Tiered Service Architecture for Remote Patient Monitoring

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Outline

1 Background and Motivation

2 Service Architecture

3 Optimal Policy

Remote Patient Monitoring

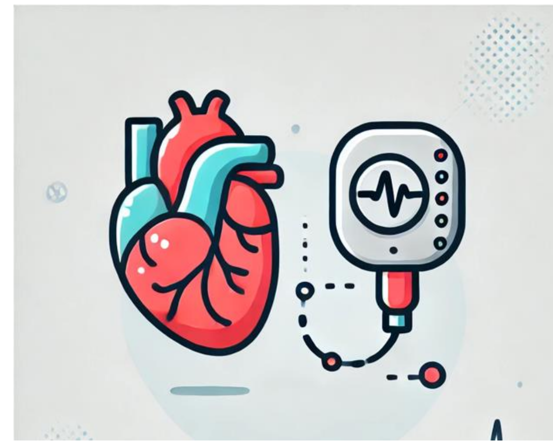
- Technology enabled healthcare

Images created using OpenAI's DALL-E 3 model. Prahalad et al. (2024). Nature Medicine, 1-9., Masoumian Hosseini et al. (2023). BMC Medical Informatics and Decision Making, 23(1), 248. , Zinzuwadia et al. (2023). In Emerging Practices in Telehealth (pp. 97-115). Academic Press.

Remote Patient Monitoring

Continuous Glucose Monitors

Smartwatches



Implantable Devices

Images created using OpenAI's DALL-E 3 model. Prahalad et al. (2024). Nature Medicine, 1-9., Masoumian Hosseini et al. (2023). BMC Medical Informatics and Decision Making, 23(1), 248. , Zinzuwadia et al. (2023). In Emerging Practices in Telehealth (pp. 97-115). Academic Press.

Remote Patient Monitoring

Ordinary

Intensive

Images created using OpenAI's DALL-E 3 model

Remote Patient Monitoring

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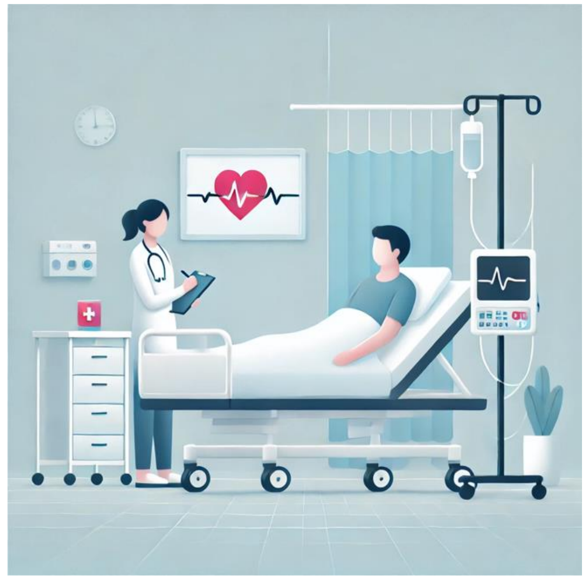
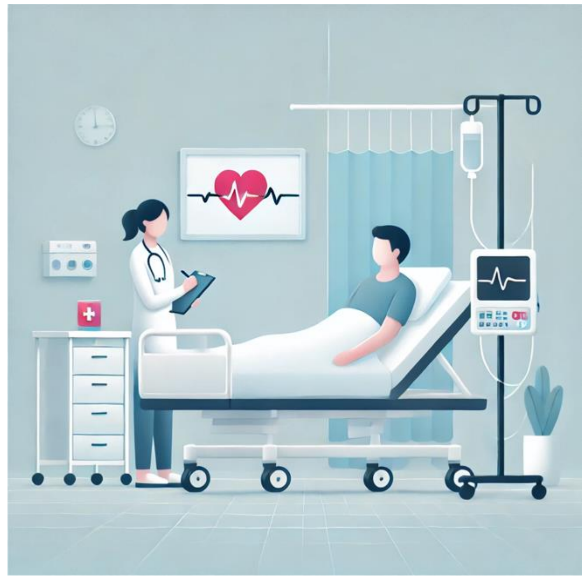
Images created using OpenAI's DALL-E 3 model

