Estimating Camera Inactivity Periods from Detection Histories

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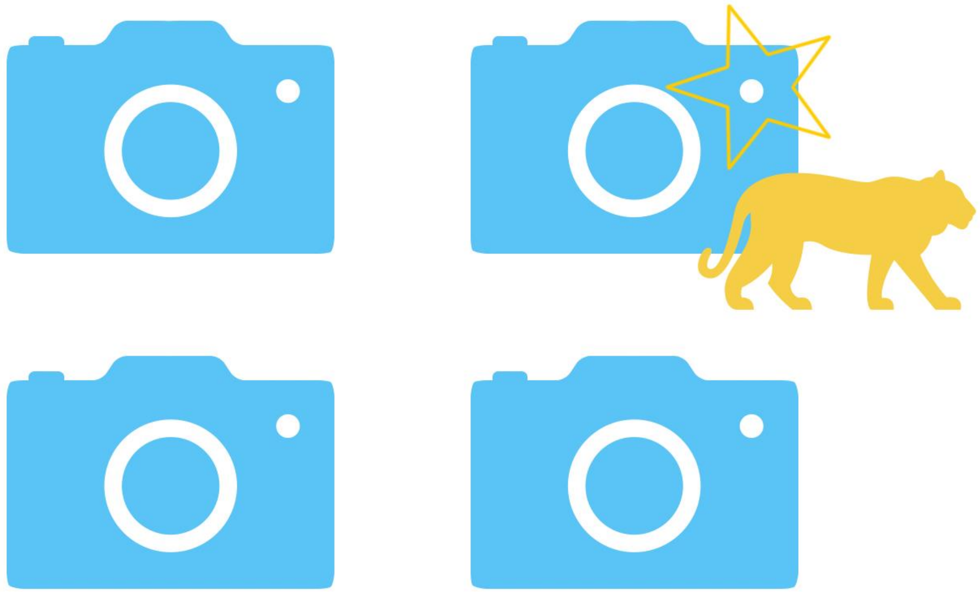
Motivation



<u>Camera Trap surveys:</u>

Cameras set up in array

Take images as individuals pass by

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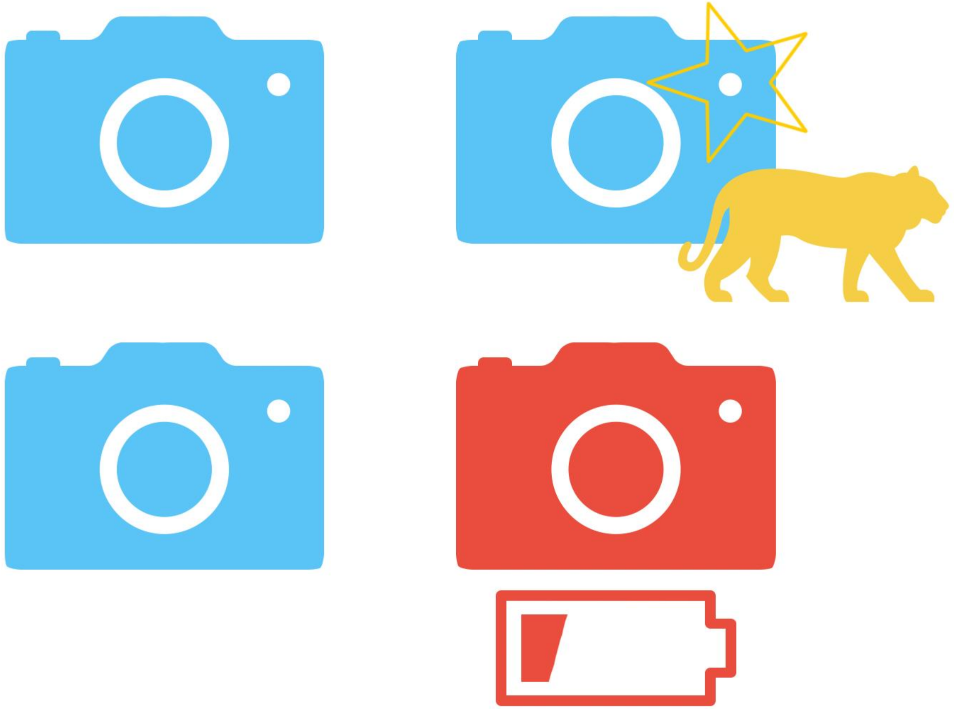

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Types of camera malfunction:

