# Queueing Networks for a Healthcare System

## Deadlocking, Reinforcement Learning & Workforce Planning

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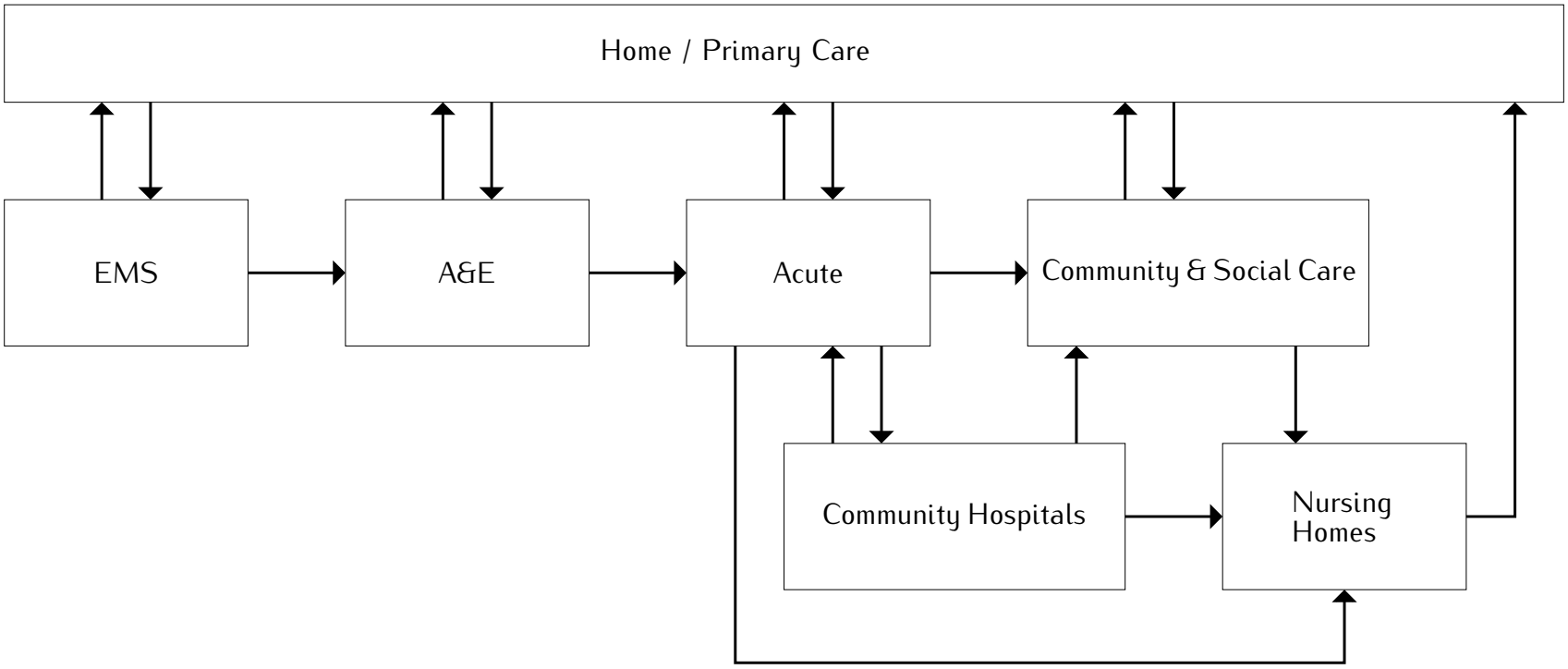
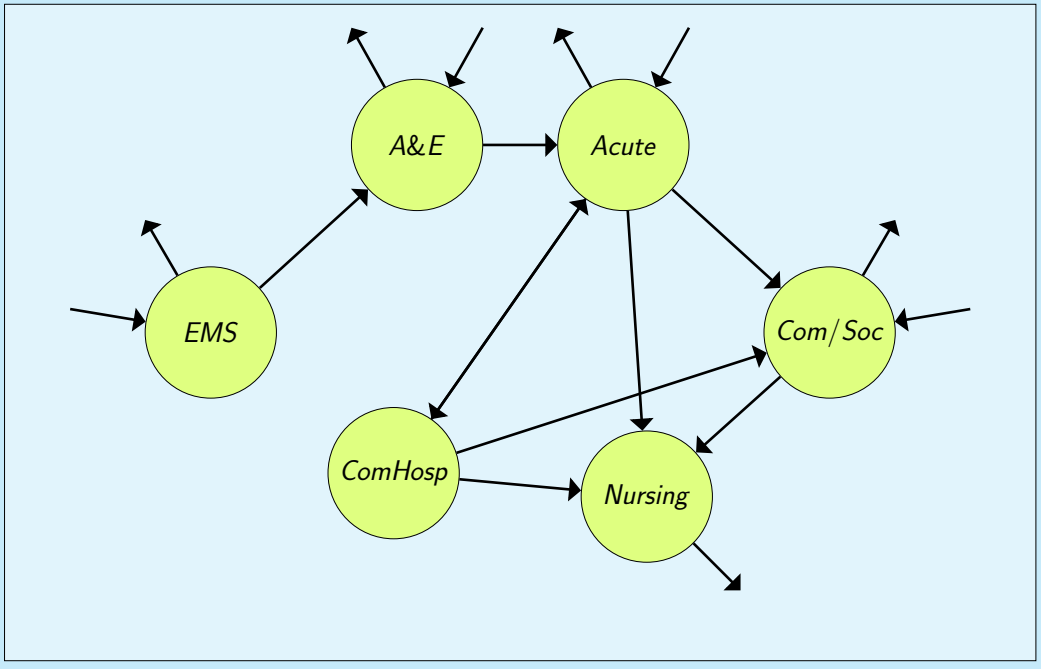
EURO 2015 - Glasgow

