# A METHOD TO IMPROVE TEAM PERFORMANCE IN THE OR THROUGH INTENT INFERENCING

**Eugene Santos Jr.[1], Keum Joo Kim[1], Fei Yu[1], Deqing Li[1], Elizabeth Jacob[1], Lindsay Katona[2], Joseph Rosen[2]**

[1]Dartmouth College, Thayer School of Engineering,
8000 Cummings Hall, Hanover, NH 03755-8000, USA
[2]Dartmouth-Hitchcock Medical Center
One Medical Center Drive, Lebanon, NH 03756, USA

*esj@dartmouth.edu*

**Abstract**

Medical care is provided by individuals who are very well trained and highly motivated for improving patient health. When these individuals work together, their communication and awareness of circumstances is the key to team performance and directly impact patient safety. The operating room (OR) is an especially vulnerable place since a wide variety of people, medical devices, as well as a range of actions and events are mixed together interacting dynamically. Due to this fact, the sharing of information and understanding of co-workers can easily break down and result in various adverse events. Consequently, there is a need to assist the OR team members' awareness of their dynamic environment/situation as well as their understanding of the goals and actions of their co-workers. To that end, in this paper, we present a computational framework that accounts for the OR team members' decision making. This also includes implicit decisions and misunderstandings among the team members such as those relating to miscommunication, miscues, and misinformation. In particular, we simulate the OR team members' understanding of their situations through intent inferencing, where an individual's intent is embodied by combining goals, supporting actions, and plans.

**Keywords: Intent Inferencing, Bayesian Knowledge Bases, Probability Reasoning**

**Presenting Author's biography**

He is currently Professor of Engineering in the Thayer School of Engineering at Dartmouth College, Hanover, NH. He is currently Editor-in-Chief for the *IEEE Transactions on Systems, Man, and Cybernetics: Part B*, an associate editor for the *International Journal of Image and Graphics,* and is also on the editorial advisor board for *System and Information Sciences Notes* and on the editorial boards for *Journal of Intelligent Information Systems* and *Journal of Experimental and Theoretical Artificial Intelligence*.

.

## 1 Introduction

It is a well known fact that many adverse events in medical practice are preventable, and that a majority of them are primarily associated with communication breakdown among medical care members [5][21]. Although enhancing medical care members' communication in the OR is essential to promoting patient safety and care quality, there are only a few conclusive findings and practical approaches to improving the communications. In this paper, we present a computational framework, which allows monitoring of the OR team members' reasoning and assists their understanding of their situations/environments and co-workers to enhance patient safety and medical care quality.

Medical care service is provided by individuals who are very well trained and highly motivated for improving patient health. When such individuals work together, their communication and sharing of information can easily break down especially in the OR, where a wide variety of people, medical devices as well as a range of actions and events are mixed together interacting dynamically [6][17]. To improve the communication and consensus among the OR team members, it is ideal that all the OR team members perform their roles and tasks with a complete and continual understanding of the surrounding dynamic situations. It is also desired that all the OR team members re-consider their current decisions and re-verify the surgical procedures to be taken when a significant discrepancy occurs among their decision making processes, for improving patient safety.

In our research, we model the OR team members' understanding of the situation through intent inferencing, where an individual's intent is defined as a combination of goals, supporting actions and plans, and inferred based on probabilistic reasoning. The team intent is derived from care team members' individual intent. In particular, we examine potential gaps in (team) understanding by comparing each individual's intent model. A situation involving all care team members with a large gap can be interpreted as a medical situation highly vulnerable to medical errors. The intent of the individual is shaped by their perceptions, knowledge, experience, and awareness of their environment, just to name a few factors. In addition, each individual's intent is also embodied by their understanding of the other team members' interactions which may be incomplete and/or inaccurate. A computational cognitive framework, proposed in this paper, represents the key components of the OR team members' reasoning processes and infers their intent by computing corresponding probabilities with observables provided through a formal probabilistic reasoning model called Bayesian Knowledge Bases (BKBs). BKBs form the basis for modeling and simulating the OR team members' decision making. By integrating the intentions and beliefs inferred from individual decision making processes, we identify the discrepancy among the OR team members' intentions and beliefs and use it as an indicator to detect potential medical errors, which could result in various adverse events in medical practices.

Modeling and simulating individual reasoning is a complex and challenging task in artificial intelligence. Major difficulties are the incomplete and inaccurate information available and the worst-case intractable computations required. Although we are still a distance away from modeling complete and full human decision making processes, with the help of the BKB's formalism for handling uncertainty and incompleteness as well as reduced computations required in the reasoning processes, we expect to move forward towards the long term goal of modeling and simulating human reasoning.