1. Battery runs out
2. Continuous mis-fires
3. False positives

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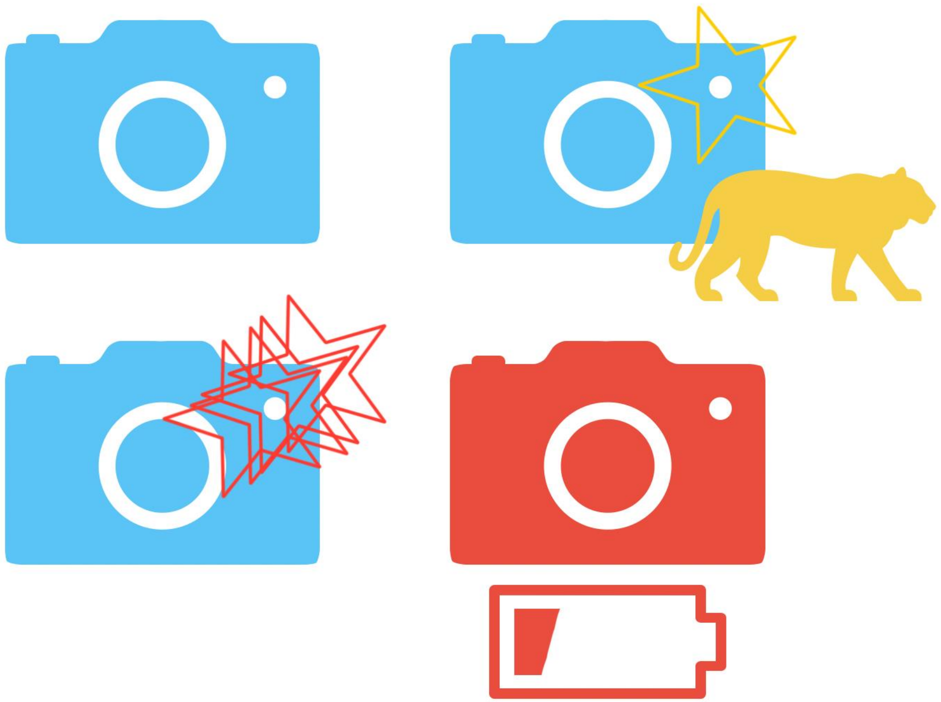

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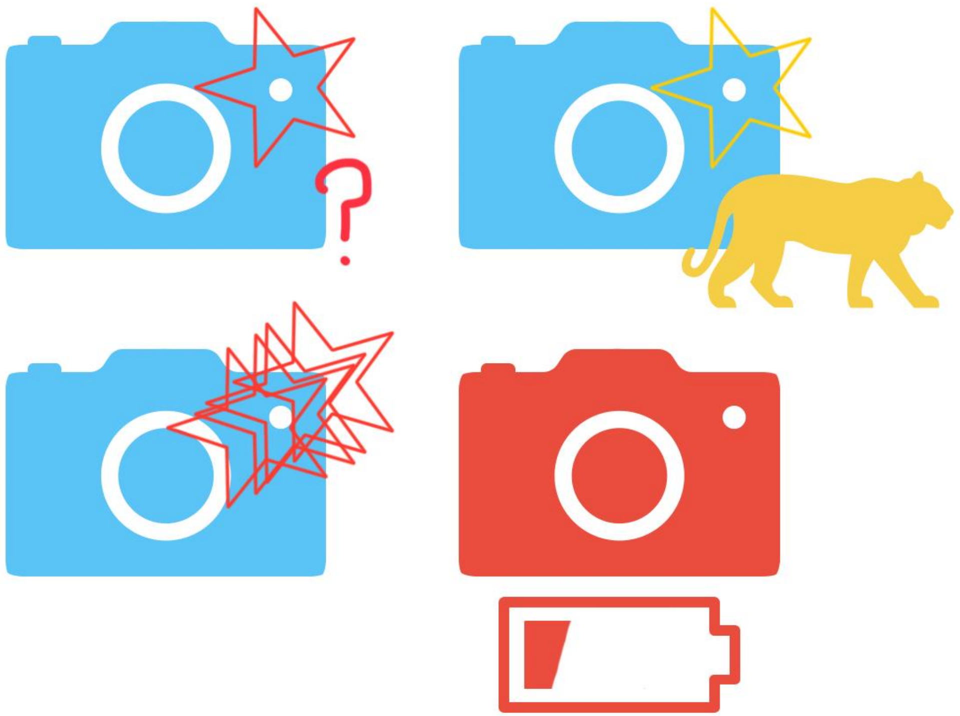

