Queueing Networks for a Healthcare System

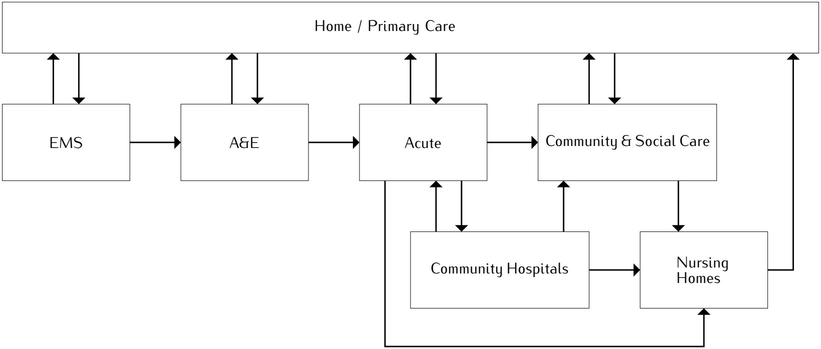
Deadlocking, Reinforcement Learning & Workforce Planning

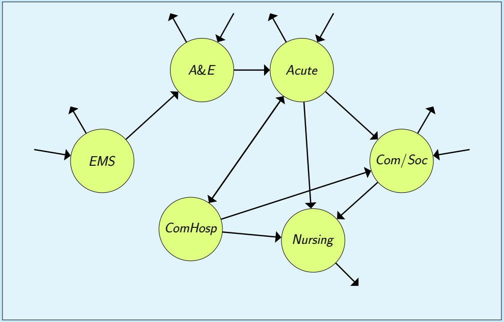
Geraint Palmer

EURO 2015 - Glasgow

Aneurin Bevan University Health Board

Map of Healthcare System





Upload Parameters

Run Analysis

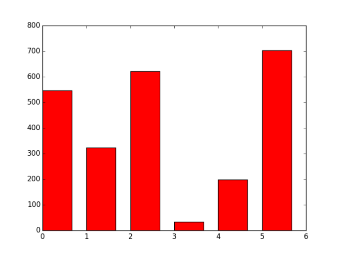
Run Simulation

View Results

Nodes:

EMS - *EDIT*
A&E - *EDIT*
Acute - *EDIT*
Community & Social Care - *EDIT*
Community Hospital - *EDIT*
Nursing Homes - *EDIT*

Community & Social Care



Winter Workforce Requirements:

Skill 1: ##### WTEs

Skill 2: ##### WTEs

Skill 3: ##### WTEs

Skill 4: ##### WTEs

Skill 5: ##### WTEs

Summer Workforce Requirements:

Skill 1: ##### WTEs

Skill 2: ##### WTEs

Skill 3: ##### WTEs

Skill 4: ##### WTEs

Skill 5: ##### WTEs

Spring Workforce Requirements:

Skill 1: ##### WTEs

Skill 2: ##### WTEs

Skill 3: ##### WTEs

Skill 4: ##### WTEs

Skill 5: ##### WTEs

Autumn Workforce Requirements:

Skill 1: ##### WTEs

Skill 2: ##### WTEs

Skill 3: ##### WTEs

Skill 4: ##### WTEs

Skill 5: ##### WTEs

Performance Measures:

