Reasoning about benefits and costs of interaction with users in real-time decision making environments with application to healthcare scenarios

Hyunggu Jung

School of Computer Science
University of Waterloo
(Supervisor: Prof. Robin Cohen)

July 23, 2010
Contents

1. Introduction
2. Background
3. Our Framework
4. Example
5. Validation
6. Discussion and Conclusions
Contents

• Introduction
• Background
• Our Framework
• Example
• Validation
• Discussion and Conclusions
Research in Computer Science

• Subfield in Artificial Intelligence
  – Models of reasoning with representations of knowledge
  – Problem solving on behalf of human users (intelligent agent)
Problem

• Problem
  – Reasoning about interaction between an intelligent agent and a user, in scenarios that are dynamic and time critical

• Intelligent agent
  – A software agent that has been designed to problem solve on behalf of its user, given a user goal and preferences, and knowledge of the environment in which it is operation
Solution

• Develop a decision-theoretic framework for deciding when an agent should enlist the problem solving assistance of a user

• Consider both the expected quality of decision and the possible cost of bothering the user
Contents

- Introduction
- **Background**
- Our Framework
- Example
- Validation
- Discussion and Conclusions
Background

• Agents and Multiagent Systems
• Mixed-Initiative Systems
• Fleming’s Model
• Adjustable Autonomy Systems
• Cheng’s Model
• Healthcare Summary
Agents and Multiagent Systems

• Intelligent agents
  – as an autonomous entity that observes and acts upon an environment and directs its activity in order to achieve its goals

• Multiagent Systems
  – systems in which several interacting, intelligent agents pursue some set of goals or perform some set of tasks
Mixed-Initiative Systems

• A system (i.e. an intelligent agent) and users form a problem solving partnership, where either party is able to take the initiative to solve the problem.

• Systems capable of mixed initiative interaction must include mechanisms for recognizing when to lead or take control of an interaction and when to relinquish control to collaborators.
Fleming’s Model

• A model for determining the interaction between the system and the user in a mixed-initiative system
• Starting point for our own research
Adjustable Autonomy Systems

- Any agent can offload decision making confine of its current task to a user or to another agent.
- Previous research led to a decision of the agent to retain decision making control or to transfer it to a single entity in the environment.
The Electric Elves Project

• Explored the challenge of adjustable autonomy multiagent systems
• Allowing agents involved in completing tasks on behalf of users to transfer decision making control to another entity in the environment, where an entity would either be another agent or one of the human users
The Electric Elves Project

• The concept of a transfer-of-control strategy: a planned sequence of transfer-of-control actions

• A plan to ask a particular entity but to wait a certain period of time before then asking a different entity, through to the end of the planned sequence

• Example $O_1[4] \rightarrow O_2[10] \rightarrow Agent$
Terminologies

• Transfer-of-Control
  – a planned sequence of transfer-of-control actions, including both those that actually transfer control and those that simply buy more time to get input

• An agent
  – responsible for making a decision

• Entities
  – n entities, $e_1, \ldots, e_n$, who can potentially make the decision; human users, other agents, or the agent itself
Terminologies

• **EQ(t)**
  – The expected quality (EQ)

• **P(t)**
  – The continuous probability distribution over time that the entity in control will respond with a decision of quality at time

• **W(t)**
  – the cost of delaying a decision until time t
  – assumed to be non-decreasing and that there is some point in time when the costs of waiting stop accumulating
Cheng’s Model

- Extends the Electric Elves model to allow each agent to reason about initiating information gathering interaction with a user before determining what to do next.
Full Transfer-of-Control (FTOC)

• Represents the agent fully transferring control to some entity at some time point \( t_i \) and writing until time point \( t_i+1 \) for a response.