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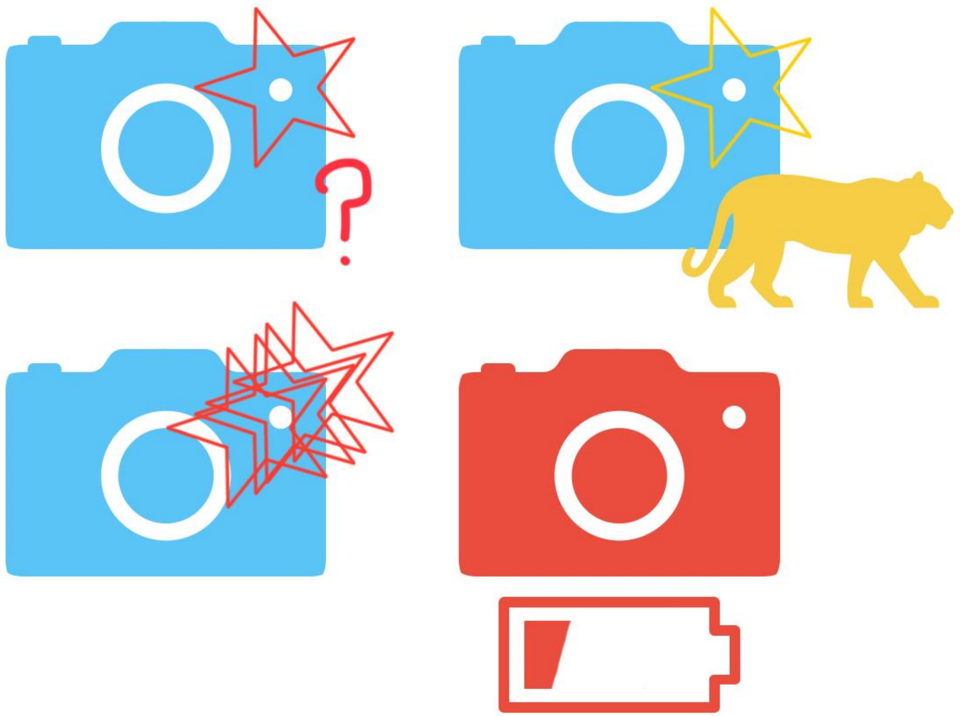

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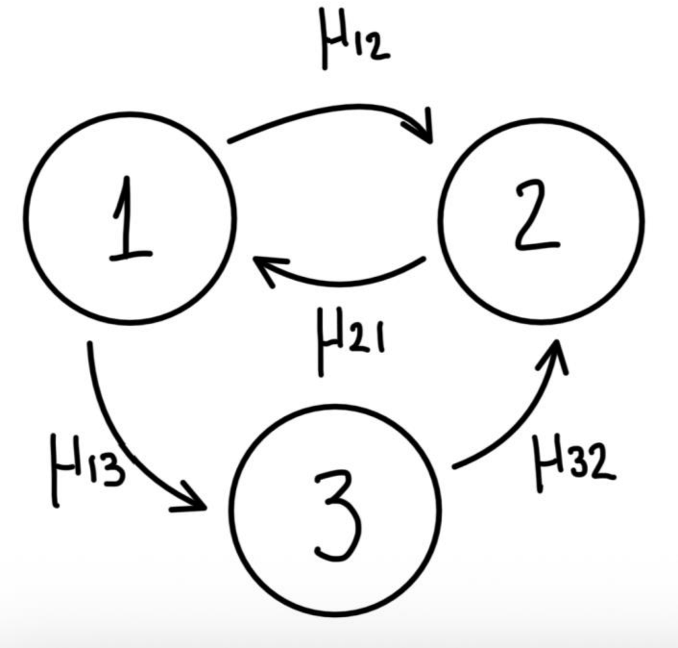
Goal:
Estimate effective effort of each camera

Markov Modulated Marked Poisson Process (MMMPP)



$$Q = \begin{pmatrix} -\mu_{12} - \mu_{13} & \mu_{12} & \mu_{13} \\ \mu_{21} & -\mu_{21} & 0 \\ 0 & \mu_{32} & -\mu_{32} \end{pmatrix}$$

n = number of cameras
E = length of survey

Latent camera states:

1. Normal
2. Broken
3. Mis-firing

Assumptions:

1. If camera repaired, must function normally
2. After a period of mis-fire, camera must break
3. Camera must start by working normally

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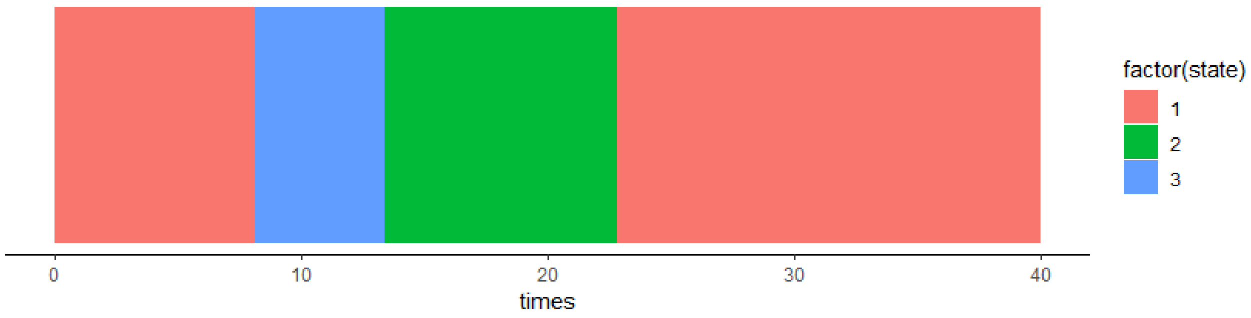

