig. 11. It comprises three layers: ontological knowledge bases, loosely-coupled web services, and a component-based user interfaces. In the following, we describe the functionality of the single parts and their relation amongst each other in detail.

The first knowledge base, the *VISO* 1 (cf. Sect. III), holds the visualization specific knowledge. It is used to annotate the data within the Data Repository 5 and to describe the visualization capabilities and the data interfaces of components. The foundation of the semantic component description is the *Mashup Component Description Ontology* (MCDO), which is part of the CRUISe mashup environment 2 [45]. It is not only extended by VISO but also by contextual meta-information. For this, we reuse the *CroCoOn* ontology 3 being part of the CroCo context service 7 [46]. Finally, we designed an ontological knowledge base to store *ratings* 4 for the mapping of selected data to the chosen component. Therefore, it refers to concepts of the VISO and MCDO.

Furthermore, we build on four different web services which heavily make use of the mentioned knowledge bases. The *Data Repository* 5 offers a homogeneous data layer for the visualization system to upload, convert, filter, and cluster the data. Furthermore, it semi-automatically augments it with VISO vocabulary like described in Sect. III. The *Component Repository* 6 – being part of CRUISe as well – allows for the semantic-driven management of visualization components based on the MCDO 2. Further, the recommendation for appropriate components (cf. Sect. IV) is integrated within this service. For this, it gathers data semantics from the Data Repository, the Context Service, and the Rating Repository. As mentioned, we reuse CroCo [46] as *Context Service* 7. The *Rating Repository* 8 offers the functionality to store all the implicit and explicit ratings of the users tracked in the user interface. Additionally, it provides an API to retrieve this score. If it is not available directly, the algorithm defined in Sect. V is applied to predict this rating.

The visualization workflow of an user is accomplished by VizBoard – a composite application based on CRUISe running within the *Mashup Runtime Environment*. It complies with the process presented in Fig. 1, where the most crucial steps are shown in Fig. 11. After uploading the data, the user has to slice and dice it to a manageable subset by using the *Data Pre-Selection* component 9 [47]. This reduced dataset is the foundation for the concrete selection of data items and structures to visualize. Since also visualization-specific characteristics, e. g., visual variables or interaction techniques, are important to select appropriate visualization components, we developed the sophisticated concept of *Weighted Faceted Browsing* [48]. The related component 10 access the Component Repository to execute the recommendation algorithm proposed in Sect. IV. In the end, the selected components are integrated 11. Thus, the user can perceive the represented data. At this stage, we explicitly and implicitly acquire users knowledge, like explained in Sect. V, and save it using the Rating Repository.

B. Implementation Details

After giving an overview of our architecture, we provide some details on its implementation. All ontologies are build on the widely adopted semantic web standards from the W3C: RDF[4], RDFS[5], and OWL[6]. To define the schemata, we mostly rely an OWL DL, which is expressive, deterministic, and allows for inferring new knowledge by using different

[4] http://www.w3.org/TR/rdf-primer/
[5] http://www.w3.org/TR/rdf-schema/
[6] http://www.w3.org/TR/owl2-overview/

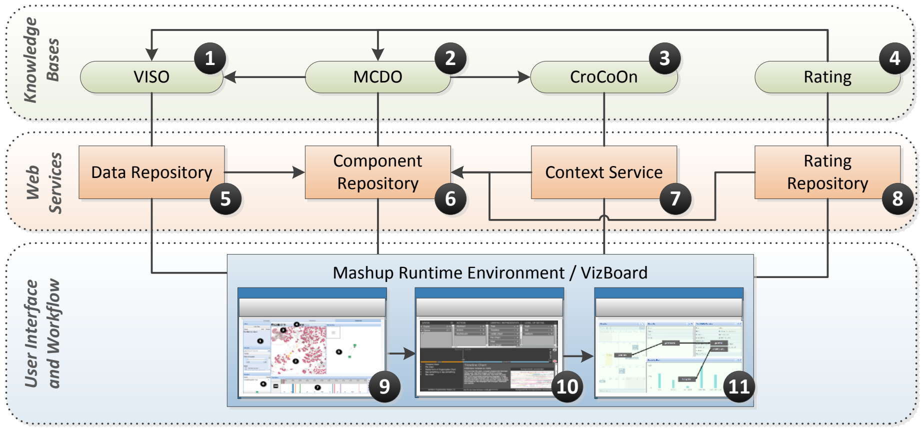

Figure 11. The architecture of our approach could be distinguished into three layers: knowledge bases, web services, and user interface.

reasoners. To query the ontologies within our services, we build on SPARQL 1.1[7].

All web services presented in the architectural overview (Fig. 11) are prototypical implemented in Java. The Data Repository is accessible through a RESTful web service API using Java Jersey[8]. Its core is a RDF triple store which allows to store and filter the datasets. To identify an appropriate one, we had to conduct a triple store benchmark [49] since the existing ones do not consider real-world datasets, SPARQL 1.1, nor reasoning which are altogether requirements in our use case. Although no store stands out in this test, we decided on Jena TDB[9] due to the existence of an extendable rule engine required for the analysis within the augmentation step.

As aforementioned, we are relying on the CRUISe ecosystem. Thus, we could reuse the Component Repository and the Context Service. Since the latter does not require any extension, the recommendation algorithm (cf. Sect. IV) is implemented in the Component Repository using the Apache Jena API and Jena rules. Additionally, we employ SPARQL to pre-select components and to generate the generic data schema like proposed in Sect. IV-A. These queries run against the semantic information of the components stored within the MCDO, particularly the operations of the component API as they are responsible to insert the data.

The Rating Repository, which manages the implicit and explicit ratings for combinations of generic data schemata and components, is accessible over a REST interface, too. To retrieve components and their ratings for a generic data schema, which could be represented as unique hashes, we employ SPARQL as well. List. 1 shows an exemplary query. Furthermore, we implemented the CFRS algorithms defined in Sect. V-B. This allows for not only to use the rating made by the user but also to predict ratings if not available.

[7]http://www.w3.org/TR/rdf-sparql-query/
[8]http://jersey.java.net/
[9]http://jena.apache.org/documentation/tdb/

```
# get ratings by given generic data schema
SELECT ?vcid ?owner ?val
WHERE {
 ?gds v-r:hasGenericDataScheme
   v-d:1296abf85e507a9596ab2131a0f933a3 .

 ?sbo v-r:hasGenericDataScheme ?gds;
   v-r:hasRating ?ratings;
   v-r:hasVisualizationComponent ?viscomp.

 ?ratings v-r:hasRatingValue ?val;
   v-r:hasOwner ?owner.

 ?viscomp mcdl:hasId ?vcid.
}
```

Listing 1. SPARQL query to retrieve all ratings for a data schema.

At the user interface layer, we use the Mashup Runtime Environment, which is implemented as purely JavaScript-based thin-server architecture and as client server architecture by using Java for the backend and JavaScript for the frontend. Both client-side implementations are extended to allow for voting the data-component-combinations. The implicit rating starts with the loading of a visualization component into the screen (Fig. 11-11). We included all three recognition modes distinguished in Sect. V-A by tracking mouse and key events in a defined time span after components' integration. Furthermore, the runtime automatically integrates rating buttons for every component beneath the graphic representation (Fig. 12).

All user interface components being part of the user-centered visualization workflow, e. g., the Data Pre-Selection, and the components to visualize the data are developed using HTML, JavaScript, e. g., frameworks like D3.js[10] or jQuery[11], and partly Adobe Flash.

[10]https://github.com/mbostock/d3
[11]http://jquery.com/

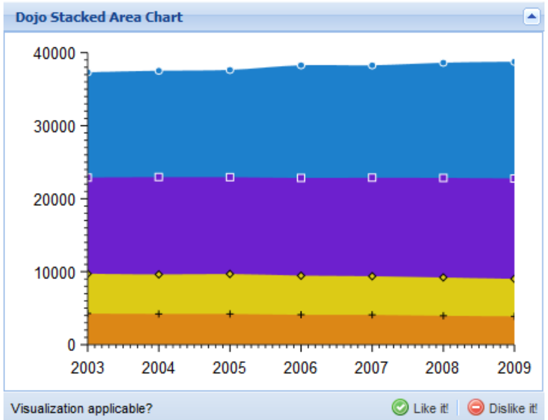

Figure 12. Visualization component with rating bar at the bottom.

VII. Conclusion and Further Work

Selecting an appropriate visualization for a specific dataset in a specific scenario remains challenging for non-experts. Therefore, we have presented a context-aware and knowledge-assisted approach to recommend suitable visualizations for semantic web data. Its foundation is the modular visualization ontology VISO, which provides the vocabulary to annotate both data sources and visualization components. Based on these shared concepts from the visualization domain, our recommendation algorithm covers both matching and context-aware ranking of suitable graphic representations. First, possible mappings from data to visual encodings are identified using the selected data, its semantics, and other functional information. Then, quantitative ratings for each mapping are calculated with respect to visualization knowledge, domain concept relations, context information, and user ratings. To the best of our knowledge, this approach is the first that employs formalized, inferred expert knowledge but also empirical, evolving knowledge from users to identify the most suitable visualization components.

Currently, we are also planning to conduct an exhaustive user study to identify and model the interdependencies between the knowledge bases employed within the ranking. Furthermore, we are working on a concept to use the a priori and empirical knowledge to assist the user in interpreting and understanding the visualized data what will underpin the usefulness of knowledge-assisted visualization.

Furthermore, many concepts presented in this work can be adapted to general semantic reasoning problems. As a goal of the SeMiWa [50], a situation reasoner within an ubiquitous, assisted live environment should forecast situations based on the current classified one. The ranking algorithm is an adaption of the one presented in this article. The *factual visualization knowledge* is conceptually similar to *factual lifecycle knowledge*, such as circadian or infradian rhythms. The *domain assignment* changes the prediction based on the current *domain* where is user is situated, e. g., at home, at work, or outside. The *user and device* information are identical since they consist of personalized context information for one user, combined with the sensoral context of the surrounding environment. An important additional benefit is the usage of *user-shared, empirical knowledge*, like it is mentioned in this work. Therefore, we also propose a collaborative filtering approach for finding “neighbors” that are acting in a similar way.

Acknowledgment

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An Ambient Assisted Living Framework with Automatic Self-Diagnosis

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***Abstract*—As the population in many countries is steadily aging, allowing elderly people to stay longer at home is a growing concern. Ambient Assisted Living (AAL) proposes new techniques to help people remain autonomous, based on ambient intelligence. We present an ontology-based framework in which ontologies enable the expression of users' preferences in order to personalize the system behavior. They are also used for the discovery and interconnection of devices, the storage and retrieval of collected data and the transmission of actions. Basing everything on ontologies allows the designer to express the behavior of the system using high-level logic rules. To render AAL systems as autonomous as possible, devices that fail should be detected at runtime. For this reason, the framework offers a diagnosis service that builds a prediction model of the values detected by sensors. It is based on information discovered *opportunistically* at run-time and knowledge about physical laws. The framework monitors the run-time behavior of the AAL system and uses the prediction model to detect inconsistencies and hence faults. Therefore, fault detection is totally dynamic and opportunistic; there are no pre-defined control loops. This paper describes an actual implementation, with precise technological details, in order to prove the feasibility of the technical choices, and provide implementation ideas for future projects.**

***Keywords*-Ambient Assisted Living (AAL); ambient intelligence; ontologies; diagnosis; fault detection; reasoning.**

I. Introduction

Due to the demographic change towards an aging population, society must find ways to assist elderly people to stay active at home longer. Currently, this support is mainly provided by human caregivers, but in the future technology is expected to play a more and more important role both for elderly persons and caregivers. In Europe, a roadmap has been defined in the last years called Ambient Assisting Living (AAL). A software platform for AAL was described in our previous paper entitled *An Ambient Assisted Living Framework Supporting Personalization Based on Ontologies* [1]. This paper is an extended version of the latter, which introduces improvements to the self-diagnostic features of the framework.

AAL [2] is part of the larger *ambient intelligence* vision [3], in which information technology supports everyday tasks in an unobtrusive way. The business context of AAL is rich in terms of technology (from tele-health systems to robotics) but also in terms of stakeholders (from service providers to policy makers, including core technology or platform developers).

The work presented here has been carried out within the CBDP project (Context-Based Digital Personality) [4], which aims at creating a framework for building various kinds of ambient-intelligent applications, based around the concept of Digital Personality for representing the preferences of users. Aside from AAL, several application domains were considered, such as digital TV guides, assistants for workers at a construction site, or marketing application on mobile phones. Therefore, the CBDP framework addresses a wide variety of requirements. However, in this paper, we focus exclusively on the parts of the CBDP framework relevant to AAL.

Our approach is entirely based on ontologies. Not only are ontologies used to capture domain knowledge, but more importantly they serve as the runtime mechanism that allows the interconnection of devices, the exchange of data and the execution of actions. The Digital Personality of the users is stored in the ontology.

On top of that, a diagnosis process is able to construct a model predicting the expected sensor readings at runtime, as a function of requested actuator commands. Using this and by observing actual sensor values found in the ontology, it is able to monitor the run-time behavior of the system and to detect unexpected patterns, that are probably caused by failed devices (sensors and actuators).

The ontology is presented in Section II. Section III describes the CBDP framework and gives implementation details. Section IV focuses on diagnosis: it explains what models are used, and how they are exploited. Section V describes a typical AAL use case, and goes through its complete realization. Section VI introduces some related work, and compares our approach with published results. Finally, Section VII gives directions for future work.

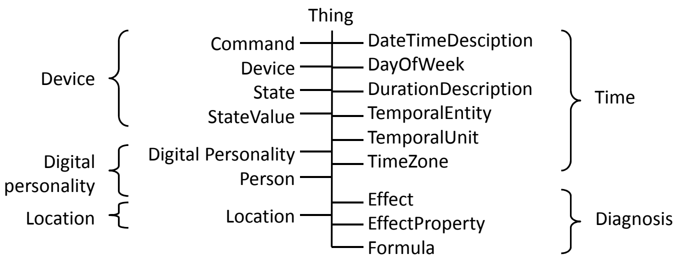

Figure 1. First level of the CBDP ontology.

II. An Ontology for AAL Applications

CBDP is built around an ontology: this section justifies this choice and describes the ontology used.

A. Why use ontologies?

AAL applications are trans-disciplinary by essence (for instance, they can mix automatic control with modeling of user behavior), therefore, the ability to reuse knowledge and integrate several knowledge domains is particularly important for them. Furthermore, the field of AAL is very open and changing, so it is not possible to base an AAL platform on a fixed set of features, on a fixed set of data models: extensibility is key. In addition, an AAL environment may require the interoperation of software and hardware devices from a variety of suppliers: there must be a standard way of exchanging knowledge.

Ontologies are well-adapted to all these needs [5]: an ontology framework provides a standard infrastructure for sharing knowledge. In addition, semantic relationships such as equivalence may be expressed between various knowledge sources, thus permitting the easy integration of several sources or domains. In addition, one can easily extend an ontology to take into account new applications or new devices. For these reasons, leading AAL projects such as OASIS (Open architecture for Accessible Services Integration and Standardisation) have put a strong emphasis on ontologies [6]. Being oriented toward personalization, CBDP explicitly introduces an ontology module for modeling the "Digital Personality" of the user.

B. Ontology used by CBDP

The ontology defined for CBDP is built around the OWL language [7], which is based on the Resource Description Framework (RDF). RDF represents knowledge as a set of *triples* or *statements* of the form {subject, predicate, object}. It models different interrelated domains in a modular way, so as to enable its easy adaptation to new applications. In order to put into practice the aforementioned notion of reusability, two of the domains are based on existing ontologies. Figure 1 depicts the first level of the ontology; the main domains are as follows:

- *Device:* this part is based on the DogOnt [8] ontology that has been simplified for our purpose, while keeping the modeling axes (typology, functionality and state).
- *Digital Personality:* a class *Person* allows the representation of a human being, and a *Digital Personality* stores the person's preferences in order to personalize the services offered to him/her.
- *Location:* a location model is required because most of the services offered in the AAL domain must know the position of the user (in/out the house, in the bedroom/in the kitchen, etc.) and of the devices (sensors and actuators).
- *Time:* we import W3C's existing Time Ontology [9] without any change.
- *Diagnosis:* we introduce the concept of physical effect (see Section IV below), to compute the expected result of the action of an actuator onto a sensor.

The ontology is loosely coupled with the framework, so to a great extent it may be changed without affecting it. However, the basic feature of sending commands to actuators rely on specific *core classes and properties* that may not be changed; this part is depicted in Figure 2.

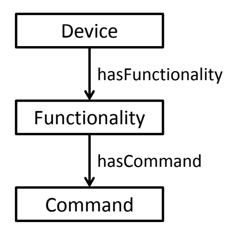

Figure 2. Ontology classes required for proper operation of the framework.

III. CBDP Framework

This section describes the CBDP framework and how it can be used to build AAL applications.

A. Architecture

The main goal of the CBDP Framework is to dynamically handle ontology data and initiate actions when specified conditions in the ontology are achieved. CBDP is written in Java; it is based on OSGi (Open Services Gateway initiative framework) [10], which allows one to build applications flexibly by combining *bundles*. In CBDP, an application is composed of CBDP's core bundles (the Context Reasoner and the Sensor/Actuator Layer, described in Sections III-B and III-C, respectively) and application-specific bundles (see Figure 3). In our case:

- AAL-specific application bundle: contains the rules that define the intended application behavior, meant to assist the user according to his/her needs.
- Zigbee Driver bundle: allows the exchange of data between the physical devices (connected via a wireless Zigbee network) and the CBDP Framework.

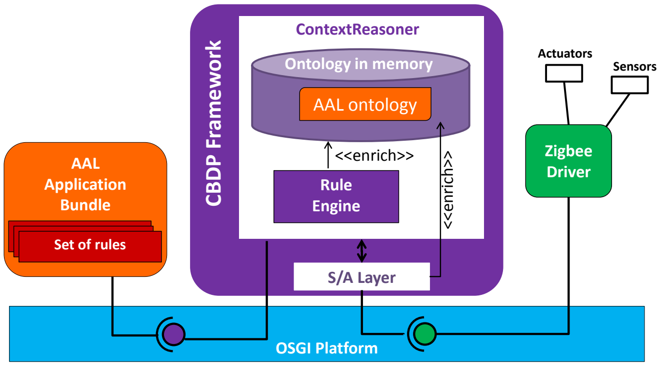

Figure 3. Architecture of the CBDP framework.

Table I
OSGI PROPERTY NAMES USED TO SPECIFY OWL TREES.

Sensor information	
instance.id	URI identifying the sensor (String)
1) When referencing a dataProperty present in the ontology	
data.property	Name of the "simple data" property (String)
data.property.value	Value (depends on property: Boolean, Double, Integer, String...)
2) When referencing an objectProperty present in the ontology	
object.property	Name of the "object" property (String)
object.property.range	Name of the class referenced by the property (String)

B. *Context Reasoner and Rules*

The Context Reasoner is in charge of managing the information coming from external components (AAL Application or Zigbee Driver) by structuring them according to the AAL ontology. Therefore, it provides methods to add new information, retrieve stored information, and perform queries about that information. Manipulation of the ontology is done using the Jena library [11].

Another feature of the Context Reasoner is its rule engine. Its purpose is to perform actions to help the user and facilitate common tasks, based on a set of application-specific rules (hence the rules are provided by the AAL Application bundle). The rules are Horn clauses [12]: a rule is composed of premises that determine the situations in which the rule applies, and a conclusion, that basically adds a new "fact" into the ontology, such as a new property value. An example of such a rule is given in Section V-A below. Rules are applied by Jena's basic reasoning engine, using forward chaining.

For performance reasons, the rule engine does not apply all rules at each instant. The rules are applied only when a change in the ontology matches a *filter* (i.e., happens in a specific part of the class hierarchy). The filters are application-specific; here they are defined by the AAL Application bundle. At first one may use a "catch-all" filter; performance can be improved later by refining the filters.

C. *Sensor/Actuator Layer*

The Sensor/Actuator layer (S/A layer) connects the sensors and actuators to the ontology. The communication is two-way:

- Sensor data (sent through Zigbee) is stored in the ontology. This allows one to perform semantic queries and semantic reasoning over sensor data.
- A command request inserted in the ontology (using a property called *hasCommand*) triggers the actual emission of a command to the actuator.

All exchanges are deterministic. They are are triggered in response to events. The module responsible for connecting the sensors to the Context Reasoner is based on the use of a specific OSGi service called *EventAdmin*. A communication protocol through OSGi events has been defined in order to allow the communication between the drivers and the S/A layer. Section III-D describes this protocol.

D. *Communication between sensors/actuators and the ontology*

This section deals with the protocol used to exchange ontology knowledge using OSGi events. An event is composed of a *topic* and of a list of *properties* ({propertyName; propertyValue} pairs). We have defined two kinds of events: 1) to report sensor data, 2) to send commands to actuators. For both kinds of events, the OSGi *topic* string is built according to the pattern `CBDP/AAL/`*`deviceClass`*. `CBDP` and `AAL` are invariant: they reference the general framework and our application-specific ontology; *`deviceClass`* is the name of the sensor class that sends data, or actuator class that is to receive data. The remainder of this section gives details on the actual *contents* (list of properties) of the events in both cases.

1) Reporting sensor data: When sensor data is reported, a sub-graph (actually a tree) must be created in the ontology. An edge in this tree may be of two kinds: connecting an object to a simple value such as an number ("dataProperty"), or connecting an object to another object ("objectProperty"). A convention using OSGi's properties allows us to completely describe the tree. At each node in the tree to be created, a set of datatype and object properties may be specified. Each edge of the tree is numbered using a simple convention: from the top of the tree, each time an edge is followed, a dot and the index of the edge under its parent node are appended to the OSGi property name (see the examples in Figure 4). This permits the description of each edge and each node to be created. The basic property names (without trailing dots) are given in Table I, and a complete example is given in Figure 4. It represents an event stating that the light level is 500 lux in the kitchen at the date {Calendar value}.

2) Sending actuator commands: Sending a command to an actuator is done using the following convention: a new

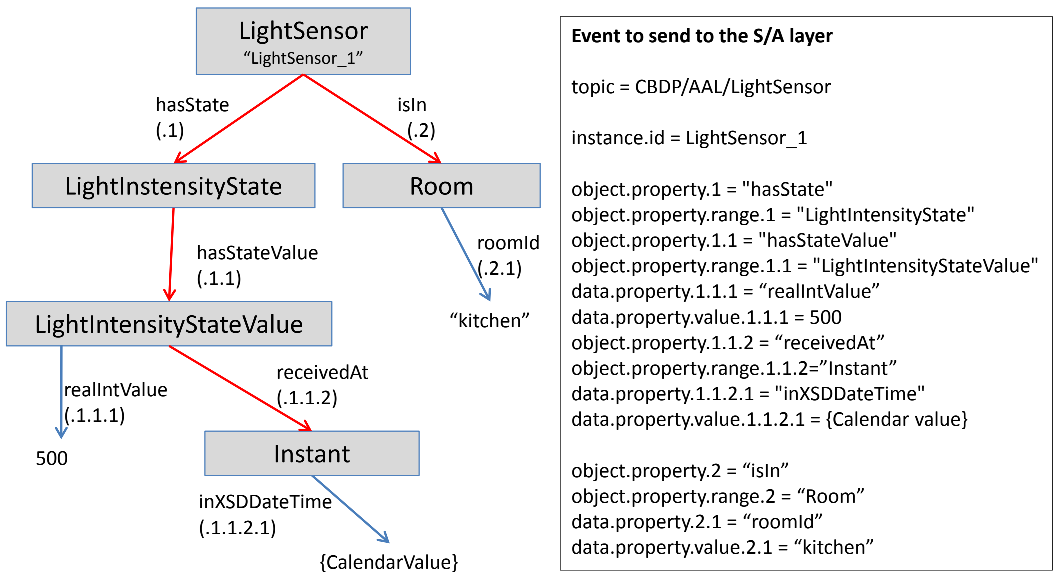

Figure 4. Example of an event containing sensor data.

statement must be added in the ontology, with a relation named "hasCommand" (see Figure 2 above). Such a statement may be added by a reasoning rule, or by application code calling the context manager.

When the S/A layer detects a new "hasCommand" statement, it serializes the corresponding sub-tree of the ontology graph into an OSGi event (using the same convention as above) and sends it to the driver of the target actuator. Figure 5 depicts the "turn light on" event graphically.

E. Deployment

The OSGi implementation used by CBDP is Apache Felix. The use of Java and OSGi permits to deploy the framework on a variety of platforms. We have conducted tests on desktop PCs (under Windows and MacOS) and on embedded systems (on a set-top-box running Linux and on Aonix Perc) [13]. Perc is a Java virtual machine for embedded systems that can be deployed on resource-constrained targets while providing real-time and safety guaranties. This demonstrates the adequacy of CBDP for its target applications, user assistance in ambient environments, i.e., in non computer-centric settings.

IV. Diagnosis

Ultimately, the goal of any AAL application is to activate some actuators, based on data provided by some sensors. However, sensors and actuators may suffer failures. Therefore, the system should check autonomously whether the intended actions are performed correctly. This need for self-diagnosis capabilities of ambient environments was outlined as early as 2001 [3]. Here we focus only on the diagnosis of hardware devices; we do not consider software bugs or runtime failures.

A. Rationale

In software, mechanisms such as exceptions and error codes report whether a procedure executes successfully or not. Likewise, an actuator can provide a return code, but generally this reflects only the way the orders are transmitted to the actuator, not their actual execution. For instance, when the system activates a light bulb, it receives an acknowledgement that confirms the switch-on of the electrical circuit, but this does not necessarily mean that the bulb is really on (the bulb may be damaged for instance). Therefore, a reliable AAL application needs a way to assess at run-time the status of its sensors and actuators.

To address the issue, the designer could apply classical control theory to pre-determine closed control loops using designated sensors. However, the particularity of ambient systems is that physical resources, mainly sensors and actuators, are not necessarily known at design time, but are dynamically discovered at run-time. In consequence, such control loops cannot be pre-determined; the diagnosis strategy needs to be automatically determined at run-time.

We propose an approach in which the system relies only on sensors already available, thereby not requiring the addition of specific devices for diagnosis purposes. The sensors that may be used to perform diagnosis are discovered at run-time. When a sensor measures a physical parameter, the system may deduce sensor/actuator "health" status by comparing actual values with *expected* sensor values.

To achieve this, we propose a diagnosis framework in which the characteristics of actuators and sensors, as well as the *physical effects* involved, are precisely described. The following paragraphs provide a high-level description of this approach; refer to [14] for more details.

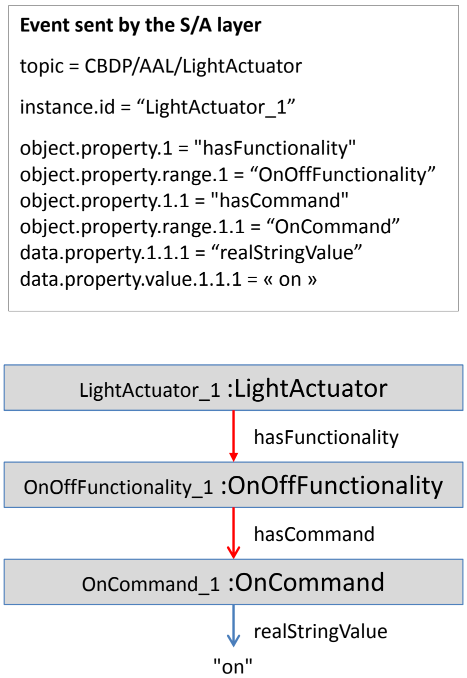

Figure 5. Example of an event containing a command, to be transmitted to an actuator.

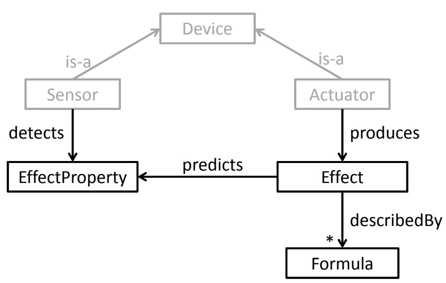

Figure 6. The diagnosis framework adds to the general-purpose ontology (gray part at the top) a few concepts to describe the effects and their detectable properties.

B. Modeling physical effects

Effects are modeled in order to predict the physical consequences of actions in an ambient environment. Each effect is characterized by a set of properties: some *define* the effect (at the source actuator, e.g., the light intensity *emitted by a light bulb*), some are *observable* by a sensor (e.g., the light intensity *received by a light sensor*).

Depending on the application's needs, an effect can be defined at various levels of granularity. For instance, the light emitted by a light bulb could be modeled either using classical laws of physics for light propagation, or using a simple boolean law (“if a light bulb is on in a room then the light sensors that are in that room should detect light”). The choice of the right level of granularity depends, among other things, on the context of use, for instance assisted living homes for blind persons may require a very detailed definition of the model for the propagation of sound waves.

We consider that an effect can be described by some mathematical formula, or set of formulae. For instance, the propagation of light within a room may be modeled by the following functions:

$$\mathtt{distance}(A,B) = \sqrt{(A.\mathtt{x}-B.\mathtt{x})^2+(A.\mathtt{y}-B.\mathtt{y})^2} \quad (1)$$

$$\mathtt{illum}(A,B) = \frac{A.\mathtt{flux}}{(\mathtt{distance}(A,B))^2} \quad (2)$$

$$B.\mathtt{illuminance} = \sum_{A\in\mathtt{LightActuators}} \mathtt{illum}(A,B) \quad (3)$$

The notation $Obj.\mathtt{prop}$ refers to property *prop* of object *Obj*. In the formulae above, A and B stand for any ambient objects modeled by the system. $\mathtt{LightActuators}$ is the set of light actuators. Formula (1) defines a function, called $\mathtt{distance}$, that computes the planar distance between two ambient objects A and B. In formula (2), $\mathtt{illum}(A,B)$ is the luminous illuminance contributed by object A onto object B. Formula (3) states that the total illuminance of object B is the sum of the individual contributions of every light actuator onto object B.

C. Using effects for linking actuators to sensors

As ambient systems are highly dynamic, one cannot explicitly link related sensors and actuators. The concept of effect allows for easy decoupling of devices, as illustrated by Figure 6. An actuator class is linked to the effects it may potentially produce. Similarly, a sensor class is linked to at least one effect property. At a generic level, there is a link between a given effect (e.g., emission of light) and the corresponding detectable properties (e.g., illuminance) through the *predicts* relation. A specialization of the abstract level of Figure 6 is presented in Figure 7.

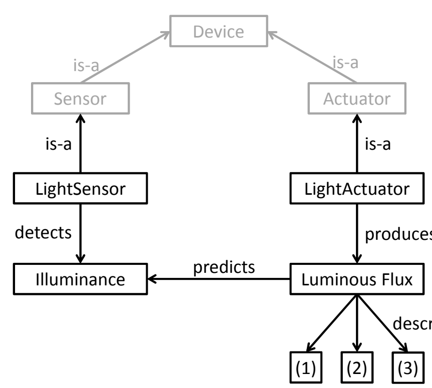

Figure 7. Specialization of the abstract ontology level to account for a specific effect: the emission of light. (1), (2) and (3) refer to the corresponding formulae defined in the text.

Knowing the effects produced by any actuator in the system, and knowing the effect properties sensed by any sensor in the system, it is therefore possible to determine and update at run-time the links between actual sensors and actuators.

We construct a *prediction model* that constitutes an instantiation of the effects for a given set of actuators and sensors, in a given configuration. The formulae are applied to actual objects; the "iterative" expressions (such as the *capital-sigma* notation used in formula (3)) are expanded in accordance to existing objects. The prediction model is updated each time a new object is introduced in the ambient environment, and each time an object is removed. However, for mere variations of property values, it is not necessary to update the model; one only needs to compute the predicted values again with the new property values.

D. Example: light sensors and actuators

Let us suppose that two light actuators `la1` and `la2`, and a light sensor `ls1`, are introduced in a room. The types of devices and the instances are presented in Figure 8. Note that initially there is absolutely no link between the actuator and the sensors. The links will be deduced automatically using available information.

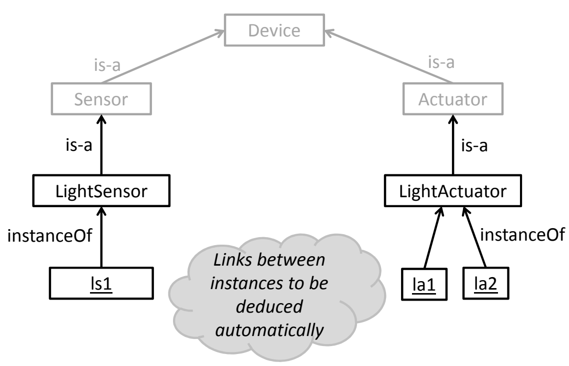

Figure 8. Instances of sensors and actuators created for the example situation, in which two light actuators and a light sensor are placed in a room.

Using formula (3), and by simple rewriting rules, we can successively deduce that:

$$\begin{aligned}&\texttt{ls1.illuminance} = \\ &\qquad \texttt{illum(la1,ls1)} + \texttt{illum(la2,ls2)}\end{aligned} \tag{4}$$

Then:

$$\begin{aligned}&\texttt{ls1.illuminance} = \\ &\frac{\texttt{la1.flux}}{(\texttt{distance(la1,ls1)})^2} + \frac{\texttt{la2.flux}}{(\texttt{distance(la2,ls1)})^2}\end{aligned} \tag{5}$$

And finally:

$$\begin{aligned}&\texttt{ls1.illuminance} = \\ &\quad \frac{\texttt{la1.flux}}{(\texttt{la1.x} - \texttt{ls1.x})^2 + (\texttt{la1.y} - \texttt{ls1.y})^2} + \\ &\quad \frac{\texttt{la2.flux}}{(\texttt{la2.x} - \texttt{ls1.x})^2 + (\texttt{la2.y} - \texttt{ls1.y})^2}\end{aligned} \tag{6}$$

We obtain what we call a *prediction model*, here a formula that depends only on object properties, and that can be used at any time to predict the expected sensor readings. Once the expected results have been determined, the system checks if they are consistent with the actual readings.

V. EXPERIMENTATION

This section introduces a complete AAL scenario in which the CBDP framework is able to automate tasks, it shows how diagnosis is performed, and it describes the experiments.

A. Use case: automatic light switch

We propose an experimental scenario that takes place in a bedroom. There is a controlled lamp, a light sensor and a presence sensor. There is also a human-operated lamp on a table, whose light level can be adjusted manually. The system may not control the latter, but the position of the adjustment knob, and hence the expected light level, is known.