# 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:

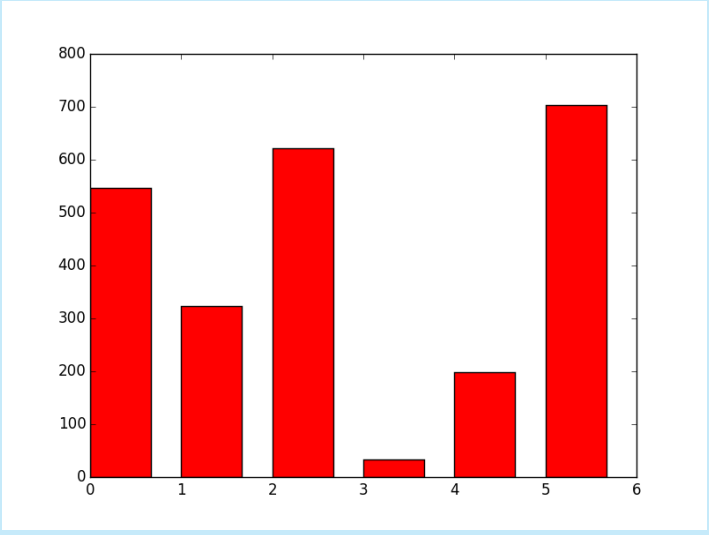
Skill 1: ##### WTEs

Skill 2: ##### WTEs

Skill 3: ##### WTEs

Skill 4: ##### WTEs

Skill 5: ##### WTEs




## Performance Measures:

Winter Expected Occupancy: #####

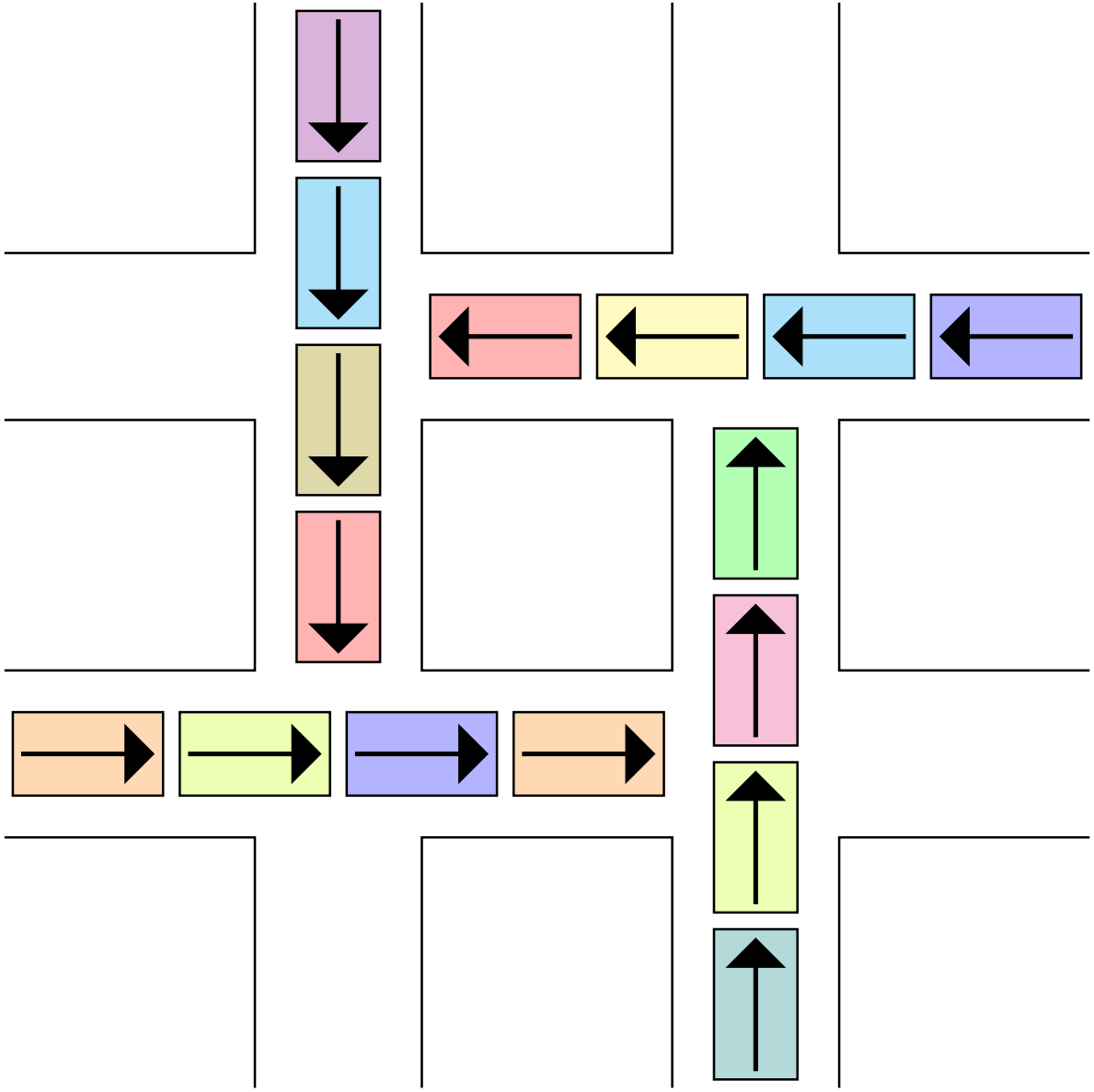
Spring Exprected Occupancy: #####

