Knowledge Technology Practical
System Report

Group 1
Alina Dima (s3919951), Júlia Vághy (s3994759), Maria Kapusheva (s3946231)

You can view the finished project here .

1 Problem

The present knowledge system focuses on diagnostics of acute abdomen in the emergency room. Acute abdomen refers to severe abdominal pain that occurs suddenly. Depending on the underlying condition, it often requires immediate surgery and is thus considered a medical emergency. The responsible medical personnel must determine the cause as soon as possible, by administering the right diagnostic tests and making fast inferences based on the results.

Experienced doctors would immediately know what tests to run and what the results mean. However, they tend to have busy schedules and might not be available at the time when an urgent diagnosis is needed. Other medical staff such as nurses or first year residents may not have such reliable knowledge, thus, it is important that they are provided with a tool to aid them in diagnosis. As time is crucial, browsing lengthy medical protocols is far from ideal. A quicker way is necessary, which is what the present project aims to provide.

Additionally, this system would be a great tool for medical students to study with, as it allows them to delve deeper into the practical methods. They could easily go through many scenarios and follow the trace to confirm their approach.

2 Expert

Expert - Dr. Katya Todorova, surgical resident in the Surgery Clinic of SofiaMed University Hospital in Sofia, Bulgaria

Our expert has graduated with an Honours Degree from the Medical University of Sofia in 2018. She has worked as a volunteer in the ER of the Military Medical Academy in Sofia from 2014 to 2016. In 2016 she worked in the Oncology Clinic of SofiaMed University Hospital. From 2017 onward, she specialises in general surgery at the same hospital. Her professional interests involve mini-invasive and laparoscopic surgeries. In January of 2022, she became the youngest Bulgarian medical professional to obtain qualification for using a Da Vinci Surgical System from the IRCAD Laparoscopic Training Center in Strasbourg.

Member of:

- Bulgarian Medical Association
- Bulgarian Surgical Society
- European Hernia Society
- European Association for Endoscopic Surgery

Although Katya works long shifts and often at night, she was very reachable and eager to help us. We mainly conducted the interviews in the evenings due to her work responsibilities. She was relatively easy to reach beyond the interviews if we had any issues and needed her opinion.

Katya shared some anecdotes from her personal experience which helped us formulate the problem. She explained that when there is a shortage of medical doctors due to rush hours in the hospital, oftentimes inexperienced medical personnel handle the ER. According to her, they often call on the doctors with false diagnosis, due to not having the expert knowledge that we are focusing on. This inhibits the medical doctors from helping other people that need their attention.

3 The role of knowledge technology

We believe that the problem of guiding inexperienced medical personnel through the diagnosis of patients with acute abdomen can be solved using knowledge technology, in particular, an expert system.

The internal workings of a knowledge system are based on a knowledge base and an inference engine. The knowledge base is a set of factual knowledge, and the inference engine allows the system to deduce new facts. In an expert system, the knowledge base is built based on expert knowledge. The user can provide and receive information through an intuitive user interface, thus they can easily use the knowledge system to help them with the task they have at hand.

This framework is ideal for our problem for several reasons. Firstly, the main issue is that an experienced doctor may not be available at the time of diagnosis. This is resolved by explicating and outsourcing their intuition to a system that can be used by other, less experienced, medical personnel. The expert's diagnostic process is based on inference which makes knowledge systems an appropriate technology for the implementation. Moreover, our expert told us that knowledge bases are already used in the medical field with great success. Secondly, due to the severity of acute abdomen, the goal is to make inference as quickly as possible and in the process perform only as many diagnostic tests as necessary. Our proposed system asks clear yes-or-no questions about diagnostic steps, such as ST elevation inside the ECG trace, and infers a medical recommendation from the answers immediately. By using backward chaining, the system only asks questions about the necessary medical tests.

4 The knowledge models

4.1 Problem-solving model

With the help of Katya's insight, we performed protocol analysis on the diagnostic process in emergency rooms. This entails extracting quantifiable steps in an expert's problem-solving process, and thereby drafting a prototype problem-solving model.

Together with our expert we decided to build the system around ten main outcomes (Section 4.2.1). As some conditions require urgent medical intervention, Katya recommended that we try to exclude the causes one at a time, from most life-threatening to least. This is the same approach that they take in the emergency room, which was also easily implementable in our system. To account for Katya's recommendation, we dealt with each outcome as a main goal in the order specified in Section 4.2.1. Thus, the top level on which we apply backward chaining would be a specific medical recommendation. The system stops when one of the medical recommendations can be considered applicable (true). This would simulate trying to exclude the medical conditions based on urgency.

