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

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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 n 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* $U_1[5]\ U_2[10]\ Agent$
  –

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, … ,e_n, who can potentially make the decision; human users, other agents, or the agent itself

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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

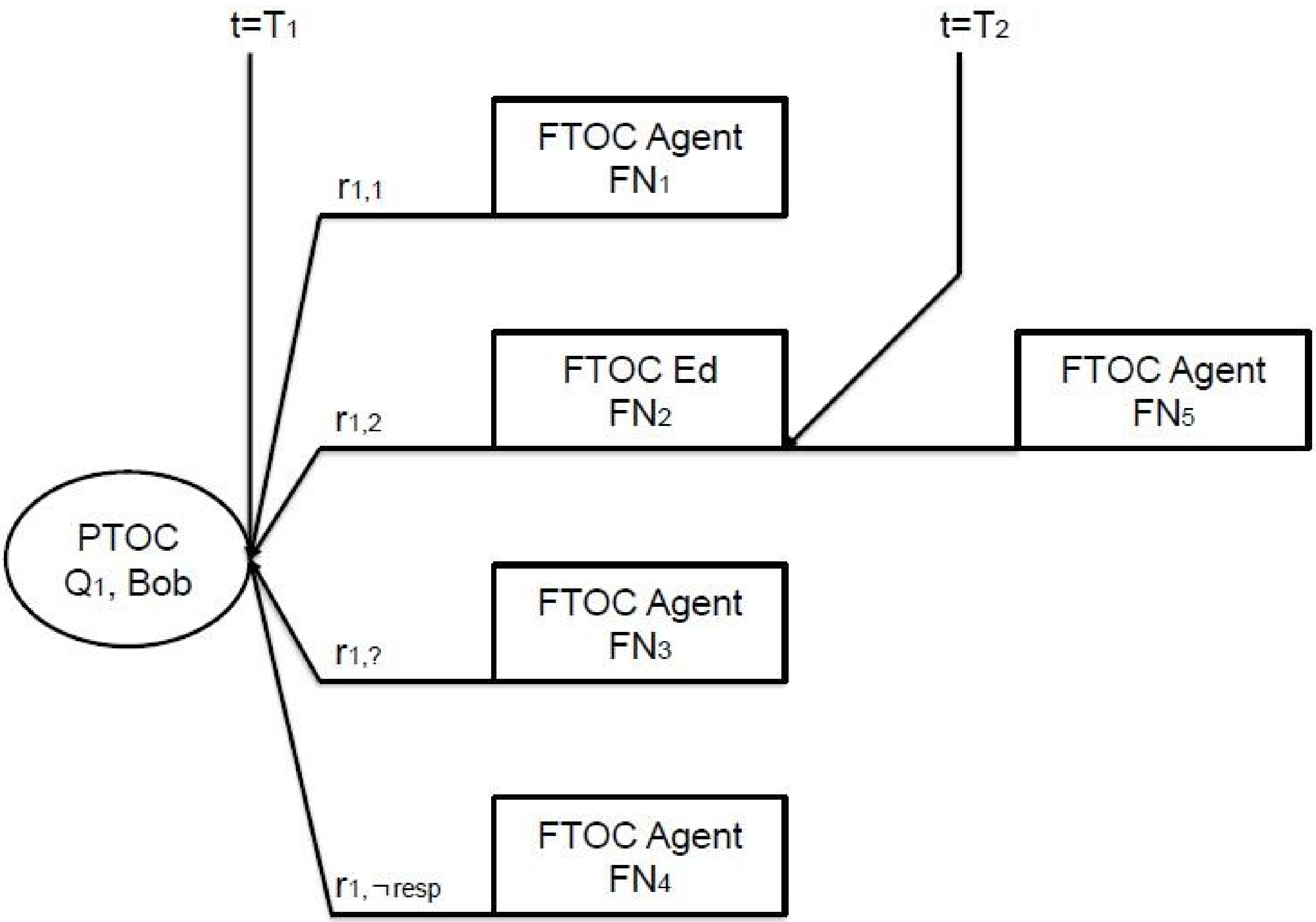
Full Transfer-of-Control (FTOC)

- Represents the agent fully transferring control to some entity at some time point ti and writing until time point ti+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 ti+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

Visual Representation



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

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

- $EQ(LN_l)$: the expected quality of the agent's decision at leaf node LN_l
- $W(T_{LN_l})$: the costs of waiting until the time of leaf node LN_l
- BC_{LN_l} : the bother cost accumulated from interacting with entities

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User Modeling

$$Init = User\_Unwillingness\_Factor$$
$$\times Attention\_State\_Factor \times TOC\_Base\_Bother\_Cost$$

