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Reasoning About Intentions in Complex Organizational Behaviors: Intentions in Surgical Handoffs

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INTRODUCTION

Naturally, military hospitals must accommodate large numbers of injured soldiers in and from the battlefield in a short time period. To enhance the soldiers' chances of survival, a significant effort has been devoted through providing a better health care environment that is able to manage uncontrolled patient volume and the variable acuity of medical encounters effectively (McNeil & Pratt, 2008). One major effort has been to provide more operating room (OR) and intensive care unit capability to satisfy the required medical and surgical needs (for examples in Iraq, see Eastridge, Jenkins, Flaherty, Schiller, & Holcomb, 2006; Montgomery, Swiecki, & Shriver, 2005). However, this solution only addresses one aspect of the problem and does not improve the injured soldiers' chances of survival in the battlefield, where environments are too complicated to be controlled as desired. Furthermore, in the ORs of both military and civilian hospitals, frequently physicians must make complicated clinical decisions with limited time and information while faced with a great number of competing demands and distractions (Kovacs & Croskerry, 1999; McIntyre, Stiegmann, & Eiseman, 2004). In addition, patients have often been transferred thousands of miles, passing through multiple teams of doctors at various places; for example, a severely injured U.S. soldier in the Middle East would likely travel through several hospitals in the region before ultimately returning to a hospital in the United States. During these transitions, the patient's information with respect to medical treatments can be easily lost or corrupted. This happens often, especially in unpredictable battlefield situations (Horwitz, Krumholz, Green, & Huot, 2006).

The OR is a critical and complex work environment that includes a wide spectrum of people, devices, and tools, in addition to various activities and events. Its complexity can be clearly demonstrated in the patient and treatment protocol, as well as in the high technologies applied and the management skills required to effectively cope with dynamically changing conditions. As noted by Christian et al. (2006) and Dalton, Samaropoulos, and Dalton (2008), there have been various studies analyzing complex health care environments such as the intensive care unit, OR, and emergency room. In particular, they have focused on the influence of interactions among components with respect to performance on quality of care and patient safety. Among the many key components that impact ~~on~~ patient safety, communication~~s~~ failure among medical care providers is common in transitional care, where the patient is moved from one place to another (e.g., the OR to the recovery room) and is handed off from one care provider to another (Landro, 2006).

AQ1 Using the definitions from the Institute of Medicine, a medical error is "the failure of a planned action to be completed as intended or the use of a wrong plan to achieve an aim," whereas an adverse event is "an injury caused by medical management rather than the underlying condition of the patient" (Kohn, Corrigan, & Donaldson, 2000). Errors in the OR can have catastrophic consequences for patients, families, and care providers (Hurwitz & Sheikh, 2009). Retained sponges, wrong-site operations, and mismatched organ transplants or blood transfusions are examples of adverse events, and only by having effective methods for detecting medical errors can they be prevented from happening. Medical errors have been known to cause from 44,000 to 98,000 deaths and more than one million injuries each year in the United States (Kohn et al., 2000). A significant portion of these deaths and injuries are preventable (Dalton et al., 2008). In addition, communication~~s~~ failure was recently identified as the leading cause of many adverse events by The Joint Commission (Parush et al., 2010), and much literature reports that communication~~s~~ failure within health care teams increases error rates and the number of adverse events (Alvarez & Coiera, 2006; Lingard et al., 2004). In the report by Wilson, Runciman, and Gibberd (1995), communications failure was associated with medical errors twice more frequently than inadequate medical skills. Bhasale, Miller, and Reid (1998) noted that medical errors due to communications breakdown accounted for 50% of all detected adverse events. An interesting study has recently investigated breakdowns in situation-related communications as a cause of medical errors in open-heart surgeries (Parush et al., 2010).

All aforementioned studies show that teamwork is an essential component to promoting patient safety in the OR and is "an important surrogate of patient safety" (Makary et al., 2006, p. 746). Due to the widespread recognition and significance of teamwork regarding patient safety, training and working in teams has been studied intensively (Guise, 2008). However, most studies published up to now are limited to developing theories rather than providing a useful framework to facilitate the medical care members who are involved in cooperative tasks.

The goal of our work is to promote patient safety by enhancing medical care members' team performance. To realize this, we provide a computational cognitive framework that represents the individuals' clinical decision-making processes and assists the medical care members' understanding of their coworkers throughout the cooperative operations.

By inferring the intentions of team members from the actions observed and environments perceived, we can capture their intent behind actions and predict future actions. In addition, we can detect potential errors caused by discrepancies among OR team members by comparing their intentions and others' beliefs about them. In particular, we focus here on individual differences and interactions among them in modeling the AQ2 members' reasoning because both of these elements are critical to inferring their intentions accurately.

In this chapter, we present the cognitive architecture that forms the basis of our surgical intent modeling. Our experiments are designed to validate whether our models are a true representation of real surgeons' decision-making processes and, as such, whether they are capable of detecting medical errors. Therefore, we will show how the potential errors caused by discrepancies among OR team members can be identified through our surgical intent modeling approach, focusing on the errors resulting from communications failure between surgeons.

We begin our discussion by providing background on intent modeling and Bayesian Knowledge Bases as the mechanism for modeling the decision-making process. Then, we model beliefs, goals, and intentions of surgeons (and any other team member). Next, we describe our real-world case study, followed by our experimental results. Finally, we provide our conclusions and directions for future research.

INTENT INFERENCING AND BAYESIAN KNOWLEDGE BASES

Originally, individual's intent, a psychological concept, is considered as a conscious subject: "capable of forming intentional states, mental states
AQ3 connected to an external reality" (Searle, 1983). Although the individual intent can be realized in various ways, it is clear that the intent leads to a course of actions. Team (organizational) intent is shaped by the individuals to pursue cooperative tasks. It is "bound to be collective to a degree, because a team consists of multiple members" (Manterea & Sillinceb,
AQ4 2007). Such collective intent can be promoted by an interconnection of individual intentions where "individuals need to be aware of, and adjust to, intentions of other members of the team" (Manterea & Sillinceb, 2007). Although strong and consistent shared intent among team members enhances the performance of the team to achieve the cooperative goals, inconsistent team intent can cause catastrophic damage in some circumstances, especially where the common goal is urgent and highly compli-
AQ5 cated such as in the surgical practice (Williams, Rose, & Simon, 1999).

Surgeons' intentions can be inferred from individuals' course of actions and perceptions of the environments. The team intent can be driven by collecting and comparing these individuals' intentions. For modeling individuals' intentions, each individual's knowledge and perceptions need to be represented appropriately. Among many knowledge representation systems, we choose Bayesian Knowledge Bases (BKBs) due to their simplicity in construction, sound semantics in modeling the human decision-making process, and low computational complexity in reasoning. In BKBs, individual differences can be implemented through various instantiations of random variables and probabilistic distributions among them.

Bayesian Knowledge Bases

BKBs are directed graphs that represent the causal relationship between knowledge (Santos & Santos, 1999). Similar to Bayesian Networks (BNs) (Pearl, 1988), BKBs integrate together graph and probability theories but provide a better formalism to handle uncertainty and incompleteness in decision making. The directed graph representation presents a formal yet visual expression of causality, whereas probability theory guarantees the semantic soundness in decision making under uncertainty. ~~As general graphs,~~ BKBs are composed of two types of nodes (I-nodes and S-nodes) and one type of directional arc. Figure 3.1 depicts a small BKB example. Knowledge is stored through random variables. A pair consisting of a random variable and an instantiation (also called state) is uniquely represented by an I-node, which is depicted as a white oval in Figure 3.1. The dependencies between I-nodes are encoded by conditional probabilities through S-nodes, indicating the likelihood of the child I-node given that a parent I-node is observed. Black dots in the figure represent S-nodes, and the weights on S-nodes represent the conditional probabilities. As mentioned previously, individual differences in the surgical intent modeling can be represented through instantiating random variables using I-nodes and probabilistic distributions of S-nodes. I-nodes are directed by arcs to demonstrate causality (e.g., if $B = b_1$, then $A = a_1$ with 80% chance). Some S-nodes, such as the nodes feeding into $B = b_1$ and $B = b_2$, have no parents. In this case, the weights refer to the prior probability of the I-nodes, that is, the probability of $B = b_1$ (or $B = b_2$) without any observation.