Then, for each medical recommendation, we decided which questions would be most relevant and which rules (Section 4.3) would aid the inference engine in finding a solution. If we inspect

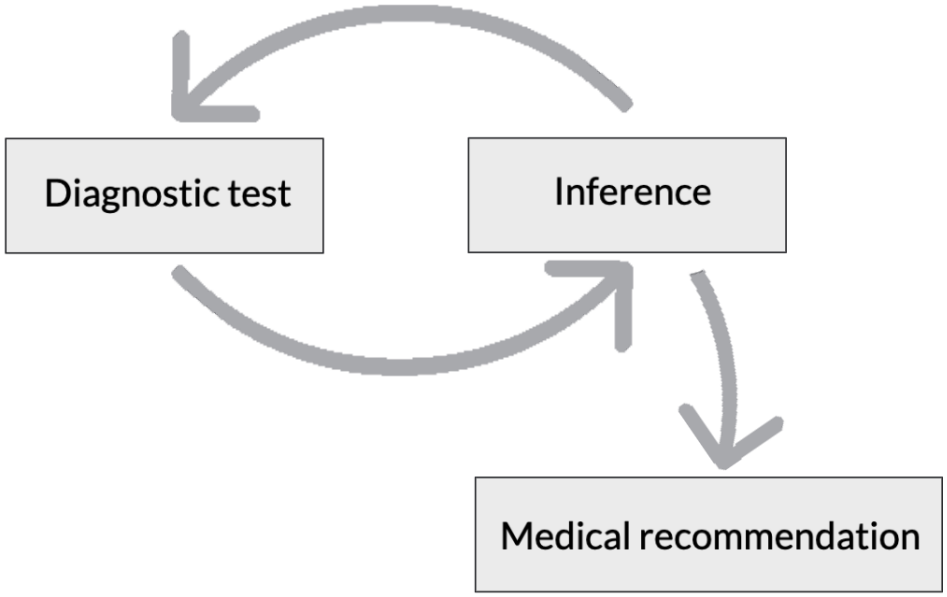

Figure 1: Problem-solving model of medical professionals in the emergency room

the rules, we might notice that a group of rules would try to arrive at a certain recommendation (e.g. Rules 5, 6, 7, 8 used to decide gynecology transfer). However, a completely modular solution is not possible in medicine, we might want to reuse previously inferred facts and not repeat questions to the user. The main outcomes might share common symptoms or might depend on the exclusion of previous outcomes to be considered valid.

As previously mentioned, we perform backward chaining on each possible outcome until one of them is true. In our opinion, this type of chaining is optimal for a diagnosis system, as, compared to forward chaining, it goes through less steps in order to find a solution. Our implementation of backward chaining determines whether the goal is true by going through the following steps:

1. If there is any question in the knowledge base that could prove the goal, then retrieve the user's answer and add their answer as an inferred fact to the knowledge base. Move to the next step.

2. If there is an inferred fact in the knowledge base that could prove the goal, then return true and do not follow the next step. Otherwise, move to the next step.

3. Check if there are any rules that could prove the goal. Each rule can have as antecedent another fact subgoal, a conjunction or a disjunction of subgoals.

    - If the antecedent is a fact, then check whether that fact is true using the same backward chaining algorithm.
    - If the antecedent is a conjunction of facts, then check, using backward chaining, that all elements of the conjunction are true.
    - If the antecedent is a disjunction of facts, then check, using backward chaining, that at least one element of the disjunction is true.

In a nutshell, when a patient comes to the emergency room, the responsible medical personnel assess the patient's state using a variety of medical tests. The results from each test allow the doctors to infer facts about the patient's health. These inferences will either lead to more tests

to make further inferences, or a final medical recommendation on where to send the patient from the emergency room.

4.2 Domain model

The domain model describes the classes and attributes of facts in the knowledge base. In our case, we can distinguish three classes of facts:

1. The goal fact (Section 4.2.1), which is the final medical recommendation at the end of the diagnostic process.
2. Facts that denote the results of the medical tests recommended by the system (Section 4.2.2).
3. Facts that denote whether or not a medical test is recommended based on the current state of inference (Section 4.2.3).

The following subsections provide an elaborate description of each class of facts. As several technical terms are used in the elaboration, we constructed a dictionary (Section 10) to aid the reader in grasping the domain. Terms that link to the dictionary are indicated with *italics text*.

4.2.1 The goal fact

The goal fact ("medical-recommendation") is a recommendation on how to further proceed in case of a patient suffering from abdominal pain. This is the final output of the system. The table below provides an explanation for what each value entails.
In our system, "medical-recommendation" $\in$ {"emergency-cardiology-consultation", "exclude-lactic-acidosis", "transfer-to-gynecology", "surgery-now", "emergency-urology-consult", "treatment-according-to-sono", "surgery-today", "surgery-tomorrow", "hospitalization", "dismiss"}.

"medical-recommendation = "	**Explanation**
"emergency-cardiology-consultation"	The patient requires emergency cardiology consultation. Some cardiovascular diseases can manifest with symptoms such as abdominal pain, nausea and gastroesophageal reflux.
"exclude-lactic-acidosis"	The patient requires emergency medical consultation for exclusion of *lactic acidosis*[7]. The clinical picture for acidosis can be similar to some symptoms of acute abdomen. The arterial blood gas analysis is the medical test that is used to exclude this diagnosis.
"transfer-to-gynecology"	The patient should be transferred to the gynecology department. The possible causes do not fall under the scope of ER, the patient might be pregnant.
"surgery-now"	The patient requires emergency surgery. Surgery should be performed now due to risk of additional complications and death if intervention is postponed.
"emergency-urology-consult"	Try to reduce *testicular torsion*[13] manually and transfer to urology for emergency consultation. It is very important to try and reduce the testicular torsion, because the chance of the organ to stay vital decreases as long as the spermatic cord stays twisted.
"treatment-according-to-sono"	Perform surgery indicated by abdominal *sonography*[11]. When the patient goes through an abdominal ultrasound, there are important findings that lead to emergency surgery. The abdominal ultrasound should only be performed by well-trained professionals, which are able to identify specific marks.
"surgery-today"	The patient needs urgent surgery (today).
"surgery-tomorrow"	The patient needs surgery that is not urgent (can be performed tomorrow). There are emergency surgical situations that can be postponed. The treatment starts with electrolyte medications, antibiotics and analgesia. This way the patient is prepared for surgery and is in better condition due to the treatment than when they were admitted.
"hospitalization"	The patient needs to be hospitalized and kept under surveillance. The patient is kept under surveillance in order to trace the development of the clinical picture. This way if there are complications or progression of their condition, the medical staff can react fast and adequate.
"dismiss"	The patient can be dismissed. Follow up in 24-48 h to check the state of the patient.