We begin our discussion in Section 2 by providing some fundamental background on our research. In Section 3, we introduce the gap analysis and how it can be applied to our domain. In Section 4, we provide our current cognitive framework of surgical intent modeling and its theoretical background on BKBs. Next, we present some real-world medical cases containing errors and provide our empirical results for validation in Section 5. Finally, we present our conclusion and directions for future research in Section 6.

## 2 Background

Using the definitions from the Institute of Medicine (IOM), 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" [21]. Errors in the OR can bring about catastrophic consequences for patients, their families, and medical care members [3]. Most kinds of adverse events, which are described as "an injury caused by medical management rather than the underlying condition of the patient", are a retained foreign body, a wrong site surgery, mismatched organ transplants, and blood transfusions [21][27].

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 [21]. It has also known that a significant portion of them are preventable [15]. Among various causes of medical errors, communication failure was recently identified as a leading cause of many adverse events by the Joint Commission on Accreditation of Healthcare organizations [6]. Besides, there is a great deal of literature that reports that communication failure within a medical care team increases error rates and the number of adverse events [6][17]. Communication failure was found to be associated with medical errors twice more frequently than medical malpractice [14].

It is also reported that the medical errors caused by communication breakdowns account for 50 percent of all detected adverse events in an Australian study [2]. Not just in the United States but also across the world, there is a strong recognition of the significance of teamwork in medical practices and that it is necessary to enhance communication and sharing of information among medical team members for improving patient safety.

Although a considerable body of literature has been published on trying to resolve this challenging problem [16], we focus in particular on research devoted to improving communications among medical care members. We classify the major research approaches into three categories: training, checklisting, and intent inferencing.

Training medical care members to enhance patient safety has a long history of research and implementation. In a paper by S. Award, et al., a special training session, which was based on crew resource management principles, was offered to surgery teams where the impact of this training was examined by a communication survey collected over a period of several months [25]. The study focused on the improvement in communications among the surgeons, anesthesiologists, and nurses after training the OR team members to be required to brief preoperatively. The results of this implementation have been investigated in some dedicated hospitals and have shown that there is significant improvement of medical care members' awareness and understanding of the procedures to be performed. Since the complexity and the dynamics of the OR parallels that of the aviation environments, many medical team training systems employed the principles of crew maneuver training and have shown meaningful improvements [1].

In addition to the team training, the checklist is another methodology adapted from aviation crew training to reduce medical errors. The key idea of the checklist [4] is to standardize processes and aid memory of the OR team members. Since this implementation has shown a significant reduction in medical errors, it has become very common to use in the OR. Among a number of variations in checklist design, two of the most popular forms are the "to-do list" and the "challenge-verification-response", where the "to-do list" contributes a systematic way of performing medical procedures and the "challenge-verification-response" serves as a tool to enhance communications among individuals involved in the same procedure in a way where one party initiates some items from the checklist and the other party completes the items [23]. Despite the apparent benefits of the checklist in the OR, some medical errors are still occurring and resulting in catastrophic outcomes. Causes of the medical errors are various: some medical care members recite the procedure from memory not from the checklist; they skip reading the checklist, which would have verified the other party's completeness; some essential items are missed in the checklist, etc.

Finally, intent inferencing is one of the most advanced techniques dedicated to promoting patient safety by employing reasoning tools from artificial intelligence [17]. This domain of the research includes all types of team cooperative tasks such as central control rooms of power plants, cockpits in aircraft and medical care members in surgery rooms. In a study by T. Kanno, et al., a two-person team operating a plant control system was simulated by detecting conflict among individuals' intentions [28]. Individual intention was inferred by applying keyhole plan recognition, which searches for a combination of individual mental components with given observables. In addition, there are multiple studies to maintain quality care by applying computational reasoning and planning such as NESTOR [9] and TraumAID [8]. Our study is in this research category. We, however, integrate gap analysis to identify potential risks of medical errors and enhance the reasoning processes with intent inferencing.

## 3 Gap Analysis

In general, surgery is delivered by several medical care members including surgeons, anesthesiologists, and nurses. In the OR, which is vulnerable to medical errors, communication among the team members can easily fall apart but needs to be strongly tied together for securing patient safety [20][22]. One of the best ways to improving team performance is to enhance team members' understanding of situations and of their co-workers. Monitoring all of the team members' internal and external behaviors enhances their awareness and is desired for quality care. To that end, we investigate discrepancies among team members in order to encourage them to enhance patient care.

### 3.1 Team intent

A team is a group of individuals working to achieve common goals. As individual intent leads to a course of actions, team intent leads to the actions of care team members towards achieving the common goals. In addition, when individuals are better aware of other team members' intentions, the team intent can be accomplished in a more effective and efficient manner. The quality of patient care, a common goal among the team members, can be better accomplished by enhancing the team intent, which is the collective intent of the team members. However, each team member's intent is not always in accord and this often leads to medical errors when it is associated with patient care.

