Reasoning about RFID-tracked Moving Objects in Symbolic Indoor Spaces

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Problem

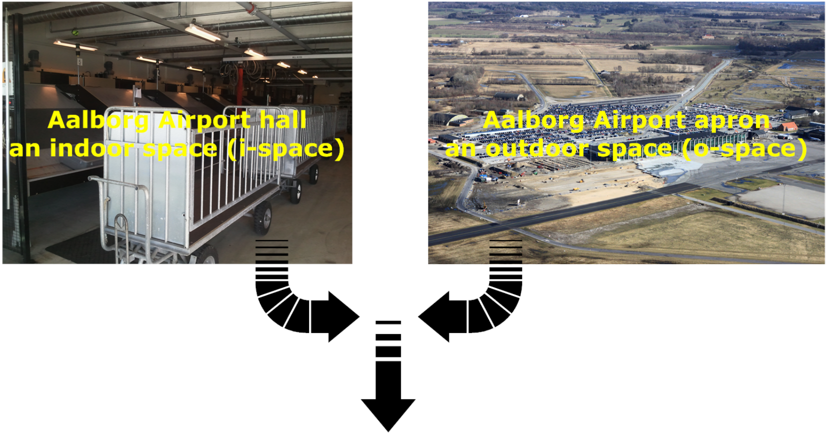
- Uniform support of reasoning applications in outdoor and indoor spaces (OI-spaces)
  - To track moving objects
  - To decide the parts that are covered by receptors
  - To determine the locations of congestion

Contributions

- Extension of a recent model of OI-spaces
- Investigation of the route observability concept
- Probabilistic translation of receptor data
- Reasoning about points of potential traffic load

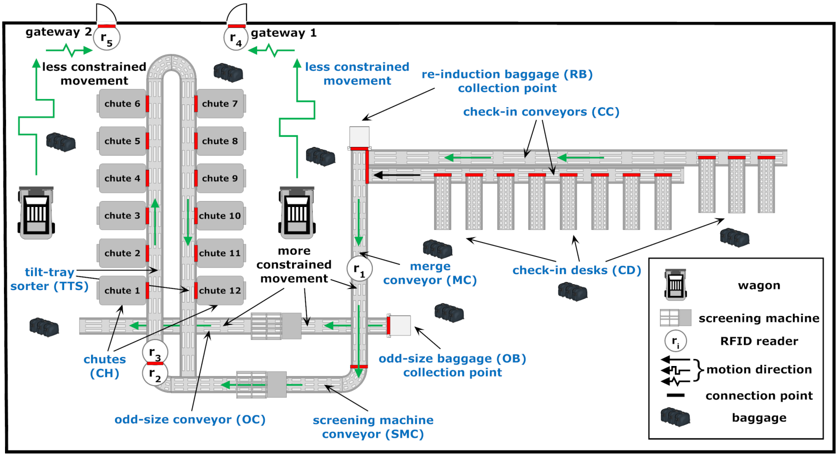
A Recent Model

- Sari Haj Hussein, Hua Lu, and Torben Bach Pedersen. Towards a unified model of outdoor and indoor spaces. In ACM SIGSPATIAL GIS 2012, Redondo Beach, California, The United States