4.2.2 Facts from questions

During the process of inference, the system asks the user several yes/no questions. Using the user's answer, a new inferred fact is added to the knowledge base. These facts will then further aid the inference process by acting as antecedents or part of antecedents in the inference rules.

A fact name can be deduced from the table below, whereas a *fact value* ∈ {"yes", "no"}. The user's answer determines the value of these facts.

Fact name	Explanation
"upper-abdominal-pain"	Is the patient experiencing upper abdominal pain?
"st-elevation"	Does the ECG indicate *ST elevation*[12]?
"post-wall-infarction"	Does the ECG indicate posterior wall infarction?
"increased-blood-glucose"	Is the blood glucose level increased?
"increased-lactate"	Is the lactate level increased?
"female"	Is the patient female?
"pos-beta-hcg"	Did the patient test positive for *beta-hCG*[2]?
"gynecological-issue"	The patient has gotten a consult from gynecology. Does the specialist suspect a gynecological issue?
"shock"	Is the patient in shock?
"bleeding"	Are there signs of bleeding?
"critical-vital-signs"	Are the vital signs critical?
"unable-to-stabilize"	Are you unable to stabilize patient?
"life-saving-surgery"	Is there an indication that life-saving surgery should be performed?
"obstruction"	Are there signs of *obstruction*[8]?
"vomiting"	Is the patient vomiting?
"hiccups"	Does the patient have hiccups?
"peritonism"	Are there signs of *peritonism*[9]?
"generalized-peritonitis"	Are there signs of *generalized peritonitis*[4]?
"sepsis"	Are there signs of *sepsis*[10]?
"ischemia"	Are there signs of *ischemia*[6]?
"need-for-imaging"	Is there an individual need for imaging?
"testicular-torsion"	Is there testicular torsion?
"unclear-sono"	You have performed an abdominal sonography. Is the abdominal sonography unclear of negative?
"surgery-indication"	Is there any indication for surgery?
"surgery-indication-ct"	You have performed an *abdomen CT with intravenous contrast*[1] and a *CT angiography*[3]. Is there any indication for surgery?
"urgent-surgery"	Is the surgery urgent?
"risk-factors"	Are there risk factors for surgical abdomen?
"dismissal"	The pain is most likely not a specific abdominal emergency. Does the patient satisfy the conditions to be dismissed?

4.2.3 Inferred facts

Other facts are inferred from the information acquired from the user based on the rule model. These are mostly recommendations for additional diagnostic tests to perform.

Similarly to the previous section, a fact name can be deduced from the table below and the *fact value* ∈ {"yes", "no"}. Inference determines the value of these facts. If *fact value*="yes", the respective medical test should be performed on the patient. The results of the tests will be provided by the user through answering yes/no questions (Section 4.2.2).

Fact name	Explanation
"consider-imaging"	Consider additional imaging.
"perform-basic-lab"	Perform lab test for blood glucose and lactate.
"abdominal-sono"	Perform abdominal sonography.
"perform-ct"	Perform CT.
"might-need-gi-tube"	*GI tube*[5] might need to be inserted. Further inference will determine whether or not this is the case.
"needs-gi-tube"	Insert GI tube.
"check-gen-peritonitis"	Check signs of generalized peritonitis.
"perform-ecg"	Perform ECG and check *troponin I level*[14]. look for indications of ST elevation or posterior wall infarction.
"check-beta-hcg"	Check beta-hCG.
"check-peritonism"	Check for signs of peritonism.
"involve-gynecology"	The patient should get a consult from a gynecologist.
"check-testicular-torsion"	Check signs of testicular torsion.
"check-sepsis-ischemia"	Check signs of sepsis or ischemia.
"check-obstruction"	Check signs of obstruction.
"activate-resuscitation-room"	Activate resuscitation room.
"check-risk-factors"	Check risk factors for surgical abdomen.
"check-vitals"	Check signs of shock, bleeding or whether the vital signs are critical.

4.3 Rule model

The system uses the following rule model to infer the consequent diagnostic steps and the final medical recommendation, based on the facts from the results provided by the user and the already established facts.

The rules are listed below. For each rule, an if-then statement is given in formal logic using the fact variables and their values. For each rule, a brief explanation is given, indicating what the rule denotes in the expert diagnostic process.

Rule 1
(upper-abdominal-pain = yes) $\rightarrow$ (perform-ecg=yes)
If the patient is experiencing upper abdominal pain, then an ECG should be performed and the troponin I level should be checked.

Rule 2
(perform-ecg=yes) $\wedge$ ((st-elevation=yes) $\vee$ (post-wall-infraction=yes))
$\rightarrow$ (medical-recommendation=emergency-cardiology-consultation)
If the ECG and troponin I check indicates ST elevation or posterior wall infarction, an emergency cardiology consulation is required.