Medical errors are often attributed to the medical care members especially when they misunderstand the patient, their co-workers, or the surrounding medical situations. For example, the wrong dose of medication is often caused by the nurse misunderstanding the doctor's order or misunderstanding the patient's condition. Wrong site operations often occur when the doctor is confused by the medical image or the nurse misunderstands the patient situation. The retained foreign body occurs when medical care team members leave any medical equipment inside the patient body when closing the incision. The most common cause of the error is the medical care members' mistakes made while performing the operation. Although an individual can make mistakes, their co-workers have the opportunity to monitor and fix the mistakes while cooperatively performing surgical procedures. In a sense, it would be anticipated that a team with more care members has a higher potential to avoid medical errors. In practice, however, team communication easily breaks down when the team is composed of a large number of individuals. The awareness and understanding of situations and co-workers is the key difference. Therefore, it is essential to enhance the medical care members' understanding and awareness of their environments to improve patient care.

### 3.2 Gaps among the OR team members

When two surgeons are supposed to cooperate to perform a medical procedure, they need to coordinate with each other when undertaking their medical actions. Although their actions are different, each has expectations (beliefs) of the other surgeon. This is also true for other medical care members such as the anesthesiologist and nurse when more care members are involved in performing the same medical procedure.

If there is a gap between their intentions and beliefs, this may indicate a potential risk for errors. This may be caused by some care members' lack of experience and knowledge, the complexity of the procedure, or their personal distractions such as fatigue. An OR nurse could make a mistake when he/she prepares for the operation, or the surgeon could make a wrong decision when he reads the medical image representing the patient's body. Sometimes, surgeons can make a wrong choice in performing the operation since body symmetry often causes confusion. Obviously, these types of mistakes are made by accident, but their consequences are devastating. Therefore, identifying gaps by comparing one of the team members' reasoning with other team members' reasoning can be a primary step to investigate the complex OR situations and to improve the quality of surgical care. To that end, we present a computational framework representing an individual's decision making processes and inferring their intentions from their observations and perceptions based on a formal probabilistic reasoning process.

## 4 Surgical Intent Inferencing

The individual's intent is a psychological concept and can be understood in various ways [19]. In our work, a surgeon' intent is inferred from his course of actions and perceptions of his environments. In order to make this feasible, we need a computational framework to represent each individual's knowledge and perceptions appropriately. To that end, we employed Bayesian Knowledge Bases (BKBs), which is capable of representing and modeling knowledge and information available in the field. In this section, we review the basic theory of BKBs and their application to intent inferencing in surgical decision making.

### 4.1 Bayesian Knowledge Bases (BKBs)

Bayesian Knowledge Bases (BKBs) are directed graphs that represent the causal relationships between knowledge. Similar to Bayesian Networks (BNs), BKBs integrate graph and probability theories. The BKBs, however, are capable of incorporating incompleteness and uncertainty in decision making [11][12]. The directed graph representation presents a formal and visual expression of causality among pieces of knowledge enclosed while probability theory guarantees the semantic soundness in decision making under uncertainty and inaccuracy. BKBs are composed of two types of nodes such as I-nodes and S-nodes, and one type of directional arc. Figure 1 depicts a small BKB example representing causal relation (dependencies) among three I-nodes, the white ovals in the figure, which store knowledge to be represented regarding two random variables of A and B. 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. The black dots represent S-nodes and the numbers on S-nodes represent the conditional probabilities. Consequently, a part of the knowledge contained in the BKB in Figure 1 represents that $A=a_1$ can occur with 80% chance when $B=b_1$.

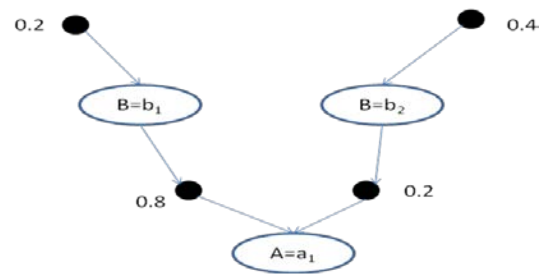


Fig. 1 BKB fragment

BKBs are framed in this way in order to preserve both simplicity and expressiveness. While BNs do not model conditional probability rules explicitly in the graph and require an additional conditional probability table containing all possible states of connected random variables, BKBs do not require complete knowledge and are capable of reducing complexity in interpreting the knowledge contained in the graph [29]. Reasoning in BKBs is based on the dependencies among pieces of information contained, which includes if-then rules and evidence observed prior to the reasoning, and the chain rule as shown in Eq. (1).

