Multi-Agent Patient Scheduling Using Decentralized MDPs

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1.Connections to hSITE

Pivot role in Theme 1: *"...systematically modeling clinical workflows, in order to identify sources of inefficiencies and threats to patient safety, and explore ways in which advanced clinical information infrastructures could improve on these inefficiencies and optimize quality of care..."*
Resource allocation: *"...some applications in real-time resource allocation methods within a hospital have been reported, in which workflow models help in allocating rooms, clinicians and equipment."*

2.Motivation

Many AI researchers have studied the problems of resource allocation and showed that finding an optimal solution is computationally expensive (NP-hard).
Multi-agent systems can provide a proper framework to address these issues in highly dynamic and real-time scenarios to optimizing the allocation of resources, and therefore, increasing throughput.

3.Contributions

We propose a multi-agent approach for scheduling patients in hospitals based on their health state and their medical pathways. This approach uses local **Markov decision processes** (MDP) to capture the stochastic nature of medical tasks and model the sequence of medical tasks. An **auction-based mechanism** is proposed to coordinate the decentralized MDPs and maximize the overall gain (minimizing suffer) among the patients under uncertainty.

4.A Subproblem

Problem: Hospitals need to optimize the use of their resources in order to maximize their throughput.
Solution: As optimal solution is computationally expensive, we propose a decentralized multi-agent resource/task scheduling technique.
Assumptions: Resources such as operating theaters, beds, medical devices (MRI, CT, etc.), physicians, and surgeons.

10.Conclusion & Future Work

- Stochastic patient scheduling model under uncertainty to find a fair and near-to-optimal allocation of resources
- Auction-based system to promote independencies whilst providing coordination

Future Directions:

- Right person, right time
- More detailed health-state function and Experimenting with real data

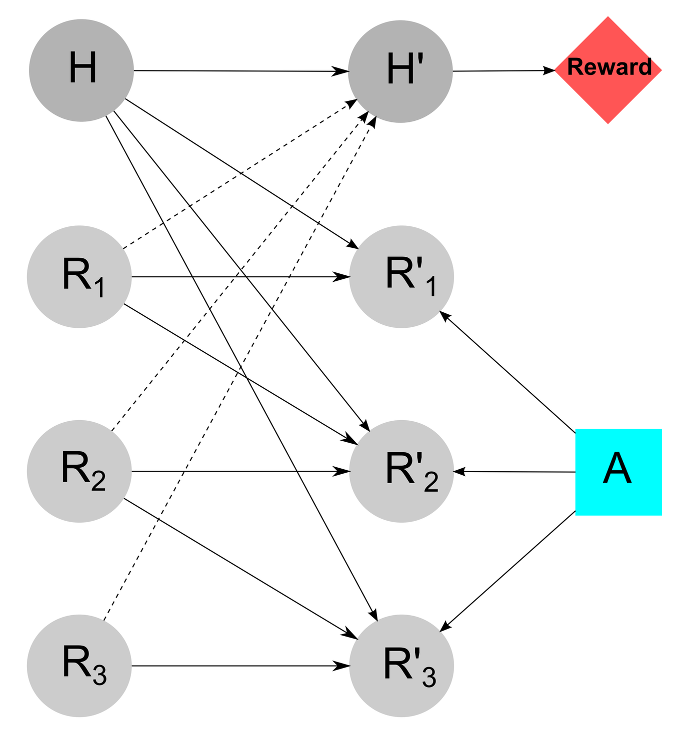
Multi-agent Resource Allocation:

- Combinatorial auctions → bundle of resources
- Mechanism design → eliciting preferences, priorities
- Exchange and Negotiation Protocols

5.Distributed Patient Scheduling

- Patients and Resources as *software agents*
- The real-time nature of emergency departments, patient arrivals is a vital factor
- Treatment and diagnosis durations are unknown, under uncertainty
- Concept of fairness: health related
- Market-based mechanism for coordinating Dec-MDPs

6.Decentralized MDPs



- Each patient maintains a Dec-MDP representing his/her tasks.
- Patients should go through a sequence of medical tests/treatments, as medical tasks are dependent to the results of the previous tests (Order is a key factor!)