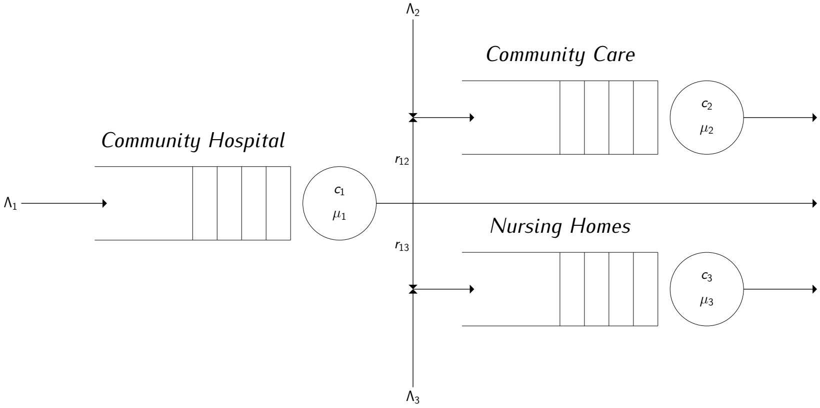
Winter Expected Occupancy: #####

Spring Exprected Occupancy: #####

Summer Expected Occupancy: #####

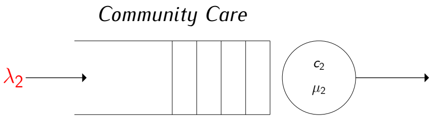
Autumn Expected Occupancy: #####

Jackson Networks



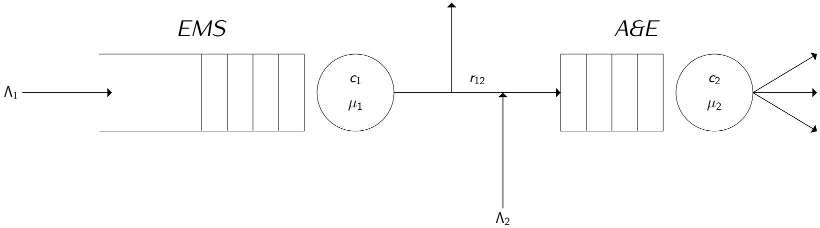
Jackson Networks

$\lambda_i = \Lambda_i + \sum_j r_{ji}\lambda_j$



$P(k_1, k_2, \ldots, k_M) = \prod_{i=1}^{M} P_i(k_i)$

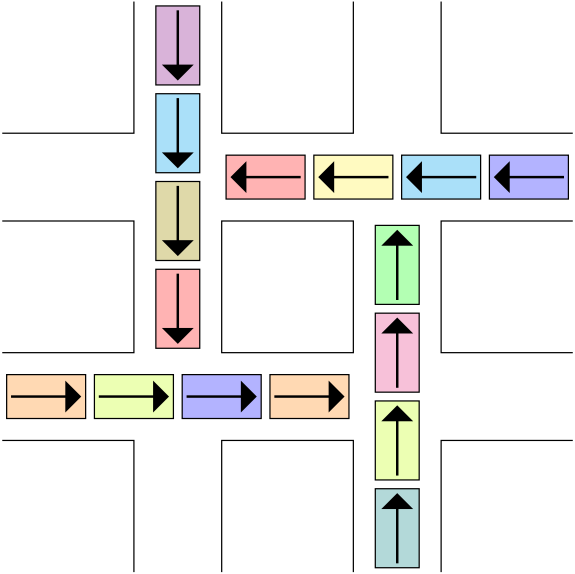
Restricted Networks

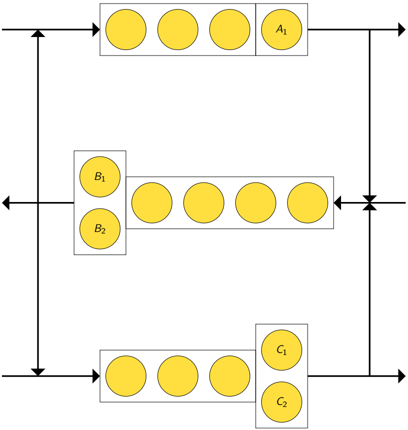


Restricted Networks

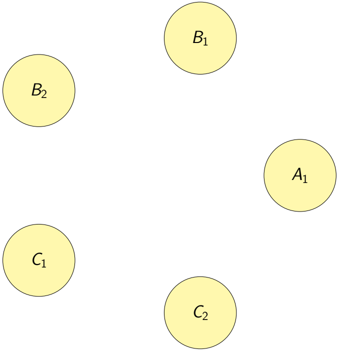
- Markov Chain Models
- Approximation Methods
- Simulation