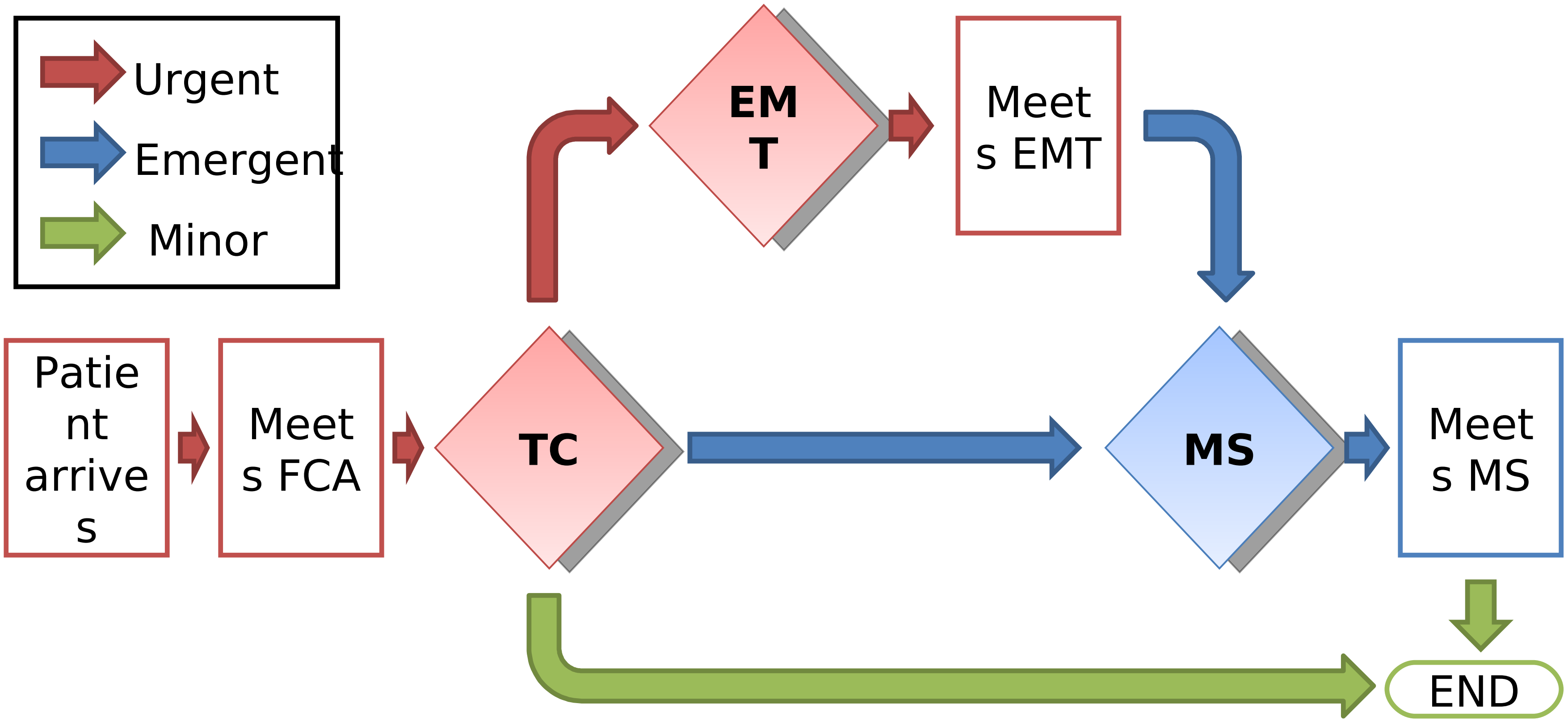
$$BSF(BotherSoFar)$$
$$= \sum_{toc \in PastTOC} TOC\_Base\_Bother\_Cost(toc) \times \beta^{t(toc)}$$

$$BotherCost(BC)$$
$$= Init + BC\_Inc\_Fn(BSF, User\_Unwillingness\_Factor)$$

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

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- Introduction
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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

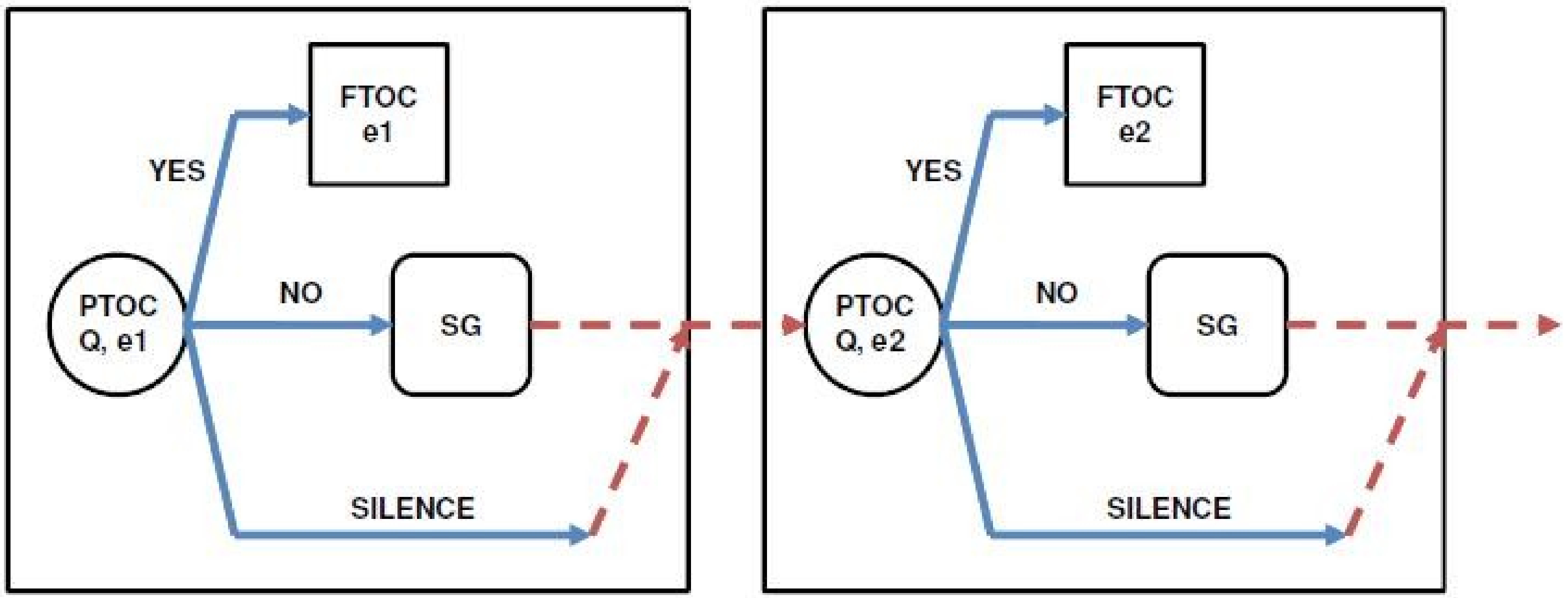
  full transfers of control (FTOCs)