• We regard the case of the agent deciding autonomously as an FTOC to the agent itself.
Partial Transfer-of-Control (PTOC)

- Represents the agent partially transferring control by asking some entity a query at some time point $t_{i+1}$ for a response.
- Each possible response to a query will be represented as a branch from the PTOC node to a strategy subtree representing what the agent should do when it receives that particular response.
Bother Cost Model

- Incorporating bother cost into reasoning about interaction
- Who to ask?
  - Proceed with the interaction only if the benefits exceed the costs
- Bother cost
  - Represents the degree to which a user would be annoyed, disrupted or inconvenienced by any interaction with the system
Expected Utility

\[ EU(s) = \sum_{LN_i} [P(LN_i) \times (EQ(LN_i) - W(T_{LN_i}) - BC_{LN_i})] \]

- **EQ(LN_i)**: the expected quality of the agent’s decision at leaf node
- **W(T_{LN_i})**: the costs of waiting until the time of leaf node
- **BC_{LN_i}**: the bother cost accumulated from interacting with entities
User Modeling

\[ Init = \text{User}_-\text{Unwillingness}_-\text{Factor} \times \text{Attention}_-\text{State}_-\text{Factor} \times \text{TOC}_-\text{Base}_-\text{Bother}_-\text{Cost} \]

\[ BSF(\text{BotherSoFar}) = \sum_{toc \in \text{PastTOC}} \text{TOC}_-\text{Base}_-\text{Bother}_-\text{Cost}(toc) \times \beta^{t(toc)} \]

\[ \text{BotherCost}(BC) = Init + BC_-\text{Inc}_-\text{Fn}(BSF,\text{User}_-\text{Unwillingness}_-\text{Factor}) \]
Healthcare Application

• Emergency room (or critical care)
• Patient: which medical expert to ask to help
  – Sensitive to bother cost
• Model for reasoning running, advising the first clinical assistants
Hospital Scenario

- FCA: First Clinical Assistant
- EMT: Emergency Medical Technician
- MS: Medical Specialist
hSITE Project

• The Healthcare Support through Information Technology Enhancements (hSITE)
  – Workflow, sensing, and networking

• The Natural Sciences and Engineering Research Council (NSERC) through its Strategic Network Grants Program [2008 - 2014]

Project our model into healthcare scenarios
Contents

• Introduction
• Background
• **Our Framework**
• Example
• Validation
• Discussion and Conclusions
Overview

• Reasoning about Interaction
  – Hybrid Transfer-of-Control Model
  – Strategy generation
  – Strategy evaluation

• User Modeling
  – Bother Cost Model
Reasoning about Interaction

• Introduce a model that can be used specifically for scenarios where an agent is reasoning about which human users to enlist to perform decision making, in an environment

• Decisions need to be made under critical time constraints and where the parameters that serve to model the human users are changing dynamically, to a significant extent
Model for Time Critical Scenarios

• Users = Medical Experts
• The strategies do not ask different entities within the same chain
  – yes, no, or silence responses
• At the end of this chain of attempts, we inject a final decision of strategy regeneration
  – Up to date parameter values
• Focus on handling the current patient: which expert to ask
Hybrid Transfer-of-Control Model

• Focus on one question:
  “Can you take over decision making?”

• Reasoning about
  partial transfers of control (PTOCs)
    - questions
  full transfers of control (FTOCs)
    - decision making

• Strategy: $U_1[t_1] U_2[t_2] U_3[t_3]$
Stream of time

No break by the end of the arrow

- Visual Representation of strategy with the FTOCs and PTOCs
- Each world occupies one square.
SG Node

• Allow a strategy chain to be regenerated
  – reflect current parameter values
• A decision is never made in a SG
  – the expected utility of a SG node (sg) is zero
• Encounter a SG node when the response from an entity is “No” or after an entire chain of silence, to the end of the strategy
• Assume that we are not considering strategies which involve the same entity more than once but are considering all possible entities

• The length of the strategy is then the maximum depth of the tree, which is the number of entities
Algorithm for Strategy Generation

GenerateStrategy (int i)
// i represents the length of the strategy chain to generate

if (i=1) // Base Case
    create a PTOC node
    create strategy by appending FTOC and SG node to the PTOC node

else
    S_(i-1) := GenerateStrategy (i-1)
    // Get the set of strategies of length i-1
    create a PTOC node, a FTOC node, and a SG node
    create strategy by appending the PTOC node to the PTOC in S_(i-1)
    create strategy by appending the FTOC and SG node to the PTOC node which
    has been just created

