

Computer Representation of Formalized View of in-Patient Departments of Hospitals

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Abstract: *This paper concerns modelling and simulation of in-patient movements in hospitals. It provides a formalized view of in-patient departments, their structure and rules of patient movements. Computer representation of the formalized view is implemented in SIMULA language to make a simulation program, which can be used not only during the design of in-patient department systems but also during their operation for making short-time decisions.*

Key words: *Formalized World View, Object-Oriented Programming, SIMULA language, Simulation, in-Patient Departments of Hospitals.*

INTRODUCTION

Formalized world viewing (*FWV*) can be considered as an aggregated knowledge representation containing representations of other pieces of knowledge as well as their applications. Regarding so called super-object-oriented programming languages like SIMULA, *FWV* is represented by a main class, in the body of which are placed declarations of local classes. In this case the main class may reflect an abstract pattern of the "world" to be simulated, while the local classes correspond to basic concepts of the "world". When programming in SIMULA, its standard class *Simulation* is the most general (universal) computer representation of *FWV* for modeling "worlds" changing their states in the Newtonian time. It is evident that if we want to simulate a given "world" (system), or a set of "worlds" (systems) mutually similar, we must first establish (build) computer representation of formalized view of the system. Therefore, we must enrich the class *Simulation* (usually stepwise) so that the resultant computer representation of formalized view of the system involves all necessary for simulating it.

The aim of this work is twofold:

- to build computer representation of formalized view of any in-patient department of the hospitals,
- to enrich the computer representation to the form that would make possible to control patient movements on the conditions of a given in-patient department.

FORMALIZED VIEW OF IN-PATIENT DEPARTMENTS

We would like to start from experience with a French software product QNOP [4], written in SIMULA and successfully applied to simulation of manufacturing and logistic systems. Its philosophy, formulated first by Tchernev [5], is based on the decomposition of simulated systems into the following three cooperating subsystems:

- physical subsystem,
- logical subsystem,
- decision subsystem.

Generally speaking, the physical subsystem involves abilities of material nature, the logical one contains the communication abilities liable to logic rules and, finally, the decision subsystem contains abilities for decision making.

Although this decomposition was originally intended for specialists who design manufacturing and logistic systems, it can be also useful for solving our problem, i.e. for making formalized view of in-patient departments of hospitals. It makes possible to separate the control (decision making) abilities from all other abilities that are often supposed not to differ during simulation experiments.

When solving our task, we suppose that the **physical subsystem** includes all the beds, rooms and sections of a given in-patient department as well as all the patients who pass through medical treatment in this department. It is evident that the basic units of the subsystem are beds, the computer representation of which is the class *g_bed* without any parameters. Each instance of the class has (among others) two important attributes giving its content (empty, occupied by a man, occupied by a women) and pertinence to a room. The only method of this class makes possible to produce an image of the bed, the color of which depends on its content. There are no life rules in the class *g_bed*.

Rooms are considered to consist of beds. The computer representation of rooms is the class *room* having two parameters: *capacity* (total number of beds) and *name* (an identification of the room). Instances of the class have three reference attributes: vector of beds, list of empty beds and list of occupied beds. Moreover, each instance of the class is capable of performing four methods that enable

- (a) to fill in the room with beds up to its capacity,
- (b) to accept a patient from the queue of patients waiting for reception,
- (c) to display the room as a set of colored images of its individual beds,
- (d) to calculate the total exploitation of the room during a simulation period.

The methods (a) and (c) are used to construct the simulation models (various initializations are previewed), the method (b) is used during the run of the simulation experiment and, finally, the method (d) is supposed to be used mainly at the end of the simulation experiments.

Life rules of the instances are very simple; they ensure creating the links of empty and occupied beds as well as placing each new room into the list of empty rooms.