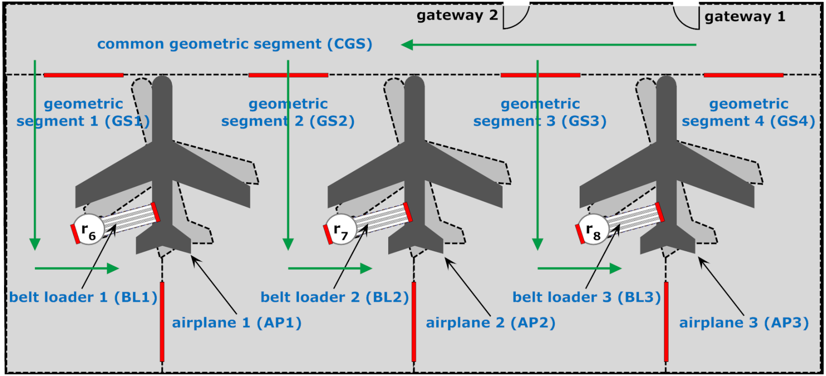
a unified oi-space model

1) semantic locations 2) connection points 3) routes



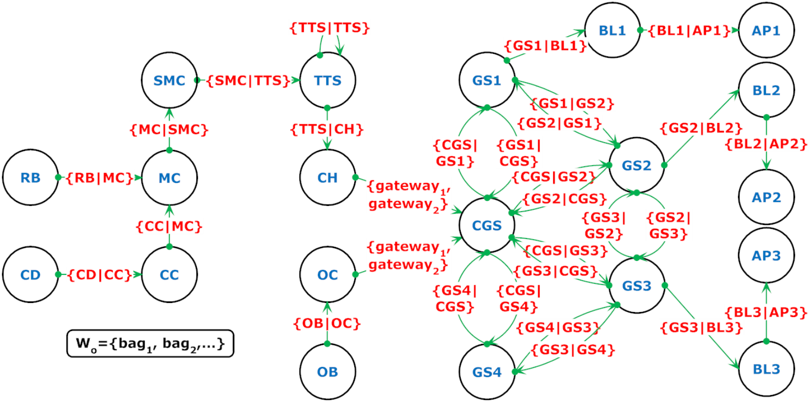
hall space plan

1) semantic locations 2) connection points 3) routes



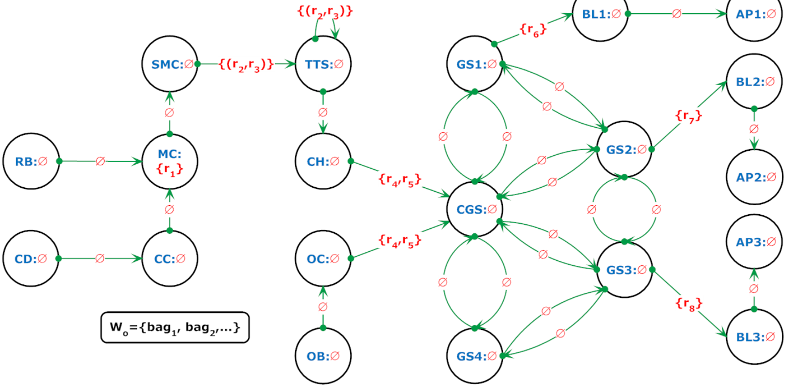
apron space plan

1) semantic locations 2) connection points 3) routes



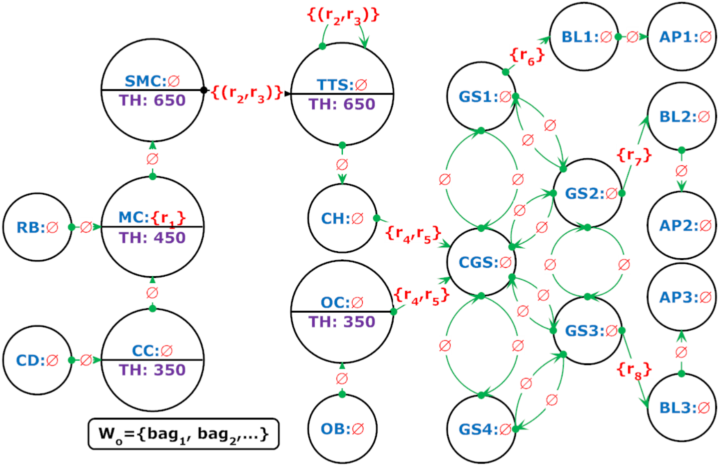
a unified oi-space model

1) semantic locations 2) readers positioning 3) routes



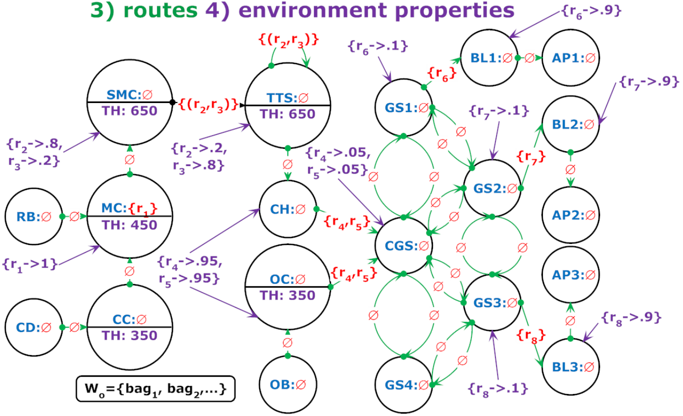
an RFID readers deployment model

1) semantic locations 2) readers positioning
3) routes 4) environment properties



an *extended* RFID readers deployment model
a *property pseudograph*

1) semantic locations 2) readers positioning
3) routes 4) environment properties

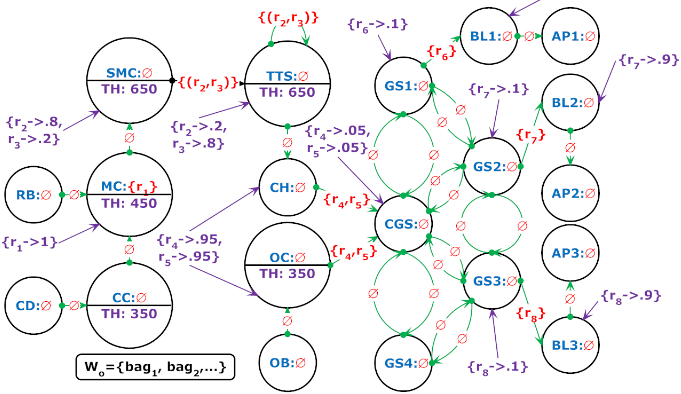


an *extended* RFID readers deployment model
a *property pseudograph*

Coverage Weight

- $c_r(l) = \{r \to w(r) = \frac{ZONE(r) \cap AREA(l)}{ZONE(r)} : ZONE(r) \cap AREA(l) \neq \emptyset\}$

1) semantic locations 2) readers positioning
3) routes 4) environment properties



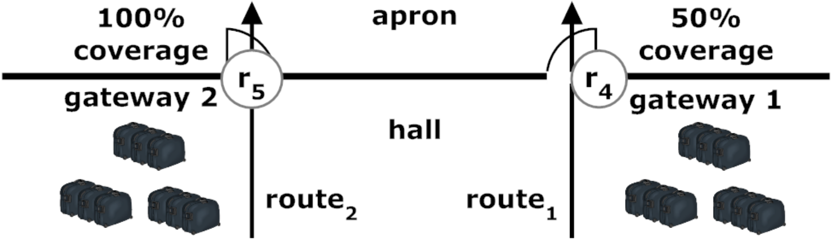
an *extended* RFID readers deployment model
a *property pseudograph*