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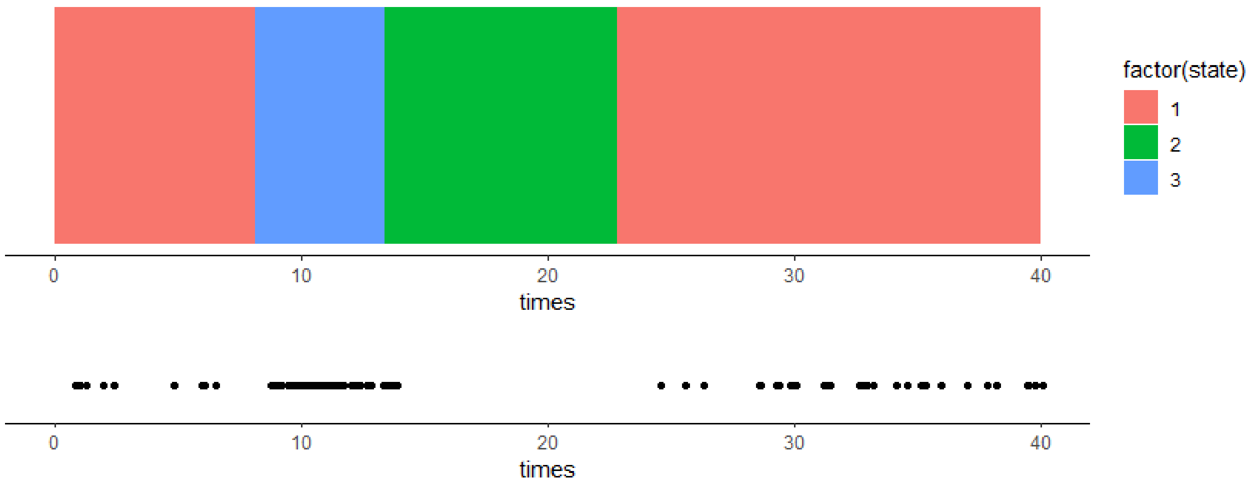

<u>Detection process:</u>

Detection rates λ_i are conditional on camera state i.
Conditions:

$$\lambda_2 = 0$$
$$\lambda_3 \gg \lambda_1$$

$$\Lambda = \begin{pmatrix} \lambda_1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & \lambda_3 \end{pmatrix}$$

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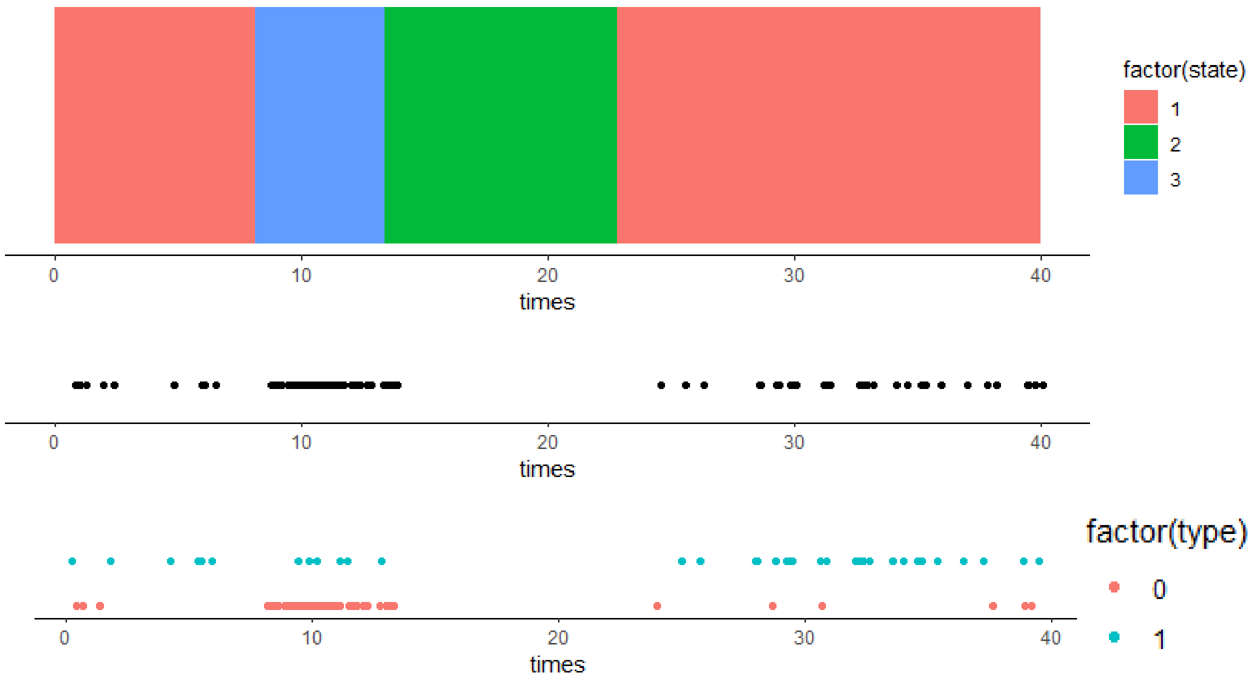


<u>Mark process:</u>

Let $\gamma_{i,k} \in \{0,1\}$ denote false positive or true positive detection k.