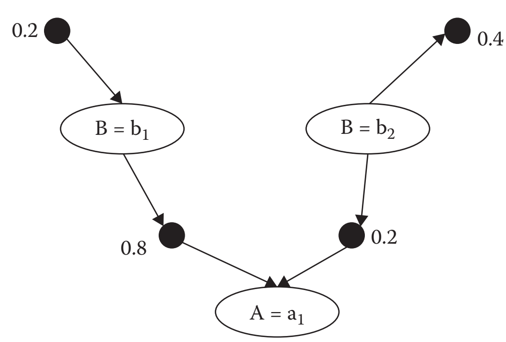

FIGURE 3.1
Bayesian Knowledge Base fragment.

BKBs are framed in this way to preserve both simplicity and expressiveness (Santos & Santos, 1999; Santos, Santos, & Shimony, 2003). BNs, on the other hand, do not explicitly model conditional probability rules in the graph and thus have to supply a conditional probability table that stores the conditional probabilities among all states of connected random variables. This is in contrast to BKBs, which do not require complete knowledge and the high complexity in interpreting the graph through the compact structure. In addition, BKBs are capable of handling cyclic knowledge and multiple information sources (Santos, Wilkinson, & Santos, 2009).

Reasoning in BKBs is based on the structure of the knowledge, which includes the if–then rules, the evidence that includes pieces of information observed prior to the reasoning, and the chain rule as shown in Equation 3.1.

$$P(X_1, X_2, \ldots, X_n) = \prod_{1}^{n} P(X_i \mid parents\,(X_i)) \tag{1}$$

There are two forms of reasoning in BKBs: belief updating and belief revision. Belief updating computes the posterior probability of each single I-node using Bayes' theorem with given evidence. It answers questions such as, "What is the probability of a random variable given the evidence?" On the other hand, belief revision solves questions such as, "What is the most probable state of the world?" In belief revision, combinations of each state of the random variables together with the evidence form a possible world, and the likelihood of the world is the joint probability of the I-nodes as calculated by the chain rule. It then searches for a world that maximizes the likelihood. Algorithms for performing belief revision and belief updating in BKBs have been discussed in detail (Santos, 1991; Santos & Santos, 1987, 1999). The major difference between belief updating and belief revision is that belief updating does not account for the joint behavior of different random variables, whereas belief revision assumes that only one state of each random variable can be true in any possible world. Moreover, belief updating computes the posterior probabilities of random variables with given evidence, whereas belief revision generates the ranks of all possible worlds. Because these worlds are inferred from the same set of evidence, the same joint probabilities are used to rank all the possible worlds. Consequently, the posterior joint probabilities are expected to be small.

Furthermore, the probabilities of the worlds may even be smaller than expected due to the incomplete knowledge. Therefore, modelers should keep in mind that the inferred solution is one possible solution among all others that supports the evidence most and is only valid with respect to the information available. In inferring surgeons' intentions, belief revision AQ6 is more appropriate because we are interested in all possible worlds of a surgeon's reasoning, which is composed of all aspects of his behavior. This also includes the comparison among all possible behaviors of a surgeon, some of which are relevant to potential medical errors caused by the surgeon's mistakes.

Intent Inference

With BKBs as the basis for capturing reasoning and decision making, we now describe our underlying approach for modeling intent. In particular, our approach is based on explicitly representing an entity's beliefs, goals, actions, and intentions and has been successfully applied in a number of domains such as user modeling (Santos & Nguyen, 2009), adversarial modeling (Santos, 2003; Santos & Zhao, 2006), and commander's intent modeling (Pioch et al., 2009). We first describe intent inferencing followed by its application to surgical intent modeling.

Because intent is an explanation of people's activities, it can be defined as the combination of the goal(s) that is being pursued, the support for the goal, and the plan to achieve the goal. A system containing these components and capable of reasoning through them is regarded as a computational representation of human intent. To capture the major elements in human intent, we incorporate the components of intent into the structure of BKBs. In particular, we categorize the I-nodes into axioms, beliefs, goals, and actions (Santos & Zhao, 2006). Axioms represent what a person believes about him- or herself; beliefs represent what a person believes about others (including other people and the world); goals represent what results a person wants to achieve; and actions represent what actions a person will take to realize his or her goal. Axioms and beliefs may influence themselves or each other. Both axioms and beliefs can contribute to goals. An action needs the support of goals and beliefs (or axioms). Actions can lead to other actions (mostly subactions). The hierarchy of interactions between the types of nodes is shown in Figure 3.2. Compliance with the hierarchy is not critical to the reasoning process but is enforced to

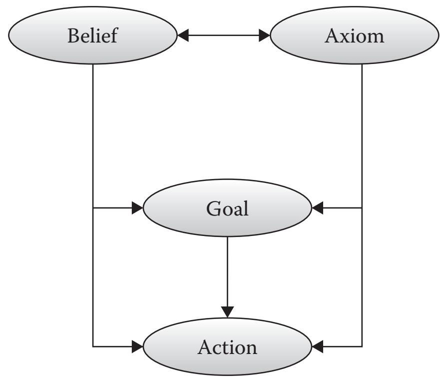

FIGURE 3.2
Hierarchy of interaction between four types of nodes in intent models.

encourage modelers to check for logical flaws, think more thoroughly about the structure of the model, and then help them systematically organize and correctly categorize their knowledge. After the dependencies between I-nodes are determined, the probabilities of S-nodes need to be estimated by experts first and then are further validated through experiments in general. Rules of thumb for constructing intent models can be found in Pioch et al. (2009) and Santos and Negri (2004).

Reasoning in intent models, called intent inferencing, follows the reasoning schemes of BKBs, which are (a) belief updating that calculates the posterior probability of individual I-nodes and (b) belief revision that obtains the most probable state of the world. In particular, two tasks are frequently used: causal reasoning and diagnostic reasoning. Causal reasoning focuses on the direction of causality and infers the effects based on causes by extending the evidence forward to the currently unknown states of the world. In contrast, diagnostic reasoning infers the causes back from the known effects. Consequently, causal reasoning helps predict the behavior of a person based on what the person thinks, and diagnostic reasoning explains one's intent by inferring what was on the person's mind according to what the person had done (the observations).

An intent model is a representation of a person's knowledge about him- or herself and about others based on his or her perceptions, which may or may not be consistent with others' views or even with the real world. The behavior inferred from observables may serve as the input to the intent model of others or to the world.

SURGICAL INTENT MODELING

In general, a surgery involves multiple steps, which are implemented by surgeons, nurses, and other supporting care members. To better achieve the common goal of improving patients' health, all medical care members need to coordinate with each other when undertaking their medical activities. To improve team performance by enhancing communication and team members' situation awareness, we propose a computational cognitive framework representing surgeons' knowledge. This is different from other methods that have been studied for detecting adverse events and medical errors, as mentioned in Murff, Patel, Hripcsak, and Bates (2003), such as chart review, detecting adverse events using coded data, and free-text clinical narratives. Although there are individual differences among medical care members, we can detect potential errors and enhance the capability of achieving the common goal by considering individual intentions together with respect to the common goal of patient safety. By simulating each individual's reasoning process starting from diagnosing the patient and continuing to each single activity in the medical procedure, we expect to understand the underlying decision-making process.

Behaviors of the medical team members can also be influenced by incidents that occur prior to, during, or after the operation. Therefore, predicting the care members' action by considering all possibilities, even though all of them may impact the team members' decision directly or indirectly, is a complicated task, and handling uncertainty and incompleteness is essentially required. By using the BKB's capability to represent uncertainty, we capture the uncertainty in team members' reasoning by the probabilistic dependency among elements of intent.

The key modules implemented to represent surgical intent are as follows: beliefs about the condition of the patient, axioms about one's own capability in performing (or assisting with, as in the case of a nurse) the surgery, goals regarding choice of procedures, and actions that are taken to perform the procedures. Sometimes the dependency between elements or the prior knowledge of an element is unattainable (e.g., it is known that surgeon A's malpractice in procedure B is low, but there is no record about his malpractice in procedure C). Because this kind of incompleteness is common, we leave the incomplete knowledge as it is through the compact and modular representation of BKBs. Because surgeons have the ~~most~~ AQ7 authority in performing medical procedures, we have initially detailed the process of building an intent model for a surgeon in this chapter.