Coverage Weight

- $c_r(l) = \{r \rightarrow w(r) = \frac{ZONE(r) \cap AREA(l)}{ZONE(r)} : ZONE(r) \cap AREA(l) \neq \emptyset\}$

Route Observability

- A measure of the extent to which a given route is covered by RFID readers



$route_2$ is *more observable* than $route_1$
albeit both routes are covered by one reader

Route Observability Function

- $obs(R) = \sum_{l \in \mathcal{V}(R)} \sum_{w(r) \in c_r(l)} \log(w(r) + 1)$

Function Bounds

- $0 \leq obs(R) \leq \sum_{l \in \mathcal{V}(R)} \log\left(\overline{c_r(l)} + |c_r(l)|\right) : \overline{c_r(l)} = \sum_{w(r) \in c_r(l)} w(r)$

Route Observability Function

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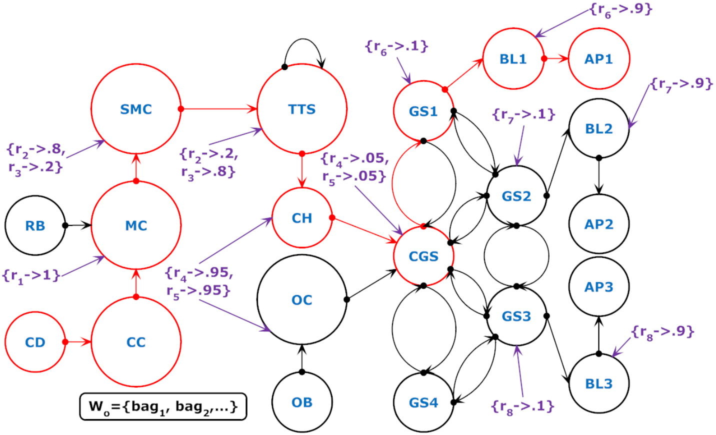


obs(CD...AP1)=6.3533
bounds(CD...AP1)=[0,8.2673]

Observability and Uncertainty

- The higher a route observability, the less the uncertainty in tracking moving objects along this route

appearance records

The trajectory of bag_1 during $[t_1, t_{37}]$

ar-id	obj-id	reader-id	s-time	e-time
ar_1	bag_1	r_1	t_1	t_2
ar_2	bag_1	r_2	t_5	t_6
ar_3	bag_1	r_3	t_7	t_8
ar_4	bag_1	r_2	t_{11}	t_{12}
ar_5	bag_1	r_3	t_{13}	t_{14}
ar_6	bag_1	r_4	t_{19}	t_{29}
ar_7	bag_1	r_7	t_{32}	t_{37}

