Extending Information-Processing Theory to Model Inhomogeneous Exceptions in Medical Care

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Representations of medical work must capture the contingent nature of medical processes. Every patient is unique, and health care providers naturally adapt to the different needs of individual patients. Simulations meant to capture the characteristics of medical work must be capable of representing this flexibility. It is the exceptions and unexpected events that create the primary need for coordination within health care organizations and that create the greatest information-processing burden on the organization.

In manufacturing and engineering, traditional methods of managing resources and work processes such as PERT charts and Gantt charts can represent large scale models, but assume that all activities can be pre-specified completely. Even agent-based simulation systems such as VDT do not have the representational flexibility in their current form to represent contingencies and exceptions in medicine. In this paper, I describe a solution for representing medical protocol exceptions and contingencies using the Virtual Design Team (VDT) and describe necessary extensions to the information-processing framework underlying VDT to model health care organizations.

Representing Exceptions in the Current Version of VDT

The high level of abstraction in VDT information-processing models makes it possible to represent diverse exceptions simply by adding work volume to the end of an existing activity. For example, in modeling the design process of cables in a satellite launch vehicle in VDT, the activity (DESIGNCABLESYSTEM), is considered *homogeneous*. Homogeneous activities are activities in which all subtasks and exceptions have the same responsible agent and utilize the same resources and coordination structures—only the work volume differentiates activities and exceptions within homogeneous activities. In routine design processes such as those modeled in VDT, modeling work as homogeneous often holds true—when a design must be redone or modified, the person originally responsible for doing that subtask is the one who must repair the design.

In service organizations such as health care, health care providers, patients and care-givers will experience exceptions to the routine activities of patient care which will require additional work to correct. Unfortunately, repair strategies for exceptions in medical work may bear little resemblance to the activity that generated them. For example, in the routine administration of chemotherapy, a patient may experience side effects that result in hospitalization. The repair strategy for a chemotherapy exception (HOSPITALIZATION) cannot be represented accurately by adding additional work to the end of the ADMINISTERCHEMOTHERAPY activity because exceptions to chemotherapy are

not homogeneous. The nurse who administered the chemotherapy would not be responsible for exceptions that required hospitalization for infection, but rather the attending physician would coordinate and manage the hospitalization. In this scenario, the person who must repair the exception, the person who must communicate with others to resolve the problem, and the person who was responsible for the activity that originated the exception are all different people. Thus the goal-directed work and the coordination work are no longer homogeneous—we cannot represent the exception in an activity as simply an extension of that activity.

In addition, not all exceptions in medical care add work to the work process. Patients may have complications or features of their disease that makes them ineligible for certain kinds of therapy, or requires the physician to substitute a different activity. For example, a patient with breast cancer may not be eligible to receive Tamoxifen if her tumor does not have receptors for estrogen or progesterone, and the activities related to Tamoxifen therapy would be deleted from the protocol. Similarly, if a patient has hemorrhagic cystitis related to chemotherapy, a different chemotherapeutic agent would be substituted. Other activities may have exceptions that do not change the time to complete an activity, but may change the resources that are used, or the person who is responsible to complete that activity. A patient who has a complication in treatment might be required to see a particular specialist, rather than a generalist. Thus, models of medical work processes have exceptions that (1) are inhomogeneous with the activities that generated them, (2) affect the work process in more complex ways than adding work volume to an activity, and (3) require modeling actors and activities at a finer granularity than routine engineering projects. The nature of medical work processes cannot be adequately modeled using Galbraith's information-processing model of exceptions.

New Exception Types in VDT

To develop an information-process model of medical tasks capable of modeling these exceptions, I examined the original BMT protocol and the case histories of patients treated on that protocol. Two principles guided my initial investigation. First, the questions I was investigating addressed the process of care and organization-level questions of coordination, communication, and management preferences. Second, the protocol represents a plan for patient care—the actual execution of that plan requires revisions during execution when exceptions arise. Plan-revision strategies used in artificial intelligence and robotics could guide strategies for on-the-fly plan revisions during simulation.

Using both the original protocol and the case histories of patients treated on the bone marrow transplantation protocol, I categorized each of the exceptions by the effect that the exception had on the plan. As in AI planning, there are a limited number of ways in which a plan can be changed, and I found that patient exceptions fell into five distinct categories. These are listed below:

- Activity Temporal Modification—When activities are reordered, the start time for a particular activity is changed. For example, a course of chemotherapy might be

delayed if the patient's white blood cell count was too low or if the patient had other complications from the previous course of chemotherapy.

- Activity Addition—Sometimes, in response to a particular exception, additional activities are added to the protocol with new responsible agents and new resources. For example, patients with fevers and infection require hospitalization; patients who become dehydrated require additional intravenous fluids; and patients with anemia might require blood transfusions.
- Activity Deletion—For some patients, certain activities may be removed from the protocol or may not be applicable to the particular clinical situation. Eligibility requirements may make certain kinds of therapies contraindicated. For example, women with breast cancer whose cancer cells do not have receptors for estrogen would not benefit from medications such as Tamoxifen, and would not be eligible for this therapy.
- Activity Substitution—Substitution allows us to represent the flexibility present in protocol alternatives. For example, patients who are unable to tolerate certain kinds of chemotherapy could have other therapies substituted. A patient who has nausea and is unable to take tablets orally may be given a substitute medication intravenously.
- Activity Modification—When an activity is modified, the activity remains a part of the protocol, but characteristics of the activity are changed. For example, an activity normally assigned to a nurse might become the responsibility of the physician if the patient's condition warranted it. The dose of a particular drug might be changed because of change in the patient's condition, or the completion time of an activity delayed because of additional coordination requirements.

With these extensions to the VDT model of activities and exceptions, it is now possible to model organizations in which the work process can change during execution or simulation. By recognizing that the traditional view of information-processing exceptions used in VDT views activities and their exceptions as homogeneous, we can extend our representation to represent exceptions that are not homogeneous with activity that generated it. Using plan revision strategies drawn from the AI and robotics literature, we can maintain a high level of abstraction, while extending the VDT framework to accommodate dynamic work processes. We believe these extensions will allow us to model service organizations such as medical care, and to predict organizational bottlenecks and error-prone processes before clinical work processes are implemented within particular clinical settings. Current work focuses on using these extensions to model real medical organizations in the VDT framework, and to validate the behavioral characteristics of these extensions.