  - decision making
- Strategy: $U_1[t_1]\ U_2[t_2]\ U_3[t_3]$

Visual Representation

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

Strategy Generation

- 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 e_{prev}
- $P_{e_{prev}}^{\{resp=Silence\}}$: the probability that asking all the previous entities the query will result in silence
- $P_{e_{prev}}^{\{resp=Yes\}}$: the probability that asking the entity ei the query will result in “Yes”
- $EQ_{e_i}^d$: the expected quality of decision, d the entity ei has
- $W(t_e - t_s)$: the cost of waiting a decision between time ts and te

Strategy Evaluation

- If the response is “no”,

$$EU_j(sg) = \prod_{pn_{prev}} p_{e_{prev}}^{\{resp=Silence\}} \times P_{e_i}^{\{resp=No\}} \times (EQ_{e_i}^{d} - W(t_e - t_s) - BC_{sg} - SGC)$$

- If the response is Silence,

$$EU_j(dfl) = \prod_{pn_{prev}} p_{e_{prev}}^{\{resp=Silence\}} \times P_{e_i}^{\{resp=Silence\}} \times (EQ_{e_i}^{d} - W(t_e - t_s) - BC_{sg} - SGC)$$

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

		Attention State Factor		
		Relaxed	**Neutral**	**Busy**
Lack of Expertise Factor	**Low**	0.5	0.75	1
	Med	0.75	1	1.25
	High	1	1.25	1.5

$$User\_Unwillingness\_Factor = Attention\_State\_Factor + Lack\_of\_Expertise\_Factor$$

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

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User Modeling

$$Init = User\_Unwillingness\_Factor$$
$$\times Attention\_State\_Factor \times TOC\_Base\_Bother\_Cost$$

$$BSF(BotherSoFar)$$
$$= \sum_{toc \in PastTOC} TOC\_Base\_Bother\_Cost(toc) \times \beta^{t(toc)}$$

$$BotherCost(BC)$$
$$= Init + BC\_Inc\_Fn(BSF, User\_Unwillingness\_Factor)$$

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

	Task Criticality		
	[0,10)	***[10, 80)***	***[80, ∞]***
Level of Task Criticality	Low	Med	High
Increasing Rate	2 %	5 %	10 %

Task Criticality

Task Criticality	High			Med			Low		
Lack_of_Expertise_Factor	Low	Med	High	Low	Med	High	Low	Med	High
Weight	10%	0%	-10%	5%	5%	-5%	0%	0%	0%

- 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

$$EQ_{e_i}^{d} \rightarrow EQ_{e_i}^{d} + (Weight \times EQ_{e_i}^{d})$$

Probability of Response

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

User Unwillingness Factor	Response		
	Yes	No	Silence
Willing	60 %	20 %	20 %
Med-Willing	50 %	30 %	20 %
Neutral	40 %	40 %	20 %
Med-Unwilling	30 %	50 %	20 %
Unwilling	20 %	60 %	20 %

Response Rate

- Assume that willingness person prefer to give a response quickly

User Unwillingness Factor	Response Rate			
	1 unit	***2 unit***	***3 unit***	***4 unit***
Willing	33 %	27 %	13 %	7 %
Med-Willing	27 %	23 %	17 %	13 %
Neutral	20 %	20 %	20 %	20 %
Med-Unwilling	13 %	17 %	23 %	27 %
Unwilling	7 %	13 %	27 %	33 %

Contents

Model Parameters

- [TOC_Base_Bother_Cost] *15*
- [Time discount factor β] *0.90*
- [initial EQ] *150*
- [Cost of Waiting, W(t)] $t^{1.5}$
- [the Number of Worlds (n)] *4*
- [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

