Probabilistic model of Episodic Memory

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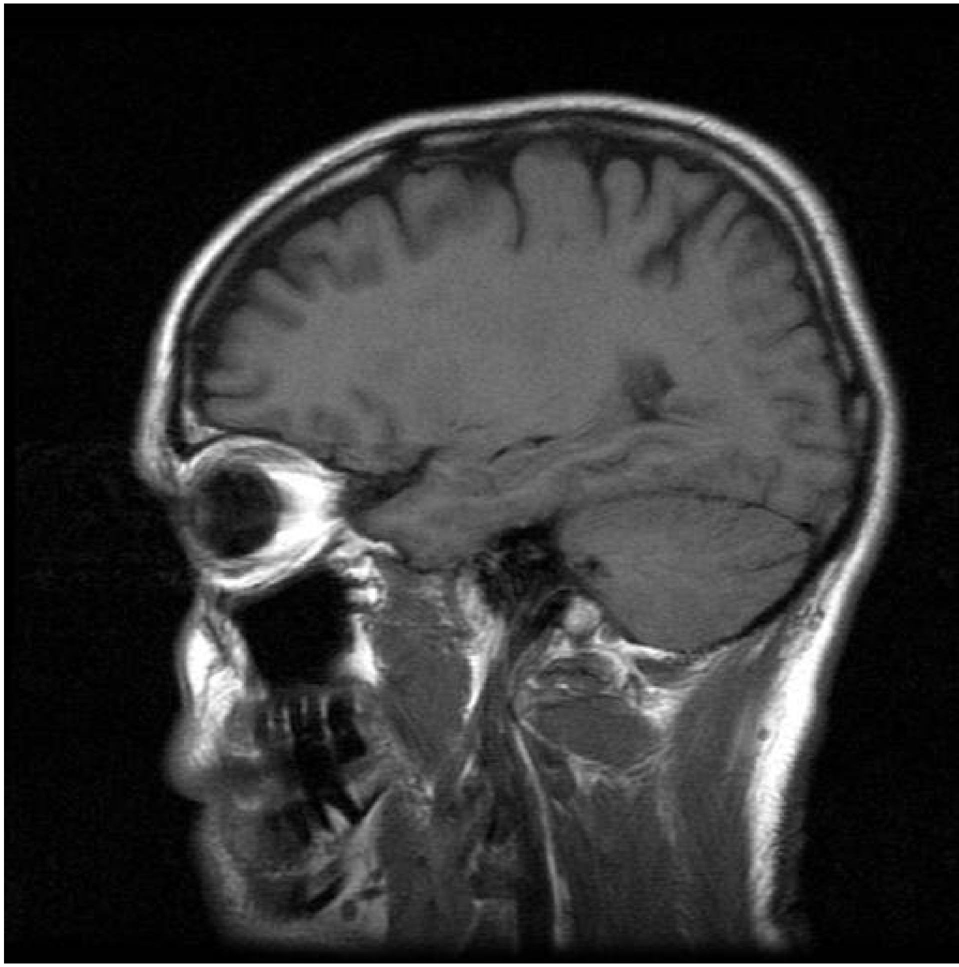
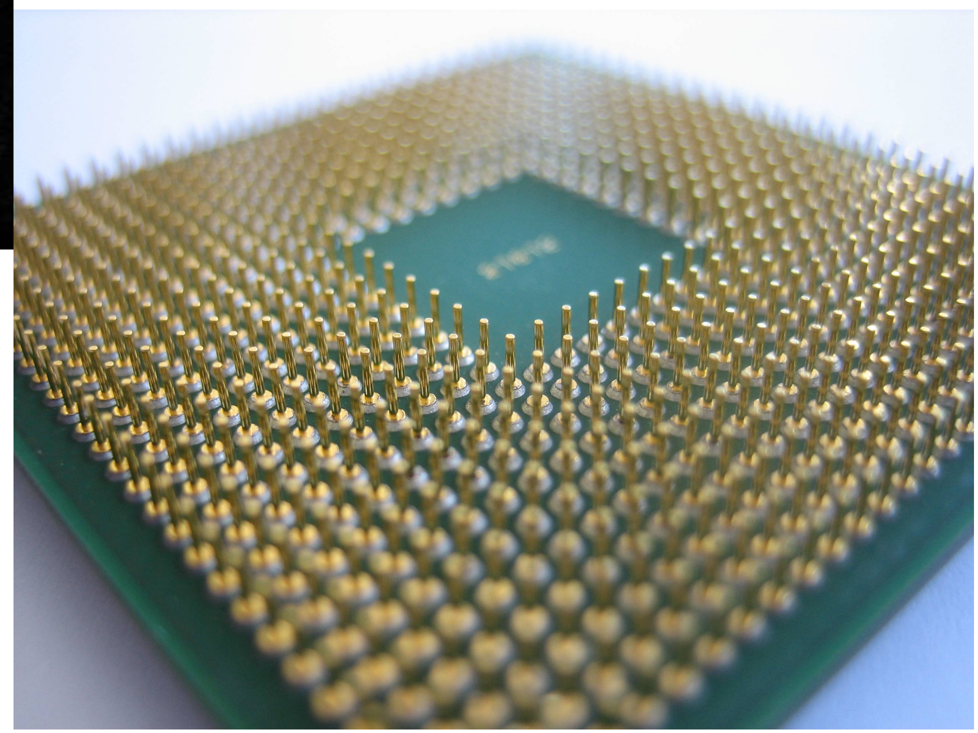
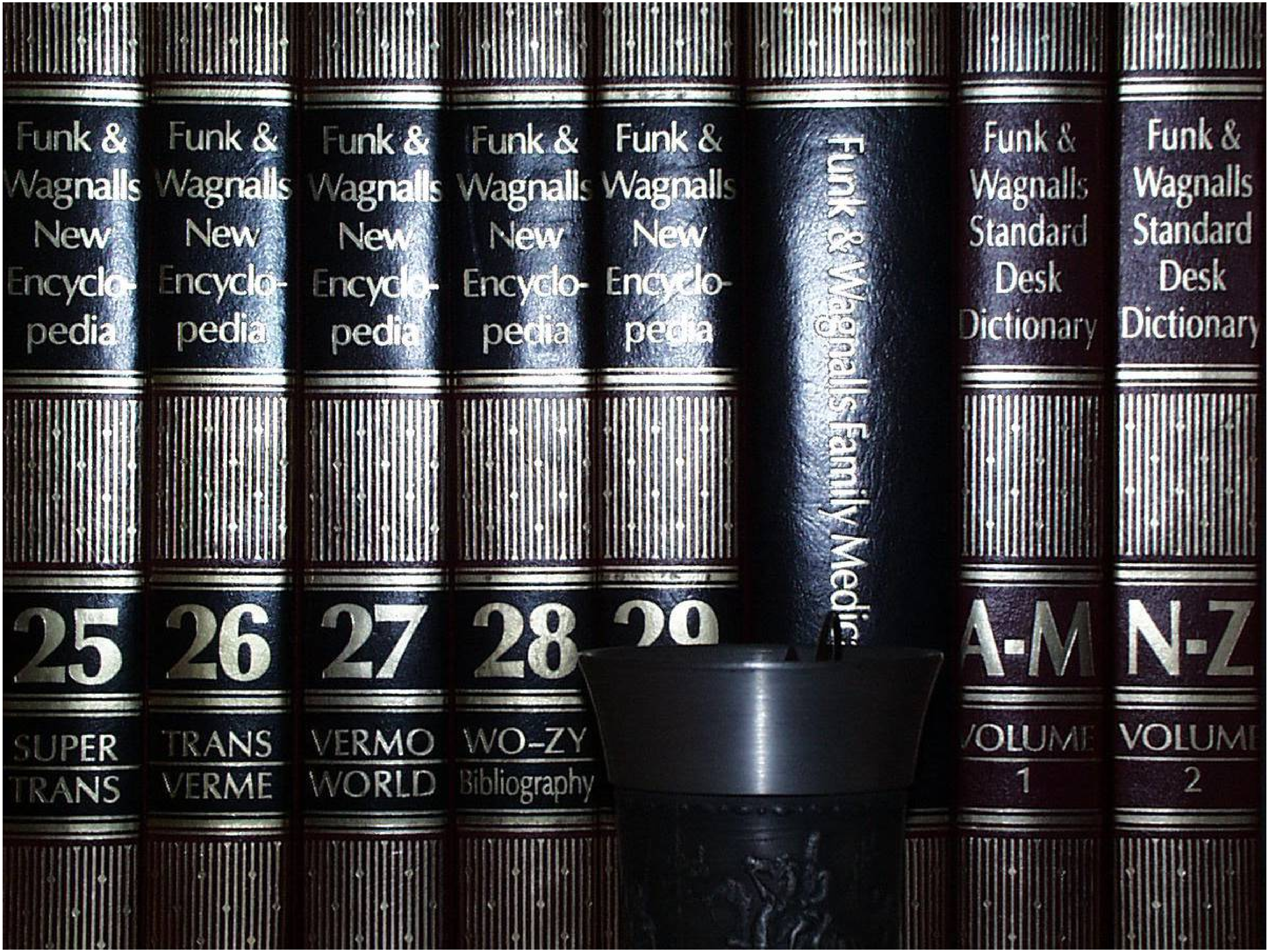
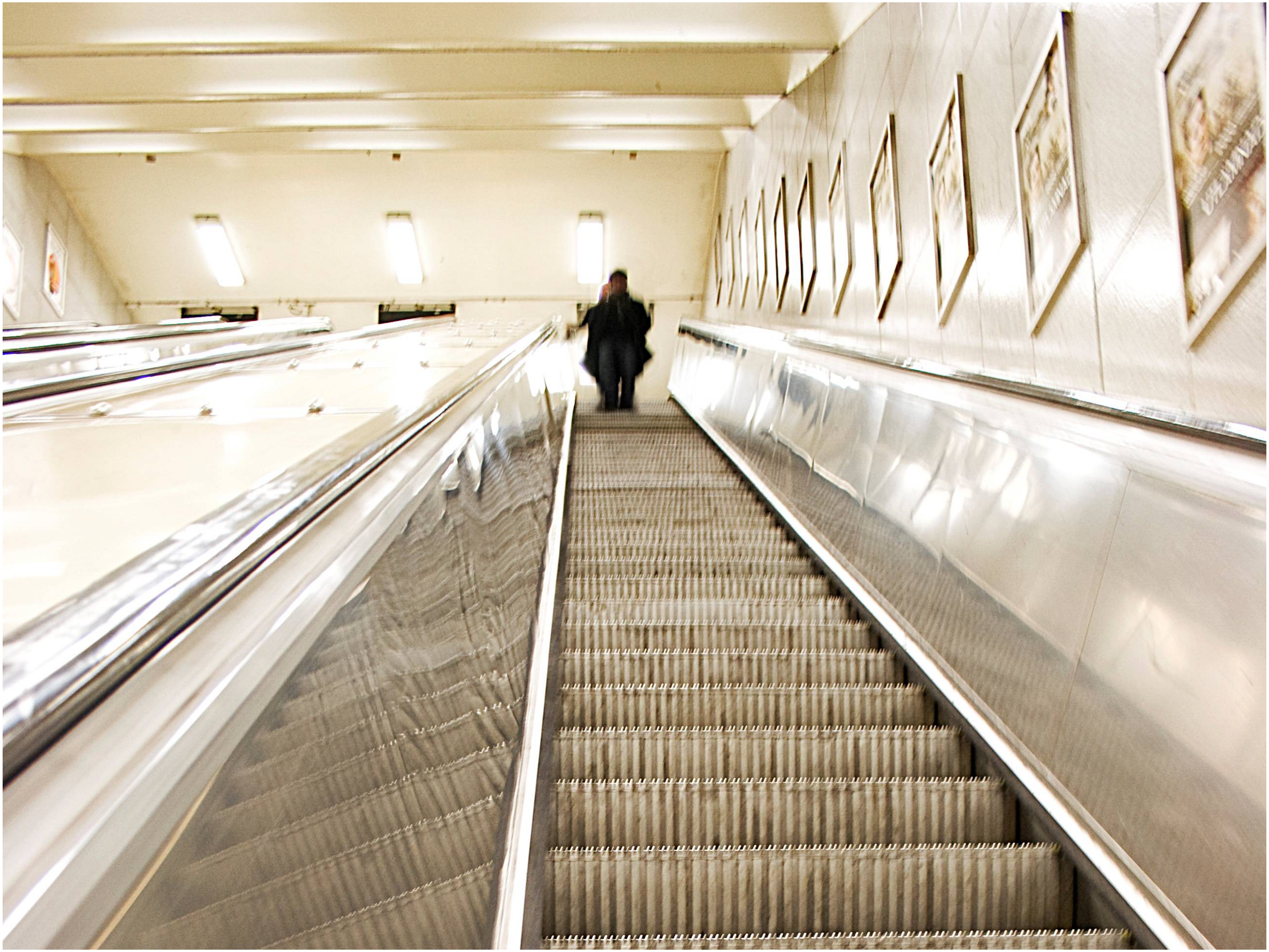