Remote Patient Monitoring



Critical State

Remote Patient Monitoring



$$$$$$$$$$

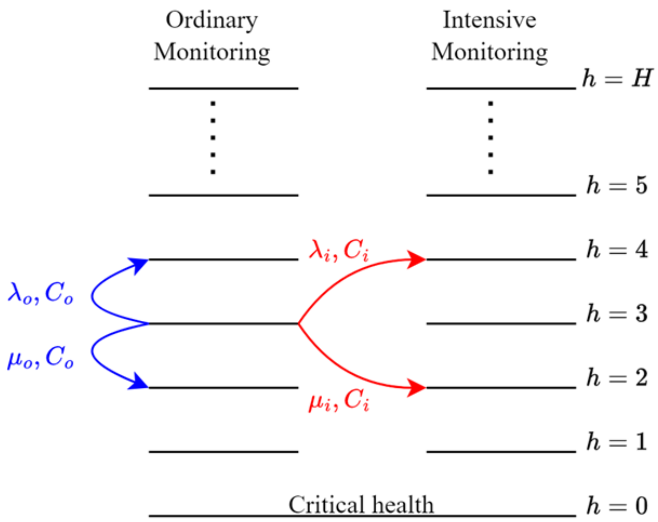
Tiered Service Architecture

The Model

- **Controlled Markov Chain**
- **Time period:** $t \in \{0,1,2 \ldots\}$
- **Health states:** $\mathrm{h}_t \in \{0,1,2 \ldots H\}$
  - **Critical State:** $h_T = 0$

The Model

- **Controlled Markov Chain**
- **Time period:** $t \in \{0,1,2 \ldots\}$
- **Health states:** $\mathrm{h}_t \in \{0,1,2 \ldots H\}$
- **Monitoring state:** $m_t \in M = \{o, i\}$
- **Overall State:** $s_t \coloneqq (m_t, h_t)$
- **Action:** $a_t \in A = \{o, i\}$
- **Costs:** C_o, C_i, C_c
- **Transition Costs**



Optimal Control

- Policy $\pi(s)$
- Value function $V_\pi(s)$

$$V_\pi(s) = \mathrm{E}\left[\sum_{t=0}^{T} \gamma^t c(s_t, a_t) + \gamma^T C_c \mid s_0 = s\right]$$

Optimal Control

- Want optimal policy π^* that minimizes V_π

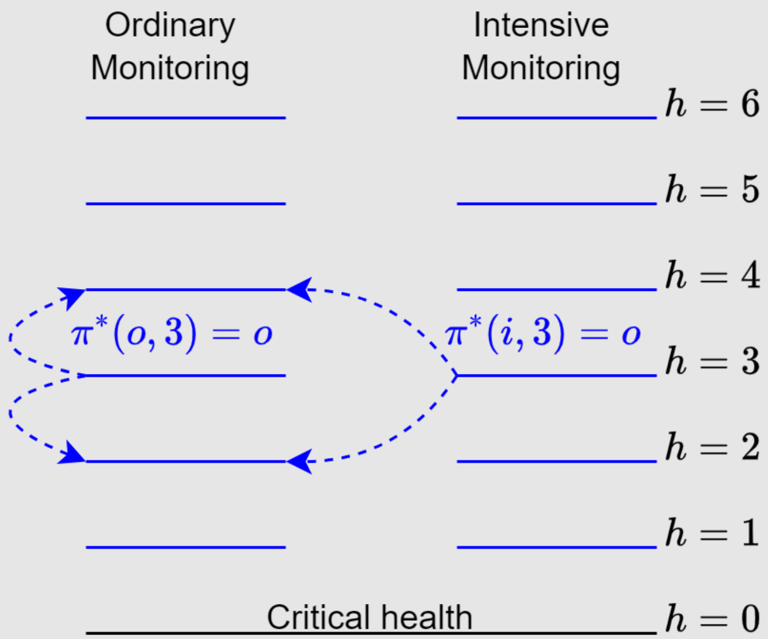
$$V_\pi^*(s) = \min_{a \in \{o,i\}} \left\{ c(s,a) + \gamma \sum_{s' \in S} P(s' | s,a) V_\pi^*(s') \right\}$$