Entity	ASF
e_1	*Relaxed*
e_2	*Relaxed*
e_3	*Busy*
e_4	*Relaxed*

Entity	Specialized Area	Number of Patients	LEF
e_1	*Cardio*	7	Med
e_2	*Cardio*	100	Low
e_3	*Cardio*	0	High
e_4	*Cardio*	0	High

Entity	Specialized Area	Number of Patients	LEF
e_1	*Neuro*	0	High
e_2	*Neuro*	0	High
e_3	*Neuro*	15	Med
e_4	*Neuro*	120	Low

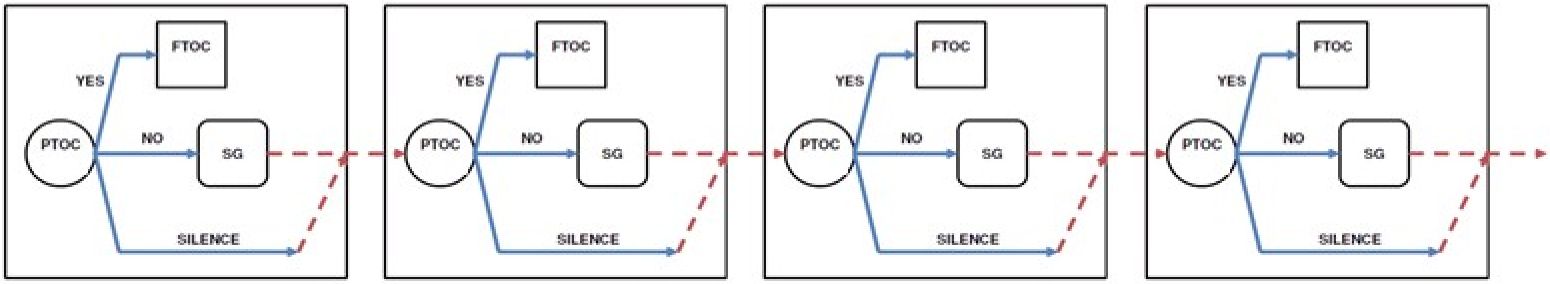
Waiting List

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

No.	Patient	Medical Problem	Task Criticality
1	p_1	$Cardio$	70
2	p_2	$Cardio$	90
3	p_3	$Neuro$	63
4	p_4	$Cardio$	82
5	p_5	$Neuro$	70

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

Entity	ASF	LEF	UUF	PR for Yes	PR for No	PR for Silence
e_1	$Relaxed$	Med	$Med - Willing$	50%	30%	20%
e_2	$Relaxed$	Low	$Willing$	60%	20%	20%
e_3	$Busy$	$High$	$Unwilling$	20%	60%	20%
e_4	$Relaxed$	$High$	$Medium$	40%	40%	20%

Entity	ASF	LEF	UUF	1 unit	2 unit	3 unit	4 unit
e_1	$Relaxed$	Med	$Med - Willing$	27%	23%	17%	13%
e_2	$Relaxed$	Low	$Willing$	33%	27%	13%	7%
e_3	$Busy$	$High$	$Unwilling$	7%	13%	27%	33%
e_4	$Relaxed$	$High$	$Medium$	20%	20%	20%	20%

Initial Values

Entity	UUF	bc_inc_fac	Init
e_1	$Med - Willing$	1	8.4375
e_2	$Willing$	0.75	5.625
e_3	$Unwilling$	1.25	28.125
e_4	$Medium$	1	11.25

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

Optimal Strategy

- The optimal strategy chain is $e_2 - e_1 - e_4 - e_3$.
- EU(s*) = *130.080393*

No.	Expected Utility (EU)	Strategy Chain
1	113.707732	e_1 - e_2 - e_3 - e_4
2	114.581042	e_1 - e_2 - e_4 - e_3
3	103.964326	e_1 - e_3 - e_2 - e_4
4	102.780795	e_1 - e_3 - e_4 - e_2
5	106.715640	e_1 - e_4 - e_3 - e_2
6	108.785957	e_1 - e_4 - e_2 - e_3
7	129.207084	e_2 - e_1 - e_3 - e_4
8	130.080393	e_2 - e_1 - e_4 - e_3
9	123.195320	e_2 - e_3 - e_1 - e_4
10	122.913160	e_2 - e_3 - e_4 - e_1
11	126.859259	e_2 - e_4 - e_3 - e_1
12	128.025983	e_2 - e_4 - e_1 - e_3
13	75.616428	e_3 - e_2 - e_1 - e_4
14	75.334268	e_3 - e_2 - e_4 - e_1
15	71.884786	e_3 - e_1 - e_2 - e_4
16	70.701255	e_3 - e_1 - e_4 - e_2
17	68.646845	e_3 - e_4 - e_1 - e_2
18	69.552732	e_3 - e_4 - e_2 - e_1
19	99.140234	e_4 - e_2 - e_3 - e_1
20	100.306958	e_4 - e_2 - e_1 - e_3
21	89.412599	e_4 - e_3 - e_2 - e_1
22	88.506712	e_4 - e_3 - e_1 - e_2
23	94.495967	e_4 - e_1 - e_3 - e_2
24	96.566284	e_4 - e_1 - e_2 - e_3