Rule 3
(upper-abdominal-pain=no) $\vee$ ((upper-abdominal-pain=yes) $\wedge$ (st-elevation=no) $\wedge$
(post-wall-infraction=no)) $\rightarrow$ (perform-basic-lab=yes)
If the patient is not experiencing upper abdominal pain, then the blood glucose and lactate should be checked.

Rule 4
(perform-basic-lab=yes) $\wedge$ ((increased-blood-glucose=yes) $\wedge$ (increased-lactate=yes))
$\rightarrow$ (medical-recommendation=exclude-lactic-acidosis)

If the blood glucose and lactate are increased, the patient requires an emergency medical consultation to exclude lactic acidosis.

Rule 5
(perform-basic-lab=yes) ∧ ((increased-blood-glucose=no) ∨ (increased-lactate=no)) ∧ (female=yes) → (check-beta-hcg=yes)
If either blood glucose and lactate are normal and the patient is female, then beta-hCG should be checked.

Rule 6
(check-beta-hcg=yes) ∧ (pos-beta-hcg=yes) → (involve-gynecology=yes)
If the patient tests positive for beta-hCG, a gynecologist should get involved.

Rule 7
(check-beta-hcg=yes) ∧ (pos-beta-hcg=no) → (involve-gynecology=no)
If the patient tests negative for beta-hCG, continue exploring non-gynecology causes.

Rule 8
(involve-gynecology=yes) ∧ (gynecological-issue=yes)
→ (medical-recommendation=transfer-to-gynecology)
If the specialist suspects a gynecological issue, the patient should be transferred to gynecology.

Rule 9
(perform-basic-lab=yes) ∧ ((increased-blood-glucose=no) ∨ (increased-lactate=no)) ∧ ((female=no) ∨ ((female=yes) ∧ ((involve-gynecology=no) ∨ (gynecological-issue=no))))
→ (check-vitals=yes)
If the patient is a male or is female with no gynecological issue, then check signs of shock, bleeding or whether the vital signs are critical.

Rule 10
(check-vitals=yes) ∧ ((shock=yes) ∨ (bleeding=yes) ∨ (critical-vital-signs=yes))
→ (activate-resuscitation-room=yes)
If the patient is exhibiting signs of shock, bleeding or critical vital signs, activate resuscitation room.

Rule 11
(activate-resuscitation-room=yes) ∧ (unable-to-stabilize=yes)
→ (medical-recommendation=surgery-now)
If the patient cannot be stabilized, perform emergency surgery.

Rule 12
(activate-resuscitation-room=yes) ∧ (unable-to-stabilize=no) → (consider-imaging=yes)
If the patient can be stabilized, consider additional imaging.

Rule 13
(consider-imaging=yes) ∧ (need-for-imaging=yes) → (perform-ct=yes)
If additional imaging is required, perform abdomen CT with intravenous contrast and CT angiography.

Rule 14
(consider-imaging=yes) ∧ (need-for-imaging=no) → (perform-ct=no)

If additional imaging is not required, determine whether issue might require surgery.

Rule 15
(perform-ct=no) ∧ (surgery-indication=yes) ∧ (urgent-surgery=yes)
→ (medical-recommendation=surgery-today)
If additional imaging is not required and there is an indication for surgery, check surgery urgency. If urgent, perform surgery today.

Rule 16
(perform-ct=no) ∧ (surgery-indication=yes) ∧ (urgent-surgery=no)
→ (medical-recommendation=surgery-tomorrow)
If additional imaging is not required and there is an indication for surgery, check surgery urgency. If not urgent, perform surgery tomorrow.

Rule 17
(check-vitals=yes) ∧ ((shock=no) ∧ (bleeding=no) ∧ (critical-vital-signs=no))
→ (check-obstruction=yes)
If the patient's vitals are normal, consider potential obstruction.

Rule 18
(check-obstruction=yes) ∧ (obstruction=yes) → (might-need-gi-tube=yes)
If there are signs of obstruction, check if patient needs a GI tube.

Rule 19
(check-obstruction=yes) ∧ (obstruction=no) → (might-need-gi-tube=no)
If there are no signs of obstruction, consider other causes.

Rule 20
(might-need-gi-tube=yes) ∧ ((vomiting=yes) ∨ (hiccups=yes)) → (needs-gi-tube=yes)
Check if patient is vomiting or has hiccups. If either is true, insert GI tube.

Rule 21
(might-need-gi-tube=yes) ∧ ((vomiting=no) ∧ (hiccups=no)) → (needs-gi-tube=no)
Check if patient is vomiting or has hiccups. If both are false, patient does not need a GI tube.

Rule 22
(might-need-gi-tube=no) ∨ (needs-gi-tube=no) ∨ (needs-gi-tube=yes)
→ (check-peritonism=yes)
If there are no signs of obstruction or if the patient is not vomiting/having hiccups or if a GI tube has already been inserted, consider peritonism.

Rule 23
(check-peritonism=yes) ∧ (peritonism=yes) → (check-sepsis-ischemia=yes)
If there are signs of peritonism, check signs of sepsis or ischemia.

Rule 24
(check-peritonism=yes) ∧ (peritonism=no) → (check-gen-peritonitis=yes)
If there are no signs of peritonism, check signs of generalized peritonitis.

Rule 25
(check-gen-peritonitis=yes) ∧ (generalized-peritonitis=yes) → (check-sepsis-ischemia=yes)

If there are signs of generalized peritonitis, check signs of sepsis or ischemia.