Funk & Wagnalls New Encyclopedia
25
SUPER TRANS
Funk & Wagnalls New Encyclopedia
26
TRANS VERME
Funk & Wagnalls New Encyclopedia
27
VERMO WORLD
Funk & Wagnalls New Encyclopedia
28
WO-ZY Bibliography
Funk & Wagnalls New Encyclopedia
Funk & Wagnalls Family Medic
Funk & Wagnalls Standard Desk Dictionary
A-M
VOLUME 1
Funk & Wagnalls Standard Desk Dictionary
N-Z
VOLUME 2


PICCADILLY LINE
PLATFORM 1
WESTBOUND


Enter



$\cancel{0}$


4 ghi
5 jkl
mno 6
7pqrs
8 tuv
wxyz9
* +
0
#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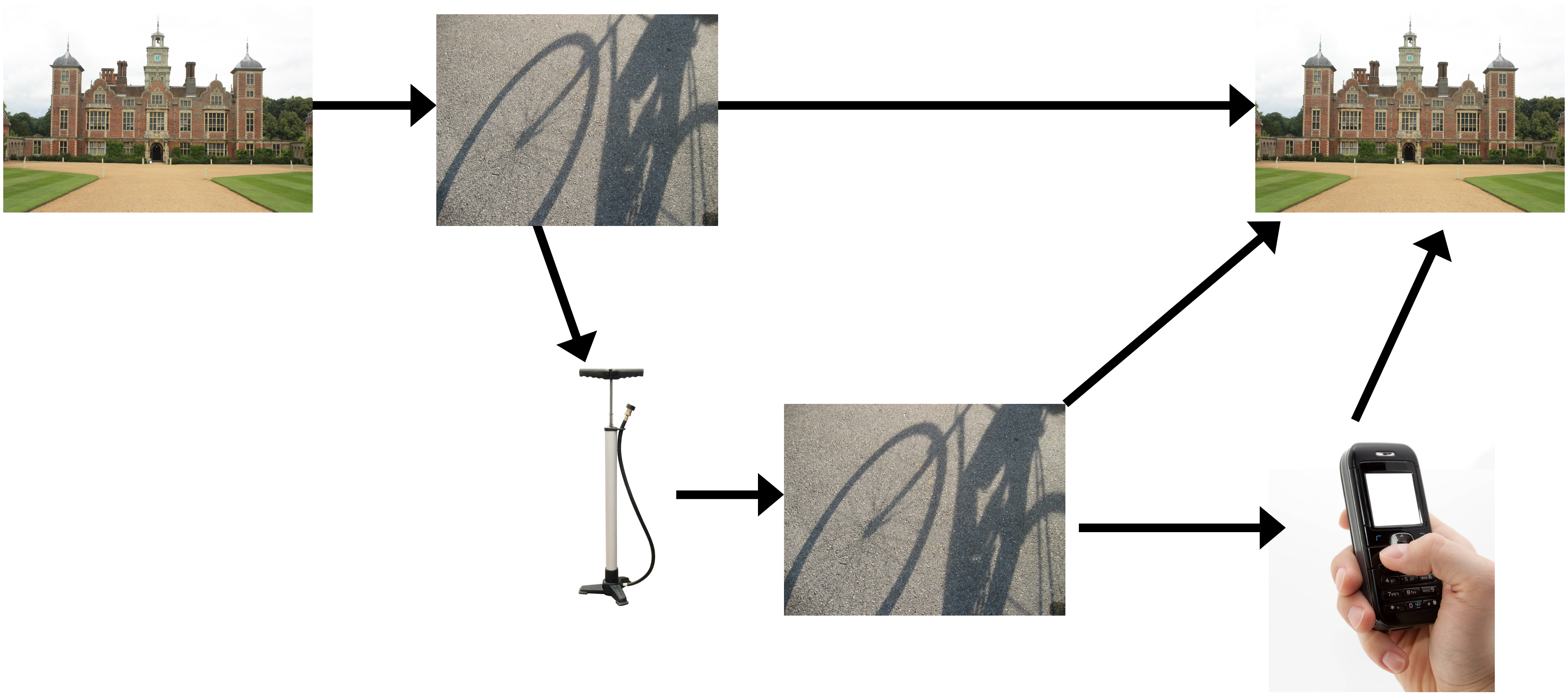
- Episode is a sequence of events
- Episodes are hierarchical
- Episodes have schemas

Normal day

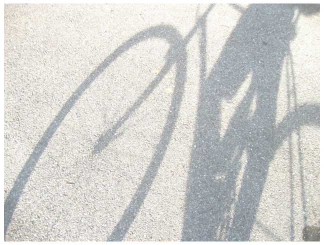
Work | Free time

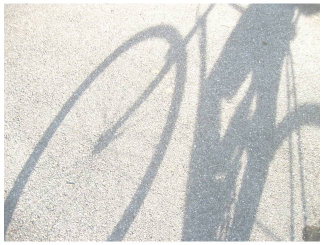
Morning routine | Commute | Office | Co | Training | At home

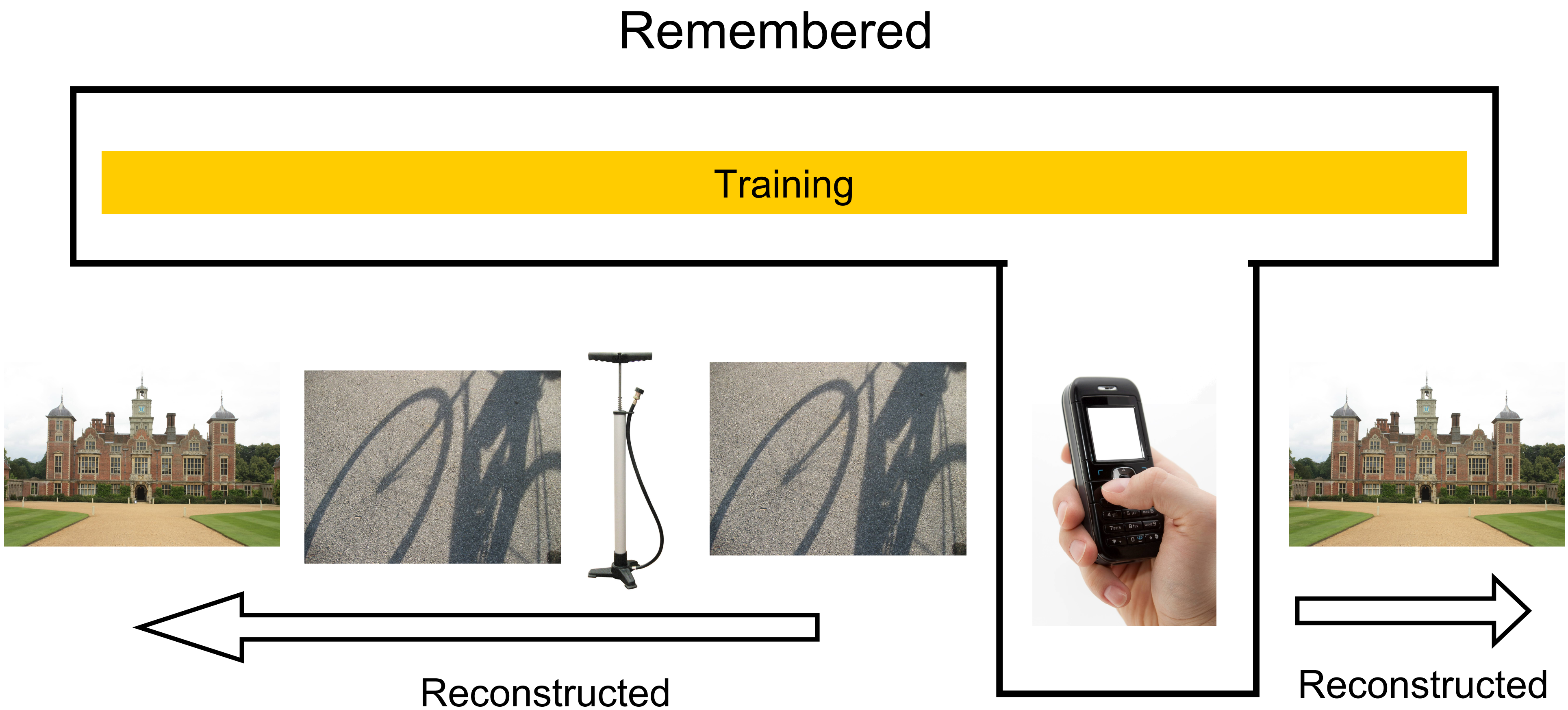
Training

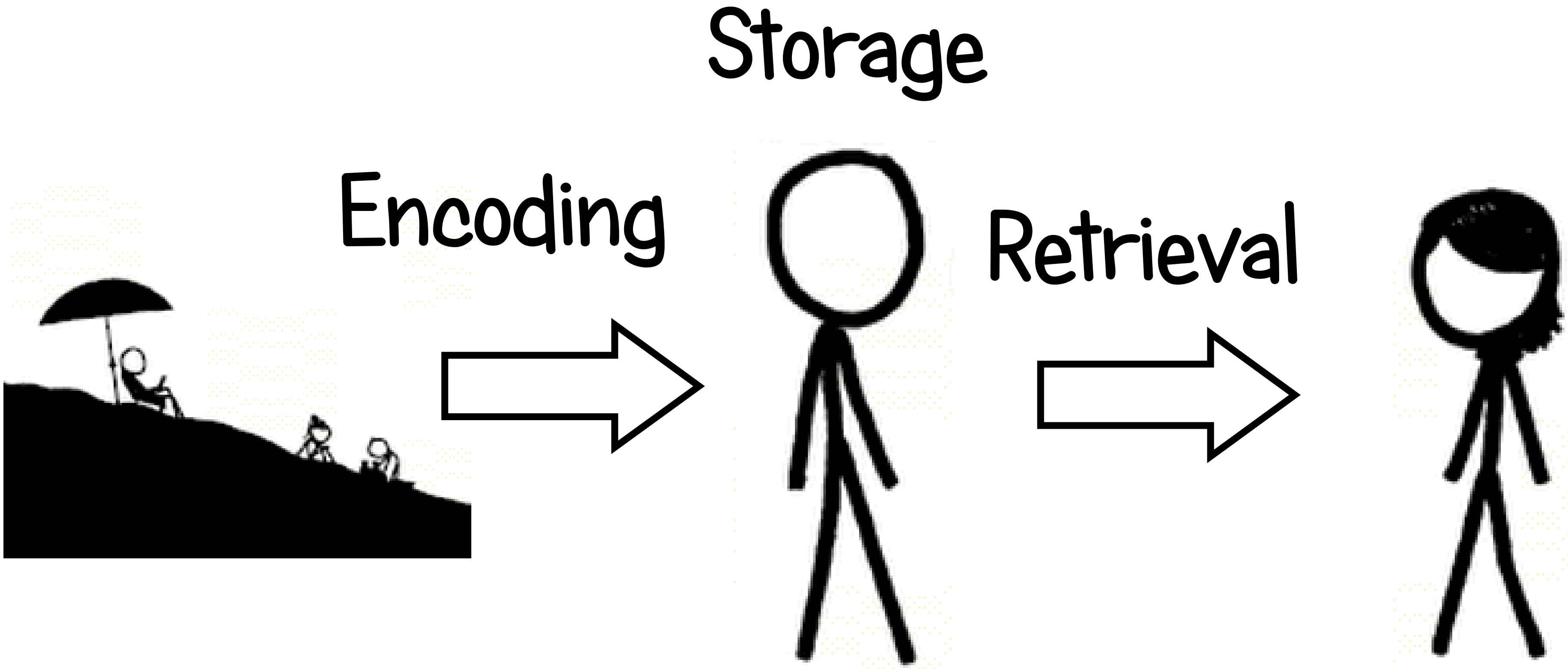


Training




Remembered
Training
Reconstructed
Reconstructed


Encoding
Storage
Retrieval

Outline

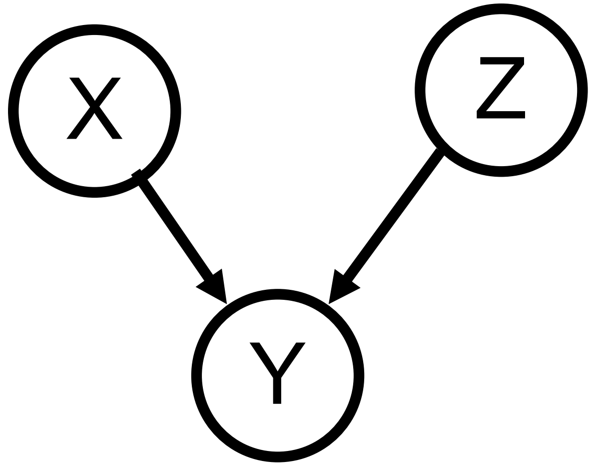
- Encoding
  - Segment events according to schemas
  - Inference of episode hierarchy
    - » Event segmentation theory [Zacks and Tversky, 2001]
  - Encode episode with respect to the schema
    - » Fuzzy-trace theory [Brainerd and Reyna, 2005]
- Storage
  - Forgetting
- Retrieval
  - Reconstructive memory retrieval