In-patient departments are usually composed of two sections, namely standard one and unit of intensive care (UIC). The computer representations of the sections are classes *a_standard* and *a_UIC*, respectively (subclasses of class *a_section*). Each of the classes has two parameters providing the section name (title) and color (indices of beds of the two sections are displayed in different colors). The instance of standard section has a few reference attributes pointing to the lists of empty rooms, fully occupied rooms, partially occupied rooms by men and partially occupied rooms by women as well as to the queues of men and women waiting for the reception. Similarly, the reference attributes of the instance of UIC section refers to the lists of empty rooms, fully occupied rooms, partially occupied rooms (irrespective of patients sex) and also to a common queue of patients waiting for the reception by this section. Instances of both sections can execute a given action (method) for all the beds placed in the sections. Life rules of the two sections ensure creating the corresponding lists and queues. They are supposed to run at the beginning of every simulation experiment.

Formalized view of patient is represented by the class *patient* with one parameter giving the patient sex. Each instance of patient has three attributes, the most important of them being its place, i.e. its bed within a given in-patient department. All patients are capable of performing (among others) the following methods that make possible

- to search for an empty bed in a given section,
- to take a bed,
- to leave a bed,
- to enter a queue of patients waiting for the reception
- to leave a queue of patients waiting for the reception.

The computer representation of patients ensures that each patient (immediately after its creation) enters so called quasi-parallel system. It means that patients are capable transmitting the control of simulation one to another during simulation experiment running on a one-processor computer.

Three important classes (subclasses of the class *patient*) are introduced:

- standard patients, who enter the standard section and after some medical treatment leave the section;
- serious patients, who are accepted by the standard section, after a certain treatment transferred to UIC section and finally returned to the standard section;
- extremely serious patients, who are accepted directly by UIC section, and after some treatment in the section transferred to the standard section.

As it was shown, the life rules of patients differ significantly from each other according to their state of health.

In our case the **logical subsystem** can be represented by tools of predicate calculus. The interpretation of the elementary predicates is explained in Table 1.

Table 1: Elementary predicates

$R(x,t)$	at time t , x is a room	$\mu(x,t)$	at time t , x is a man
$S(x,t)$	at time t , x is a standard room	$\Phi(x,t)$	at time t , x is a room for women
$B(x,t)$	at time t , x is a bed	$M(x,t)$	at time t , x is a room for men
$P(x,t)$	at time t , x is a patient	$L(p,b,t)$	at time t , p occupies bed b
$\phi(x,t)$	at time t , x is a woman	$E(b,r,t)$	at time t , b is installed in r

The variables t , u , v and w are used to represent time, i.e. real values from a certain non-degenerated interval I of real numbers; instead of $\forall t \in I$ only $\forall t$ will be written.

The axioms expressing the invariancy of predicates with respect to time are given in Table 2.

Table 2: Axioms of invariancy

Axiom	Formulation	Interpretation
(A1)	$\forall x(\exists t P(x,t) \rightarrow \forall t P(x,t))$	If x is sometimes a patient, it is always patient
(A2)	$\forall x(\exists t B(x,t) \rightarrow \forall t B(x,t))$	If x is sometimes a bed, it is always bed
(A3)	$\forall x(\exists t R(x,t) \rightarrow \forall t R(x,t))$	If x is sometimes a room, it is always room
(A4)	$\forall x(\exists t \mu(x,t) \rightarrow \forall t \mu(x,t))$	If x is sometimes a man, it is always man
(A5)	$\forall x(\exists t \phi(x,t) \rightarrow \forall t \phi(x,t))$	If x is sometimes a woman, it is always woman
(A6)	$\forall x(\exists t E(x,y,t) \rightarrow \forall t E(x,y,t))$	If x is sometimes a bed in a room y , it is always bed in that room

Therefore, we can omit time argument and write simply $P(x)$, $B(x)$, $R(x)$, $\mu(x)$, $\phi(x)$ and $E(x,y)$.