Assumptions

- The transition probabilities satisfy: $\lambda_i \geq \lambda_o$
- The costs satisfy: $0 \leq C_o \leq C_i << C_c$

Optimal Policies

- Ordinary monitoring

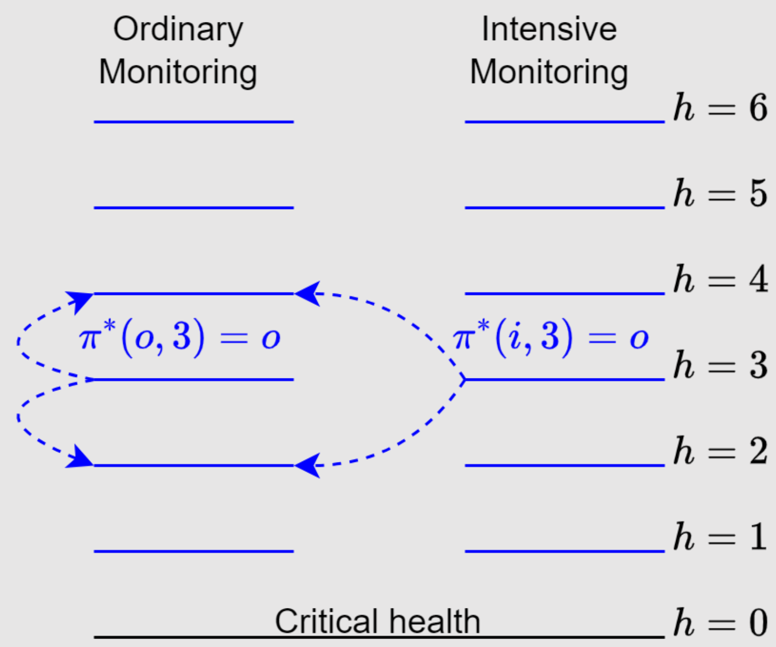


$\lambda_o = .2, \lambda_i = .3, C_c = 20, C_i = 1, C_o = 0, \gamma = .9$

Optimal Policies

Theorem 1. Policy π_o is optimal when

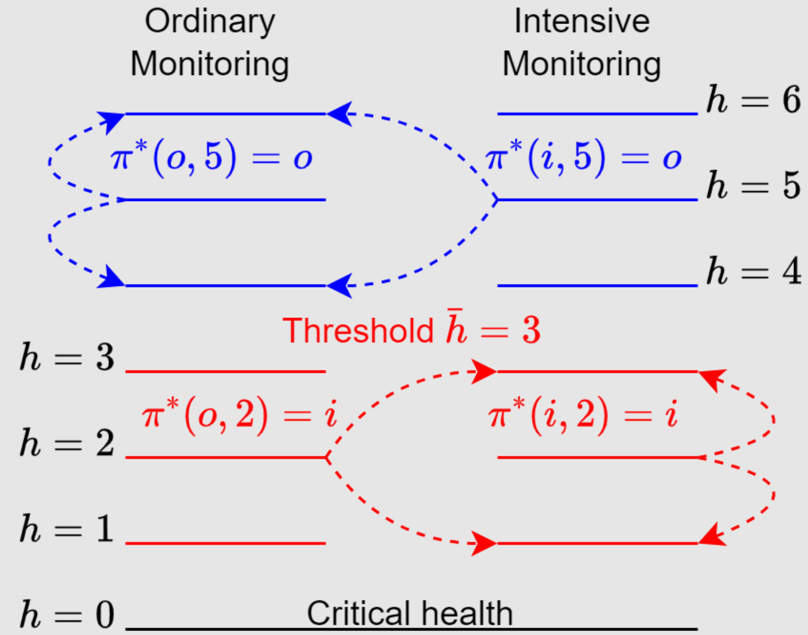
$$\gamma(\lambda_i - \lambda_o)(1 - \phi^2) \leq C_i / C_c$$