The purpose of the scenario is to help elderly people avoid finding themselves lost in the dark. The expected system behavior may be summarized by this rule: "if the ambient light level is under a threshold (specified in the Digital Personality of the user) and if the user is present in the room, then the light must be turned on". Although simple, this scenario demonstrates all the aspects of the system: sensor data gathering, reasoning, command of actuators and diagnosis.

Figure 9 shows what input and output devices are used for this experimentation. They are all Zigbee devices controlled by the aforementioned Zigbee driver, which connects to the CBDP platform through OSGi. Note that the light sensor detects light emitted by both lamps, the controlled one and the human-operated one.

Let us suppose that the illuminance in the room is 80 lux (due to the human-operated lamp being dimmed for instance). Then, the user comes in. His Digital Personality states that he does not like to be in a room where the illuminance is under 100 lux. The system takes the following steps:

1) The current illuminance (80 lux) has already been detected and updated in the ontology. When the user enters the bedroom, the presence sensor sends a notification to the driver through the Zigbee network. The driver sends then an event to the framework and the ontology is updated accordingly.

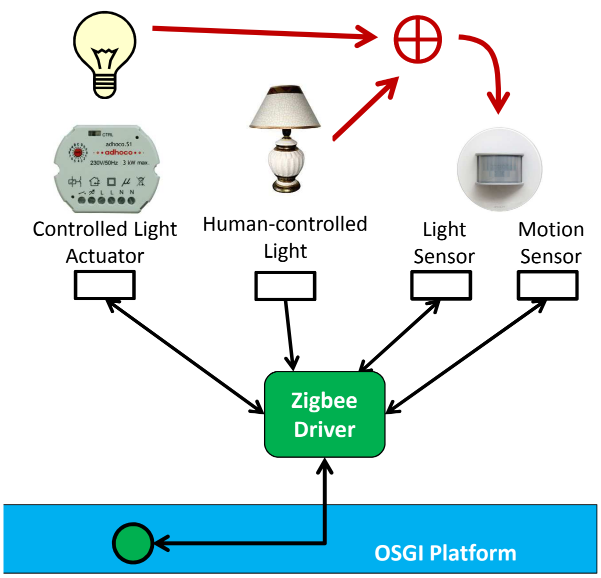

Figure 9. Input/output configuration of the experimentation.

2) The framework detects that the value of a PresenceSensor has changed in the ontology, so the rule outlined in Figure 10 must be evaluated (cf. III-B). Pseudo-natural language is used in Figure 10 for the sake of simplicity; in practice, it is expressed in the formal syntax specific to the Jena reasoning engine as shown in Figure 11.
The reasoning engine reads the current light level, the current presence status and the user preferences in the ontology. The premises of the rule are true, so the conclusion must be executed. To determine which rules to apply, Jena uses a classical *forward chaining* reasoning algorithm.
3) The rule causes a new statement to be added in the ontology: {LightActuator, hasCommand, "on"} (cf. III-C and III-D). The *hasCommand* predicate is detected by the Sensor/Actuator layer, and in consequence, the framework sends an event to the driver asking for the LightActuator to be turned on.
4) The driver commands the light actuator through the Zigbee network. This actually turns the light on.

B. Diagnosis

At this point, the framework performs diagnosis so as to determine if the action has been executed correctly. Both LightActuators are "light effect" producers; the LightSensor measures the "illuminance" value of "light effect". They are all described independently, The system deduces automatically a *prediction model* that links them (see Section IV-C). Here, the prediction model was built at system startup since the objects did not move afterwards. The procedure followed to obtain the prediction model and the eventual

```
IF a LightSensor value is <
   {userPreference in the Digital Personality}

   AND a PresenceSensor detects somebody

   AND the LightSensor, the PresenceSensor
    and a controllable LightActuator
    are in the same room

THEN Turn the LightActuator on
```

Figure 10. Example of rule ("turn the light on") expressed in pseudo-natural language.

```
[CMD_LIGHT_ON:
    (?MS RDF:type AMI:PresenceSensor),
    (?LS RDF:type AMI:LightSensor),
    (?LA RDF:type AMI:ControlledLightActuator),
    (?R RDF:type ?RT),
    (?RT RDFS:subClassOf AMI:Room),
    (?MS AMI:isIn ?R),
    (?LS AMI:isIn ?R),
    (?LA AMI:isIn ?R),
    (?DP RDF:type AMI:AAL_DP),
    (?DP AMI:isCurentDP ?curDP),
    equal(?curDP,'true'),
    (?DP AMI:low_AAL_LightThreshold ?LLT),
    (?MS CORE:realStateStringValue 'personInside'),
    (?LS AMI:realIntValue ?LMV),
    lessThan(?LMV,?LLT),
    (?F RDF:type AMI:OnOffFunctionality),
    (?LA AMI:hasFunctionality ?F),
    (?C RDF:type AMI:OnCommand)
                    -> (?F AMI:hasCommand ?C) ]
```

Figure 11. Example of rule ("turn the light on") expressed in Jena's syntax.

prediction model built have been described in Section IV-D. The prediction model is Formula (6). All the system has to do now is use this formula to calculate the expected illuminance in the room. The steps go on like this:

5) Applying Formula (6) with the current values for all object attribute yields 120 lux, which is the value expected to be read by the light sensor.
6) The illuminance actually measured by the light sensor is still 80 lux, so the system deduces that there is a failure: either the actuator or the sensor is broken. However, it may well be the case that there is another light sensor in the room. In this situation, it will be automatically discovered just like the first one. If the second light sensor reads the same value as the first one, then the faulty component is most probably the light bulb. If conversely the second light sensor detects an illuminance value close to the theoretical expected value, then the first light sensor is most probably faulty.
7) The system finds it most probable that the bulb is burnt out. An error notification is generated so that the user 1) confirms the cause the problem, and 2) possibly to fixes it (often, even an elderly person is capable of replacing a light bulb). Therefore, a "negative"

diagnosis should generate an error notification of some sort asking the user to replace or to check the real state of the light bulb (for a discussion on the acceptability of notifications in a home environment, see for instance [15]). The user's feedback can be added as a statement to the ontology, and can be useful for further reasoning about the light bulb. We can imagine a case in which the user's feedback confirms that the light bulb is properly illuminated even though the system says it is not; in that case, the system deduces that the sensors are not functioning properly.

C. Implementation and Results

This experiment uses the standard CBDP framework, with a bundle containing its specific rules. An interface allows one to choose which user (characterized by their *digital personality*) should be simulated (Figure 12). In a real setting, there would be sensors to detect the particular user: these could be a set of RFID tags and readers, or the Ubisense system [16] for example.

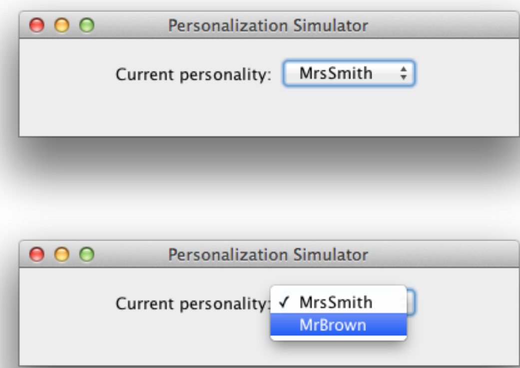

Figure 12. Selection of the digital personality of the user.

The experiment was conducted in two ways:

- using a simulator of the sensors, actuators and physical environment,
- using physical devices in an actual room.

Figure 13 shows the interface of the simulation environment. The experimenters can act on the light level of the human-controlled lamp, on the motion sensor, and they can also introduce a defect in the controlled light bulb. Both in simulation and in real conditions the system displays a message with the current diagnosis (Figure 14). The tests performed showed that the example runs as expected.

VI. Related work

Ontologies are often at the heart of ambient-intelligent systems, and especially AAL systems, such as in OASIS [6]. In 2003, CoBrA (Context Broker Architecture) was an ontology-based framework for ambient settings [17]. In 2004, SOUPA (Standard Ontology for Ubiquitous and Pervasive Applications) [18] was one of the first attempts to define an application-agnostic ontology for ambient systems, but it is specifically aimed at agent-based architectures. More recently, Paganelli et al. [19] introduces a tele-health platform, which is based on an ontology for describing context and medical conditions. The SOPRANO project [20], [21] defines a specific ontology that serves as a unifying vocabulary between software components. In our work, the ontology is specifically used to personalize the system; it stores preferences, and contains application-specific modules. Moreover, we not only reason to infer new facts about context as done in many platforms [22], but also to trigger application-specific behavior, and to actually *trigger actions*, i.e., send commands to actuators. This makes the framework flexible and allows the easy integration of additional services such as the diagnosis framework described in Section IV.

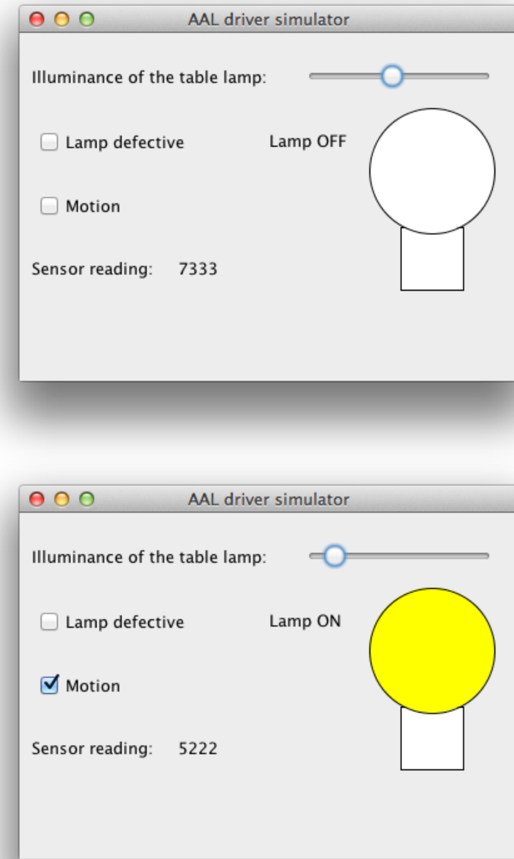

Figure 13. Interface of the simulated environment. The user may act on the human-controlled table lamp, as well as on the presence of motion. The interface displays the current state of the system-controlled lamp.

Our choice of using the OSGi middleware was motivated

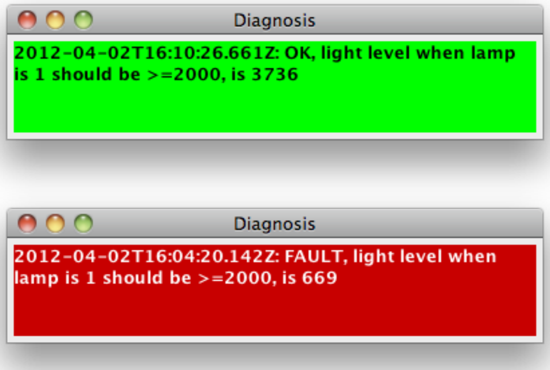

Figure 14. Window showing the results of the diagnosis.

by previous successful attempts in the field of ambient intelligence, such as in the AMIGO IST project [23]. CBDP's generalized reliance on ontologies makes the use of OSGi very consistent with the rest of the framework.

Some works focus on ontologies for specific domains. For instance, Hois [24] describes a well-grounded framework for the description of spatial relationships and spatial reasoning. This kind of contributions could be integrated into the CBDP framework, due to the reusable nature of ontologies.

Sun [25] cites three challenges for AAL systems. Our work is focused on technology, not on social aspects, so we do not address the challenge of having people accept AAL systems. However, we propose solutions to the two other challenges: the dynamic availability of services is handled by relying on an ontology-supported OSGi architecture; the ontology is used for mapping the available services and devices. For instance, relations between a sensor and an actuator may be deduced automatically.

The detection of faults induced by incorrect adaptation patterns in context-aware adaptive application has been studied, and methods based on *static* analysis have been proposed [26]. While it could be interesting to apply these tools AAL systems, we have chosen to focus instead on the detection on *runtime* failures due to unexpected hardware faults. The two approaches are complementary: the former deals with the correctness of adaptation patterns; the latter deals with runtime breakdowns.

The need for self-diagnosis of systems at runtime has been highlighted in the context of autonomic computing [27]. This naturally applies to pervasive systems and ambient environments as well. A vast amount of work has been done to diagnose sensors. For instance, Bourdenas [28] categorizes the classes of faults at sensors, in term of erroneous readings, and explains how to cope with them (self-healing). Indeed, a faulty sensor may be identified by recognizing specific patterns in its readings. Likewise, one can monitor processes or computing devices by analyzing the messages they send and their current state (running threads, memory and power consumption, etc.) [29]. In contrast, realizing that an actuator has become faulty is a different matter, that necessitates to take into account the physical phenomena induced by this actuator. This is where the framework presented here comes into play.

VII. Conclusion and Future work

We have presented a complete framework that supports the creation of AAL applications. This framework is based on the use of an ontology at the core of the system. This ontology contains application-specific knowledge and stores user preferences ("Digital Personality"). Besides, it handles all the run-time information flows: it aggregates sensor data, allows rules to be applied on this data so as to generate commands, stores the commands, and provides the commands to the actuators.

Using an ontology allows one to specify the behavior of an AAL application in terms of easy-to-write logic rules. These rules can rely on any piece of knowledge present in the ontology, therefore, they are not limited in any way by the core ontology that comes with the CBDP framework. Such extensibility is made easy by the use of widespread knowledge engineering standards, namely RDF/OWL.

The other significant contribution of this paper is the diagnosis framework that monitors the run-time behavior of an AAL system by observing changes in the ontology. Currently we take into account only the current state of the system. In reality, the relevant measure might not be the current absolute value of a physical parameter, but rather its *relative evolution*. For instance, when light is switched on, it may be most relevant to consider the *relative increase of the light level*, as the absolute value may vary other time without any action being taken (depending of the intensity of the sun for instance). This prompts us to introduce *dynamics* in the diagnosis framework. Likewise, some physical laws may depend upon quantitative *time* (for instance, the effect of a radiator in an initially chilly room is a slow increase of temperature over time). This is currently being investigated.

We also plan to test such a system in real scale, for example at the homes of elderly people. This will allow us to refine the rules that define the system behavior.

Acknowledgement

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A Critical Insight into the Evaluation of e-Government Policies: Reflections on the Concept of Public Interest

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***Abstract*–The concept of e-government was expected to support the development of the new public sector paradigm and the emerging socio-political trends, endorsing efforts for deliberative and democratic decision-making processes, and advocating the effective, accountable and transparent management of public affairs. In reality, very little of the above-mentioned was achieved, indicating that the current policy-making in the e-government field is inadequate, whereas lacking comprehensive and objective evaluation methodologies consequently results in poor quality planning and implementation of e-government policies. Despite the growing research interest in the last decade or so, the existing evaluation methodologies have been often only marginally and superficially targeting and evaluating the notion of the public interest articulated and addressed by the e-government policies. Moreover, the evaluation of the public interest dimensions is frequently rendered particularly with the evaluation of financial benefits of the e-government policies, additionally reducing the applicability of the evaluation methodologies and undermining the legitimacy of the evaluation results used for strategic planning. Paper provides an analysis of more than 50 methodologies for the evaluation of e-government policies, exploring their capacity and extent to which they facilitate the evaluation of the public interest implemented by the e-government policies. Analysis offers an insight into the current evaluation practice enabling detection of its deficiencies, and could facilitate a significant contribution to the inclusion of the public interest concept in the future design of the evaluation methodologies and provide support to more evidence-based policy-making in the e-government field.**

Keywords-e-government policy; evaluation methodology; analysis; evaluation levels; public interest

I. INTRODUCTION

The paper is an extended version of the conference paper entitled "Evaluation of e-Government Policies: Overlooked Aspect of Public Interest" presented at the SOTICS 2012: The Second International Conference on Social Eco-Informatics, October 21 - 26, 2012 - Venice, Italy [1]. In this extended version, we provide a substantially revised paper including a review of the recent developments in the e-government research field, more elaborate description of the public interest concept, and a comprehensive analysis of the methodologies for the evaluation of e-government policies regarding their maturity, evaluation focus and ultimately the extent to which they facilitate the evaluation of the public interest concept implemented by the e-government policies. The paper at hand additionally features a discussion of the research results and future trends in the design and implementation of e-government policies.

The research of the e-government phenomenon, being generically defined as the continuous redefinition of the government operations based on the use of Information and Communication Technology (ICT) and other internet-related applications in its everyday internal and external transactions, has expanded heavily in the short development era. In the field of business informatics, the attention of researchers has moved from purely technological solutions and perspectives, to business processes, organizational and economic viewpoints of ICT integration, and the similar shift can be noticed in the case of e-government. Namely, until the first half of the previous decade, technological aspects of e-government research have been prevalent. However, later on, the attention has started moving rapidly towards questions related to usability and usage of e-government services, and in the last years, issues related to successful planning and implementation of e-government policies on different levels (national, regional, local) and in different sectors (e-health, e-education, e-social affairs, etc.) are becoming increasingly important. This shift in research focus is understandable; since various studies indicate that further e-government development is one of the most important factors of public sector rationalization [2][3][4], as well as faster countries' development [5][6][7]. Despite considerable investments in e-government in recent years (European Union (EU) countries are investing approximately 2.2% of Gross Domestic Product (GDP) in ICT in the field of public sector [8][9][10]) the expected effects in terms of reducing costs and increasing the effectiveness of public sector are still rather ambiguous, while user acceptance of e-government services is far below government anticipations. Disclosed issues and present public finance situation along with increasingly stringent austerity measures require careful direction of further e-government investments, particularly focusing on the proficient evaluation of e-government policies and their effects – be it on national, local or sectoral level.

Past experience in the field necessitates the development of the methodologies for the evaluation of e-government policies (the collective term "methodologies" will be used hereinafter, denoting different approaches, indicator models, benchmarking measurements, assessment frameworks and similar undertakings for the evaluation of e-government policies), which could enable e-government decision-makers to conduct more qualified and quantified preparation, execution and evaluation of e-government policies including their broader societal implications. Considering e-government development so far, we have been witnessing a big gap between supply and demand of public e-services in most countries, which can be prevailingly attributed to "politically driven" development rather than "evidence based" evaluation and selection of e-government policies [11][12][13]. Earlier research has shown that some countries [14][15][16] have been accomplishing much better results in evaluation and implementation of e-government policies compared to several other countries with much higher investments. Past experience in the field and public finance trends evidently require the development of the methodologies for the evaluation of e-government policies which could enable e-government decision-makers to conduct more qualified and quantified preparation, execution and evaluation of e-government policies – be it before or after their implementation (ex-ante or ex-post).

The existing methodologies for the evaluation of e-government policies lack a unified and clear theoretical framework [13], implying they are mostly arbitrarily designed, and aimed at specific evaluation needs and objectives. The latter arise from various reasons: different (EU, UN, Brown University, Economist Intelligence Unit, etc.) and heterogeneous promoters (international, national, consulting, research institutions, etc.), diverse environments, various rationales and contextual background as well as the number and selection of indicators. Significant differences between the evaluation methodologies are reflected within their main evaluation focus and evolving stage. Namely, the evaluation methodologies vary widely depending on the evaluation levels within e-government policies they are predominantly focused on (infrastructural level, project level, organizational level, etc.), and the development levels they achieved, describing the degree of their application in practice (conceptual framework, pilot application, practical application).

Notwithstanding the increasing number of the different evaluation methodologies emerging in the last years [14][15][16], some aspects of the evaluation of e-government policies have been largely disregarded, particularly public interest, as one of the foundations of public policy-making. This rather unsatisfactory state of affairs has led to growing calls for a reassessment and rebalancing of the rationalizations in the evaluation of e-government policies, and in particular for a greater weight to be given to the public interest [17].

The paper discusses the main features of the existing methodologies for the evaluation of e-government policies and analyzes their evaluation foci trying to establish the extent to which the existing methodologies facilitate the evaluation of the public interest. Deriving from the aforementioned research objectives, the paper is focusing primarily on the following interrelated research questions:

1) Overview and study of the existing methodologies for the evaluation of e-government policies and summary of their characteristics.
2) Analysis of the existing methodologies for the evaluation of e-government policies regarding the aspect of public interest.

From the methodological point of view, research represents an in-depth analysis, while research activities are embedded in two-phase incremental methodological framework. Combining different techniques of qualitative research methods [18], the initial part of the study has focused on the analysis of primary and secondary sources, whereas deriving from obtained research results, the conclusive part of the research is striving to integrate theoretical and practical aspects regarding the research subject. Selection of research methods was adapted to the research field [18][19] given the complexity of e-government evaluation initiatives.

Following the introduction, the second section of the paper presents the concept of public interest and an overview of the relevant literature while outlining various directions in the evaluation of e-government policies, key evaluation levels within the existing evaluation practice, and related issues and barriers. The third section provides an analysis of the existing methodologies for the evaluation of e-government policies and summary of their general characteristics. The fourth section explores the presence of the public interest aspect and sketches the research findings regarding the representation of the public interest dimensions in the existing evaluation methodologies. The discussion of the research results emphasizing the future trends in conceptualization and implementation of e-government policies is contained in the fifth section. The last section outlines the limitations and applications of the proposed research, and subsequently submits the final arguments and observations regarding the research results and future work.

II. Concept of Public Interest and Methodologies for the Evaluation of E-Government Policies – State of the Art

The public interest is not a unitary concept: different public interests are relevant in different scenarios and need to be weighted differently depending on the circumstances [16]. Public policy makers, expert public and citizens have to find the appropriate balance of the numerous public interests that may exist in any given situation. Finding this balance will not only involve comparing the relative importance of one public interest to another but also involve the contemplation of the interconnection of public interests and considering the broader impact that these may have in turn on other public interest networks [20].

Although there are different conceptions of public interest inaugurating different research perspectives, most frequently, public interest is viewed as a set of substantive ideals against which all policy proposals should be judged. The concept is thus recognized as a symbol to which all agree (few people are opposed to the public interest) and to which special interests appeal in order to rationalize their policy desires [21]. Regarding the contextual platform consisted of political and cultural framework of a particular society and the economic resources at its disposal, the public interest is defined as the aggregate of the fundamental goals that the society seeks to achieve for all of its members – not for a majority of its members or for any large and powerful group, but for all of the people within the society. Considered separately, a society's goals are often in conflict with one another, and in that case there must be a balancing. Thus, the art of government consists of achieving a harmonious rather than a destructive balance among conflicting goals [22]. Some authors have studied the public interest concept from the aspect of substantive truths or principles. These truths or principals are not formal tests that any public policy must meet; however, general they may be and however, much skill may be required to apply them in particular cases, they provide substantive guidance to the proper content of public policy [23]. While others consider public interest and its dimensions primarily as a process of public action, primarily bargaining and competition between different interest groups, resulting in the overall social consensus [24]. Summarizing numerous and occasionally complex definitions of the public interest concept, it can be generally regarded as a set of commonly agreed goals arising from the inclusive and transparent deliberating procedure, based on compromise and shared values of well-defined social community.

Despite its complexity and diversity of research approaches and perspectives, the public interest concept is elaborated relatively well in theory, whereas it has failed to gain significant attention in the majority of e-government evaluation undertakings. Consideration of the public interest concept in methodologies for the evaluation of e-government policies is often inadequate and superficial covering prevailingly financial factors and omitting all other societal aspects while reducing the potential of the evaluation process for objective and comprehensive evaluation.

A. Methodologies for the evaluation of e-government policies

In parallel to e-government development, there have emerged numerous methodologies, trying to evaluate its development and effects on different parameters of government operation. According to their characteristics and subject of the evaluation, these methodologies could be classified in typical groups presented below.

1) Front-office maturity and readiness

The most known benchmark measurements on the EU level have been conducted by Capgemini [8][9][10], while the most renowned benchmark measurements on the global scale have been carried out by the UN [15][25], Accenture [26] and Brown University [27]. While focusing primarily on the web site analysis, these methodologies used completely different indicators (from measuring 20 specific e-government services to web-based analysis of national portals, particular ministry portal, etc.). Indicators from these methodologies are not precise enough to ensure the comprehensive evaluation and validation of e-government policies on the national level (see critical analysis of such benchmark measurements from [13][28][29], etc.). On the other hand, some important benchmark measurements dealing with e-readiness or so-called e-government readiness, which could form the basis for planning of the necessary infrastructure for e-government development are: The Global Information Technology Report [16], Digital economy rankings [30] and United Nations e-Government Survey [15][25]. These benchmark measurements deploy different sets of indicators for benchmarking e-readiness and information society in general. Being predominantly focused on front-office change and infrastructural requirements during the conceptualization and implementation of e-government policies, these rather extensive methodologies are hardly providing the evaluation of the public interest, incapacitating its incorporation in the process of further e-government development.

2) Effects and impacts of e-government policies

Within a number of methodologies focusing on ex-ante and ex-post evaluation of e-government policies we could highlight: MAREVA [31], eGEP [32], WiBe 4.0 [33] and Australian AGIMO [34]. MAREVA and accompanying tools are dealing with the ex-ante and ex-post evaluations of e-government policies on the basis of parameters such as profitability, risks, benefits to external users and civil servants, services and project necessity; similar aspects are evaluated by WiBe 4.0. Main purpose of eGEP is to identify and analyze costs of establishment, provision and maintenance of e-government services on the EU level, as well as to develop methodology for the evaluation of their performance, and conduct an economic analysis of e-government impacts. AGIMO has additionally developed the demand and value assessment methodology. In general, we could find these methodologies very exhaustive in terms of the large number of indicators; however, they rarely address the concept of public interest comprehensively, while particular narrow dimensions of public interest are normally amalgamated with financial benefits.

Implementation of e-government policies significantly affects public sector organizations. Focusing on different organizational dimensions Klievink and Janssen [35] analyze joined-up e-government model, Fleur van Veenstra et al. [36] explore organizational changes in the direction of network government, Schedler and Schmidt [37] analyze management, organizational culture and external factors, which affect e-government development, Scholl [38][39] studies business process change, information management capacity and organizational capabilities, while Leitner and Kreuzeder [40] highlight organizational culture aspect as being the one most affected by the e-government initiatives.

An overview of related methodologies reveals there is no clear consensus on organizational changes caused by e-government implementation, and consequently no comprehensible methodology to measure significant implications of transformed public sector organizations for the various social aspects and implementation of public interest.

3) National-level development

External factors have very significant impact on e-government development; surveys often highlight political and sociological factors as the most important external factors. This aspect is partially discussed in United Nations e-Government Survey [15][25] through indicators such as e-participation, e-inclusion, e-consultations, e-decision-making. Study of Martin and Byrne [41] focused on critical factors of information society development and analyzed components of this concept. Their survey provides a set of political and sociological indicators for the evaluation of e-government such as accessibility, digital divide, north-south divide, human rights, social welfare, social inclusion, economic sustainability and life-long learning. However, we can see that such indicators are very general and it is hard to incorporate them in a national context and determine their actual impact and correlation with e-government development. Activities on national economic level could significantly affect e-government development in individual country [12], so national economic factors must not be neglected. Bavec and Vintar [42] developed a model in their study, which aimed to identify relationships between national economic indicators and e-government indicators on the national level and on the EU level. National economic indicators surveyed in presented study comprised: GDP per capita, competitiveness, economic performance, government efficiency, use of ICT in the private sector, innovation index and internet access. The study above is one of the few trying to define correlation between national economic indicators and e-government development indicators. Research work in this field is rather limited; Kim [12] and Singh et al. [43] are partially dealing with national economic indicators and their implications for e-government within their research work. The aspect of public interest within outlined methodologies is poorly elaborated and thus inadequately evaluated, while it appears that identification and formulation of vaguely indicated long-term public goals is hardly reached by public consensus.

4) Evaluation of e-government policies – issues and barriers

Evaluation of e-government policies is generally difficult [7][9][28][29], given the numerous obstacles to the evaluation (Table 1) [44], complexity of the public interest and frequent lack of clarity of objectives owing to the different and often competing views held by different stakeholders. In addition, overlapping initiatives and policies and their continuous fine-tuning related to volatile public opinion complicate monitoring and evaluation. The fact that e-government is relatively new is probably the main reason for fewer models and actual outcome experiences that can be used for benchmarking [44] and inclusion of public interest dimension. Problems addressed become aggravated trying to evaluate particular e-government projects. ICT projects are hard to evaluate because of the pervasive nature of ICTs, the integration of ICT goals with public policy goals and the organizational changes that necessarily accompany e-government initiatives. In addition, evaluators are often faced with a lack of data caused by the piecemeal management of the project documentation. Although materially incomplete and discrepant to the actual data, the project documentation is usually tailored to the financial reporting standards, which additionally distorts the real picture and consequently prevents quality evaluation process.

TABLE I. OBSTACLES TO E-GOVERNMENT EVALUATION

Obstacle	Example
Lack of clarity of objectives - stated goals may not have associated measures of progress; there may be multiple objectives	Hard to measure "quality of life".
Hard to define success	If people are spending more time online, is that good or bad?
Easy to be too ambitious	Several countries have set targets of "all services online" by specific dates. But not all services are appropriate to put online.
Information paradox	The benefits of ICT investment may not be visible for some time.
Question of who are the clients; multiple clients	Should one evaluate benefits for the users, the employees, the government at large, partners, etc.?
Hard to measure shared benefits	Shared infrastructure, multiple projects benefiting from shared portal, etc.
Private sector tools may not work for governments	Governments place importance on social values that are not incorporated into private sector tools and objectives.
Available indicators may not be the good ones	Current indicators (such as number of employees with internet connections) are helpful, but have limits.
Government definitions and methodologies vary from one country to the next	Collecting data is easier at the local level, but at that level administrations are highly decentralized.
Incentives to misstate evaluation results	If an organization succeeds in saving money, telling others may result in their losing that money.
Challenge of sharing results	Hard to get organizations to report unsatisfactory results.
What you measure may become focus of organization	If you measure number of services online, but not service quality, priority will be on putting services online but not on service quality.

The effective evaluation including the aspect of public interest requires good metrics, regular monitoring and reporting, disciplined and professional use of the robust evaluation frameworks, and use of the long-term evaluation practices. These qualities depend on a government's overall evaluation culture [44]. E-government project failures could have been mitigated by appropriate and comprehensive evaluation in the course of their conceptualization and planning [13][45][46]. The identification and elimination of the main obstacles to e-government evaluation, which obviously extend to several areas, such as: institutional, political, social, and cultural area, will require a broad consensus and strong commitment of all stakeholders

B. *Key evaluation levels within e-government policies*

Besides categorization according to the subject of evaluation, overview of the existing evaluation methodologies reveals they can be applied on the different evaluation levels within e-government policies. Majority of the methodologies mentioned so far are partial and mostly focused on the particular evaluation level within e-government policy. These evaluation levels are not explicitly defined, although a detailed analysis of the current evaluation practice facilitates the extraction and synthesis of the relatively stable and constant evaluation levels, which are covered by the existing evaluation methodologies. These evaluation levels are illustrated in Figure 1, and outlined below:

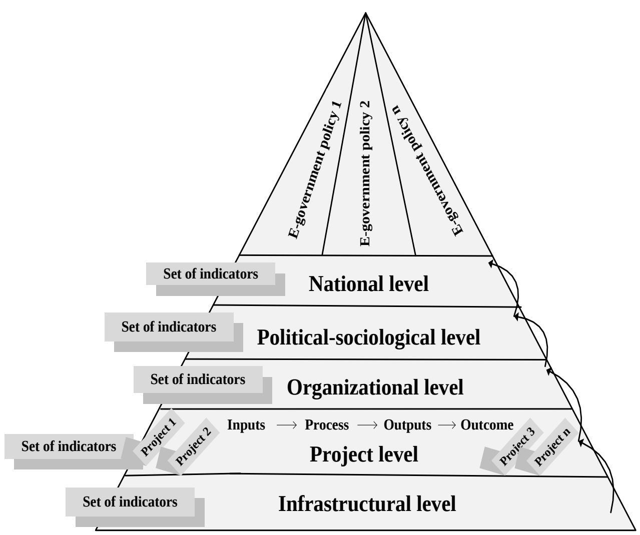

Figure 1. Evaluation levels within e-government policies.

- Evaluation of infrastructure investments: costs of ICT infrastructure, data infrastructure, human resources, legal framework (infrastructural level);
- Evaluation of inputs, processes, services, operational and maintenance costs, outputs and outcomes of e-government projects (project level);
- Evaluation of transformational effects: changes in back-office, the reduction of hierarchical levels, business process reengineering, outsourcing, reduction of administrative barriers, costs and burdens, etc. (organizational level);
- Evaluation of political and sociological effects: transparency, openness, corruption, user satisfaction, democratization, participation (political-sociological level);
- Evaluation of economic impacts: costs, public benefits, effects on GDP, competitiveness index, economic growth, sustainable development (national level).

1) *Infrastructural level*

Infrastructural level primarily refers to maturity or environmental readiness for e-government and e-commerce. Research in this area is focused either on the internal or external aspect of e-government. The internal aspect research is primarily engaged in [47][48]: strategies, policies and action plans for development of e-government, the legal frameworks for e-business, policies for ICT usage, the existence and use of appropriate information infrastructure, training of human resources for e-government, knowledge management about the benefits and pitfalls of e-business, financial issues, motives and obstacles for the development of e-government. Research on the external aspect of the environment maturity is particularly concerned with [47][48]: ownership, user interest and degree of ICT infrastructure usage (including the digital divide), the obstacles and reasons for lack of e-government services usage and opinions related to the development of e-government in general. Most studies of the environment maturity do not treat internal and external aspects separately.

2) *Project level*

Project level consists of the research primarily engaged in: 1) ex-ante evaluations of projects aiming to establish priorities for further development, 2) ex-post evaluations of projects aiming to evaluate the effects of projects, 3) decisions on the external and / or internal implementation of projects (in/outsourcing). Regarding the first two points, a review of research shows that methodologies of this type often underestimate public benefits (public value) and so-called intangible (hidden) costs such as costs of organizational change. The third point notes significant advantages in outsourcing of ICT projects, however, outsourcing initiatives must be carefully scrutinized, while the impact of the short-term cost-effectiveness and its potential implications on the achievement of long-term goals of public sector organizations must be elaborated and evaluated. Studies [49][50][51] often reveal the hidden costs, vendor-lock in as well as loss of control and competencies as the most problematic segments of outsourcing. On the other hand, research is rarely dealing with the other negative consequences of outsourcing, which may pose a potential threat [52][53][54].