Deadlock

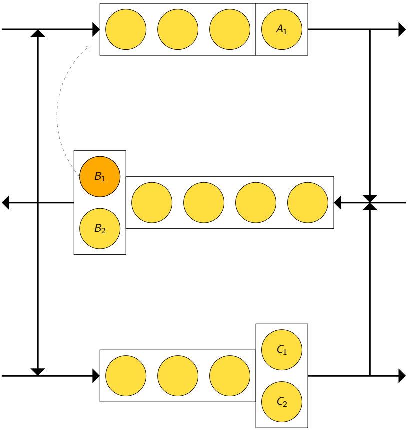


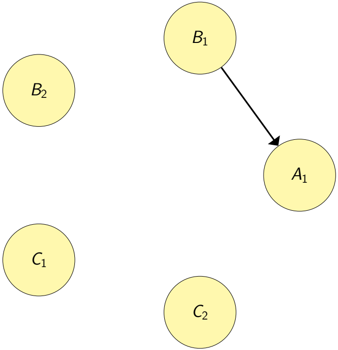


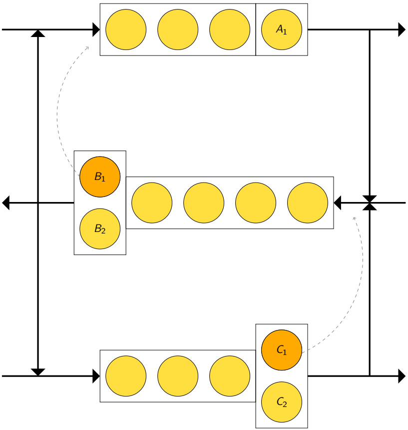
A_1
B_1
B_2
C_1
C_2



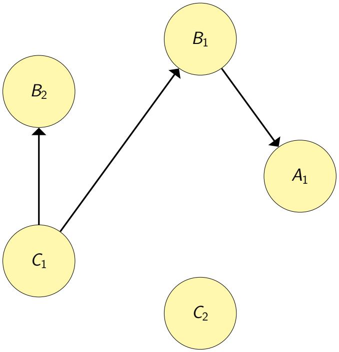
B_1
B_2
A_1
C_1
C_2


A_1
B_1
B_2
C_1
C_2

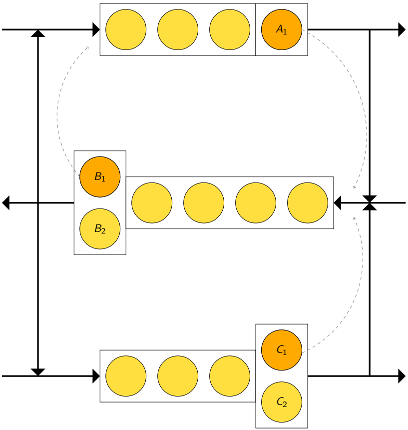

B_1
B_2
A_1
C_1
C_2



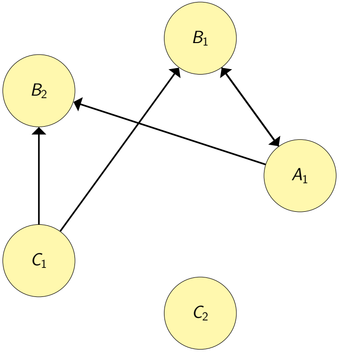
A_1
B_1
B_2
C_1
C_2



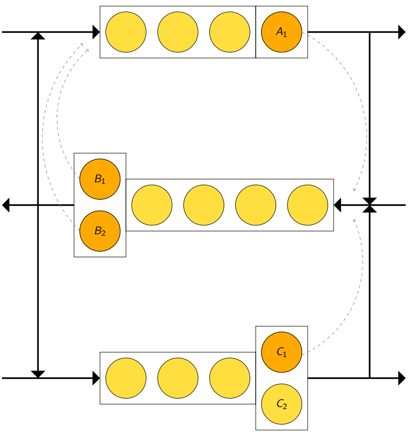
B_1
B_2
A_1
C_1
C_2



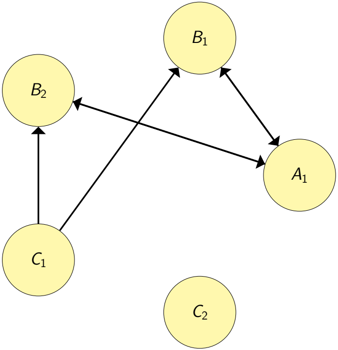
A_1
B_1
B_2
C_1
C_2



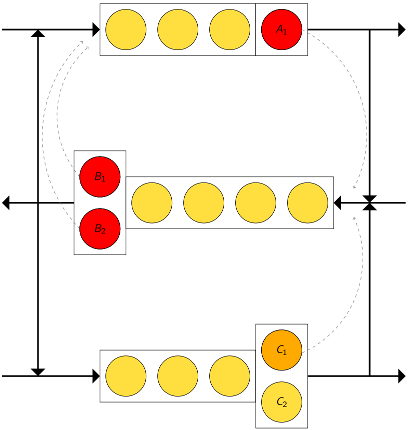
B_1
B_2
A_1
C_1
C_2

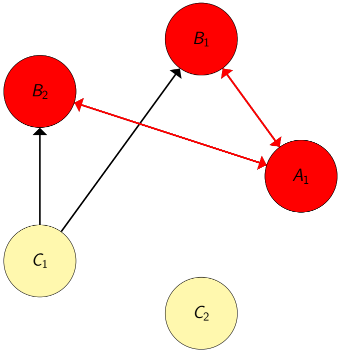


A_1
B_1
B_2
C_1
C_2

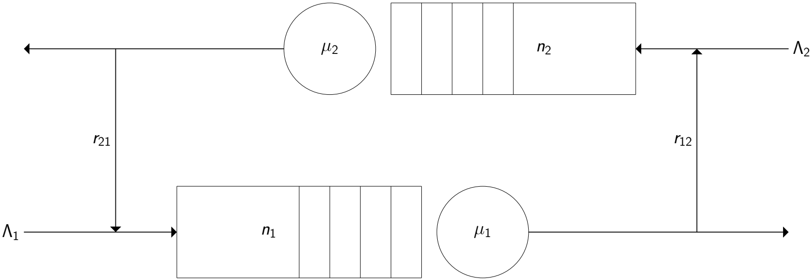


B_1
B_2
A_1
C_1
C_2


A_1
B_1
B_2
C_1
C_2


B_1
B_2
A_1
C_1
C_2

Markovian Model of Deadlock



$$(i, j)$$

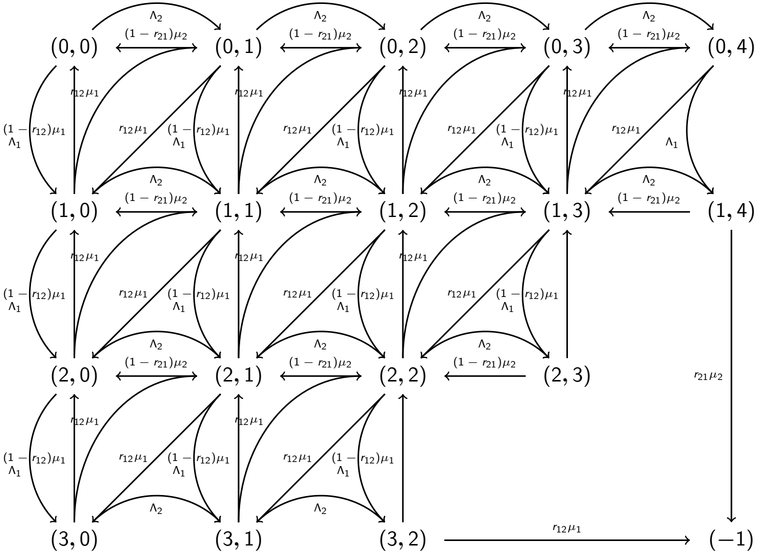
$$S = \{(i,j) \in \mathbb{N}^{(n_1+2\times n_2+2)} | 0 \le i+j \le n_1+n_2+2\} \cup \{(-1)\}$$