$\lambda_o = .2, \lambda_i = .3, C_c = 20, C_i = 1, C_o = 0, \gamma = .9$

Optimal Policies

- Ordinary monitoring above threshold



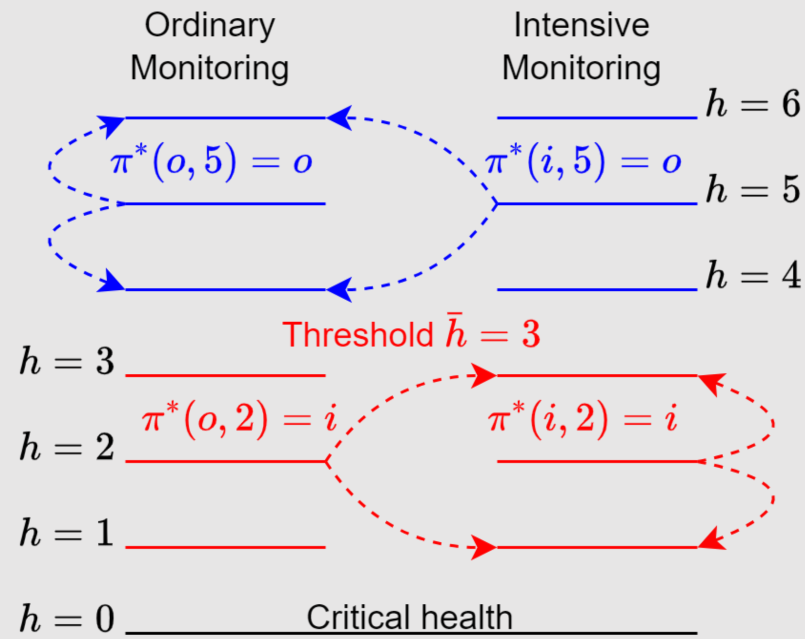
$\lambda_o = .2, \lambda_i = .3, C_c = 60, C_i = 1, C_o = 0, \gamma = .9$

Optimal Policies

Theorem 2. Policy $\pi_{t,\bar{h}}$ is optimal for some threshold $\bar{h}$ when:

$$\gamma(\lambda_i - \lambda_o)(1 - \phi^2) > C_i/C_c$$

$$\frac{\gamma\mu_o(1 + \gamma\mu_o)}{1 - \gamma^2\lambda_o\mu_o} \leq 1$$



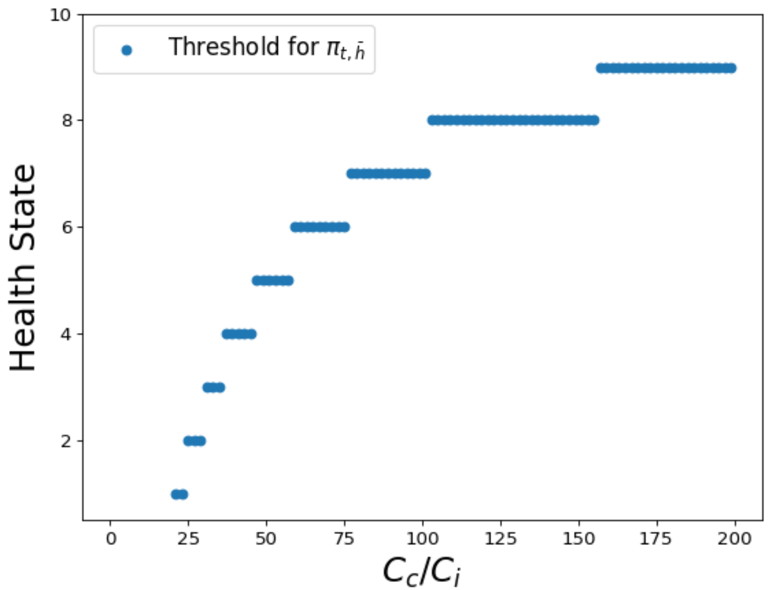
$\lambda_o = .2, \lambda_i = .3, C_c = 60, C_i = 1, C_o = 0, \gamma = .9$

Optimal Policies

- Optimal policy is a threshold policy
  1. Ordinary monitoring only
  2. Intensive monitoring below some health state threshold