7.Rewarding and Pricing

Reward: Health-based utility function

- Utility of completing all medical tasks (Reward): $Reward^p(t) = H^p_{max} - H^p(t)$
- Assuming that by finishing your medical pathway, you reach max health state

The value of preempting a resource in a patient's medical pathway is used as a patient's final bid, and is calculated using the Bellman equation:

$$V^*(r,h) = \Phi(r,h) + \max_a \gamma \sum_{r' \in \vec{R}} P(r'|h,r,a)V^*(r',h') \quad (1)$$

8.Coordination

Auction-Based Mechanism:

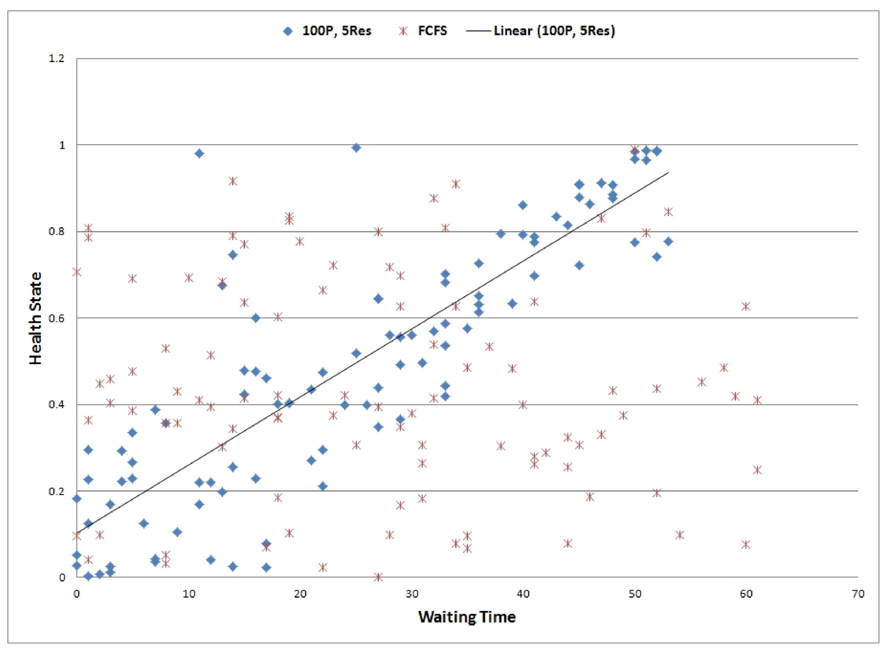
- Patients as Bidders
- Resources as Auctioneers

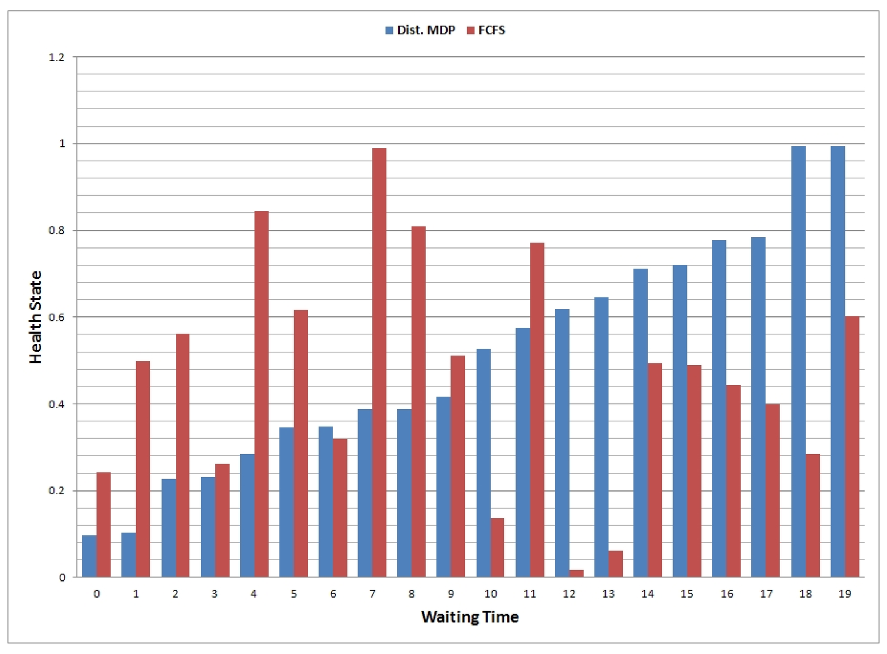
Pricing Mechanism:

- $V^*(r,h)$: Value of preempting resource r, given health condition and current state.
- Willingness to Pay: a patient's value to move to the next state (task) in her medical process.
- Waiting has a positive weight on final bid: No starvation.