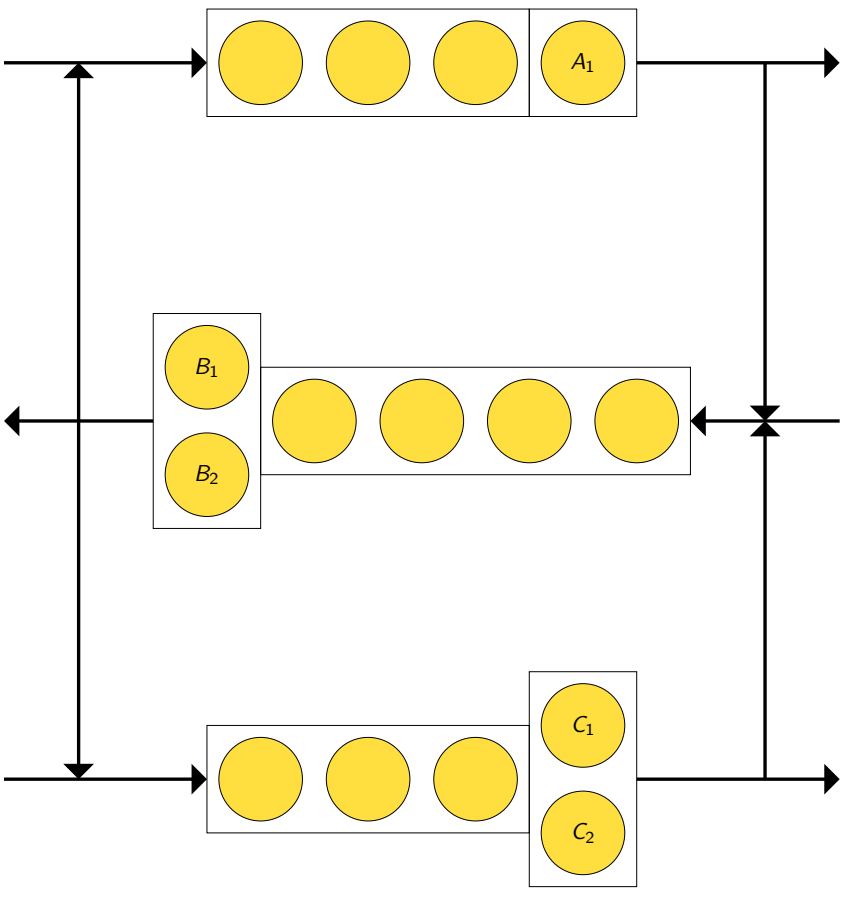
Summer Expected Occupancy: #####

Autumn Expected Occupancy: #####

- Queueing Networks
- Deadlock
- Reinforcement Learning

# Deadlock





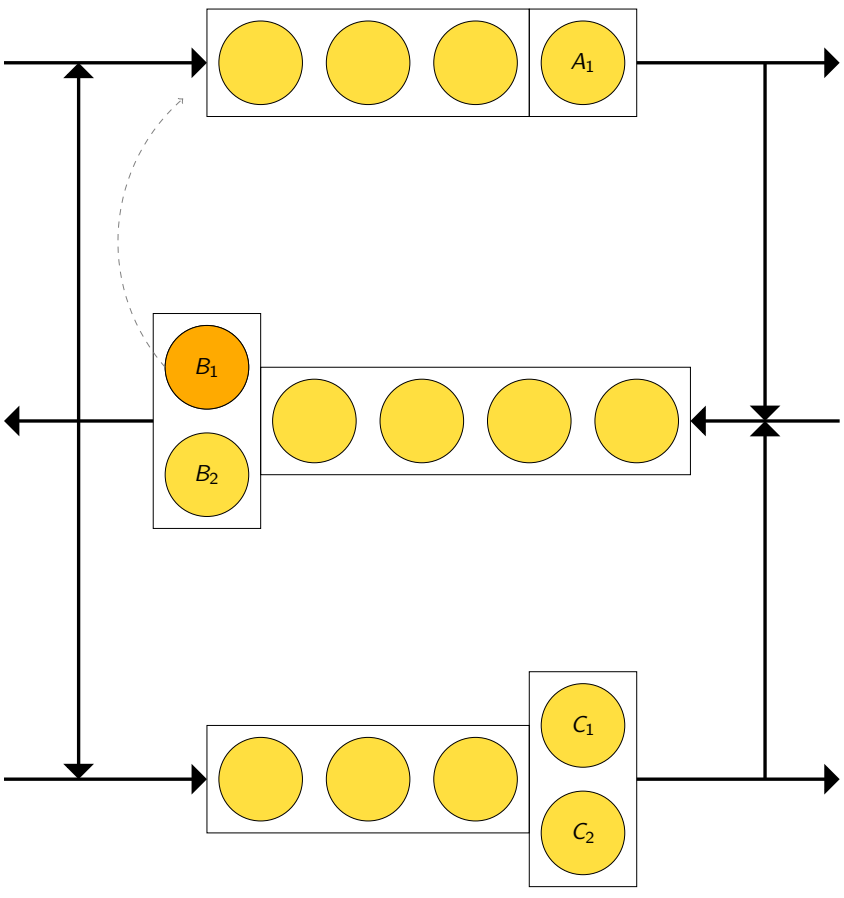

$B_1$

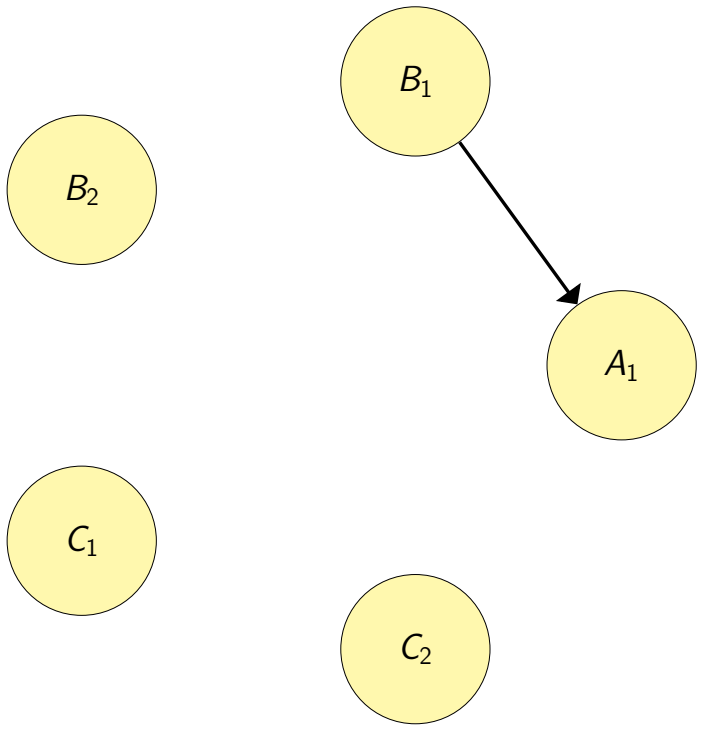
$B_2$

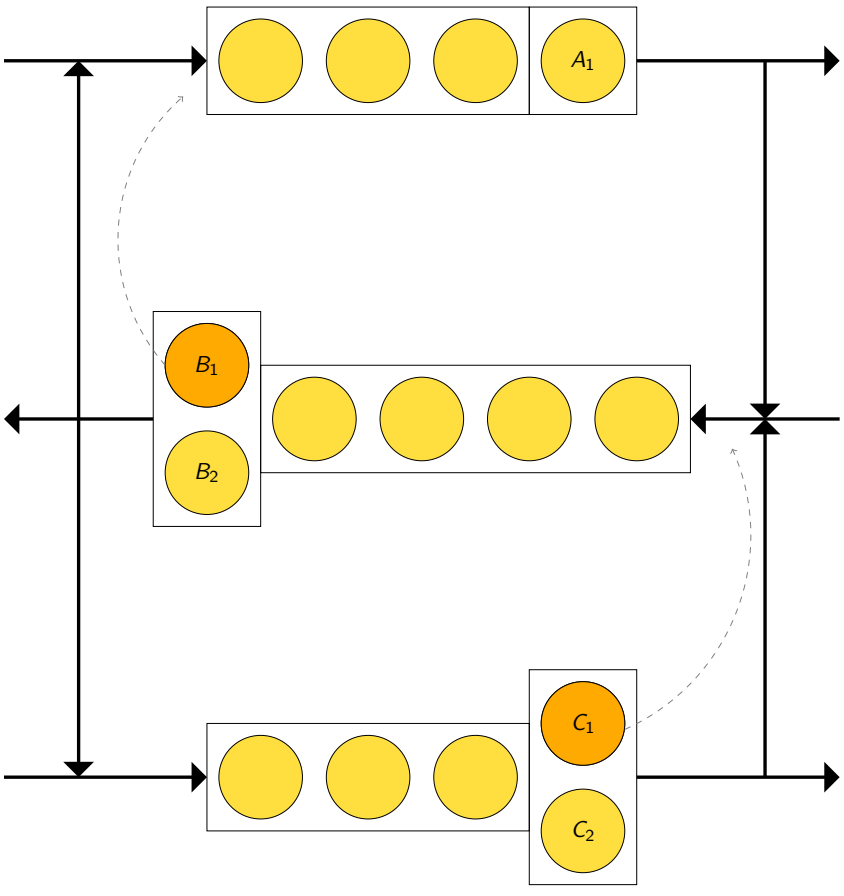