When defining one more predicate N , representing the statement that patient p lies at time t in room r , by the relation

$$N(p,r,t) \equiv \exists b (L(p,b,t) \vee E(b,r)),$$

we can formulate all the remaining axioms (see Table 3).

The patient sex is taken into account by means of axioms (A7)-(A10). In order to distinguish among patients, beds and rooms, axioms (A11)-(A12) are introduced. Axioms (A13)-(A15) concern the relations between patients and beds, while axioms (A16)-(A17) concern the relations between beds and rooms. The axioms (A18)-(A22) define the relations between patients and rooms. Axiom (A23) tells that when a patient enters a bed, it occupies it for a certain non-degenerated time interval in future. Axiom (A24) is a certain complement to it, telling that when a patient leaves a bed, it does not occupy it during a

certain non-degenerated time interval in future. More details about the axioms (including the consequences following from them) are given in our recent work [2].

Table 3: List of remaining axioms

Axiom	Formulation	Interpretation
(A7)	$\forall x (\mu(x) \rightarrow P(x))$	Each man is a patient
(A8)	$\forall x (\phi(x) \rightarrow P(x))$	Each woman is a patient
(A9)	$\forall x (P(x) \rightarrow \mu(x) \vee \phi(x))$	Every patient is either a man or a woman
(A10)	$\forall x \neg(\mu(x) \wedge \phi(x))$	No entity is both a man and a woman
(A11)	$\forall p (P(p) \rightarrow \neg(B(p) \vee R(p)))$	No patient is a bed or a room
(A12)	$\forall b (B(b) \rightarrow \neg R(b))$	No bed is a room
(A13)	$\forall p \forall b \forall t (L(p, b, t) \rightarrow P(p) \wedge B(b))$	The relation of occupying exists only between a patient and a bed
(A14)	$\forall p \forall b \forall t (P(p) \wedge B(b) \wedge L(p, b, t) \rightarrow \forall c (L(p, c, t) \rightarrow c = b))$	No patient can occupy more beds at the same time
(A15)	$\forall p \forall b \forall t (P(p) \wedge B(b) \wedge L(p, b, t) \rightarrow \forall q (L(q, b, t) \rightarrow p = q))$	No bed can be occupied by more patients at the same time
(A16)	$\forall b \forall r (E(b, r) \rightarrow (B(b) \wedge R(r)))$	Relation "being installed" exists only between a bed and a room
(A17)	$\forall b \forall r (B(b) \wedge R(r) \wedge E(b, r) \rightarrow \forall s (E(b, s) \rightarrow s = r))$	No bed can be installed in more rooms
(A18)	$\forall r \forall t ((S(r, t) \wedge \exists p (N(p, r, t)) \rightarrow (\Phi(r, t) \vee M(r, t)))$	Each non-empty standard room is either men's room or women's room
(A19)	$\forall r \forall t (R(r) \wedge \Phi(r, t) \rightarrow \forall p (P(p) \wedge N(p, r, t) \rightarrow \phi(p)))$	Patients placed in a women's room are women
(A20)	$\forall r \forall t (R(r) \wedge M(r, t) \rightarrow \forall p (P(p) \wedge N(p, r, t) \rightarrow \mu(p)))$	Patients placed in a men's room are men
(A21)	$\forall r \forall t (R(r) \rightarrow \neg(\Phi(r, t) \wedge M(r, t)))$	No room can be men's and women's at the same time
(A22)	$\forall r (S(r) \rightarrow R(r))$	Standard rooms are rooms
(A23)	$\forall p \forall b \forall t ((L(p, b, t) \wedge \exists u (u < t \wedge \forall w (u < w < t \rightarrow \neg L(p, b, w))) \rightarrow \exists v (v > t \wedge \forall w (t < w < v \rightarrow L(p, b, w))))$	
(A24)	$\forall p \forall b \forall t ((\neg L(p, b, t) \wedge \exists u (u < t \wedge \forall w (u < w < t \rightarrow L(p, b, w))) \rightarrow \exists v (v > t \wedge \forall w (t < w < v \rightarrow L(p, b, w))))$	

Regarding an in-patient department, the **decision subsystem** should contain the tools for anticipating the consequences of short-time decisions of the department

management. Our general formalized view of such department involved no special means for decision making and watching their consequences, but some special means corresponding to decision rules in individual departments in Czech hospitals are prepared in the manner that is outlined in the next section.