// Stage 1. Translation based on $\mathcal{D}_{rfid}$.

for each $l \in \mathcal{W}_l$ **do**
    if $ar_i.reader\text{-}id \in c_l(l)$ **then**
        insert $\langle ar_i, ar_i.obj\text{-}id, l, ar_i.s\text{-}time, ar_i.e\text{-}time \rangle$ into inter-ds
        break
for each $m = (l_i, l_j) \in \mathcal{W}_m : l_i, l_j \in \mathcal{W}_l$ **do**
    if $(ar_i.reader\text{-}id \in c_m(m)$ or
    $(ar_i.reader\text{-}id, ar_{i+1}.reader\text{-}id) \in c_m(m))$ **then**
        insert $\langle ar_i, ar_i.obj\text{-}id, l_i, ar_i.s\text{-}time, ar_i.e\text{-}time \rangle$ and
        $\langle ar_i, ar_i.obj\text{-}id, l_j, ar_i.s\text{-}time, ar_i.e\text{-}time \rangle$ into inter-ds

The intermediate records of bag_1 during $[t_1, t_{37}]$

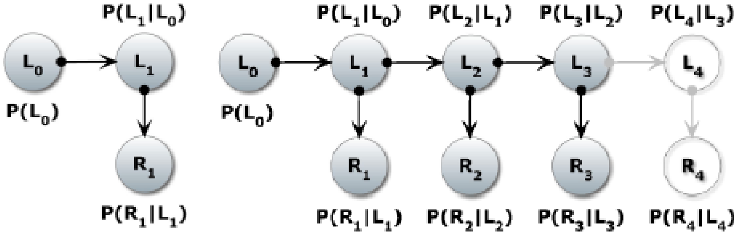
ar-id	obj-id	loc	s-time	e-time
ar_1	bag_1	MC	t_1	t_2
ar_2	bag_1	SMC	t_5	t_6
ar_2	bag_1	TTS	t_5	t_6
ar_2	bag_1	TTS	t_5	t_6
ar_2	bag_1	TTS	t_5	t_6
ar_3	bag_1	SMC	t_7	t_8
ar_3	bag_1	TTS	t_7	t_8
ar_3	bag_1	TTS	t_7	t_8
ar_3	bag_1	TTS	t_7	t_8
ar_4	bag_1	SMC	t_{11}	t_{12}
ar_4	bag_1	TTS	t_{11}	t_{12}
ar_4	bag_1	TTS	t_{11}	t_{12}
ar_4	bag_1	TTS	t_{11}	t_{12}
ar_5	bag_1	SMC	t_{13}	t_{14}
ar_5	bag_1	TTS	t_{13}	t_{14}
ar_5	bag_1	TTS	t_{13}	t_{14}
ar_5	bag_1	TTS	t_{13}	t_{14}
ar_6	bag_1	CH	t_{19}	t_{29}
ar_6	bag_1	CGS	t_{19}	t_{29}
ar_6	bag_1	OC	t_{19}	t_{29}
ar_6	bag_1	CGS	t_{19}	t_{29}
ar_7	bag_1	GS2	t_{32}	t_{37}
ar_7	bag_1	BL2	t_{32}	t_{37}

// Stage 2. Transformation.
Transform inter-ds into prob-ds.

The probabilistic records of bag_1 during $[t_1, t_{37}]$

obj-id	prob-loc	s-time	e-time
bag_1	[MC : 1]	t_1	t_2
bag_1	[SMC : .25, TTS : .75]	t_5	t_6
bag_1	[SMC : .25, TTS : .75]	t_7	t_8
bag_1	[SMC : .25, TTS : .75]	t_{11}	t_{12}
bag_1	[SMC : .25, TTS : .75]	t_{13}	t_{14}
bag_1	[CH : .25, OC : .25, CGS : .5]	t_{19}	t_{29}
bag_1	[GS2 : .5, BL2 : .5]	t_{32}	t_{37}