- The condition of the patient has the highest priority in determining the surgeon's choice of procedure (Healey & Jacobson, 1994). The condition refers to the patient's disease and the risk of performing the medical procedure. The patient's condition is not restricted to the diagnosed illness, but also includes any related symptoms that may help the surgeons make decisions. The risk of performing the surgery includes all factors that may reduce the patient's chance of surviving the surgery such as age, allergy, pregnancy, and medical history. Patients may also take tests to assess their ~~sustainability~~ in the procedure such as a blood test. Both of these elements are encoded as the surgeons' beliefs as depicted in Figure 3.3, which is a snippet of a surgical intent model built for our case study (described in the next section) in which *(B)* stands for belief and *(G)* stands for goal. The surgeon's belief in the patient's ~~sustainability~~ in procedure *19180* is determined by the patient's bleeding status (*Coagulation_Profile_PT*, *Coagulation_Profile_INR*, and *Coagulation_Profile_PTT*), and the decision on the procedure directly depends on the patient's disease (*ICD_V07.5* and *ICD_610.1*).
- A surgeon confirms the procedure determined in the previous module depending on his or her personal competence. Usually the surgeon first considers the complexity of the procedure. The least complex procedure is most preferred due to the low risk and high success rate. When a complex procedure is inevitable, a surgeon prefers what he or she is more familiar with as well as more skilled in performing. Thus, the complexity of the procedure and the surgeon's experience (as well as malpractice history) in conducting the procedure serve as effective measures of the surgeon's preference. Complexity of procedures is represented as beliefs, whereas experience and malpractice are represented as axioms. This module can be extended by integrating the surgeon's confidence and fatigue as additional entities to represent the surgeon's personality and status of controlling capability. A BKB example of this dependency is shown in Figure 3.4. All three factors are concerned with the surgeon's competence and thus are modularized by an axiom (*competence_in_19180*). The competence influences the chances of staying with the original plan

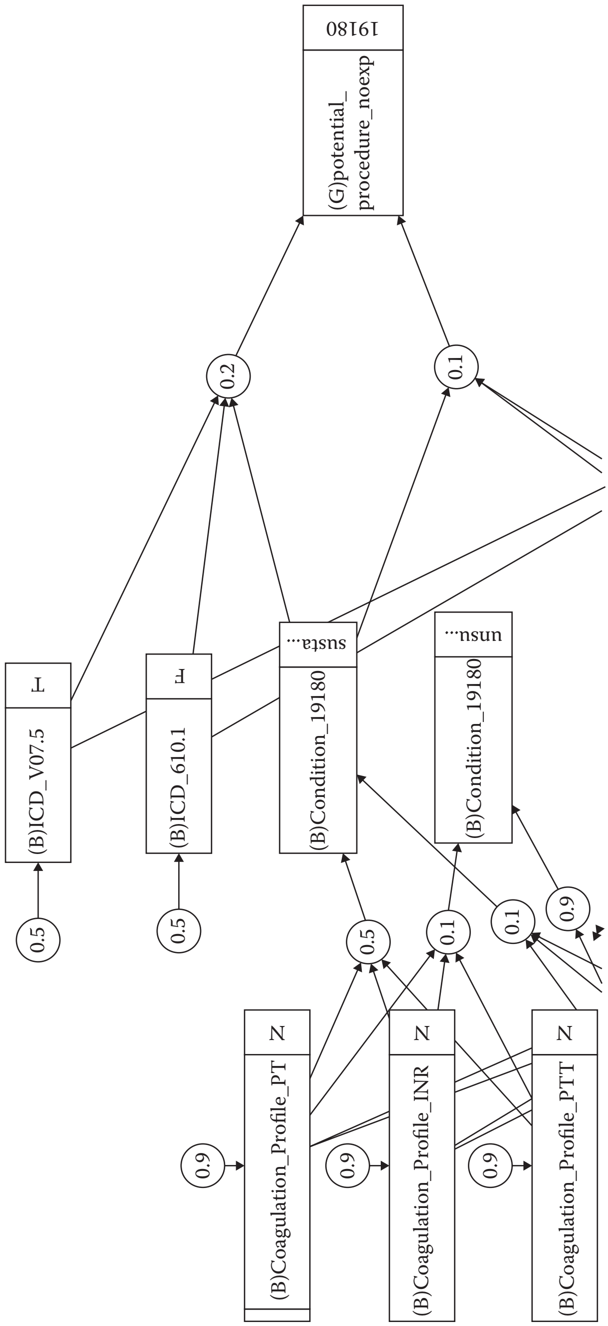

FIGURE 3.3
Example of Surgical Intent Model I.

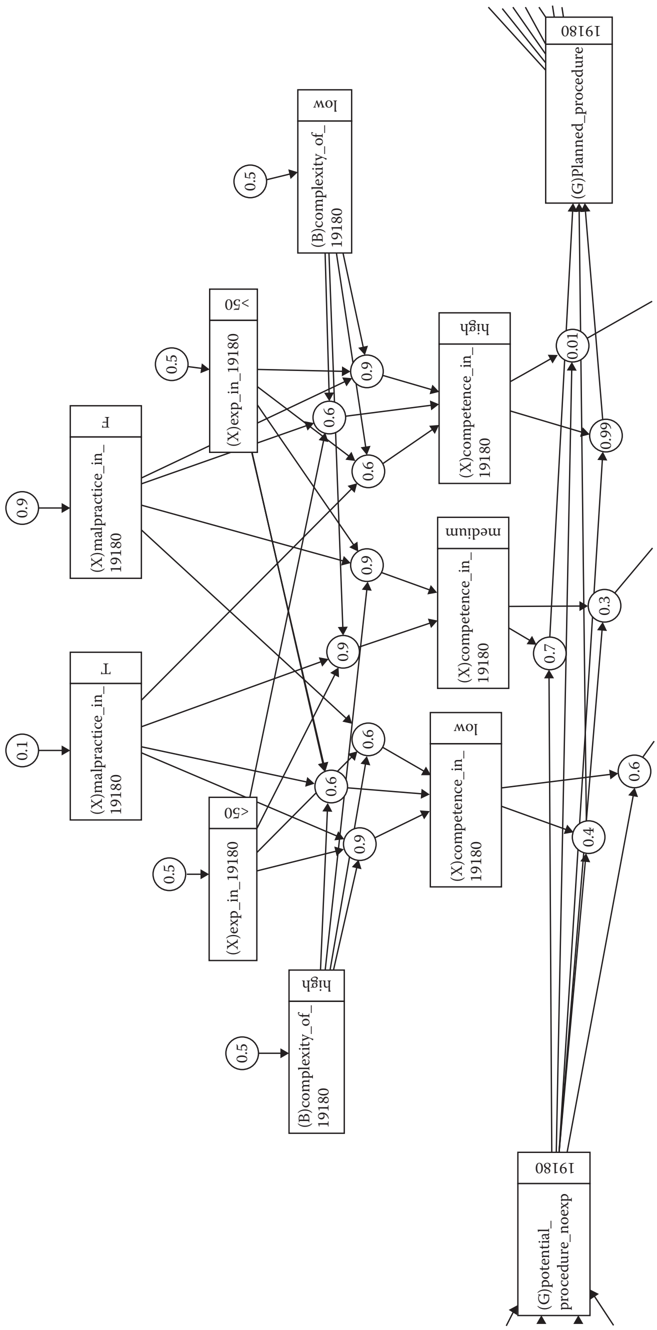

FIGURE 3.4
Example of Surgical Intent Model II.

(*Planned_Procedure=19180*) or switching to the alternative (*Planned_Procedure=19182*).
- In the surgical intent model, goals refer to the surgeon's intended procedures, and actions refer to the sequence of activities involved in the procedure. As the only observable in the OR, action is directly determined by the surgeon's goal. The status of an operation is determined by the previous actions and their completeness and is implemented by adding belief nodes indicating the actions as completed. As Figure 3.5 shows, together with the goal (*Planned_Procedure*), the belief nodes (*Completed_IAD*) contribute to the selection of the next action (*Action*).

The construction of the intent model is subject to change depending on the specific case and the role and characteristics of the surgeon (or other team member). Elements in each module are not restricted to the ones we propose here. As a simple extension, the fatigue of the surgeon can be integrated into the competence module. Also note that it is possible to take actions out of order due to the surgeon's incompetence.