3) *Organizational level*

E-government implementation initiates changes at the organizational and inter-organizational level. Previous research dealing with this field is primarily focused on: changes in the organizational structure, business process reengineering and changes in organizational culture and human resources. Studies dealing with changes in the organizational structure are focusing on the reduction of hierarchical levels, decentralization of activities, standardization of procedures, coordination, control and transformation of the existing relations inside and outside the organization [35][55][56]. Research dealing with the business process reengineering is analyzing horizontal implementation of processes (integration of functions and services), vertical implementation of processes (integration of organizations), speed of information exchange, changes in process definition rules and changes in time and place of operation [38][57][58]. Research exploring the change in organizational culture is primarily dealing with: changes in the philosophy of employees and leaders, strengthening the sense of affiliation to the organization and enhancing confidence in organizations [37][59]. Changes in human resources refer to the new skills and knowledge that employees need to comprehend due to e-government implementation, while managers should be able to combine knowledge of ICT and understand the process dimension of the organization [40]. However, most of the studies address all of these organizational dimensions at least indirectly, suggesting that the analysis and evaluation of organizational changes when introducing e-government should be multi-dimensional and requires a comprehensive strategic approach.

4) Political-sociological level

Proliferation of advanced ICT solutions and development of e-government have changed the social structure and political-sociological paradigm of the country as the widest social community [15][60]. Political-sociological effects of ICT and e-government on the society in general are very complex. They have a significant impact on changes of the social environment, they are affecting old and creating new forms of work and mindsets, they are changing perception of the world and social relations [61][62][63][64]. Accordingly, the existing methodologies are converging on the following aspects of e-government evaluation: accessibility [5][25][59], citizens' trust and confidence [26][65][66], digital divide [5][44][60][67], social stratification and cohesion, citizens' rights and democratic participation [6][16][41], openness, transparency and corruption [10][15][25]. Notwithstanding that reliable and adequate evaluation of wide-ranging e-government impacts could provide key information to policy makers needed for steering the development of e-government and e-services to the right direction [7][10], integrated methodologies covering comprehensively political-sociological aspects of evaluating e-government policies, are rather scarce.

5) National level

Research on national level is focusing on a clear difference in the efficiency and effectiveness of different countries regarding the implementation of e-government policies and the evaluation of national economic indicators and their impacts on e-government policy. Namely, economic activities on the national level are significantly affecting the level of e-government development in each country. Up to date research considers the basic and most important economic indicator on the national level, affecting the development of e-government, to be GDP per capita [42][43]. Sing et al. [43] assume that GDP plays a crucial role in the development of e-government via three influential factors (technological infrastructure, human capital and management index). Other prospective indicators at national economic level are: competitiveness, economic performance, government efficiency, use of ICT in the private sector, innovation index [42], education and urbanization [12]. National level indicators are obviously overlapping with the political-sociological level indicators through political institutions, legal environment, tradition of governance, political culture, socio-cultural environment and civil liberties [68][69].

Numerous difficulties were encountered trying to delineate the above itemized evaluation levels covered by particular methodology, since the contained indicators are not clearly defined, enabling their speculative use on the different evaluation levels. Moreover, associated indicators are appearing in dozens of different methodologies, including a large number of overlapping. Definitions of the indicators vary widely, while the evaluations are carried out on completely different methodological basis. Consequently the results of the evaluations, even if they are methodologically quite objectively conducted, are very difficult to compare.

Development of a comprehensive and practically applicable methodology for the evaluation of e-government policies is obviously a difficult task. Namely, the majority of methodologies, which have tried to cover several evaluation levels within e-government policies, are developed only up to the conceptual framework or maximum pilot application. The latter shows that covering larger number of evaluation levels usually means that the evaluation methodology has achieved a lower degree of sophistication, which consequently reduces the potential of the methodology for its practical application. This is not unexpected, since the focus on several evaluation levels means more complex methodology structure and a larger number of indicators, which exacerbates the transparency and complicates the use of the methodology itself. Research results indicate that achievement of the highest degree of sophistication and practical application of the methodologies for the evaluation of e-government policies is largely dependent on the number of evaluation levels the methodology is focused on, and vice versa, meaning that the comprehensiveness of the evaluation methodologies is to a large extent conversely related to their degree of sophistication.

III. Analysis of the Existing Methodologies for the Evaluation of E-Government Policies

The review and meta-analysis of the existing methodologies and various alternative approaches for the evaluation of e-government policies was conducted in the second half of 2011. During that time we conducted an analysis of primary and secondary online resources, policy papers, reports, books, strategic documents, action plans and other documents containing e-government related research. Due to the nature of the research problems, the inquiry included the sources that are freely available online as well as the sources, which are indexed in subscribable bibliographic databases such as Web of Science, Scopus and ScienceDirect. In the initial phase of the review, we used keywords of evaluation, assessment, measurement, monitoring, indicator models, e-government projects, e-government policies and effects (impacts) of e-government policies (including the logical coordinating conjunctions "and", "or" when appropriate). Using the specialized search engine we subsequently identified and retrieved 380 related references in total (Fig. 2).

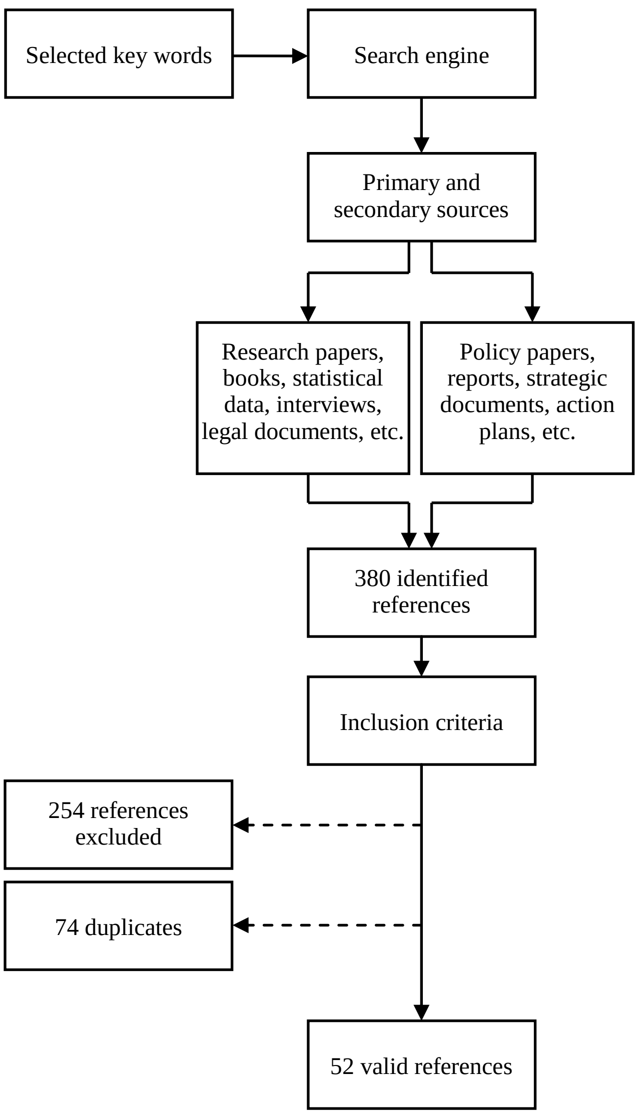

Figure 2. Literature research sequence diagram.

The frequency of references is becoming much higher in the second half of the last decade, proving the field is evolving rapidly and the interest of both the research community as well as policy makers on national and international level is increasing. In the second phase of the review, the identified references were tested by the inclusion into the research framework containing two criteria, namely 1) identified reference must be completed project where the evaluation of e-government policies is clearly outlined as the main research objective and 2) the reference must contain explicit indicators or benchmarks for the evaluation of e-government policies. Duplicated references and references, which did not comply with both criteria as set out in the research framework, were eliminated. After substantive verification and filtration, the vast majority of the items were excluded, leaving only 52 valid references (Fig. 2). The identified methodologies and their publication types are catalogued in Table 2.

TABLE II. IDENTIFIED METHODOLOGIES FOR THE EVALUATION OF E-GOVERNMENT POLICIES

Author(s) – Year	Publication type
[31] [32] [33] [34] [70] [71] [72] [73]	Handbook / Tool
[10] [15] [25] [44] [74] [75] [76]	Policy paper
[12] [35] [36] [37] [39] [40] [41] [42] [43] [55] [56] [57] [58] [59] [60] [65] [66] [68] [77] [78] [79] [80] [81] [82] [83] [84] [85] [86] [87] [88]	Academic paper / Book
[14] [16] [89] [90] [91] [92] [93]	Report

Conducting our review we have identified basically three types of references dealing with our subject of discourse. Taking into account their development level we categorized the identified methodologies into three groups: 1) purely theoretical papers aiming to develop some kind of conceptual framework for the evaluation of e-government policies, 2) research efforts developed up to the degree of pilot application, and 3) methodologies developed in the practice for the practice (practical application).

Analyzing the diverse variety of the evaluation methodologies identified in this area, certain general characteristics were identified and summarized below:

- The majority of the identified methodologies (30) for the evaluation of e-government policies are presented in scholarly papers and books.
- Certain methodologies are rather abstract containing speculatively selected indicators often encompassing non evidence-based theoretical platforms, while their utilization does not facilitate the acquirement of quantifiable evaluation results.
- Accredited methodologies are to a large extent narrowly focused assessing predominantly one of the various evaluation aspects.
- More mature methodologies are consisted of a large number of indicators, which are normally aligned for the evaluation of e-government policies in the originating countries.

- The majority of the identified methodologies are not providing a comprehensive evaluation of complex e-government policies impacts and their potential long-term outcomes.

After general characterization of the identified evaluation methodologies we focused more closely on the most prominent ones, such as MAREVA [31], WiBe 4.0 [33] and AGIMO [34], which have been most extensively used in everyday evaluation practice.

MAREVA methodology was launched in 2005 by the French eGovernment Agency (ADAE) and has already been applied in hundreds of e-government initiatives in various ministries and public sector organizations all over the country. MAREVA methodology was devised for ex-ante and ex-post evaluation of ICT projects, as well as monitoring of their progress. Whereas the evaluation methodologies in the field tend to be rather complicated and complex, MAREVA methodology has managed to keep the evaluation process relatively simple, by providing common and standard evaluation criteria, and generating the evaluation summary reports easily understandable by all actors in the ICT project (from decision-makers to project leaders and executives). MAREVA methodology provides the evaluation of ICT projects through 5 analysis grids and restores the value on a five-axis radar graph, containing the following dimensions: 1) state financial value (Net Present Value, Internal Rate of Return, break-even point), 2) public service social & operational value (state employees valorization, improvement in public services efficiency, help the decentralization implementation, additional financial value – public services without state), 3) direct customer value (number of users impacted, saved time/money, improvement in service quality, promotion of the information society, impact of an intermediary), 4) project necessity (necessity for other ICT projects, legal or political obligation, state's policies efficiency), and 5) risk (project risk, technical risk, legal risk, and deployment risk). Deriving from the evaluation objectives, MAREVA methodology is expected to facilitate prioritization of e-government initiatives by evaluating and comparing different projects, early identification of project risks and pitfalls and adoption of appropriate measures, informed decision-making and knowledge building, evaluation of the project value by integrating financial categories and impacts, and monitoring of different stages of the project life cycle. MAREVA methodology has influenced many evaluation initiatives in France and other countries and has been acclaimed as an example of good practice.

WiBe 4.0 methodology was introduced in 1992 by the German Federal Ministry of the Interior, and has been regularly tested, and extensively used and updated since. WiBe 4.0 methodology is focusing on four dimensions of the evaluation: 1) economic efficiency in a monetary sense – profitability, 2) urgency of the ICT measure, 3) qualitative and strategic importance of the ICT measure, and 4) external effects of the ICT measure. Each dimension represents a wide-ranging set of indicators, too exhaustive for inclusion in the text (see [33]). Pursuant to the general administrative regulation in Germany, the application of WIBE 4.0 methodology is mandatory in all administrative organizations on the federal level, federal states, and municipal organizations when making budget planning and facing complex investment decisions on large-scale ICT projects. Although designed primarily for ex-ante evaluation and focused predominantly on the economic efficiency of the ICT investments, evaluation of monetary aspects, project costs and benefits (internal and external), and simulation of budget-relevant outcomes, WiBe 4.0 methodology also facilitates qualitative evaluation of designated non-monetary aspects and benefits analysis, reflecting the long-term effects of planned ICT investments. In addition, the technical concept of WiBe 4.0 methodology itself is transferable and usable in other public policy areas as well. On the other hand, WiBe 4.0 methodology does not contain a specific category of indicators for the evaluation of the potential risks and threats, which represent an important decision-making factor, especially in the context of larger and long-term oriented e-government projects.

AGIMO methodology was introduced in 2004 and is derived from a number of previous documents of Australian government relating to the effective implementation and evaluation of e-government policies and projects. It has been widely used in Australian public sector and is considered one of the most comprehensive evaluation methodologies in the e-government field. AGIMO methodology [34] consists of five steps: 1) outline the business case (program identification: objectives, scope, outcomes, outputs, when/who applies), 2) define the business need (demand assessment: sources of demand, demand context, demand measurement, scope), 3) estimate the value (value assessment: social value, user financial value, governance value), 4) conduct a cost & benefit analysis (costs: agency financial value, capital expenditure, operating expenses, benefits, cash flow & ROI, summary charts; benefits: agency values/worth, strategic value, program summary), and 5) assess risk and review (impacts, likelihood & consequence of risk: risk assessment, strategy/alignment, architecture/integration, delivery capability, benefits and value). In accordance with an extensive range of indicators (listed are only the first level indicators) AGIMO methodology provides a framework for measuring social and financial benefits and cost, and a platform for the evaluation of project value, risks assessment, and related decision-making. Adequate application of the AGIMO methodology should allow for articulation of the drivers of benefits and costs, comparison and ranking of alternative ICT projects, and alignment of individual public sector organization objectives with broader government strategies.

All three methodologies are based on relatively simple software platform, which on the one hand simplifies their use and increases transparency, while on the other hand, it considerably limits a wide range of functionality such as simulation, visualization and sensitivity analysis, which could significantly assist decision-makers in adopting more sound decision. Analyzed methodologies are based on national characteristics of the administrative system and include material, procedural, legislative and other specifics of the public sector from which they originate. They are extremely detailed and extensive, containing a large number of indicators, which are specifically tailored for the evaluation of adequately documented e-government policies from the well-structured and organized administrative environment. These and similar particularities substantially restrain their transfer and application in environments such as Slovenia, where the evaluation efforts are still in the early stage, and similar projects are rather poorly documented, preventing the collection of necessary data for the detailed list of indicators, as required by the aforementioned methodologies.

All of the above-mentioned methodologies are undoubtedly applicable to the certain extent and can improve the quality of decision-making processes in the e-government field, however, they reveal important limitations and deficiencies, and consequently fail to facilitate the evaluation of e-government policies in an all-encompassing manner. Although all of the outlined methodologies have achieved a high level of maturity, some crucial aspects of the public policy evaluation, such as the public interest, are unreasonably understated and marginalized. Depending on the nature of public policies and their declared purpose, one would expect that evaluation of the public interest implementation, should take a more central place in all evaluation experiments, and given the current situation in the field, try to compel the policy-makers to reconsider the strategies for future development of e-government.

IV. PRESENCE OF THE PUBLIC INTEREST ASPECT IN THE EXISTING EVALUATION METHODOLOGIES

The concept of public interest, or public value as it is also referred to, is gradually becoming the innovative driver in modern e-government endeavors [94][95]. Regardless of their perception of e-government, the increasing number of authors [96][97] argue that the conceptualization and ensuing implementation of the public interest is one of the e-government explicit priorities. ICT-induced reform of the public sector organizations [98] should aim at producing public value for citizens [97], facilitation of their empowerment [99], and promote the use of e-government to increase the odds of the public interest implementation [96].

Nevertheless, e-government is often described as simply the means of automation, without any broader societal considerations. Simultaneously and somewhat surprisingly, an up-to-date evaluation practice in the field has failed to provide compelling evidence of benefit that is required to make a real impact on mainstream policy debates. It is for these reasons that the use of the concept of public value in relation to e-government has much to commend it. As an analytical framework referring to the value created for citizens by government, public value can be used to aid decision making, to assess performance and, in the e-government context, to provide a bridge between the technology and wider policy communities [98].

Quest for protection of the public interest, as presented in theory [17][23][24], should be at the heart of every e-government policy-making process, while its various dimensions should be comprehensively covered in the setting of the long-term public goals. The latter assumption requires accountability of public policy makers and evidence-based decision making, which must be based on comprehensive and balanced methodologies facilitating the evaluation of various aspects of the designated e-government policy, its effects and the potential far-reaching consequences. Deliberation between public stakeholders [69], transparent policy-making process and definitive public consensus will increase the viability of high investments in e-government and facilitate positive response to the e-government policy, and more beneficial acceptance of new e-services while allowing the pursuit of public interest and overall social development.

Growing number of the evaluation methodologies and their substantial diversity regarding the evaluation focus and the degree of sophistication significantly complicate the establishment of a theoretical framework that would allow a detailed analysis of the public interest concept and its representation within the addressed evaluation attempts. As has been stated earlier, despite the importance of adequate evaluation of e-government policies and their impacts [7][10], integrated methodologies covering the aspect of public interest comprehensively, are rather scarce. Findings regarding the public interest aspect contained within the existing methodologies are categorized below:

- The aspect of public interest is assigned a peripheral role in most of the existing methodologies for the evaluation of e-government policies.
- The concept of public interest is not clearly elaborated and categorized in the existing methodologies, preventing its comprehensive inclusion in the actual evaluation undertakings.
- Methodologies are applying large number of indicators when focusing on the evaluation of the costs, benefits and risks (the most segments of public interest aspect are usually incorporated with benefits). However, the aspect of public interest in its individual form is usually allocated a very small number of indicators.
- Covering public interest in the existing methodologies is particularized, usually including arbitrarily selected dimension of public interest.
- Aspect of the public interest presented in the methodologies is often inadequate and superficial focusing predominantly on financial benefits and omitting all other societal aspects while reducing the potential of the evaluation process for objective and comprehensive evaluation.
- The existing examples of the integration of public interest aspect in the methodologies are speculative, since the segments of the public interest within the methodology were developed by policy makers without appropriate deliberation procedure and public consensus.

Accordingly, inclusion of the public interest concept into the comprehensive methodology for the evaluation of e-government policies should encompass the following activities:

- Analyze the overall evaluation field and define the particular aspects of the evaluation within e-government policy (e.g., infrastructural aspect, organizational aspect, political aspect, etc.).
- Define and clearly structure the notion of public interest and associated components. Constructs should not be too abstract, because it could prevent the acquisition of the required data, establishment of the indicators and their measurement in practice, decreasing the overall evaluation success.
- Concept of the public interest should constitute a relatively autonomous category, preventing the dissipation of its components between other aspects of the evaluation, which could significantly diminish its importance.
- Delineate the aspects of the evaluation as much as possible and prevent overlapping and transition of the indicators from different aspects of the evaluation.
- Conceptualize adequate and measurable indicators containing precisely specified object and unit of measurement, structure, context, etc.
- Indicators should be specifically focused on the evaluation of the long-term public interest and goals that have been set out in the designated e-government policy. Evaluation of the public interest concept should be multidimensional including the demand side of e-government services (user preferences, needs and satisfaction, etc.), general value of e-government policy for all social groups, its contribution to sustainable and inclusive social development, human rights and liberties, development of democratic values, etc.
- Assign appropriate weight to the concept of public interest and its components in the final aggregation of the evaluation results.

When trying to integrate the concept of public interest into the comprehensive methodology for the evaluation of e-government policies, we need to consider that besides formal activities some other important substantive issues have to be catered for as well. Namely, the specificity of the public interest concept requires the utilization of the creative and applicable indicators, which must be focused on three important sources, which generate the public value, such as [98]: 1) quality of services, since the perceptions of services are driven by a series of factors such as their availability, the satisfaction of users, the perceived importance of the service and the fairness of its provision and finally its cost, 2) achievement of outcomes that are seen as desirable by the public such as improvements in health, reduced poverty or environmental improvements, and 3) trust in public institutions is an important source of public value, making citizens more likely both to accept government action and to feel a sense of association with it.

V. Discussion

While the study of public policy began almost 100 years ago [100][101], the researchers are still trying to unravel the defining characteristics of this phenomenon and erect a theoretical framework for understanding the intricate effects and mechanisms of public policies. The general understanding of the public interest and especially the design of the public policies have undergone various stages during this period, while recently it is possible to identify the presumably three key factors that will determine the future trajectory of public policy-making: 1) progress in the field of social sciences and the development of policy analysis as an emerging social science discipline, which uses multiple research methods in order to generate the simulation and (ex-ante and/or ex-post) evaluation of the effects of public policies, and provide policy-makers with relevant and applicably clustered information, pertinent for decision-making in the designated field, 2) trends of democratization, growing public engagement of citizens and participation in decision-making on public issues, increasingly proactive role of the civil associations and non-governmental organizations in policy-making processes and protection of the public interest in all phases of the policy-making cycle, and 3) redefinition of socio-political priorities and conceptualization of public policies, which address the public issues as part of a comprehensive and long-term strategy, taking into account the requirements for protection of the public interest, on one hand, and budgetary capabilities in providing the conditions for balanced economic and sustainable development, on the other. Despite the conceptual divisions and differences in the perception of public policy notion, the definition and articulation of public interest issues, and transparent public policy-making procedures continue to be vital in addressing social concerns.

Stemming from the general premises concerning the future trends in the field of public policy-making, which summarize the critical success factors and frame the boundaries of the public policy concept itself, trends in the development of e-government policies and services have been declaratively diverging in two directions: 1) transformation of the public sector organizations in terms of increased efficiency, effectiveness and provision of more user-oriented services, through business process reengineering and integration and reorganization of back-office operations, transparent and accountable management of material and immaterial resources, extensive integration of data repositories and ensuring the interoperability of fragmented information systems, and 2) reconceptualization of e-government in terms of redefinition of content and delivery channels of e-services, increased focus on demand, rather than supply side, promotion of user acceptance and accessibility, reduction of administrative burdens and barriers (temporal and financial losses), improved performance and integration of customized e-services, citizen empowerment and inclusion of underprivileged groups, open access to information, and stimulation of the penetration and adoption of e-government services in the different spheres of society (health care, social welfare, environmental issues, education, justice, entrepreneurship, etc.).

However, the current state of affairs concerning the improved conceptualization and implementation of e-government policies is rather discouraging, as more and more evidence indicates a considerable gap between the declarative positions of e-government policies and everyday practice. According to many authors in the field, the concept of e-government has fallen short in an area where we expected the most, namely in promoting, implementing and protecting the public interest. There are many reasons for the present situation, which evidently depends on the complex socio-political dynamics in modern societies. However, all the facts suggest that one of the main reasons for the discrepancies between expectations and actual experiences (reality) is the inadequacy of current approaches used for the evaluation of e-government policies and related decision-making. Lacking formal procedures and reliable methodologies for the evaluation of e-government policies and their long-term effects consequently results in poor quality conceptualization, planning and implementation of e-government policies. While focusing on recent developments in the field and the analysis of identified methodologies for the evaluation of e-government policies, literature overview revealed a multitude of topic-related approaches, which have been used in previous research studies and the evaluation endeavors in this area, but still, their utilization in the process of the comprehensive evaluation of e-government policies is only conditionally exploitable.

Given the existing political debate, focusing predominantly on economic issues and rigorous budgetary restrictions, and disregarding the support for the development of more applicable evaluation methodologies in the field, the current e-government situation is likely to remain unchanged for some time. Irrespective of the fact that renewed and complemented evaluation methodologies could assist policy-makers in all three steps of the public policy-making process, namely: agenda-setting, option-formulation, and implementation. Alarming socio-economic situation in Slovenia could jeopardize the latest reform efforts and compel the government to concentrate on predominantly short-term economic issues and lower the investments for development of e-government in general, which could result in far-reaching implications for the public sector. Determination to resolve the pertaining problems with e-government development and implementation, enable better exploitation of ICT in the public sector organizations and eventually provide tangible benefits for providers and users, will therefore require the mobilization of all stakeholders and experts in the field, construction of the comprehensive and applicable analysis and evaluation tools, and a broad consensus about the priority areas within the e-government domain.

VI. Conclusion and Future Work

Analysis of the methodologies for the evaluation of e-government policies has emerged as a very challenging mission. Despite limitations, seen mainly in the large diversity of the evaluation methodologies and absence of a unified and clear theoretical framework, conducted analysis provides a valuable insight into the current e-government evaluation practice and facilitates exposure of inadequately evaluated public interest areas in the domain of e-government policies. Present public finance situation along with increasingly stringent austerity measures require careful direction of further e-government investments, particularly focusing on the proficient development of suitable ICT-supported solutions, which could enable enhanced policy-making procedures and optimization of the public sector in general. The analysis results represent an advance in research of the evaluation metrics and may eventually provide a solid platform for the establishment of a comprehensive methodology for the evaluation of e-government policies including the public interest aspect. This could enable e-government decision-makers to conduct more qualified and quantified planning, implementation and evaluation of e-government policies – be it before or after their execution (ex-ante or ex-post), which should consequently initiate more user oriented, cost effective and performance-based development of e-government and enhance its overall harmonization with the public interest.

It is evident that problems in the development of e-government are strongly interrelated with the low quality and underdeveloped methodologies for the evaluation of e-government policies and their public effects. A wide range of research and the existing evaluation methodologies reveal that the past development of e-government, and particularly e-services was based primarily on political preferences and only exceptionally on professionally verifiable and measurable impacts of these services. Addressed shortcomings will have to be resolved, in order to ensure quality evaluation and disclosure of objective situation in the field, which could ultimately initiate the broader inclusion of the public interest dimensions into the e-government policy-making procedures, and accelerate the overall development of e-government policies and appropriate e-services with added value for all stakeholders.

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Promoting Effective Health Advocacy to Promote Global Health: The Case of the Global Advocacy Leadership Academy (GALA)

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***Abstract*—Health advocacy can make significant contributions to promoting global health by shaping health promotion programs that are responsive to the needs of consumers. Health care consumers have a major stake in the health care system, yet have had difficulty influencing health policies and practices due to the limited power typically afforded them within the modern health care system. Strategic health advocacy communication can help to recalibrate the balance of power in health care and health promotion efforts, facilitating important influences on health policies and practices, Health advocates can help make health programs responsive and adaptive to consumer needs by communicating consumers' perspectives in compelling ways to key audiences using a variety of key media. This article describes the communication demands of effective health advocacy, the need to help advocates develop strategic communication knowledge and competencies, and presents a case study of the Global Advocacy Leadership Academy (GALA) program designed to promote effective health advocacy.**

Keywords-patient advocacy organizations; leadership; media relations; corporate relations; health care systems; government agencies; stakeholders; personnel management; health promotion; media advocacy.

I. INTRODUCTION

Health care consumers around the globe have a major stake in the quality of health care, health education, and health promotion programs provided within the modern health care system. Yet consumers have had difficulty shaping health policies and practices both locally and globally due to a major longstanding power imbalance within the modern health care system that accords far more authority to health care providers and administrators than to patients and family caregivers [1, 2, 3]. This traditional power imbalance limits consumer participation and influence within the modern health care system despite the fact that a large body of research demonstrates that increases in consumer participation in health care and health promotion efforts can significantly improve the quality of important health outcomes [4, 5, 6, 7].

Health advocates, whether working as individuals, or as parts of health advocacy groups and organizations, have the potential to recalibrate the traditional imbalance of power in health care and health promotion efforts as a powerful social mechanism for promoting consumer-driven participation and change within the health care system [1, 8]. Health advocacy leaders can actively represent the voices, concerns, and needs of consumers within the health care system. Advocates have great opportunities to help make health care programs responsive and adaptive to consumer needs through the use of strategic health communication [1]. Strategic health advocacy communication can promote important influences on the development and refinement of health policies and practices. However, health advocates must learn how to communicate patients' perspectives and needs in compelling ways to key audiences using a variety of different communication channels and media to influence often entrenched health policies and practices [9]. This article describes the important communication activities that health advocates can perform to effectively represent the needs of consumers for reforming modern health care systems. The article also examines major communication challenges facing health advocates and suggests strategies for promoting effective health advocacy around the globe.

II. THE NATURE OF HEALTH ADVOCACY

Health advocacy typically occurs on multiple levels. The two most common levels for the delivery of health advocacy are the individual and the group levels. On the individual level health advocates work directly with specific patients to promote quality of care and informed decision-making for these consumers, while on the group level advocacy groups and organizations represent the needs of many consumers confronting similar health challenges. Both of these levels of advocacy depend on effective and strategic health communication to be successful.

Individual level advocacy is delivered both informally and formally. At the informal level family members often serve as personal advocates for their own familial loved ones, particularly when these loved ones face serious health challenges or when the loved ones have difficulty representing their own health needs (perhaps due to reduced capacity related to their health conditions). Family advocates regularly support the health needs of children and elderly family members, but all health care consumers can benefit from effective personal health advocacy. There is tremendous potential for many people, particularly those who are well educated and those who are familiar with the health care system, to serve as advocates for their friends, relatives, and others who are seeking health care services. Personal health advocacy can also help others adopt healthy behaviors and reduce significant health risks through education, support, and encouragement.

Individual level health advocacy is increasingly being delivered by formally trained care professionals, including health navigators, consumer advocates, patient educators, home health nurses, personal trainers, and social workers who can be assigned to work with specific consumers to help promote the best possible health outcomes for these consumers. Research has shown that these health advocates can dramatically enhance health consumer satisfaction, understanding, quality of care, and important health outcomes [10, 11]. Individual level health advocates provide invaluable support for health care consumers to insure these consumers receive the best care and advice to promote their health and well-being. These advocates depend on their strategic communication skills to gather relevant information concerning consumer's health concerns, interpreting health care recommendations and advice, and sharing this information clearly and compellingly with consumers.

There are also many different health advocacy groups and organizations that have been established to focus on promoting health and wellness for a large number of consumers experiencing specific similar health challenges, such as different cancers, heart disease, diabetes, and other health care issues. These advocacy organizations encourage focused research on specific health issues, influence legislation to promote consumer rights and responsive health care regulations, and help to refine health care delivery system programs, practices, and policies. Some of the larger and most well established health advocacy organizations have become familiar names such as the American Cancer Society, the Susan Komen Foundation, the Alzheimer's Association, and the American Heart Association. There are also numerous smaller (mom and pop) advocacy organizations and groups that are typically developed by consumers and/or their caregivers to address serious personal concerns they have had with the health care system based upon the care they (or their loved ones) have received. The leaders of both the large and small health advocacy groups/organizations depend on strategic health communication to achieve their goals. This article focuses primarily on the ways the leaders of health advocacy organizations can use strategic health communication to shape health policies and practices to support the needs of the health care consumers they represent.

There is a long history of health advocacy in the US that has powerfully influenced relevant health care research, as well as the development of important health policies and practices [8]. For example, the American Cancer Society which was founded in 1913 as the American Society for the Control of Cancer by a group of prominent physicians and business leaders, has developed many influential programs to enhance the quality of cancer care and provide support to cancer patients. Prominent individuals have also had major influences on consumer advocacy by establishing influential health advocacy organizations. For example, Mary Woodward Lasker, who founded the Citizens Committee for the Conquest of Cancer when her husband Albert Lasker died from intestinal cancer in the early 1950s, was instrumental in promoting the introduction of the National Cancer Act of 1971 in the US that was signed into law by then President Richard Nixon. This landmark federal legislation initiated the national "War Against Cancer," which has spurred the development of important health organizations (such as the National Cancer Institute), the expenditure of billions of dollars of federal funding for important cancer research, the development of new cancer treatment strategies and medications, as well as the establishment of myriad new programs to support cancer prevention and control. However, it must be noted that it was not easy for individual advocates or their health advocacy organizations to accomplish such sweeping influences on public health policies. It took concerted strategic communication efforts, including the development of effective media relations programs, fundraising efforts, lobbying strategies, and the establishment of powerful public/private partnerships to achieve these important health promotion goals. Achieving similar health advocacy outcomes in other countries may be even more challenging, since there is not a long history of consumer advocacy in health care in many parts of the world.

III. THE ROLE OF COMMUNICATION AND INFORMATION IN HEALTH ADVOCACY AND HEALTH PROMOTION

Communication is at the center of effective health care and health promotion, because communication provides consumers and providers with the relevant health information they need to get the best care and make their best health decisions [5]. Relevant and timely health information is a critical resource in health care and health promotion because it is the essential resource needed by practitioners who must guide strategic health behaviors, treatments, and decisions, as well as by consumers of health care who need to make important informed choices concerning the prevention of health risks, the promotion of their health, and the best health care treatments for them [4]. Health information includes the knowledge gleaned from health care interviews and laboratory tests used to diagnose health problems, the precedents developed through clinical research and practice used to determine the best available treatment strategies for specific health threats, the data gathered in checkups used to assess the efficacy of health care treatments, the input practitioners and consumers need to evaluate bioethical issues and weigh consequences in making complex health care decisions, the recognition of warning signs needed to detect imminent health risks, and the direct health behaviors that have been determined to help individuals avoid these risks [5]. Health care providers and consumers depend on their abilities to communicate effectively to generate, access, and exchange relevant health information for making important treatment decisions, for adjusting to changing health conditions, and for coordinating health-preserving activities. The process of communication also enables health promotion specialists to develop persuasive messages for dissemination over salient channels to provide target audiences with relevant health information to influence their health knowledge, attitudes, and behaviors. Health advocacy organizations have developed to help support these critically important health information needs.

Access to and effective use of relevant, accurate, and timely health information is critically important for guiding the important health-related decisions that consumers and providers must make across the continuum of care to promote health and well-being [12, 13]. This includes decisions about the prevention of health risks, health promotion behaviors, the detection and diagnosis of health problems, health care treatment strategies, and best practices for living with health threats (successful survivorship) [12]. Yet, health information is complex, with many different kinds of health risks, each with different causes, stages, symptoms, detection processes, and treatment strategies. Health care knowledge is rapidly evolving with advances in research and applications concerning etiology, prevention, detection, diagnosis, and treatment of health problems. It is extremely difficult for consumer, as well as many health care providers, to stay on top of all the health information they need to make their best health decisions. They need support to manage the complex and evolving health information environment.

A primary goal of health advocacy organizations is to help break through the complexity of health and health care by disseminating relevant, timely, accurate, and clear health information to consumers and providers to help guide informed health decision making. However, there are significant barriers to the dissemination of health information, especially for at-risk populations, due to limited access to health information, health literacy challenges, limited education levels, and the complexity of health research and health care processes [3; 14; 15]. Health advocacy leaders must develop strategic communication programs for gathering relevant health information, interpreting that information, and presenting the information in meaningful ways to those who most need that information for guiding important health decisions.