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

Reasoning in BKBs comes in two types: belief updating and belief revision. Belief updating is about computing the posterior probability of each single I-node using Bayes' theorem when evidence is specified. Belief revision identifies the most probable instantiation of all random variables with given evidence by computing joint probability of the I-nodes through applying the chain rule. Algorithms performing these BKB reasoning processes have been discussed in detail in the references.

### 4.2 Intent Inferencing

Intent inferencing has been studied for many decades with the purpose of representing and understanding human decision making processes and behaviors. Intent is an explanation of people's actions and is defined as a combination of goals that is being pursued, the support for the goals, and plans to achieve them [26]. In order to represent human intent through computation, we have designed a system containing these components plus the capability to reason through them. Previously, we have successfully applied this to various domains such as adversary intent inferencing and war-gaming [10]. In particular, our system incorporates the components of intent into the structure of BKBs. We categorize the instantiation of random variable (I-nodes) into the four types of axioms, beliefs, goals and actions as relevant components to human intent, where axioms represent what a person believes about himself; 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 goal. Axioms and beliefs may influence themselves or each other. Both axioms and beliefs can contribute to goals (mostly sub-goals). The hierarchy of interactions between these components is depicted in Figure 2. Compliance with the hierarchy is not critical to the reasoning process, but is enforced to 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.

An intent model is a representation of a person's knowledge about himself and about others based on his perceptions. These perceptions, naturally, may not be consistent with others' perceptions or even with the real world. Therefore, when a group of individual intent models are collected to compose the team intent, discrepancies among individual models are natural. However, if they are undertaking their roles under a certain common goal, the discrepancies among them can have a special meaning such as a potential risk of errors in medical practices as aforementioned.

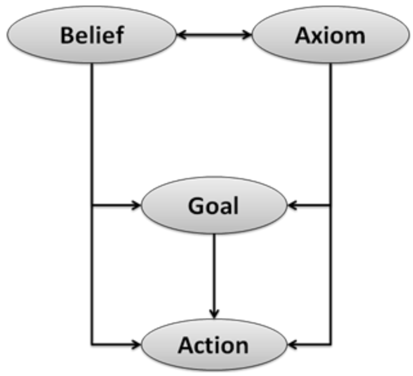


Fig. 2 Hierarchy of interaction between four types of nodes in intent models

### 4.3 Surgical Decision Making

Surgical decision making can be modeled through three major components: diagnosis and determination of potential medical procedure to be taken based on the patient information; confirming the procedure to be taken depending on the surgeon's personal competence; and, predicting the most probable actions to be taken depending on the procedure confirmed.

Figure 3 shows the skeleton of the surgical intent model. In Patient Condition/History/Profile, the information associated with the patient's disease, patient's history of operations, and patient's family history or genetic information can be included. Experience/Mal-practice/Complexity/Fatigue contains the care member's personal knowledge and experience associated with the procedure in addition to his complexity and fatigue. After a care member pre-determines his medical procedure to perform based on the patient information, he may maintain his previous decision or change the procedure depending on his personal competence. Based on his post decision made, the highly probable action to take can be predicted in the module of course of actions for procedure.

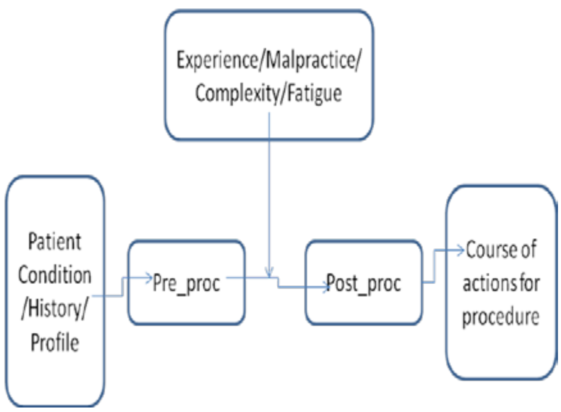


Fig. 3 The skeleton of surgical intent model

Figure 4 shows the module of surgeon's post decision making depending on his personal competence in performing a certain procedure. In addition to our previous consideration of experience, malpractice and complexity, we address the impact of a surgeon's fatigue in his post procedure determination. For example, a surgeon having high experience and low mal-practice can have a lower (medium) competence level when he becomes highly fatigued.