CASE STUDY

To demonstrate the practical aspects of our intent modeling approach, we consider a handoff case where the patient, a 45-year-old woman having breast pain, is transferred from one surgeon to another. Such a handoff is particularly vulnerable to information loss. This case can be described in three stages: ~~pre-OR, in-OR, and post-OR~~. The woman was diagnosed with idiopathic breast pain from fibrocystic disease. Her pain is related to fibrocystic disease but with no evidence of breast cancer. Some patients have chronic pain that is not relieved through nonsurgical methods and therefore require surgical removal of the involved breast tissue, but this usually does not involve the nipple–areola complex. In the case of breast cancer, the nipple–areola complex is removed, but when the breast pain is a result of noncancerous causes, the nipple–areola complex can be left intact.

Two surgeons were involved in the care of this patient. The general surgeon expected to do a subcutaneous mastectomy (or skin-sparing

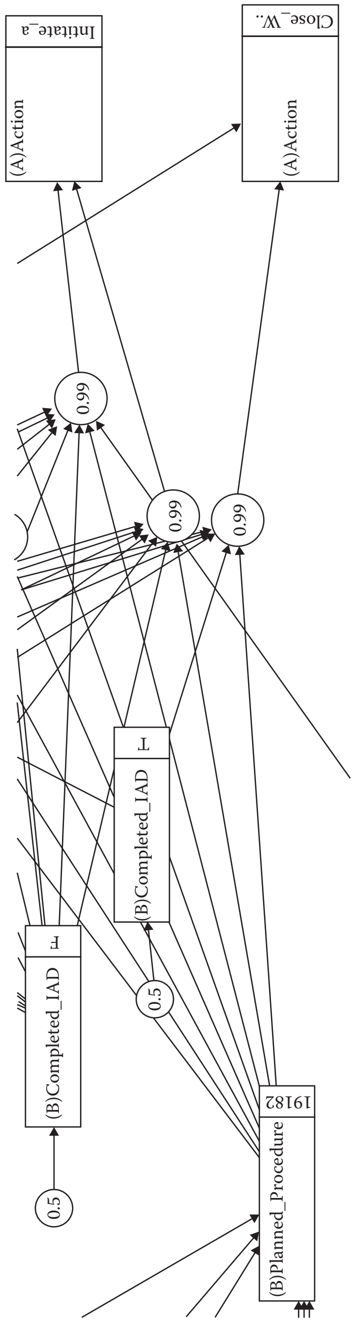

FIGURE 3.5
Example of Surgical Intent Model III.

mastectomy); this can be done in either one of two ways—leaving the nipple–areola attached via a small pedicle for blood supply or removing it entirely (separating it from the patient and re-attaching it as a full-thickness graft). Unfortunately, the plastic surgeon thought the general surgeon's mastectomy included the removal of the nipple–areola complex and believed that this was a case of breast disease that involved breast cancer or a severe case of fibrocystic disease. The plastic surgeon felt that the general surgeon was going to perform a simple mastectomy, which involves the removal of the breast tissue and the nipple–areola complex. There was confusion over the accepted definitions of a simple mastectomy and a subcutaneous mastectomy. The patient was seen by the general surgeon, and a decision was made by the general surgeon to do a subcutaneous mastectomy. This was defined to the patient as removing the breast tissue but *not* the nipple–areola complex. The patient was referred to the plastic surgeon to assist in the reconstruction, but no clear discussion occurred of what would happen to the nipple—whether the nipple–areola complex would be saved or whether it would be removed and replaced with a reconstructed nipple. The patient was seen preoperatively by the general surgeon but not by the plastic surgeon. The patient gave signed permission to operate but only gave combined consent, rather than an agreement to each surgeon's procedure. ~~The plastic surgeon came over to see the patient in the OR but not prior to the procedure~~.

The patient was brought into the OR, where the nurse explained what operation was going to be done; the surgeon agreed with this and proceeded. This was *not* repeated when the second surgeon (plastic surgeon) came into the room. The general surgeon performed bilateral subcutaneous mastectomies, removing the breast tissue along with the nipple–areola complexes. These were passed to the back table where the tissue remained until the plastic surgeon came into the room after the general surgeon had left. The plastic surgeon assumed that the specimen was to go to pathology, and the specimen included breast tissue and nipple–areola complex. However, in this case, he should have known that in a subcutaneous mastectomy, the nipple–areola can be saved and put back onto the patient. The operation that the plastic surgeon had planned and had previously had the patient sign for was the immediate replacement of the removed breast tissue for breast implants. He assumed that the nipple–areola complex would go to pathology and, at a later time, AQ8
he would reconstruct new nipple–areola complexes, as is done in breast

reconstruction surgery. The plastic surgeon was asked repeatedly by the nurses if he wanted to save the nipples from the specimens, but he told them *no*, that this was not necessary, and he would be making a nipple later. There was a communication loss between the general surgeon, nurses, and plastic surgeon. The nurses should have known that, in this case, the nipples should have been kept. However, the confusing part for the plastic surgeon was that the nipple–areola came off with the specimen rather than being left attached to the breast. The patient left the OR without her nipple–areola complexes; they instead went unnecessarily to pathology for a patient with breast pain and not cancer. Although a subcutaneous mastectomy is an uncommon procedure, most surgeons are aware of it. However, sometimes it is confused with a simple mastectomy because a simple mastectomy is performed more frequently.

The patient was not aware that she had lost her nipples until several days later when the dressings were taken off by the general surgeon. This quickly set the tone of the follow-up care. When the plastic surgeon saw the patient, he tried to explain that he can make nipples better than her original, but this was not a satisfactory solution to the patient. Subsequently, she had multiple complications with tissue loss, partly related to the closure under tension due to the large size of the implants placed, the loss of the additional tissue (the nipple–areola), and the patient's persistent smoking, overall resulting in the patient being a breast cripple.

EXPERIMENTAL STUDY

Our empirical study is aimed at validating the capability of the intent model to represent a real case in medical practice with the purpose of enhancing patient safety. To model the surgeons' reasoning and intentions in the case study, we built BKBs from the behavioral patterns and the perceptions of the general and plastic surgeons. Table 3.1 shows the size of BKBs built for the general and plastic surgeons. With the BKBs, each surgeon's intent was inferred by computing the most probable instantiation of the world composed of random variables under consideration. Because we assumed that the surgeons' ~~intentions~~ are the same as their procedures to

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TABLE 3.1

Size of Bayesian Knowledge Bases

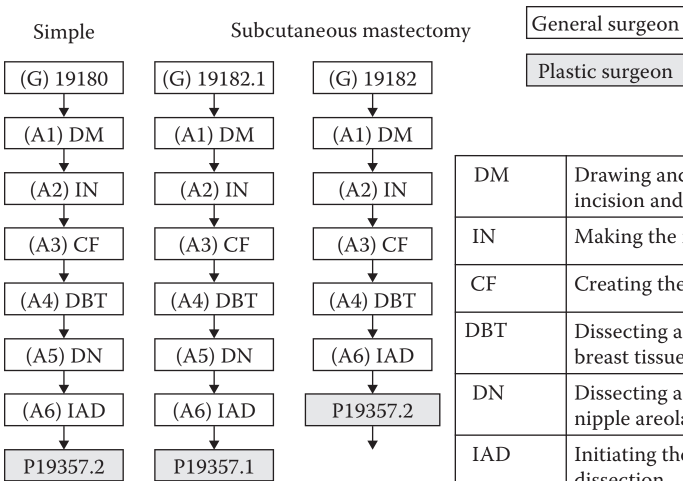
	Random variables	I-nodes	Connectivity	S-nodes (rules)	Average condition for each rule
General surgeon	25	57	5.5	91	2.4
Plastic surgeon	27	57	4.5	84	2.0

carry out the patient's treatment, we set our target variable with *planned_procedure* representing the surgeon's decision. Because the two surgeons are involved in the overall breast care at different time intervals, their observations and perceptions are different. Naturally, the observations used to infer each surgeon's intent are different.

Experimental Setup

The ~~set~~ of evidence used for validating the two surgeons' models ~~is~~ different because ~~they~~ are involved in the operation at different times with different tasks to accomplish. To validate the general surgeon's model, we set the evidence with the patient's conditions, the surgeon's competence, and the status of completed actions, whereas we used the patient's condition, the status of the patient's nipple, and the surgeon's experience for the plastic surgeon's model. The target variable (*planned_procedure*) represents the procedure planned by the surgeon in both models. By comparing the value inferred with our expected values, we confirmed the model's correctness when obtaining identical values.

