Statistical learning on period app data to advance personalized health care for women

AMLD2020

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Women* menstruate

* women = shortcut for the female biological sex or for “individuals who experience menstruations”

The menstrual cycle is crucial for reproduction

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Because of **its crucial role for the survival of the species**, it should not surprise anyone that **the menstrual cycle has far-reaching effects** on our **health**, **behaviors** and **emotional states**, beyond its reproductive dimension and that the **hormonal regulation pathways are redundant, robust and complex**.

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There are active estrogen receptors in virtually every tissue of the human body

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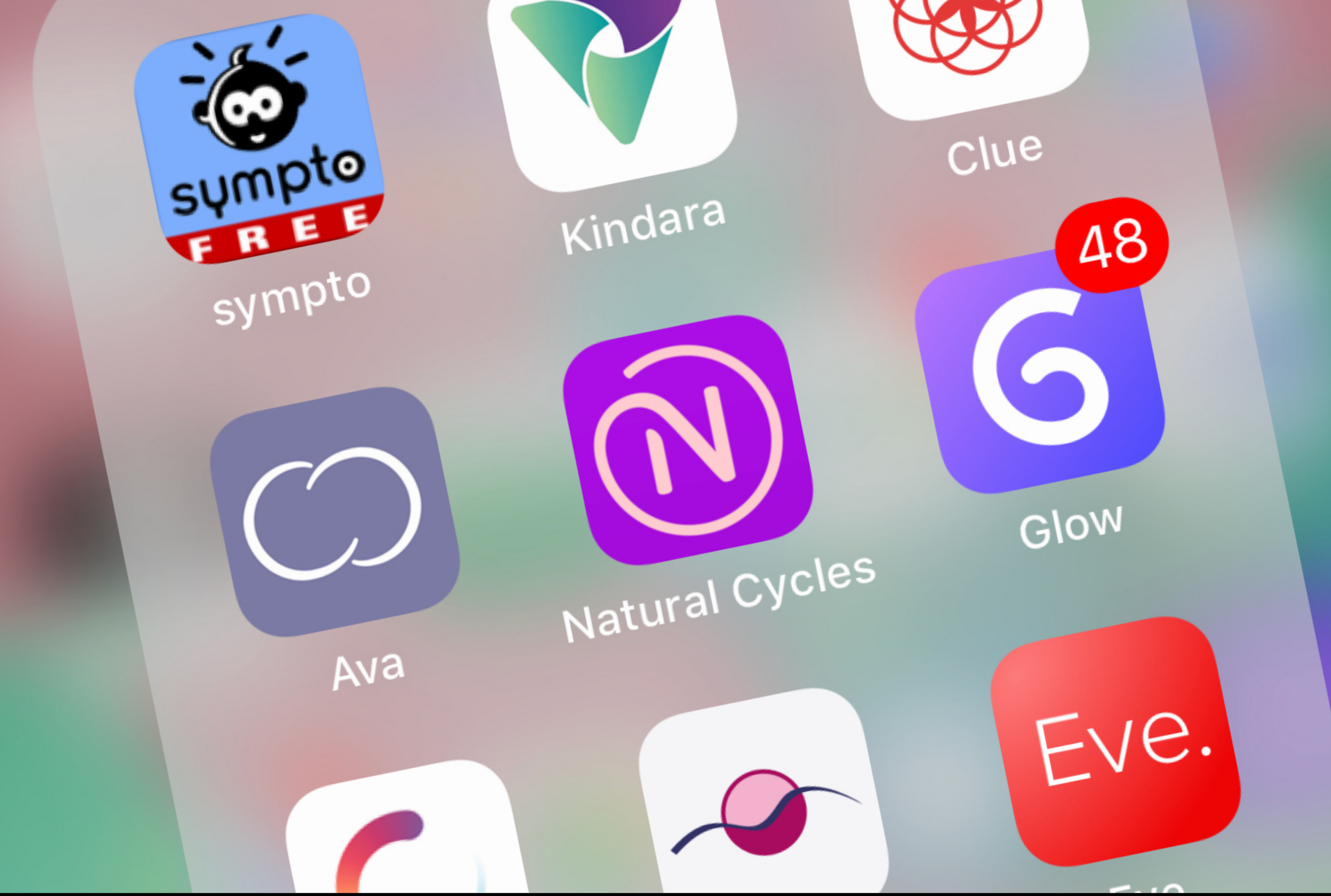

Millions of women now use apps & wearables to track their cycle

Long term tracking

Long term tracking of 2 app users (top user likely sub-fertile; bottom users: pregnancy)