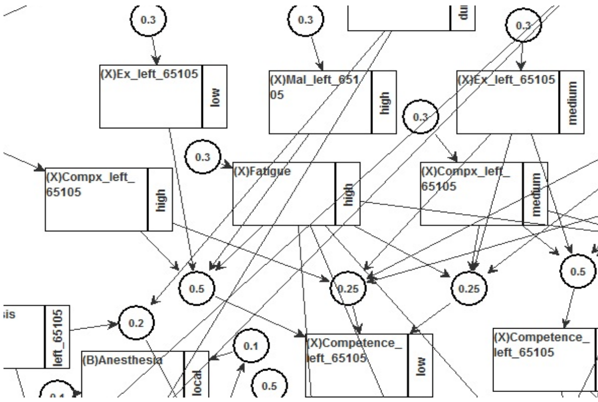


Fig. 4 A part of BKB Inferencing Competence

## 5 Simulation Results

In order to demonstrate the practical aspects of our intent modeling approach, we consider two medical cases associated with medical errors. One of them is a handoff case and the other is a wrong side surgery case.

### 5.1 Test Case I: A Hand-off Case

The hand-off case where the patient, a 45 year old woman having breast pain, was chosen as our first case since when she is to be transferred from a general surgeon to a plastic surgeon, this situation can be particularly vulnerable to information loss. 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.

Two surgeons were involved in the care of this patient. The general surgeon expected to do a subcutaneous mastectomy, which 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 with the expectation of reattaching it later. Unfortunately, the plastic surgeon thought the general surgeon's mastectomy included the entire removal of the nipple areola complex and believed that this was a case of breast disease that includes breast cancer or a severe case of fibrocystic disease. The plastic surgeon felt that the general surgeon was going to perform a simple mastectomy – removing the breast tissue and the nipple areola complex altogether. Due to the miscommunication between the general and plastic surgeons, the patient left the OR without her nipple areola complexes reattached, which was not expected since the patient expected to keep her natural nipple when he consulted with the general surgeon and signed the consent form with that intent.

#### 5.1.1 Experimental Setup

We built BKBs from the behavioral patterns and the perceptions of the general and plastic surgeons. Table 1 shows the size of BKBs built for the general and plastic surgeons, where the number of random variables, number of I-nodes, the average connectivity, the number of S-nodes (rules) and the average number of conditions for each rule in the BKBs constructed are contained. With the BKBs, each surgeon's intent was inferred by computing the most probable world composed of random variables under consideration. We assumed that the surgeons' intentions are identified as their procedures to be carried out for treating the patient.

Tab. 1 Size of BKBs

| | RVS. | I-no. | CON. | S-no. (rules) | Cond. |
|---|---|---|---|---|---|
| General surgeon | 25 | 57 | 5.5 | 91 | 2.4 |
| Plastic surgeon | 27 | 57 | 4.5 | 84 | 2.0 |

#### 5.1.2 Validation

Among of the set of I-nodes used for simulating Test Case I, we chose the I-nodes directly associated with a surgeon's decision making processes and medical errors, and list them together with their names and instantiations in Table 2. 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 two types of mastectomy is detailed in [13]. *(B) Breast Pain* and *(B) Breast Cancer* were used to represent patient condition. I-nodes from *(B) Drawing and Mapping* to *(B) Initiate Auxiliary Dissection* represent the status of the operation in the OR. We set initial values for evidence and obtained target values through intent inferencing with the general surgeon's and the plastic surgeon's BKBs. The filled cells in Table 2 mean that those I-nodes were not considered in intent inferencing of the corresponding individual. For example, the status of an action, represented with *(B) Drawing and Mapping*, was not taken into account in the plastic surgeon's intent inferencing although it was used for the general surgeon's decision making.

Tab. 2 Intent Inferencing for Test Case I

| Name of I-nodes | Instantiation | | |
|---|---|---|---|
| (B)Breast Pain | T | | |
| (B)Breast Cancer | F | | |
| (B)Drawing and Mapping | T | | |
| (B)Create Flap | T | | |
| (B)Dissecting Breast Tissue | T | | |
| (B)Dissecting Nipple | F | | |
| (B)Initiate Auxiliary Dissection | F | | |
| (B)PS_procedure | ProcC | | |
| (B)GS_nipple_removal | | T | |
| (X)Exp_in_19182 | | L | H |
| (A)Action | DN | | |
| (G)Planned_procedure | ProcB | ProcD | ProcC |
| (B)GS_procedure | | ProcA | ProcB |

Although we conducted multiple experiments for validating the BKBs representing the two surgeons [13], we present only the results of the simulation directly relevant to medical errors regarding Test Case I for this paper. (Additional details of the experiments can be found in [13].) The four procedures we considered for the case were simple mastectomy (19180), subcutaneous mastectomy (19182), and breast reconstruction with nipple reattachment (19357.1) and without nipple reattachment (19357.2) (American Medical Association, 2004), which are denoted as *ProcA*, *ProcB*, *ProcC* and *ProcD* in Table 2 respectively. The left most column of instantiation represents general surgeon's intent inferencing, where he decides to take the action of *DN (Dissecting Nipple)* as a part of performing subcutaneous mastectomy (i.e. *(G) Planned_procedure=ProcB)*, when the patient has pain without cancer, some of the required actions are completed and other actions are anticipated. At the same time, the general surgeon believes that the plastic surgeon will perform the breast reconstruction with nipple reattachment (i.e. *(B)PS_procedure=ProcC*). If he does not dissect the patient nipple, he may expect the plastic surgeon to perform Breast Reconstruction without nipple reattachments (i.e. *(B)PS_procedure=ProcD*), which was omitted here but provided in [13].