IMPLEMENTATION

The computer representations of formalized view of an in-patient department were implemented using object-oriented technique in SIMULA [1,3]. Evidently there is a lot of in-patient departments, mutually differing not only by the configuration of their sections and rooms but also by rules applied for managing patient movements. The most general computer representation contains only basic tools for building formalized view of any in-patient department, namely declaration of main classes *g_bed*, *room*, *a_standard*, *a_UIC* and *patient*. This computer representation (let it be called *FV1*) was enriched to get the formalized representation *FV2* by introducing the tools for automated animation of simulation experiment as well as for making reset of such experiment. The rooms are mapped as sets of images of beds – the color of every image of a bed expresses whether that bed is occupied by a man (blue) or by a women (red) or whether it is not occupied (green), and the indices (sequential numbers) of the bed image informs whether the bed is in a standard section (black) or in the units of intensive care (yellow). The computer representation *FV2* was enriched to *FV3* in order to enable a user for easy construction of the simulated system configuration (rooms and their beds) by means of mouse. Patterns of the configuration are stored at files and during the initial dialogue the user chooses such a file and gets the items stored at it. The next *FV4* contains in addition the tools for introducing both the initial system configuration and the starting values of the parameters of simulation experiment from an input file or manually. Finally, the computer representation *FV4* was enriched to *FV5*, which makes possible to generate the patients of three different types (standard, serious and extremely serious) as well as to provide the final statistical evaluation of any simulation experiment. The representation *FV5* can be considered to be an external simulation model of any in-patient department. As it was stated earlier, this representation contains no tools for managing patient movements within the framework of a given in-patient department.

The input parameters of the external simulation model involves:

- frequency of patient input flow,
- quotients of serious and extremely serious patients from total number of patients,
- mean duration of patient stay in standard rooms
- mean duration of patient stay at UIC,
- time of the end of simulation experiment,
- duration of one simulation step (when simulating step by step),
- configuration (structure) of in-patient department (introduced from a file or manually).

The output data given at the end of simulation experiment consist of:

- global exploitation of each room and all the individual beds installed in it,
- mean length of queues of men and women waiting for the reception by in-patient department,
- mean length of queue of patients waiting for placing at UIC.

In the second stage of our experiments we introduced one more computer representation *FV6* containing the tools for anticipating patient movements on the conditions of a concrete in-patient department. This representation can be considered to be an internal simulation model of the corresponding in-patient department. In this case it is necessary to introduce additional items of information, first the time of the beginning of simulation experiment. For each bed of the department the following data are required:

- type of the bed occupation (none, man, woman),

- time at which the patient (if any) leaves the bed,
- sort of the patient (standard, serious, extremely serious),
- stage of the patient stay in the department (entering, concluding).

The internal simulation models were established for a few in-patient departments of the Motol hospital in Prague, namely for nuclear medicine and some units of surgery.

CONCLUSIONS AND FUTURE WORK

The external simulation model is available for understanding patient movements within a given in-patient department during the stage of its design, while the internal one allows the department manager to watch (in a quite simple way) the consequences of his short-time decisions.

Our future work will be oriented to establishing a more complicated simulation model of a given in-patient department, a model including the department manager (equipped with a computer) whose operation (activities) will be algorithmized. It means that the manager will watch the department environment and include the results of observations into his own simulation model. This model can be considered as nested in the external simulation model described above. In other words, it represents a formalized view of higher order when comparing it with our external simulation model. The both simulation models concern the same system; they are very close one to another but they are not identical.

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