$A_1$

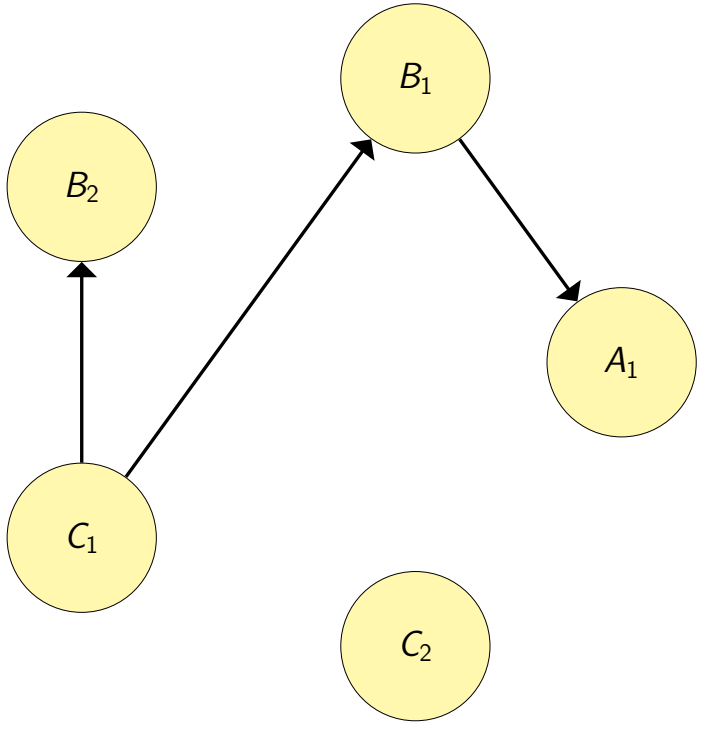
$C_1$

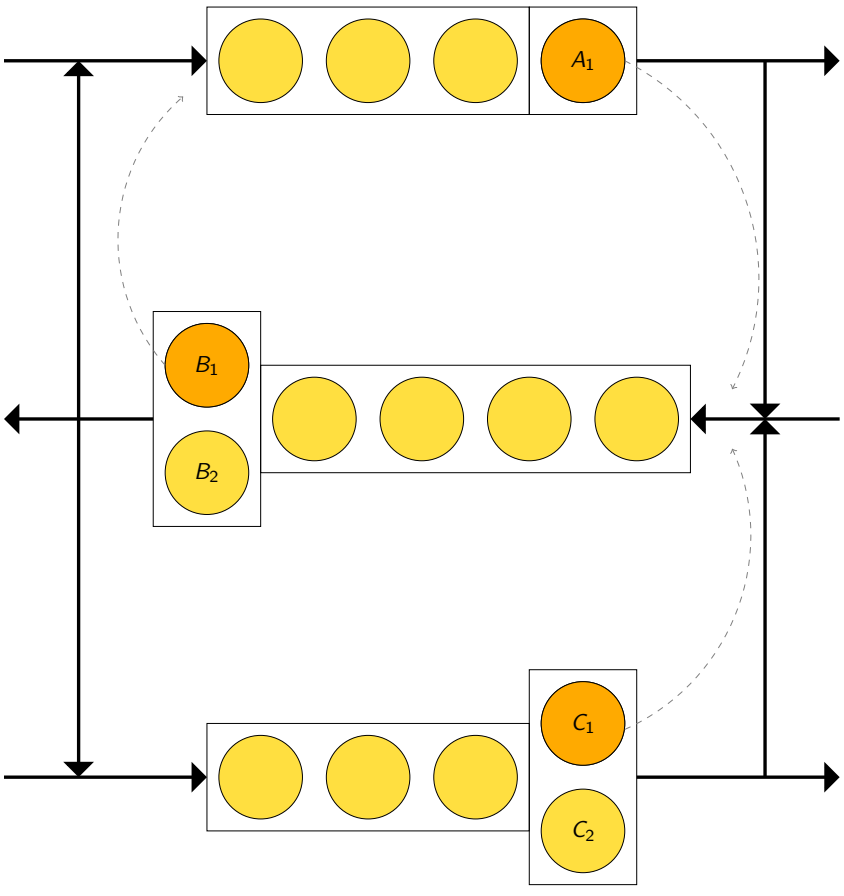
$C_2$

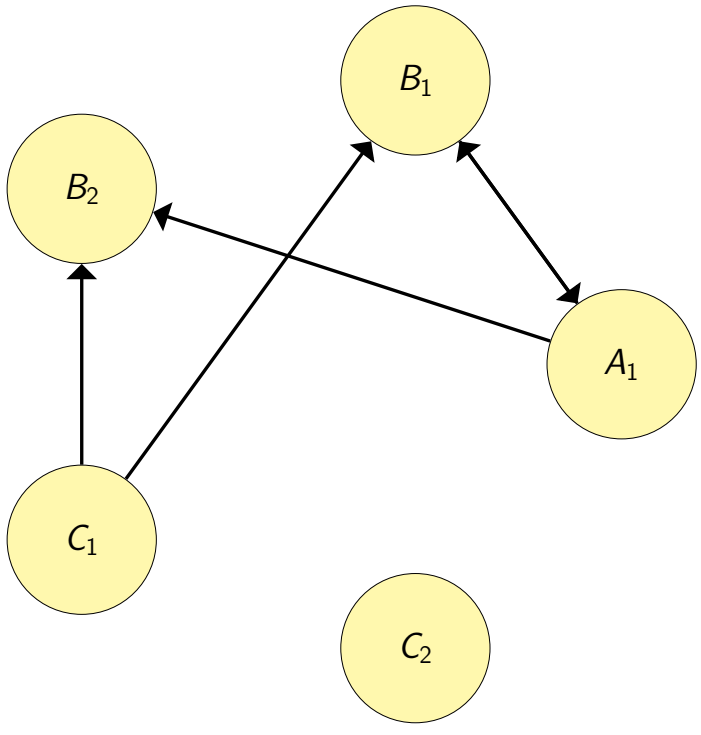

$A_1$
$B_1$
$B_2$
$C_1$
$C_2$

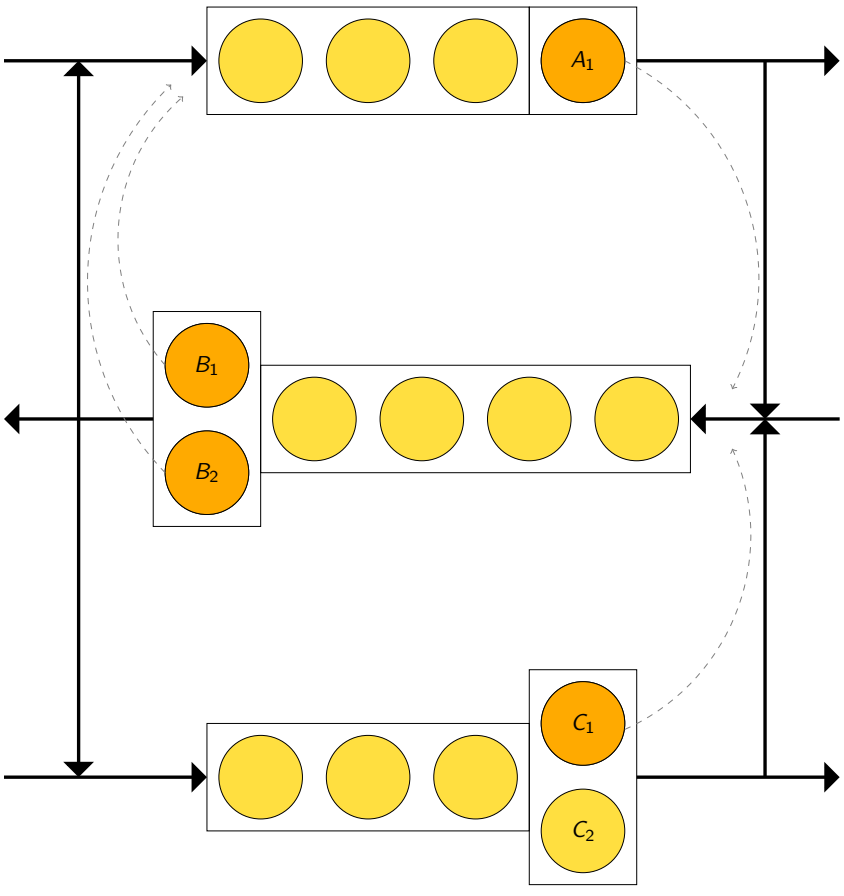

$B_1$
$B_2$
$A_1$
$C_1$
$C_2$

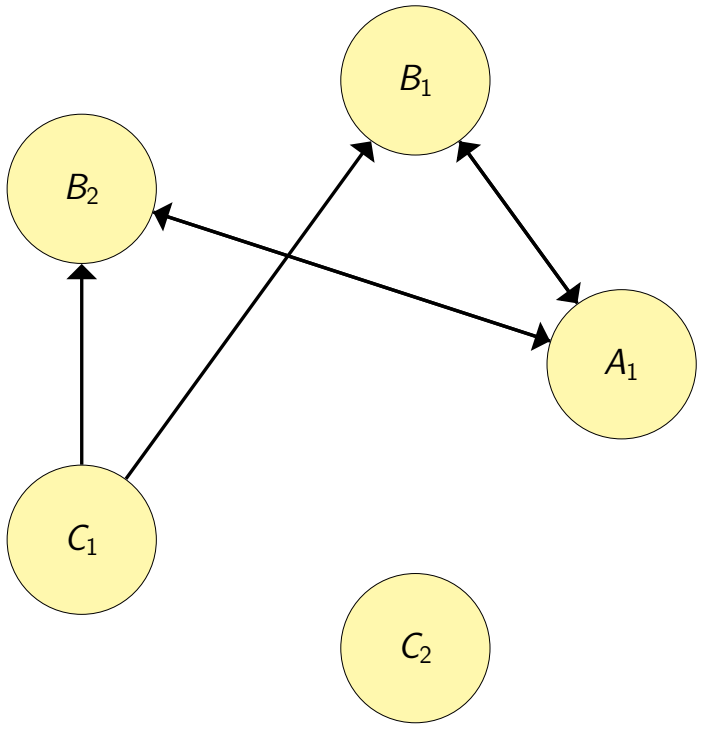

$A_1$
$B_1$
$B_2$
$C_1$