Rule 26
(check-gen-peritonitis=yes) ∧ (generalized-peritonitis=no) ∧ (female=no)
→ (check-testicular-torsion=yes)
If there are no signs of generalized peritonitis and the patient is male, check testicular torsion.

Rule 27
(check-gen-peritonitis=yes) ∧ (generalized-peritonitis=no) ∧ (female=yes)
→ (check-sepsis-ischemia=yes)
If there are no signs of generalized peritonitis and the patient is female, check signs of sepsis or ischemia.

Rule 28
(check-sepsis-ischemia=yes) ∧ ((sepsis=yes) ∨ (ischemia=yes)) → (consider-imaging=yes)
If there are signs of sepsis or ischemia, consider additional imaging.

Rule 29
(check-sepsis-ischemia=yes) ∧ ((sepsis=no) ∧ (ischemia=no)) → (check-testicular-torsion=yes)
If there are no signs of sepsis or ischemia, check testicular torsion.

Rule 30
(check-testicular-torsion=yes) ∧ (female=no) ∧ (testicular-torsion=yes)
→ (medical-recommendation=emergency-urology-consult)
If there are signs of testicular torsion, the patient requires an emergency urology consult.

Rule 31
(check-testicular-torsion=yes) ∧ ((testicular-torsion=no) ∨ (female=yes))
→ (abdominal-sono=yes)
If there are no signs of testicular torsion or if the patient is female, perform abdominal sonography.

Rule 32
(abdominal-sono=yes) ∧ (unclear-sono=no) → (medical-recommendation=treatment-according-to-sono)
If the results of the abdominal sonography are clear, perform surgery accordingly.

Rule 33
(abdominal-sono=yes) ∧ (unclear-sono=yes) ∧ (female=yes) → (involve-gynecology=yes)
If the results of the abdominal sonography are unclear and the patient is female, consult gynecology.

Rule 34
(abdominal-sono=yes) ∧ (unclear-sono=yes) ∧ ((female=no) ∨
((female=yes) ∧ (gynecological-issue=no))) → (check-risk-factors=yes)
If the results of the abdominal sonography are unclear and the patient is male or is a female with no gynecological issue, check for risk factors for surgical abdomen.

Rule 35
(check-risk-factors=yes) ∧ (risk-factors=yes) → (perform-ct=yes)
If risk factors can be identified for the patient, perform abdomen CT with intravenous contrast

and CT angiography.

Rule 36
(perform-ct=no) ∧ ((surgery-indication=no) ∨ (surgery-indication-ct=no))
→ (medical-recommendation=hospitalization)
If the performed CTs do not indicate surgery, hospitalize patient.

Rule 37
(perform-ct=yes) ∧ (surgery-indication-ct=yes) ∧ (urgent-surgery=yes)
→ (medical-recommendation=surgery-today)
If the performed CTs serve as indication for surgery, assess urgency of surgery. If the surgery is urgent, perform surgery today.

Rule 38
(perform-ct=yes) ∧ (surgery-indication-ct=yes) ∧ (urgent-surgery=no)
→ (medical-recommendation=surgery-tomorrow)
If the performed CTs serve as indication for surgery, assess urgency of surgery. If the surgery is not urgent, perform surgery tomorrow.

Rule 39
(perform-ct=yes) ∧ (surgery-indication-ct=no) → (medical-recommendation=hospitalization)
If the performed CTs do not serve as indication for surgery, hospitalize patient.

Rule 40
(check-risk-factors=yes) ∧ (risk-factors=no) ∧ (dismissal=yes)
→ (medical-recommendation=dismiss)
If no risk factors can be identified for the patient, consider non-specific abdominal pain. If non-specific pain is suspected and the patient satisfies the conditions for dismissal, dismiss patient and do a follow up consultation.

Rule 41
(check-risk-factors=yes) ∧ (risk-factors=no) ∧ (dismissal=no)
→ (medical-recommendation=hospitalization)
If no risk factors can be identified for the patient, consider non-specific abdominal pain. If non-specific pain is suspected and the patient does not satisfy the conditions for dismissal, hospitalize patient.

5 User Interface & Functionality

We implemented a clean and minimalistic user interface (UI). Our reasoning was guided by how time is essential in the emergency room. Therefore, the UI should be (immediately) intuitive. Additionally, as our tool could be used by training professionals, it should not distract from information.

In order to make the UI as non-distracting as possible, we decided to focus on a limited colour palette. Hence, we chose analogous colours for the background and question box. Moreover, we wanted the user to focus on information, so we made sure to have a high contrast between text elements and their backgrounds. The only exceptions are for the "Reset" and "Analysis" buttons. In these cases, we decreased contrast by making the text darker. We wanted them to be visible enough in case they are needed, while integrating more within the background and letting the focus be on the question and analysis panel (if activated by the user). As soon as the user starts the system and passes the welcome message (Figure 2), the only elements of