4	102.780795	e_1 - e_3 - e_4 - e_2
5	106.715640	e_1 - e_4 - e_3 - e_2
6	108.785957	e_1 - e_4 - e_2 - e_3
7	129.207084	e_2 - e_1 - e_3 - e_4
8	130.080393	e_2 - e_1 - e_4 - e_3
9	123.195320	e_2 - e_3 - e_1 - e_4
10	122.913160	e_2 - e_3 - e_4 - e_1
11	126.859259	e_2 - e_4 - e_3 - e_1

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

Entity	ASF
e_1	*Relaxed*
e_2	*Busy*
e_3	*Busy*
e_4	*Relaxed*

Entity	Specialized Area	Number of Patients	LEF
e_1	*Cardio*	7	Med
e_2	*Cardio*	100	Low
e_3	*Cardio*	0	High
e_4	*Cardio*	0	High

Entity	Specialized Area	Number of Patients	LEF
e_1	*Neuro*	0	High
e_2	*Neuro*	0	High
e_3	*Neuro*	15	Med
e_4	*Neuro*	120	Low

Optimal Strategy

- The optimal strategy chain is $e_1 - e_2 - e_4 - e_3$.
- EU(s*) = *110.031364*

No.	Expected Utility (EU)	Strategy Chain
1	109.158054	e_1 - e_2 - e_3 - e_4
2	110.031364	e_1 - e_2 - e_4 - e_3
3	103.040701	e_1 - e_3 - e_2 - e_4
4	102.608701	e_1 - e_3 - e_4 - e_2
5	106.566054	e_1 - e_4 - e_3 - e_2
6	107.871364	e_1 - e_4 - e_2 - e_3
7	107.738381	e_2 - e_1 - e_3 - e_4
8	108.611691	e_2 - e_1 - e_4 - e_3
9	101.726617	e_2 - e_3 - e_1 - e_4
10	101.444457	e_2 - e_3 - e_4 - e_1
11	105.390556	e_2 - e_4 - e_3 - e_1
12	106.557280	e_2 - e_4 - e_1 - e_3
13	71.066750	e_3 - e_2 - e_1 - e_4
14	70.784590	e_3 - e_2 - e_4 - e_1
15	70.961161	e_3 - e_1 - e_2 - e_4
16	70.529161	e_3 - e_1 - e_4 - e_2
17	68.474750	e_3 - e_4 - e_1 - e_2
18	68.624590	e_3 - e_4 - e_2 - e_1
19	94.590556	e_4 - e_2 - e_3 - e_1
20	95.757280	e_4 - e_2 - e_1 - e_3
21	88.484457	e_4 - e_3 - e_2 - e_1
22	88.334617	e_4 - e_3 - e_1 - e_2
23	94.346381	e_4 - e_1 - e_3 - e_2
24	95.651691	e_4 - e_1 - e_2 - e_3

1	109.158054	e_1 - e_2 - e_3 - e_4
2	110.031364	e_1 - e_2 - e_4 - e_3
3	103.040701	e_1 - e_3 - e_2 - e_4
4	102.608701	e_1 - e_3 - e_4 - e_2
5	106.566054	e_1 - e_4 - e_3 - e_2
6	107.871364	e_1 - e_4 - e_2 - e_3
7	107.738381	e_2 - e_1 - e_3 - e_4
8	108.611691	e_2 - e_1 - e_4 - e_3

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

Entity	ASF
e_1	*Busy*
e_2	*Busy*
e_3	*Busy*
e_4	*Relaxed*

Entity	Specialized Area	Number of Patients	LEF
e_1	*Cardio*	7	Med
e_2	*Cardio*	100	Low
e_3	*Cardio*	2	High
e_4	*Cardio*	2	High

Entity	Specialized Area	Number of Patients	LEF
e_1	*Neuro*	2	High
e_2	*Neuro*	2	High
e_3	*Neuro*	15	Med
e_4	*Neuro*	120	Low

Optimal Strategy

- The optimal strategy chain is $e_1 - e_2 - e_4 - e_3$.
- EU(s*) = *105.848998*

No.	Expected Utility (EU)	Strategy Chain
1	92.028054	e_1 - e_2 - e_3 - e_4
2	92.901364	e_1 - e_2 - e_4 - e_3
3	90.230701	e_1 - e_3 - e_2 - e_4
4	90.182701	e_1 - e_3 - e_4 - e_2
5	94.140054	e_1 - e_4 - e_3 - e_2
6	95.061364	e_1 - e_4 - e_2 - e_3
7	94.415688	e_2 - e_1 - e_3 - e_4
8	95.288998	e_2 - e_1 - e_4 - e_3
9	92.469555	e_2 - e_3 - e_1 - e_4
10	92.230492	e_2 - e_3 - e_4 - e_1
11	96.199099	e_2 - e_4 - e_3 - e_1
12	97.300218	e_2 - e_4 - e_1 - e_3
13	81.009687	e_3 - e_2 - e_1 - e_4
14	80.770625	e_3 - e_2 - e_4 - e_1
15	81.158468	e_3 - e_1 - e_2 - e_4
16	81.110468	e_3 - e_1 - e_4 - e_2
17	83.121687	e_3 - e_4 - e_1 - e_2
18	82.930625	e_3 - e_4 - e_2 - e_1
19	104.599099	e_4 - e_2 - e_3 - e_1
20	105.700218	e_4 - e_2 - e_1 - e_3
21	102.790492	e_4 - e_3 - e_2 - e_1
22	102.981555	e_4 - e_3 - e_1 - e_2
23	104.927688	e_4 - e_1 - e_3 - e_2
24	105.848998	e_4 - e_1 - e_2 - e_3