The next two columns show the intent inferencing of two virtual plastic surgeons, who has either low or high experience in subcutaneous mastectomy (19182). Although the general surgeon expects Breast Reconstruction with nipple reattachment (19357.1) from the plastic surgeon (i.e. *(B)PS_procedure=ProcD* as represented in the previous column), the plastic surgeon determines his procedure to perform based on the given evidence and his preference. When the plastic surgeon does not have high experience in the subcutaneous mastectomy *(i.e. (X)Exp_in_19182=L)*, he can easily misunderstand that the general surgeon will perform the simple mastectomy (i.e. *(G) Planned_procedure=ProcA)* and simply performs the Beast reconstruction without nipple reattachments (19357.2) *(i.e. (G)Planned_procedure=ProcD)*, which explains exactly what happened in the real-world case.

Only when the plastic surgeon has high experience in subcutaneous mastectomy *(i.e. (X)Exp_in_19182 =H, the right most column)*, can he understand the general surgeon's intention correctly (i.e. *(G) Planned_procedure=ProcB)* and perform the Breast Reconstruction with nipple reattachment (19357.1) *(i.e. (G)Planned_procedure=ProcC).*

Comparing these two possible intent inferencings of the plastic surgeons with that of the general surgeon, we can identify a possible error caused by the plastic surgeon's lack of experience through analyzing the gap between their decision making processes, a part of which can be explained by *(G) Planned_procedure=ProcB* of the general surgeon's intent and *(B) GS_procedure=ProcA* of the plastic surgeon's belief on the general surgeon. In addition, our simulation results validated that the surgeon's experience impacts the probability of selecting the right procedure by showing that probability value of the plastic surgeon with low experience is about 10 times smaller than that of the plastic surgeon with high experience.

### 5.2 Test Case II: A Wrong Site Surgery

The original case was reported in a paper by B. Jericho, et al. associated with wrong site surgery [7]. Although the wrong-site surgery was prevented in the literature, we explored a what-if scenario for our simulation based on the case. A male, 18 year old, has come to the hospital with blindness caused by a gunshot wound that he had sustained five months ago. His left eye became blind, painful, and phthisical (involuted) due to the injured eye globe. He was scheduled for two consecutive procedures under general anesthesia: left enucleation with implant and left suture tarsorrhaphy. He has a history of tobacco, alcohol, and substance abuse but all vital signs are normal except for his ophthalmologic problem. In addition, he has a dark blue tattoo by the right eye marking the initials "ILL". An OR nurse inspecting the care of the patient initially took the tattoo of initials as the surgical site marking and prepared the right eye for the surgery. Although there was a chance to re-verify the correct site of the operation indicated on the consent form, the OR nurse mistakenly confirmed that the tattoo of initials was the surgical site marking and proceeded with the surgery regardless of the surgical consent form. Both the anesthesiologist and the surgeon (ophthalmologist) performed the operation on the right eye of the patient. The medical mistake was discovered when the patient recovered several hours later. Although the outcome of the case is catastrophic, the correct site of surgery can be identified before the operation if the surgeon or anesthesiologist reviews the consent form or patient's medical history and condition correctly. Next, we will present how our proposed gap analyses approach could be used to detect and prevent this medical error.

### 5.2.1 Experimental Setup

Three medical care members are modeled: eye surgeon (ophthalmologist), the anesthesiologist, and the OR nurse. Table 3 shows the size of BKBs built for our experiments. With the BKBs, each care member's intent was inferred by computing the most probable instantiation of the random variables with the given evidence.

Tab. 3 Size of BKBs

| | RVS. | I-no. | CON. | S-no. (rules) | Cond. |
|---|---|---|---|---|---|
| Ophthal. | 32 | 112 | 4.02 | 149 | 2.02 |
| Anesthesia | 13 | 33 | 4.88 | 60 | 1.68 |
| OR nurse | 21 | 52 | 4.48 | 82 | 1.84 |

### 5.2.2 Validation

Table 4 shows an ophthalmologist's intent inferencing by providing a set of I-nodes used for evidence and target variables while simulating the Test Case II. Patient condition includes blindness, pain, and phthisis of eyes. Each BKB has I-nodes representing one's own goal and his belief about his co-workers as represented with (G) and (B) in the names of the I-nodes. Therefore, the I-node *(G) S_Plan* represents the goal of the ophthalmologist (in the ophthalmolosit's BKB) while *(B) S_Plan* represents others' belief on the ophthalmologist (in the anesthesiologist's and the OR nurse's BKBs). Reasoning processes of the care members are similar in determining a medical procedure to be taken, which is mainly based on the patient condition and the care member's personal competence. Their actions to be taken, however, are different from each other since they are supposed to play different roles in performing the shared medical procedure.