Return set of all newly created strategies

if (i == the number of entities)
    create a Default node
    create strategy by appending Default node to S_(the number of entities)
Strategy Evaluation

\[ EU_j(fn_l) = \prod_{pn_{prev}} p_{e_{prev}}^{\{resp=Silence\}} \times P_{e_i}^{\{resp=Yes\}} \times (EQ_{e_i}^d - W(t_e - t_s) - BC_{fn_l}) \]

- \( EU_j(fn_l) \) : the expected utility in the jth world of full transfer-of-control
- \( pn_{prev} \) : a partial transfer of entity
- \( p_{e_{prev}}^{\{resp=Silence\}} \) : the probability that asking all the previous entities the query will result in silence
- \( P_{e_i}^{\{resp=Yes\}} \) : the probability that asking the entity \( e_i \) the query will result in “Yes”
- \( EQ_{e_i}^d \) : the expected quality of decision, \( d \) the entity \( e_i \) has
- \( : \) the cost of waiting a decision between time \( t_s \) and \( t_e \)
Strategy Evaluation

• If the response is “no”,

\[ EU_j(\text{sg}) = \prod_{pn_{\text{prev}}} p^{\{\text{resp=Silence}\}}_{e_{\text{prev}}} \times P^{\{\text{resp=No}\}}_{e_i} \times (EQ_{e_i}^d - W(t_e - t_s) - BC_{sg} - SGC) \]

• If the response is Silence,

\[ EU_j(\text{dfl}) = \prod_{pn_{\text{prev}}} p^{\{\text{resp=Silence}\}}_{e_{\text{prev}}} \times P^{\{\text{resp=Silence}\}}_{e_i} \times (EQ_{e_i}^d - W(t_e - t_s) - BC_{sg} - SGC) \]
Expected Utility

\[ EU(s) = EU_n(dfl) + \sum_{j=1}^{n} (EU_j(fn_l) + EU_j(sg)) \]

• Want strategy with:
  – best quality of decision
  – least bother
User Modeling

- Attention State Factor
- Level of Expertise
- User Unwillingness Factor
- Task Criticality
- Probability of Response
Attention State Factor

• Whether the medical expert is occupied with another patient, for the scenario of hospital decision making

• RELAXED or BUSY
Level of Expertise

• User's knowledge as how likely it is that the user will have the required knowledge to answer the question
• Evaluates the knowledge to answer “Yes” for the specific question, “Can you take over the decision making?” in PTOC nodes
Lack of Expertise Factor

• Help to record the general level of expertise of each doctor, with respect to the kind of medical problem that the patient is exhibiting

• A high Lack of Expertise = a low level of expertise
User Unwillingness Factor

<table>
<thead>
<tr>
<th>Lack of Expertise Factor</th>
<th>Attention State Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Relaxed</td>
</tr>
<tr>
<td>Low</td>
<td>0.5</td>
</tr>
<tr>
<td>Med</td>
<td>0.75</td>
</tr>
<tr>
<td>High</td>
<td>1</td>
</tr>
</tbody>
</table>

User _Unwillingness _Factor =

Attention _State _Factor + Lack _of _Expertise _Factor

BotherCost(BC) = Init + BC _Inc _Fn(BSF,User _Unwillingness)
User Modeling

\[ Init = \text{User\_Unwillingness\_Factor} \times \text{Attention\_State\_Factor} \times \text{TOC\_Base\_Bother\_Cost} \]

\[ BSF(\text{BotherSoFar}) = \sum_{toc \in \text{Past\_TOC}} \text{TOC\_Base\_Bother\_Cost}(toc) \times \beta^{t(toc)} \]

\[ \text{BotherCost}(BC) = Init + BC\_Inc\_Fn(BSF, User\_Unwillingness\_Factor) \]
Task Criticality

- The TC of a patient who is not treated increases as time passes.
- Different increasing rates for each TC level:
  - low, medium, and high

<table>
<thead>
<tr>
<th>Task Criticality</th>
<th>[0,10)</th>
<th>[10, 80)</th>
<th>[80, ∞)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level of Task</strong></td>
<td>Low</td>
<td>Med</td>
<td>High</td>
</tr>
<tr>
<td><strong>Increasing Rate</strong></td>
<td>2 %</td>
<td>5 %</td>
<td>10 %</td>
</tr>
</tbody>
</table>
Task Criticality

Enable the expected quality of a decision to be weighted more heavily in the overall calculation of expected utility when the case at hand is very critical:

\[ \text{EQ}^d_{ei} \rightarrow \text{EQ}^d_{ei} + (\text{Weight} \times \text{EQ}^d_{ei}) \]
## Probability of Response

- The probability of response of users is influenced by the user’s willingness.