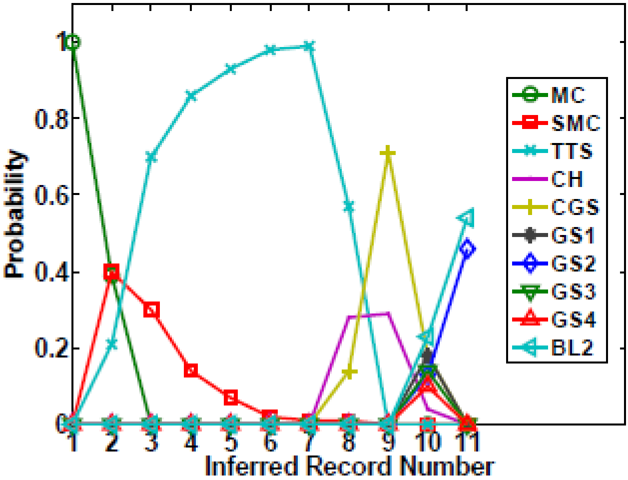
```
// Stage 3. Inferring the information gaps.
for each p-rec_i ∈ prob-ds do
    inject p-rec_i.prob-loc and p-rec_i+1.prob-loc as evidence into DBN
    update DBN beliefs using EPIS-BN
    bel1 ← first-DBN-belief
    beln ← last-DBN-belief
    insert ⟨p-rec_i.obj-id, bel1, p-rec_i.s-time, p-rec_i.e-time⟩ and
   ⟨p-rec_i+1.obj-id, beln, p-rec_i+1.s-time, p-rec_i+1.e-time⟩
   into infer-ds
    start ← p-rec_i.e-time + inv
    end ← p-rec_i+1.s-time − 1
    if start <= end then
        evolve infer-loc from DBN
        insert ⟨p-rec_i.obj-id, infer-loc, start, end⟩ into infer-ds
```



(a) DBN (b) Unrolled DBN

The inferred route of bag_1 during $[t_1, t_{37}]$

obj-id	infer-loc	s-time	e-time
bag_1	[MC : 1]	t_1	t_2
bag_1	[MC : .39, SMC : .40, TTS : .21]	t_3	t_4
bag_1	[SMC : .30, TTS : .70]	t_5	t_6
bag_1	[SMC : .14, TTS : .86]	t_7	t_8
bag_1	[SMC : .07, TTS : .93]	t_9	t_{10}
bag_1	[SMC : .02, TTS : .98]	t_{11}	t_{12}
bag_1	[SMC : .01, TTS : .99]	t_{13}	t_{14}
bag_1	[SMC : .01, TTS : .57, CH : .28, CGS : .14]	t_{15}	t_{18}
bag_1	[CH : .29, CGS : .71]	t_{19}	t_{29}
bag_1	[CH : .04, CGS : .18, GS1 : .18, GS2 : .13, GS3 : .14, GS4 : .10, BL2 : .23]	t_{30}	t_{31}
bag_1	[GS2 : .46, BL2 : .54]	t_{32}	t_{37}


1
0.8
0.6
0.4
0.2
0
Probability
1 2 3 4 5 6 7 8 9 10 11
Inferred Record Number
MC
SMC
TTS
CH
CGS
GS1
GS2
GS3
GS4
BL2

Dynamic BP Estimate

- Given:
  - An RFID graph $\mathcal{D}_{rfid} = (\mathcal{W}_l, \mathcal{W}_m, c_l, c_m, c_r)$
  - The infer – ds
  - A monitoring period T of a location $l \in \mathcal{W}_l$
- $\forall l \in \mathcal{W}_l : E_{BP}^{T}(l) = Pr(obj_1 \;\; at \;\; l, \ldots, obj_n \;\; at \;\; l) : obj_i \in \mathcal{W}_o$

Dynamic BP Monitoring Query

- $BPMQ^T = \{E^T_{BP}(l) : l \in \mathcal{W}_l\}$

Algorithm Answering a BPMQ

Input: $\mathcal{D}_{rfid} = (\mathcal{W}_l, \mathcal{W}_m, c_l, c_m, c_r)$, the infer-ds, a monitoring period T, a probability tweaking parameter η, and a normalization function ψ to [0, 1].

