ICT-powered Health Care Processes
(Position Paper)

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Abstract. The efficient use of health care ressources requires the use of Information and Communication Technology (ICT). During a treatment process, patients have often been tested and partially treated with different diagnoses in mind before the precise diagnosis is identified. To use ressources well it becomes necessary to adapt the prescribed treatments to make use of the tests and partial treatments already performed, rather than always starting from square one. We propose to facilitate this through the design of *declarative process models* accounting for the involvement of distributed groups of medical specialists and the adaptation of treatments, and through the evaluation of the *trustworthiness of models* taking account of test results and actual treatments compared to the clinical guidelines.

Keywords: Clinical guidelines, declarative and stochastic process models, adaptability, trustworthiness.

1 Challenges and Project Hypothesis

Health care is a fundamental service offered by the society, and as a consequence of the demographic development and the discovery of new medical treatments there is an increasing pressure on getting more and better health care from a fixed budget. A key trend is the use of better work flow in order to reduce errors [47] and make more efficient use of health care resources, and this increasingly dictates the use of Information and Communication Technology (ICT) powered Health Care Processes.

A particular challenge in the health care sector is that the needs of patients are individual and do not directly fit standard work flows (or pathways) as seen in e.g. originally developed for mass production of consumer goods. The patient may have a number of general or specific symptoms, some of which may be variations over normality, whereas others could point to different diagnoses requiring different treatments or tests.

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Seen from the point of view of the traditional organization of health care, the general practitioner performs an initial screening of the symptoms before patients are referred to more specialized treatment; each group of specialists will focus on one particular type of diagnosis, making further tests and examinations, and carry out treatment only if the hypothesized diagnosis is confirmed.

Seen from the point of view of the patient, this may lead to a sequence of partial treatments and re-referrals before end of treatment. Even more challenging are the needs of patients with co-morbidities — patients suffering from several illnesses at the same time and where symptoms may overlap and there may even be conflicts between the treatments offered by different groups of specialists.

We therefore see the Electronic Health Record (EHR) as giving a record of both tests and partial treatments, representing (multiple) diagnosis, that change with executed experiments and tests and, therapies given to reflect these (multiple) diagnoses. As new tests are made, and as the recovery of the patient is evaluated, the treatment plan may be adjusted to focus on alternative or more specialized diagnoses. There is a need to be able to exploit previous tests and treatments, and to match them to the new prescribed treatment as well as possible, rather than starting out all over again.

The processes of diagnosis and treatment of these multimorbid conditions are, seen in their entirety, thus generally spread between GPs, hospitals, specialty doctors and maybe combined with social service or nursing by the local municipal health units. This makes control, coordination, communication and compliance a special challenge.

Also, a very intensive trend in the e- and mHealth agendas, is the active involvement of the patient via cooperation active roles within the processes or direct patient control. The patient, with the rights of a citizen, takes an active role as an extra provider of own healthcare services and executes (sub)segments of the clinical procedure, reports data directly to the EHR or enters them via telemonitoring equipment or a telemedicine communication channel [8].

This project will study these challenges in the area of cancer treatment, in collaboration with Region Hovedstaden (one of the key Danish health care providers and responsible for the treatment of all Danes living around Copenhagen). In the words of the Danish National Board of Health 2008 (translated by Naja Holten Møller):

> A significant number of patients may not follow the course of a pathway from start to finish. These are, for instance, patients with other diseases or conditions that will affect the diagnosing and treatment. These also include patients where the picture of suspected or [later on] confirmed cancer is unclear. Or it may be patients with relapse after end of treatment.

As described here, it is necessary for the formulation and ICT support of such distributed health care processes to not only reflect the clinical content and data, but also to represent coordination, initiation and assignment of roles to the different steps in a procedure. Examples are

- elective, booked procedures and/or services, incl. self-booked,
- time-slot procedures and/or services (come when you like),
- self service, self initiated or self managed procedures and/or services.

This nature of cross-sectorial cooperation, handover of control, patient empowerment and online medicine makes it necessary to widen the scope of procedure definition beyond traditional flow models.

The main hypothesis of the project is that ICT powered *process models*, as studied in embedded, workflow management and service oriented systems, can be adapted to fit these challenges better than techniques based on procedural workflows and pathways. This involves the difficult question of how to design *declarative process models* to account for the involvement of distributed groups of specialists that need to collaborate in a virtual manner in confirming the diagnosis (or diagnoses) of the patient, adapting and carrying out treatments that are both cost-effective and of high quality. It also involves the difficult question of how to evaluate the *trustworthiness of models* of both the data representing test results, of the diagnoses that may fit the symptoms in varying degrees, and of the conformance of the actual treatment to the one prescribed in clinical guidelines.

The results of this project are likely to benefit the future organization of health care and to lead to new ICT systems that may be developed by software companies. As part of the project we will prepare researchers to take part in working with both health care providers and software companies in achieving these goals.