<table>
<thead>
<tr>
<th>User Unwillingness</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Willing</strong></td>
<td>60%</td>
</tr>
<tr>
<td><strong>Med-Willing</strong></td>
<td>50%</td>
</tr>
<tr>
<td><strong>Neutral</strong></td>
<td>40%</td>
</tr>
<tr>
<td><strong>Med-Unwilling</strong></td>
<td>30%</td>
</tr>
<tr>
<td><strong>Unwilling</strong></td>
<td>20%</td>
</tr>
</tbody>
</table>
Response Rate

- Assume that willingness person prefer to give a response quickly

<table>
<thead>
<tr>
<th>User Unwillingness Factor</th>
<th>1 unit</th>
<th>2 unit</th>
<th>3 unit</th>
<th>4 unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Willing</td>
<td>33 %</td>
<td>27 %</td>
<td>13 %</td>
<td>7 %</td>
</tr>
<tr>
<td>Med-Willing</td>
<td>27 %</td>
<td>23 %</td>
<td>17 %</td>
<td>13 %</td>
</tr>
<tr>
<td>Neutral</td>
<td>20 %</td>
<td>20 %</td>
<td>20 %</td>
<td>20 %</td>
</tr>
<tr>
<td>Med-Unwilling</td>
<td>13 %</td>
<td>17 %</td>
<td>23 %</td>
<td>27 %</td>
</tr>
<tr>
<td>Unwilling</td>
<td>7 %</td>
<td>13 %</td>
<td>27 %</td>
<td>33 %</td>
</tr>
</tbody>
</table>
Contents

• Introduction
• Background
• Our Framework
• Example
• Validation
• Discussion and Conclusions
Model Parameters

- \([\text{TOC\_Base\_Bother\_Cost}]\) 15
- \([\text{Time discount factor } \beta]\) 0.90
- \([\text{initial EQ}]\) 150
- \([\text{Cost of Waiting, } W(t)]\) 
  \[t^{0.6}\]
- \([\text{the Number of Worlds (n)}]\) 4
- \([\text{SGC}]\) 0 cost
Scenario 1

• For a patient with high criticality
• The expert chosen to be first in the strategy is the one who will deliver the best expected quality of decision and is also enduring the least bother
Profiles of Entities

- 4 medical experts in the emergency room

<table>
<thead>
<tr>
<th>Entity</th>
<th>ASF</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e_1$</td>
<td>Relaxed</td>
</tr>
<tr>
<td>$e_2$</td>
<td>Relaxed</td>
</tr>
<tr>
<td>$e_3$</td>
<td>Busy</td>
</tr>
<tr>
<td>$e_4$</td>
<td>Relaxed</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Entity</th>
<th>Specialized Area</th>
<th>Number of Patients</th>
<th>LEF</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e_1$</td>
<td>Cardio</td>
<td>7</td>
<td>Med</td>
</tr>
<tr>
<td>$e_2$</td>
<td>Cardio</td>
<td>100</td>
<td>Low</td>
</tr>
<tr>
<td>$e_3$</td>
<td>Cardio</td>
<td>0</td>
<td>High</td>
</tr>
<tr>
<td>$e_4$</td>
<td>Cardio</td>
<td>0</td>
<td>High</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Entity</th>
<th>Specialized Area</th>
<th>Number of Patients</th>
<th>LEF</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e_1$</td>
<td>Neuro</td>
<td>0</td>
<td>High</td>
</tr>
<tr>
<td>$e_2$</td>
<td>Neuro</td>
<td>0</td>
<td>High</td>
</tr>
<tr>
<td>$e_3$</td>
<td>Neuro</td>
<td>15</td>
<td>Med</td>
</tr>
<tr>
<td>$e_4$</td>
<td>Neuro</td>
<td>120</td>
<td>Low</td>
</tr>
</tbody>
</table>
Waiting List