$C_2$


$B_1$
$B_2$
$A_1$
$C_1$
$C_2$


$A_1$
$B_1$
$B_2$
$C_1$
$C_2$


$B_1$
$B_2$
$A_1$
$C_1$
$C_2$


$A_1$
$B_1$
$B_2$
$C_1$
$C_2$


$B_1$
$B_2$
$A_1$
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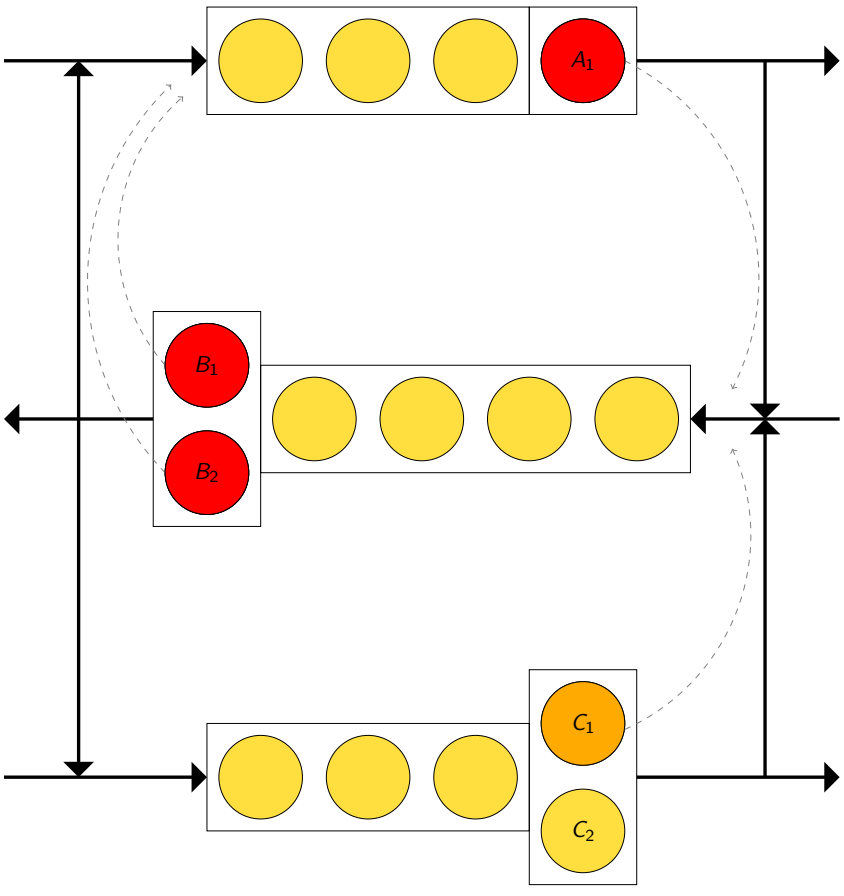
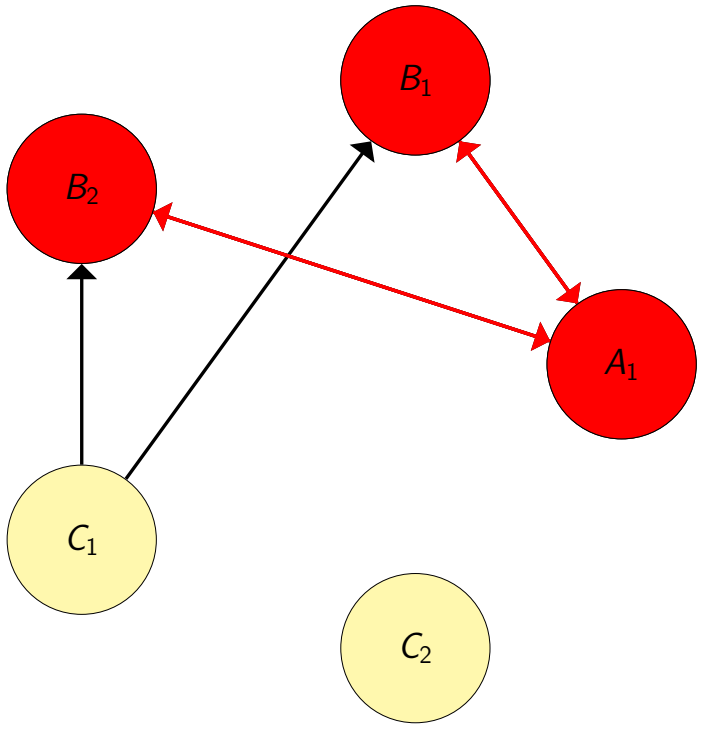
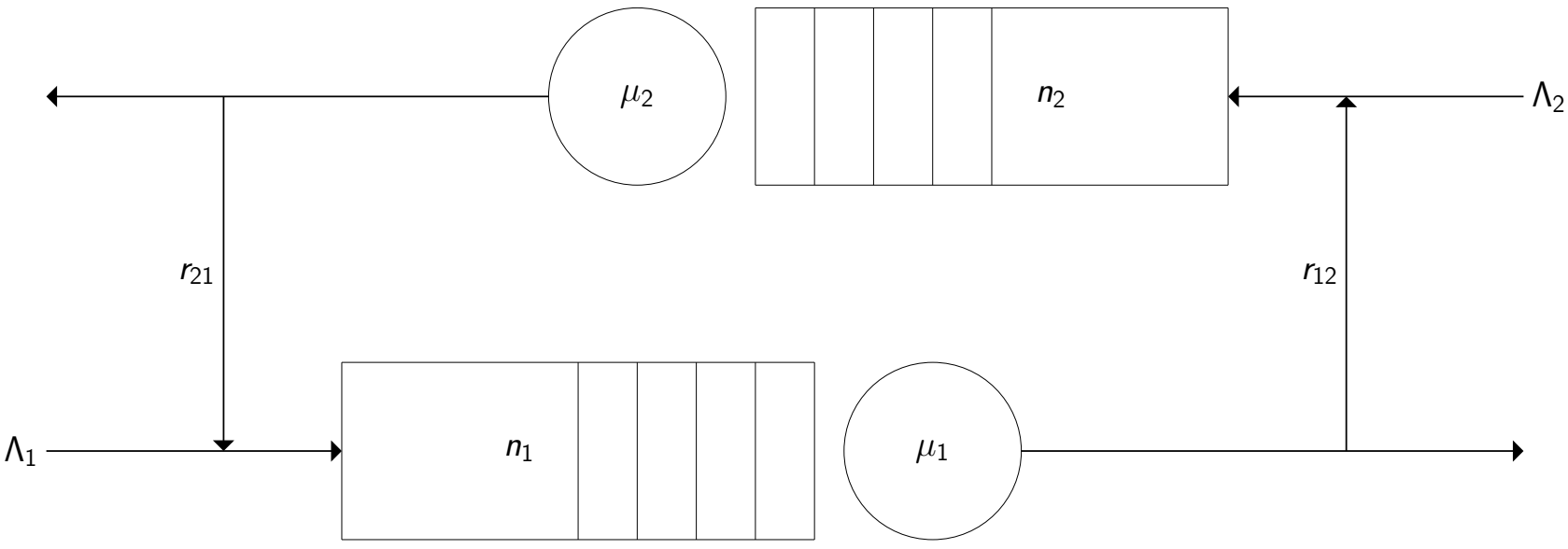