(Machine) Learning about Cats&Dogs

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Deep Learning

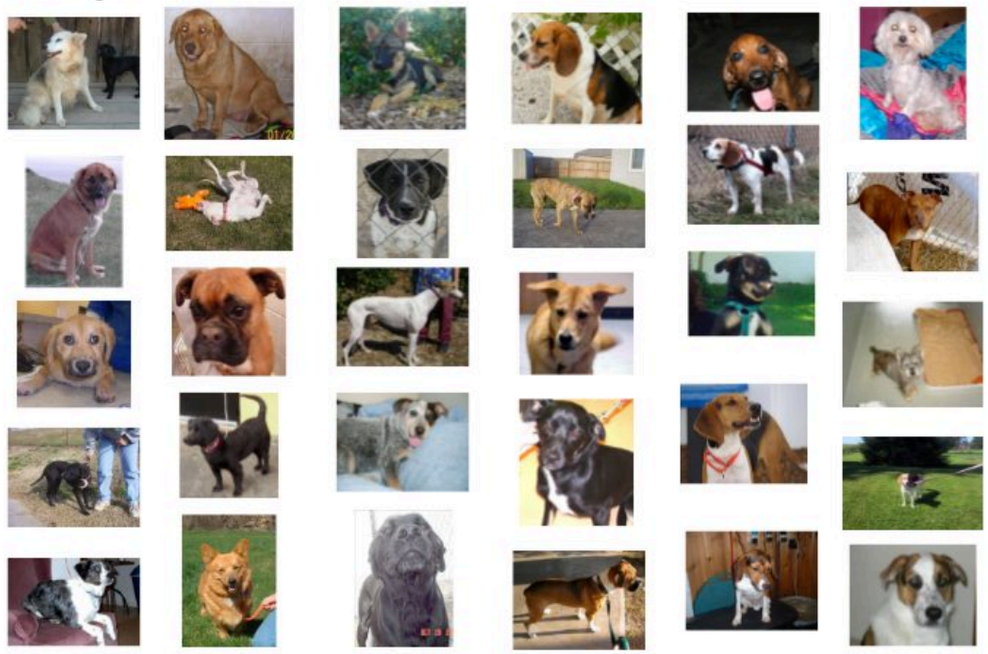
Human-like Learning

(Machine) Learning about Cats&Dogs

Deep Learning

A TON of labeled examples

Dogs



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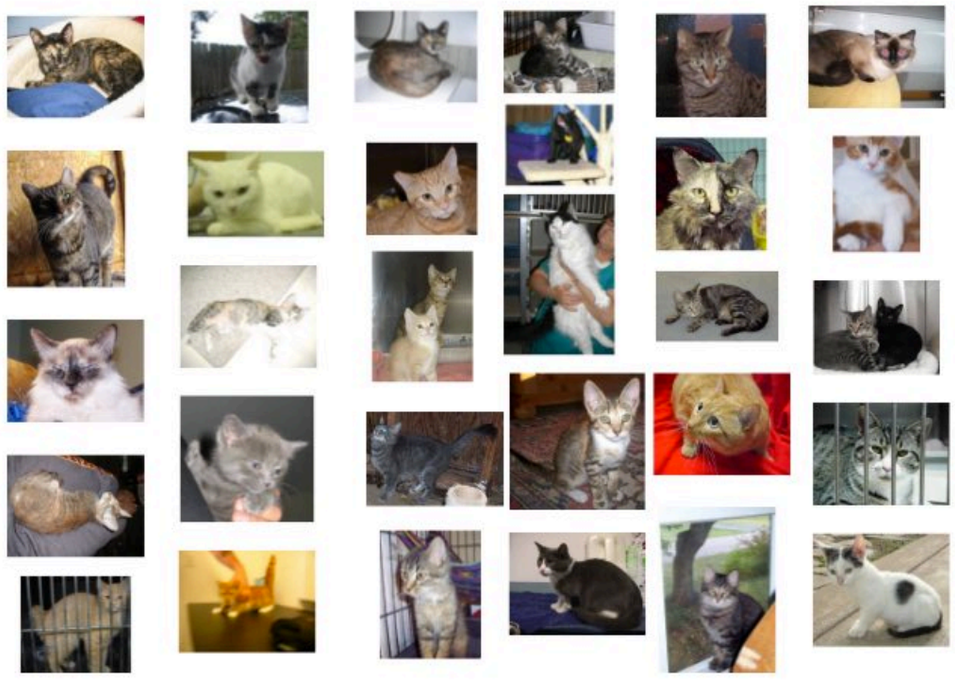