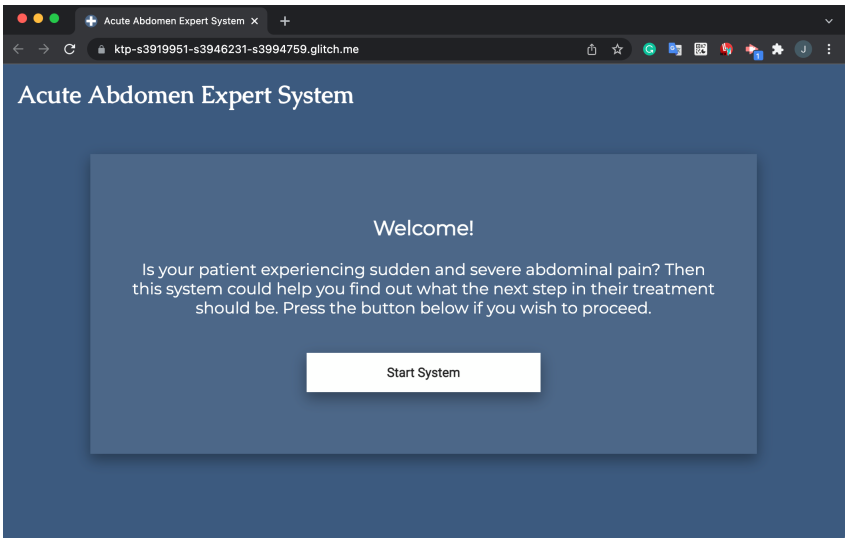

Figure 2: User interface demo - Welcome message

our UI are a header, a box that contains the yes/no questions, a reset button, and a button ("Analysis") to view the trace of inference: the inferred facts and the descriptions of applied rules. A limited number of elements ensures that the UI is easy to use and easy to master.

The user interface was exclusively built using HTML and CSS.

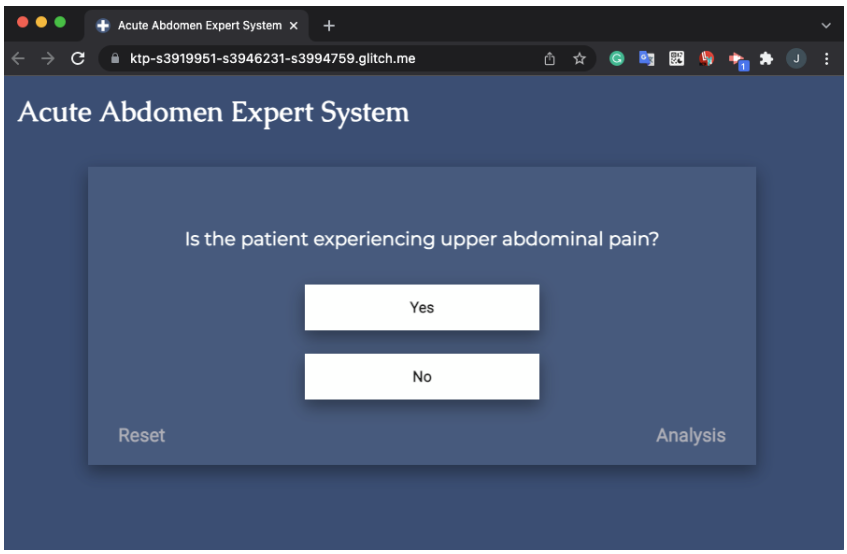

Figure 3: User interface demo - Question

Question answering takes place during the process of inference, which has been implemented in JavaScript. The backward chaining approach gives the efficiency of the system. Answers to the questions listed in Section 4.2.2 give *fact values* $\in$ {"yes", "no"}, which are then passed back to further inference of *fact values* $\in$ {"yes", "no"} about the recommended tests listed in Section 4.2.3. The process continues until the system is able to deduce the value of the goal fact "medical-recommendation" $\in$ {"emergency-cardiology-consultation", "exclude-lactic-acidosis", "transfer-to-gynecology", "surgery-now", "emergency-urology-consult", "treatment-according-to-sono", "surgery-today", "surgery-tomorrow", "hospitalization", "dismiss"}. When a goal fact is inferred, no further questions are asked and the final medical recommendation is printed to the user interface. An example question is shown in Figure 3, and an example final recommendation in Figure 4.

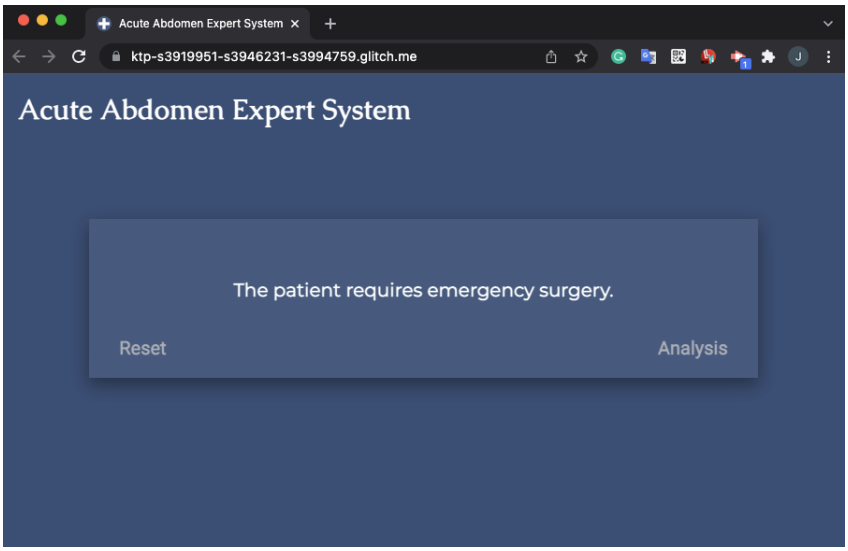

Figure 4: User interface demo - Final medical recommendation

The user can easily restart the session if they wish to start over at any point of the inference, using the `Reset` button. This option clears the trace, restores the knowledge base to default and restarts the system. We decided to add this functionality for convenience.