LET’S GET FORMAL


FORGED
STEEL

Bayesian Networks

X	
a	0.2
b	0.8



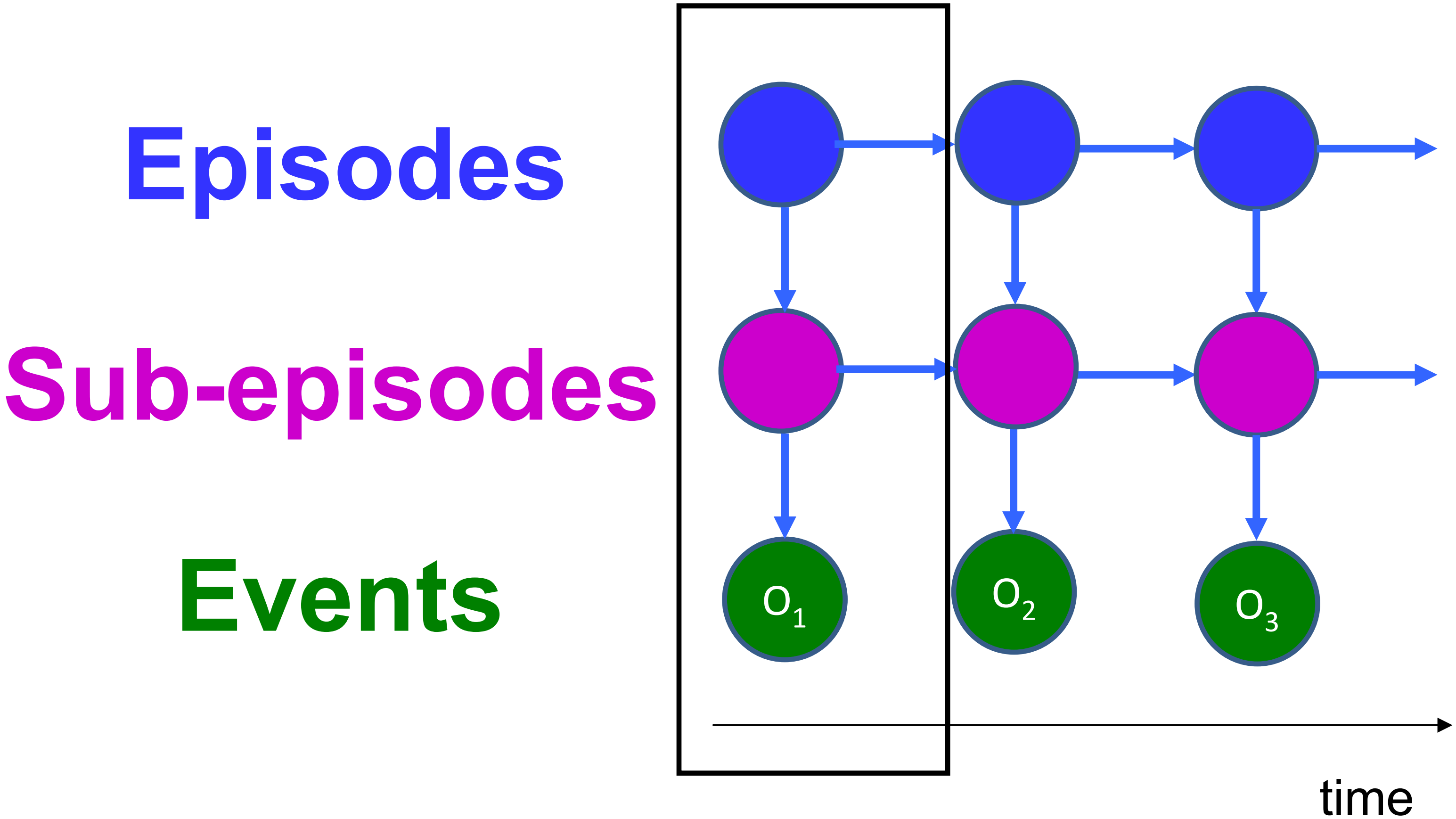
Z	
v	0.9
w	0.1

X
random variable

D(X) = {a,b}
domain of X are a and b

Z	X\Y	g	h
v	a	0.5	0.5
	b	0.3	0.7
w	a	0.1	0.9
	b	0.6	0.4

Dynamic Bayesian Networks



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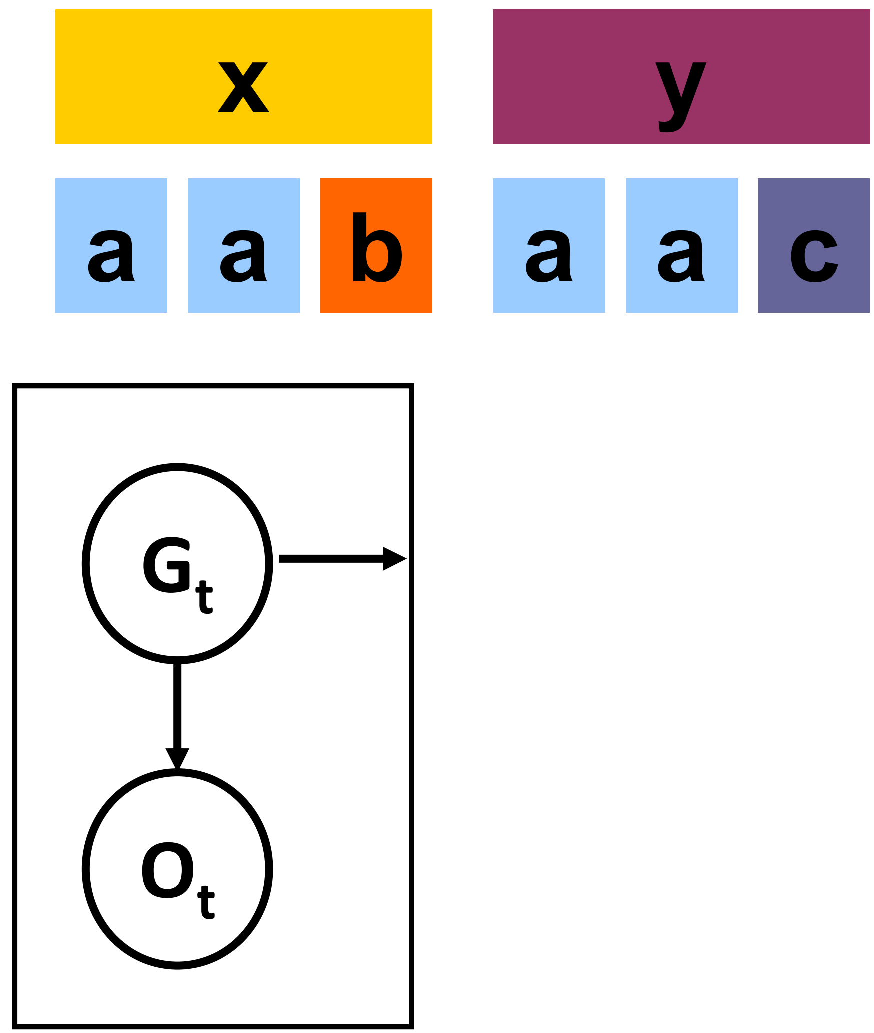
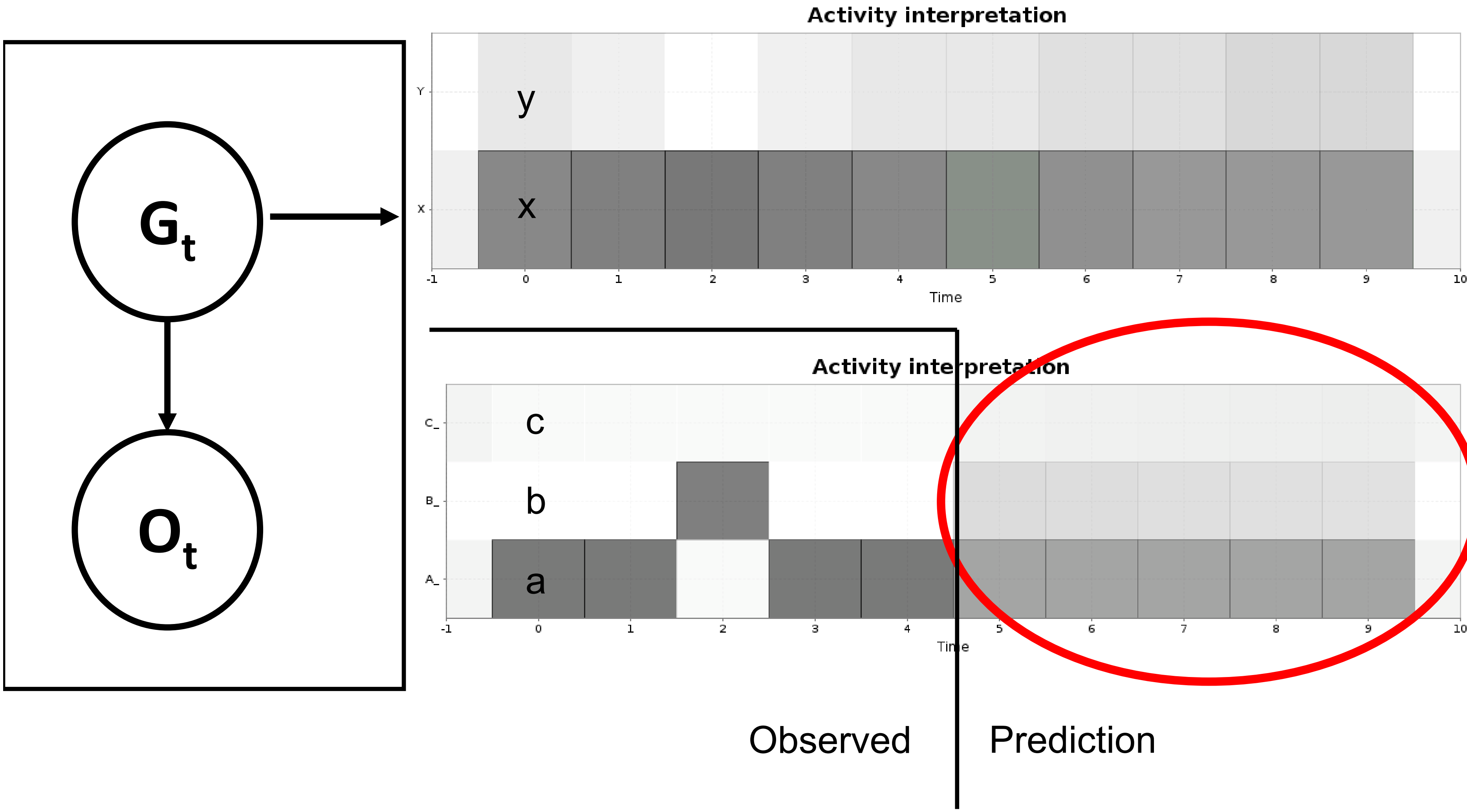
Example

D(G) = {x, y}
D(O) = {a, b, c}

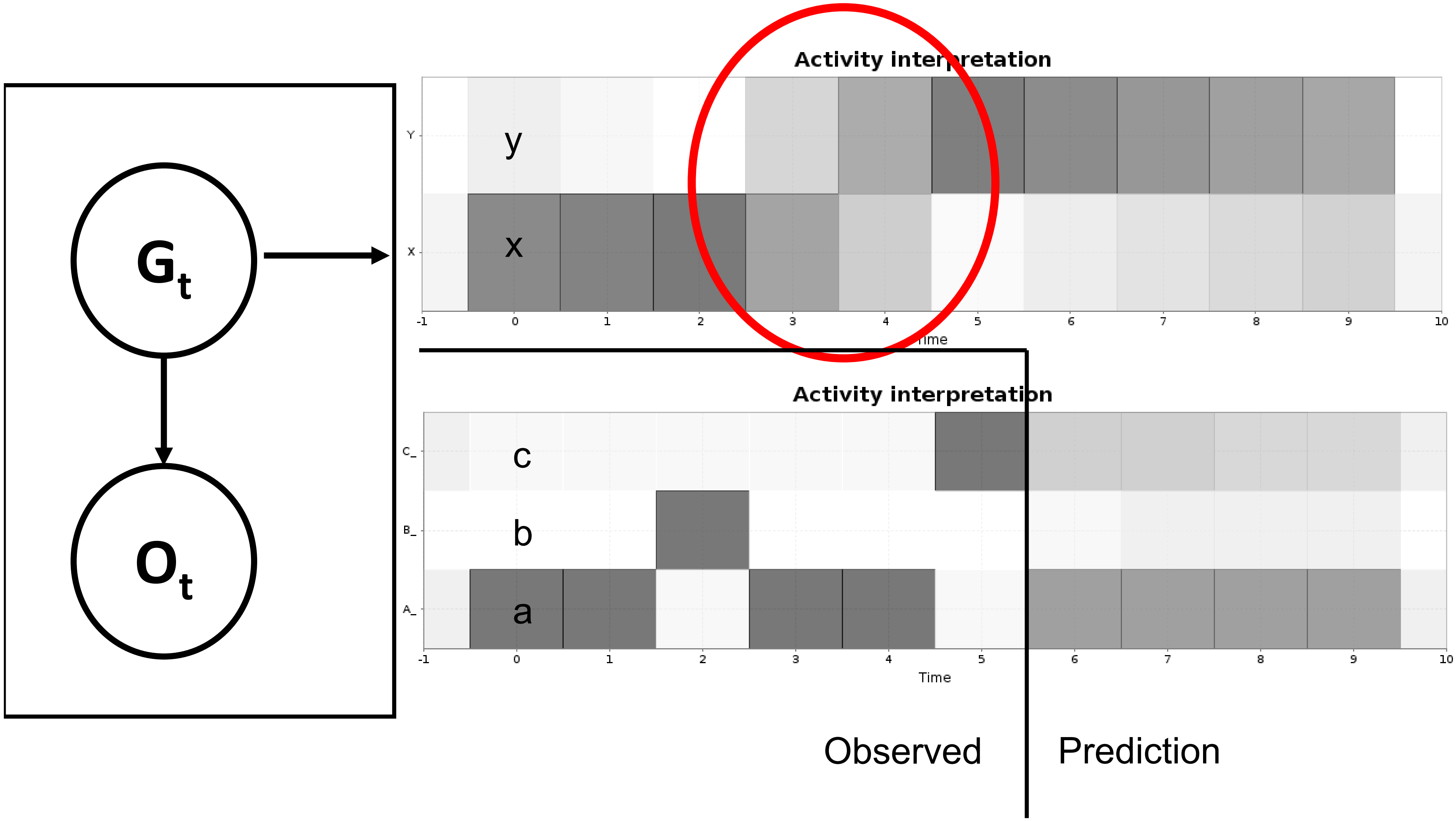
$P(x \rightarrow y) = 1/3$
$P(x \rightarrow x) = 2/3$