- Choose p2 since the task criticality of p2 is highest among patients

<table>
<thead>
<tr>
<th>No.</th>
<th>Patient</th>
<th>Medical Problem</th>
<th>Task Criticality</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>p1</td>
<td>Cardio</td>
<td>70</td>
</tr>
<tr>
<td>2</td>
<td>p2</td>
<td>Cardio</td>
<td>90</td>
</tr>
<tr>
<td>3</td>
<td>p3</td>
<td>Neuro</td>
<td>63</td>
</tr>
<tr>
<td>4</td>
<td>p4</td>
<td>Cardio</td>
<td>82</td>
</tr>
<tr>
<td>5</td>
<td>p5</td>
<td>Neuro</td>
<td>70</td>
</tr>
</tbody>
</table>
Strategy Generation

• 4! Strategies are generated as there are 4 entities attending in this scenario.
Strategy Evaluation

• Set values of parameters for each entity based on the profile of the current patient
• Set the following parameters: lack of expertise factor, probability of response for answer, and response rate, bc_inc_fac, and Init
• Determine the bother cost of each entity using these parameter values
## Probability of Response

<table>
<thead>
<tr>
<th>Entity</th>
<th>ASF</th>
<th>LEF</th>
<th>UUF</th>
<th>PR for Yes</th>
<th>PR for No</th>
<th>PR for Silence</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e_1$</td>
<td>Relaxed</td>
<td>Med</td>
<td>Med – Willing</td>
<td>50%</td>
<td>30%</td>
<td>20%</td>
</tr>
<tr>
<td>$e_2$</td>
<td>Relaxed</td>
<td>Low</td>
<td>Willing</td>
<td>60%</td>
<td>20%</td>
<td>20%</td>
</tr>
<tr>
<td>$e_3$</td>
<td>Busy</td>
<td>High</td>
<td>Unwilling</td>
<td>20%</td>
<td>60%</td>
<td>20%</td>
</tr>
<tr>
<td>$e_4$</td>
<td>Relaxed</td>
<td>High</td>
<td>Medium</td>
<td>40%</td>
<td>40%</td>
<td>20%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Entity</th>
<th>ASF</th>
<th>LEF</th>
<th>UUF</th>
<th>1 unit</th>
<th>2 unit</th>
<th>3 unit</th>
<th>4 unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e_1$</td>
<td>Relaxed</td>
<td>Med</td>
<td>Med – Willing</td>
<td>27%</td>
<td>23%</td>
<td>17%</td>
<td>13%</td>
</tr>
<tr>
<td>$e_2$</td>
<td>Relaxed</td>
<td>Low</td>
<td>Willing</td>
<td>33%</td>
<td>27%</td>
<td>13%</td>
<td>7%</td>
</tr>
<tr>
<td>$e_3$</td>
<td>Busy</td>
<td>High</td>
<td>Unwilling</td>
<td>7%</td>
<td>13%</td>
<td>27%</td>
<td>33%</td>
</tr>
<tr>
<td>$e_4$</td>
<td>Relaxed</td>
<td>High</td>
<td>Medium</td>
<td>20%</td>
<td>20%</td>
<td>20%</td>
<td>20%</td>
</tr>
</tbody>
</table>
### Initial Values

<table>
<thead>
<tr>
<th>Entity</th>
<th>UUF</th>
<th>bc_inc_fac</th>
<th>Init</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e_1$</td>
<td>Med – Willing</td>
<td>1</td>
<td>8.4375</td>
</tr>
<tr>
<td>$e_2$</td>
<td>Willing</td>
<td>0.75</td>
<td>5.625</td>
</tr>
<tr>
<td>$e_3$</td>
<td>Unwilling</td>
<td>1.25</td>
<td>28.125</td>
</tr>
<tr>
<td>$e_4$</td>
<td>Medium</td>
<td>1</td>
<td>11.25</td>
</tr>
</tbody>
</table>