$A_1$
$B_1$
$B_2$
$C_1$
$C_2$


$B_1$
$B_2$
$A_1$
$C_1$
$C_2$

# Markovian Model of Deadlock




$(i, j)$

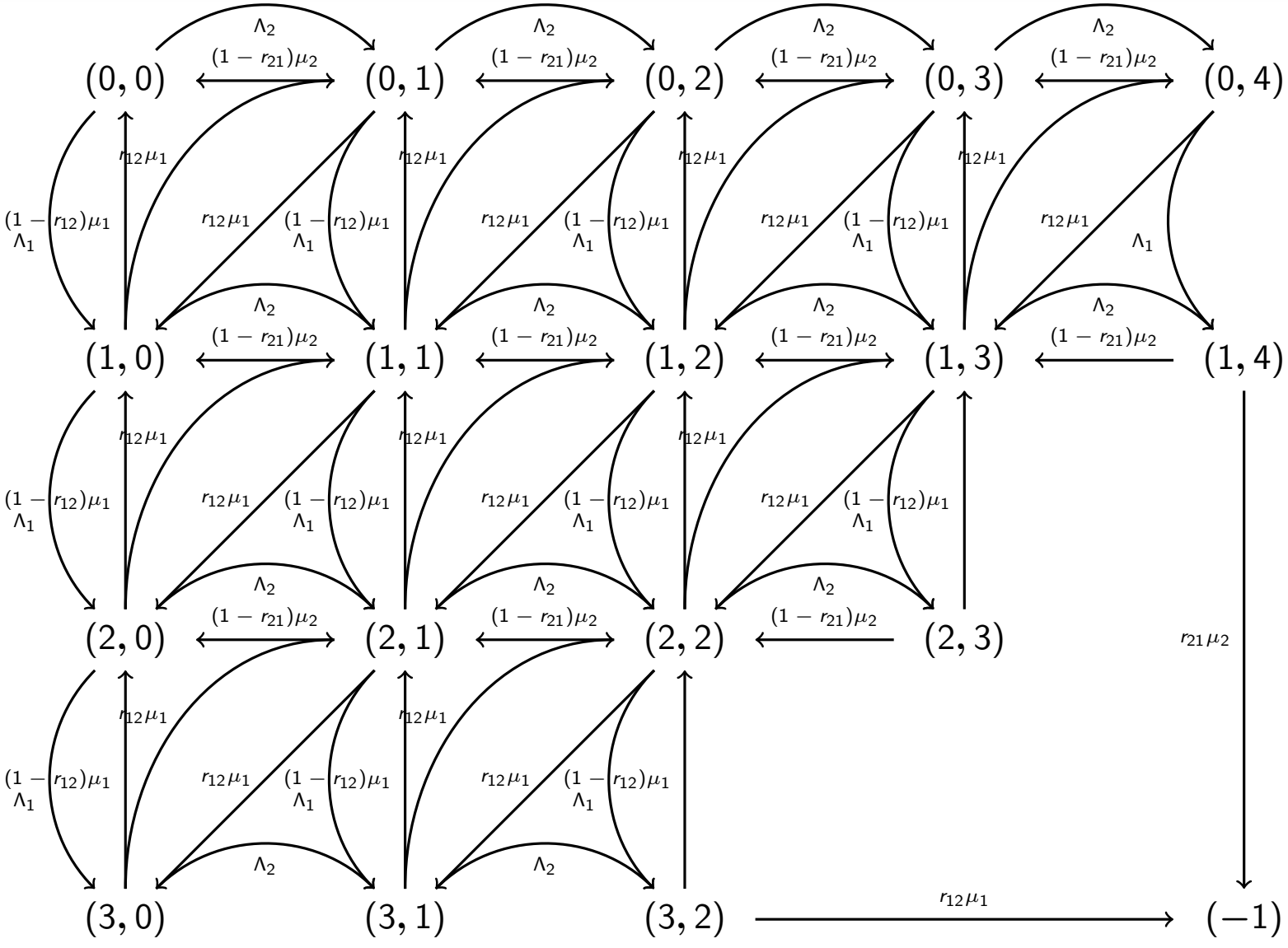
$$S = \{(i,j) \in \mathbb{N}^{(n_1+2 \times n_2+2)} | 0 \leq i+j \leq n_1+n_2+2\} \cup \{(-1)\}$$