Define $\delta = (i_2, j_2) - (i_1, j_1)$

$$q_{(i_1,j_1),(i_2,j_2)} = \begin{cases} \left.\begin{matrix} \Lambda_1 & \text{if } i_1 \le n_1 \\ 0 & \text{otherwise} \end{matrix}\right\} & \text{if } \delta = (1,0) \\ \left.\begin{matrix} \Lambda_2 & \text{if } j_1 \le n_2 \\ 0 & \text{otherwise} \end{matrix}\right\} & \text{if } \delta = (0,1) \\ \left.\begin{matrix} (1-r_{12})\mu_1 & \text{if } j_1 < n_1+2 \\ 0 & \text{otherwise} \end{matrix}\right\} & \text{if } \delta = (-1,0) \\ \left.\begin{matrix} (1-r_{21})\mu_2 & \text{if } i_1 < n_1+2 \\ 0 & \text{otherwise} \end{matrix}\right\} & \text{if } \delta = (0,-1) \\ \left.\begin{matrix} r_{12}\mu_1 & \text{if } j_1 < n_2+2 \\ 0 & \text{otherwise} \end{matrix}\right\} & \text{if } \delta = (-1,1) \\ \left.\begin{matrix} r_{21}\mu_2 & \text{if } i_1 < n_1+2 \\ 0 & \text{otherwise} \end{matrix}\right\} & \text{if } \delta = (1,-1) \\ 0 & \text{otherwise} \end{cases}$$