IV. MEDIATING THE COMPLEXITIES OF THE MODERN HEALTH CARE SYSTEM

Health advocates must learn about the complex structures and processes that have been developed for delivering care and promoting health in the modern world. These health care structures are likely to operate quite differently from one location to another, particularly across different national health systems. Effective advocacy demands a detailed understanding of the different ways that health care delivery systems are organized and managed; the ways that health care services are financed; the ways that relevant treatments, medications, and technologies are developed, tested, and implemented; the ways that research programs are conducted to study health care and the promotion of health; as well as the ways that regulatory mechanisms and guidelines for governing the delivery of care are implemented.

This means that health advocates must be able to gather a great deal of complex information about health care systems and practices. They must learn about a wide range of different relevant health industries, including health care delivery systems, pharmaceutical companies, insurance organizations, and medical technology and supply industries. They need to learn about the many local, regional, and national government agencies that regulate heath care. They need to understand the ways that research programs are conducted to study health care tools, treatments, and processes. Moreover, they must learn the best ways to communicate with representatives of these different health care systems to promote cooperation and partnerships in for refining health care practices and policies. In addition, health advocates need to understand the best ways to disseminate relevant information about the health care system to key audiences, particularly in reference to specific health consumers' needs and concerns. There is clearly a lot of information for health care advocates to gather and make sense of, as well as to strategically communicate to key audience to effectively advocate for meeting the health needs of consumers!

V. COORDINATING ADVOCACY EFFORTS

There is also a daunting administrative communication demand to developing effective and influential health advocacy organizations. Health advocacy group leaders cannot possibly accomplish the complex goals of influencing health care policies and practices to promote the goals of health care consumers all by themselves. They need to actively recruit followers who will become advocacy group members and volunteers to carry the group's messages and support group causes. Advocacy group leaders need to motivate, train, direct, and supervise these members to make sure they work effectively and cooperatively on behalf of the advocacy group/organization. Effective and adaptive leadership communication skills are needed to recruit, motivate, train, direct, and supervise personnel and volunteers [1].

Advocacy group leaders also need to learn how to raise funds effectively to support health advocacy efforts. This is not an easy social influence process to accomplish! Fund raising is a complex strategic communication activity. Care must be taken to identify the most relevant audiences who are good potential sources for the donation of funds to specific health advocacy groups/organizations. Health advocacy group leaders must learn how to develop strategic development campaigns to motivate potential donors to provide financial support to advocacy organizations. These campaigns need to be strategically designed to capture the attention of key audiences of potential donors, elicit a strong sense of involvement with the advocacy organization among these audiences, and motivate commitment to provide needed financial support for health advocacy. This intricate communication process for eliciting financial support for health advocacy is complex and challenging. Moreover, there is tremendous competition between health advocacy groups for financial and material support. Health advocacy leadership demands strategic communication to navigate the complexities of raising funds to support advocacy organizations and the important activities of these organizations.

VI. MEDIA AND HEALTH ADVOCACY

Popular media are primary tools for disseminating relevant health information concerning the health needs and issues affecting consumers. The right media coverage using the best media channels can be instrumental in helping advocacy organizations reach and influence key audiences. For example, advocacy organizations can use popular media to reach people who are concerned about the issues being championed by the organization to encourage these audience members to serve as potential members and volunteers. They need to reach potential donors to convince these audiences to provide financial and material support to the advocacy organization. They need to use the media to motivate public support for relevant legislation and policies. They also need media to encourage support from key public officials. However, it is not easy to control media messages and coverage. Strategic communication is needed to influence media cooperation with advocacy organizations.

The most direct way to control media coverage is for advocacy organization leaders to purchase media spots and advertising. Unfortunately, this can be very expensive, especially when paying for the use of the most dramatic and popular entertainment media, particularly television and film time, and to a lesser extent radio time. Another strategy for getting media coverage is for advocacy organization leaders to ask for it. For example, advocacy leaders often submit public service announcements to media outlets for free dissemination. Unfortunately, these public service announcements, even when accepted for presentation, rarely gain much exposure because they are typically programed for inexpensive time periods. It is much more cost effective for health advocacy leaders to encourage free media coverage by earning it through the use of media advocacy [16].

Media advocacy is an intricate communication strategy for motivating mass media representatives to cover key stories that enhance the visibility and legitimacy of health advocacy organizations issues because the stories are attractive to these media representatives and promise to appeal to key audiences. In essence, advocacy leaders try to create news and encourage coverage of relevant and interesting stories. They can do this by building cooperative relationships with media representatives, staging news worthy events, linking advocacy group issues to breaking news or existing stories, as well as by providing editorial pieces and commentary on relevant issues.

Advocacy leaders can also encourage media advocacy coverage by preparing relevant stories, materials, and media kits for media representatives that make it easy for these representatives to cover the advocacy group stories [17]. They can provide succinct and persuasive summaries of advocacy organizations' positions of key public issues. They can distribute relevant fact sheets that provide compelling data and evidence in support of key issues they want covered. They can provide interesting press releases, with names and contact information of potential sources for the stories. They can also provide relevant background articles to media representatives, as well as providing clear and compelling background information about the advocacy organization.

By encouraging voluntary media coverage the health advocate hopes to encourage key support for the advocacy organization. The goal is to use free media coverage to influence and shape public debate, put pressure on policy makers, and encourage community support for the advocacy organization's key issues. Media coverage can help set the public agenda concerning health advocacy concerns by raising awareness about key issues, encouraging public discussion of these issues, and influencing private conversations about the issues to motivate support for social change [18].

Building active collaborations with media representatives is critically important for motivating effective media coverage of health advocacy issues. There are several key questions that the health advocate needs to be able to answer. Who are the media representatives for the media outlets you want to cover your health advocacy issues? Are your messages right for the specific medium selected? Who are the audiences these media channels serve? What kinds of stories do these media outlets want to cover? What problems do you want addressed by the media? What are the ideal solutions to these problems? Who has the power to address these issues and must be mobilized to enact relevant social change? What messages would convince these key audiences to act on these issues? Do your messages have "news value" for the audiences the media outlets serve? How can you pitch your story to them? Can you help the media representatives do a good job? Are you responsive to media constraints (such as media time/space available for your story, the topics the media tends to cover, adjusting the level of complexity of ideas/language used to the appropriate level for the medium, the media outlets need for good visuals and/or sound-bites, and the need for good personal testimony to humanize the story)? To utilize media channels effectively health advocacy leaders must be able to address these questions effectively. They must be able to develop strategic health communication responses to these questions so they can design compelling messages and encourage media support for disseminating these messages to key audiences.

VII. HEALTH ADVOCACY AND NEW MEDIA

An increasingly important channel for communicating health advocacy messages in the use of new, digital, e-health media [19]. For example, the website has become a ubiquitous and pervasive part of the communication mix for health advocacy organizations [20]. The website is critical in helping to establish an identity for the advocacy organization and it is also can serve as a primary portal for communication with key constituents if it is designed to be interactive. Unfortunately, too many health organization websites do not effectively utilize strategic interactive ehealth communication features and fail to maximize communication with key audiences [21]. Many health websites fail to be particularly interactive, engaging, or dynamic [22]. To be effective, digital health programs must leverage the abilities of digital media to communicate vividly, interactively, and adaptively through the use of specialized mobile and interactive applications, video, tailored message systems, message boards, and social media [21]. For example, the use of tailored information systems allows health advocacy organizations to adapt online communication to meet the unique needs, interests, orientations, and backgrounds of specific individuals, ensuring that online communication is personal and relevant for users [23].

The website has morphed from being a mere repository of health information to being a portal to a range of exciting communication opportunities to connect, inform, and engage constituents of health advocacy groups. For example, health advocacy websites are often an entry point for access to online support groups, discussion boards, webinars, news feeds, and social media. Online support groups have become a staple health communication medium for many health advocacy organizations, enabling constituents who are confronting challenging health issues to connect with others confronting similar challenges to exchange ideas and to provide needed social support [24]. Evidence suggests that online support groups can be even more effective for supporting the needs of health care consumers than in-person support groups because they afford group members greater freedom to connect when they are in need, eliminate the need for travel to participate in the support group, and afford support group members a higher level of privacy and anonymity than in-person support groups [19]. Online support groups have even begun to drive research about new therapies for challenging diseases [25]. Perhaps one of the greatest opportunities to health advocacy organizations is to leverage the use of digital media to promote collaborations, through the sharing of relevant information and the building of social action partnerships to promote change [26]. As technology advances, there will be increasing opportunities to adopt new and powerful digital communication applications to promote the use of strategic communication to achieve the goals of health advocacy

VIII. THE CASE OF THE GLOBAL ADVOCACY LEADERSHIP ACADEMY (GALA)

The Global Advocacy Leadership Academy (GALA) is a new public health educational initiative designed to facilitate needed training and support for leaders of health advocacy organizations around the world. Leadership of health advocacy organizations is a complex enterprise that demands a tremendous amount of specialized knowledge about the health care system and constituent groups, adaptability to evolving health care systems, and the ability to reach, influence, and collaborate with a wide range of individuals from different sectors of the health care system through strategic health communication. The GALA program is introducing a unique international training and support model to prepare health advocacy leaders to meet the challenges of building and sustaining strong consumer advocacy organizations to champion the needs of patients and their caregivers within the modern health care system.

Effective leadership of health advocacy organizations is a demanding and complicated enterprise. While many aspiring advocacy organization leaders are passionate about helping to improve the modern health care system and to represent the needs of health care consumers, they may not be particularly well prepared to meet the demands of achieving these goals. The development of the GALA program grew out of the work of its founders (Gary Kreps and Paula Kim) in advising new health advocacy leaders from around the globe to achieve their goals. We recognized the many challenges that advocacy leaders face in influencing health research, health care practices, and health care policies and decided the best way to assist these leaders was to develop a formal system (GALA) for building advocacy organization leadership capacity. Moreover, we realized that health advocacy organizations were situated within a global health care system, concerning many of the same health care problems that affect consumers around the world. There was a tremendous need to link health advocacy organizations within a global advocacy network to promote international cooperation and collaboration for achieving shared goals of consumer empowerment and support within an interdependent, challenging, and evolving global health care system [27]. This paper outlines the goals and strategies of the GALA program for supporting the development of effective and influential health advocacy leaders and organizations.

IX. MEETING HEALTH ADVOCACY CHALLENGES

The GALA program is designed to help leaders understand the unique sociopolitical structure of the modern health care system, both on a broad societal level and also within the unique health issue communities that address the specific areas of direct interest to different health consumer groups (for example, communities interested in lung cancer, diabetes, Lupus, kidney transplantation, hemophilia, or other challenging health issues). Strong and effective health advocacy organization leaders need to understand the lay of the land within the rapidly evolving health care system so they can help influence health care policies and practices to reflect the needs and goals of the health care consumers they represent.

Health advocacy leaders also need to know which specific organizations and individuals exert influences in the delivery of care, development of health policies, conduct of health research, and translation of research into health practices within the health domains in which they want to support the needs of consumers. Effective leaders must build collaborative relationships with key organizational representatives to exchange relevant information and cooperate on issues of importance to consumers. There is a daunting amount of information to learn to prepare for effective advocacy group leadership and a vast number of relational connections to establish for new advocacy leaders. Often, new health advocacy leaders have serious information deficits and limited relational connections that limit their abilities to accomplish important consumer support goals.

The GALA program is introducing new and relevant training, support, advising, and collaboration training programs to help health advocacy leaders build their knowledge base and learn how to work effectively with key representatives of different segments of the health care system. GALA will help connect advocacy leaders to relevant health researchers, educators, government and regulatory agency officials, health care delivery system personnel, health product and services corporation leaders (pharmaceuticals, health equipment, medical devices, insurance companies, and health informatics firms), media, representatives, as well as leaders of other related advocacy and support organizations. Not only is the GALA program designed to teach leaders about these different relevant segments of the health care system, but the GALA program will introduce health advocacy leaders to key representatives of these health sectors to initiate development of cooperative relationships for achieving advocacy goals.

The GALA program is also designed to help educate advocacy leaders about the nature of health research, including how research is funded, who conducts health research, how research results are reported, how to make sense of health research findings, and how research is translated into relevant health care policies and practices. The GALA program will help advocacy leaders understand the intricacies of the modern health care system, including the design of health care delivery systems, the key roles performed by different professionals and support personnel working within the health care system, and the evolving policies governing health care delivery and reimbursement. The GALA program will also educate advocacy leaders about the development of government legislation for health care policies, programs, and research, corporate influences on the health care system, and the unique roles performed within the health care system by professional associations, regulatory agencies, educational institutions, support organizations, foundations, and other assorted non-profit, for-profit, and government agencies.

X. HEALTH INFORMATION DEMANDS

Access to and effective use of relevant, accurate, and timely health information is critically important for guiding the important health-related decisions that consumers and providers must make across the continuum of care to promote health and well-being [28]. This includes decisions about the prevention of health risks, health promotion behaviors, the detection and diagnosis of health problems, health care treatment strategies, and best practices for living with health threats (successful survivorship) [29]. Yet, health information is complex, with many different kinds of health risks, each with different causes, stages, symptoms, detection processes, and treatment strategies. Health care knowledge is rapidly evolving with advances in research and applications concerning etiology, prevention, detection, diagnosis, and treatment of health problems.

Health advocacy organizations have the potential to help break through the complexity of health and health care by disseminating relevant, timely, accurate, and clear health information to consumers to help guide informed health decision making. However, there are significant barriers to the dissemination of health information, especially for at-risk populations, due to limited access to health information, health literacy challenges, limited education levels, and the complexity of health research and health care processes [30]. The GALA program is designed to help health advocacy leaders develop a wide range of necessary knowledge and skills to enable them to achieve important consumer goals. For example, GALA can help health advocacy leaders learn how to support the information needs of the health care consumers they represent, providing these consumers with access to relevant, timely, and accurate health information. The GALA program is also designed to help advocacy organization leaders learn how to promote and advocate for increased funding for relevant health research needed to improve prevention, detection, treatment, and survivorship for the consumers they represent.

The GALA program will help leaders learn how to run effective advocacy organizations to serve the needs of their constituents and influence health practices. Strategies for recruiting, mobilizing, and serving the needs of organizational volunteers and personnel will be examined. Fund raising, investment, and fiscal management demands will be carefully examined. Strategies for using funds wisely for disseminating information, influencing legislation and policies, and planning and implementing influential health campaigns will also be examined.

The GALA program will help advocacy organization leaders learn how to disseminate relevant health information through a variety of media to raise awareness and educate health policy makers, health care administrators, providers, and consumers about the health issues of concern to their constituents. The GALA program will help advocacy organization leaders learn how to lobby legislators, regulators, and health care administrators to improve health care policies and practices. The health advocacy leaders will learn how to provide needed support and assistance to consumers confronting challenging health care problems, as well as to support the needs of their caregivers, family members, and loved ones. Perhaps most importantly, the GALA program is designed to promote local and global cooperation within the health care system to support health promotion, prevention, early detection, the best treatments, and successful survivorship for the health issues of concern to their constituents.

XI. THE UNIQUE GALA DELIVERY MODEL

The GALA program is designed to provide advocacy leaders with relevant information and strategies for working effectively with key internal and external groups. For example, training programs will be conducted concerning development of effective relationships and collaborations with media representatives, government representatives, corporate leaders, researchers, and health care system representatives. Moreover, the GALA program will provide advocacy leaders with ongoing information support, consultation, updates on new opportunities/constraints, and continuing education to meet changing needs and refine advocacy knowledge and skills.

GALA programs will be delivered in several different complementary ways. Advocacy leaders will be invited to attend training programs conducted at a centralized site (George Mason University), where they will also be introduced to relevant government, corporate, and health care system representatives, researchers and scientists, legal, fiscal, and administration advisers, campaign planners and fundraising experts, as well as experienced and successful health advocacy group leaders. In addition to centralized training programs, GALA program educators will travel to advocacy organizations in different parts of the world to provide on-site training programs. Arrangements will be made on demand to provide individual follow-up personal consultation with advocacy leaders to address specific emergent issues and concerns. Field experience opportunities will also guide advocates to participate in important meetings, conferences, and other relevant events, as well as to examine with GALA personnel the implications of these meetings. GALA is also proposing to link advocacy leaders and their constituents with an online information system (a collaboratory) to provide continuous support, on-line educational modules, repositories of health information documents, case studies, and media, as well as networking/collaboration opportunities for solving problems and developing new health advocacy initiatives.

The GALA training programs will model effective health advocacy leadership strategies. Leaders will learn how to establish and build effective advocacy organizations. They will learn how to recruit volunteers, organization members, and support staff. They will develop strategies for collaborating with other advocacy groups, locally, nationally, and internationally. They will develop skills for establishing working relationship with government representatives, corporate leaders, media representatives, educators, and researchers. They will also learn how to raise, manage, and invest funds for achieving advocacy goals.

The global nature of the GALA program is designed to promote international cooperation and collaboration for addressing advocacy issues, sharing resources, and implementing new policies and practices within the health care system. Advocacy leaders from different parts of the world who may be addressing similar issues will be linked to share information and resources for addressing these common issues. These leaders will be encouraged to build international collaborations for influencing global health practices and policies. The GALA program will combine support for leveraging research, theory, policies, and innovative applications to promote development of robust and adaptive advocacy programs to support the needs of health care consumers and their caregivers.

XII. ESTABLISHING DEMAND AND CHARTING THE COURSE FOR GALA DEVELOPMENT

The development of effective health communication intervention programs, such as GALA, depend on careful audience and needs analysis formative evaluation research efforts to guide evidence-based program design, implementation, and refinement [31, 32]. To this end, the GALA project team has conducted a series of in-depth, semi-structured, qualitative personal interviews with a purposive sample of active health advocacy leaders and influential health promotion professionals representing a range of important health care domains (including different forms of cancer, cardiac-related diseases, neurological disorders, HIV/AIDS, and chronic disease problems) across selected global health communities to learn more about the concerns of health advocacy leaders and the unique issues they face. The survey data collected is being used to expand our understanding about the unique training needs of health advocacy leaders and the best strategies we can develop for meeting these training needs.

In our first wave of survey data collection we conducted 28 in-depth personal interviews, with representatives from four different continents, and five different countries (USA, Taiwan, Estonia, Japan, and New Zealand). We described the GALA Mission Statement as "The Global Advocacy Leadership Academy (GALA) was established as a public health educational initiative of the Center for Health and Risk Communication of George Mason University to facilitate training, skills building and support for leaders of health advocacy organizations around the world." After reading the mission statement of the Global Advocacy Leadership Academy, we asked whether the respondents agreed with the stated goals. None of the respondents disagreed with the stated goals. One respondent did not answer this question, 26 respondents agreed with the goals, and one was unsure whether to agree or disagree. Overall, there was strong support for the stated mission of GALA, with one representative respondent explaining: "GALA goals are relevant in Estonia. Skills-building is essential to maximize our effectiveness in our work. As we have a very small staff, we cannot afford to run programs that yield no or limited results. Support from larger or more experiences organizations would give us the confidence and encouragement to continue our mission work and also provide the ammunition we need to show our partners the potential for positive results." Another respondent stated, "Yes, I think many health advocacy organizations are well meaning but lacking in skills and knowledge." Another respondent emphatically stated, "Yes! There is a deep need for more educated consumer advocates to participate fully in health reform in the US."

We next asked the respondents to describe the primary goals of advocacy organizations. All 28 respondents answered this question. Goals identified included:

- breaking down barriers to care,
- promoting health education for consumers,
- identifying relevant treatment options,
- promoting patient-centered care,
- encouraging prevention,
- building capacity and access to quality health care,
- lobbying for health policy initiatives to improve the health care system,
- promoting the rights of patients,
- building positive partnerships between patients and providers,
- promoting cooperation and information sharing,
- explaining complex health care concepts to consumers,
- securing funding for health research,
- changing public policies,
- representing the needs of consumers,
- meeting patient/caregiver needs,
- improving health and wellbeing
- advancing the cause of patients and providers,
- improving prevention and treatments,
- identifying cures for health issues,
- raising awareness about diseases,
- supporting patients,
- making things better for patients/caregivers,
- promoting the agenda of pharmaceutical companies and research organizations,
- setting up new systems to promote health,
- encouraging governments to address health problems,
- improving the intersection between government and science,
- providing researchers and providers with information about patients' perspectives,
- encouraging more participatory care,
- promoting more patient engagement in their care,
- educating the public about the health care system,
- promoting more effective health care processes,
- promoting their organizations,
- providing consulting services,
- helping consumers understand how to achieve the best health outcomes,
- promoting drug and health device safety,
- building socially coherent support networks,
- setting up standards for health communication,

- helping the health care system focus on patient needs,
- disseminating relevant health information

We asked the respondents to identify challenges that may make it difficult for health advocacy organizations to achieve these goals. Some of the primary challenges identified included the:

- need to develop programs to sustain and treat low income populations,
- lack of buy-in and support for advocacy organizations by physicians and clinical staff,
- cultural differences between participants within the health care system,
- resistance by consumers to confront their health care specialists,
- complexity and fast-changing nature of health information,
- difficulty to build group consensus,
- lack of needed communication skills by advocates,
- insufficient funds to sustain advocacy programs,
- difficulty in designing and implementing effective health campaigns,
- consumer apathy about health issues and screening,
- challenge to influence government policies and legislation,
- power discrepancies between consumers and providers in health care,
- lack of patient understanding, time, and resources,
- limited advocacy staff and resources,
- prioritization of limited public resources,
- disease war competition among advocacy groups,
- government inertia,
- need to build networks with other organizations,
- lack of knowledge,
- lack of experienced leadership,
- lack of strategy in advocacy organizations,
- the complexity of fundraising,
- resistance to change within the health care system,
- need to recruit volunteers,
- lack of traditions of effective advocacy,
- difficult economic climate,
- cynicism among the public,
- bureaucracy is difficult to overcome,
- lack of credibility with those in positions of power,
- need for training within advocacy organizations,
- opposing interests and lack of focus,
- need for research funding,
- need for support networks,
- lack of education,
- competition with food, drug, health care industries,
- difficulty building support for long-term solutions,
- lack of suitable information technology,
- pay for performance profit-driven US health care system,
- belief that collective solutions to health problems infringe on individual freedoms,
- expense of health promotion efforts

We asked what the primary benefits were providing training for leaders of health advocacy organizations. Respondents described the following benefits:

- building a solid knowledge base concerning health care,
- enhancing patient care,
- reinforcing patient rights,
- learning new techniques to improve programs,
- promoting effective lobbying,
- developing good media relations,
- teaching leaders how to lead,
- communicating advocacy skills and standards,
- providing advocates with tools to build successful organizations,
- preparing advocates with tools to be successful,
- building effective support groups,
- leveraging knowledge to promote change,
- promoting collaboration among advocacy leaders,
- focusing the missions of advocacy groups,
- increasing awareness about important health issues,
- promoting changes and societal support for combatting health problems,
- promoting skill-building and collaborative problem solving,
- establishing professional standards for advocacy,
- increasing the credibility of advocates,
- making more compelling cases for supporting advocacy goals,
- amplifying the efforts of stakeholders,
- introducing new ideas to influence public policies,
- promoting more cooperation across advocacy organizations,
- empowering advocates,
- setting quality standards for advocacy,
- advancing the field of advocacy,
- increasing the effectiveness of advocacy organizations

We asked the respondents to identify the biggest training needs of advocacy group leaders. They suggested the following areas for developing useful training and support programs for health advocacy group leaders:

- access to a centralized database for assistance and networking,

- easy access to different training programs,
- opportunities to interact with and educate other health advocates,
- workshops about sharing resources with other advocacy groups,
- strategies for gaining public and corporate support,
- best approaches for influencing health legislation at local and national levels,
- strategies for improving relations between patients and health care workers,
- leadership skills training,
- communication training,
- strategic thinking and long-range planning training,
- management skills and strategies,
- understanding public policy and politics,
- social influence strategies,
- fundraising training,
- how to build sustainable networks from grass roots activism,
- understanding regulatory and legal processes,
- staffing and management of volunteers,
- social media use training,
- new campaign and public influence strategies,
- understanding health care finance,
- grant writing skills training,
- social mobilization and empowerment training,
- new models of health advocacy,
- support for answering questions and providing recommendations,
- education about the economics of business and health care,
- not-for-profit management training,
- public speaking training,
- media relations training,
- team building and communication training,
- negotiation skills training,
- coalition building training,
- understanding the health care ecosystem,
- facilitation skills training,
- diplomacy skills training,
- government relations training,
- fiscal management training

We asked the respondents whether their own organizational already providing training programs for health advocacy leaders. Of the 28 respondents, 20 replied that their organizations did not provide any training for health advocacy leaders, 1 respondent was unsure about any training programs offered, and 7 other mentioned minimal training programs. This suggests that there is an unmet need for training programs designed for health advocacy group leaders.

We asked the respondents how researchers could help support health advocacy leadership. They mentioned that researchers could help with:

- developing marketing strategies specific to community needs,
- developing productive partnerships with advocacy group leaders,
- educating advocacy leaders about promising medical and public health breakthroughs,
- educating advocacy leaders about applications of the scientific process,
- identifying best practices for health advocacy,
- describing recent grant funding programs, clinical trials, and new government initiatives,
- providing data on policymakers' perspective on key advocacy issues,
- establishing case studies of best practices in health advocacy,
- providing updates on the political and policy environments,
- holding regular training sessions about health research,
- updating advocates concerning relevant new research and publications,
- participating on advocacy group advisory boards,
- educating advocacy leaders about learning styles, use of social media, and providing appropriate social support,
- demonstrating the benefit of research for patients,
- including patients in developing research priorities and trials,
- giving presentations about research findings, and new areas for relevant research,
- describing research finding that help answer real-world questions,
- providing evidence to support advocacy efforts,
- providing insights into evidence-based best practices,
- including health advocacy organizations in the design and conduct of relevant health research programs,
- sharing mega-trends in public health,
- helping to create communication/education programs to help the public navigate relevant health issues,
- translating complex research findings into layperson's language,
- providing relevant case studies about health advocacy,
- training health advocates to understand and present research findings,
- conducting research on prevention, detection, treatment, and effective survivorship

We asked the respondents to describe the roles that media representatives could perform for health advocacy organizations. They suggested that media representatives could:

- increase awareness about relevant issues,

- collaborate with health advocacy organizations,
- report on issues related to justice for health care consumers,
- deliver prevention messages to the general public,
- air health education film clips and public service announcements,
- publish news articles about health advocacy topics,
- distribute advocacy group campaign messages and media,
- report on advocacy group activities,
- deliver advocates positions on important issues to key opinion leaders,
- raise policy makers awareness about key health advocacy issues,
- increase the visibility of advocacy organizations,
- provide accurate information about health issues in collaboration with health advocates,
- customize information for different audiences,
- assist with the use of social media

We asked the respondents what role leadership, teamwork, and skills building should play in developing and maintaining effective health advocacy organizations. They agreed unanimously that these were important aspects of health advocacy and suggested that advocacy organization needed:

- marketing training,
- continuing education and certification,
- develop clear missions,
- leadership, teambuilding, and skills building training,
- strategic management training,
- communication, public speaking, consensus building, and listening skills training,
- change management training,
- collaboration skills training

Finally, we asked the respondents whether there were any other issues or topics they wanted to mention. They replied that:

- nurse navigators are an important part of effective health advocacy,
- love and sharing are important aspects of effective health advocacy,
- be aware that some pharmaceutical companies are developing similar initiatives for health advocates,
- take advantage of available experts to help train health advocates,
- provide a centralized forum for sharing information with health advocacy group leaders,
- expand training programs to the boards of directors that oversee health advocacy organizations,
- help advocacy group leaders understand that the primary role of advocacy organizations is to help consumers and not self-perpetuation of the advocacy organization,
- help advocacy group leaders keep overhead low and services to consumers high,
- help promote high quality in health advocacy groups,
- develop a strategy for positioning GALA to stand out from other training programs,
- a training program for nurturing health advocacy leaders would be of great value,
- let me know how I can help with GALA,
- train for multiple roles that different actors can perform

The responses from the survey have clearly validated the need for training programs, like GALA, to support the development of effective advocacy group leadership. However, the list of issues that a comprehensive health advocacy training program should cover is daunting. Health advocacy leaders have important needs to develop a deeper understanding of the health care delivery system, the legal and regulatory health care environment, the corporate players in the health care system, the health research environment and processes, as well as the influences of media on achieving health advocacy goals. Moreover, the survey suggested that is critically important for health advocacy leaders to develop a number of important communication, leadership, team-building, fund-raising, and financial management competencies and skills. There is also a strong demand for building collaborations across advocacy groups and with key partners from the health care industries, government agencies, research institutions, and media organizations. To be effective, the GALA program must not only provide relevant training for health advocacy leaders. It must also facilitate partnership building, collaborative problem solving, and effective media relations. The GALA program must develop a forum for introducing representatives from different key organizations to advocacy group leaders. It must provide ongoing consultation, advisory services, and problem solving support to health advocacy leaders. It also must provide a repository for storing and disseminating key information about relevant research, best practices for health advocacy, and new opportunities and constraints that are relevant to health advocacy organizations. The results of this survey have been instrumental in guiding the development of GALA program activities and resources. We will continue to gather data and feedback from health advocacy leaders to help us refine and expand GALA programs, especially as the health care system evolves and the demands of effective health advocacy leaders and organization change. In this way, the GALA program can grow, expand, and, continually be responsive to the needs of health care advocacy group leaders.

To promote the ongoing growth and development of the GALA program, new strategies are being examined for seeking government and corporate support for GALA training and outreach programs. GALA team members are identifying leading experts to work with the program to serve as mentors and trainers for aspiring advocacy leaders. New training modules, educational materials, and instructional guides are being designed and refined to use with the program. The GALA online collaboratory system is being designed and information is being collected to include in the collaboratory's online repository of documents, case studies, articles, research and funding opportunities, advocacy resources, and media programs. Information about the GALA program is being disseminated to key individuals and organizations around the globe to increase awareness and support for the new and exciting GALA health advocacy leadership activities.

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Communication Support System Between Persons with Dementia and Family based on Memory Recollection and Life Story

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***Abstract*— Family caregivers who support persons with dementia are deeply stressful because they do not have sufficient knowledge of dementia and give care to them by trial and error. Memory recollection and memory communication are found to be effective for intelligence and emotion of persons with dementia. We aim to support persons with dementia recall memory by talking about their memories together, place them in their life history, and communicate with their caregivers. The proposed system uses photographs as triggers for memory recollection. The demonstration verified that recollection support of memory using photographs is promising as triggers for conversation and organization of memory. In this evaluation, it is shown that the life story has a high possibility to promote communication with person with dementia and the family. Thus, we also propose a communication support system which focuses on the life story. This system supports the communication by comparing the life stories of family, and supports the memory recollection of the person with dementia by using "family life story."**

Keywords-Persons with dementia; caregivers; memory recollection; photograph; communication; sharing of life story.

I. INTRODUCTION

Recently, Japan has progressed into an aging society. Figure 1 indicates the population aging rate of 5 countries and shows that Japan has the highest rate of aging population. This situation causes an increase of persons with dementia because an elderly person has high incidence of dementia [2] [3]. Figure 2 shows the incidence rate of person with dementia for each generation in Japan. Over 85 years old, incidence of dementia reaches more than 25.0%, that is, one of four people will develop dementia over 85 years old.

The symptoms of dementia change depending on the type of disease, the main symptoms can be divided into core symptoms and BPSD (Behavioral and Psychological Symptoms of Dementia). The core symptoms are the decline of aspects of intelligence function, such as defects wandering and hallucinations, which become a heavy burden for care workers. For the family members and other relatives it seems that persons with dementia cannot understand anything. A decline in emotional function, however, does not always accompany the decline in intelligence function. Therefore, sufficient consideration is needed when caring for dementia patients.

In Japan, family caregivers often support persons with dementia in addition to using day-care facilities, but their circumstances are deeply stressful, because they often do not have sufficient knowledge of dementia and so give care to them by trial and error, and they cannot take their eyes off their patient. It is also often hard to obtain cooperation with surrounding communities, due to the negative image of dementia and low social recognition.

In this study, we aim to support the recall of memories of a patient and his or her family, the most familiar presence for persons with dementia. Family caregivers talk together about their memory. This is not an act of the caregiver taking care of the patient alone, but one which creates a good environment in order to help each other. Also, if neither the person with dementia nor the family can recall the memories, we provide a trigger for recollection by presenting social events and information similar to the lost memory. As a result, persons with dementia can recall memories about their family, and family caregivers are able to actively communicate with other members including the person with dementia.

The evaluation results show that our system is effective for the memory recollection, and that it promotes the communication with person with dementia and the family caregivers. In the evaluation, it is shown that the life story is a good content for the memory recollection and communication. Thus, we also propose an extended system which focuses on the life story. In this system, by comparing the life stories of all the family, they can talk about them. In addition, based on the registered life stories, the system proposes the expected life story of a person with dementia. By using the proposed life story, the family talks about them with person with dementia, and create true life story by modifying it.

A brief outline of this paper follows. Section II describes the significance and role of memory, which is lost by dementia. Section III describes research trends of persons with dementia and caregivers. Section IV and V describe system proposal and system functions, which is based on the consideration in Section III. Section VI describes evaluation of the system. Finally, Section VII and Section VIII describe development study and future works.

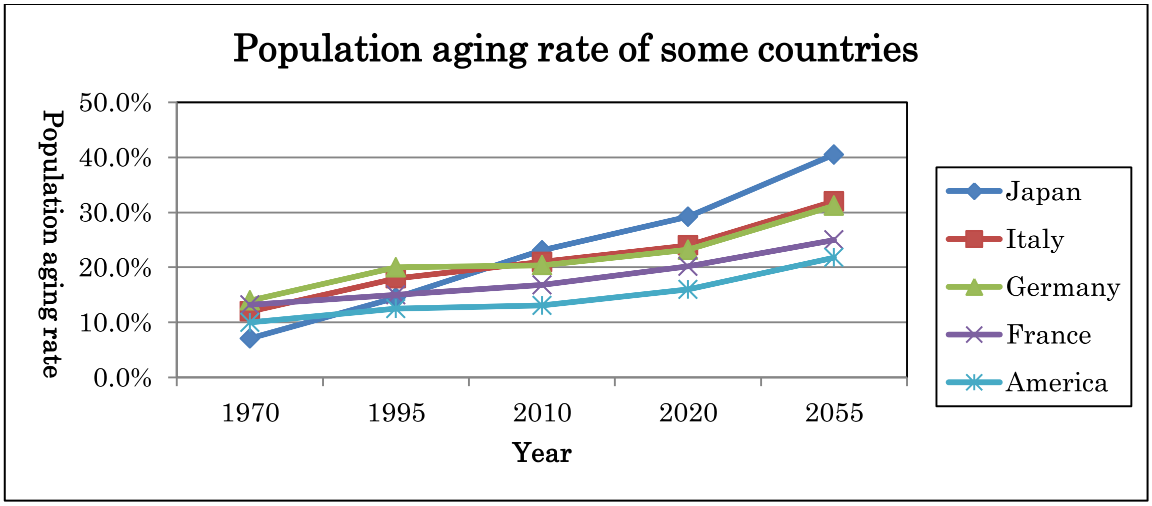

Figure 1. The population aging rate of some countries.