The evidence is chosen based on its causal relationship with the target variable. The patient condition includes whether the patient has breast pain or cancer. The surgeon's competence on a procedure is determined by a combination of his experience, malpractice history, and the complexity of the procedure. The course of actions for the mastectomy is shown in Figure 3.6, where P19357.1 and 19357.2 represent the breast reconstruction with reattaching the nipple complexes and the breast reconstruction without reattaching the nipple complexes, respectively (American Medical Association, 2004). For the subcutaneous mastectomy, dissecting and removing the nipple–areola complexes is optional, as shown in Figure 3.6.



DM	Drawing and mapping the incision and skip flap
IN	Making the incision
CF	Creating the skin flap
DBT	Dissecting and removing the breast tissue
DN	Dissecting and removing the nipple areola complexes
IAD	Initiating the auxiliary dissection
P19357.1	Breast reconstruction for 19182.1
P19357.2	Breast reconstruction for 19182.2 and 19180

FIGURE 3.6
Course of actions in a mastectomy.

To validate the surgical intent models, deviations between the model and the real intent of the surgeon are indicative of conflicts between the results obtained from simulation and the hypotheses we had expected during modeling. It may come from the conditional probabilities, the causal rules, or the violation of the hierarchy of the four types of nodes. Model reconstruction and validation should be iteratively performed until the model is verified to be consistent with the hypotheses. The validation of BKBs is extensively studied in Santos and Dinh (2008) and Santos (2001). The consistency of the models built for the case study is confirmed by the tool used in Santos and Dinh (2008).

The following experiments are designed to investigate the model's applicability in detecting or removing potential errors in real medical situations. We checked whether we can recognize the error occurring in the case study when simulating the case through our models. As shown in the following section, all our experimental results support that our models represent the two surgeons' decision making correctly. In addition, we observed the communication failure while comparing each individual's intent with others' belief on the individual.

Experimental Results

Our experimental results are presented here from two perspectives. First, the results are arranged to show that our model is a true representation of the surgeon's diagnosis of the patient having certain medical conditions. Second, the experimental results are provided with respect to the case study, and the potential error is detected by comparing individual intents and beliefs inferred from the surgeon's observations and perceptions.

The patient's conditions are the first determinant of the choice of procedure (*potential_procedure*), whereas the decision (*planned_procedure*) is confirmed by the surgeon's competence level later. ~~For validating~~ whether the general surgeon's (GS) model truly represents the surgeon's decision making, we hypothesized that when the patient has breast pain and is ~~sustainable in~~ a subcutaneous mastectomy, ~~a subcutaneous mastectomy~~ is chosen ~~as the most probable procedure~~ because ~~subcutaneous mastectomy~~ is a better treatment for curing breast pain than the simple mastectomy. The "most probable potential procedure" refers to the chosen procedure that is not deterministic but most likely among all the possible procedures. The patient's condition includes her disease and her ~~sustainability in~~ each procedure. The evidence representing the patient's disease is set with *ICD_V07.5* (breast cancer) and *ICD_610.1* (breast pain), whereas the evidence on the patient's ~~sustainability~~ is set with *Condition_19182* (patient's condition in subcutaneous mastectomy) and *Condition_19180* (patient's condition in simple mastectomy). We vary the patient's disease and her ~~sustainability~~ in the subcutaneous mastectomy or the simple mastectomy. The detailed experimental settings are listed in Table 3.2. In each of the settings, belief revision is conducted searching for the most probable world with given evidence. In this particular experiment, we focus on the state of the potential procedure in each possible world. The result shows that the expectations are satisfied, which justifies the general surgeon's choice of potential procedure based on the patient's condition.

The confirmation of the procedure to be performed is influenced by both the potential procedure and the surgeon's competence. In other words, the final decision is weighed by the surgeon's preference in addition to the patient's condition. The elements that determine a surgeon's competence are his experience in conducting the procedure (*experience_in_##*, where *##* represents the code of a procedure), his malpractice history (*malpractice_in_##*), and the complexity of the procedure

TABLE 3.2

Validation With the Patient Condition

Evidence				
(B) ICD_610.1	**(B) ICD_V07.5**	**(B) Condition_ 19182**	**(B) Condition_ 19180**	***Expectation of potential procedure* (G) potential_procedure**
T	F	~~Sustainable~~	N/A	19182
		~~Unsustainable~~	N/A	Unknown
F	T	N/A	~~Sustainable~~	19180
		N/A	~~Unsustainable~~	Unknown

Note: N/A = not applicable.

(*complexity_of_##*). These elements form the set of evidence in this test. We validate the surgeon's competence in two parts: the inference of competence and the influence of competence. In the inference of competence, we test how different factors, including personal factors and procedural factors, influence the competence of a surgeon in a particular procedure; whereas in the influence of competence, we target the joint effect of the potential procedure and competence on the planned procedure. The settings of the inference of competence are provided in Table 3.3. Overall, we expect that high competence results from ample experience, low malpractice, and low complexity and that low competence results from the opposite states of these factors. With both personal factors contributing to low

TABLE 3.3

Validation With the Inference of the General Surgeon's Competence

Evidence			
(X) exp_in_##	**(X) malpractice_in_##**	**(B) complexity_of_##**	***Expectation of competence in ##* (X) competence_in_##**
>50	F	Low	High
<50	F	Low	High
>50	T	Low	High
<50	T	Low	Medium
>50	F	High	Medium
<50	T	High	Low
>50	T	High	Low
<50	F	High	Low

competence and the complexity of the procedure being low, the surgeon is regarded as medium in competence.

To test the influence of the general surgeon's competence, we fix the potential procedure, vary the general surgeon's competences in subcutaneous mastectomy and simple mastectomy, and observe the planned procedure. Although it is inappropriate to set competence as evidence because competence is not an external observable (although it can be inferred from the evidence of experience, etc.), we use it as evidence here for the purpose of focusing on the direct impact of competence on surgeon's decision making. Given that the potential procedure is subcutaneous mastectomy, the general surgeon is expected to plan a subcutaneous mastectomy if his competence in it is high, regardless of the competence in a simple mastectomy. However, if the general surgeon's competence in the subcutaneous mastectomy procedure is low, he will select the simple mastectomy procedure unless his competence in the latter is low as well. If the general surgeon's competence in subcutaneous mastectomy is medium ~~and the competence in simple mastectomy is *not* high~~, he is ~~supposed~~ to stick to the original choice of procedure. If the surgeon's competence in simple mastectomy is ~~high~~, which heavily depends on the characteristics of the particular surgeon (although all other expectations are also subject to individual difference), the general surgeon is ~~supposed~~ to perform a simple mastectomy. Table 3.4 details the evidence setting for this experiment. Both the inference of competence and the influence of competence are confirmed by the results obtained.

In this experiment, we are particularly interested in the cases where the general surgeon's competences in the two procedures are equally high or equally low. When he is equally competent in the two procedures, he is expected to have enough knowledge about both procedures and sound judgment in choosing the most effective procedure that is least biased by his personal factors. In contrast, when he is not competent in a procedure, his final choice of procedure is heavily biased and even may override the condition of the patient. Our result shows that when the general surgeon's competence in subcutaneous mastectomy is low, he always tends to choose the simple mastectomy regardless of his competence in performing a simple mastectomy. In the case of both being low, the general surgeon is diffident in choosing the appropriate procedure and fluctuates between the two procedures. We show the joint probability of the both-low case in Table 3.5.

TABLE 3.4

Validation With the Influence of the General Surgeon's Competence

Evidence			
(G) potential_ procedure	**(X) competence_ in_19182**	**(X) competence_ in_19180**	***Expectation of planned procedure* (G) planned_procedure**
19182	High	High	19182
		Medium	19182
		Low	19182
	Medium	High	19182
		Medium	19182
		Low	19182
	Low	High	19180
		Medium	19180
		Low	19182 or 19180 with similar probability

The last validation on the general surgeon's model tests the order of actions because following the correct order of actions is critical when performing a medical procedure. By testing the order of actions, we make sure that (a) the surgeon's actions are in correct order and (b) the surgeon is doing what he is supposed to do. The second point concerns whether the surgeon is carrying out his planned procedure and whether his actions are consistent with other surgeons' actions. In this case study, although the general surgeon plans a simple mastectomy, it is necessary to dissect the patient's nipple, but if he plans a subcutaneous mastectomy, whether to dissect the nipple is partially determined by his belief about the plastic

TABLE 3.5

Validation With the Influence of the General Surgeon's Competence

Evidence			*Result*	
(G) potential_ procedure	**(X) competence_ in_19182**	**(X) competence_ in_19180**	**(G) planned_ procedure**	**Joint probability**
19182	Low	Low	19180	7.49114e–06
			19182	4.99409e–06

surgeon's (PS) procedure. Therefore, when the planned procedure is determined, the most probable actions are investigated depending on the status of the overall operations. The target variable is *action*, and the evidence is *planned_procedure*, *PS_procedure* (general surgeon's belief on plastic surgeon's procedure), and *completed_XX* (the completeness of action *XX* [*XX* represents the abbreviation of an action]). Because the evidence setting of the experiment regarding simple mastectomy is subsumed by that of subcutaneous mastectomy, we assume that the subcutaneous mastectomy is planned. We vary the belief about the plastic surgeon's procedure and the completed actions. At each instant, we observe that the action that is being carried out by the general surgeon follows the correct order of actions in each procedure as shown in Figure 3.6. Table 3.6 lists the details of this experimental setting.