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

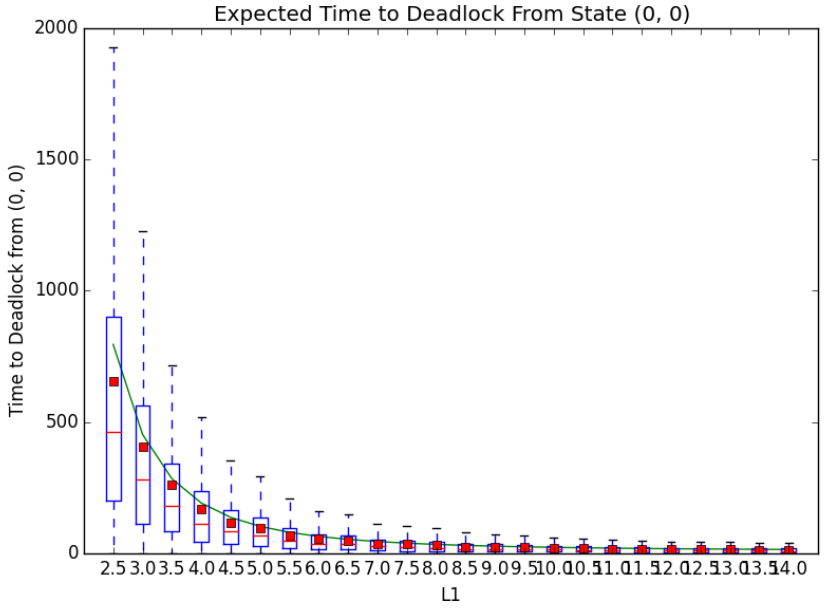
$$q_{(i_1,j_1),(i_2,j_2)} = \begin{cases} \left.\begin{array}{rl} \Lambda_1 & \text{if } i_1 \leq n_1 \\ 0 & \text{otherwise} \end{array}\right\} & \text{if } \delta = (1,0) \\ \left.\begin{array}{rl} \Lambda_2 & \text{if } j_1 \leq n_2 \\ 0 & \text{otherwise} \end{array}\right\} & \text{if } \delta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

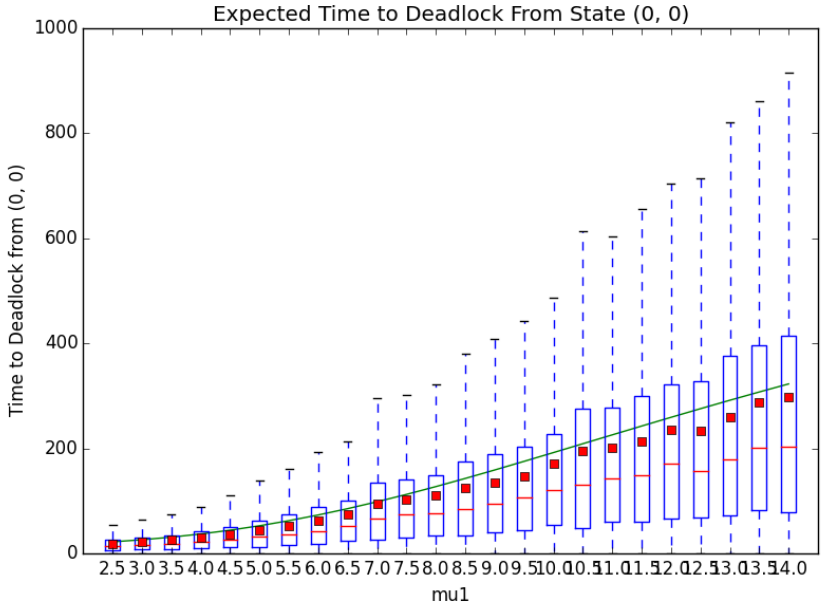
$$q_{(i_1,j_1),(-1)} = \begin{cases} r_{21}\mu_2 & \text{if } (i,j) = (n_1, n_2+2) \\ r_{12}\mu_1 & \text{if } (i,j) = (n_1+2, n_2) \\ 0 & \text{otherwise} \end{cases}$$

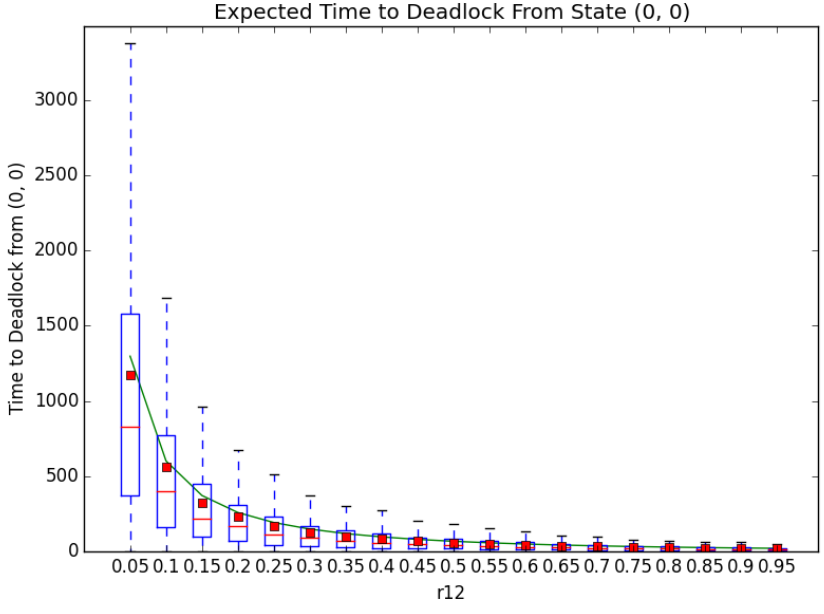
$$q_{-1,s} = 0$$

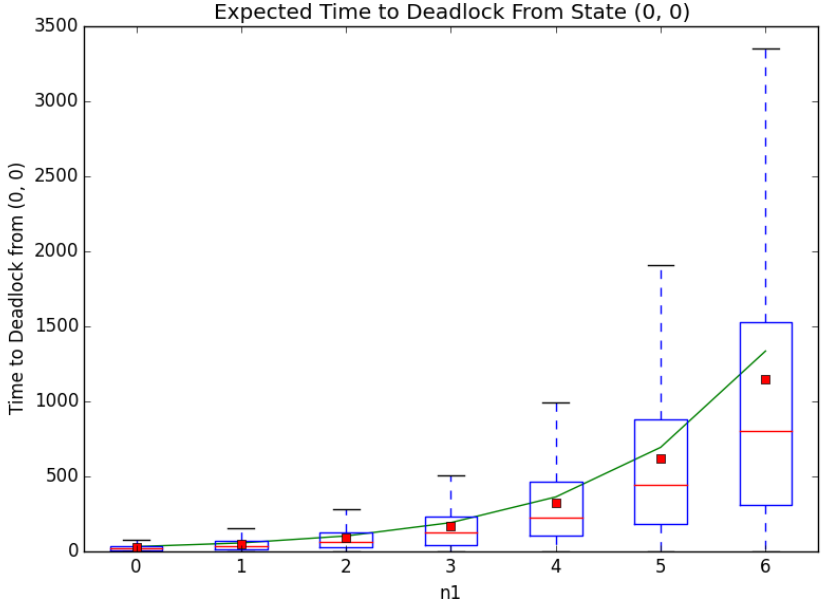

(0, 0)
(0, 1)
(0, 2)
(0, 3)
(0, 4)
(1, 0)
(1, 1)
(1, 2)
(1, 3)
(1, 4)
(2, 0)
(2, 1)
(2, 2)
(2, 3)
(3, 0)
(3, 1)
(3, 2)
(−1)
Λ2
(1 − r21)μ2
r12μ1
(1 − r12)μ1
Λ1
r21μ2