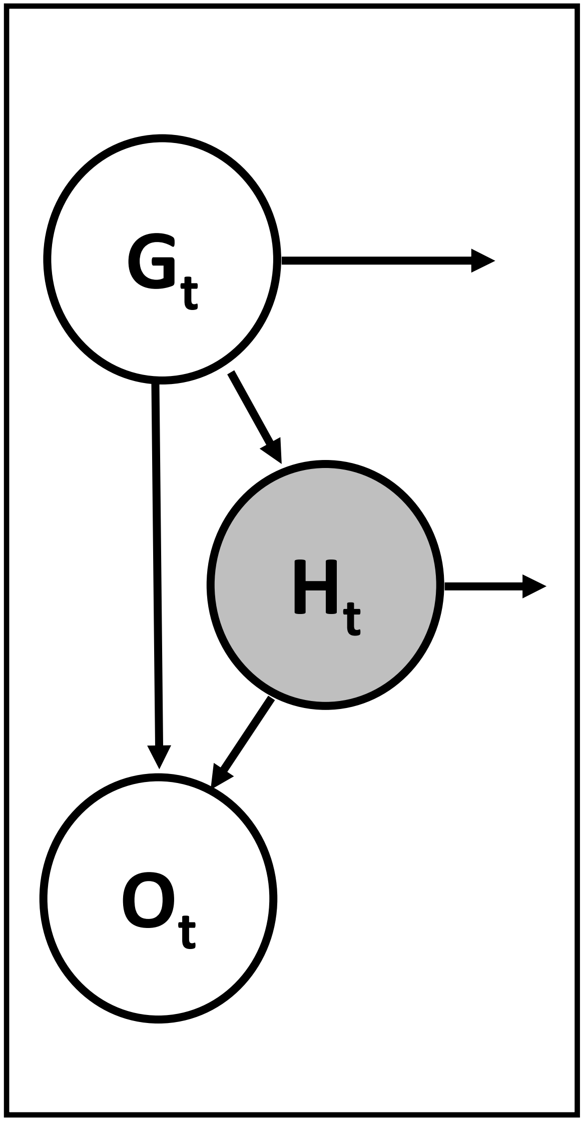




G_t
O_t
Activity interpretation
Y
X
y
x
Time
Activity interpretation
C_
B_
A_
c
b
a
Time
Observed
Prediction

We need different model

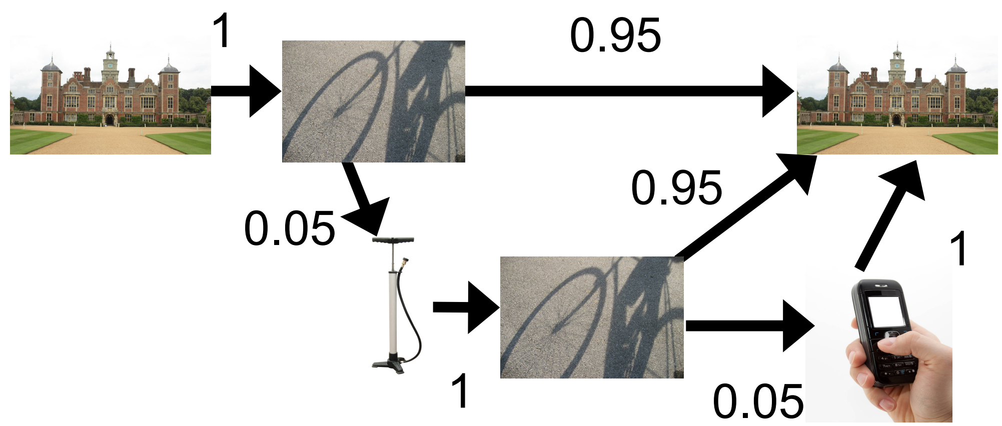


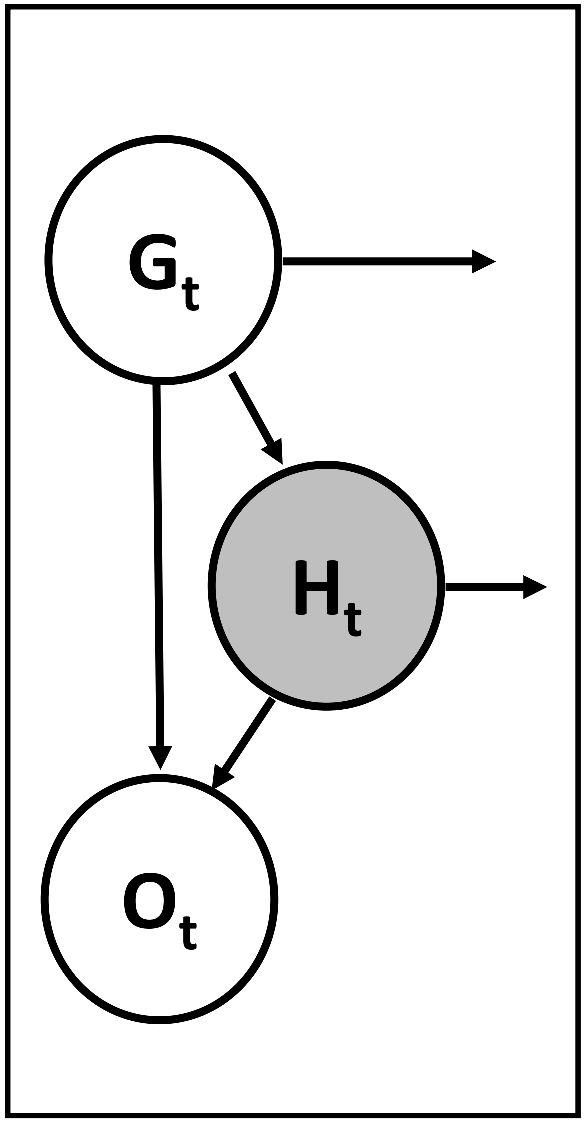


H_t … unobserved/hidden/latent variable

G, O … in training data

H represents probabilistic FSM associated with G

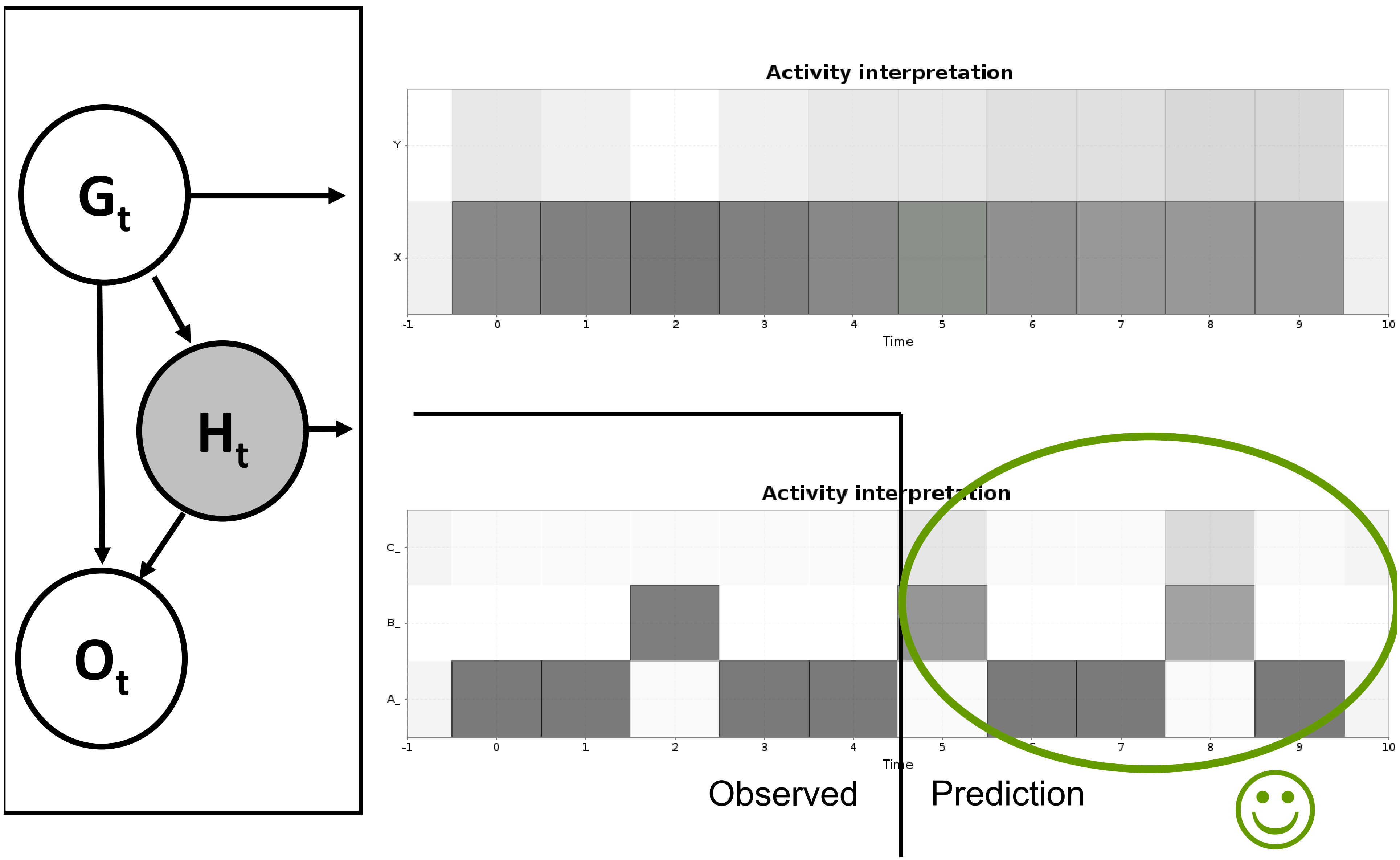




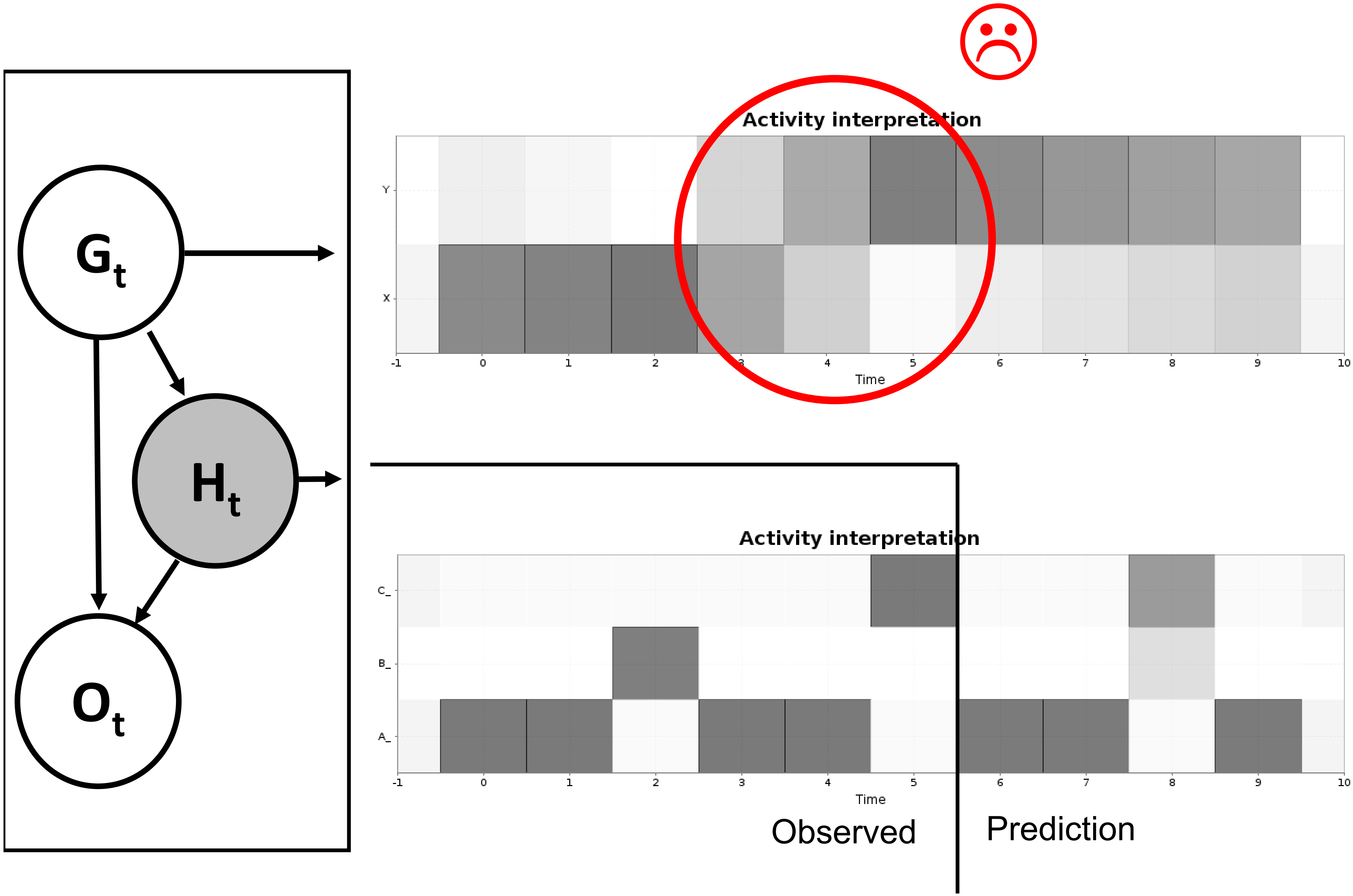
How to get FSMs represented by H?