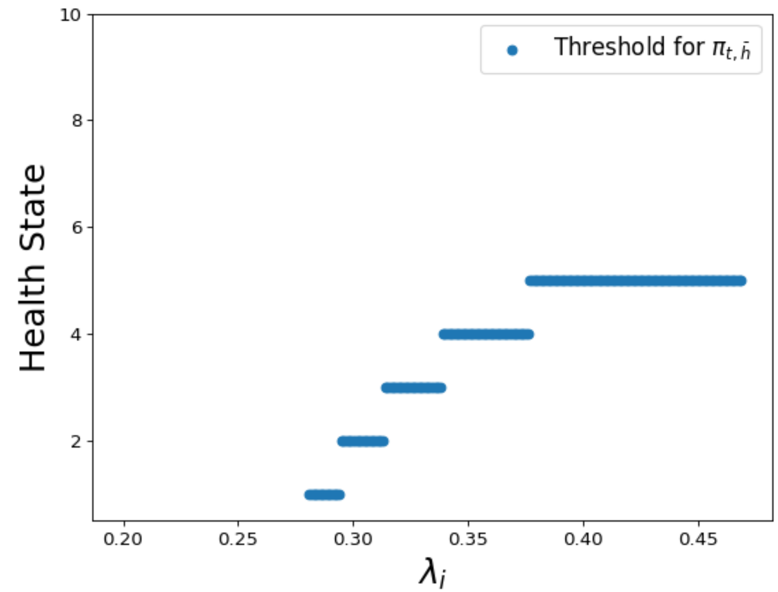
Varying Parameters

Varying C_c/C_i



$\lambda_o = .2, \lambda_i = .4, C_i = 1, C_o = 0, \gamma = .9$

Varying λ_i



$\lambda_o = .2, C_c = 50, C_i = 1, C_o = 0, \gamma = .9$

Conclusion

- Develop tiered monitoring system
- Theoretical and numerical results for tier assignments
- Identify threshold policy
- Extensions
  - Multidimensional health states
  - State varying parameters

Thank You

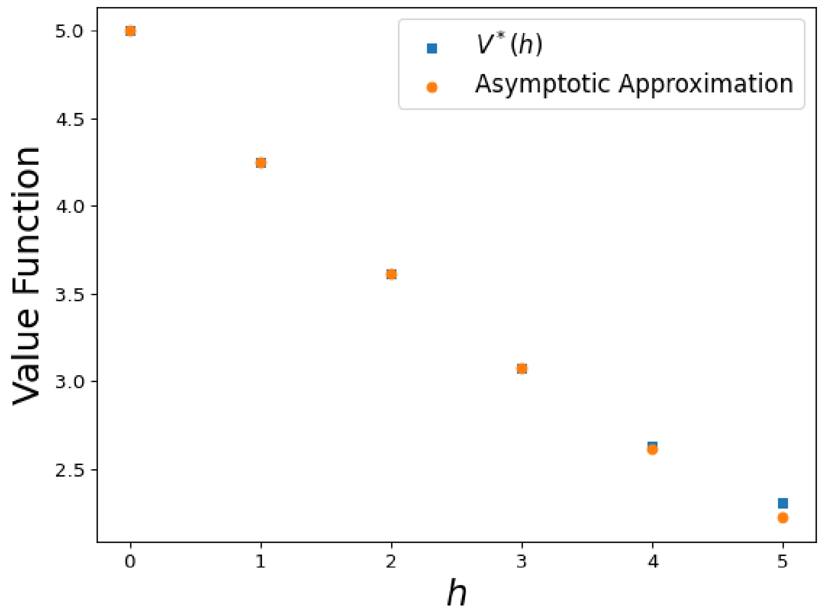
Appendix

- Assumptions for theoretical results
  - The number of health states is very large ($H \rightarrow \infty$)
  - Under ordinary monitoring, health drifts downwards

$$\lambda_o < .5, \quad \mu_o > .5$$

Appendix

- Asymptotic results closely approximate numerical results



$H = 5, \lambda_o = .2, \lambda_i = .4, C_c = 5, C_i = 1, C_o = 0, \gamma = .9.$

Appendix

- Intensive monitoring only
  - Extreme cases when H is very small or gamma close to 1