- $Init(e_1) = User\ Unwillingness\ Factor \times Attention\ State\ Factor \times TOC\ BaseBotherCost = 0.75 \times 0.75 \times 15 = 8.4375$
- $Init(e_2) = 0.5 \times 0.75 \times 15 = 5.625$
- $Init(e_3) = 1.5 \times 1.25 \times 15 = 28.125$
- $Init(e_4) = 1 \times 0.75 \times 15 = 11.25$
Optimal Strategy

• The optimal strategy chain is \( e_2 - e_1 - e_4 - e_3 \).
• \( EU(s^*) = 130.080393 \)
Scenario 2

• For a patient with high criticality
• A tension between choosing the best expert for this important task against the cost of bother, since this expert is currently at a high bother level as well
### Profiles of Entities

- 4 medical experts in the emergency room

<table>
<thead>
<tr>
<th>Entity</th>
<th>ASF</th>
<th>Specialized Area</th>
<th>Number of Patients</th>
<th>LEF</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e_1$</td>
<td><em>Relaxed</em></td>
<td>Cardio</td>
<td>7</td>
<td>Med</td>
</tr>
<tr>
<td>$e_2$</td>
<td><em>Busy</em></td>
<td>Cardio</td>
<td>100</td>
<td>Low</td>
</tr>
<tr>
<td>$e_3$</td>
<td><em>Busy</em></td>
<td>Cardio</td>
<td>0</td>
<td>High</td>
</tr>
<tr>
<td>$e_4$</td>
<td><em>Relaxed</em></td>
<td>Cardio</td>
<td>0</td>
<td>High</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Entity</th>
<th>Specialized Area</th>
<th>Number of Patients</th>
<th>LEF</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e_1$</td>
<td>Neuro</td>
<td>0</td>
<td>High</td>
</tr>
<tr>
<td>$e_2$</td>
<td>Neuro</td>
<td>0</td>
<td>High</td>
</tr>
<tr>
<td>$e_3$</td>
<td>Neuro</td>
<td>15</td>
<td>Med</td>
</tr>
<tr>
<td>$e_4$</td>
<td>Neuro</td>
<td>120</td>
<td>Low</td>
</tr>
</tbody>
</table>
Optimal Strategy

- The optimal strategy chain is $e_2 - e_4 - e_3$.
- $\text{EU}(s^*) = 110.031364$
Scenario 3

• For a patient with low criticality
• There is a best expert who is at a high state of bother, but where perhaps an expert with low bother and lower expertise will be adequate to approach
Profiles of Entities

- 4 medical experts in the emergency room

<table>
<thead>
<tr>
<th>Entity</th>
<th>ASF</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e_1$</td>
<td>Busy</td>
</tr>
<tr>
<td>$e_2$</td>
<td>Busy</td>
</tr>
<tr>
<td>$e_3$</td>
<td>Busy</td>
</tr>
<tr>
<td>$e_4$</td>
<td>Relaxed</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Entity</th>
<th>Specialized Area</th>
<th>Number of Patients</th>
<th>LEF</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e_1$</td>
<td>Cardio</td>
<td>7</td>
<td>Med</td>
</tr>
<tr>
<td>$e_2$</td>
<td>Cardio</td>
<td>100</td>
<td>Low</td>
</tr>
<tr>
<td>$e_3$</td>
<td>Cardio</td>
<td>2</td>
<td>High</td>
</tr>
<tr>
<td>$e_4$</td>
<td>Cardio</td>
<td>2</td>
<td>High</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Entity</th>
<th>Specialized Area</th>
<th>Number of Patients</th>
<th>LEF</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e_1$</td>
<td>Neuro</td>
<td>2</td>
<td>High</td>
</tr>
<tr>
<td>$e_2$</td>
<td>Neuro</td>
<td>2</td>
<td>High</td>
</tr>
<tr>
<td>$e_3$</td>
<td>Neuro</td>
<td>15</td>
<td>Med</td>
</tr>
<tr>
<td>$e_4$</td>
<td>Neuro</td>
<td>120</td>
<td>Low</td>
</tr>
</tbody>
</table>
Optimal Strategy

- The optimal strategy chain is $e_1 - e_2 - e_4 - e_3$.
- $\text{EU}(s^*) = 105.848998$
Contents

• Introduction
• Background
• Our Framework
• Example
• **Validation**
• Discussion and Conclusions
Experimental Setup

- **Software**
  - Matlab (R2010a)
- **Machine**
  - AMD athlon(tm) 64 X2 Dual, Core Processor 5600+, 2.91 GHz, and 3.25 GB of RAM
Experimental Setup

- 4 entities on the entity list and 5 patients on the waiting list.