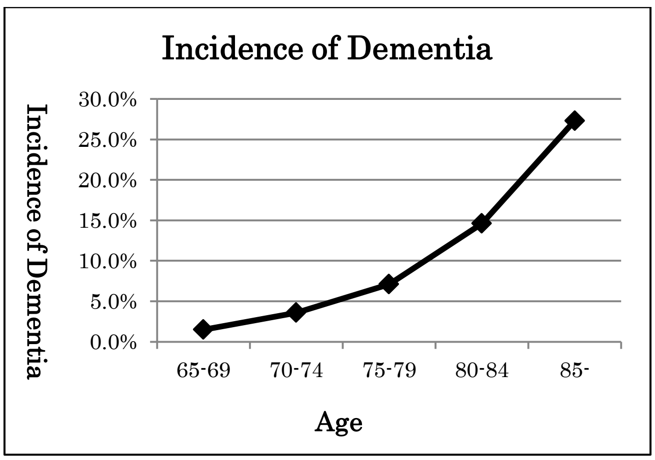

Figure 2. Incidence of Dementia in Japan.

II. Function of Memory

This section describes the significance and role of memory, which is lost by dementia.

Memories are our own private episodes, formed from an individual person's experiences in the past. Even if people experienced the same episode, how they feel about it may differ from person to person [4]. Moreover, our present "egos" has been formed by the accumulation of our own episodes. Memories are fully private unless we talk to someone about them. Thus, memory has the role of reminding us of our consciousness of self.

Viewed from another side, people talk about their memories to prompt mutual understanding. Talking together on the pasts means exposing and exchanging a part of their egos. As a result, people are able to prompt mutual understanding. Thus, memory has a role of building and maintaining human relationships.

However, people forget memories as time goes on. People find it hard to recall memories which they have not recalled for a long time, and thus triggers are required to recall them. Examples of triggers include seeing a photograph, reading a diary, talking with family and friends, hearing a long-forgotten tune, and smelling an old familiar perfume. In particular, photographs hold variety of types of information. They are associated with a specific annotation, such as date and time, place, and events. A photograph helps people indulge in reminiscence alone and share their memories with others, led by various annotations involved in it.

A. *Memory Communication*

Memory has two roles: first one is to remind us of our past experiences, and second is to build and maintain human relationships, as stated above. In addition, having a conversation with others promotes memory sharing and increasing our memories. Normal actions such as talking with family and friends are communication carried out unconsciously; but can be characterized as memory exchanging or 'Memory Communication' [5].

Memory Communication requires the following three elements.

a) The communication methods and partner(s).
b) The memory and a related episode.
c) Something that acts as the trigger to recall the memory.

Many elderly persons talk with family and friends on a regular basis. Talking about memories is an effective way to communicate with a stranger in nursing care homes or hospitals. Communication methods are to meet and talk in person, and bring photographs. Further, recently cell phones and the Internet have been developed, allowing people to communicate with others even if they are far away. It can be predicted that triggers will be different for each elderly person, but looking at photographs of past eras and listening to old popular songs certainly promote remembering.

The significance and role of memory have been described in this section. Memory belongs to each individual person and is an important element for expressing one's personality. However, persons with dementia gradually lose their memory, thus losing proof of their existences.

III. RESEARCH TRENDS

A. Support Systems for Persons with Dementia

Recently, widespread use of cell phones and the Internet is progressing. As a result, support systems which utilize such equipment have been rapidly increasing, such as, a movement navigation system using photographs [6], and a remote interactive support system [7].

a) Movement navigation system using photographs.

Traditional map-based movement support systems are not effective for persons with dementia because it is difficult for them to learn the route and recognize landmarks. Consider this problem and developed a system which encourages understanding of the route by using photographs and animations on a cell phone. It shows a direction to turn at a junction and indicates important signs which show the correct route to a destination, as shown in Figure 3.

b) Remote interactive support system.

This system uses a videophone, and is able to show photographs and videos about memorable episodes even from a distance (Figure 4). Persons with dementia and their caregivers can reminisce and share memories at home, looking at the same photographs and videos, without going to a public institution. As a result, persons with dementia can obtain some stabilization of their mental state, and this system can reduce the burden on the caregiver.

B. Organization Support for Caregivers

There have been only a few attempts to support in-home care. Examples of support services for caregivers include the use of nursing home care and care helpers. However, these services cannot sufficiently reduce the burdens on family caregivers, because the use of nursing home care is expensive and the utility time is limited.

Under this situation, there have been some movements in which caregivers have taken the initiative to confront the difficulties of care. For example, the Male Caregiver Network is an organization of which the members comprise of male caregivers [8]. The activities of the organization include holding exchange parties and lectures for male caregivers. Many of the participants include both veteran caregivers and beginners. These events are a great reassurance to beginners because they can consult with caregivers in similar circumstances. Conversely, veteran caregivers can reflect on their care history through communication with the participants. The members can generate motivation to continue care. In this way, the organization aims to provide a place to talk about and share the worries of care between caregivers.

Figure 3. Movement navigation system.

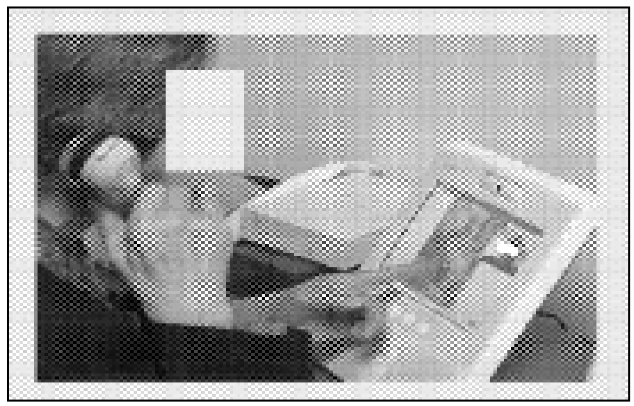

Figure 4. Remote interactive support system.

C. Consideration

Researches which use information technology to support persons with dementia share the aim to enable them to live an independent life. If they can lead their lives as independent as possible in their home, this will reduce the burden of caregivers. Most researches do not aim to target caregivers directly.

However, providing support for caregivers, not only for persons with dementia, is necessary because if persons with dementia live in their own homes, they need help from their family caregivers. They need plenty of nursing care time, and as a result, the burden on caregivers increases and they become exhausted. An environment which supports the caregiver and listens to their troubles is required. Caregivers are taking initiatives themselves such as in the 'Caregivers Male Network', but not every caregiver can participate in these activities. Furthermore, previous research focuses on only negative aspects of home care [9]. The burden of care of persons with dementia has been found to be greater than care of persons without dementia. Recent studies have identified a need to approach the positive aspects of home care [10]. Although caring for family members is recognized as a road which everyone must eventually take, on the other hand, it is difficult to continue due to the heavy burden. Therefore it is necessary to develop a support system for in-home care as part of the social system.

The research trends have been described in this section. Not only focus on persons with dementia, need to consider how support for their caregivers.

IV. System Proposal

A. System Summary

The focus of this study is on the recollection of memory of person with dementia. By communicating with person with dementia and his families about their memory, it is expected that the person with dementia recall his memory and, moreover, that the communication between them is activated. Such active communication will lead to reduction of burden of caregivers.

The system aims to support persons with dementia recall memory. Photographs are used as a trigger to recall memory. People can extract rich information from photographs because they contain variety of visual cues about their contents. People have a tendency to promote their bonding by confirming the shared experiences and photographs provide an opportunity to start a conversation about shared memories of the family. Furthermore, most families have kept photographs in the family album for many generations.

Rich information of photographs can be classified as follows:

a) Date and time, location when the photograph was taken.
b) Reason why the photograph was taken at that place
c) Relationships with person(s) in the photograph.
d) Feelings about the scenery and objects in the photograph.

Thus, the information obtained from one single photograph can be abundant. The system registers the event, location, and date and time as information about each photograph. As many photographs simply show daily life spent with family, these photographs are useful for recalling memories of happy past days and promoting bonding of family through communication of shared happiness.

B. Proposed Method

Users (persons with dementia, family, and family caregivers) register annotation of each photograph - event, location, and date - as a set into the photograph information database. When a photograph is selected, the system displays the event, the location, and the day, in that order. This is because the event, which we place first, is considered as an experienced and repeated memory. Experienced and repeated memory is comparatively well retained.

However, it is difficult for persons with dementia to recall the details of memory just by looking the registered information of the photograph. Furthermore, the family caregiver may not always remember the event shown in the photograph. Therefore, the system shows another photograph registered with similar information or associated social events, as information to aid memory recollection. The content in the social events database stores effective information for recollection, such as social events which occurred during the same period or information associated with the dementia patient’s hobby.

In addition, by registering and displaying the life story of the person with dementia that are recalled, they are able to look back on their own history and place each episode in order on the timeline.

The following steps indicate how to use the system and Figure 5 shows a graphical representation of the system process.

a) Users register the annotations of photographs: the location, the date, and the event.
b) When a photograph is selected, the system shows the annotation. If the annotations are not enough to trigger recollection, show another photograph with similar annotation.
c) If both the dementia patient and the family caregiver do not remember the photograph, and effective content which is judged to help recollection exists in the social events database, the system refers to the social events database.
d) The system shows the result of the inquiry.
e) The family members share the recalled memories through conversation about the period, the location, or the event of the photograph. Then, if a new memory is recalled, the content is added to the photograph database.

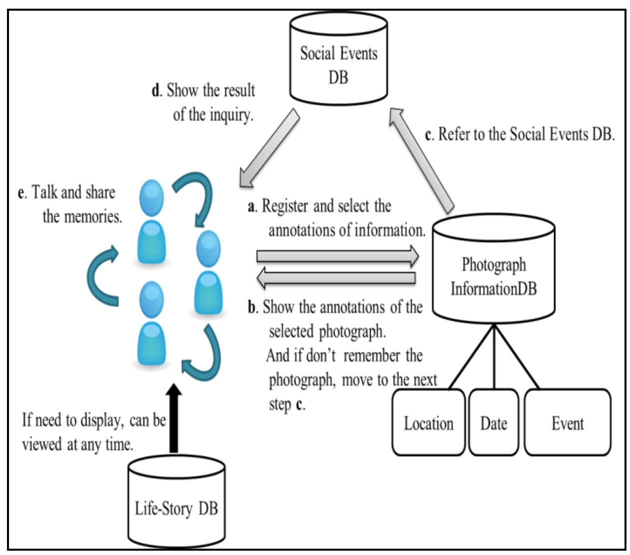

Figure 5. The system process.

V. SYSTEM FUNCTIONS

A. Registration Function

Using the registration function, the system registers a photograph, the photograph annotation, social events information, and life story information. Photographs are stored one by one in a special folder, and photograph annotation, social events information, and life story information are stored in a corresponding database respectively.

a) Registration Function of Photograph Annotation

Figure 6 shows an example of the photograph annotation registration screen. When a registrant presses "Register" button after selecting a photograph, this registration screen is displayed. In this page, the registrant inputs the episode, place, time of the selected photograph. The photograph name is set to the photograph's date and time of registration to aid smooth use of the system. The reason why the system uses the date and time of registration as the photograph name is that it would be difficult for persons with dementia to decide and input names for photographs. In addition, the reason why the system registers the photographs one by one is that users are expected to recall some related memories by looking at each photograph.

b) Registration Function of Social Events Information

Figure 7 shows an example of registration screen of the social events information. For an event which the user wants to register, the user inputs the content and year of the event. When the user wants to confirm the registered information, press the "Show all registered information" button. Then the registered information is displayed in ascending order by years.

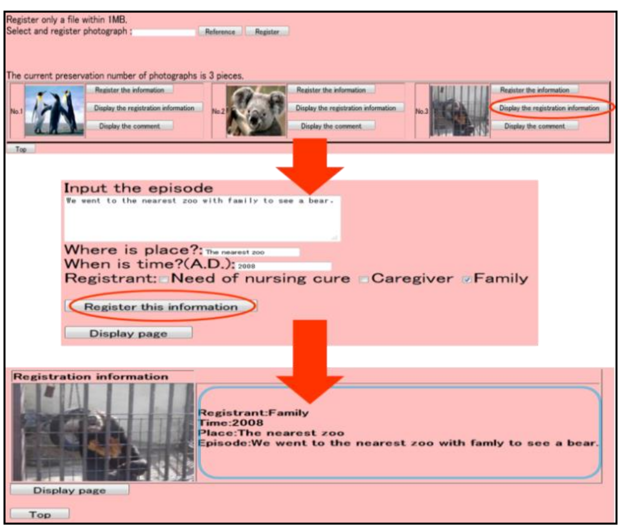

Figure 6. Example of photograph annotation registration screen.

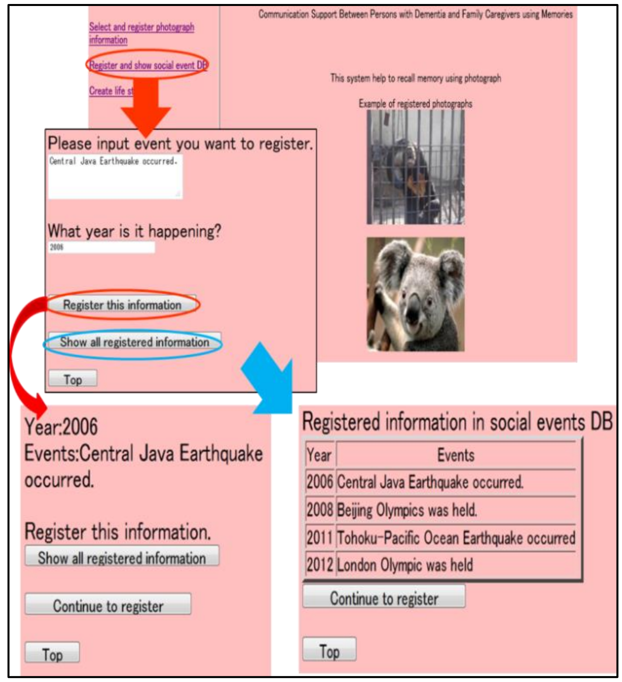

Figure 7. Example of social events information registration screen

c) Registration Function of Life Story Information

Figure 8 shows an example of the life story information registration screen. Input the content of life story, years and age at that time. Like above b), the registered information is displayed in ascending order by years.

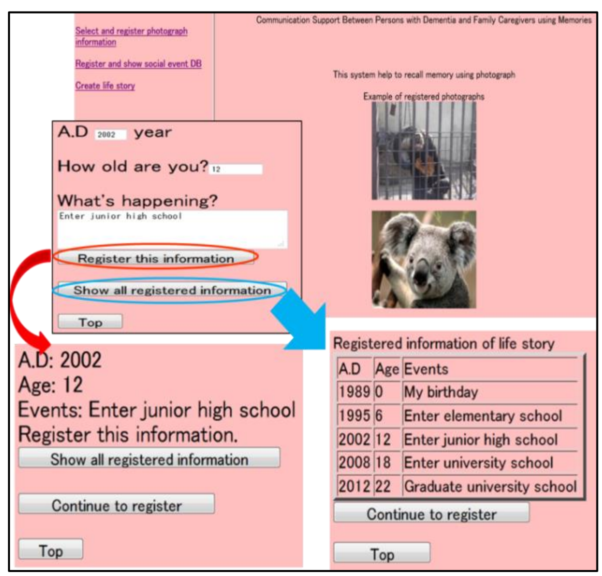

Figure 8. Example of life story information registration screen

B. Recollection Support Function

The registered photographs are displayed in chronological order. When a photograph is selected, its annotation is shown. When the system shows the selected photograph's annotation, it displays the event, the location, and the date in that order, as stated above.

Afterwards, to support the recollection of the user, the system shows some additional information for the selected photograph. The additional information shown in the system is described below.

a) Another registered photograph taken during the same period and its photograph annotation (Figure 9),
b) The social events of a similar time, taken from the social database (Figure 10), and
c) The dementia patient's life story (Figure 11).

The reason why the system shows photograph annotation taken during the same period is that photographs of the same period are assumed to have some kind of relationship with the selected photograph, and users may recall the memory even if they do not remember the details of the photograph. In this system, "same period" is defined as when the registration year is the same. In addition, the system shows the life story of the person with dementia in order to support recollection. The life story information is not always shown, however. Users can show or hide the life story information optionally. The system supports recollection by using life story, enabling dementia patients to look back on their lives.

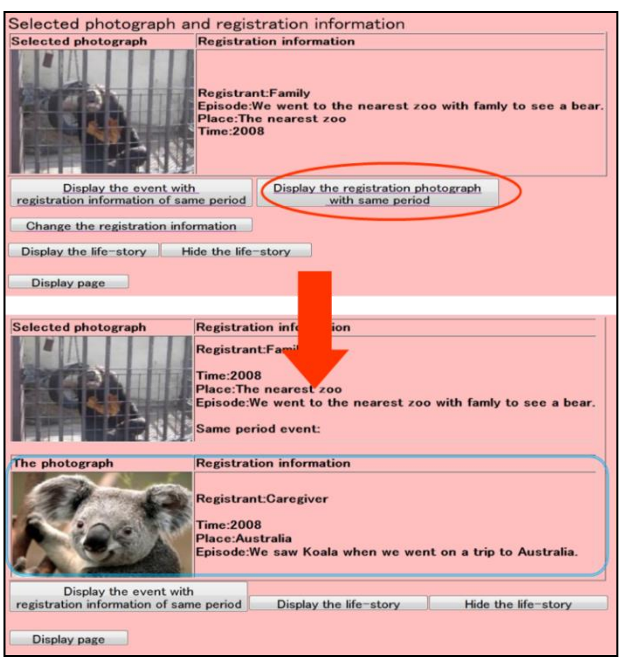

Figure 9. Example of a photograph taken at a similar time

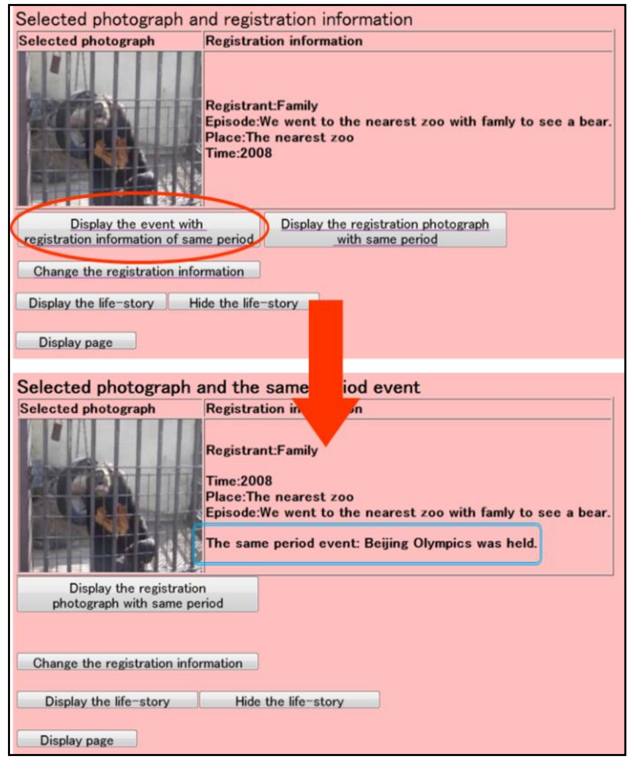

Figure 10. Example of photograph of events of a similar time

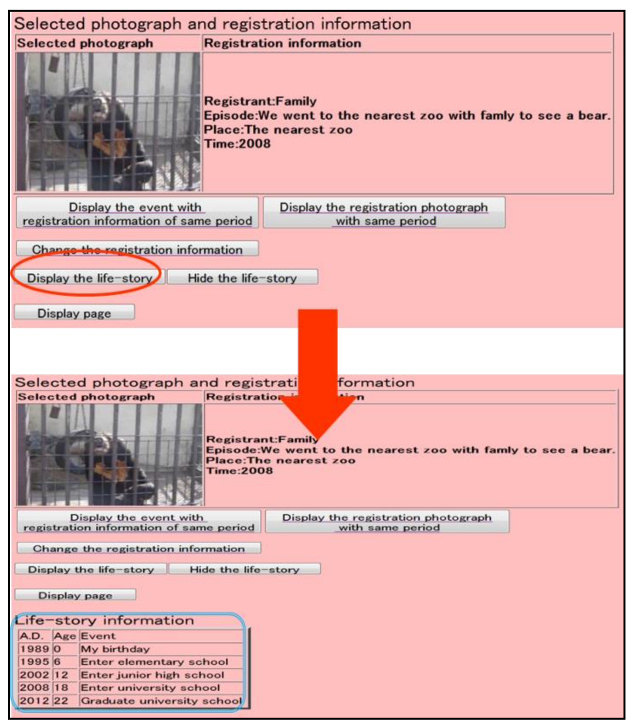

Figure 11. Example of dementia patient's life story

VI. Evaluation

A. Evaluation Summary

An evaluation experiment was conducted with the cooperation of four participants, A and B were family caregivers, C and D were veteran caregivers. The evaluation method was to ask them to use the system and discuss on the information of each registration, then afterwards, to answer a questionnaire on a 4-point scale (1: Strongly disagree, 2: Disagree, 3: Agree, 4: Strongly agree). In addition to the questionnaire, we asked them to write free comments about the system.

B. Evaluation Results

Table I shows the questionnaire items, and Table II shows the evaluation results. In Table II, 1-point means that it is difficult and there are many works, and 4-point means that it is appropriate.

a) Easiness to use the system

As is evident from the results in Table II, there was variation in the answers about inputting the information into each database. This was largely dependent on the user's experience level of personal computers. In fact, one of the evaluation participants had never used a personal computer before, and answered that it was hard to input the information into each database. Therefore it is necessary to develop the man-machine interface to improve ease of input for people who have never used a personal computer.

Regarding the registration works for three databases in this system, we obtained feedback that "there are many works overall." Because registration works are carried out by hand and each registration content (photograph, events and life story) are input one by one. As mentioned above, extended activity will become heavy burden for persons with dementia and a person who had never used a personal computer before. Although the registration works are hard, it provides opportunities to communicate with persons with dementia during the registration process and recall various episodes which anyone does not know. Especially, when the users register about life story, they have possibilities to recall the memory of his or her childhood which family had never heard.

b) Efficiency of using memories

Regarding the efficiency of using memories, we obtained positive opinion that "memories are useful for supporting elderly persons, because they often talk about old times."

Some participants pointed out a very interesting possibility that the recollection stories might be different depending on the user's gender. For example, in the man's case, he would talk about his acts of heroism and events of the days of working. But in the woman's case, she would talk about child-rearing. This kind of difference may generate different attention according to gender of caregivers. In this experiment, all participants were men, and this possibility was not confirmed.

There was the negative opinion that the system will be difficult for persons with dementia to use, because usefulness of the system will be influenced by their mental state at the time of use. If their state is unbalanced, they will be unable to use the system.

Another negative feedback indicated that the system may not be useful for all persons with dementia, because there may be memories that they do not want to recall. Such situations should be considered in using this system for persons with dementia.

Regarding the recollection support function, the opinion was obtained that the system encouraged recollection of memory that preserves the user's uniqueness. The information which is registered in each database depends on the individual. Furthermore, the life story is useful for the recollection of old memories, because it represents one's own history. Talking about old memories and one's life story is effective communication. However, the life story function is still poor in this system. The life story function needs to be improved to efficiently aid memory recollection and sharing.

The responses to Questions 9 and 10 suggest that this system has the ability to aid recollection of memory and better communication with others. If a new memory is recalled, it becomes a common memory, and the users can talk about it and communicate with each other.

TABLE I. Questionnaire Content

Q1	Photograph information DB: Can you input smoothly?
Q2	Photograph information DB: Does it take a lot of work to use?
Q3	Social events DB: Can you input smoothly?
Q4	Social events DB: Does it take a lot of work to use?
Q5	Life story information DB: Can you input smoothly?
Q6	Life story information DB: Does it take a lot of work to use?
Q7	Life story: Do you feel the life story is useful for recall?
Q8	Life story: Were you able to visualize or recall that time?
Q9	Effectiveness: Did you recall anything other than the information which was displayed by the system?
Q10	Effectiveness: Could you communicate with your partner well?

TABLE II. Evaluation Results

	Q1	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**	**Q9**	**Q10**
A	3	2	3	2	2	2	2	3	3	3
B	1	3	1	3	3	3	2	2	3	4
C	3	2	3	2	3	2	3	2	3	3
D	2	2	2	2	3	2	3	3	3	4

VII. Development Study

From the evaluation results, it is shown that using photograph and its information is useful to recall memory and promote communication with the person with dementia and family. In addition, it is found that life story is effective content as the recollection support function. However, there is still room for improvement of the function of the life story in this system. In this system, all the family including a person with dementia must input their life stories to the system. This task may be hard for the person with dementia. In addition, each life story is shown independently while the life stories of family are related to each other. Thus, in this section, we focus on the life story and propose the extended system.

In this system, all the family inputs their life story as they know. Based on the registered stories, the system shows the related life stories to the users. By comparing the life stories, they can take a communication through the found of the difference of experiences at the same age and the experiences before he or she met with spouse. In addition, by using the life stories of family, the system creates the life story of person with dementia because the person may not be able to recall his or her life story. Thus we propose the system that provides a place where each family sympathized with persons with dementia's memory.

A. *Life Story*

This section describes that why we focus on life story. Life story is formed by accumulated life log and life history. Diaries and albums are used to keep a record of personal life logs. However, these items may be lost due to disasters and accidents. And so recently, "digitalization of information," in which the data of diary and album are stored in computers, is progressing. In addition, by development of the Internet, a life log also has attracted attention as a communication tool, like Weblog and SNS (Social Networking Service). On Weblog and SNS, a user often writes a comment to registered photographs and then uses them to communication.

Life story of a person is a collection of significant events for the person, which may be not important for others. However, talking about a life story of a person with his/her family or friends becomes a tool of communication with others and understanding of difference perspectives. Through such communication about life story, a person can give meaning to its own life. Recently, talking about life story has attracted attention for integration of egos [11]. In this research, talking about life stories is used in group work. As studies which focus on the efforts for the individual, in [12], the personal narrative is pointed out to be necessary, and in [13], Blankenburg argued that if a log of life story does not specialize on individual then it may not attract others' notice. Personally characterized episodes are an important element of communication.

The human life generally will be long period until old ages from childhood, and so, elderly persons have various episodes in their life story. Elderly persons can talk about their rich experiences and find meaning of their life through the talking. Young persons who talk with elderly persons about their life stories compare themselves with the elderly ones, and consider their own lives. Thus, talking about the life story can be a communication tool for generations. In [14], it is shown that talking about life story is one of methods to understand the past well and it can apply own experience to the future.

From the result of section VI, it is known that elderly persons want to talk about their experiences, regardless of sex. Therefore, the extended system uses the life story to communication tools with persons with dementia and caregivers.

B. *Research Trends*

As a study using the life story, there is a system, called "yourStory" [15]. In this system, a user summarizes its own life story to recollect memory. This system focused on a "community" which users have been belonged in their lives. In this system, a community is defined as elementary school, junior high school, extracurricular activities and company etc., which are considered as organizations to which the most people have belonged. Many people belong to some communities, and people in a community have a common purpose and place. By summarizing events of a life story according to each community, the registered events may become a trigger of memory recollection of another event.

Figure 12 shows an example screen shot of this system. In this system, the horizontal axis is the time and the vertical axis is the communities which the user have been belonged. When the user click an area, the photograph and some episodes are displayed.

C. *System Proposal*

In development study, we propose a communication system with person with dementia and family caregivers by using their life stories. The system supports not only the registration of each life story, but also the share of life story and the comparison with other life stories, which is a trigger of communication and memory recollection. Then, the event of life story is classified to one in a period of a life, such as childhood, elementary school, junior high school, and so on. The user can compare some life stories in the same period, and find the differences of experiences at the same age. The life stories ordered in time is also shown.

In addition, based on the life stories of each member of a family, "family life story" can be created. Family life story consists of common and impressive events with family.

Figure 12. Example screen of your Story

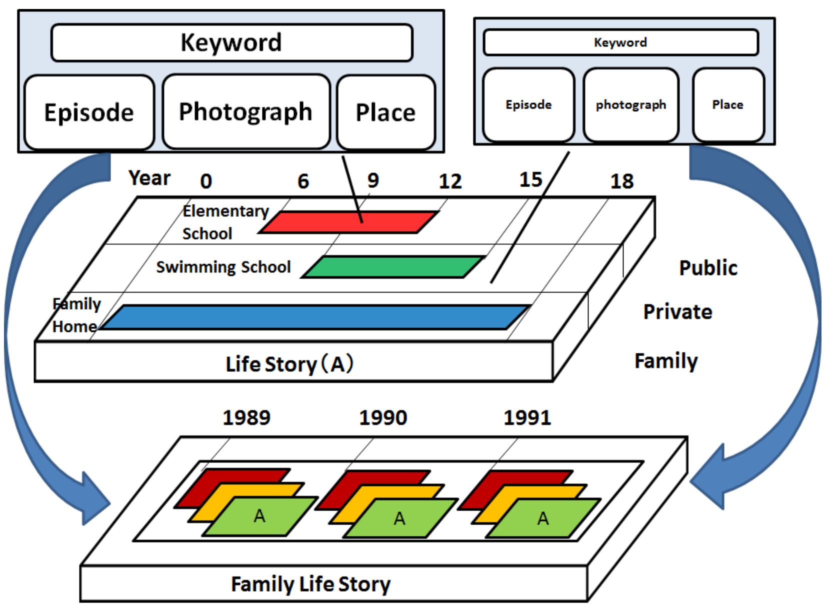

Figure 13. System image of the extended system

Table III. Example of Community

Community	Example	Category
Schools Education	Nursery school Elementary school University etc.	Public
Hobby Activity	Lesson, Club activity Volunteer body etc.	Private
Family life	Family home Apartment etc.	Family

In what follows, the details of the extended system are explained. Figure 13 shows the system image of our extended system. For each event of life story, its episode, photograph, location, community, time, and keywords are registered. The community is defined by the same way as the previous study introduced in Section VII-B. Communities are categories according to the Table III.

Next, how to use this system is shown.

a) If there is the same community and keyword in the other users' life stories, all information about such stories are shown in the near area. Then the user can compare these life stories and associate with each episode. Regardless of the similarity and differences of the episodes, talking about the memory and episode promotes communication.

b) If there is the same community, but there is no common keyword in the other users' life stories, only the keywords and photographs of these stories are shown in the near area. That is, the details of episodes are hidden from the users. By hiding the episodes, the communication is done guessing the episode.

c) If there is an impressive event in a life story for all the family, the user can create "family life story" by adding this event to family life story. The users can know the history of the family visually by filling in a blank of the family life story.

d) If the person with dementia and his family caregivers cannot recall his memory, the system proposes his life story by guessing from the episodes of life stories of the family and the family life story. Through the communication based on this temporary life story, they can recall the true memory and modify it.

VIII. CONCLUSION AND FUTURE WORK

In order to realize the promotion of communication with persons with dementia and family caregivers, a new system is proposed that supports memory recollection by using photographs and associated information. The system supports the recollection of memory via information about a selected photograph and the related social events. By talking about them, the activation of family communication is aimed to be intensified. In this study, it is known that the life story of the person with dementia will be a good trigger of communication and memory recollection. Then, we also proposed the life story sharing support system to promote a communication with person with dementia and the family.

The next step of this study is to implement the extended system, and to evaluate the system with the help of persons with dementia.

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Using Modelling and Simulation to Improve Elderly Care in Ireland: A Case Study

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Abstract—**Health care services are encountering critical issues due to the increasing demand for services at the time of economic recession. Hospital performance is subject to many constraints, and planning is made more difficult by the complexity and uncertainty of demand. Population ageing is creating immense pressures on healthcare facilities across the world, leaving them struggling to cope with the growing demand for elderly healthcare services. Current demand-supply gaps result in prolonged waiting times for patients and substantial cost burdens for healthcare systems due to delayed discharges. This paper discusses on a project that uses modelling and simulation to address elderly care pathways in the Irish healthcare sector. The faster management of frail patients admitted to acute hospitals and the introduction of new intermediate care beds are alternative interventions that healthcare executives are interested in simulating to examine their impact on the performance of the elderly care system. Using a detailed simulation model along with statistical analysis, hospital managers can assess the critical performance and financial issues of the current system and highlight the decision variables that could significantly improve the flow of elderly patients.**

Keywords—Population Ageing, Elderly Care, Discrete Event Simulation, Discharge Planning.

I. INTRODUCTION

This study builds on and extends our previous research presented to the SIMUL 2012 Conference, in Lisbon, Portugal [1]: this extended version includes more detail in all sections.

Advances in pharmaceutical and medical technology during the last century caused a major shift in global demographics, increasing life expectancy to unprecedented figures. So there are now more aged people than ever before - in both developing and developed countries which can be seen as an indicator of advances in global health [2]. Worldwide, there are around 600 million people aged 60 years and over: as Fig. 1-a shows, this total is expected to double by 2025 and to reach virtually two billion by 2050 (World Health Organization - WHO) [3]. In Europe, there are currently 108 million elderly people who constitute 15% of the continent's population, a figure which is forecast to increase to 26% by 2050 [4], a trend which is reflected in Ireland where the elderly population is projected to grow from $500,000$ to 1.3 million over the next 30 years [5]. As Fig. 1-b shows, projections by the Irish National Council on Ageing and Older People (2002) show female and male 'seniors' (65 years and over) accounting, respectively, for 16.4% and 14.1% of the Irish population by 2021[6]. Older people are the major users of health and social care services while elderly patients currently represent 11% of the Irish population, they are estimated to account for up to 50% of hospital bed usage [5]. At the same time as increasing the demand for health and social care services generally, population ageing is affecting the supply of health and social care professionals as the health workforce will have to grow to cope with the demands of the ageing population. These projections constitute a major challenge that is critical to prosperity and quality of life of society as a whole, and promise to put great demand on national healthcare organizations.