2 Theoretical Foundations

Process calculi and algebras [30] have been developed to describe the higher-level functioning of modern IT systems, which are to a large extent distributed and operating concurrently. More recent process algebras focus on *coordination* mechanisms between distributed agents, on the *orchestration* of a number of distributed services offered by various agents, and on the *choreography* of a number of distributed and independent services performed by agents that are not under central control; many of these development have been funded by European Union projects, mentioning just Software Engineering for Service-Oriented Overlay Computers (SENSORIA) [45] in which we participated.

Declarative specifications expressed using adaptations of mathematical logic, such as Linear Temporal Logic and Computation Tree Logic [1], provide the basis for model checking hardware components and software systems against specifications and are used extensively by major companies like Intel and Microsoft. During the last five years declarative process notations with implicit control flow, including our own work on Dynamic Condition Response Graphs [33], have been researched as a means to provide support for *flexibility in execution* [51] and *dynamic adaptability* of business process and workflow management systems in general [32–34, 40, 41], and health care processes in particular [27, 35, 36]. Currently, a working group under the Object Management Group (OMG) is preparing a proposal of a declarative case management modeling notation [54] to extend the Business Processing Model and Notation (BPMN 2.0) [39], the current industrial standard for business process modeling defined by the OMG. In the proposed project, we aim to research to which degree declarative models allow to adapt the prescribed operation by adding and removing new activities and constraints, as may result from initiating a new concurrent diagnosis or treatment subprocess within a treatment process.

Trustworthiness is a problem well known from ICT systems where security challenges include both confidentiality (or privacy) and integrity (or trust) of the data. In particular, the notion of trust seems relevant for tagging data bases and EPRs with information about the extent to which test results, diagnoses and treatments can be trusted. During the last two decades there has been numerous work on type systems for the confidentiality of data, and type systems for integrity of data are often dual to these (in a precise formal sense); examples include the Decentralized Label Model [37] developed for the programming language Java. The challenge will be to formulate type systems for *process models* that can accurately propagate trustworthiness information throughout the processes so as to make qualified decisions about the quality of treatment. A recent addition is our own Quality Calculus [16] addressing the problems of how to prescribe actions when insufficient guidance has been received and how to determine the quality of the actions performed under such circumstances. In particular, we aim to research the extent to which a given sequence of partial treatments live up to the expectations as may be prescribed in clinical guidelines. For the latter we anticipate that important insights may be obtained from constraint solving (of both hard and soft constraints [2]) as well as stochastic model checking [1] (using reward and cost structures). In short, given a process model one may construct the set of acceptable traces and consider whether the process model is consistent with a given specification.

Supplementary Methods and Techniques. Along the primary project dimensions of *Declarative Process Models* and *Trustworthiness of Models* we anticipate incorporating a number of cross-cutting methods and techniques, in particular *Type and Effect Systems* [38], *Session Types* [20], *Stochastic Model Checking* [1] and *Constraint Solving* [2].

Type and Effect Systems is a method for annotating software programs with high-level information about their behavior, which can be verified by performing *type checking* before the program is executed. Type systems traditionally just focus on making sure that data types are used consistently like not trying to add integers to character strings. They have been extended also with considerations from security like confidentiality and integrity levels. Effect systems go one step further and provide summaries of the communications performed by the software programs (see e.g. [38]). *Session Types*, also referred to as *behavioral types*, is a refinement of type and effect systems for annotating distributed process models with the behavioral patterns of interaction between the individual actors and ICT systems (see e.g. [20]). That is, in addition to ensuring that the interchanged data has the correct format, the behavioral types also guarantee that each participant follows the same protocol. In this way, session type checking can sometimes guarantee that actors will never end in a deadlock situation, waiting for each other and not being able to progress. *Stochastic Model Checking* is a set of fully automatic techniques for determining whether process models live up to expectations as expressed using mathematical logic (see e.g [1]). The consideration of stochastic models and logics makes it possible to deal with probabilities (including probabilities of events that are not stochastically independent) as well as expectations of waiting times. Recent work has extended models and logics with reward (or cost) structures that make it possible to obtain information about the expected quality of behavior (like waiting times exceeding the recommendations from the clinical guidelines). *Constraint Solving*

traditionally focuses on *hard* constraints that must be met [2]. More recent work also incorporates *soft* constraints that express preferences and where the objective is to obtain as high a score as possible while adhering to the hard constraints. This is made more challenging in the presence of multiple optimization criteria in which case the identification of Pareto frontiers (as studied in Economics) may be the best one can hope for. Solvers are often developed using the framework of Satisfaction Modulo Theories [9].

3 Work Packages and Milestones

WP1: Processes and Practice Cases. This work package is mainly to be conducted by a postdoc hired for one year and should start as soon as possible after the project has been granted. The purpose of WP1 (Processes and Practice Cases) is to identify a set of representative and critical healthcare processes within cancer treatment, and to study the challenges in the current workflows for handling these processes. Focus will be on previously identified challenges related to ad-hoc initiated pre-diagnosis processes, co-morbidities, and distributed collaboration [31]. This will likely involve some amount of interviewing health care professionals in order to describe workflows, the challenges in existing workflows, and the challenges in interactions between existing cancer treatment packages. In addition to a description of the study itself, an important delivery of the work package is a number of representative cases of healthcare processes and current medical practice in the primary and/or secondary health care sector. These need to be described in such a way that they can be approached by the PhD students; they will mainly have a background in Information and Communication Technology, and will approach the cases with the more technically oriented techniques of declarative process models (the topic of WP2) and trustworthiness of models (the topic of WP3). This work should start well before the other work packages and should terminate during the first year of work packages WP2 and WP3.