Hand code them … ☹

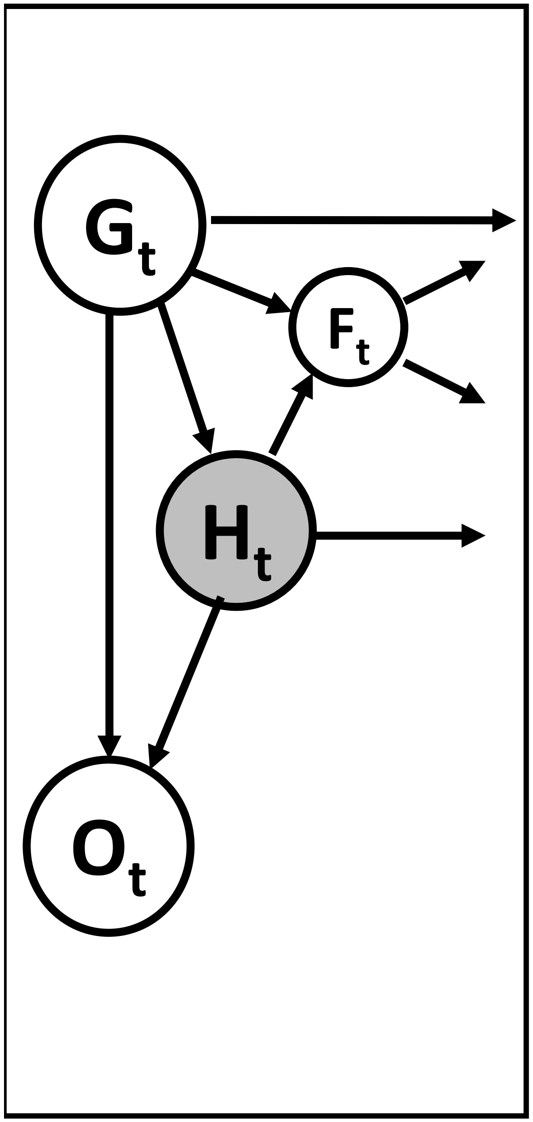
Learn them! ~ EM algorithm



G_t
H_t
O_t
Activity interpretation
Y
X
-1 0 1 2 3 4 5 6 7 8 9 10
Time
Activity interpretation
C_
B_
A_
-1 0 1 2 3 4 5 7 8 9 10
Time
Observed
Prediction

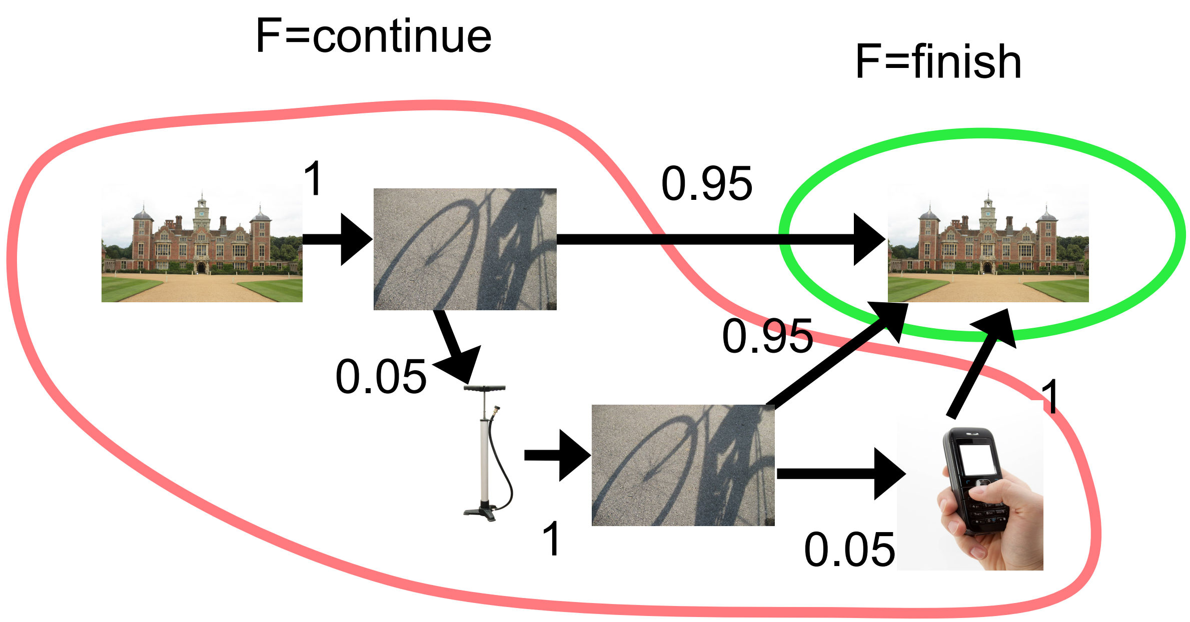


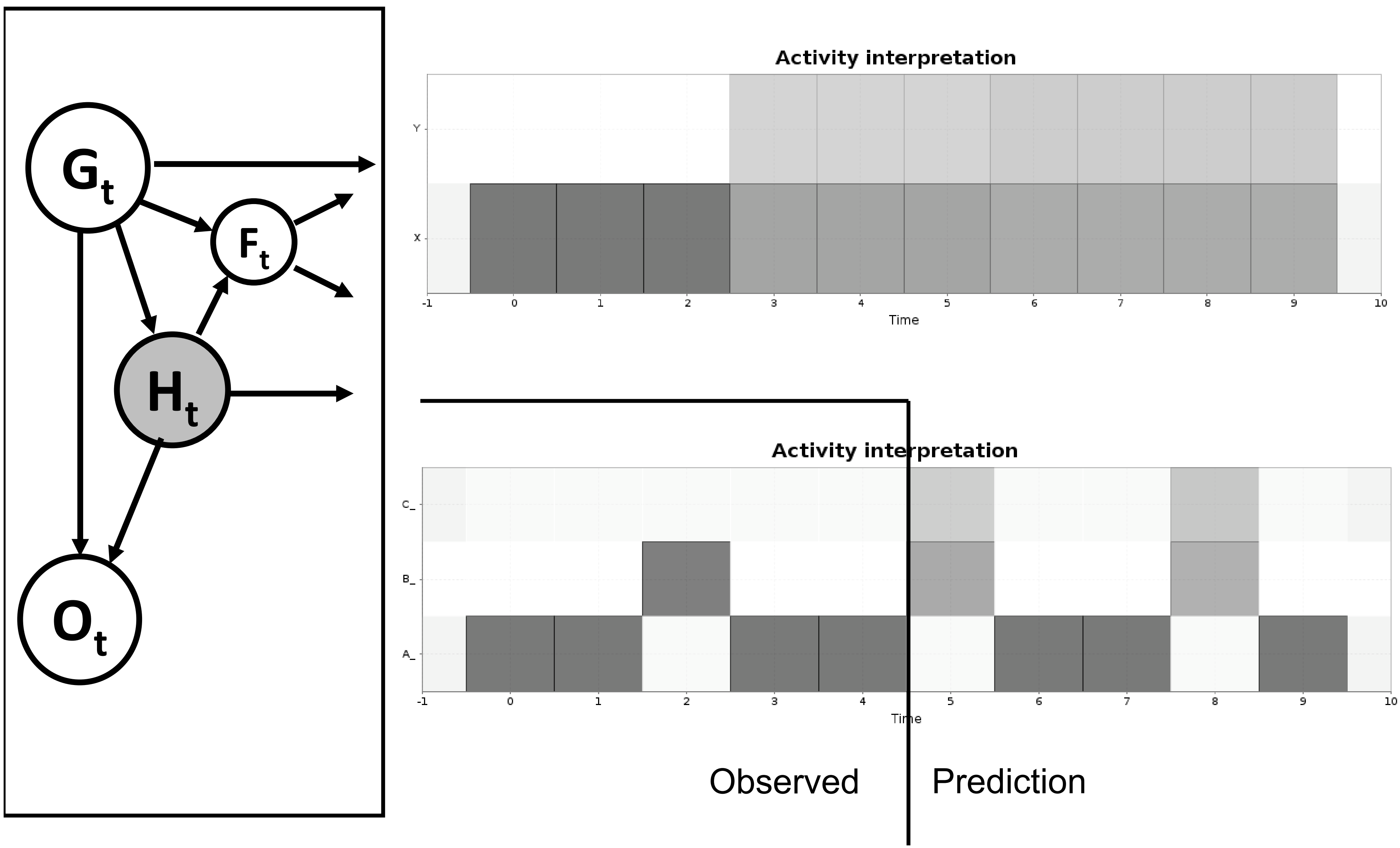
G_t
H_t
O_t
Activity interpretation
Y
X
-1
0
1
2
3
4
5
6
7
8
9
10
Time
Activity interpretation
C_
B_
A_
-1
0
1
2
3
4
5
6
7
8
9
10
Time
Observed
Prediction



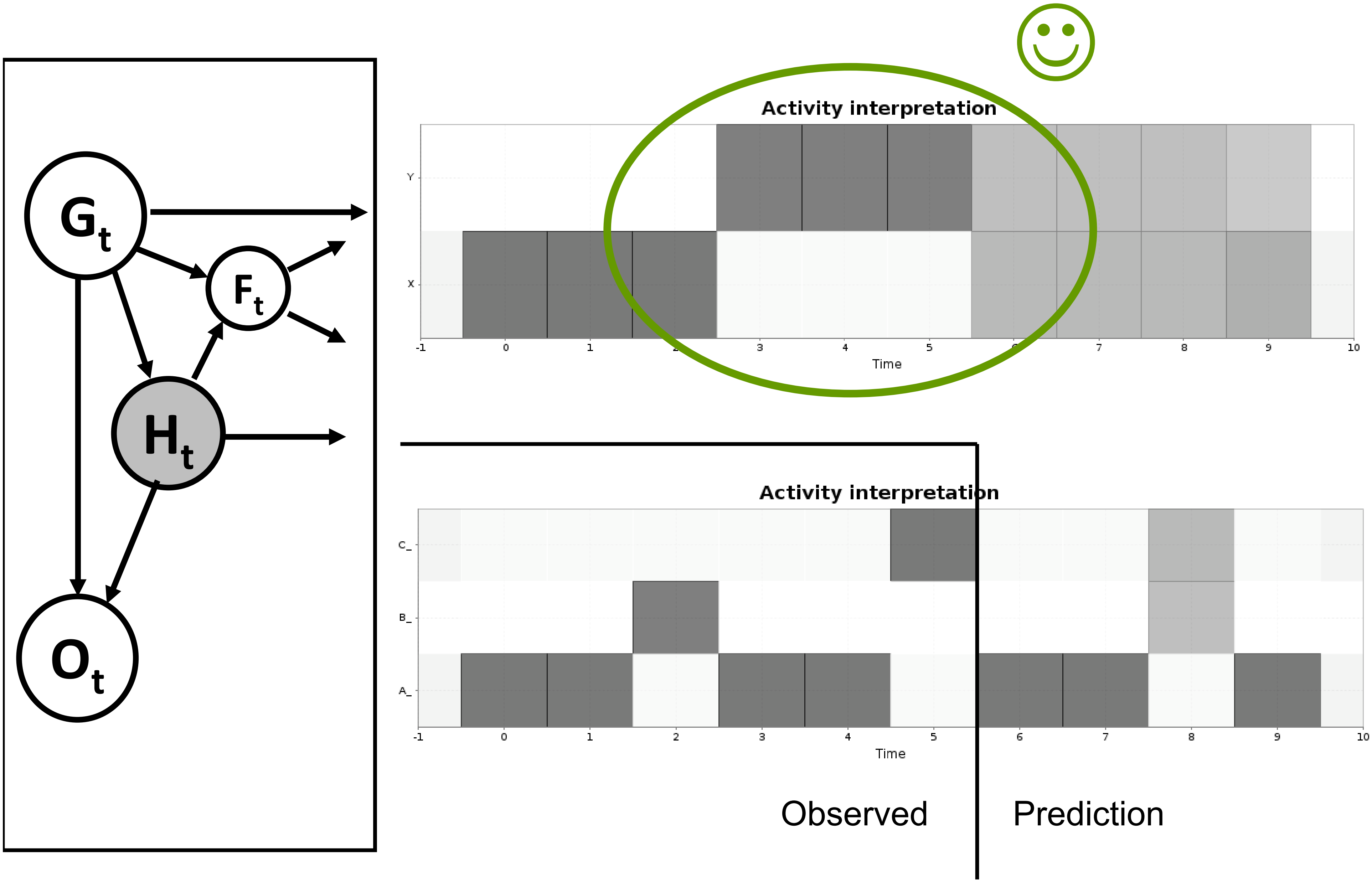
F_t … finish variable

F labels states in D(H) where the episode ends





G_t
F_t
H_t
O_t
Activity interpretation
Y
X
-1
0
1
2
3
4
5
6
7
8
9
10
Time
Activity interpretation
C_
B_
A_
-1
0
1
2
3
4
5
6
7
8
9
10
Time
Observed
Prediction



