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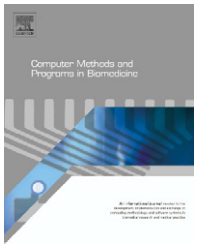

Formal interaction specification in public health surveillance systems using π-calculus☆

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ABSTRACT

This paper provides formal specification of interactions in typical public health surveillance systems involving healthcare agencies at local, state and federal levels. Although few standards exist for exchange of healthcare information, there is a general lack of formal models of the protocols involved in the interactions between the agencies. The quality of medical care provided is an end result of a well designed choreography of diverse services provided by different healthcare entities. One of the major challenges in this field appears to be explicit formal specification of such interactions. Such formal specification work is the first step leading to both design and verification of important properties of public healthcare systems. π-calculus is a formal modeling technique for precise specification of semantics in interacting concurrent systems where mobility is involved. Two different configurations of public health surveillance systems are modelled using π-calculus in this paper.

1. Introduction

Public Health infrastructure and preparedness are some of the fundamental yardsticks of progress of a developed nation. Semi-formal descriptions of the protocols involved in interactions between public healthcare entities are not adequate for either design or verification of desired system properties. Semi-formal models based on modeling languages such as UML (Unified Modeling Language) fail to capture some of the constraints and the finer details of the semantics of concurrency of such complex interactions. Formal specifications address this precise need for describing systems in a mathematical way that is amenable to analysis and downstream automated verification of correctness. The need for a precise formal specification of such a system is therefore of utmost importance and relevance. Healthcare messaging standards such as HL7 (Health Level 7 standard) [1–3] do not formally describe the complex global interactions that take place between the participating healthcare entities although the latest version (HL7 Version 3) does describe simple application to application interactions using UML sequence diagrams. Protocol descriptions at a more precise and formal level of detail are available in the context of other related application domains [4–6] although there is a general lack of literature along similar lines in public health informatics. The interactions that take place between the healthcare agencies are often at the core of the complexity of any healthcare system. *This paper provides for the first time, formal specifications of the interactions of the different entities involved in public health surveillance systems as a result of changes in their configuration. This model is the starting point toward further work on verification of desired properties as well as design of such systems.*

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Section 2 provides the backround definitions of public health surveillance systems. It also introduces the need for formal modeling in this domain [5,4] and describes the specific case study used as an example in this paper. Section 3 describes briefly the process algebra of π-calculus and its notation. Section 4 provides formal specification of the case study in its two configurations followed by discussions. Finally, Section 5 concludes the paper.

2. Background

2.1. Basic definitions

The major entities invovled in a typical public health surveillance system in United States of America [7] are the following. Similar entities analogous to the ones defined below are invovled in other countries although the model may differ in some respects.

- Hospital Information System (HIS): These are facilities that serve as entry points for patient medical record information. Patient demographics, laboratory results in either manual or electronic form constitute the main information recorded in these systems.
- Local Public Health System (LPHS): Local public health systems gather information from hospital information systems and other primary patient record collection entry points to identify trends in occurence of diseases in a specific locality. They are typically required to report aggregated disease events to their respective State Public Health System.
- State Public Health System (SPHS): State public health information systems have the primary responsibility of collecting information about patients at a specific state to detect patterns of outbreaks, etc. They also need to report confirmed cases of disease events to the federal healthcare agencies.
- Federal Public Health System (FPHS): The federal public health system is the primary agency for public health surveillance of a country. It sets the standards for reporting of specific diseases to the states. It also uses those disease reports to detect disease outbreak patterns and feed back corrective measures to other agencies (mainly state and local public health systems) to maintian public health objectives of the country.

2.2. Need for formal methods

Formal models are used at different levels in software engineering all the way from specification to automated theorem proving [8]. Lack of clarity in specifying unambigously the exact functioning of the different parts of a system and its interactions are often at the root of any problem. Formal methods of software specification have a wide range of paradigms that evolved from state-based techniques to process-based techniques. A process algebra such as π-calculus is one of the more advanced and flexible specification formalisms that can deal with mobility in communication channels of concurrent systems. Such a model can be transformed to standard model checking specification languages for verification of system properties [9]. Verification of application software is an emerging area of research driving the use of formal specification. There is a growing realization in the application software community of the inadequacies of testing as a means to provide guarantees of absence of undesirable behaviours in systems since testing can only confirm presence of such errors, not their absence [10].

Public health surveillance systems are typically designed by specifying the requirements in an ad hoc manner without much clarity on the interactions and protocols that take place between the different entities of the system. The processes in each of the entities perform a sequence of activities internally by handling, generating and aggregating events. On top of that, these processes interact concurrently with each other in many different ways to provide services to the end-users. Moreover, the configurations in which such a system interacts are also dynamic. Semi-formal descriptions in terms of sequence diagrams and activity diagrams fail to capture the details at a level that can useful for verification of properties [11] deemed to hold for such a system. The π-calculus descriptions capture, in a very elegant way, the specification of the processes in such a system with the flexibility of modeling mobility when the healthcare entities start interacting in a new configuration from an initial one.

2.3. Case study

Fig. 1 shows a schematic diagram of the data flows and interactions between the healthcare agencies at a high level in public health surveillance systems at the initial configuration. Hospital Information Systems (HIS) register patient information as patients get admitted and discharged as shown by his_1 and his_2. This information is relayed to Local Public Health System (LPHS) *lph* via HL7 ADT (Admission Discharge and Transfer) messages based on various events that take place in his_1 and his_2. Once this information is received by *lph* for a metro or a city, it is stored after an initial cleanup of the content of the message. The same type of interaction takes place between the *lph* and the *sph*. These electronic laboratory reports (ELR) received by the *sph* are used to identify confirmed cases requiring investigation of specific diseases. Finally, confirmed cases of disease reports are transmitted to the federal public health system *fph* via Nationally Notifiable Disease (NND) messages.

Fig. 2 shows a new configuration of the same system. Flexibility and mobility of interactions and of electronic records are inherent in any public health surveillance system. In the new configuration, the second hospital information systems his_2 is directed to communicate directly with the original SPHS *sph*1. This scenario can arise either for reasons of business reorganization or security. The other change in this configuration is in the possibility of a direct interation between two SPHSs residing typically at two neighboring states for transferring, for example, confirmed case reports. This is shown by the new SPHS *sph*2. This is an example of mobility of communcation channels between different healthcare entities.

Specific types of internal events (e.g., admission, discharge, transfer) result in different HL7 ADT messges to flow between HIS (his_1 and his_2), LPHS (*lph*) and SPHS (sph_1 and sph_2). The payload of these ADT messages vary depend-