To validate the inference of target variables (*GS_procedure* and *potential_procedure*) on the plastic surgeon's model, we examined them with a varying set of evidence as shown in Table 3.7. *GS_procedure* denotes the plastic surgeon's belief on the general surgeon's procedure, and *potential_procedure* represents the procedure the plastic surgeon ~~determines~~ to carry out. First, we collected the status of the target variables when *GS_nipple_removal* is the only evidence given to the plastic surgeon, and the results obtained are shown in Table 3.7. When the nipple is removed, the plastic surgeon considers both the simple (19180) and the subcutaneous (19182) mastectomies as the general surgeon's procedure with the same highest probability. Thinking that the general surgeon plans the simple mastectomy (19180), the plastic surgeon plans the breast reconstruction without nipple reattachment (19357.2) with the highest probability. If he believes that the general surgeon plans the subcutaneous mastectomy (19182), he needs to consider two ways to reconstruct the breast—with (19357.1) or without (19357.2) reattaching the nipple complexes. When the nipple is not removed by the general surgeon, the plastic surgeon can easily plan the breast reconstruction without reattaching the nipple (19357.2) with the highest probability regardless of his belief on the general surgeon's procedure. Because the evidence of *GS_nipple_removal* is independent from *GS_procedure*, which is inferred from the patient condition, both the simple and the subcutaneous mastectomies can be chosen with the same probability when the nipple complexes are left behind.

Table 3.7 shows the results obtained from our experiments, and all of them fit to our expectations, where "No. of Answers" and "First Rank

TABLE 3.6

Action Prediction

Evidence								
(G) Planned_ Procedure	**(B) PS_ procedure**	**(B) Completed_ DM**	**(B) Completed_ In**	**(B) Completed_ CF**	**(B) Completed_ DBT**	**(B) Completed_ DN**	**(B) Completed_ IAD**	***Most probable next action* (A) Action**
19182	19357.1	F	F	F	F	F	F	Draw_Map
		T	F	F	F	F	F	Incision
		T	T	F	F	F	F	Create_Flap
		T	T	T	F	F	F	Dissect_Breast_Tissue
		T	T	T	T	F	F	Dissect_Nipple
		T	T	T	T	T	F	Initiate_Auxiliary_ Dissection
		T	T	T	T	T	T	Close_Wound
	19357.2	F	F	F	F	F	F	Draw_Map
		T	F	F	F	F	F	Incision
		T	T	F	F	F	F	Create_Flap
		T	T	T	F	F	F	Dissect_Breast_Tissue
		T	T	T	T	F	F	Initiate_Auxiliary_ Dissection
		T	T	T	T	F	T	Close_Wound

Probability" denote the possible number of state of the world and the highest probability obtained, respectively. For example, we can get 2,688 possible states of the world represented by the BKB by setting the evidence "GS_nipple_removal" with "T." Among them, 44 states are highly probable, and both alternatives have the same number of possible states of the world, which means that the plastic surgeon considers both the simple (19180) and the subcutaneous (19182) mastectomies as the general surgeon's procedure with the same highest probability (1.03003e–08). Thinking that the general surgeon plans the simple mastectomy (19180), the plastic surgeon plans the breast reconstruction without nipple reattachment (19357.2) in 20 possible states of the world. If he believes that the general surgeon plans the subcutaneous mastectomy (19182), he needs to consider two ways to reconstruct the breast, with reattaching the nipple complexes (19357.1) in 12 possible states or without reattaching the nipple complexes (19357.2) in 10 possible states.

The plastic surgeon believes the subcutaneous mastectomy (19182) is planned by the general surgeon because it is the common procedure for the patient with breast pain (ICD_610.1) not cancer (ICD_v07.5), as shown in Table 3.8. Because the nipple can be removed or kept with the same probability, the plastic surgeon plans the breast reconstruction with reattaching the nipple complexes (19357.1) and the breast reconstruction without reattaching the nipple (19357.2) with the same probability. When

TABLE 3.7

Inference With Status of the Patient's Nipple

Evidence	*Target Variables*				
GS_ nipple_ removal	**(B) GS_ procedure**	**(G) Potential_ procedure**	**Total no. of answers**	**No. of answers in first rank**	**First rank probability**
T	19180	19357.1	2,688	0/42	1.03003e–08
	19180	19357.2		20/42	
	19182	19357.1		12/42	
	19182	19357.2		10/42	
F	19180	19357.1	2,560	0/40	1.03003e–08
	19180	19357.2		20/40	
	19182	19357.1		0/40	
	19182	19357.2		20/40	

TABLE 3.8

Inference With Patient Conditions

Evidence		*Target variables*				
ICD_610.1	ICD_ V07.5	(B) GS_ procedure	(G) Potential_ procedure	Total no. of answers	No. of answers in first rank	First rank probability
T	F	19180	19357.1	2,624	0/42	1.03003e–08
		19180	19357.2		0/42	
		19182	19357.1		12/42	
		19182	19357.2		30/42	
F	T	19180	19357.1	2,624	0/40	1.03003e–08
		19180	19357.2		40/40	
		19182	19357.1		0/40	
		19182	19357.2		0/40	

ICD_V07.5 is T, which means that the patient has a cancer rather than ~~a sole~~ breast pain, the plastic surgeon believes the simple mastectomy (191820) is planned by the general surgeon. To follow the general surgeon's procedure, the plastic surgeon plans the breast reconstruction (19357.2) with the highest probability.

When the subcutaneous mastectomy (19182) is inferred ~~to~~ the general surgeon's procedure, the nipple complexes can be removed or not with the same probability due to the two types of subcutaneous mastectomy, which are described in Table 3.9. If the nipple complexes are removed by the general surgeon, the plastic surgeon needs to reattach them (19357.1). Otherwise, the plastic surgeon plans the breast reconstruction without the reattachment (19357.2). When the simple mastectomy (19180) is inferred ~~to~~ the general surgeon's procedure, the plastic surgeon plans the breast reconstruction without reattaching the nipple complexes (19357.2) with the highest probability regardless of the nipple removal. However, the plastic surgeon may doubt the evidence given to him because the nipple complexes are always expected to be removed during the simple mastectomy (19180) even if his designated plan (19357.2) remains the same.

To further investigate the impact of the plastic surgeon's experience on his decision making, we use four random variables as the evidence in inferring the plastic surgeon's belief and goal. As previously mentioned, the *GS_procedure* is inferred from the patient profile and does not count

TABLE 3.9

Inference With Patient Information Combined

Evidence			*Target variables*				
ICD_610.1	**ICD_V07.5**	**Nipple_ removal**	**(B) GS_procedure**	**(G) Potential_ procedure**	**Total no. of answers**	**No. of answers in first rank**	**First rank probability**
T	F	T	19182	19357.1	1,344	12/22	1.03003e–08
			19182	19357.2		10/22	
		F	19182	19357.2	1,280	20/20	1.03003e–08
F	T	T	19180	19357.2	1,344	20/20	1.03003e–08
		F	19180	19357.2	1,280	20/20	1.03003e–08

on the status of the patient's nipple and the plastic surgeon's experience. However, the plastic surgeon's belief on the general surgeon's procedure can change by additional evidence such as the nipple complexes removed and his own experience in the procedure. To represent the belief changed by additional evidence, we add another target variable (*GS_procedure_post*) and investigate how this variable changes when some of the evidence conflicts with other evidence, as shown in Table 3.10.