<table>
<thead>
<tr>
<th>Entity</th>
<th>ASF</th>
<th>Specialized Area</th>
<th>Number of Patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>e₁</td>
<td>Relaxed</td>
<td>Cardio</td>
<td>7</td>
</tr>
<tr>
<td>e₂</td>
<td>Relaxed</td>
<td>Cardio</td>
<td>100</td>
</tr>
<tr>
<td>e₃</td>
<td>Relaxed</td>
<td>Neuro</td>
<td>15</td>
</tr>
<tr>
<td>e₄</td>
<td>Relaxed</td>
<td>Neuro</td>
<td>120</td>
</tr>
<tr>
<td>*e₅</td>
<td>Relaxed</td>
<td>Neuro</td>
<td>240</td>
</tr>
<tr>
<td>*e₆</td>
<td>Relaxed</td>
<td>Cardio</td>
<td>98</td>
</tr>
</tbody>
</table>
Purpose

• To show performance of our model reflecting dynamic and time critical aspects by comparing it with one that is missing the following factors:
  – Time Cost and Bother Cost
  – Strategy Regeneration
  – Task Criticality
Method

• The task criticality of each patient is changed dynamically as time progresses

• If the task criticality of the a patient increased over 100, we model this as a dead patient

• By comparing the number of dead patients simulated by our model, we validate whether our model reflects dynamic and time critical domains effectively.
Strategy Regeneration

![Graph 1: Number of Dead Patients (4 entity case)](image1)

- **With SG**
- **W/O SG**

![Graph 2: Number of Dead Patients (6 entity case)](image2)

- **With SG**
- **W/O SG**
Task Criticality

- With Weights
- Without Weights

Number of Dead Patients
(4 entity case)

Frequency

Number of Dead Patients
(6 entity case)

Frequency
Contents

• Introduction
• Background
• Our Framework
• Example
• Validation
• **Discussion and Conclusions**
Future Work

• Sensor and Learning Techniques
• Probability of Response
• Attention State Factor
• Lack of Expertise Factor
• User Unwillingness Factor

• Enhancing the PTOC Question
• Calculating the Timing in the Strategy Chains
• Revisiting Strategy Regeneration
• Task and Resource Allocation Problem
• Exploring other Application Areas
Sensor and Learning Techniques

From sensors

- Assess the attentional state of the medical experts based on devices which register patient status
- The time and location of the medical experts could be known and this could be another influence in determining the expected quality of decision

By learning techniques

- The parameter values obtained by using learning techniques do not reflect the current situation as effectively as using the sensor
- Gives the system less burden to use the learning techniques
• Worthwhile to integrate into the estimate for probability of response a calculation of how much stress the doctor has been under, due to workload with patients that day

• For example, if the doctor has been relaxed longer than other doctors at this point, more relaxed doctor would have less stress
Task and Resource Allocation Problem

• Multiple tasks that need to be addressed at once and multiple resources that can be brought to bear in order to address those tasks

• Effective task and resource allocation scheme, whereby tasks that are executed simultaneously do not try to make use of exactly the same resources at the same time
Related Work

- Mixed-initiative and adjustable autonomy systems
  - Fleming [1]
  - Cheng [2]
- Modeling Bother Cost
  - Raskutti and Zukerman [3]
  - Horvitz et al. [4]
Conclusions

• Examines the challenge of having agents reason about whether to interact with users, in multiagent, multi-user scenarios

• Extends previous efforts in reasoning about interaction with users, as part of either mixed-initiative or adjustable autonomy multiagent systems

• Value for reasoning about medical experts to assist in emergency room
Reference