Consequently, pressures are now rising on Irish hospitals, not only due to the increased demand for acute hospital beds, but also because elderly patients use hospital resources disproportionately: these demographic changes mean that Irish hospitals are struggling to fill the existing gap between supply and demand while maintaining their service quality[5]. The global economic crisis has inflicted severe cuts on available healthcare funds and led to a 'limited resource' policy in hospitals and other healthcare services. Thus Irish hospitals and elderly healthcare facilities both face equally grave capacity planning challenges if they are to respond effectively to current and projected demand increases [7].

The shortage of beds resulting from this demand increase has had numerous facets that have adversely impacted the overall performance of the Irish healthcare system. Firstly, bed shortages have significantly increased overcrowding in Emergency Departments (EDs), with high percentages of patients leaving without having been seen, and increased mortality rates for elderly patients [5]. Several national reports have highlighted the growing demand for emergency care and the simultaneous decrease in the number of EDs operating to meet this demand; mainly due to economic constraints. Over 1.1 million individuals attended the 33 Irish EDs during 2010, 30% of whom were admitted to hospitals as emergency admissions [8]. Secondly, shortage of community care beds leads to delayed discharges from acute hospitals, which not only delays new admissions to hospitals, but also burdens hospitals with high and unjustified costs, since acute beds are among the most expensive resources of the entire healthcare system [9]. Further complications associated with delayed patient discharges can

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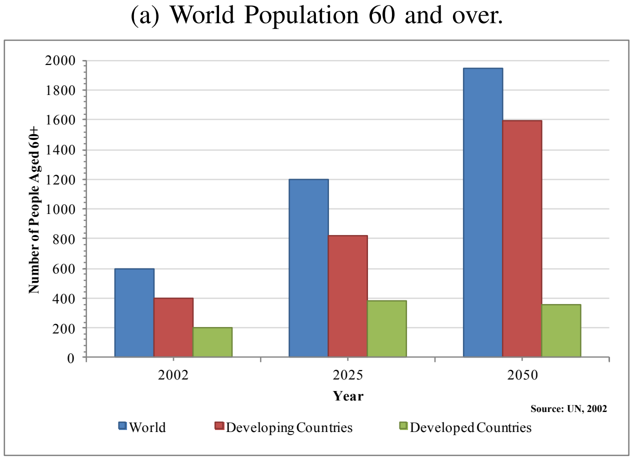


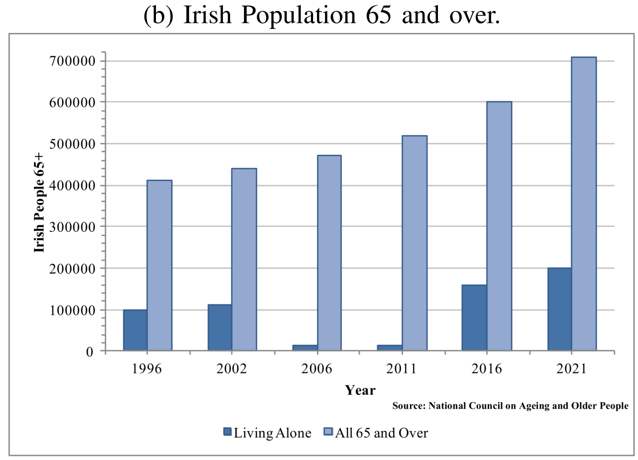


Fig. 1. Statistics for the worldwide people aged 60 years and over (a) and the Irish population aged 65 and over (b).

adversely affect acute hospitals' abilities to cut their waiting lists and deliver their services efficiently and effectively [10]. Finally, delays due to the lack of short- and long-term bed availability create substantial waiting times at many other stages of healthcare systems. As in other sectors, long waiting times in elderly care services are the most frequent source of complaints reported by patients to healthcare executives every year [5]. In Ireland, prolonged waiting times have been reported with more than 500 patients waiting on trolleys for hospital admission every day; 18% of patients are waiting more than 24 hours and 40% between $10 - 24$ hours [8]. It is clear that Irish healthcare already operates over capacity,- and the overcrowding in EDs can lead to compromises in quality of care and patient safety [11, 12].

This paper presents a project implemented to support Irish health executives in taking decisions regarding the management of the care of elderly patients. By modelling their dispatch pathways, we developed a model that enables healthcare decision makers to examine the dynamics of their care systems, and also highlights the variability in patients' dispatch delays, and the limitations on the resources available in healthcare facilities. The model also provides a holistic capacity-planning model that can be used to assess proposed strategies to handle existing bottlenecks and improve the overall experience for elderly patients attending EDs, and throughout the Irish hospital system. The paper reviews literature on discrete event simulation and its applications in healthcare domains, then introduces the conceptual model depicting the elderly patients' journeys through the healthcare system and their different discharge destinations. The development phases of the simulation model including data collection, coding, and then validation are presented. The proposed model is then used to examine two scenarios proposed by healthcare policy makers to improve patient flow, after which experiments and statistical analyses are conducted to determine the most significant factors that affect patient flows and the magnitudes of their impact.

II. LITERATURE REVIEW

Business environments exhibit two types of complexities: combinatorial and dynamic [13]. Combinatorial (or detailed) complexity describes how complex a problem is in terms of alternatives, which may point to the possibility of very large numbers of potential solutions [14, 15] and can be used to represent any combinatorial problem such as scheduling flight legs [16]. In contrast, dynamic complexity relates to non-linear interactions of system components over time, and may appear in even simple systems [13, 17, 18]. System complexity complicates, and thus can adversely affect, human decision-making processes, which can result in sub-optimal, or even unintended, results (side effects), which are mainly due to the bounded rationality of decision makers [19-21]; misperception and the non-linearity of the complexity [22, 23].

Complexity in healthcare systems stems from various causes, as there are many elements and components involved which interact with and mutually impact each other. Such interactions may be circular, are not easy to capture, so the results of actions and decisions are not immediately obvious or measurable. For example, there will be a delay between when hospital expansion is recognized as being necessary to satisfy increased demand and when the expanded hospital is fully functioning, and there will be time delays and variations between when health problems appear and when actions are taken to restore the system to the desirable state of being able to meet demand. Such non-linear relationships also make it hard to forecast the dynamics of healthcare systems accurately, and complicates decision making processes. For example, the relationship between length of stay (LOS) and admission waiting times is non-linear: if a patient is admitted quickly, it can be expected that his/her medication period will be short - but if s/he has waited for a long time to be admitted, the medication time is likely to be significantly longer indeed the patient's situation may have worsened considerably while waiting for medication, especially if they are elderly. These make the results of policies intended to improve system's performance may be disappointing, as they may be subject to resistance from staff, in particular consultants, and counter-intuitive behaviour on the part of the policy makers. Simulation and modelling can be an effective and flexible tool to apply with several of these concerns and so contribute towards improved health system performance and better health care provision [25].

In most recent studies of simulation an modelling, discrete event simulation (DES) has been the most widely used in many applications. The system's functions are modelled as a finite-state machine in which transitions occur based on events [26, 27]. DES system modelling can be viewed as a queuing network: individual entities (here, patients) go through a process (a consecutive series of activities), each of which may have a queue of other entities waiting to be processed. Individual entities have attributes that reflect their particular characteristics and which determine what happens to them during their journey through the system. The selection of probability distributions is subject to the modeller's decisions, historical data, literatures and the nature of the particular problem being modelled. Traditionally, DES models were applied to deal with details, process, decision rules, queues and scheduling activities at both operational and tactical levels. Such models require large amounts of quantitative numerical data, and their intrinsic stochastic nature means they need extensive statistical analysis and design experiments. The main objective of these models is performance prediction, comparison of scenarios and optimizing performance measurement with accompanying optimization algorithms [28, 29].

Healthcare administrators can benefit from DES to assess current settings and in predicting changes in performance after proposed operational changes. DES models can be effective tools to deal with hospital problem areas, like operating theatres and emergency departments, where healthcare demand will be variable but resources are likely to be limited [30, 31], and to identify possible areas of improvement that could be achieved via reorganization and re-allocation of existing resources [32, 33]. Many studies have discussed the suitability of DES for modelling healthcare processes in detail [27, 34-37], and they used them to examine outpatient clinics [38, 39], planning for healthcare services [40, 41]; ambulance scheduling [42]; and improving capacity utilization in intensive care units [43]. A previous study has used a stochastic simulation model for bed occupancy[44], and other applications have included settings - such as emergency departments [25, 45-47], operating theatres [48]; and pre-operative process [49] - in which resources are scarce and patients arrive at irregular times, where modelling can facilitate the effective evaluation and testing of the outcomes of various alternatives and interventions [39]. The dynamic capabilities of simulation can allow a more accurate interpretation of the utilization of hospital resources to be envisaged [50], supporting hospital managers' decisions on bed usage and patient flow through the hospital [51] by modelling problems of patient flows [52], and then using scenarios to illustrate the consequences of possible suggested solutions by hospital management on performance[53].

III. PROBLEM CONTEXTUALIZATION

A. Background

Elderly patients are usually defined as those who are aged 65 and older and this study adheres to that convention [54]. The most challenging elderly patients are those referred to as frail - as suffering from an array of medical conditions that individually may be curable, but collectively create complex and potentially overwhelming burdens of disease [2]. Frail patients constitute $18 - 20\%$ of the Irish elderly population and usually require longer treatment in the healthcare facilities, followed by rehabilitation and/or community care. In terms of length of stay (LOS), frail patients are characterized in this study as those needing treatment in acute systems (i.e., hospitals) for more than 15 days: The remaining $80 - 82\%$ of elderly patients (who receive shorter treatment periods) are referred to as non-frail. While this study focused initially just on frail patients, since all 65+ patients use the same healthcare system resources, it was found necessary to widen the project's scope to encompass all elderly patients, both frail and non-frail. Although elderly patients utilize a wide range of resources, the initial phase of the proposed model gives special attention to bed capacity in healthcare facilities based on a request from healthcare executives: thus elderly care services that do not involve admissions - such as outpatient clinics - are excluded from the model because they do not affect hospital bed utilization.

B. Conceptualization

Elderly patients' journeys through hospital systems usually begin with their arrival at ED by ambulance, walk-in or following a referral by a General Practitioner (GP). After admission, elderly patients receive treatment in acute beds until they are assigned care pathways according to their diagnosis and frailty level. The duration of treatment ranges from few days to two weeks for non-frail patients, but usually exceeds 45 days for frail patients. After their stay in acute beds, elderly patients are discharged to one of the following destinations:

- *Another Hospital*: Certain medical procedures may require equipment that is unavailable in the acute hospital where an elderly patient has been admitted, and they need to be transferred to another hospital where the technology required for the procedure they need is available. Discharge figures to another hospital (6% of all elderly patients) include patients who are moved to undergo certain procedures, and those who are returned to their original hospital after such procedures
- *Rehabilitation*: Patients whose are deemed 'frail', but who are judged as having the potential to improve towards functional independence are discharged to an on- or off-site facility where they receive rehabilitation. Such facilities can be seen as intermediate destinations suitable to the situation where they are no longer categorized as acutely ill, but still need close medical observation in the hope that they will recover [55]. After rehabilitation, the majority of patients (80%) are discharged home, and the remaining 20%, who have not recovered, to long term care.

- *Convalescence*: Around 10% of non-frail patients are discharged to a convalescent care facility for a short stay to recover from a medical procedure. Convalescence offers less intensive care than rehabilitation, as it essentially prepares patients to go home, and may take place within dedicated short stay beds in nursing home facilities.
- *Long Term Care (LTC)*: More than a quarter of frail elderly patients will be unable to live alone at their homes as they are unable to care for themselves, and may require ongoing medical supervision. Such patients are discharged to a public or private nursing home to receive LTC, where they usually stay for years until they die. This prolonged stay in nursing homes hampers the supply of LTC beds in the healthcare system, and can result in waiting times that amount to several months. In addition to hospital demand, there is also a demand from frail patients in the community who need LTC, and must wait in their homes for a nursing home place.
- *Home*: The vast majority of non-frail elderly patients - 88.9% in all - are eventually discharged to their homes, whether directly or after a short stay in convalescence. 24% of frail patients are discharged directly to their homes, and another 28.8% go home after a period of rehabilitation. More than half of them will continue to require medical care in their own homes, and are given Home Care Packages (HCP), which comprise a set of state-provided services that may include home help, nursing, physiotherapy, occupational therapy and other services [5].
- *Other Destinations*: In addition to these destinations, 6% of elderly patients are likely to die during their acute stay, with the probability of mortality increasing proportionally with the frailty level, while another minimal number of patients (slightly more than 1%) with special conditions are discharged to 'other' destinations (e.g., prisons, psychiatric facilities, etc).

Elderly patients' alternative care pathways and their required bed resources are illustrated in Fig. 2, and the percentages of patients discharged to each destination listed in Table I. However, shortages of LTC and HCP bed or service capacities may be the main reasons behind delayed discharges from acute hospitals. Elderly patients can often occupy acute beds for extended LOS, that exceed their treatment periods, not because they continue to require acute health services, but because they are waiting to be discharged [56].

C. Data Collection

The overall aim of this project is to develop a simulation model to address the problem of the delayed discharge of elderly patients in Ireland. Interviews and observations are qualitative, which is of a great benefit in understanding and modelling work flows in the healthcare facility. Data quality and precision determines the validity of the simulation model, so the data collection phase represents a critical element of any simulation project. Historical admission and discharge data was collected from the Hospital In-Patient Enquiry Scheme (HIPE), a computer-based system designed to collect demographic, clinical and administrative data on discharges and deaths from acute hospitals nationally, while bed capacities and LOS data were gathered through surveys conducted nationally, and included valuable information about patients and their care journeys, such as arrival times, sources and times of admission and times and destinations of discharge. As in other healthcare modelling projects, collecting the relevant modelling data presented considerable challenges [57]. The first was the dearth of data about certain parameters that were not captured by the HIPE. (It is worth noting that the lack of relevant data caused a similar project studying care of the elderly in the UK to alter its objectives from producing quantitative results to only building a simulation model [55].) The second challenge was that the data was provided in aggregate figures e.g., the numbers of patients discharged to multiple destinations was combined into a single number, while modelling inputs require such figures to be broken down into their individual elements. The third problem with data in this case was inconsistencies between different data sources, such as variations in figures between hospitals data and annual reports. After numerous extended meetings with hospital officials, the absence of certain data and lack of information on how to decompose aggregated figures were overcome by the use of assumptions based on the opinions of experts in the field [58]. Gaining a deeper understanding of what each figure reflected revealed that, in most cases, misunderstandings of terminology or scope were the reasons behind what seemed to be inconsistencies in the data available.

Patient information was extricated from the raw data by data manipulation and reorganization, after which data analysis was used to extrapolate important inputs for the model, such as admission and discharge patterns, and to segment frail patient data. The admission pattern of all elderly patients is shown in Fig. 3. Fig. 3-a shows the daily patients admission histogram distribution during 2010. More than 75% of days saw average daily admission rates of between 575 and 675 elderly patients (average 587, standard deviation 88.26). Fig. 3-b presents the monthly demand of patients as a percentage of the total annual demand, which shows the distribution of demand across the months is approximately uniform. Although admission numbers for December are significantly lower than for other months - which may be due to demand decay during the Christmas holidays - demand levels return to normal in January.

While these figures give an overview of the elderly care demand pattern, it would be inaccurate to think all patients present the same demand characteristics: elderly patients' needs and the severity of those needs differ. Accordingly, it was essential to manipulate different admission patterns to reflect the characteristics and needs of different groups of patients. Admission data were clustered to group frail patients into five categories (coded numerically from $0-4$) according to their acute LOS, which representing the degree of complexity (DOC) of their needs, based on the validated assumption that the most complex cases spend more time in hospital. All 65+ patient data was also categorized into five clusters by age group. Based on the data analysis and

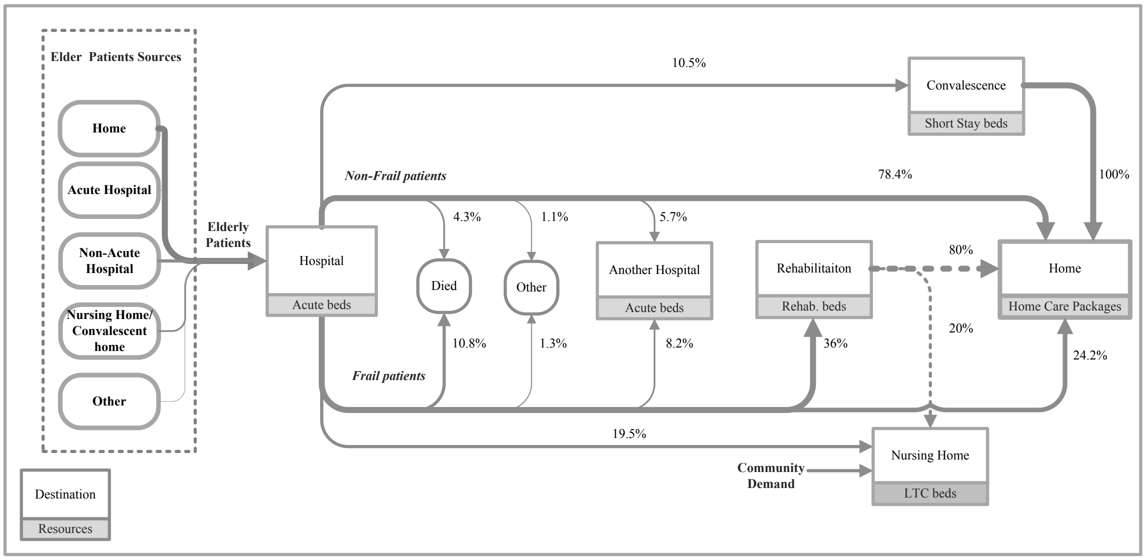


Fig. 2. This figure depicts the Elderly patients care pathways.

TABLE I. DISCHARGE DESTINATIONS PERCENTAGES.

Discharge Destinations	Percentage of Patients		
	Frail	Non-frail	All 65+ Patients
Home	24.2%	78.4%	68.6%
Another Hospital	8.2%	5.7%	6.1%
Rehabilitation	36%	0%	6.5%
Convalescence	0%	10.5%	8.6%
Long Term Care	19.5%	0%	3.5%
Died	10.8%	4.3%	6.1%
Other	1.3%	1.1%	1.1%

this segmentation, elderly patients' degrees of complexity and age groups were used during simulation to define their care pathways through the model. Fig. 4-a shows the percentages of elderly patients classified in each degree of complexity: About 82% are classified as non-frail patients (with zero complexity), the other 18% are classified as frail patients with different degree of complexities. Fig. 4-b shows the different sources of admission categorized by age group. About 90% of all elderly patients came directly from home: as the figure shows, that percentage decreased as patients got more elderly, sloping down from 93% of $65-69$ year-old patients coming from home to about 84% for the for $85+$ age group, which reflects the pattern of their health care demands and emphasizes how elderly people - in particular frail patients - need more care and treatment which they cannot be provided with at home.

D. Model Development and Validation

Based on conceptual model development and empirical data analysis, a comprehensive discrete-event simulation model was developed, with an input/output MS Excel spreadsheet as a user-friendly interface - as requested by the executive team. Simulation model modules were connected in the same way to the conceptual flow chart, which eased the model construction phase, with, the top level of the simulation model defining the overall model structure, and sub-level blocks comprising additional modules with more details. Object-oriented programming was used to customize pre-defined blocks for constructing the simulation model. The main entities for the simulation were elderly patients, each of which was assigned a set of attributes reflecting a mix of characteristics (such as their degree of complexity and age group) to determine their discharge destination. Statistical assumptions were included by using a Poisson distribution for the admission rate and exponential distributions for service times [56]. These assumptions were validated using the Kolmogorov Smirnov test for goodness of fit with a 95% confidence level. Days were used as the time unit for all modelling inputs and outputs. The measured Key Performance Indicators (KPIs) were saved onto a database after each simulation run, and then exported in tabular form for further analysis and validation.

To reduce the model development cycle time and to increase the confidence in the simulation model's results, verification and validation were carried out throughout the development phase to confirm the model represented actual patient flows [57], and to ensure each model development phase aligned with

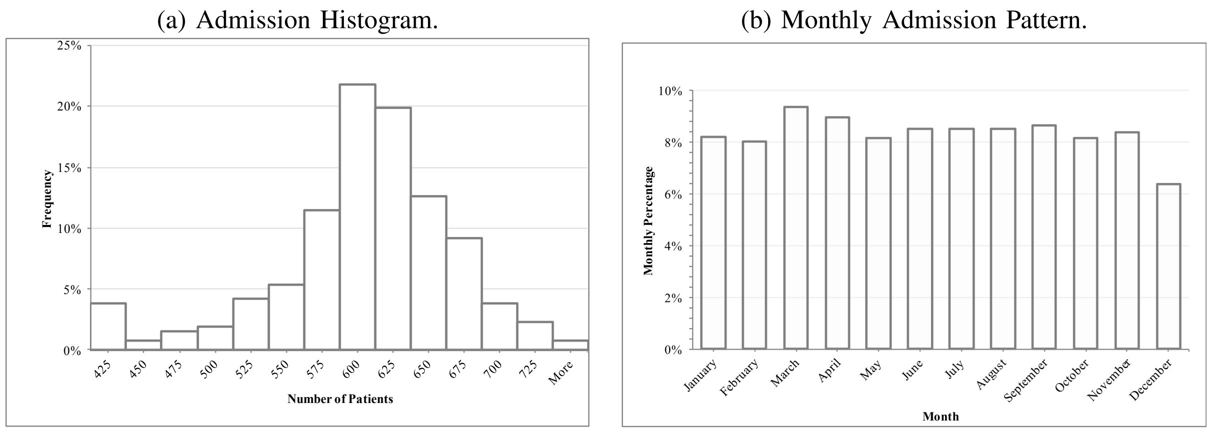


Fig. 3. The Admission data of Elderly patients. (a) presents the admission distribution and (b) shows the monthly admission.

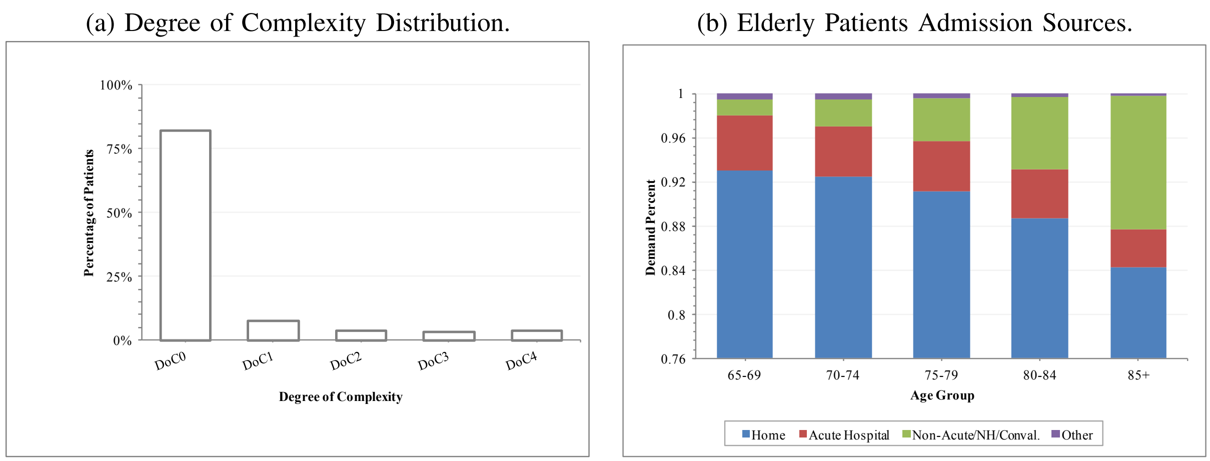
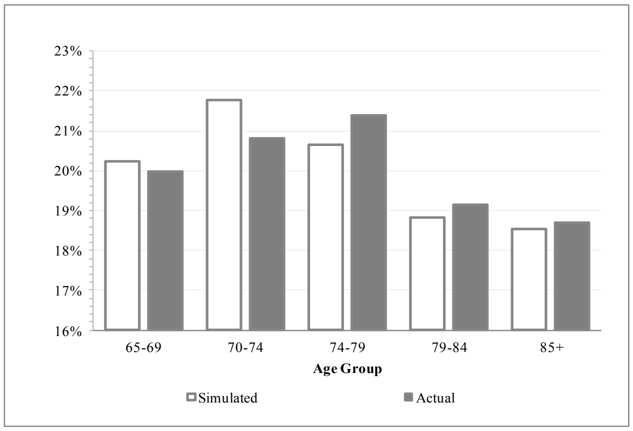


Fig. 4. The degree of complexity distribution in (a) and the different sources of admissions and their percentages in (b).

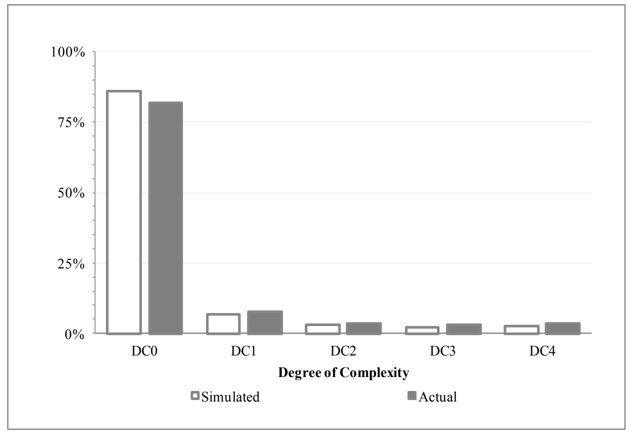
previously completed phases. The model logic was verified to ensure that patients followed the expected care pathways, by visually tracking patients using animation and by checking intermediate output values such as queue lengths and waiting times. Queues at each patient care stage were initially set as empty and idle, and a three months 'warm-up' period used to mitigate any bias introduced in the simulation model's initial conditions until a steady state was achieved. To compare model results for each scenario with the data provided, we generated results for one year by running the model for 465 days and discarding the results for the first 100 day which is the warm up period. Different numbers of runs (i.e., replicates) were tested and it was found that 10 runs per scenario were sufficient to obtain unbiased estimators of the expected average of each KPI. The results of the 'as-is' model were validated in two ways. First, stakeholder validation was completed by meeting executives and presenting the simulation model final results to them, and second, the model was validated by comparing simulated figures with the actual figures for patients discharge per age group, per degree of complexity, and per discharge destination (see Fig. 5). Fig. 5-a compares the percentage of discharged patients grouped by age for actual ans simulated. Fig. 5-b compares between simulated and actual percentage of discharged patient in terms of degree of complexity. While Fig. 5-c compares between actual and simulated discharge destinations.

The architecture of the elderly care simulations consists of three main layers (see Fig. 6). Firstly, the simulation model layer, which represents the system structure and logic. The simulation model reflects the interactions between system entities (patients) and different types of resources by creating a network of processes and represents what happens to patients after their admission (patient's pathway). Animated interfaces were provided to the model's users, which are particularly useful for end users who need to see the dynamics of the problem and its impact. The second layer is the input output layer, which uses Excel as an external database for input and output variables, to simplify and automate user interaction and policy testing. It enables model users to test different policies related to capacities (i.e., Acute Beds, Rehab Beds, Transitional Beds,...), to see the effects of changes in demand under different scenarios on performance measures, and to quantify the effects of changes in model parameters (i.e., average LOS, Discharge percentages,...) on overall performance.

(a) Discharge per age group.



(b) Discharge per DoC.



(c) Discharge per Destination.

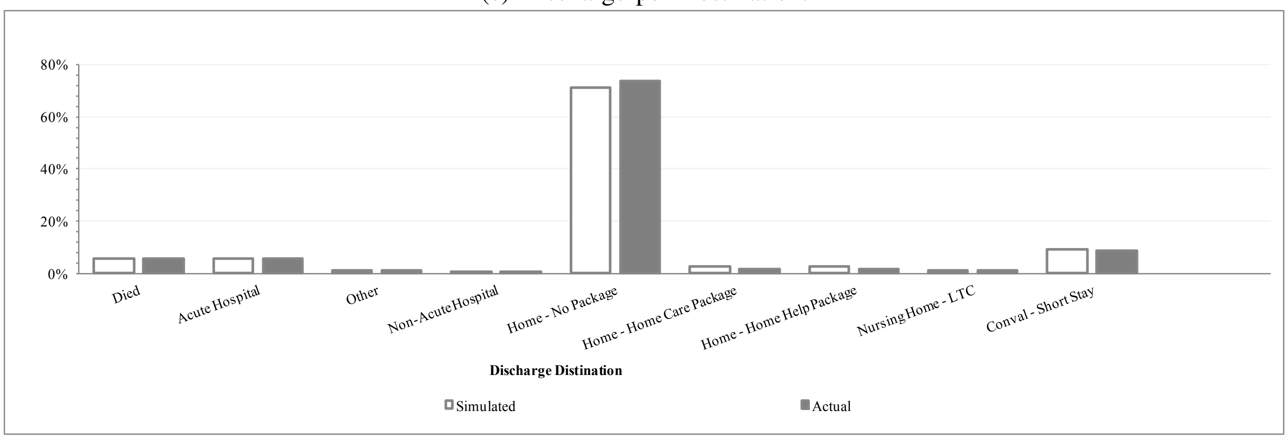


Fig. 5. Model Validation comparing Simulated vs. Actual.

At the start of a simulation run, the model reads input variables from the input data files and stores them in its embedded database in order to speed up the run. At each time step, the simulation model writes the output variables (Queues, resources, and entities related information) to its embedded database, and then to Excel output file for further analysis. After the simulation runs are completed, the Excel output files store output datasets which reflect what happened during the simulation. These datasets need to be analyzed to generate informative reports to the users (the decision makers), which necessitates a mechanism for displaying the relevant output information. MS Excel report generation layer (third layer) is used to analyze the output datasets automatically, and generate reports that include statistical summaries, analysis and figures which simplify the output presentation for the end users.

E. Delayed Discharge

Table II presents the reasons for delays in the discharge of elderly patients, and shows that about half of them were waiting to get rehabilitation beds and the other half for long term care beds. On average about $2,258$ elder patients occupied about $314,711$ acute bed days while waiting for rehabilitation care, which represented about 50% of total acute bed days occupied and 17.24% of the total annual acute bed capacity. Their mean waiting time for rehabilitation care was 139 days. Similarly, about $2,720$ elderly patients occupied $317,928$ extra acute bed days inappropriately (waiting about 118 on average) whilst waiting for long term care (LTC) accommodation. These delays affected both the cost of running health services and patients' wellbeing negatively [10, 59, 60]. Overall, about one-third of the total annual capacity of acute beds was occupied inappropriately by elderly patients, whose need for acute beds had ended and who were ready to be discharged. This depletion of about one-third of the annual acute bed capacity highlights how delays in discharge is a significant problem for acute hospitals: difficulties in accessing rehabilitation facilities or long term care services were the main factors for these high discharge rate delays.

IV. SCENARIOS

Hospital executives proposed a number of strategies to the project team to improve patient flow: this section examines these scenarios and considers the key performance metrics involved.

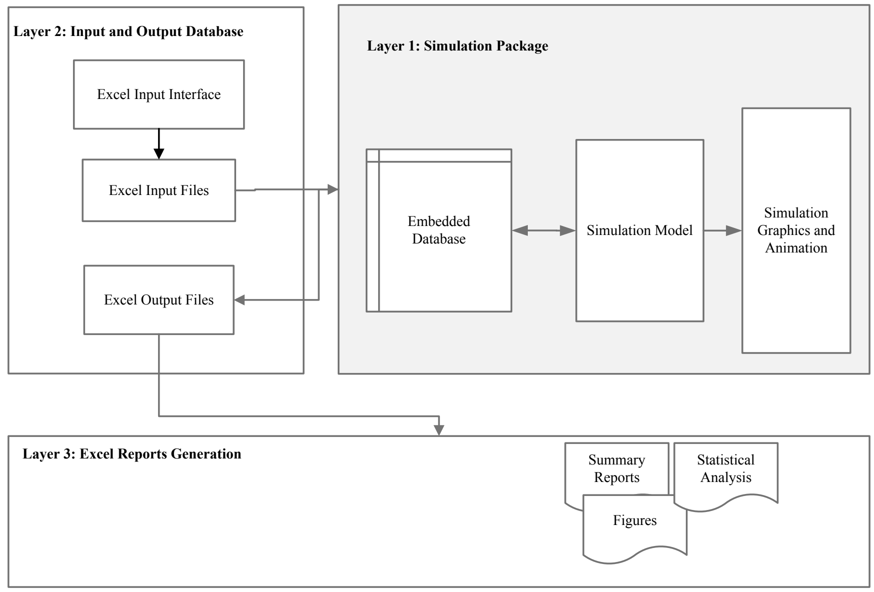


Fig. 6. Elderly simulation model architecture.

TABLE II. REASONS OF DELAYED DISCHARGE

Reasons of Delayed Discharge	Average of Patients Waiting	Average Acute Bed Days Consumed / Patient	Total Consumed Acute Bed Nights	% of occupied acute Beds inappropriately	% of Total Acute Bed Days
Await For Rehabilitation Bed	2, 258	139	314, 711	49.75%	17.24%
Await for Long Term Care (LTC) Bed	2, 720	116	317928	50.25%	17.42%
Total Bed Nights inappropriately Occupied			632, 639.5	100%	
Total Annual Bed Nights Available			1, 825, 000		34.66%

A. Key Performance Indicators

Although the model produced a portfolio of results, the following KPIs that focus on acute hospital measures were selected:

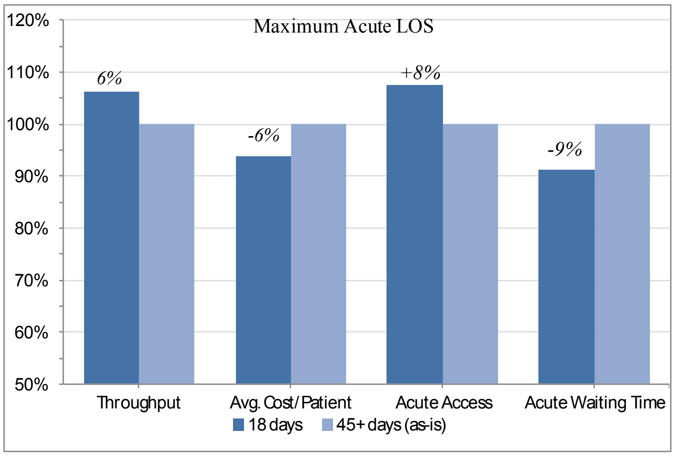
- *Acute waiting time*: the average time spent by patients waiting for admission to an acute hospital.
- *Acute access*: the ratio of admitted elderly patients to the overall demand for admission.
- *Average cost per patient*: this cost perspective was added to the model to reflect financial effects of different scenarios. The average cost per patient was calculated by dividing total cost incurred through bed usage by the total number of discharged patients. Due to data confidentiality, the results reported for each scenario in this paper have been anonymized by normalization, i.e., setting the current ‘as-is’ values at one and reporting scenario results as percentages relative to those figures.
- *Throughput rate*: the total number of elderly patients discharged per year

B. Shorter Acute LOS for Frail Patients Scenario

One of the first strategies the management team proposed to improve patient flow was to set a target for how long maximum acute LOS for frail elderly patients - whose current average LOS exceeds 45 days - should stay in acute hospital beds. Where this length was exceeded, hospitals would be instructed to make earlier decisions about an elderly patient’s medical needs and degree of frailty to accelerate their discharge from hospital. A scenario was tested assuming that frail elderly patients would have a maximum acute LOS of 18 days (only slightly longer than the average for non-frail patients).