λ_+ = true positive rate
λ_-^1 = false positive rate in state 1
λ_-^3 = false positive rate in state 3

$$\lambda_1 = \lambda_+ + \lambda_-^1$$
$$\lambda_3 = \lambda_+ + \lambda_-^3$$

Let $s_{i,k}$ denote the state of detection k:

$$P(\gamma_{i,k} | s_{i,k} = s) = \begin{cases} \lambda_+ / \lambda_s & \text{if } \gamma_{i,k} = 1, \\ \lambda_-^s / \lambda_s & \text{otherwise.} \end{cases}$$

Markov Modulated Marked Poisson Process (MMMPP)

The likelihood function for camera i with K_i detections at times $x_{i,k}$ is:

$$\mathcal{L}_i = \underbrace{[1,0,0]} \left\{ \prod_{k=1}^{K_i} \underbrace{\Theta(x_{i,k} - x_{i,k-1})} \underbrace{\Lambda \mathrm{diag}(P_{i,k})} \right\} \Theta(E - x_{i,K_i}) \mathbf{e}$$

<u>Initial state probabilities</u>

<u>Transition matrix:</u>
$[\Theta(\Delta x)]_{i,j}$ the probability of going to state j and making no detections within time Δx given you started in state i.

<u>Detection and mark distribution</u>

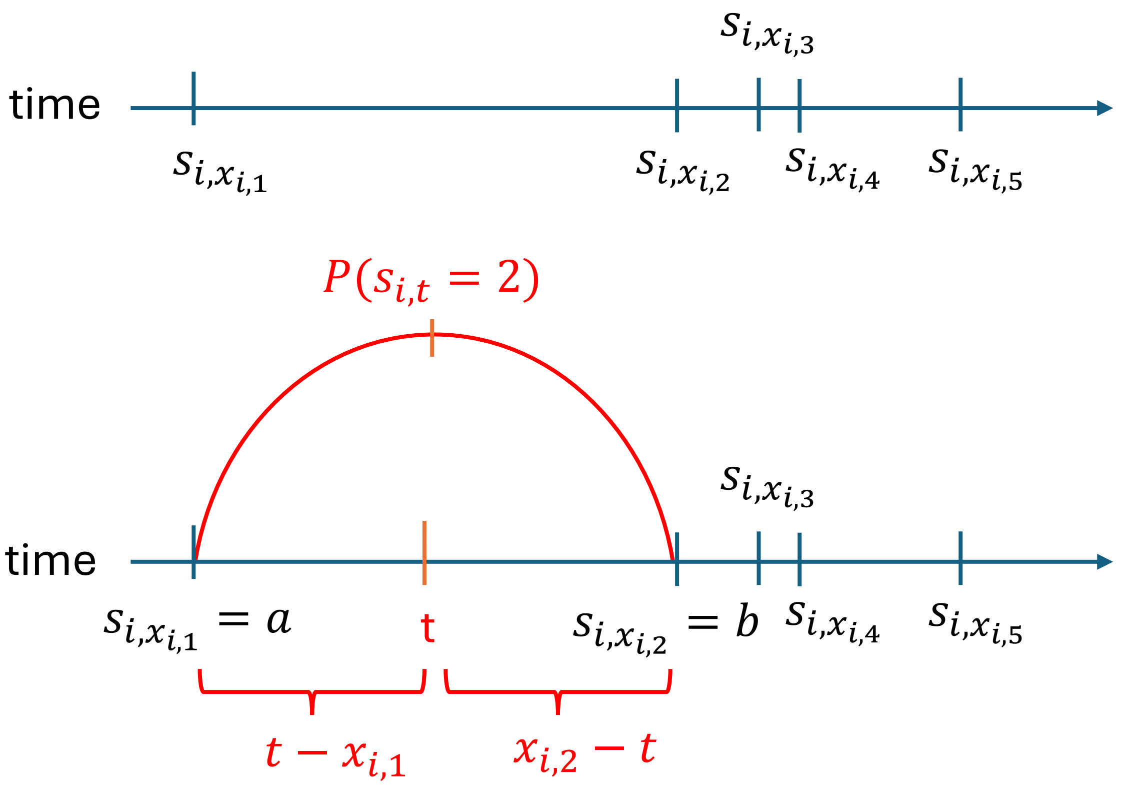
$$\Theta(\Delta x) = \exp((Q - \Lambda)\Delta x)$$

Effective Effort

To determine state of camera i at time t, denoted $s_{i,t}$, we:

1. Determine state $s_{i,x_{i,k}}$ at detection times $x_{i,k}$:
   Viterbi Algorithm

Effective Effort



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1. Determine state $s_{i,x_{i,k}}$ at detection times $x_{i,k}$:
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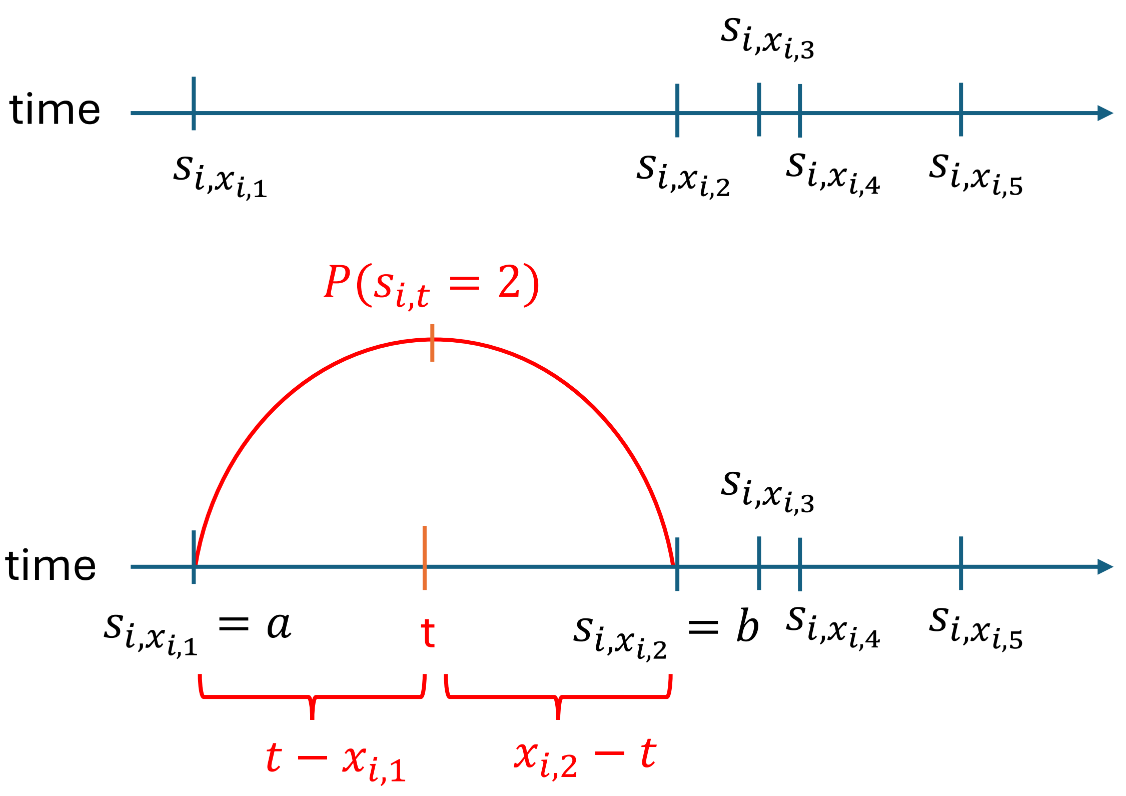
2. Determine state at time t between detection points:

$$\mathbb{P}(s_{i,t} = 2) = \frac{[\Theta(t - x_{i,k})]_{a,2}[\Theta(x_{i,k+1} - t)]_{2,b}}{[\Theta(x_{i,k+1} - x_{i,k})]_{a,b}}$$

Effective Effort



To determine state of camera i at time t, denoted $s_{i,t}$, we:

1. Determine state $s_{i,x_{i,k}}$ at detection times $x_{i,k}$: Viterbi Algorithm
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Let U_i be the fractional effort of camera i:

$$U_i = \frac{1}{E}\sum_{k=0}^{K_i}\left(\int_{x_{i,k}}^{x_{i,k+1}} \mathbb{P}(s_{i,t} = 1)dt\right)$$