G
t
F
t
H
t
O
t
Activity interpretation
Y
X
-1 0 1 2 3 4 5 6 7 8 9 10
Time
Activity interpretation
C_
B_
A_
-1 0 1 2 3 4 5 6 7 8 9 10
Time
Observed
Prediction

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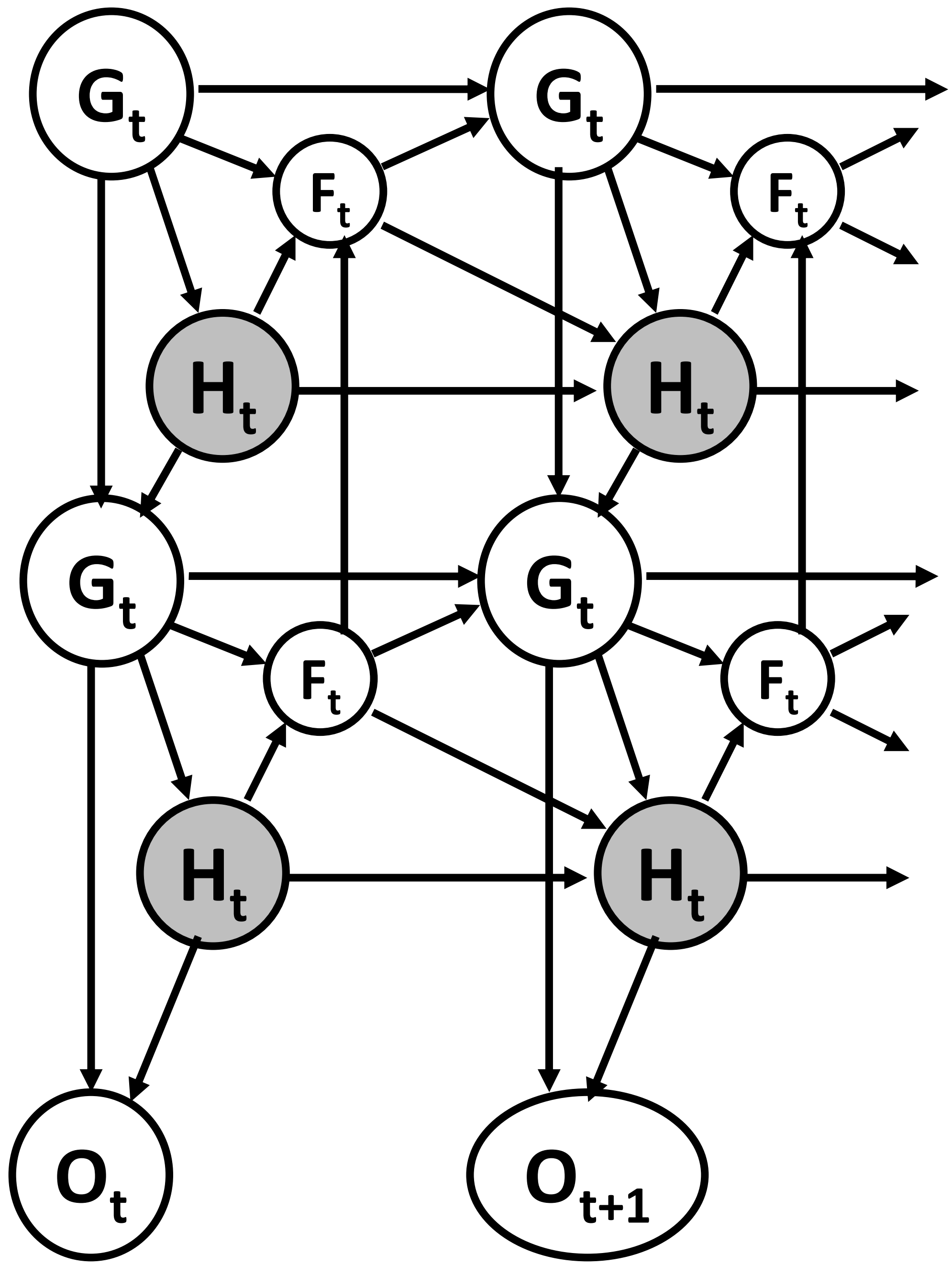
  - Forgetting
- Retrieval
  - Reconstructive memory retrieval



[Bui 2003, IJCAI]

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- Idea
  - remember event where prior and posterior distributions differ most.
- Tool
  - Kullback-Liebler divergence (information gain, information divergence, relative entropy)

$$KL(P \to Q) = \sum_i P(i) ln \frac{P(i)}{Q(i)}$$

1. Pick most memorable event
2. Reconstruct episode given memory of this event
3. Go to 1

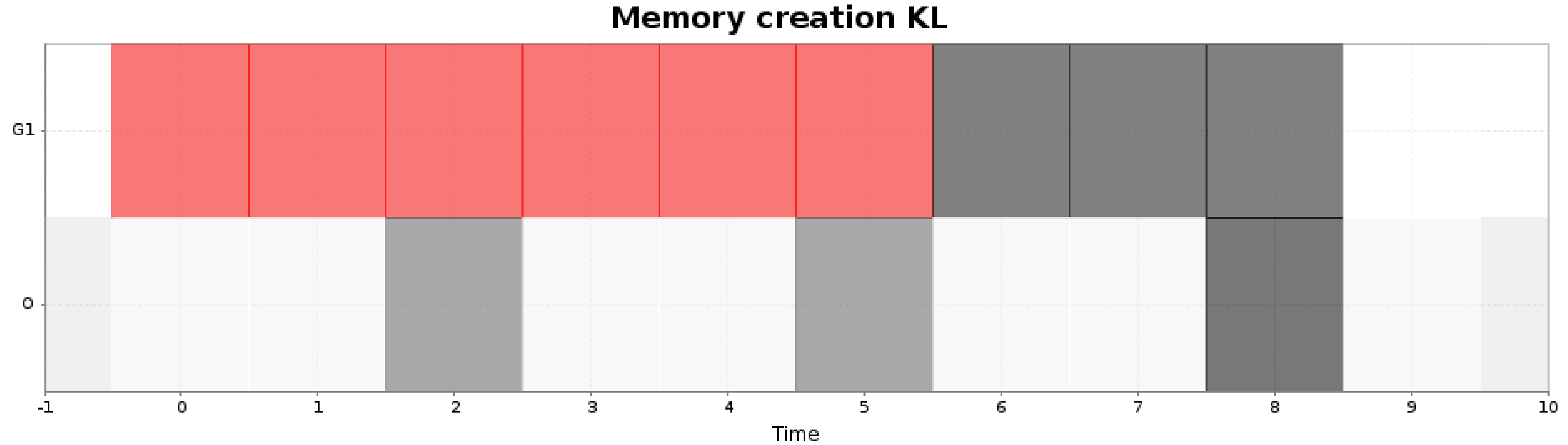
Most surprising event

procedure $\textsc{Storage}(o_{0:N})$
  $mems \leftarrow empty$ ▷ List of mems is empty
  while continue **do**
    $X \leftarrow \arg\max_{Y \in \mathcal{V}} KL(P(Y|mems) \rightarrow P(Y|O_{0:N} = o_{0:N}))$
    $x_{max} \leftarrow \arg\max_{x \in D(X)} P(X = x|mems)$
    $mems.add(\langle X, x_{max} \rangle)$
  end while
  return $mems$
end procedure

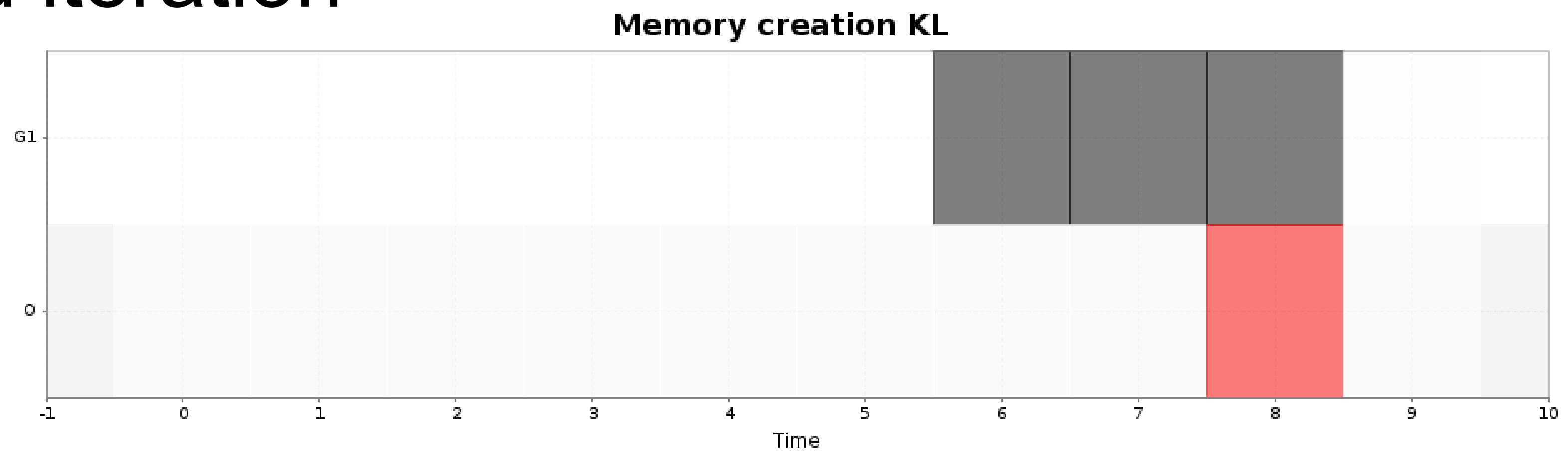
Event describing most of the episode

$$X_{i:j} \leftarrow \underset{Y_{i:j} \in ToIntervals(o_{0:N})}{\arg\min} \sum_{Z \in \mathcal{V}} KL(P(Z|Y_{i:j} = y_{max}, mems) \rightarrow P(Z|O_{0:N} = o_{0:N}))$$