It is also possible to view the trace of reasoning by pressing on the `Analysis` button, which ensures the transparency of the system. This is important for when a medical professional wants to confirm that the system indeed works correctly, or when the responsible medical staff gives an explanation to the patient. It could be also useful for medical staff in training, as they are able to conveniently go through many scenarios and check the trace to confirm that their approach would be in line with the standard diagnosis procedure. If the user chooses the `Analysis` option, a text box with two sections pops up on the right of the user interface. The two sections provide the user with the real-time inferred facts ("Inferred facts" section), as well as a list of the rules that were used to infer the said facts ("Rule Analysis" section), as demonstrated in Figure 5.

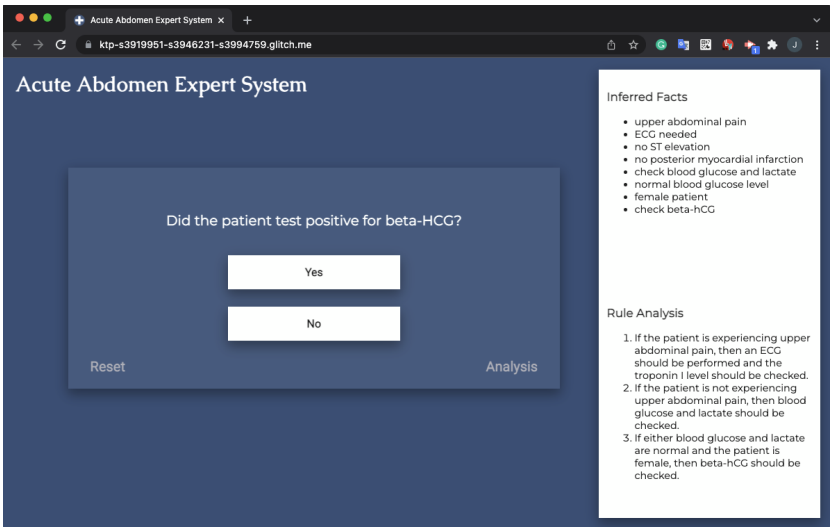

Figure 5: User interface demo - Analysis option

6 Walkthrough

A female patient walks into the ER and expresses concern about severe abdominal pain that she has been experiencing in the past days. No experienced doctor is available at the moment, so a first year resident opens up the user interface and starts the examination.

The system would first try to exclude the need for an emergency cardiological consultation. Therefore, it tries to check whether it applies to the patient. This goal would be true if Rule 2 would be true. Since that rule is a conjunction, the system tries to prove the first conjunct, *perform-ecg=true*. An ECG should be performed if the patient is experiencing upper abdominal pain. Thus, the first question pops up: "Is the patient experiencing upper abdominal pain?". The resident asks the patient, who answers no, the pain is in the lower abdomen. The resident presses on the button "No", and the system stores the fact "upper-abdominal-pain"="no". This answer means that no ECG is needed, so a cardiology emergency is excluded.

The next possible outcome is lactic acidosis. The system tries to prove Rule 4 in order to indicate acidosis. The result would be true if all conjuncts are true. Next, it tries to prove that there is a need for additional basic labs (Rule 3). From this, it infers a fact for the next medical test, namely "perform-basic-lab"="yes". This is the case as the patient is not experiencing abdominal pain. Then the system tries to prove the second conjunct of Rule 4. The resident opens the `Analysis` option, seeing that the currently inferred facts are "no upper abdominal pain" and "check blood glucose and lactate", and that this results from the system applying the rule "If the patient is not experiencing upper abdominal pain, then blood glucose and lactate should be checked" (Rule 3).

The resident performs the basic lab. He answers the next question "Is the blood glucose level increased?" with a "Yes", from which the system stores the fact "increased-blood-glucose"="yes". No rules can be applied yet. The next question asks "Is the lactate level increased?". Answering with a "No", the system stores "increased-lactate"="no". This leads to Rule 4 being false, lactic acidosis being excluded as a possible diagnosis.

Now the system tries to check if the patient needs to be transferred to gynecology. It tries to prove Rule 8, so the first conjunct, involving gynecology, is then being checked. A patient should be sent to gynecology if their beta-hCG has been checked and is positive (Rule 6). Beta-hCG should be checked if previous basic tests have been done, but they did not indicate acidosis and if the patient is female (Rule 5). The only conjunct with an unknown value is whether the patient is female, so the next question is "Is the patient female?". The resident answers "Yes". The system stores the fact "female"="yes". This indicates that indeed beta-hCG should be checked.