The results of testing this scenario (presented in the Fig. 7-a) show some improvement in patient flow. Throughput rate and acute access are increased by 6% and 8% respectively, while acute waiting time and cost/patient decrease by similar percentages. It is likely that performance improvements in this scenario would be somewhat limited, since frail patients whose LOS currently exceeds 18 days constitute 54% of all frail patients, but only 10% of the entire elderly population, so reducing this duration would not have a major impact on the efficiency of the system globally. Despite their interest in testing this scenario, healthcare policy makers foresaw its drawbacks. The dependence of acute LOS on patient diagnosis and the medical procedures required could hamper the implementation of a maximum LOS policy, and might face resistance from medical staff. Hence, other more effective and pertinent solutions needed to be sought.

(a) Impact of reducing maximum acute LOS to 18 days.



(b) Effect of introducing intermediate care beds on KPIs.

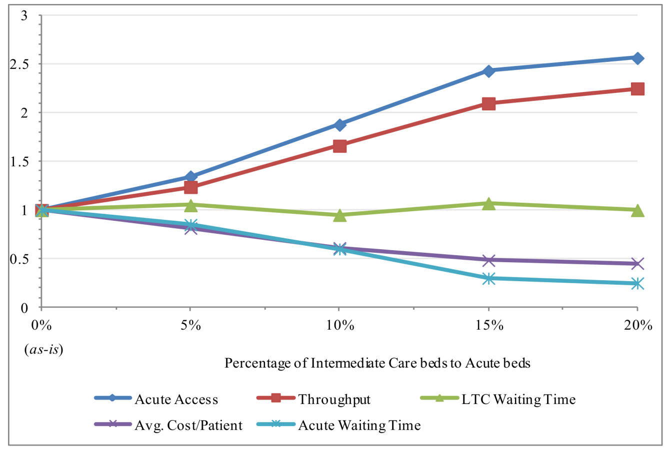


Fig. 7. Two different scenarios and their impacts on the KPIs.

C. Intermediate Care Scenario

The second strategy proposed was the introduction of a new service similar to the Intermediate Care initiative in the UK that could serve patients who were only using acute or rehabilitation beds for prolonged periods because they were awaiting discharge to LTC [55]. Intermediate care beds would be mostly located offsite in what would be a 'transitional' venue, where frail elderly patients could spend time before being assigned a place in a long term facility. Intermediate Care option can contribute significantly to the efficacy of acute healthcare services by reducing unnecessary acute care admissions and assisting the more timely discharge from acute care beds, which could yield significant cost savings, as the costs of intermediate care beds are estimated to only about half those of acute beds. To assess the impact of this service on the elderly care system, different alternatives of this scenario were examined using the simulation model developed for this study, with each experiment using different intermediate care beds capacities. These alternatives were based on a gradient increase in intermediate care beds in proportion to a static number of acute beds in the system, starting with 5% of the acute bed capacity and increasing in subsequent versions to 20%.

Introducing intermediate care beds appears to have an overall positive effect on patient flow by noticeably increasing throughput rate and acute access by factors of up to 2.5, while reducing acute waiting times and costs/patient by up to 50% of the current figures (as Fig. 7-b shows). Intermediate care beds can reduce waiting times for both acute and rehabilitation admissions because they accelerate the release of acute and rehabilitation beds back into the system, so more beds are available to meet the incoming demand. Despite the fact that intermediate care would be the last stage that precedes LTC, it is observed that it has almost no effect on LTC waiting time. This was not unexpected, as LTC waiting time is constrained by LTC bed supply, regardless of where elderly patients are while they await LTC placement.

D. Design of Experiments and ANOVA

In addition to evaluating these two scenarios, healthcare executives were interested in trying to gain insights into the dynamics of the elderly care system, and also to identify the most significant factors affecting its overall performance. Using an orthogonal array ($L27$) a factorial design of experiment was conducted [61, 62]. three The Taguchi method uses orthogonal array from the design of experiments theory to study a large number of variables with a small number of experiments. The $L27$ design allows for testing up to 13 factors at each of three levels: high (3), medium (2) and low (1) ($H - M - L$). Six selected factors were tested and the values for $H - M - L$ levels were determined based on the current figures (with one of the three levels set as the 'as-is' value. Twenty-seven experiments were carried out based on the selected orthogonal array, with the system's throughput rate, acute access rate, and acute waiting time as the responses (i.e., outputs) measured in each experiment, as healthcare executives recommended. $L27$ design for mixed factors was selected and analysed to develop the experimental matrix in Table III . This was followed by a two-way Analysis Of Variance (ANOVA) test to determine the significance of the six selected factors: Number of acute beds, number of rehabilitation beds, number of LTC beds, Acute care average LOS, rehabilitation average LOS, percentage of rehabilitation patients, and their interactions. The main and interaction effects of the studied factors were analysed using 95% confidence interval (Table IV). The main effect analysis is conducted by changing one single factor at a time while all other parameters are fixed, whereas the interaction effect is based on changing two or more factors and examine their impacts on the KPIs.

The ANOVA results showed that the number of acute bed, rehabilitation average LOS, and percentage of rehabilitation patients were the significant factors that influenced all KPIs with ($P - value < 0.05$), while acute average LOS has a significant impact on the acute average waiting time. It is interesting to note that LTC bed capacity has no effect on any of the KPIs at 5% significance level. This is due to the

TABLE III. DESIGN MATRIX FOR FACTORS COMBINATION UNDER KPIS.

Experiment	Factors						Key Performance Indicators (Responses)		
	A: NO. Acute Beds	B: No. Rehab Beds	C: No. LTC Beds	D: Acute AVLOS	E: Rehab AVLOS	% Rehab Patients	Acute Access Rate	Throughput Rate	Acute Waiting Time
1	1	1	1	1	1	1	1	0.958	0.003
2	1	1	1	1	2	2	0.6	0.587	55.847
3	1	1	1	1	3	3	0.31	0.314	88.908
4	1	2	2	2	1	1	0.95	0.939	12.639
5	1	2	2	2	2	2	0.81	0.803	34.562
6	1	2	2	2	3	3	0.41	0.421	97.864
7	1	3	3	3	1	1	0.81	0.827	47.413
8	1	3	3	3	2	2	0.81	0.813	40.18
9	1	3	3	3	3	3	0.58	0.61	91.327
10	2	1	2	3	1	2	0.98	0.951	3.647
11	2	1	2	3	2	3	0.51	0.509	49.016
12	2	1	2	3	3	1	0.86	0.837	14.141
13	2	2	3	1	1	2	1	0.977	0
14	2	2	3	1	2	3	0.78	0.763	24.614
15	2	2	3	1	3	1	1	0.968	0.007
16	2	3	1	2	1	2	1	0.959	0.009
17	2	3	1	2	2	3	0.94	0.901	8.351
18	2	3	1	2	3	1	1	0.953	0.025
19	3	1	3	2	1	3	0.98	0.948	0.457
20	3	1	3	2	2	1	1	0.968	0
21	3	1	3	2	3	2	0.8	0.774	12.895
22	3	2	1	3	1	3	1	0.957	0
23	3	2	1	3	2	1	1	0.955	0.001
24	3	2	1	3	3	2	0.89	0.848	8.243
25	3	3	2	1	1	3	1	0.968	0
26	3	3	2	1	2	1	1	0.967	0
27	3	3	2	1	3	2	1	0.954	0.002

average LOS in LTC beds is huge (long term) and the impacts of LTC bed capacity expansion appears on long term witch not reflected in this model. Furthermore,These results illustrate that the acute beds and rehabilitation service represent bottlenecks in healthcare systems that impact on patient flows, and hence negatively affect the whole healthcare process. Interaction between Rehabilitation average LOS (E)and % of Rehabilitation patients (F) have a significant impact on both acute access are and acute waiting time. This is due to that factor (F) controls the inflow to rehabilitation service (Demand), while factor (E) controls the outflow (discharge) from rehabilitation service. Additionally, the interactions of these factor (E and F) with all other factors show significant influences on the acute waiting time. To determine the relationships between main factors and KPIs, and to quantify their impacts magnitude, multiple regression analysis was applied to the significant factors for each KPI individually.

E. Regression analysis

An investigation off all significant factors against the KPIs (responses) was conducted to determine if the relationships were curvilinear or not, so as to determine the appropriate mathematical transformation, but found all the relationships were linear. Hence multiple linear regression analysis was used to explore the causality relationships between factors and KPIs, and also tested and validated all the regression model assumptions. Table V presents the summary results of the regression analysis for the three KPIs against their main significant factors at 95% confidence level - all three regression models were significant with $P-value < 0.00001$ and all individual factors were also significant. The regression models were investigated explicitly for assumptions of homoscedasticity, independence, linearity, and normality. The residuals - the residuals between actual and fitted values -, were used to test model assumptions, and any outliers investigated and tested using Cook's distance statistics.

F. Discussion

The regression analysis for throughput rate revealed that acute and rehabilitation bed capacities positively affected the throughput rate, while rehabilitation average LOS and percentage of rehabilitation patients were inversely proportionate to the throughput rate. Thus, increasing numbers of either type of bed improved the throughput rate: increasing acute capacity directly increased numbers of patients who could be admitted , provided beds were available at the discharge destinations and the provision of more rehabilitation beds increased the rate of discharge from acute care beds, again improving the throughput rate. On the other hand, increasing average LOS on the rehabilitation care service reduced admissions to rehabilitation care, and thus the discharge rate from

TABLE IV. MAIN AND INTERACTION EFFECT OF FACTORS AGAINST KPIS.

Source of Variation	Degrees of Freedom	Throughput Rate			Acute Access Rate			Acute Waiting Time		
		Sum of Squares [Partial]	F Ratio	P Value	Sum of Squares [Partial]	F Ratio	P Value	Sum of Squares [Partial]	F Ratio	P Value
Model	18	0.0482	16.3698	0.0002	1.0236	17.6592	0.0002	24300	20.6482	0.0000
A:Acute Beds	1	0.0272	9.2441	0.0161	0.0376	11.685	0.0091	1045	16.0096	0.0039
B:Rehabilitation Beds	1	0.0037	1.2573	0.2947	0.0027	0.8283	0.3894	71	1.0961	0.3257
C:LTC Beds	1	0.0011	0.3566	0.5669	0.0046	1.4228	0.2671	195	3.0024	0.1214
D:Acute AVLOS	1	0.0102	3.4698	0.0995	0.0149	4.6182	0.0639	368.	5.6462	0.0448
E:Rehabilitation AVLOS	1	0.0671	22.8008	0.0014	0.0734	22.7957	0.0014	1648	25.2536	0.001
F:% Rehabilitaion Patients	1	0.0617	20.9646	0.0018	0.0656	20.3722	0.002	470	7.2044	0.0277
AB	1	0.0029	1.0005	0.3465	0.004	1.2576	0.2946	14	0.2184	0.6527
AC	1	0.0056	1.9165	0.2036	0.0068	2.0977	0.1856	129	1.9788	0.1972
AE	1	0.0038	1.2824	0.2903	0.0057	1.7682	0.2203	716	10.9758	0.0107
AF	1	0.002	0.6796	0.4336	0.0019	0.594	0.463	0.3996	0.0061	0.9396
BC	1	0.0054	1.8211	0.2141	0.0067	2.0754	0.1877	268	4.1067	0.0773
BE	1	0.0033	1.1083	0.3232	0.0047	1.4695	0.26	320	4.9169	0.0574
BF	1	0.009	3.065	0.1181	0.012	3.7331	0.0894	461	7.0665	0.0289
CE	1	0.0057	1.9457	0.2006	0.0079	2.4452	0.1565	381	5.837	0.0421
CF	1	0.0055	1.8736	0.2083	0.0077	2.3934	0.1604	384	5.8921	0.0414
DE	1	0.0062	2.1218	0.1833	0.0087	2.6875	0.1398	395	6.0582	0.0392
DF	1	0.0055	1.8607	0.2097	0.0076	2.3507	0.1638	383	5.8806	0.0415
EF	1	0.0141	4.7899	0.0601	0.0186	5.7648	0.0431	930	14.2604	0.0054
Residual	8	0.0029			0.0258			522		
Lack of Fit	8	0.0029			0.0258			522		
Total	26	0.8913			1.0493			24800		

TABLE V. REGRESSION ANALYSIS RESULTS

Factors	KPIs								
	Throughput Rate			Average Acute Waiting Time			Acute Access Rate		
	Coefficient	P-value	VIF	Coefficient	P-value	VIF	Coefficient	P-value	VIF
Constant	0.7801	0.000		30.5192	0.0857		0.7716	0.000	
A: Acute Beds	0.000046	0.000	1.0	−0.0094	0.000	1.0	0.0000531	0.00	1.0
B: Rehabilitation	0.00013	0.01	1.0	-	-	-	0.0001	0.019	1.0
E: Rehabilitation AVLOS	−0.00334	0.000	1.0	0.41616	0.0029	1.0	−0.035	0.000	1.0
F: % of Rehabilitation Patients	−0.728	0.000	1.0	104.8641	0.0008	1.0	−0.775	0.000	1.0
Model-Significance	P-value$<$ 0.00001			P-value$<$ 0.00001			P-value$<$ 0.00001		
R^2	78.8%			72.4%			78.3%		
$R^2(Adjusted)$	74.6%			68.8%			74.3%		
Significance Level $\alpha = 5\%$									

rehabilitation care, so negatively affecting the throughput rate. Also, increasing percentage of patients discharged from acute care to rehabilitation increased demand on the rehabilitation service, which could increase its waiting lists, so reducing the rate of discharge from - and thus the rate of admission to - acute care, again, eventually, reducing the whole systems throughput rate. These significant factors explained the 78.8% of the system's throughput variations: Fig. 8-a reveals their effects.

The regression analysis for acute waiting times showed that 72.4% of its variations can be explained by acute bed capacity, rehabilitation average LOS, and percentage of rehabilitation patients. Normally, acute waiting times decrease as the acute bed capacity increases - this relationship is clearly straightforward. The provision of acute care beds increases acute care admission rates, reducing waiting lists and waiting times. Conversely, average waiting times for acute care admission are directly proportionate to both rehabilitation average LOS and percentage of rehabilitation patients. But increasing rehabilitation average LOS hinders the acceptance of new patients who are discharged from acute beds for rehabilitation care - so, the rehabilitation care waiting list increases and those patients stay in hospital consuming acute bed resources, so increasing both the acute bed waiting lists and average times. Likewise, increasing the percentage of acute care patients discharged to rehabilitation care increases rehabilitation waiting lists and times - as rehabilitation beds are limited - directly magnifying acute care average LOS, reducing acute care admission rates and lengthening average acute care waiting times. Fig. 8-b illustrates the effect of these factors on average acute waiting times.

Acute and rehabilitation bed capacities, rehabilitation aver-

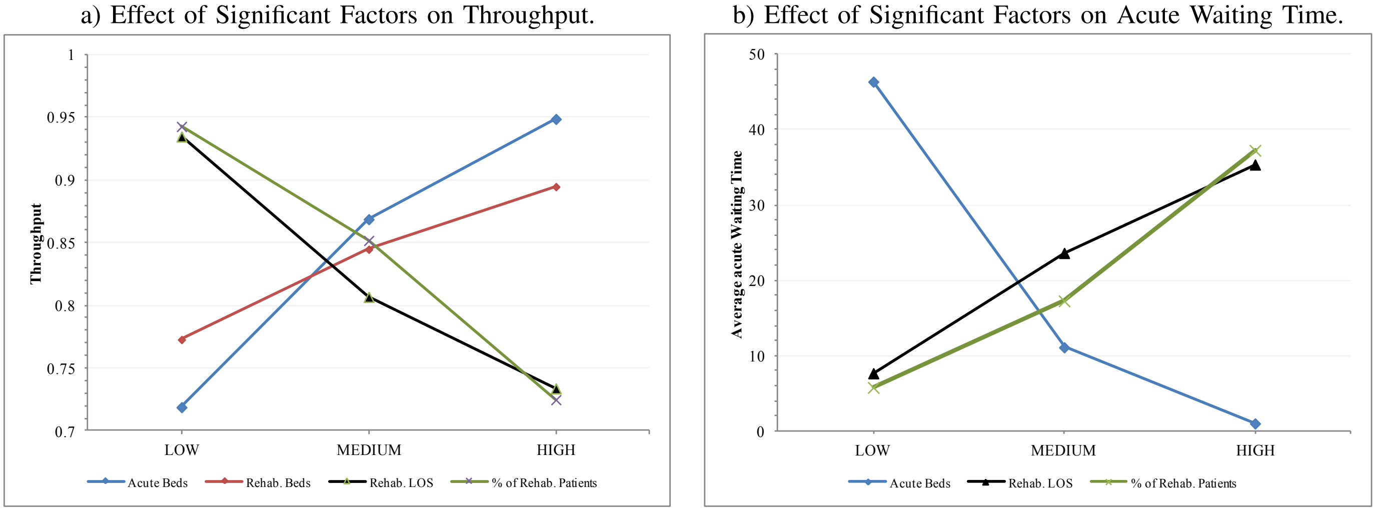


Fig. 8. The effect of significant factors on Throughput and Acute Waiting Time.

age LOS and percentage of rehabilitation patients explained about 78.3% of the variation in the acute access rate. The influence of both acute and rehabilitation bed numbers on acute access rates are positive, but the influence of both rehabilitation average LOS and the percentage of rehabilitation patients are negative. We found that factors affecting throughput rates were the same as those effecting acute access rates, and that their influences had the same sign. The explanation behind this is that acute access rate is the ratio of admitted elderly patients to the demand for acute care admission thus ratio of acute care out to acute care in in other words, it is a definition of acute care throughput rate. The overall system's throughput rate is positively and highly related to the throughput rates of all its subsystems but, as the acute care subsystem is the core subsystem in an acute hospital (and as many elderly patients encounter it) its throughput rate is likely to significantly determine that of the whole system - and certainly, they are highly and positively correlated.

V. CONCLUSION AND FUTURE WORK

the mounting demand for elderly healthcare services driven by increasing population ageing is confronting Irish healthcare executives with critical capacity planning challenges. Developing a simulation model to investigate service constraints in healthcare systems was found to be an approach that was well-suited to provide decision makers with a tool to evaluate their proposed strategies. Conceptual modelling was used to illustrate different elderly patient care pathways and improve understanding of the resources required during their care journeys. This phase was followed by developing a discrete-event simulation model with the object of investigating the impact of demand uncertainty on available capacity, which was of great benefit to policy makers in forecasting the outcomes of potential strategies they wanted to investigate. The reduction of average length of stay of patients using acute beds in hospitals, if possible, only promised minor improvements in patient flows, but results showed that introducing intermediate care beds could enhance the system's performance significantly, reducing delays and the cost of patient stays by almost 50%. The model we developed also had the potential to examine the economic feasibility of implementing this intermediate bed solution fully, based on a cost-benefit analysis, as well as testing other scenarios the policy makers proposed. An ANOVA statistical analysis revealed that the rehabilitation stage was a bottleneck that affected onward patient flows, so it could be concluded that efforts to improve the flow of elderly patients through the healthcare system should be directed more towards rehabilitation than to other stages of the patient treatment journey, and it is strongly recommended that future research should study the impact of the rehabilitation stage and its capacity on overall patient throughput. Potential strategies that might be considered include setting a maximum rehabilitation LOS and transferring a number of acute beds to used for rehabilitation.

It is worth emphasizing that the main challenge in this study was the data collection phase. Problems varied between irrelevant or insufficient data and issues of data accuracy, and assumptions made by healthcare experts had to be used to overcome the lack of data in several instances. Comprehensive and periodic collection of elderly patient data is strongly recommended to provide decision makers with a solid foundation to use for process improvement strategies. Another limitation was that a detailed real cost analysis was not possible in this study phase due to two main reasons; (1) lack of cost related information and, (2) the high variability of cost models used in Irish public hospitals, which created a high level of complexity. A further problem is that one of this model's limitations is that it assumes demand is static (due to data availability), although this can be overcome by considering it through a dynamic module designed to deal with demographic changes, or via sensitivity analysis. A project recently launched by 3S group will attempt to create a financial model for Irish public hospitals in order to facilitate better cost analysis of decisions.

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Inference of Gene Regulatory Networks to Detect Toxicity-Specific Effects in Human Embryonic Stem Cells

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***Abstract*—Environmental chemicals are known to cause serious developmental problems in embryos. To prevent injurious chemical effects, knowledge of the chemical toxicity mechanisms in human embryos is important. To reveal the functional mechanisms in living cells, inferring a gene regulatory network is a useful approach. We applied our developed statistical methods based on Structural Equation Modeling to infer the gene regulatory networks in human embryonic stem cells. In this study, we improved the SEM approach and applied this enhanced version to expression profiles in human embryonic stem cells exposed to various chemicals. For almost all of the tested chemicals, the cell differentiation-related genes and the neuron development-related genes were intermixed in the inferred networks. Since the chemicals' networks displayed diffusion type shapes, the effects of chemical toxicity are considered to affect a few target genes at first, and then ultimately many genes via regulatory mechanisms. Furthermore, the genes that were finally affected were conserved among chemicals with the same toxicity: Tuj1 in Neurotoxic chemicals, Oct3/4 and Pax6 in Genotoxic chemicals, and Oct3/4 in Carcinogenic chemicals. These finally affected genes are considered to be the results of toxicity-specific effects in ES cells, and they reflected the features of the toxicity. We also found that some chemicals shared the same regulatory mechanism. The detected toxicity-specific effects are valuable for developing methods to prevent chemicals from disturbing normal development.**

Keywords-Structural Equation Modeling; Gene Regulatory Network; Embryonic Stem Cell; Environmental Chemicals

I. INTRODUCTION

We are exposed to many chemicals, which are produced by our usual life activities. Since the toxicity of environmental chemicals is known as one of the typical factors causing developmental toxicity, we investigate the specific effects of chemical toxicity [1]. Developmental toxicity is either a structural or functional alteration, and these alterations interfere with the normal developmental programming in early embryos. These interferences can cause abnormal development and diseases [2][3]. For example, Methylmercury is known as a developmental toxin that affects fetal development [4][5]. Furthermore, certain chemicals can cause serious developmental problems and abnormal cell differentiation in embryos [6][7][8].

To prevent the harmful effects of chemicals, elucidation of the toxic stress response in embryonic cells is crucial [9][10]. A gene regulatory network is a useful approach to reveal the regulatory mechanisms in living cells. Using the gene expression information, the regulatory networks among the genes can be inferred. Various algorithms, including Boolean and Bayesian networks, have been developed to infer complex functional gene networks [11][12]. In our previous investigation, we developed an approach based on graphical Gaussian modeling (GGM). The GGM approach is combined with hierarchical clustering for calculations with massive amounts of gene expression data, and we can infer the huge network among all of the genes by this approach [13][14]. However, GGM infers only the undirected graph, whereas the Boolean and Bayesian models infer the directed graph, which shows causality. Although all of these approaches are suitable for establishing the relationships among the genes, they cannot reveal the relationships between un-observed factors and genes, due to insufficient information in the gene expression profiles. To clarify the mechanisms of biological processes in living cells, un-observed factors that affect the target gene's expression should also be considered. Thus, an alternative approach that includes un-observed factors should be applied.

Recently, we developed a new statistical approach, based on Structural Equation Modeling (SEM) in combination with factor analysis and a four-step procedure [15][16]. This approach allowed us to reconstruct a model of transcriptional regulation that involves protein-DNA interactions from only the gene expression data, in the absence of protein information [15]. The significant features of SEM are the inclusion of latent variables within the constructed model and the ability to infer the network, including its cyclic structure. Furthermore, the SEM approach allows us to strictly evaluate the inferred model by using fitting scores. The SEM approach is useful for detecting the causality among selected genes, as the linear relationships between genes are assumed to minimize the difference between the model's covariance matrix and the calculated sample covariance matrix [17][18][19]. Some fitting indices are defined for evaluating the model adaptability, and thus the most suitable model can be selected by SEM [1][19].

Here, we applied the SEM approach to infer the regulatory network among 9 development-related genes. The mRNA levels of these 9 genes were measured in human embryonic stem cells exposed to 15 environmental chemicals. The chemicals were considered to have developmental toxicities that adversely affect the developmental process in human embryos. Thus, inferring the gene regulatory network among development-related genes will help us to elucidate the toxic stress response in the human embryo. Furthermore, we improved our SEM approach for constructing preliminary initial models from the time-series data, in the absence of known regulatory interactions among the genes. We applied this improved SEM approach to infer the chemical-specific regulatory network among the development-related genes.

II. MATERIALS AND METHODS

A. Expression data

We utilized expression data that were measured to clarify the effects of chemical toxicity on neuronal differentiation [7][20]. In these expression data, nine genes considered to be affected by chemicals were measured in human embryonic stem cells: GATA2, Nanog, Oct3/4, Nodal, Lmx1A, MAP2, Nestin, Pax6, and Tuj1 [7][20]. Among the 9 genes, GATA2, Nanog, Oct3/4, and Nodal are mainly related to cell differentiation, and the other genes are related to neuron development. As an internal control, the expression of beta-actin was also measured. The expression data of these 10 genes were obtained from human embryonic stem cells exposed to 15 chemicals: Methylmercury (MeHg), 2-Nitropropane (2-NP), Acrylamide (ACA), p-Nitroaniline (p-NA), 4-hydroxy PCB107 (PCB), Benzo[a] pyrene (BZP), Diethylnitrosamine (DENA), Diethylaminofluorene (DEAF), Phenobarbital (PB), Tamoxifen (TMX), Diethylstilbestrol (DES), TCDD (TCDD), Thalidomide (THAL), Bisphenol-A (BPA), and Permethrin (PER) [7][20]. The toxicity of each chemical was classified into one of four types: Neurotoxic (MeHg, 2-NP, ACA, p-NA, and PCB), Genotoxic (BZP, DENA, and DEAF), Carcinogenic (PB, TMX, DES, and TCDD), and others (THAL, BPA, and PER). The human embryonic cells were exposed to each chemical for several time periods: 24 hours, 48 hours, 72 hours, and 96 hours. Each chemical was also tested at 5 concentrations: very low, low, middle, high, and very high. The expression of the genes was measured twice under each condition by RT-PCR, and thus 600 (15 chemicals x 4 time periods x 5 concentration types x 2 repeats) expression patterns per gene were measured [20].

First, the expression level of each gene was normalized to the internal beta-actin control and averaged, as follows:

$$E_g = \frac{1}{N}\sum_{i=1}^{N}\log_2\left(\frac{e_g^i}{e_{bActin}^i}\right) \quad (1)$$

Here, N is the number of repeated experiments, $e_g{}^i$ is the measured expression level of gene g under one set of conditions, and $e_{bActin}{}^i$ is the beta-actin expression level measured under the same conditions. The expression level of each gene was divided by that of beta-actin, for intracellular normalization. To minimize the experimental error, the logarithms of the normalized expression data were obtained and averaged.

B. Multi-factor analysis of variance

In this study, the data contained three factors that affect gene expression: chemicals, exposure times, and concentrations. To detect the significant factors for differences in gene expression, we applied the analysis of variance (ANOVA) for multiple factors [21]. Although the multi-factor ANOVA model includes each factor's effect and all combinations of interactions between the factors, the triple interactions among the factors were confounded with error terms, because the data lacked repetition [21]. Therefore, we used the linear effects model for analysis:

$$E_{ijk}=\mu+\alpha_i+\beta_j+\gamma_k+(\alpha\beta)_{ij}+(\alpha\gamma)_{ik}+(\beta\gamma)_{jk}+\varepsilon_{ijk} \quad (2)$$

where E_{ijk} is the expression level of each gene under one condition, μ is the averaged value of all measured data, α_i is the effect of factor A, β_j is the effect of factor B, γ_k is the effect of factor C, $(\alpha\beta)_{ij}$ is the interaction between factors A and B, and ε_{ijk} is the error term.

Depending on the linear effects model, the total some of squares, S_{Total} could be decomposed into the following components:

$$S_{Total}=S_A+S_B+S_C+S_{AB}+S_{AC}+S_{BC}+S_e \quad (3)$$

where S_A, S_B, and S_C mean the sum of the squared differences between each factor's marginal mean and the overall mean; S_{AB}, S_{AC}, and S_{BC} mean the sum of the squared differences for particular corresponding data means, marginal means, and overall mean; and S_e measures the difference between S_{Total} and the total sum of squares of all effects. The degree of freedom for S_{Total} was the number of all observed data minus one, and the degrees of freedom for S_A, S_B, and S_C were the number of levels for the factor minus one. The mean square values for S_A, S_B, and S_C were the sums of the squares divided by the numbers of degrees of freedom. In S_e, the degree of freedom was the total degrees of freedom minus the sum of the factor degrees of freedom. The mean square of S_e was the sum of the squares divided by the number of degrees of freedom. In the analysis of variance, S_{Total} accounted for the factor effects (S_A, S_B, S_C, S_{AB}, S_{AC}, S_{BC}) and the contribution of S_e.

To compare the factor effects, the statistical *F*-test was used. The *F* statistic is the mean square for the factor divided by the mean square of the error terms. This *F* statistic is known to follow an *F* distribution with degrees of freedom for each factor effect and degrees of freedom for the error terms. Thus, we could calculate the probabilities of the factor effects from the *F* statistics.

C. Extraction of causalities from expression data

In an SEM analysis, an initial model should be assumed, but no regulations were defined among the selected genes in this study. Thus, we had to construct an initial model among the 9 genes for each chemical. To detect the regulatory relationships between the gene pairs from the measured time series expression data, we applied cross correlation coefficients to the expression profiles measured for each chemical and each concentration.

Cross correlation is utilized as a measure of similarity between two waves in signal processing by a time-lag application, and it is also applicable to pattern recognition [22]. The cross correlation values ranged between −1 and +1. In a time series analysis, the cross correlation between two time series describes the normalized cross covariance function. Let $X_t = \{x_1, \ldots, x_N\}$, $Y_t = \{y_1, \ldots, y_N\}$ represent two time series data including *N* time points. The cross correlation is then given by

$$r_{xy} = \frac{\sum_{t=1}^{N}(x_i - \bar{x})(y_{i+d} - \bar{y})}{\sqrt{\sum_{t=1}^{N}(x_i - \bar{x})^2}\sqrt{\sum_{t=1}^{N}(y_{i+d} - \bar{y})^2}} \quad (4)$$

where *d* is the time-lag between variables *x* and *y*. In this case, the expression profiles were measured at four time points, and thus three cross correlations of each gene pair were calculated with $d = -1, 0, +1$.

D. Construction of the initial model

In this study, we inferred the chemical-specific regulatory network, and thus the differences between times and concentrations could be merged for the construction of the initial model. Fig. 1 shows the new method developed for constructing an initial model of each chemical, with the merging of several conditions. First, we constructed lag matrices to merge the time difference. The time difference was summarized by the time lag values in the cross correlations among genes. Since the time lags indicated the order of the expression pattern among the gene pairs, the rough causality between all gene pairs could be extracted. In this study, three cross correlations were calculated with three lags, −1, 0, and +1, and the three absolute values of the cross correlations were compared. The value *d* with the highest absolute value was selected as the causal information between the gene pairs, and the selected lag value *d* wasarranged as a matrix element in a lag matrix.

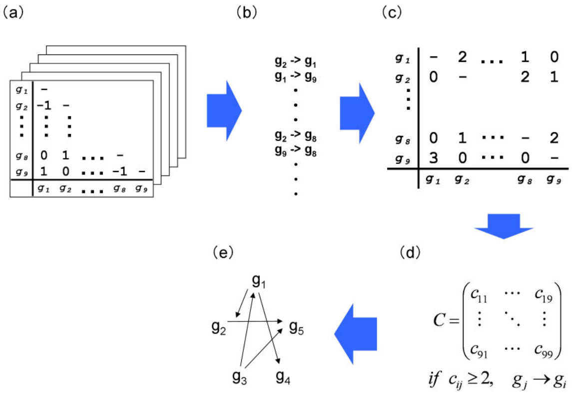

Figure 1. Procedure for initial model construction: (a) Time-lag matrices for each chemical. Five time-lag matrices were obtained for each chemical. (b) Binomial relationships. (c) Frequency matrix of causal relationships between all gene pairs. (d) Selection of possible causal relationships from the frequency matrix. (e) Construction of an initial model with selected causal relationships.

Lag Matrices were constructed for each concentration of a chemical. Thus, five time lag matrices were constructed for each chemical (Fig. 1a).

We subsequently merged the concentration difference of each chemical. For each chemical, there are five lag matrices according to the chemical concentrations, and we considered that the chemical-specific relationships among the genes would be conserved in several lag matrices. To obtain the chemical-specific relationships among the genes, we extracted the binary relationships between gene pairs from the five lag matrices for each chemical. If the same relationships existed in several lag matrices, then the binomial relationships were duplicated (Fig. 1b).

In the next step, we constructed one frequency matrix for each chemical. From the binary relationships, we counted the frequencies of all gene regulatory pairs, and each frequency number was arranged as an element of a frequency matrix (Fig. 1c). In this step, the concentration difference could be merged, since the elements of the frequency matrix indicate the information for the different concentrations. We subsequently selected the gene pairs with frequency matrix values greater than or equal to two, as the chemical-specific regulation (Fig. 1d). At the final step, we constructed an initial model for each chemical from the extracted relationships between the genes (Fig. 1e). These initial models included the time series information as the directions of edges, and the different concentrations of each chemical were summarized as the existence of edges in the model. By using this approach, an initial model can include cyclic structures.

E. Structural Equation Modeling without Latent Variables (SEM without LV)

After the construction of an initial model for each chemical, we applied the SEM calculation to infer the network model that fit the measured expression data. In general, SEM is a comprehensive statistical model that includes two types of variables: observed and latent. These variables constitute the structural models that consider the relationships between the latent variables and the measurement models that consider the relationships between the observed variables and the latent variables. These relationships can be presented both algebraically, as a system of equations, and graphically, as path diagrams.