First iteration



Second iteration



$$\text{Mems} = \{g_{0:5}=x,\ o_8=c\}$$

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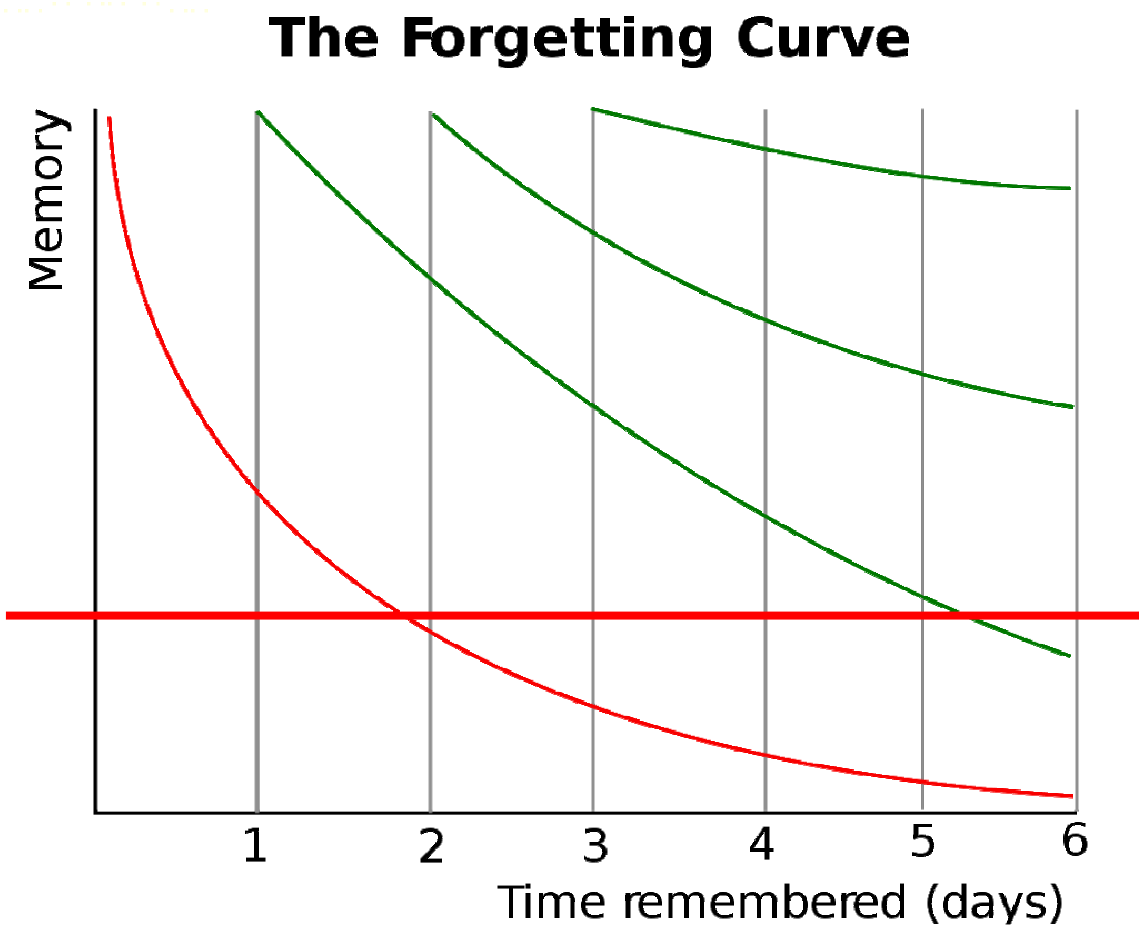
$$R = e^{-\frac{t}{S}}$$

R … retention

t …. time

S … initial strength of memory ~ KL



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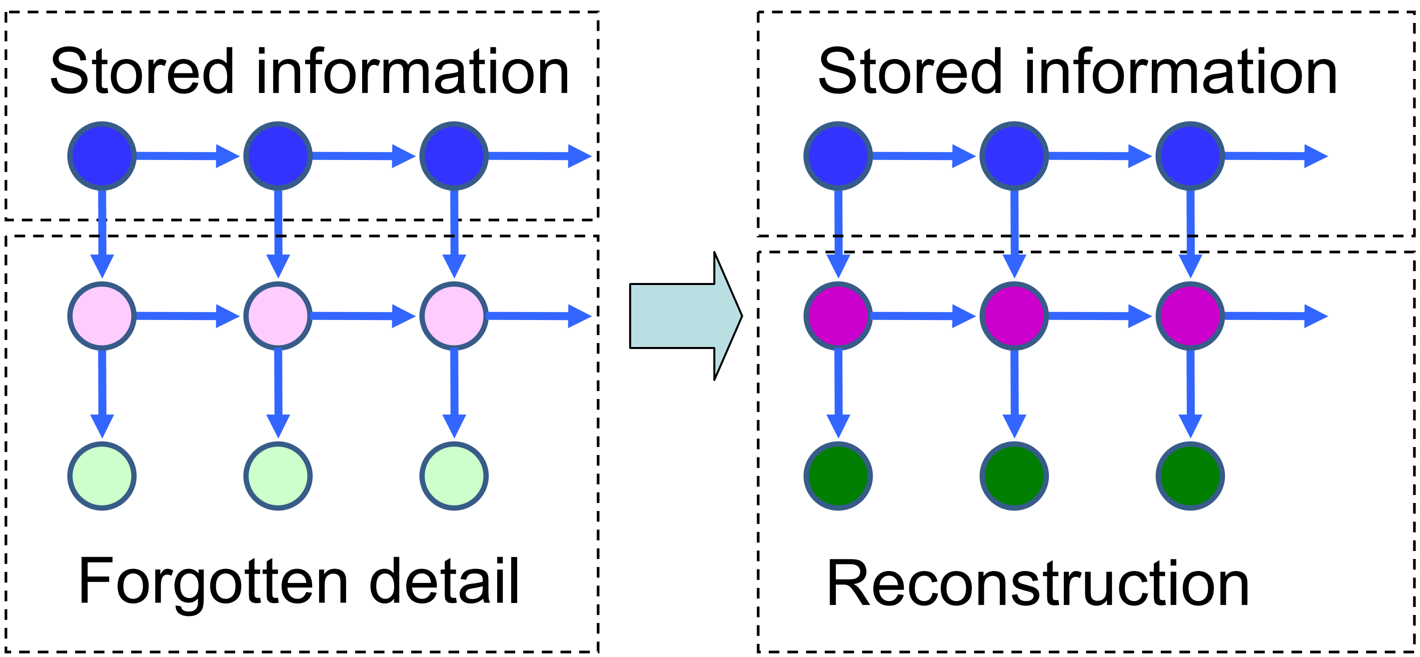
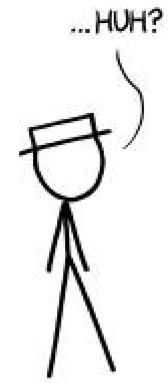
$$P(O_{0:t} | semantic, mems)$$

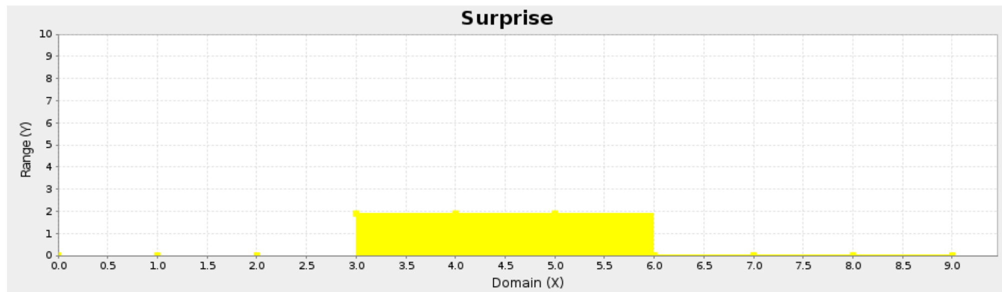


What we have for free

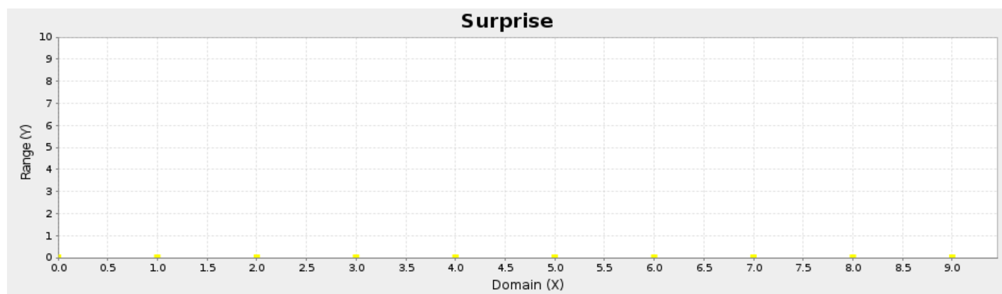


- Measure of surprise - G

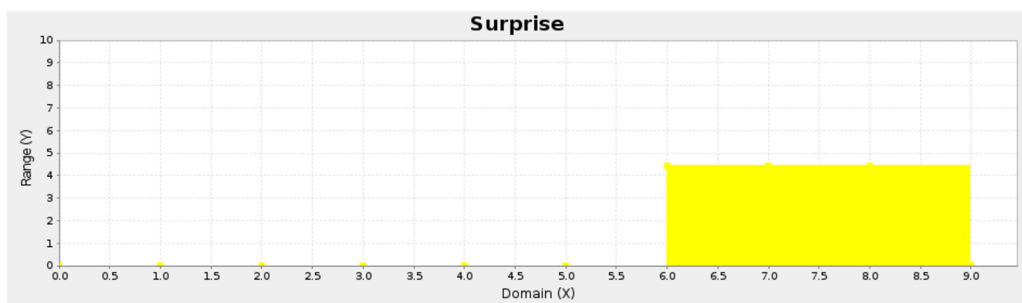
t=5
o=aabaab



t=6
o=aabaaba



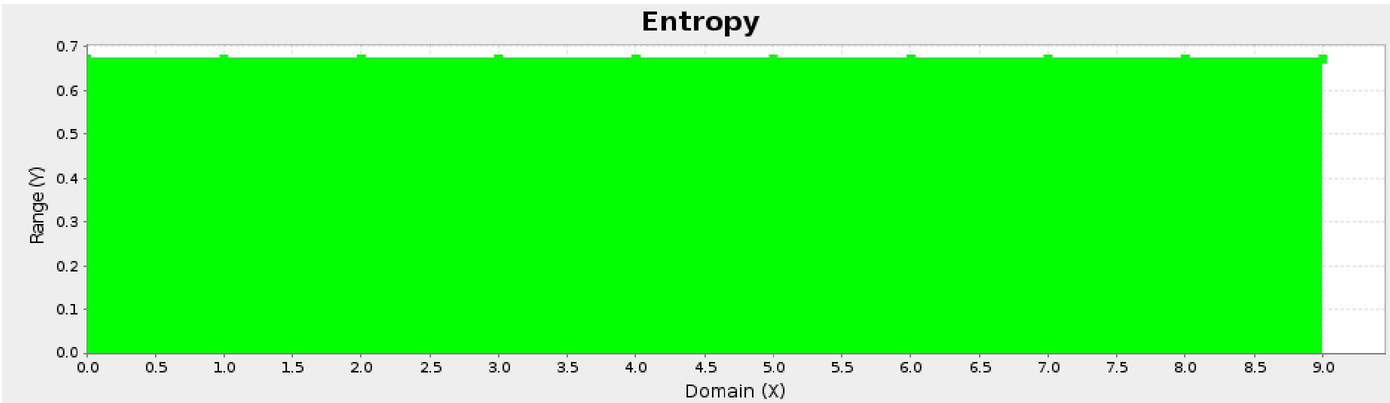
t=8
o=aabaabaac



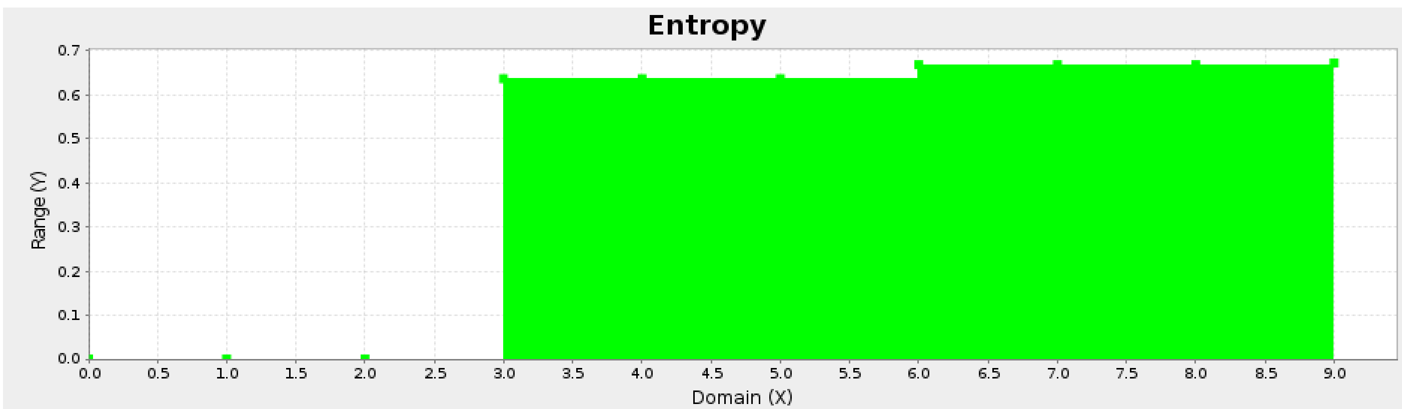
What we have for free

- Measure of certainty - Entropy(G)