Milestones of WP1: 1) Survey of previously identified challenges related to ad-hoc initiated pre-diagnosis pro- cesses, co-morbidities, and distributed collaboration 2) A set of representative and critical healthcare processes within cancer treatment.

WP2: Declarative Process Models. This work package is mainly to be conducted by a PhD student who should be hired within six months of commencing the project and should work for three years. Based on the cases of processes and practice from work package WP1, a PhD student will in this work package be guided towards a background in declarative process models. The initial focus of WP2 (Declarative Process Models) will be on extending and modifying existing technologies for declarative process models [7,18,21,44,48,51,52] to be able to deal with the challenges offered by the cases. The subsequent focus will be on extending and modifying existing methods and techniques for distribution [11,17,19,24,43,50,53], adaptation [10,25,40,49] and analysis [13,29] of declarative process models in order to provide qualitative (and perhaps quantitative) information about the quality of service. Especially in the initial phase we foresee considerable interaction with work package WP3; in the later phase we foresee interaction with work packages WP4 and WP5.

Milestones of WP2: 1) PhD student trained in declarative process models. 2) Existing technologies for declarative process models extended to be able to deal with the challenges offered by the cases identified in WP1. 3) Existing methods and techniques for distribution, adaptation, and analysis of declarative process models extended to provide qualitative (and perhaps quantitative) information about the quality of service.

WP3: Trustworthiness of Models. This work package is mainly to be conducted by a PhD student who should be hired within six months of commencing the project and should work for three years. Based on the cases of processes and practice from work package WP1, a PhD student will in this work package be guided towards a background in trust models and their formalisation [6]. The initial focus of WP3 (Trustworthiness of Models) will be on extending and modifying existing formalisms for trust models [6] to be able to deal with the challenges offered by the cases. The subsequent focus will be on extending and modifying existing methods and techniques for the analysis of trust process models in order to provide qualitative (and perhaps quantitative) information about the quality of service. Especially in the initial phase we foresee considerable interaction with work package WP2; in the later phase we foresee interaction with work packages WP4 and WP5.

Milestones of WP3: 1) PhD student trained in trust models and their formalisation. 2) Existing technologies for trust models extended to be able to deal with the challenges offered by the cases identified in WP1. 3) Existing methods and techniques for analysis of trust process models extended to provide qualitative (and perhaps quantitative) information about the quality of service.

WP4: Stochastic Analysis or Constraint Solving. This work package is mainly to be conducted by a postdoc hired for one year during the second half of the project; the exact time will depend on the needs of the project and the availability of the right person (likely a PhD graduate or postdoc from the MT-LAB research centre). The focus of WP4 (Stochastic Analysis or Constraint Solving) is to apply techniques for stochastic analysis and constraint solving to the models resulting from WP2-WP3 We anticipate that our consideration of probabilistic and stochastic phenomena may present new challenges beyond those normally studied in embedded and service oriented systems. We also anticipate that our consideration of hard and soft constraints may require solution techniques beyond our current repertoire of techniques. We therefore intend to hire a PhD graduate or postdoc with expertise in one of these areas. This work should interact with work packages WP2 and WP3.

Milestones of WP4: Demonstration of Stochastic Analysis or Constraint Solving for process models identified in WP 2-3.

WP5: Prototype Development. This work package is mainly to be conducted by a postdoc hired for one year during the second half of the project; the exact time will depend on the needs of the project and the availability of the right person (likely a PhD graduate from an industrial PhD programme). Towards the end of the project we would like to assess the feasibility of the results coming out of primarily work packages WP2 and

WP3. To facilitate assessing the feasibility of the results coming out of in particular WP2 and WP3 we have created a special work package (WP5) for prototype development, and decided to allocate a postdoc with experience in the field, to make sure that there is enough focus and man power on this important part of the project. This work should interact strongly with our end users as well as work packages WP2 and WP3.

Milestones of WP5: Prototype(s) demonstrating ICT-powered Health Care services based on WP2 and WP3.

4 Conclusion

We have described a research project proposal focussed on the design of *declarative process models* and *formal models of trustworthiness* for healthcare treatment processes, accounting for the involvement of distributed groups of medical specialists, dynamic adaptation of partially completed treatment processes, and evaluation of the *trustworthiness of models* by applying techniques for stochastic analyasis and/or constraint solving, taking account of test results and actual treatments compared to the clinical guidelines.

We have so far established a collaboration with the *SOAMED* graduate school in Berlin. In addition to the IT, Medico and Telephony (IMT) section in the capital region of Denmark, we have identified an industrial partner who has experience in collaborating with universities and is specialized in developing case and knowledge management systems base on declarative process models. We are currently applying for funding for the research project and we are continuously looking for potential collaborators and related projects.

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