In this study, the 9 genes (GATA2, Nanog, Oct3/4, Nodal, Lmx1A, MAP2, Nestin, Pax6, and Tuj1) were defined as the observed variables. Meanwhile, none were defined as latent variables, since considerations about the common regulator of several genes are dispensable for this study. The un-observed factor, which affected each gene's expression, was calculated as an error. All observed variables were categorized into one of two types of variables, exogenous and endogenous, according to their interactions with other variables. Exogenous variables are those that are not regulated by the other variables, and endogenous variables are regulated by the others. In the initial model, the starting genes are defined as exogenous variables, while all other genes are defined as endogenous variables. Regulatory relationships exist between the observed variables in the network models. The model is defined as follows:

$$y=\Lambda y+e \tag{5}$$

Here, y is a vector of p observed variables (measured gene expression patterns), and Λ is a p x p matrix representing the regulatory relationships between the observed variables. Errors that affect the observed endogenous variables are denoted by e.

The SEM software package SPSS AMOS 17.0 (IBM, USA) was used to fit the model to the data. The quality of the fit was estimated by the Chi-square statistic (CMIN), the goodness-of-fit index (GFI), which measures the relative discrepancy between the empirical data and the inferred model, and the adjusted GFI (AGFI), which is the GFI modified according to the degrees of freedom. Furthermore, we used CFI and RMSEA as fitting scores, to evaluate the model fitting. Since these indices have threshold values, as criteria to decide whether the model is suitable to obtain data independent of a huge sample number, they were considered to be useful to clarify the degree of model fitting in this study.

F. Parameter estimation

Parameter estimation was performed by comparing the actual covariance matrix, calculated from the measured data, with the estimated covariance matrices of the constructed model. Maximum likelihood is commonly used as a fitting function to estimate SEM parameters:

$$F_{ML}(S, \Sigma(\theta))=\log|\Sigma(\theta)|-\log|S|+tr(\Sigma(\theta)^{-1}S)-p \tag{6}$$

Here, $\Sigma(\theta)$ is the estimated covariance matrix, S is the sample covariance matrix, $|\Sigma|$ is the determinant of matrix Σ, $tr(\Sigma)$ is the trace of matrix Σ, and p is the number of observed variables. The principal objective of SEM is to minimize $F_{ML}(S, \Sigma(\theta))$, which is the objective function and is used to obtain the maximum likelihood. Generally, $F_{ML}(S, \Sigma(\theta))$ is a nonlinear function. Therefore, iterative optimization is required to minimize $F_{ML}(S, \Sigma(\theta))$ and to find the solutions [23].

G. Iteration for the optimal model

The regulatory network analysis by SEM consists of two parts: parameter fitting and structure fitting. After the parameters of the constructed model are estimated by maximum likelihood, the network structures are evaluated according to the goodness of fit between the constructed model and the measured data. Through acceptance or rejection of the models, the optimal model that describes the measured data can be selected.

In the network model, the covariance matrix between variables is calculated by the estimated parameters. The similarity between the constructed model and the actual relationships is predicted by comparing the matrix calculated from the network model to the matrix calculated from the actual data. To detect the quantitative similarity between a constructed model and an actual relationship, fitting scores are usually utilized. In this study, the quality of the fit was predicted by four different fitting scores: CMIN(Prob), GFI, AGFI, CFI, and RMSEA. The value of CMIN(Prob) is calculated by the Chi-square statistic divided by the degrees of freedom, and a CMIN(Prob) value higher than 0.05 is considered as a good model fit. Values of GFI, AGFI, and CFI above 0.90 are required for a good model fit. RMSEA is one of the most popular parsimony indexes displayed in the table, and RMSEA values below 0.05 represent a good model fit [24]. Furthermore, RMSEA values of 0.10 or more are considered to indicate that the constructed model is far from the actual data.

To optimize the model, an iteration algorithm was developed, as follows:

Step 1: Deletion of a non-significant edge from the model. Use 0.05 as the significance level for the determination of the significant regulation among the variables. After the parameters are estimated, the inverse matrix of the Fisher information matrix of parameters is calculated. The inverse matrix of Fisher information represents the asymptotic parameters' covariance matrix. The probability of each parameter is calculated by using this asymptotic parameters' matrix, since all of the parameters are usually normally distributed.

Step 2: Reconstruction of the network model. The structure of the network model without the non-significant edge is different from that of the former model. Thus, all parameters should be re-calculated from the reconstructed model, and the similarity of the network structure is also re-calculated.

Step 3: Iteration of Steps 1 and 2 until all edges become significant. Since the probabilities of all of the edges in the reconstructed models have also changed, the deletion of the non-significant edges is executed step-by-step.

Step 4: Addition of a possible causal edge to the reconstructed model. According to the Modification Index (MI), we add a new causal edge between the observed variables. The MI measures how much the chi-square statistic is expected to decrease if a particular parameter setting is constrained [24]. The MI value indicates the possibility of new causality between the variables, and thus we add a new edge according to the highest MI score.

Step 5: Iteration from Steps 1 to 3. The addition of a new edge to a constructed model changes the structure of the network model. In other words, all parameters, including the probabilities of all edges, have also changed again. Thus, we execute the iteration from Step 1 to Step 3 again.

Step 6: Determination of significant relationships among error terms. After all of the edges are significant and all of the MI scores are lower than 10.0 in the constructed model, significant relationships between error terms are estimated by the MI scores. The relationships among the error terms have no direction, and thus they are a correlation between error terms. These relationships were used for the calculations, but were not incorporated within the network.

H. *Extraction of association rules by affinity analysis*

We applied affinity analysis to discover the similar regulatory mechanism models among the 15 chemicals' networks. To detect the relative chemical pairs as association rules, we created a binary dataset with conserved regulations among different chemicals. According to the original definition of association rule mining [25], we defined the problem of association rule mining as follows: Let $I = \{ i_1,\ldots, i_n \}$ be a set of n binary attributes called items. Let $T = \{ t_1,\ldots, t_m \}$ be a set of database transactions. Each transaction t_k is represented by the binary vector $t_k = (t_k^1, t_k^2, \ldots, t_k^n)$, which includes n elements. The value of t_k^l indicates the appearance of transaction t_k in item i_l. In this study, the 15 chemicals were defined as a set of items, and each conserved gene regulation between the different chemicals was considered as one transaction. Thus, the value of 1 indicated the appearance of the conserved gene regulation in the chemical's network, while the value of 0 indicated its absence.

An association rule is defined as the implication of the form $I_a => I_b$, where I_a and I_b are sets of some items in I, but some of the same items are not present in I_a and I_b. To detect the association rules, we used some constraints: support, confidence and lift. Support is defined as the proportion of transactions that contain the item set to all transactions. Thus, $support(I_a,I_b)=prob(I_a,I_b)$ was calculated as the joint probability of I_a and I_b. The confidence constraint is displayed as $conf(I_a => I_b)$, and it is defined as the conditional probability $prob(I_a|I_b)$. Thus, we calculated $conf(I_a => I_b)$ from the proportion of transactions with the item set I_b to the transactions with the item set I_a. The lift constraint is defined as:

$$lift(I_a => I_b) = conf(I_a => I_b)/prob(I_b) \tag{7}$$

Lift is a measure of the performance of an association rule with respect to the population as a whole, against the random choice. Thus, lift was obtained by calculating the ratio of the target response to the average response. In general, a lift value over 1 is suitable for association rules.

III. RESULTS AND DISCUSSION

A. *Chemical concentrations had no effect*

In this study, gene expression was measured in the presence of different concentrations of various chemicals, with several exposure times. To reveal the most effective factor for gene expression, multi-factor ANOVA was applied to the measured data. In statistics, ANOVA is utilized to detect differences between groups in terms of some variables. Usually, the chance of committing a type I error will increase by performing multiple two-sample t-tests, and a statistical test is needed to determine whether or not the means of more than two groups should be applied, such as Tukey's HSD test and so on. Although these post-hoc tests are useful for detecting the factor pairs with significant differences between them, the factor pairs are not important in this study. Instead, we wanted to determine factors, which caused gene expression differences, and thus we compared three factors: chemicals, time differences, and concentrations.

The 15 chemicals were divided into 3 categories by their toxicities: Neurotoxic chemicals, Genotoxic chemicals, Carcinogenic chemicals, and other type chemicals. We compared the gene expression differences between these toxicity types. We calculated a p-value from the F statistic for each gene. The p-value is the probability that the variation between conditions may have occurred by chance, so genes with smaller p-values vary more significantly. Thus, the gene's variation is less likely to have occurred by chance, and is conversely more likely to be connected to the difference in conditions. The probabilities of expression differences for each gene, grouped by each factor, are shown in Table I. Interestingly, the expression of all of the genes was significantly different among the chemicals and the time differences. However, the chemical concentrations showed almost no significant differences in terms of the expression of the genes. Thus, the concentrations of the chemicals had no effect on the expression of the tested genes in the ES cells.

TABLE I. RESULTS OF MULTI-FACTOR ANOVA

	Chemical (a)	Concentration (b)	Time (c)	a * b	a* c	b * c
GATA2	<0.01	0.076	<0.01	0.559	<0.01	0.450
Nanog	<0.01	<0.01	<0.01	0.011	<0.01	0.022
Oct34	<0.01	<0.01	<0.01	0.055	<0.01	0.044
Nodal	<0.01	0.130	<0.01	<0.01	<0.01	0.040
Lmx1A	<0.01	0.714	<0.01	<0.01	<0.01	0.787
MAP2	<0.01	0.479	<0.01	<0.01	<0.01	0.576
Nestin	<0.01	<0.01	<0.01	0.012	<0.01	0.548
Pax6	<0.01	0.575	<0.01	<0.01	<0.01	0.861
Tuj1	<0.01	0.011	<0.01	0.810	<0.01	0.097

a. Probabilities were calculated from the F statistics and the degrees of freedom.

b. Significant probabilities are displayed as "<0.01" in this table.

B. The complexities of the initial models are related to the chemical toxicity

We utilized our newly developed method to construct the initial gene regulatory network models under the conditions with 15 chemicals. One of the distinguishing features of our new method is its ability to include a cyclic structure in the network model. Cyclic regulation, such as feedback regulation, is considered to be important for cells to control normal gene expression, and the new method is useful to detect cyclic regulation from the gene expression data. Fig. 2 shows the constructed initial network models.

In Fig. 2, the components of the constructed models were: 9 genes with 22 relationships in MeHg, 9 genes with 23 relationships in 2-NP, 9 genes with 19 relationships in ACA, 9 genes with 23 relationships in p-NA, 9 genes with17 relationships in PCB, 9 genes with 9 relationships in BZP, 8 genes with 14 relationships in DENA, 8 genes with 10 relationships in DEAF, 8 genes with 19 relationships in PB, 9 genes with 23 relationships in TMX, 7 genes with 9 relationships in DES, 9 genes with 23 relationships in TCDD, 8 genes with 10 relationships in THAL, 6 genes with 9 relationships in BPA, and 8 genes with 10 relationships in PER. The distribution of the number of relationships according to the toxicity type is displayed in Fig. 3. In Figs. 2 and 3, the numbers of edges were obviously different, according to the chemicals' toxicity. Neurotoxic and Carcinogenic chemicals contained more relationships than

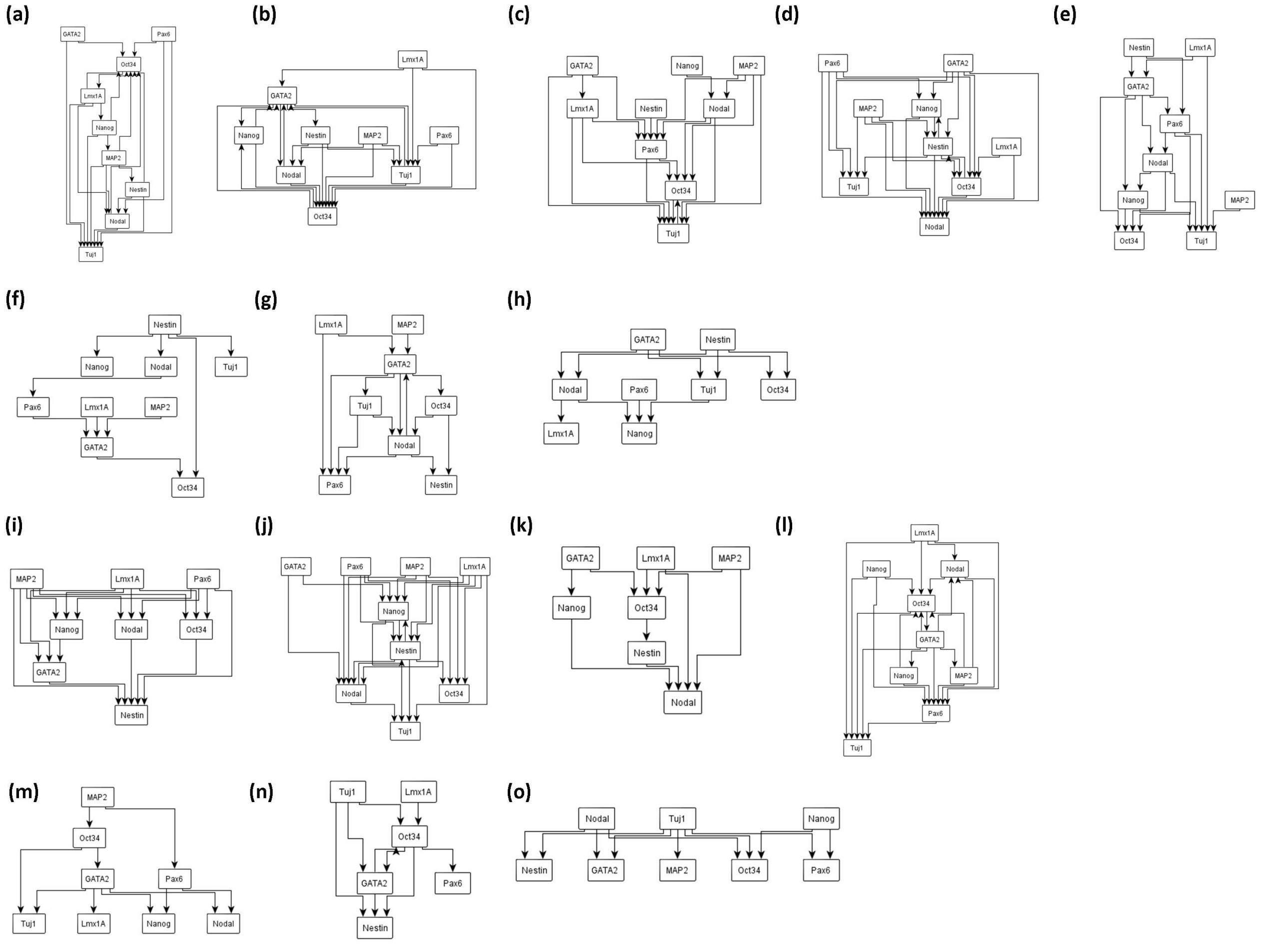

Figure 2. Initial network models: (a) MeHg, (b) 2-Np, (c) ACA, (d) p-NA, (e) PCB, (f) BZP, (g) DENA, (h) DEAF, (i) PB, (j) TMX, (k) DES, (l) TCDD, (m) THAL, (n) BPA, (o) PER. The networks with the same toxicity are arranged on the same line.

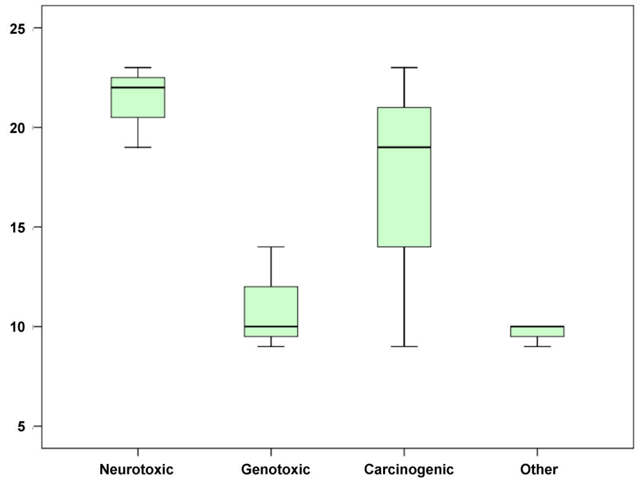

Figure 3. Box plot of edge numbers: Distribution of the number of edges in each initial model.

Genotoxic and other chemicals. Furthermore, only one or two genes were arranged as the last endogenous genes in the initial models with Neurotoxic and Carcinogenic chemicals, as opposed to two or more genes in the initial models of Genotoxic and other chemicals. Thus, the effects of the Neurotoxic or Carcinogenic chemicals were complicated, but could be summarized into only one or two target genes. In contrast, the expressions of many genes were finally affected by Genotoxic and other chemicals, via simple regulatory networks. These differences between chemical toxicity types summarized the distinctive gene expression profiles for each chemical.

All of the initial models included some duplicated gene interactions, such as a direct interaction between two genes and an indirect interaction between them. Before the SEM calculation, we simplified all of the initial models. To simplify these duplicated interactions, we only retained the longest path between two genes. In the initial model, the edges do not represent the direct regulation, but the time provenience information. In other words, the difference between direct and indirect interactions in the initial model is not very important. Thus, the regulation displayed by a direct path could be replaced by indirect paths in the model. By retaining the longest paths, all of the preceding information was included, as the simplest diagram.

C. *Structures of inferred networks*

The final inferred networks for each chemical are depicted in Fig. 4, and the goodness of fit scores are displayed in Table II. From Table II, almost all of the models were considered to fit well with the measured data by some fitting scores, CMIN(Prob), CFI, and RMSEA, except for the DES network. In the DES network, all of the fitting scores indicated that the inferred network could not be judged as a well-fitted model. Since the obtained fitting scores were the best scores in this analysis, we considered the network inference for DES to need more expression data.

The inferred networks of chemicals revealed distinct structures. The cell differentiation-related genes and the neuron development-related genes were intermixed in almost all of the inferred networks, except for MeHg and BPA. In the inferred network of MeHg, the regulations among cell differentiation-related genes and the regulation among neuron development-related genes were separated to the right and left. This specific shape means that the effects of MeHg appeared differently between neuronal and other development. This difference may be related to the two different effects of MeHg: developmental deficits in children [26], and risk of cardiovascular disease in adults [27]. On the other hand, cell differentiation-related genes and neuron development-related genes were separated at the top and bottom in the BPA network. In the BPA network, neuron development-related genes were only disturbed by cell differentiation-related genes.

TABLE II. FITTING SCORES OF INFERRED NETWORKS

	Neurotoxic					Genotoxic			Carcinogenic				Other		
	MeHg	2-NP	ACA	p-NA	PCB	BZP	DENA	DEAF	PB	TMX	DES	TCDD	THAL	BPA	PER
CMIN (*Prob*)	0.50	0.34	0.06	0.26	0.30	0.44	0.16	0.11	0.01	0.27	0.00	0.63	0.31	0.52	0.11
GFI	0.76	0.82	0.83	0.78	0.79	0.79	0.84	0.77	0.75	0.81	0.74	0.83	0.83	0.78	0.78
AGFI	0.60	0.63	0.61	0.59	0.61	0.62	0.65	0.60	0.54	0.61	0.52	0.64	0.60	0.64	0.56
CFI	1.00	0.99	0.96	0.97	0.98	1.00	0.97	0.94	0.90	0.98	0.88	1.00	0.99	1.00	0.96
RMSEA	0.00	0.07	0.15	0.10	0.08	0.03	0.12	0.14	0.21	0.09	0.23	0.00	0.08	0.00	0.14

a. Five fitting scores were utilized for measuring the fitness level between the constructed model and the measured data.

b. The well-fitted threshold of each score is: CMIN(Prob) is P>0.05, GFI > 0.90, AGFI> 0.90, CFI>0.90, RMSEA< 0.05.

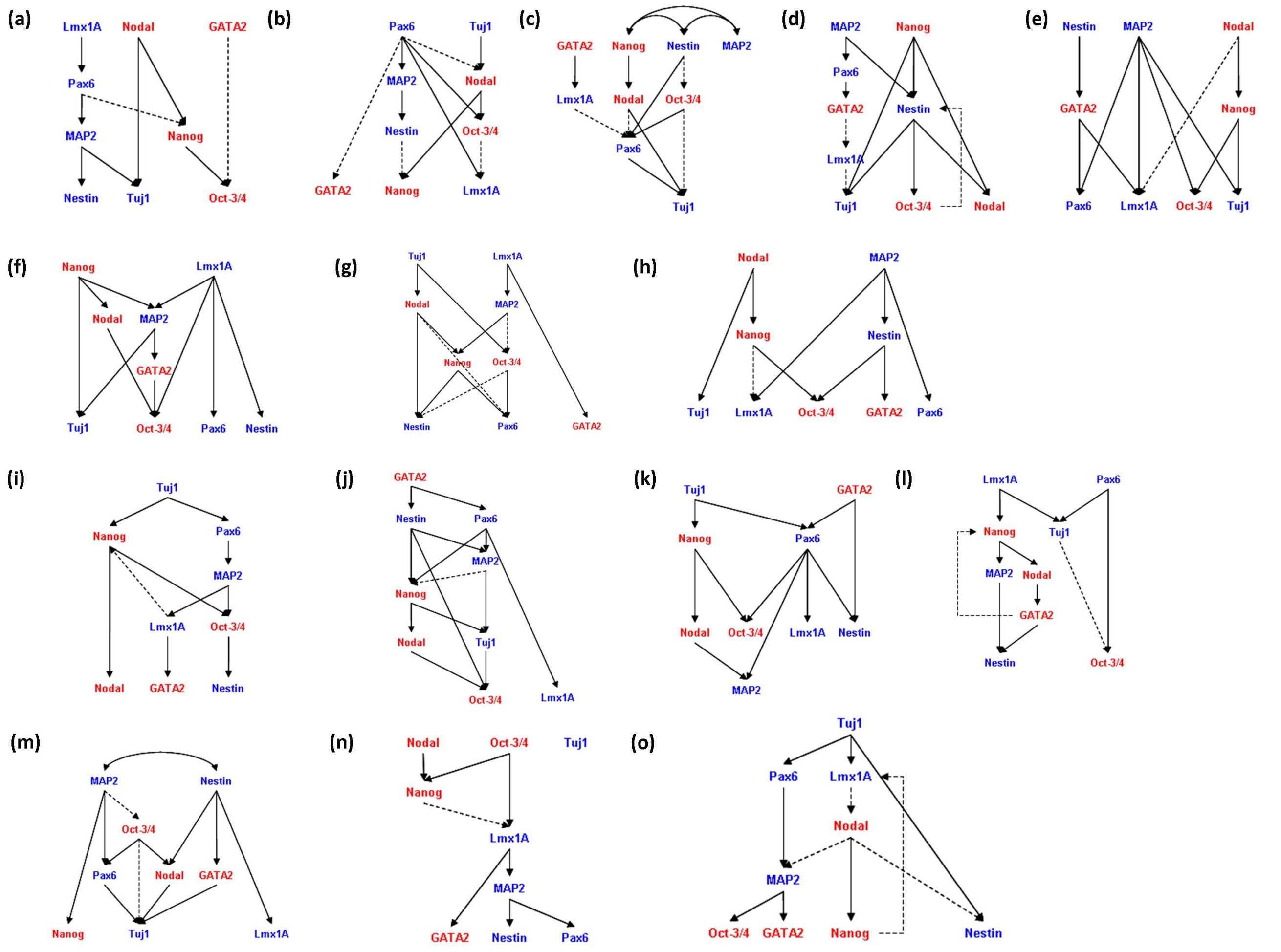

Figure 4. Inferred chemical networks: A positive relationship between genes is displayed with a solid arrow. A negative relationship between genes is displayed with a dashed arrow. Gene names with blue characters indicate "neuron development-related genes", and genes with red characters indicate "cell differentiation-related genes". (a) MeHg, (b) 2-Np, (c) ACA, (d) p-NA, (e) PCB, (f) BZP, (g) DENA, (h) DEAF, (i) PB, (j) TMX, (k) DES, (l) TCDD, (m) THAL, (n) BPA, (o) PER. The networks with the same toxicity are arranged on the same line.

Concerning the shapes of the inferred networks, we defined the network shape by comparing the numbers of genes at the top phase ($N(top)$) and the final phase ($N(bottom)$) within each chemical network. One of the specific shapes was a centralized model, which was defined as $N(top)-N(bottom) \geq 2$. In this model, many genes were arranged at the top phase, and only a few genes were arranged at the final phase in the network structure. The ACA network was the only network with a centralized model. The other specific shape was a diffusion model. The shape of a diffusion model is defined as $N(bottom)-N(top) \geq 2$. Among the well-fitted models, four networks were classified into diffusion models: BZP, DEAF, PB, and PER. The shape of the BPA network was different from those of the other networks, and resembled a bow-tie like model.

Fundamentally, the genes were hierarchically controlled in the inferred networks, but there were a few recursive relationships. Interestingly, the values of the regression weights of the recursive regulations among all of the inferred networks were negative: regulation from Oct3/4 to Nestin in the p-Na network, regulation from GATA2 to Nanog in TCDD, and regulation from Nanog to Lmx1A in PER. These recursive regulations indicated that feedback regulation exists in ES cells.

D. Detection of Toxicity-Specific Effects

To detect the specific features that were dependent on the toxicity type, we monitored the position of each gene in the inferred networks. Table III displays the number and probability of incoming edges and those of outgoing edges for each gene. Among the Neurotoxic chemicals' networks, Tuj1 has significantly few incoming edges and significantly many outgoing edges. Actually, Tuj1 was arranged as a result of network regulation in almost all of the Neurotoxic networks.

TABLE III. INTERACTING EDGES OF EACH GENE

	Neurotoxic				Genotoxic				Carcinogenic			
	OUTPUT		INPUT		OUTPUT		INPUT		OUTPUT		INPUT	
	Num	P	Num	P	Num	P	Num	P	Num	P	Num	P
Oct3/4	4	0.113	8	0.111	2	0.120	7*	0.032	1*	0.043	9*	0.042
GATA2	5	0.135	3	0.083	1	0.091	3	0.222	6	0.146	2	0.070
Lmx1A	3	0.084	7	0.141	6	0.101	2	0.145	4	0.141	3	0.114
MAP2	9	0.077	2	0.049	7	0.070	3	0.222	5	0.155	6	0.160
Nanog	7	0.132	5	0.146	7	0.070	3	0.222	7	0.118	8	0.079
Newtin	7	0.132	5	0.146	2	0.120	5	0.174	3	0.111	6	0.160
Nodal	8	0.107	5	0.146	6	0.101	2	0.145	4	0.141	4	0.154
Pax6	9	0.077	8	0.111	0	0.060	5	0.174	10*	0.025	4	0.154
Tuj1	1*	0.031	10*	0.043	2	0.120	3	0.222	6	0.146	4	0.154

a. The significant values ($P<0.05$) are highlighted with *.

This means that the toxicities of Neurotoxic chemicals are considered to finally affect Tuj1, which is known to contribute to microtubule stability in neuronal cells [28]. Although the expression levels of 5 genes were measured as neuron development-related genes, Tuj1 was detected as the final target of Neurotoxicity.

Among the Genotoxic chemicals' networks, Oct3/4 exhibited a significant number of incoming edges. Furthermore, both Pax6 and Oct3/4 were arranged at the lower phase in all Genotoxic networks. Oct3/4 is one of the key regulators of pluripotency [29], and Pax6 is known as a key transcription factor for the development of the cerebral cortex and other sensory organs [30]. Considering the features of both Pax6 and Oct3/4, developmental processes, such as normal cell differentiation, were disturbed by Genotoxic chemicals.

In the Carcinogenic networks, both the incoming and outgoing edges of Oct3/4 were significant, and Oct3/4 was arranged as a result in almost all of the Carcinogenic networks. The chemicals that were classified as either Genotoxic or Carcinogenic are known as carcinogens [31][32]. Thus, the Genotoxic and Carcinogenic features indicated that the chemical disturbance of Oct3/4 is related to cancer. The other feature of the Carcinogenic networks, regulation from Nanog to Nodal, was conserved among all of the Carcinogenic networks. Both Nanog and Nodal are important for normal early embryonic development. Nanog is a key factor for maintaining pluripotency in embryonic stem cells [33][34]. Nodal is related to the development of the left-right axial structure [35][36], and its signaling pathway is known to be important very early in development, for cell fate determination and many other developmental processes [36]. Although the Carcinogenic chemicals do not affect genetic structures, the regulatory mechanisms of these carcinogenic chemicals may be similar.

To compare the conserved gene relationships among chemicals with the same toxicity, we extracted the conserved gene regulations from the chemicals' networks. The numbers of conserved regulations were: 13 within Neurotoxic chemicals, 2 within Genotoxic chemicals, and 11 within Carcinogenic chemicals. Even though the average numbers of edges in the inferred models were similar among the three toxicity types (10.6 in Neurotoxic, 10.1 in Genotoxic, and 12.5 in Carcinogenic), the numbers of conserved regulations were different. From this feature, it is considered that a similar regulatory mechanism controlled the Neurotoxic chemicals' effects and the Carcinogenic chemicals' effects in ES cells, but the gene regulation by each Genotoxic chemical was independent of the toxicity type.

E. Similar mechanisms between chemicals

By utilizing the data mining method, we identified the chemicals with similar regulation. First, we constructed a transaction Table about the conserved regulation for each chemical, as shown in Table IV. Each row of data indicates the conserved regulation between genes, and each column indicates one chemical. In this transaction table, the value of 1 means that the corresponding regulation appeared with the chemical, whereas the value of 0 means that the regulation did not exist in the chemical's network.

In the affinity analysis, we set the thresholds as: Support > 0.5, Confidence > 0.5, and lift > 1. According to these restrictions, 2 rules were extracted. One is *BPA => DEAF*, and the other is *DEAF => PCB*. These results reflected the finding that the regulations in the *BPA* network were also conserved in the *DEAF* network. Furthermore, the regulations in the *DEAF* network were conserved in the *PCB* network. Although these three chemicals were categorized into different types of toxicities, they may share the same regulatory mechanisms to affect the ES cells.

IV. Conclusion

We applied an improved SEM approach to reconstruct a gene regulatory model from gene expression data in human embryonic stem cells. Our results confirmed that SEM is a powerful approach to estimate the gene regulation caused by chemical toxicity. The shapes of the inferred network models for the various chemicals were different, but the inferred networks had a tendency to finally affect the same gene by their toxicity type. One of the neuron development-related genes, Tuj1, was arranged as the result of almost all of the Neurotoxic toxicity networks. Furthermore, Oct3/4 was important for both the Genotoxic and Carcinogenic networks. Since the Genotoxic chemicals are also carcinogenic, Oct3/4 is considered to be carcinogenic in ES cells. We detected some specific features for each toxicity type, and thus the inferred network among genes can be utilized for the estimation of a chemical's effects, from experimentally obtained expression profiles. The ability to identify expression profiles and the corresponding biological functions is expected to provide further possibilities for SEM in the inference of regulatory mechanisms by chemical toxicity.

TABLE IV. TRANSACTION TABLE OF CONSERVED REGULATIONS

edge info.		Neurotoxic chemicals					Genotoxic chemicals			Carcinogenic chemicals				Other chemicals		
parent	child	MeHg	2-Np	ACA	p-NA	PCB	BZP	DENA	DEAF	PB	TMX	DES	TCDD	THAL	BPA	PER
Oct34	Lmx1A	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0
Oct34	Nestin	0	0	0	1	0	0	1	0	1	0	0	0	0	0	0
Oct34	Pax6	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0
Oct34	Tuj1	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0
GATA2	Oct34	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
GATA2	Lmx1A	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0
GATA2	Nestin	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0
GATA2	Pax6	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0
Lmx1A	GATA2	0	0	0	0	0	0	1	0	1	0	0	0	0	1	0
Lmx1A	MAP2	0	0	0	0	0	1	1	0	0	0	0	0	0	1	0
Lmx1A	Nanog	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0
Lmx1A	Pax6	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0
Lmx1A	Tuj1	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0
MAP2	Oct34	0	0	0	0	1	0	1	0	1	0	0	0	1	0	1
MAP2	GATA2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
MAP2	Lmx1A	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0
MAP2	Nanog	0	0	0	0	0	0	1	0	0	1	0	0	1	0	0
MAP2	Nestin	1	1	0	1	0	0	0	1	0	0	0	1	0	1	0
MAP2	Pax6	0	0	0	1	1	0	0	1	0	0	0	0	1	1	0
MAP2	Tuj1	1	0	0	0	1	1	0	0	0	1	0	0	0	0	0
Nanog	Oct34	1	0	0	0	1	0	0	1	1	0	1	0	0	0	0
Nanog	Lmx1A	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1
Nanog	MAP2	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0
Nanog	Nestin	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0
Nanog	Nodal	0	0	1	1	0	1	0	0	1	1	1	1	0	0	0
Nanog	Tuj1	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0
Nestin	Oct34	0	0	1	1	0	0	0	1	0	1	0	0	0	0	0
Nestin	GATA2	0	0	0	0	1	0	0	1	0	0	0	0	1	0	0
Nestin	Nanog	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0
Nestin	Nodal	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0
Nodal	Oct34	0	1	0	0	0	1	0	0	0	1	0	0	0	0	0
Nodal	MAP2	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
Nodal	Nanog	1	1	0	0	1	0	1	1	0	0	0	0	0	1	1
Nodal	Nestin	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
Nodal	Pax6	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0
Nodal	Tuj1	1	0	1	0	0	0	0	1	0	1	0	0	1	0	0
Pax6	Oct34	0	1	0	0	0	0	0	0	0	0	1	1	0	0	0
Pax6	GATA2	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
Pax6	Lmx1A	0	1	0	0	0	0	0	0	0	1	1	0	0	0	0
Pax6	MAP2	1	1	0	0	0	0	0	0	1	1	1	0	0	0	1
Pax6	Nanog	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Pax6	Tuj1	0	0	1	0	0	0	0	0	0	0	0	1	1	0	0
Tuj1	Oct34	0	0	0	0	0	0	1	0	0	1	0	1	0	0	0
Tuj1	Nanog	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0
Tuj1	Nodal	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0
Tuj1	Pax6	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1

a. The first column indicates the starting gene of one edge, and the second column indicates the end gene of the same edge.

b. The value of 1 means that the corresponding regulation appeared with the chemical, whereas the value of 0 means that the regulation did not exist in the chemical's network.

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