When the plastic surgeon believes that the general surgeon plans the subcutaneous mastectomy (19182) from the patient profile and finds that the patient's nipple complexes are removed, there are two possible cases. First, he can change his belief from *GS_procedure* to *GS_procedure_post* that the general surgeon plans the simple mastectomy (19180) and not the subcutaneous mastectomy (19182). However, if he has more experience/knowledge in the subcutaneous mastectomy (19182), he can bring up a type of subcutaneous mastectomy (19182.1) that includes dissecting and reattaching the nipple complexes, and plans the breast reconstruction including the nipple reattachment (19357.1) with the highest probability. However, if the nipple complexes are not removed, the plastic surgeon confirms that the general surgeon plans the subcutaneous mastectomy (19182) and plans his own procedure, the breast reconstruction without the reattachment (19357.2). In this situation, the communication between the two surgeons can be cleared easily, and the level of the plastic surgeon's experience does not change his previous belief and final goal.

When the plastic surgeon believes that the general surgeon plans the simple mastectomy (19180), the removed nipple complexes support his previous belief. Therefore, the plastic surgeon confirms his belief on the general surgeon's procedure and plans his own procedure, the breast reconstruction without reattaching the nipple complexes (19357.2), with the highest probability. However, when the nipple complexes are left behind, the plastic surgeon has difficulty in understanding the general surgeon's plan. Although the plastic surgeon believes that the simple mastectomy (19180) should be chosen to cure the patient's cancer with the highest probability, the nipple complexes remaining make him wonder as to whether the general surgeon plans another alternative procedure, which is represented as 19180.1 in Table 3.10. We represent this with *GS_procedure_post*, which represents the plastic surgeon's belief on the general surgeon's procedure after considering additional evidence, the status of the patient's nipple. However, because he believes that the breast

TABLE 3.10

Inference out of Considering Experience

Evidence				*Target variables*					
ICD_610.1	**ICD_ V07.5**	**Nipple_ removal**	**Experience**	**(B) GS_procedure**	**(B) GS_ procedure (post)**	**(G) Potential_ procedure**	**Total no. of answers**	**No. of answers in first rank**	**First rank probability**
T	F	T	Low	19182	19180	19357.2	640	10	1.03003e–08
			High	19182	19182.1	19357.1	704	12	1.03003e–08
T	F	F	Low	19182	19182	19357.2	640	10	1.03003e–08
			High	19182	19182	19357.2	640	10	1.03003e–08
F	T	T	Low	19180	19180	19357.2	640	10	1.03003e–08
			High	19180	19180	19357.2	704	10	1.03003e–08
F	T	F	Low	19180	19180.1	19357.2	640	10	1.03003e–08
			High	19180	19180.1	19357.2	640	10	1.03003e–08

reconstruction without reattaching the nipple complexes (19357.2) is the most appropriate procedure, he keeps his plan with the highest probability despite the discrepancy.

Errors in the Case Study

The errors in the case study came from two conflicts: One is the conflict between the general surgeon's planned procedure and the plastic surgeon's belief of the general surgeon's procedure, and the other is the conflict between the plastic surgeon's planned procedure and the general surgeon's belief of the plastic surgeon's procedure. By combining individual models, which represent the two surgeons separately in our case study, and comparing one's belief with the other's intent inferred, we can recognize the communication gap between the two surgeons.

Tables 3.11 and 3.12 show the evidence and the target variables used for this experiment. Although the breast pain T means that ICD_610.1=T and ICD_V07.5=F, the drawing and mapping T means that the general surgeon completed the action "drawing and mapping the incision and skin flap," which is one of the actions included in the mastectomy. Therefore, the breast pain represents the patient's condition, and the drawing and mapping denote the completeness of the actions by the general surgeon at a certain time. In the same stream, the plastic surgeon plans his procedure

TABLE 3.11

Evidence for the Overall Inference

Evidence				Specialty
Breast pain	T	F	T	G, P
Breast cancer	F	T	F	G, P
Drawing and mapping	T	T	T	G
Create flap	T	T	T	G
Dissecting breast tissue	T	T	T	G
Dissecting nipple	F	F	F	G
Initiate auxiliary dissection	F	F	F	G
PS procedure	19357.1	19357.2	19357.2	G
GS_nipple_removal	T	T	F	P
Exp_in_19182	Low High	Low High	Low High	P
SET ID	1.1 1.2	2	3	

TABLE 3.12

Results Inferred With Evidence Given in Table 3.11

Target variables					Specialty
(A) Action	Dissecting nipple			Initiate auxiliary dissection	G
(G) Planned_procedure	19182		19180	19182	G
(B) GS_procedure	19180	19182	19180	19182	P
(G) Planned_procedure	19357.2	19357.1	19357.2	19357.2	P
SET ID	1.1	1.2	2	3	

based on the patient profile and the status of the patient's nipple complexes. The far right columns of each table represent to which surgeon the evidence is given or from which surgeon the value of the target variable is inferred during the experiments. G represents the general surgeon, and P represents the plastic surgeon. With the given evidence including his belief on the plastic surgeon's procedure, the general surgeon's intent was inferred to the subcutaneous mastectomy or the simple mastectomy depending on the patient condition and the status of completed actions. When the general surgeon plans to dissect the patient's nipple, he can plan the subcutaneous mastectomy when he believes that the plastic surgeon will reattach it, which is the case with SET ID 1.1 and 1.2. The plastic surgeon's belief on the general surgeon's procedure is varied depending on his experience in the subcutaneous mastectomy. He changes his belief to the simple mastectomy when he considers the patient's nipple being removed as an obvious outcome of the simple mastectomy due to his lack of experience (i.e., exp_in_19182=low), although the simple mastectomy is not the appropriate treatment for the patient having a breast pain in general, which is addressed with SET ID 1.1 in Tables 3.11 and 3.12. However, an experienced plastic surgeon (i.e., exp_in_19182=high) keeps his belief and plans nipple reattachment, which is addressed with SET ID 1.2. When the patient has breast cancer and the nipple complexes are removed, the plastic surgeon believes that the general surgeon plans the simple mastectomy and plans his procedure without any difficulty, which is represented with SET ID 2. This is same as when the patient has breast pain and the nipple complexes remain; the plastic surgeon believes that the general surgeon plans the subcutaneous mastectomy and plans his procedure easily, which corresponds to SET ID 3.

When we compare both surgeons' inference results, the error happens when the general surgeon believes that the plastic surgeon plans the breast reconstruction with reattaching the nipple (19357.1), while the plastic surgeon does not consider the reattachment at all (19257.2) due to his lack of knowledge/experience, which corresponds to SET ID 1.1. However, it can AQ10 also be explained by the plastic surgeon being unaware of the fact that the general surgeon plans the subcutaneous mastectomy (19182) due to his lack of knowledge. Both of these interpretations can fit the communication failure that occurred between the two surgeons in the patient's care.

CONCLUSION AND FUTURE WORK

Our main contribution here is to provide the cognitive architecture that forms the basis of surgical intent modeling and a principled approach for realizing and creating the model. In addition, we apply our models to improving team coordination by considering individuals' intents and beliefs associated with others. To validate our model, we chose a real-world patient handoff case and modeled each surgeon's reasoning by considering his behavioral patterns and his perceptions associated with the case. In particular, we implemented the surgeons' intents, which were interpreted as their goal in treating the patient, inferred from their observations and perceptions.

Given our current results obtained from models built for this case study, we identified the following issues for future research.

- Level of detail: In our current implementation, we have considered sets of actions for the simple mastectomy, the subcutaneous mastectomy, and the breast reconstruction. It was reasonable to consider specific actions when the overall patient care includes only a few procedures carried out by a small number of surgeons. However, some cases require several procedures, and critical communication failures occur during the transition time between any pair of consecutive procedures. Therefore, considering the surgeons' reasoning in the procedure level seems more appropriate for modeling in general.
- Order of actions/procedures: Some actions/procedures are preemptive and reversible, whereas others are not. The actions/procedures

in the case study were considered irreversibly and nonpreemptively, and partial orders were not considered. This is because the actions in the mastectomy result in adverse medical events if they are performed out of order. In order to perform procedures without causing any harmful effect in practice when they are out of order, partial orders should be considered if the target case permits this.

- Roles in the overall patient care: The plastic surgeon's decision making begins at a different time point from that of the general surgeon because the plastic surgeon enters the OR after the general surgeon has left the OR in the case study. Although all observations of the plastic surgeon are associated with the general surgeon's actions, the models built for the two surgeons had little commonality because their specialties are very unique. However, some surgeons can have very similar knowledge. For example, a general surgeon may carry out his assigned procedure before an anesthesiologist, and another general surgeon may take part after the anesthesiologist. Models for these two general surgeons are expected to be very similar. In general, the level of specification of modeling individuals is difficult to be clarified.