Output: $\psi(E_{BP}^{T})$.

extract $I\text{-}REC(T)$ from the infer-ds
$increase = 1.0 + \eta/100.0$
$decrease = 1.0 - \eta/100.0$
for each $l \in \mathcal{W}_l$ **do**
    $E_{BP}^{T}(l) = |\{i\text{-}rec \in I\text{-}REC(T) : l \in i\text{-}rec\}|$
    for each $i\text{-}rec \in I\text{-}REC(T)$ **do**
        $t = i\text{-}rec.e\text{-}time - i\text{-}rec.s\text{-}time$
        if $i\text{-}rec.pr(obj\ at\ l) > 0$ **then**
            $E_{BP}^{T}(l) = E_{BP}^{T}(l) \times i\text{-}rec.pr(obj\ at\ l)$
            repeat t times
                $E_{BP}^{T}(l) = E_{BP}^{T}(l) \times increase$
        else
            repeat t times
                $E_{BP}^{T}(l) = E_{BP}^{T}(l) \times decrease$
return $\psi(E_{BP}^{T})$

The inferred route of bag_1 during $[t_1, t_{37}]$

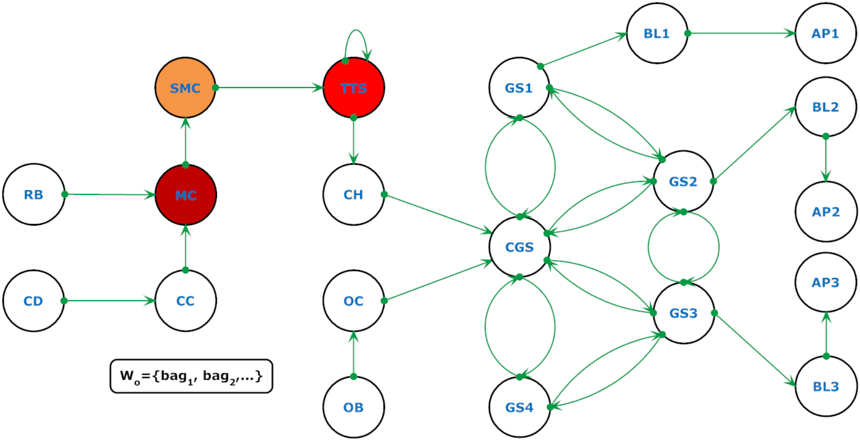
obj-id	infer-loc	s-time	e-time
bag_1	[MC : 1]	t_1	t_2
bag_1	[MC : .39, SMC : .40, TTS : .21]	t_3	t_4
bag_1	[SMC : .30, TTS : .70]	t_5	t_6
bag_1	[SMC : .14, TTS : .86]	t_7	t_8
bag_1	[SMC : .07, TTS : .93]	t_9	t_{10}
bag_1	[SMC : .02, TTS : .98]	t_{11}	t_{12}
bag_1	[SMC : .01, TTS : .99]	t_{13}	t_{14}
bag_1	[SMC : .01, TTS : .57, CH : .28, CGS : .14]	t_{15}	t_{18}
bag_1	[CH : .29, CGS : .71]	t_{19}	t_{29}
bag_1	[CH : .04, CGS : .18, GS1 : .18, GS2 : .13, GS3 : .14, GS4 : .10, BL2 : .23]	t_{30}	t_{31}
bag_1	[GS2 : .46, BL2 : .54]	t_{32}	t_{37}

The inferred route of bag_2 during $[t_3, t_{28}]$

obj-id	infer-loc	s-time	e-time
bag_2	[MC : 1]	t_3	t_4
bag_2	[MC : .32, SMC : .45, TTS : .23]	t_5	t_7
bag_2	[SMC : .06; TTS : .94]	t_8	t_{10}
bag_2	[CH : .31, CGS : .69]	t_{11}	t_{25}
bag_2	[GS1 : .41; BL1 : .59]	t_{26}	t_{28}

$I\text{-}REC([t_1, t_7])$ extracted from the infer-ds

obj-id	infer-loc	s-time	e-time
bag_1	[MC : 1]	t_1	t_2
bag_1	[MC : .39, SMC : .40, TTS : .21]	t_3	t_4
bag_1	[SMC : .30, TTS : .70]	t_5	t_6
bag_1	[SMC : .14, TTS : .86]	t_7	t_8
bag_2	[MC : 1]	t_3	t_4
bag_2	[MC : .32, SMC : .45, TTS : .23]	t_5	t_7



$$E_{BP}^{[t_1,t_7]}(\text{MC}) = 4 \times .39 \times .32 \times .9^2 \times 1.1^5 = .6512$$
$$E_{BP}^{[t_1,t_7]}(\text{SMC}) = 4 \times .40 \times .30 \times .14 \times .45 \times .9^2 \times 1.1^5 = .0394$$
$$E_{BP}^{[t_1,t_7]}(\text{TTS}) = 4 \times .21 \times .70 \times .86 \times .23 \times .9^2 \times 1.1^5 = .1517$$
$$E_{BP}^{[t_1,t_7]}(\text{rest of locations}) = 0$$

Thank You!