Tab. 4 Intent Inferencing for Test Case II (ophthalmologist)

| Name of I-nodes | Instantiation | | |
|---|---|---|---|
| (B)Blind | L | R | N |
| (B)Pain | L | R | N |
| (B)Phthisis | L | R | N |
| (G)S_Plan | L, R | R, L | N, L, R |
| (B)A_Plan | L, R | R, L | N, L, R |
| (B)N_Plan | L, R | R, L | N, L, R |

The cause of the wrong site surgery is the natural symmetry of the human body and an artifact in this case, the tattoo. To simulate the medical errors in our experiments, we designed all three care members BKBs including possible mistakes in determining the correct site operations, which can increase due to several factors such as fatigue, malpractice, etc. As shown in Table 4, when the patient has a blindness, pain and phthisis in his left eye (i.e. *(B)Blind=L*, *(B)Pain=L* and *(B)Phthisis=L*), the ophthalmologist plans enucleation (65105) on the left side with the highest probability (i.e. (*G)S_Plan=L*) and believes that both the anesthesiologist and OR nurse assist to perform the same procedure (i.e. *(B)A_Plan=L* and *(B)N_Plan=L*). In addition, as mentioned already, there is a chance of making a mistake that the ophthalmologist plans enucleation (65105) on the right side (i.e. *(G)S_plan=R*) although it is less likely to happen. When the patient has a blindness, pain and phthisis in his right eye (i.e. *(B)Blind=R*, *(B)Pain=R* and *(B)Phthisis=R*), the simulation results obtained were analogous to the left side. If the patient does not have any of these symptoms (i.e. *(B)Blind=N*, *(B)Pain=N*, and *(B)Phthisis=N*), no surgery can be determined with the highest probability (i.e. *(G)S_Plan=N*) and other procedures such as L and R can be determined by a low probability. The results obtained from the anesthesiologist's and OR nurse' intent inferencing are similar to Table 4 and we did not make separate tables here. When the OR nurse makes a wrong decision to prepare the right (incorrect) side of the patient, which happened in the Test Case II, her belief about the ophthalmologist's intention inferred as R, is different from L inferred in the surgeon's and anesthesiologist' intent inferencing. Consequently, the gap among these care members intentions and beliefs indicates a high risk of wrong side operation and inquires additional steps to prevent the adverse event from happening. Our proposed gap analyses in this situation involve the probabilistic differences among care team members reasoning processes in understanding procedures and performing actions. Currently, we need additional validation of the BKBs for the surgeon, anesthesiologist, and nurse in this test case. In our next steps, we will be conducting an exhaustive empirical analysis after validation is completed

## 6 Conclusions

In this study, we present a cognitive computational framework to simulate reasoning processes of medical team members to reduce medical errors by identifying and resolving gaps among individual intent. Communication breakdown among medical team members has been known to be a major cause of adverse events and we expect our approach to contribute to mitigating the communication loss and assisting medical care members to better understand the dynamic environments and their co-workers. Among various types of medical errors, we have investigated a hand-off case and wrong-site surgery due to their high occurrence in practice. To accomplish our ultimate research goal, promoting patient safety in the OR, it is desired to monitor all medical care members' reasoning processes continuously and to accelerate their awareness of situations and understanding of their co-workers.

For our future work, we consider two directions: temporal relations among pieces of information and generalization among various medical procedures. To simulate medical practices dynamically, reasoning and inferencing knowledge with respect to time is essential. Although there is a theory of temporal BKBs [24], the computational complexity hinders its immediate applicability. In addition, general components of surgical intent inferencing need to be formulated, which would be different from the hierarchy of intent inferencing in other domains.

## 7 References


[1] A. Alonso, et al., "Reducing medical error in the Military Health System: How can team training help?", *Human Resource Management Review* 16, 396-415, 2006.

[2] A. Bhasake, G. Miller, S. Reid, "Analyzing potential ham in Australian general practice: an incident-monitoring study, *Medical Journal of Australia* 169, 73-6, 1998.