REFERENCES

Alvarez, G., & Coiera, E. (2006). Interdisciplinary communication: An uncharted source of medical error? *Journal of Critical Care, 21*, 236–242.

American Medical Association. (2004). *Current procedural terminology (CPT)* (Standard ed.). Chicago: Author.

Bhasale, A., Miller, G., & Reid, S. (1998). Analysing potential harm in Australian general practice: An incident-monitoring study. *Medical Journal of Australia, 169*, 73–76.

Christian, C. K., Gustafson, M. L., Roth, E. M., Sheridan, T. B., Gandhi, T. K., Dwyer, K., et al. (2006). A prospective study of patient safety in the operating room. *Surgery, 139*, 159–173.

Dalton, G. D., Samaropoulos, X. F., & Dalton, A. C. (2008). Improvements in the safety of patient care can help end the medical malpractice crisis in the United States. *Health Policy, 86*, 153–162.

Eastridge, B. J., Jenkins, D., Flaherty, S., Schiller, H., & Holcomb, J. B. (2006). Trauma system development in a theater of war: Experiences from Operation Iraqi Freedom and Operation Enduring Freedom. *Journal of Trauma, 61*, 1366–1372.

Guise, J. M. (2008). Teamwork in obstetric critical care. *Best Practice & Research Clinical Obstetrics and Gynaecology, 22*, 937–951.

Healey, P. M., & Jacobson, E. J. (1994). *Common medical diagnoses: An algorithmic approach* (2nd ed.). Philadelphia: W.B. Saunders Co.

Horwitz, L. I., Krumholz, H. M., Green, M. L., & Huot, S. J. (2006). Transfers of patient care between house staff on internal medicine wards: A national survey. *Archives of Internal Medicine, 166*, 1173–1177.

Hurwitz, B., & Sheikh, A. (2009). *Health care errors and patient safety* (1st ed.). Boston: BMJ Books.

Kohn, L., Corrigan, J., & Donaldson, M. (2000). *To err is human*. Washington, DC: National Academy Press.

Kovacs, G., & Croskerry, P. (1999). Clinical decision making: An emergency medicine perspective. *Academic Emergency Medicine, 6*, 947–952.

Landro, L. (2006, June 28). Hospitals combat errors at the "hand-off." *The Wall Street Journal.*

Lingard, L., Espin, S., Whyte, S., Regehr, G., Bajer, G., Reznick, R., et al. (2004). Communication failure in the operating room: Observational classification of recurrent types and effects. *Quality and Safety in Healthcare, 13*, 330–334.

Makary, M. A., Sexton, J. B., Freischlag, J. A., Holzmueller, C. G., Millman, E. A., Rowen, L., et al. (2006). Operating room teamwork among physicians and nurses: Teamwork in the eye of the beholder. *Journal of the American College of Surgeons, 202*, 746–752.

Manterea, S., & Sillinceb, J. A. (2007). Strategic intent as a rhetorical device. *Scandinavian Journal of Management, 23*, 406–423.

McIntyre, R., Stiegmann, G. V., & Eiseman, B. (2004). *Surgical decision making* (5th ed.). Philadelphia: Saunders.

McNeil, J. D., & Pratt, J. (2008). Combat casualty care in an air force theater hospital: Perspectives of recently developed cardiothoracic surgeons. *Seminars in Thoracic and Cardiovascular Surgery, 20*, 78–84.

Montgomery, S. P., Swiecki, C. W., & Shriver, C. D. (2005). The evaluation of casualties from Operation Iraqi Freedom on return to the continental United States from March to June 2003. *Journal of the American College of Surgeons, 201*, 7–12.

Murff, H. J., Patel, V. L., Hripcsak, G., & Bates, D. W. (2003). Detecting adverse events for patient safety research: A review of current methodologies. *Journal of Biomedical Informatics, 36*, 131–143.

Parush, A., Kramer, C., Foster-Hunt, T., Momtahan, K., Hunter, A., & Sohmer, B. (2010, April 8). Communication and team situation awareness in the OR: Implications for augmentative information display. *Journal of Biomedical Informatics* [Epub ahead of print].

Pearl, J. (1988). *Probabilistic reasoning in intelligent systems*. San Francisco: Morgan Kaufmann.

Pioch, N. J., Melhuish, J., Seidel, A., Santos, E., Jr., Li, D., & Gorniak, N. (2009). Adversarial intent modeling using embedded simulation and temporal Bayesian knowledge bases. *SPIE Defense, Security and Sensing, 7348*, 1–14.

Rosen, T., Shimony, S., & Santos, E., Jr. (2004). Reasoning with BKBs: Algorithms and complexity. *Annals of Mathematics and Artificial Intelligence, 40*, 403–425.

Santos, E., Jr. (1991). On the generation of alternative explanations with implications for belief revision. *Proceedings of the Seventh Conference on Uncertainty in Artificial Intelligence*, 337–347.

Santos, E., Jr. (2001). Verification and validation of knowledge-bases under uncertainty. *Data and Knowledge Engineering, 37*, 307–329.

Santos, E., Jr. (2003). A cognitive architecture for adversary intent inferencing: Knowledge structure and computation. *Proceedings of the SPIE 17th Annual International Symposium on Aerospace/Defense Sensing and Controls: AeroSense 2003,* 182–193.

Santos, E., Jr., & Dinh, H. T. (2008). Automatic knowledge validation for Bayesian knowledge bases. *Data and Knowledge Engineering, 64*, 218–241.

Santos, E., Jr., & Negri, A. (2004). Constructing adversarial models for threat intent prediction and inferencing. *Proceedings of the SPIE Defense & Security Symposium, 5423*, 77–88.

Santos, E., Jr., & Nguyen, H. (2009). Modeling users for adaptive information retrieval by capturing user intent. In M. Chevalier, C. Julien, & C. Soule-Depuy (Eds.), *Collaborative and social information retrieval and access: Techniques for improved user modeling* (pp. 88–118). New York: Information Science Reference.

Santos, E., Jr., & Santos, E. E. (1999). A framework for building knowledge-based under uncertainty. *Journal of Experimental and Theoretical Artificial Intelligence, 11*, 265–286.

Santos, E., Jr., Santos, E. E., & Shimony, S. E. (2003). Implicitly preserving semantics during incremental knowledge base acquisition under uncertainty. *International Journal of Approximate Reasoning, 33*, 71–94.

Santos, E., Jr., Wilkinson, J. T., & Santos, E. E. (2009). Bayesian knowledge fusion. In *22nd International FLAIRS Conference*. Menlo Park, CA: AAAI Press.

Santos, E., Jr., & Zhao, Q. (2006). Adversarial models for opponent intent inferencing. In A. Kott & W. McEneaney (Eds.), *Adversarial reasoning: Computational approaches to reading the opponents mind* (pp. 1–22). London: Chapman & Hall/CRC.

Santos, E. S., & Santos, E., Jr. (1987). Reasoning with uncertainty in a knowledge-based system. *Proceedings of the Seventeenth International Symposium on Multiple-Valued Logic,* 75–81.

Searle, J. R. (1983). *Intentionality: An essay in the philosophy of mind*. Cambridge, UK: Cambridge University Press.

Wilson, R., Runciman, W., & Gibberd, R. (1995). The quality in Australian health care study. *Medical Journal of Australia, 163*, 458–471.

Author Queries

AQ1: Please provide exact page number for the quoted material in sentence beginning "Using the definitions from the Institute of Medicine...."

AQ2: Sentence beginning "In particular, we focus here on individual differences..." okay as edited?

AQ3: Please provide exact page number for quoted material from Searle, 1983.

AQ4: Please provide exact page numbers for both quotes from Manterea & Sillinceb, 2007.

AQ5: There is no reference in the reference list that corresponds to the Williams, Rose, & Simon, 1999, citation. Please provide a reference for this citation.

AQ6: Sentence beginning "In inferring surgeons' intentions, belief revision..." okay as edited?

AQ7: Sentence beginning "Because surgeons have the most authority..." correct as meant?

AQ8: Sentence beginning "He assumed that the nipple–areola complex would go to pathology..." okay as edited?

AQ9: Please review all tables in the chapter and confirm that they are correct.

AQ10: Sentence beginning "However, it can also be explained by the plastic surgeon..." okay as edited?