16	81.110468	e_3 - e_1 - e_4 - e_2
17	83.121687	e_3 - e_4 - e_1 - e_2
18	82.930625	e_3 - e_4 - e_2 - e_1
19	104.599099	e_4 - e_2 - e_3 - e_1
20	105.700218	e_4 - e_2 - e_1 - e_3
21	102.790492	e_4 - e_3 - e_2 - e_1
22	102.981555	e_4 - e_3 - e_1 - e_2
23	104.927688	e_4 - e_1 - e_3 - e_2
24	105.848998	e_4 - e_1 - e_2 - e_3

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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 th

Entity	ASF	Specialized Area	Number of Patients
e_1	*Relaxed*	*Cardio*	7
e_2	*Relaxed*	*Cardio*	100
e_3	*Relaxed*	*Neuro*	15
e_4	*Relaxed*	*Neuro*	120
$*e_5$	*Relaxed*	*Neuro*	240
$*e_6$	*Relaxed*	*Cardio*	98

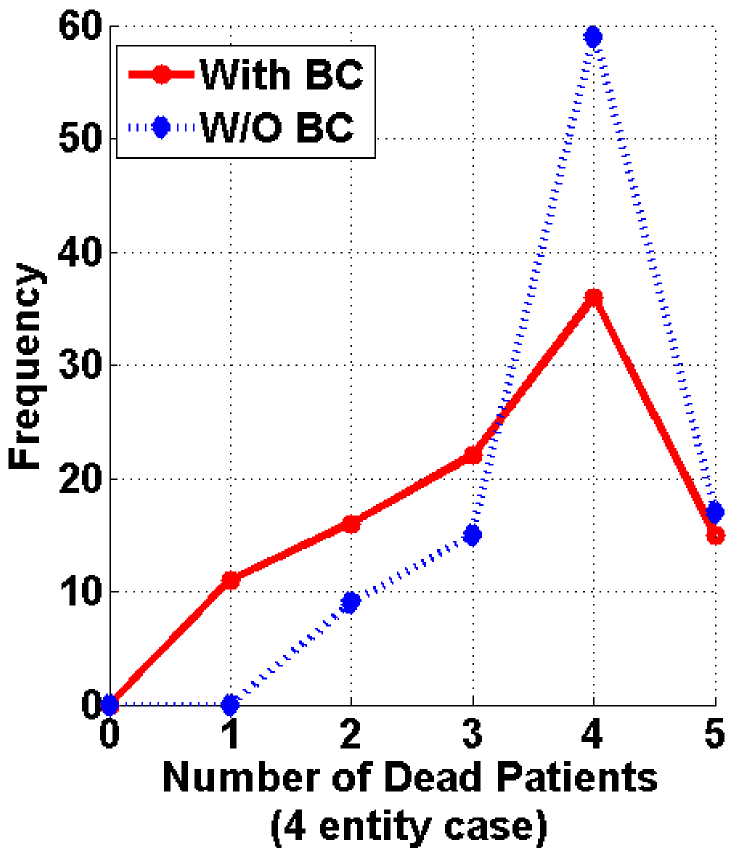
Purpose

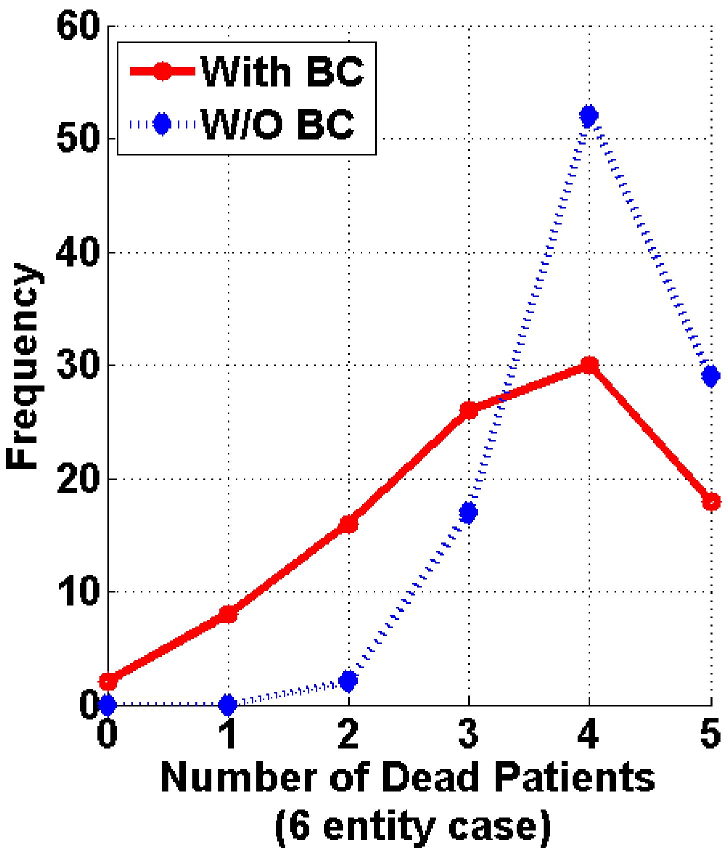
- To show performance of our model reflecting dynamic and time critical aspects
  by comparing it with one that is missing the following factors:
  - Time Cost and Bother Cost
  - Strategy Regeneration
  - Task Criticality