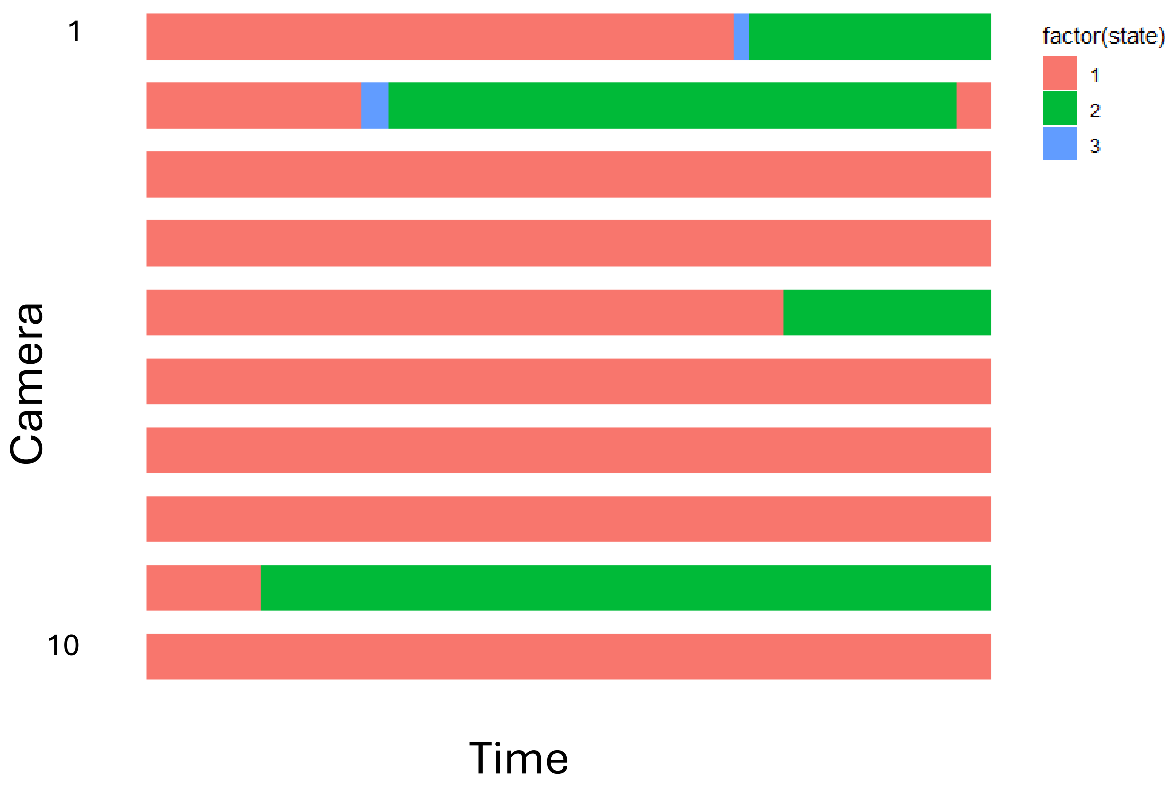
Simulation

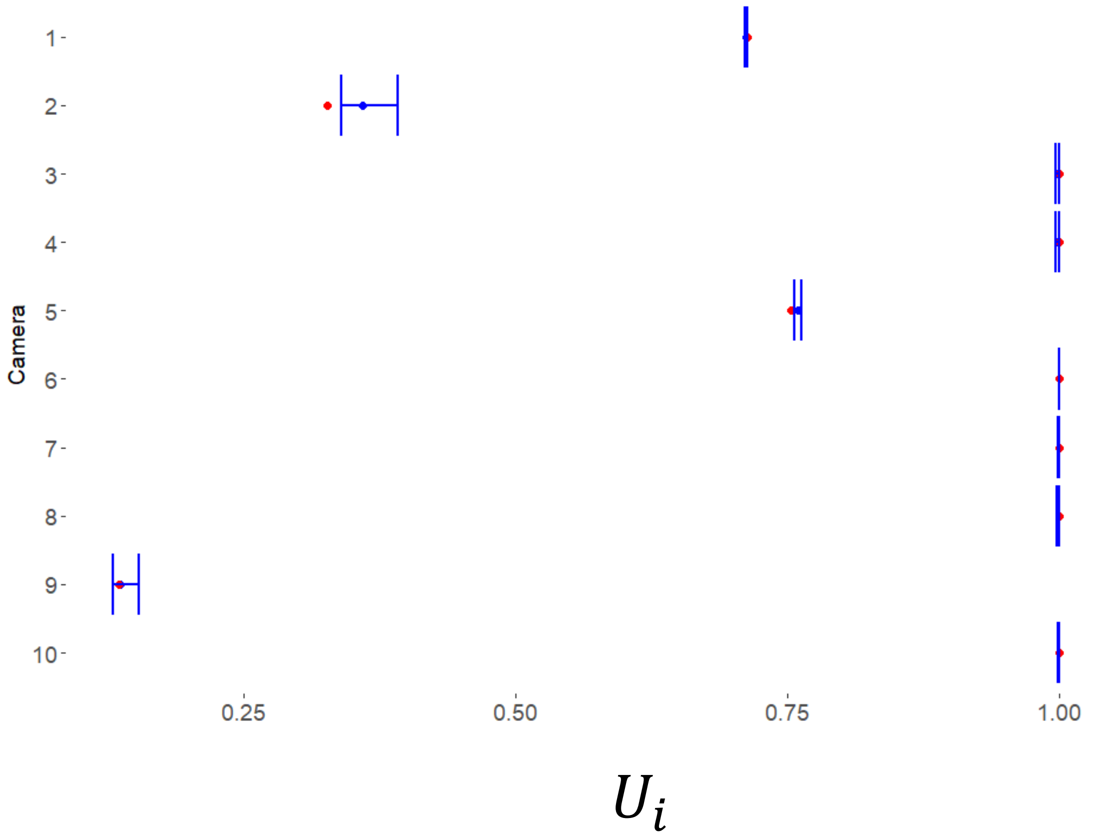
n=10 cameras
E = 40 days

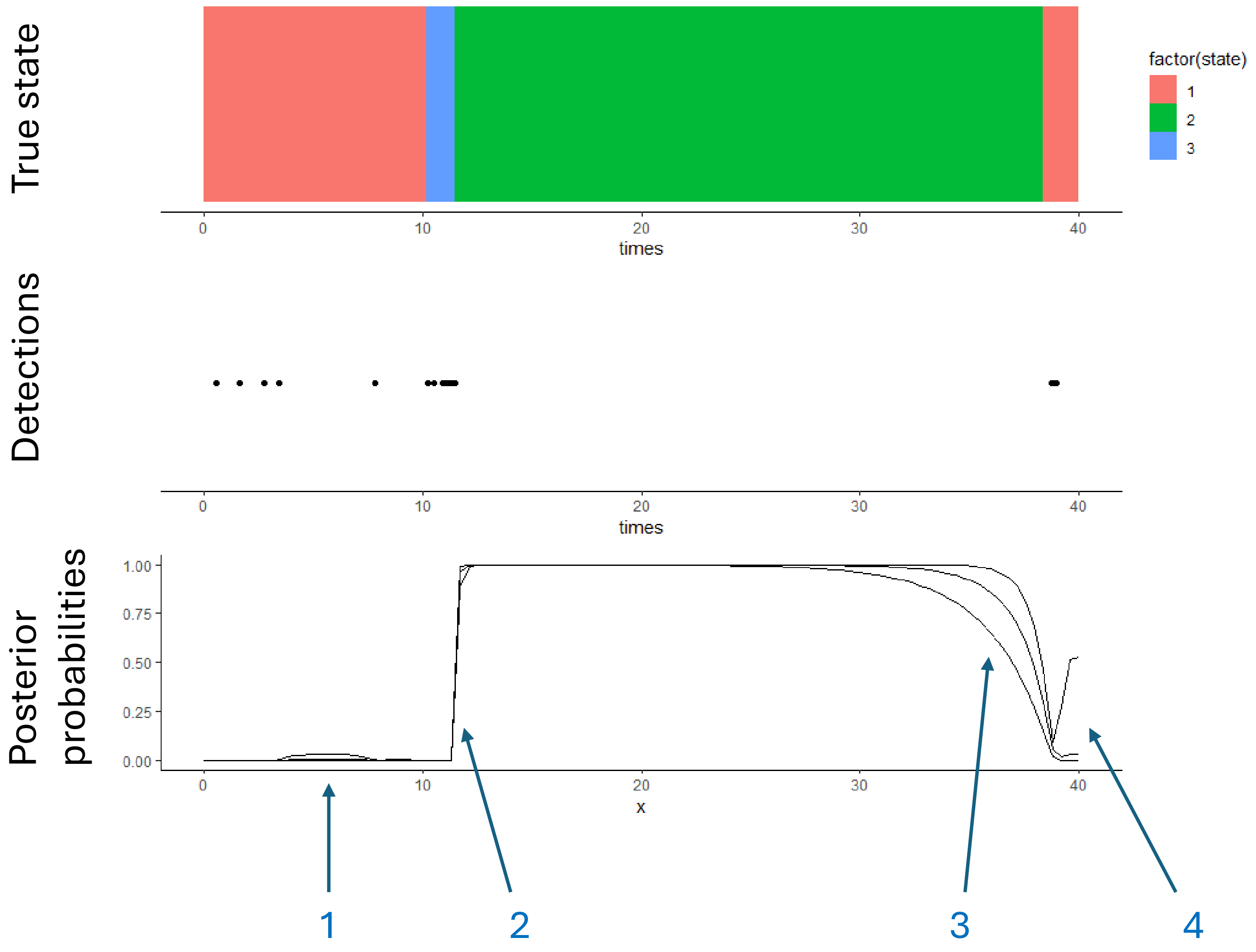
$$(\mu_{12}, \mu_{13}, \mu_{21}, \mu_{32}) = \left(\frac{1}{100}, \frac{1}{300}, \frac{1}{50}, 1\right)$$

$$\left.\begin{array}{l} \lambda_{+} \in (0.3, 1.5) \\ \lambda_{-}^{1} \in (0.1, 0.9) \end{array}\right\} \text{Between camera heterogeneity}$$

$$\lambda_{-}^{3} = 10$$







True state
factor(state)
1
2
3
0
10
20
30
40
times
Detections
0
10
20
30
40
times
Posterior probabilities
1.00
0.75
0.50
0.25
0.00
0
10
20
30
40
x
1
2
3
4

Assumptions & Further Work

Assumptions:

- Cameras share transition rates
- $\mu_{31} = 0$ and $\mu_{23} = 0$
- Detection rates and transition rates are time-homogeneous

Further Work:

- Covariates
- Absence of mark process
- State at collection
- Spatial models for detection
- $\mu_{21} = 0$ and $\mu_{13} = 0$

Thank you

Questions?

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