The resident then tests the patient for beta-HCG, which turns out to be positive. He answers "Did the patient test positive for beta-HCG?" with a "Yes". The fact is stored, Rule 6 is applied, and now the Analysis window now looks like this:

Inferred Facts

- no upper abdominal pain
- check blood glucose and lactate
- increased blood glucose level
- normal lactate level
- female patient
- check beta-hCG
- patient is likely pregnant

- gynecological opinion needed

Rule Analysis

1. If the patient is not experiencing upper abdominal pain, then blood glucose and lactate should be checked.

2. If either blood glucose and lactate are normal and the patient is female, then beta-hCG should be checked.

3. If the patient tests positive for beta-hCG, a gynecologist should get involved.

The resident calls a gynecologist who confirms that the patient is likely pregnant. The next question "The patient has gotten a consult from gynecology. Does the specialist suspect a gynecological issue?" is answered with a "Yes", and the system stores the fact "gynecological-issue"="yes". Finally, the rule "If the specialist suspects a gynecological issue, the patient should be transferred to gynecology" (Rule 8) passes, the system confirms the goal fact: "medical-recommendation"= "transfer-to-gynecology".

The final recommendation "The patient should be transferred to the gynecology department. The possible causes do not fall under the scope of ER, the patient might be pregnant." is presented on the user interface. Quickly skimming the Analysis box, the resident informs the patient that her beta-hCG levels indicated pregnancy and she should proceed to the gynecology department.

7 Project milestones and validation

User interface. After we finalised who our expert would be, we built a simple reactive website with HTML, CSS, and JavaScript and hosted it on glitch.com. We hard-coded a few reasoning steps in order to try out the user interface that we would later integrate with our reasoning system.

Topic choice. In the meantime, we had our first discussion with Katya, and came up with two ideas: dermatological diagnosis for the general public and emergency room diagnosis for medical professionals. We decided to go with the latter, as it seemed like a more pressing problem. General ER diagnosis would have been too broad for a short-term project, so we narrowed it down to ER diagnosis of acute abdomen, as Katya is experienced in this domain.

Knowledge base. During a second call with Katya, we had a structured discussion about the diagnostic process of acute abdomen. We then organised our notes into logical rules, and created a knowledge base - an XML file that we could run using the inference engine hosted at kat.ikhoefgeen.nl. During a third call with Katya, we explained to her in detail what we understood from the previous discussion and walked her through our knowledge base using the kat.ikhoefgeen.nl inference engine. She pointed out some inaccuracies in our reasoning, which we corrected after the session.

Inference engine. Then, in Javascript, we built the inference engine using backward chaining on a simplified knowledge base. We implemented all main components such as looking for an inferred fact in the knowledge base, asking the user about their opinion and trying to apply rules to infer new facts. After these all worked for the test knowledge base, we provided the system with the full knowledge base and fixed bugs that we did not previously notice.

Integration. Once we were sure that the knowledge base, inference engine, and user interface work as intended, we moved on to integrating these, and in the process, we improved on the aesthetic of the user interface.

Final touches. We got the feedback that we should show a trace and use more elaborate final medical recommendations, so we implemented the `Analysis` box and broadened the goal fact descriptions. During the final discussion with Katya, we showed her our close-to-finished

project. She confirmed that the presented information and inference were valid, and helped us formulate more elaborate final recommendations.

8 Task division

We collaborated closely on each part of the project, having frequent in-person meetings and calls on Discord. We approached the task division in a modular way as well. Each of us had the responsibility to organize and supervise one part of the project, but everyone was involved. We can describe our main responsibilities as follows:
Alina Dima - Implementation
Maria Kapusheva - Keeping in touch with the expert
Júlia Vághy - Report

9 Reflection, Conclusion

We believe that our project milestones were well-structured and working together was efficient. It was a good idea to build the system in a modular way before integrating everything. This way, we could validate each part separately, so it was simpler to find bugs and improve on inaccuracies.

The system could be further extended though. We would have liked to add a more robust base of checking whether the patient shows signs of sepsis, ischemia, peritonism or generalized peritonitis. Due to the complexity of each process and the limited time, we had to abandon these extensions.

Additionally, user functionality could be improved by adding a `Previous` button. Currently, if the user makes a mistake while answering, then they have to restart the whole system. This is quite inconvenient, but we did not have time to implement this feature.

Overall, we are happy with the finished product, especially because we built a framework that could potentially be used in real life. In fact, after we showed the finished system, Katya asked for our permission to introduce it to the medical staff in the ER Department of the SofiaMed University Hospital. Besides aiding inexperienced medical personnel, systems like our project could also be used in training medical students. Moreover, if the knowledge base is extended to domains beyond the acute abdomen, it could become a general diagnostic tool in ER.

10 Dictionary

1. **Abdomen CT with intravenous contrast** - Computer tomography on the abdominal area, when the patient has taken a substance that improves the visibility of the area during the imaging
2. **Beta-hCG** - hormone that helps distinguish pregnancy from dysfunctional uterine bleeding
3. **CT angiography** - medical test that uses computer tomography and an injected dye to produce better imaging of the blood vessels
4. **Generalized peritonitis** - Widespread inflammation of the abdominal tissue
5. **GI tube** - Gastronomy tube for feeding
6. **Ischemia** - Restricted or reduced blood flow to a part of the body
7. **Lactic acidosis** - Condition when lactic acid is accumulated in the blood

8. **Obstruction** - Blockage
9. **Peritonism** - Inflammation of the abdominal tissue
10. **Sepsis** - A condition when there is already an inflammation and the body's reaction targets and destroys its own tissues
11. **Sonography** - Medical procedure that uses sound waves for imaging
12. **ST elevation** - elevation of the ST segment in an electrocardiogram
13. **Testicular tortion** - Condition when the testicles twist and block the spermatic cord that provides blood to the organ
14. **Troponin I** - Complex of three regulatory proteins. It might indicate recent hearth attack