# Times to Deadlock

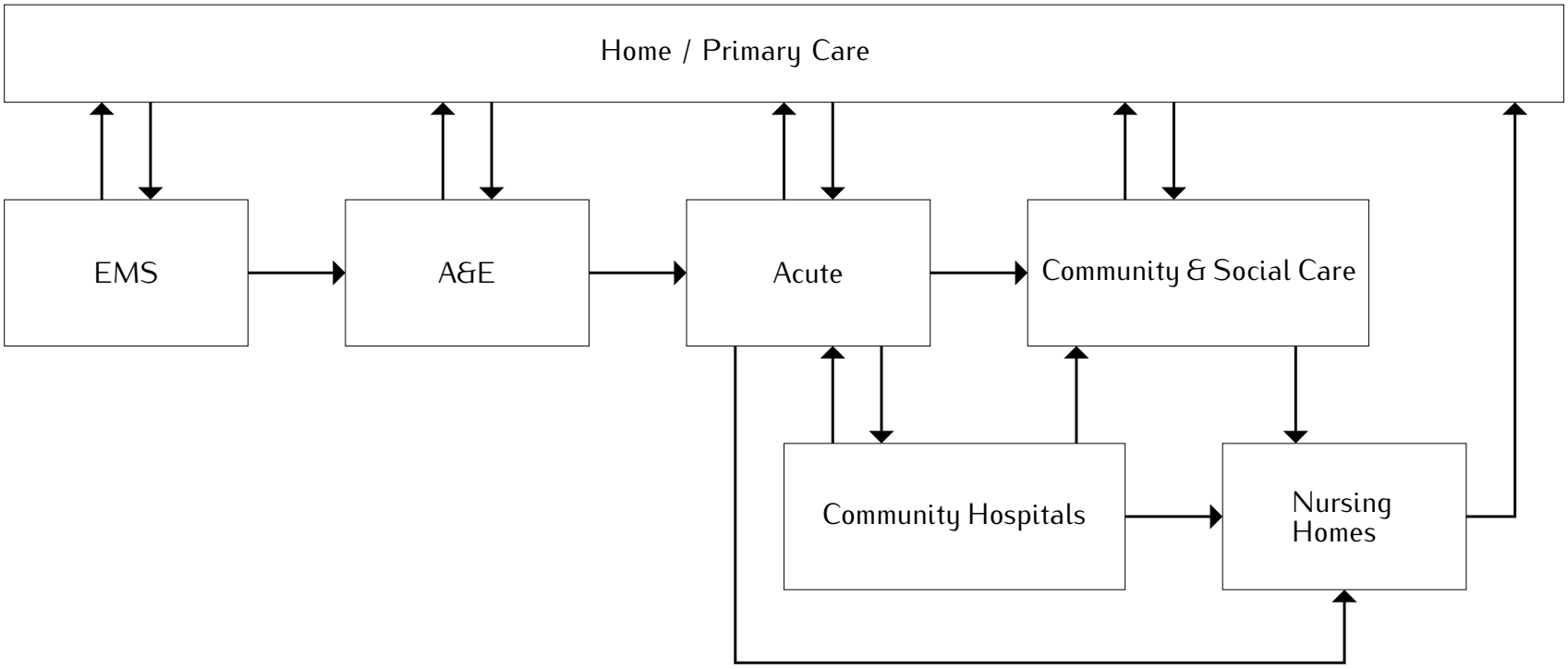


# Reinforcement Leanrning



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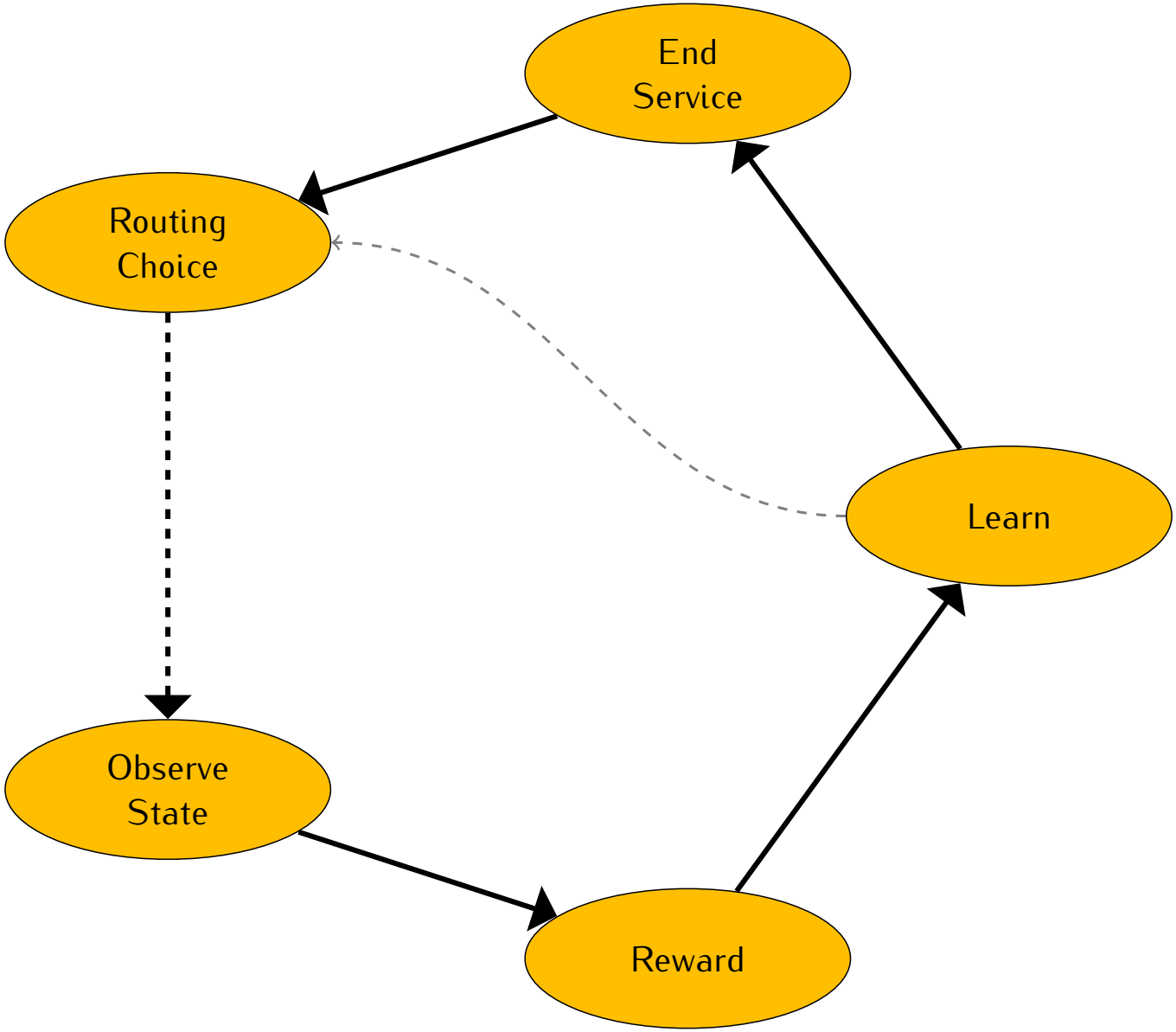

# Reinforcement Leanrning

Q-Learning

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

# Diolch - Thank You

https://github.com/geraintpalmer/Presentations