[3] A. Bognar, et al., "Errors and the Burden of Errors: Attitudes, Perceptions, and the Culture of Safety in Pediatric Cardiac Surgical Team", *The Annals of Thoracic Surgery* 85, 1374-1381, 2008

[4] A. Gawande, *The Checklist Manifesto: How to Get Things Right*, New York, New York, Metropolitan Books, 2009

[5] A. Martin, et al., "Operating Room Teamwork among Physicians and Nurses: Teamwork in the Eye of the Beholder," *Journal of the American College of Surgeons* 202 (5), 746-752, 2006.

[6] A. Parush, C. Kramer, T. Foster-Hunt et al., "Communication and Team Situation Awareness in the OR: Implications for Augmentative Information Display," *Journal of Biomedical Informatics*, 2010.

[7] B. Jericho, et al, "Facial Tattoo and Wrong Site Surgery: Which side are you working on?" *The Internet Journal of Anesthesiology* 21:2, 2009.

[8] B. Webber, et al, "Exploiting multiple goals and intentions in decision support for the management of multiple trauma: a review of the TraumAID project", *Artificial Intelligence* 105, 263-293, 1998.

[9] D. Glenn, H. Edward, et al, "A Computational Model of Reasoning from the Clinical Literature," *AI Magazine* 10(1): 49-57, 1989.

[10] E. Santos, Jr. "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*, Orlando, FL, 2003.

[11] E. Santos, Jr. and E. S. Santos, "A framework for building knowledge-based under uncertainty", *Journal of Experimental and Theoretical Artificial Intelligence,* vol. 11, pp. 265-286, 1999.

[12] E. Santos, Jr., "Verification and Validation of Knowledge-Bases under Uncertainty," *Data and Knowledge Engineering* 37, 307-329, 2001.

[13] E. Santos, Jr., et al., "Reasoning about intentions in complex organizational behaviors – intentions in surgical handoffs," DI2AG Technical Report-2010-100, Thayer School of Engineering, Dartmouth College, 2010.

[14] G. Alvarez, E. Coiera, "Interdisciplinary communication: an uncharted source of medical error?" *Journal of Critical Care* 21, 236-242, 2006.

[15] G. Dalton, X. Samaropoulos, A. Dalton, "Improvement of the safety of patient care can help end the medical malpractice crisis in the United States," *Heath Policy* 86 (2-3), 153-162, 2008.

[16] H. Murff, et al., "Detecting adverse events for patient safety research: a review of current methodologies," *Journal of Biomedical Informatics* 36, 131-143, 2003.

[17] J. Guise, "Teamwork in obstetric critical care", *Best Practice & Research clinical Obstetrics and Gynecology* 22 (5), 937-951, 2008.

[18] J. Pearl, *Probabilistic Reasoning in Intelligent Systems*, San Francisco, CA, Morgan Kaufmann, 1988.

[19] J. Searle, *Intentionality: An essay in the philosophy of mind*, Cambridge University Press, 1983.
[20] K. Williams, et al, "Teamwork in Emergency Medical Services", *Air Medical Journal* 18:4, 1999.
[21] L. Kohn, J. Corrigan, M. Donaldson, *To err is human*, Washington DC, National Academy Press, 2000.
[22] L. Lingard, et al., "Communication Failure in the operating room: observational classification of recurrent types and effects, *Quality and Safety in Healthcare* 13 (5), 330-334, 2004.
[23] M. Frakes, et al., "Effectiveness of a Challenge-and-Respond Checklist in Ensuring Safety Behavior Compliance by Medical Team members at a Rotor-Wing Ait Medical Program," *Air medical Journal* 26:5, 2007.
[24] N. Pioch, J. Melhuish, A. Seidel, E. Santos, Jr., D. Li and M. Gorniak, "Adversarial intent modeling using embedded simulation and temporal Bayesian knowledge bases", *Proc. SPIE Defense, Security and Sensing 2009*, vol. 7348, Orlando, FL, 2009.
[25] S. Award, et al., "Bridging the communication gap in the operating room with medical team training", *The American Journal of Surgery* 190, 770-774, 2005.
[26] S. Manterea, J. Sillinceb, "Strategic intent as a rhetorical device," *Scandinavian Journal of Management* 23, 406-423, 2007.
[27] S. Seiden, P. Barach, "Wrong-side/Wrong-site, Wrong-Procedure and Wrong Patient Adverse Events," *Archives of Surgery* 141, 931-939, 2006.
[28] T. Kanno, K. Nakata, K. Furuta, "A method for conflict detection based on team intention inference", *Interacting with Computers* 18, 747-769, 2006.
[29] T. Rosen, S. Shimony and E. Santos, Jr., "Reasoning with BKBs – Algorithms and Complexity," *Annals of Mathematics and Artificial Intelligence* 40(3-4), 403-425, 2004.