Method

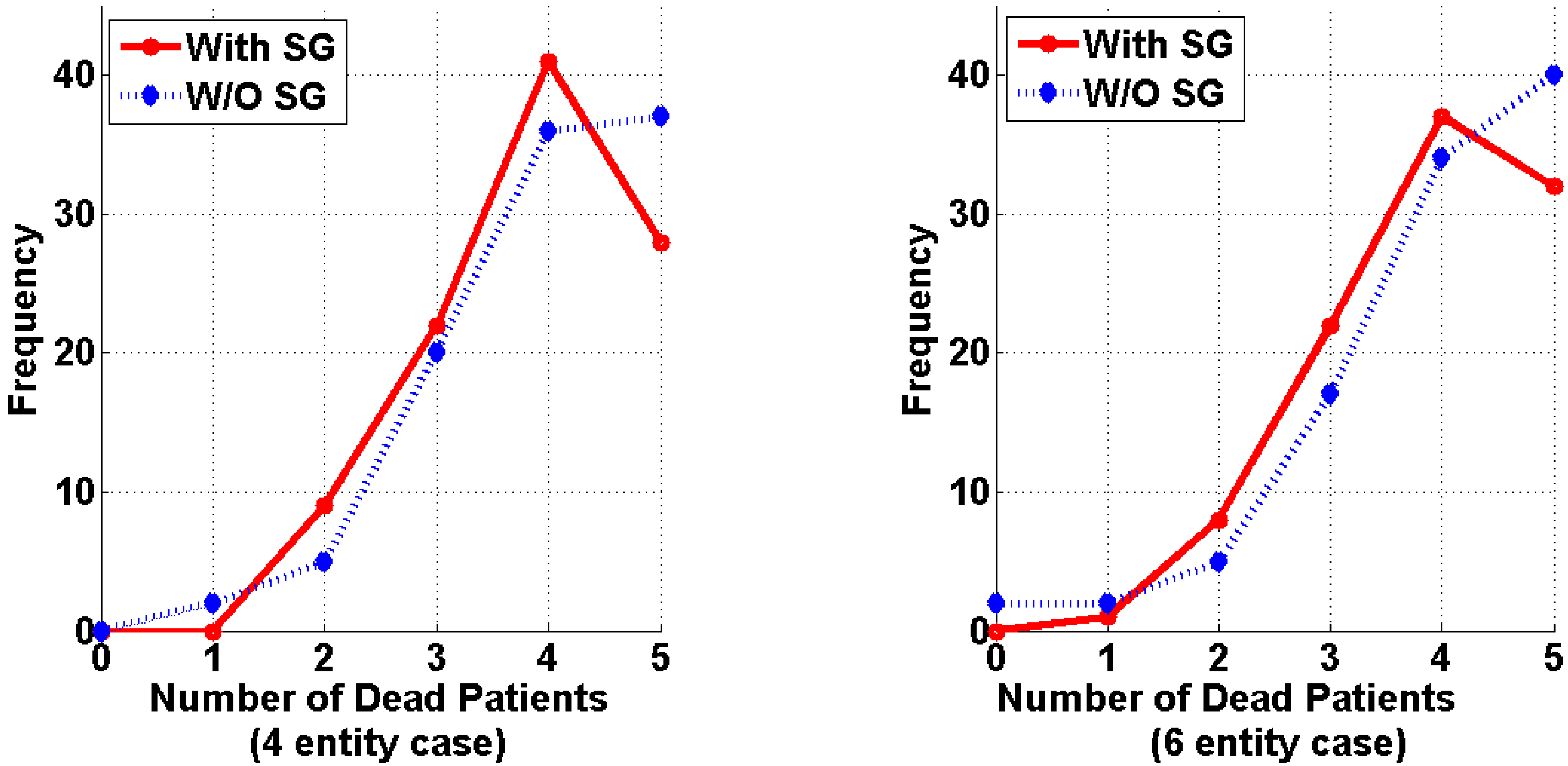
- The task criticality of each patient is changed dynamically as time progresses
- If the task criticality of the a patient increased over *100*, we model this as a dead patient
- By comparing the number of dead patients simulated by our model, we validate whether our model reflects dynamic and time critical domains