t=1
o=aa



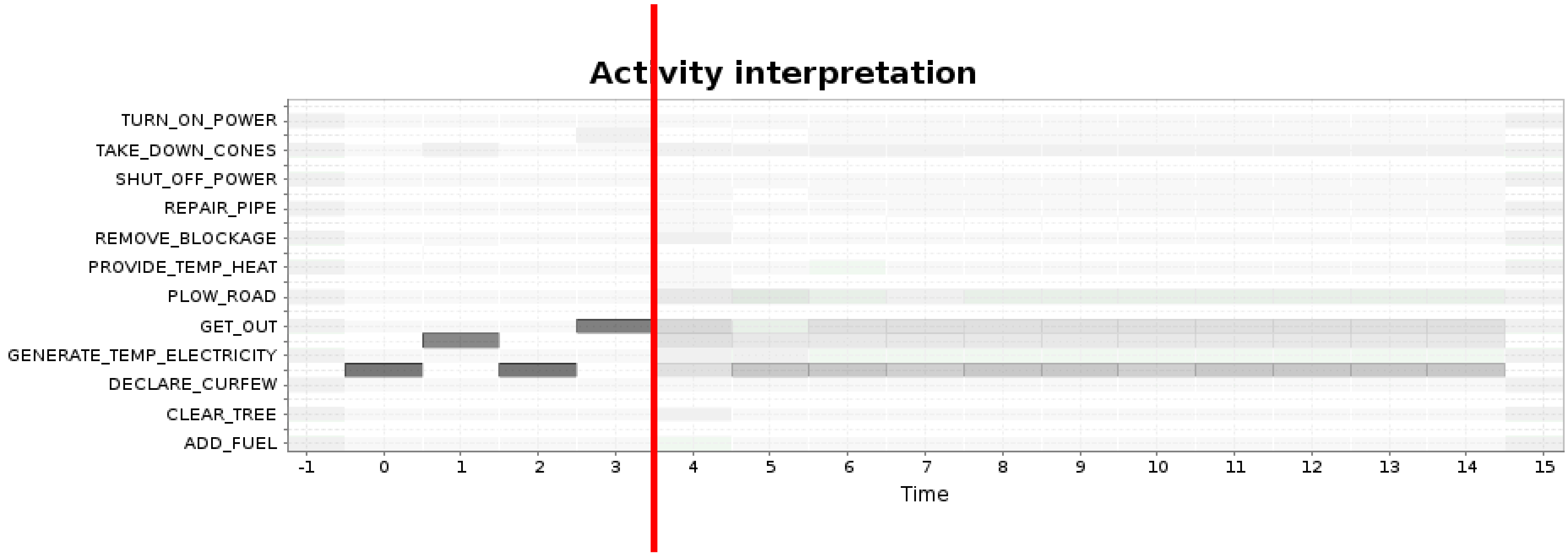
t=2
o=aab

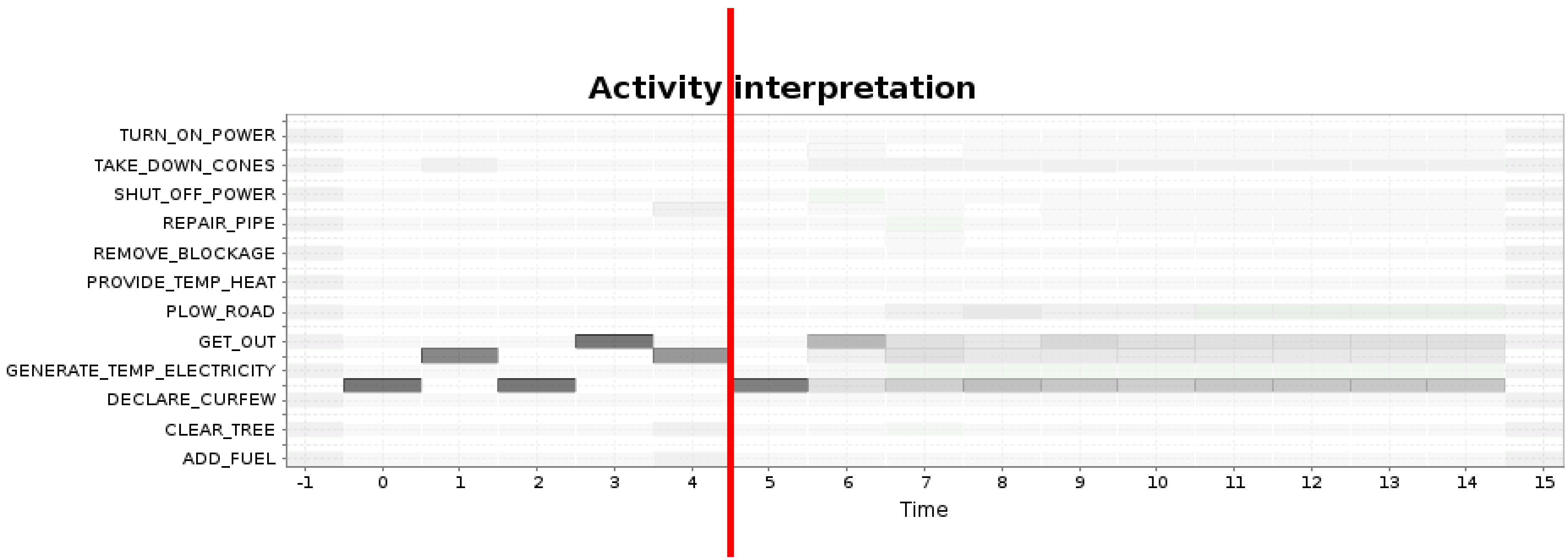


Next steps

- HTN planner
  - Monroe corpus

```
((CLEAR-ROAD-WRECK PITTSFORD-PLAZA AIRPORT)
          ((SET-UP-CONES PITTSFORD-PLAZA AIRPORT)
                    ((GET-TO TCREW1 PITTSFORD-PLAZA)
                              ((GET-TO WTRUCK1 BRIGHTON-DUMP)
                                        ((DRIVE-TO WCREW1 WTRUCK1 BRIGHTON-DUMP)
                                                  (!NAVEGATE-VEHICLE WCREW1 WTRUCK1 BRIGHTON-DUMP)))
                                        ((GET-IN TCREW1 WTRUCK1)
                                                  (!CLIMB-IN TCREW1 WTRUCK1))
```


Activity interpretation
TURN_ON_POWER
TAKE_DOWN_CONES
SHUT_OFF_POWER
REPAIR_PIPE
REMOVE_BLOCKAGE
PROVIDE_TEMP_HEAT
PLOW_ROAD
GET_OUT
GENERATE_TEMP_ELECTRICITY
DECLARE_CURFEW
CLEAR_TREE
ADD_FUEL
-1 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Time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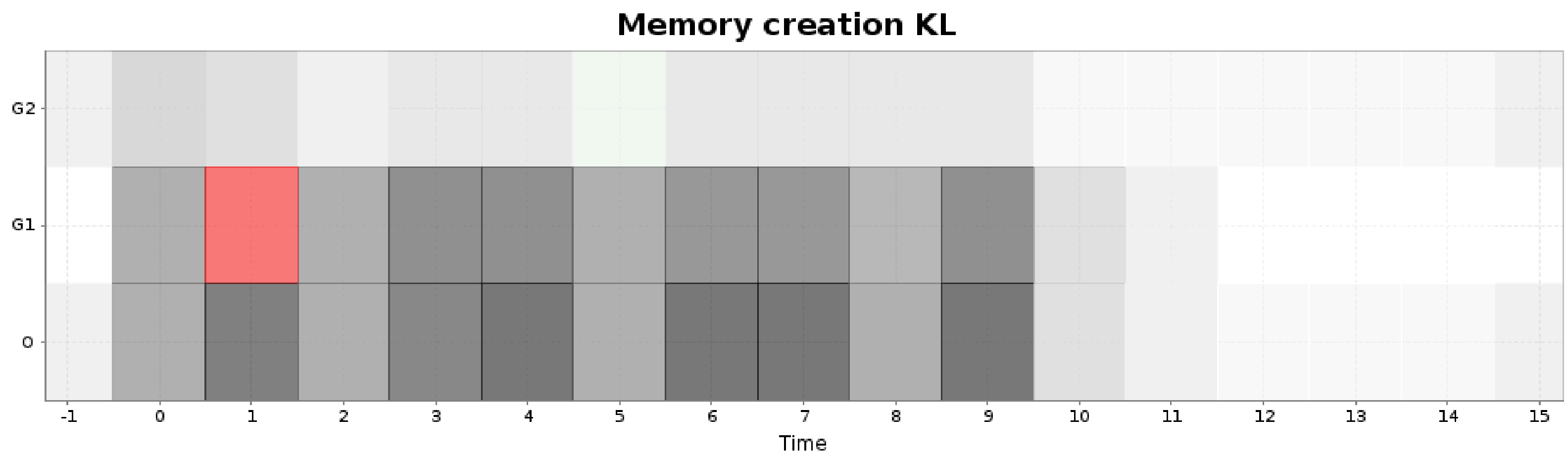
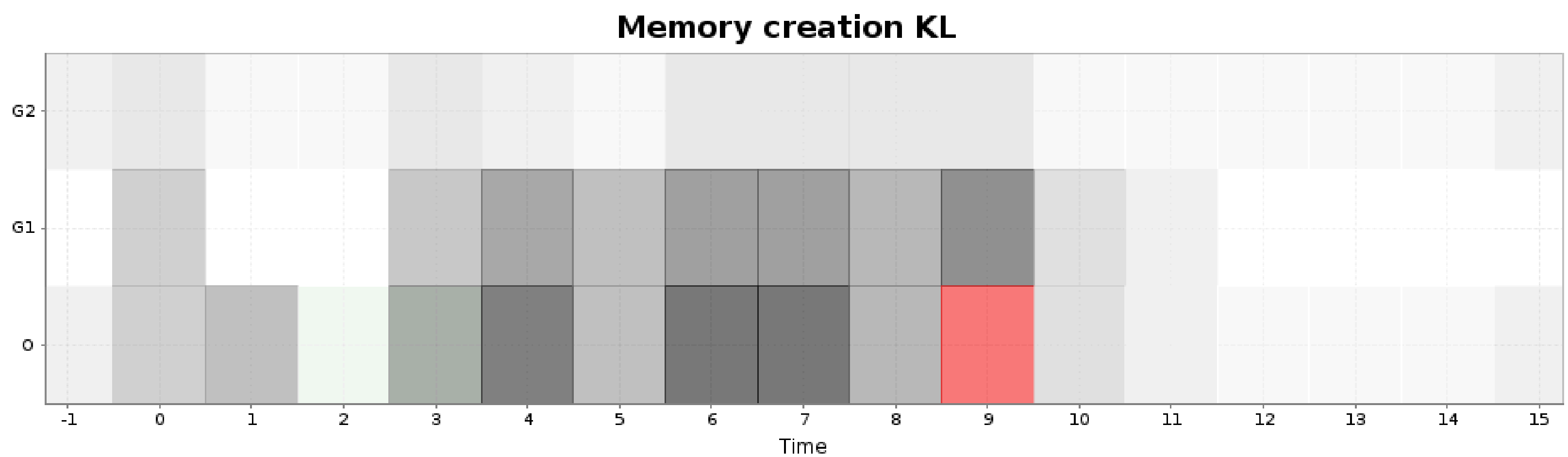
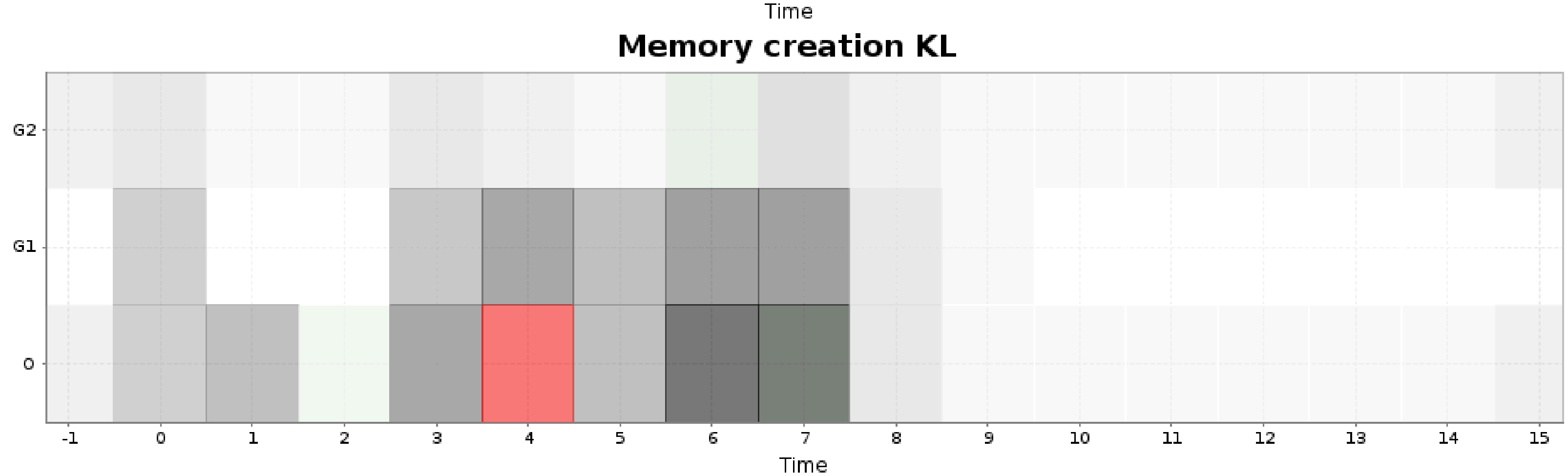


Memory creation KL
G2
G1
O
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Time



Memory creation KL
G2
G1
O
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Time



Memory creation KL
G2
G1
O
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Time

Thanks to

- klsmith77 for photo of tightrope walker (http://www.sxc.hu/photo/577013)
- XKCD graphics used on slides 26, 53 and 54 (http://xkcd.com/1110/, http://xkcd.com/1126/, http://xkcd.com/1120/)