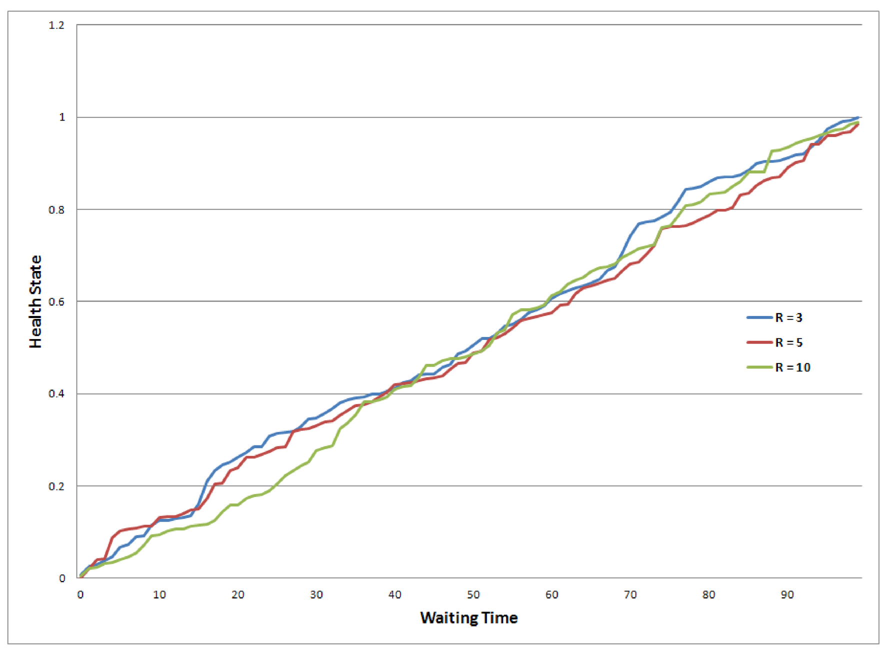
9.Results

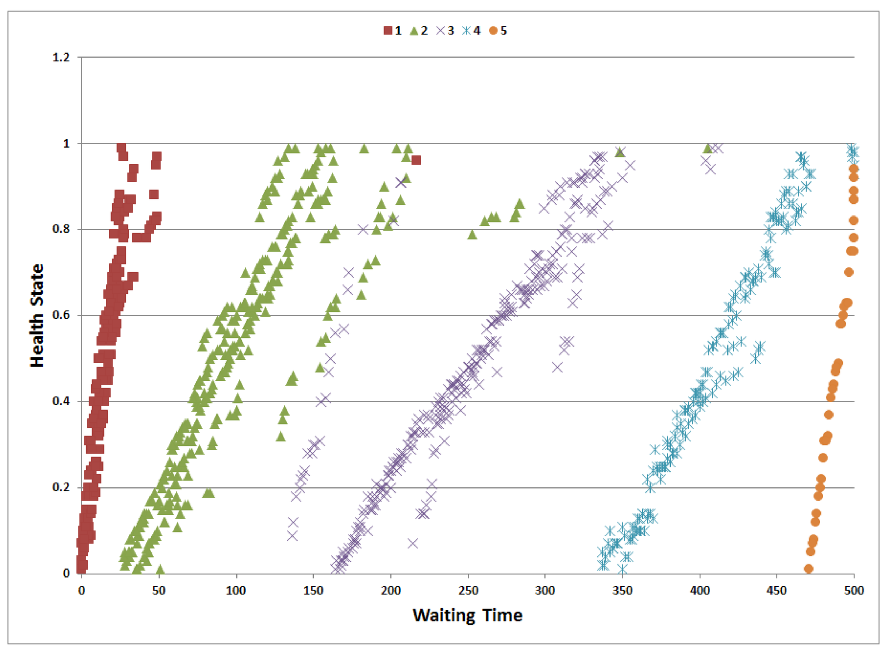
Our approach gives on average 10% improvement over FCFS compared to [1]; however, considering: 1) Health state of patients, 2) Order of tasks as a key factor, 3) Stochastic nature of medical states.





Patients' health state is the actual factor affecting the waiting times rather than arrival time basis, assuring fairness with respect to the severity/criticality of health conditions. Intuitively, less number of tasks yield to smaller waiting times.





Left: Patients with equal number of medical tasks. *Right*: Mixed group of patients with different number of tasks.

11.References

(1) T.O. Paulussen, N.R. Jennings, K.S. Decker, and A. Heinzl. Distributed patient scheduling in hospitals. In International Joint Conference on Artificial Intelligence, volume 18, pages 1224-1232. Citeseer, 2003.