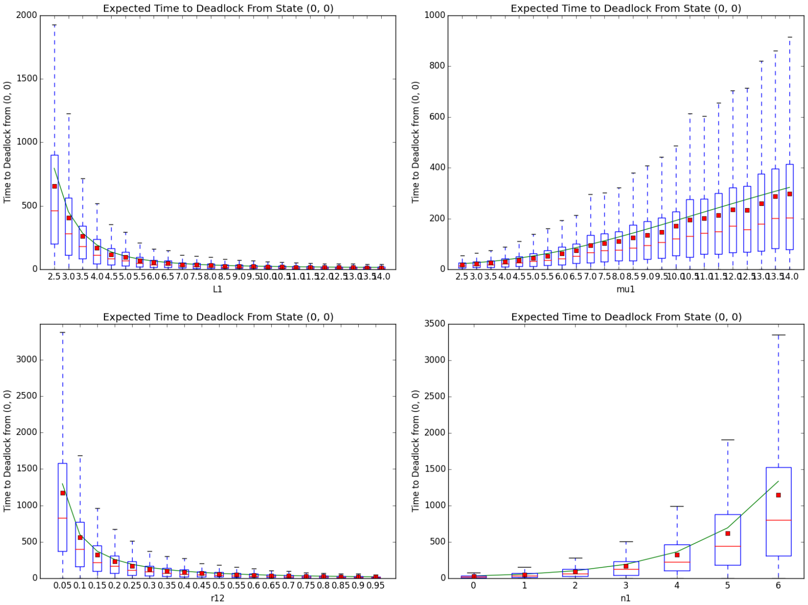
$$q_{(i_1,j_1),(-1)} = \begin{cases} r_{21}\mu_2 & \text{if } (i,j) = (n_1, n_2+2) \\ r_{12}\mu_1 & \text{if } (i,j) = (n_1+2, n_2) \\ 0 & \text{otherwise} \end{cases}$$

$$q_{-1,s} = 0$$

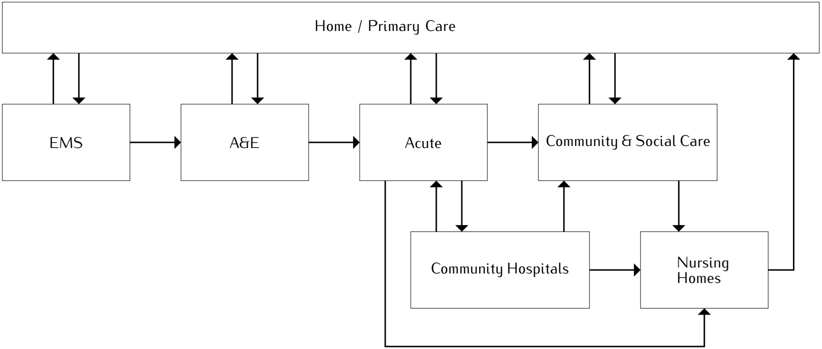


(0, 0)
(0, 1)
(0, 2)
(0, 3)
(0, 4)
(1, 0)
(1, 1)
(1, 2)
(1, 3)
(1, 4)
(2, 0)
(2, 1)
(2, 2)
(2, 3)
(3, 0)
(3, 1)
(3, 2)
(−1)
Λ_2
$(1-r_{21})\mu_2$
$r_{12}\mu_1$
$(1-r_{12})\mu_1$
Λ_1
$r_{21}\mu_2$

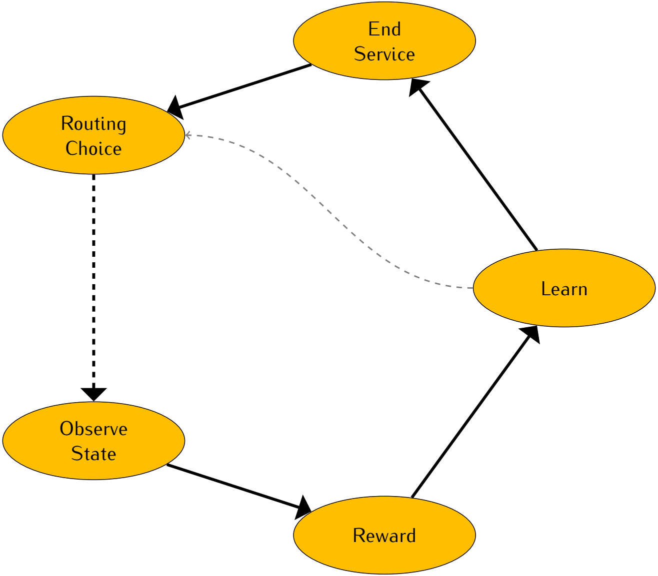
Times to Deadlock



Reinforcement Leanrning



Reinforcement Leanrning



Reinforcement Leanrning

Q-Learning

$$Q(s,a) \leftarrow Q(s,a) + \alpha[r + \gamma \text{max}_{a'} Q(s',a') - Q(s,a)]$$

Diolch – Thank You

https://github.com/geraintpalmer/Presentations