Time Cost and Bother Cost

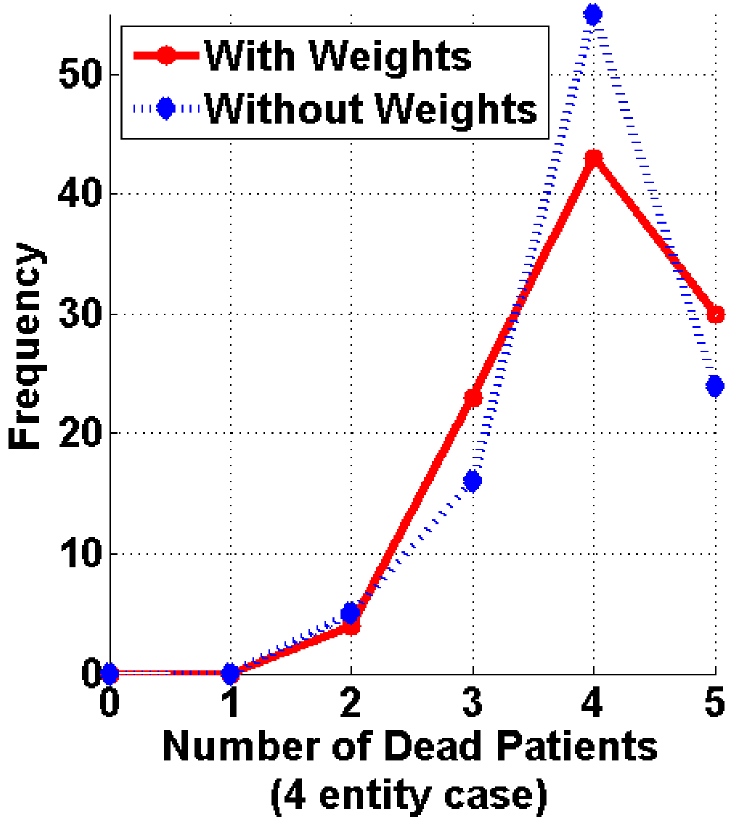


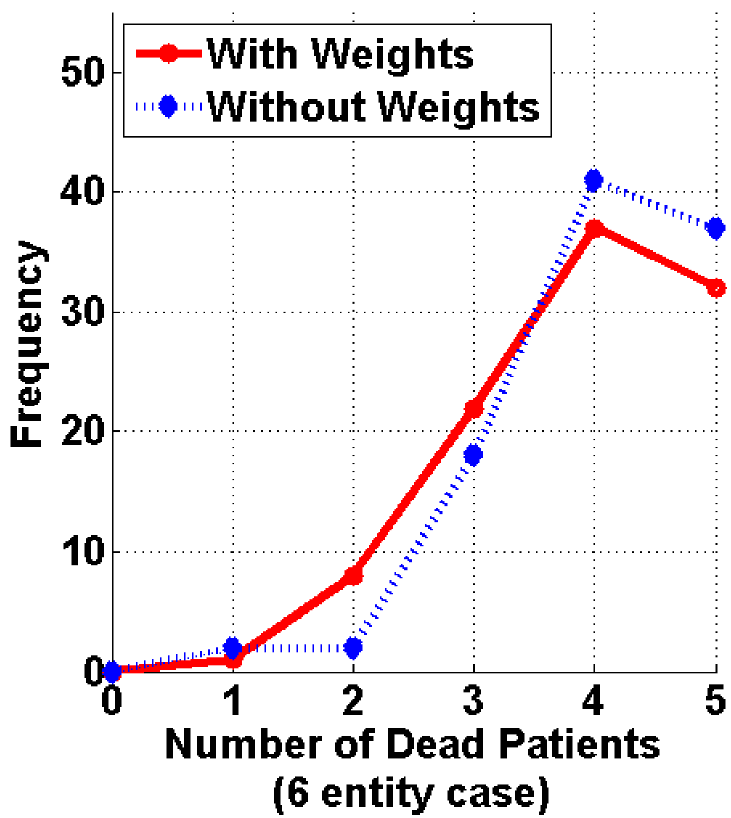


Strategy Regeneration



Task Criticality





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Future Work

- Sensor and Learning Techniques
- Probability of Response
- Attention State Factor
- Lack of Expertise Factor
- User Unwillingness Factor
- Expected Quality of Decision
- 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

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Probability of Response

- 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

[1] M. Fleming. Reasoning about Interaction in Mixed-Initiative Artificial Intelligence Systems. PhD thesis, University of Waterloo, 2003.

[2] M. Cheng. A hybrid transfer of control approach to designing adjustable autonomy multiagent systems. Master of Mathematics thesis, University of Waterloo, Waterloo, Ontario, 2005.

[3] B. Raskutti and I. Zukerman. Generating queries and replies during informationseeking interactions. International Journal of Human Computer Studies, 47(6):689-734, 1997.

[4] E. Horvitz and J. Apacible. Learning and reasoning about interruption. In Proceedings of the 5th International Conference on Multimodal Interfaces (ICMI'03), pages 20-27, 2003.