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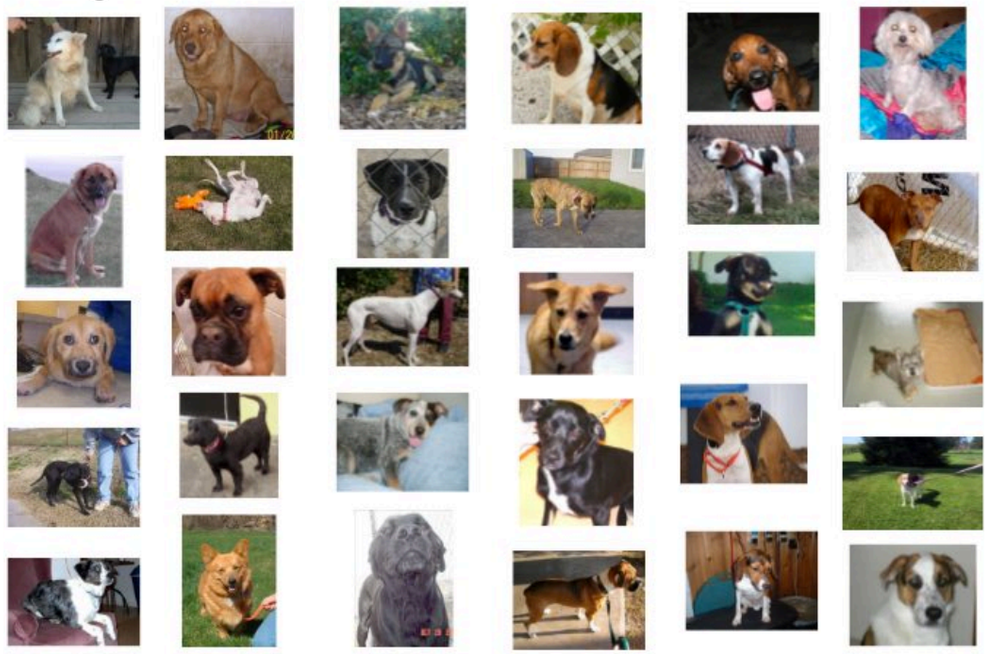

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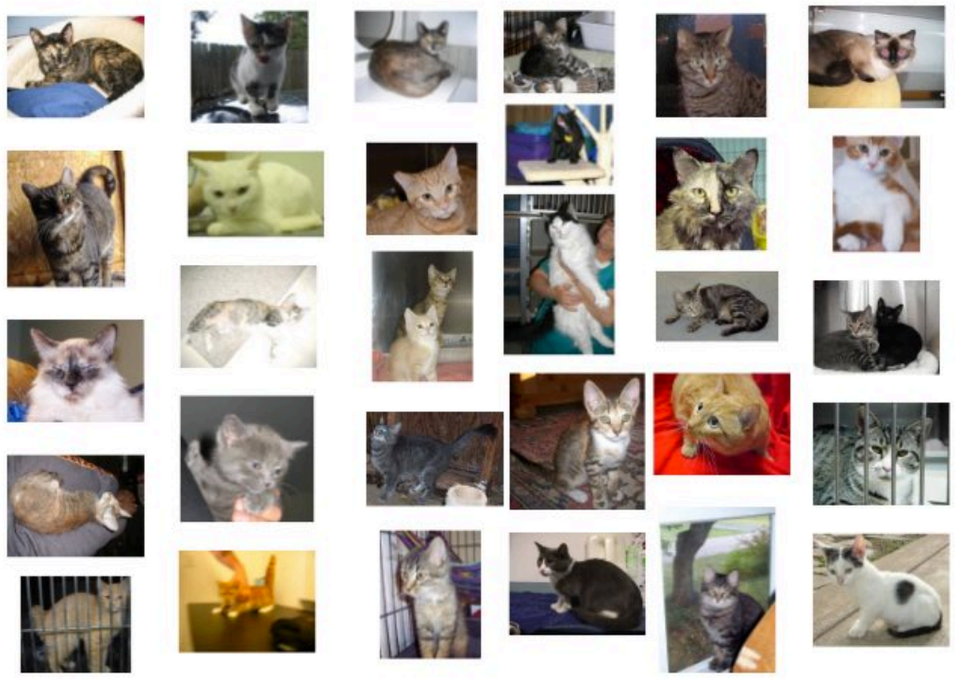

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Facts, contrasting information

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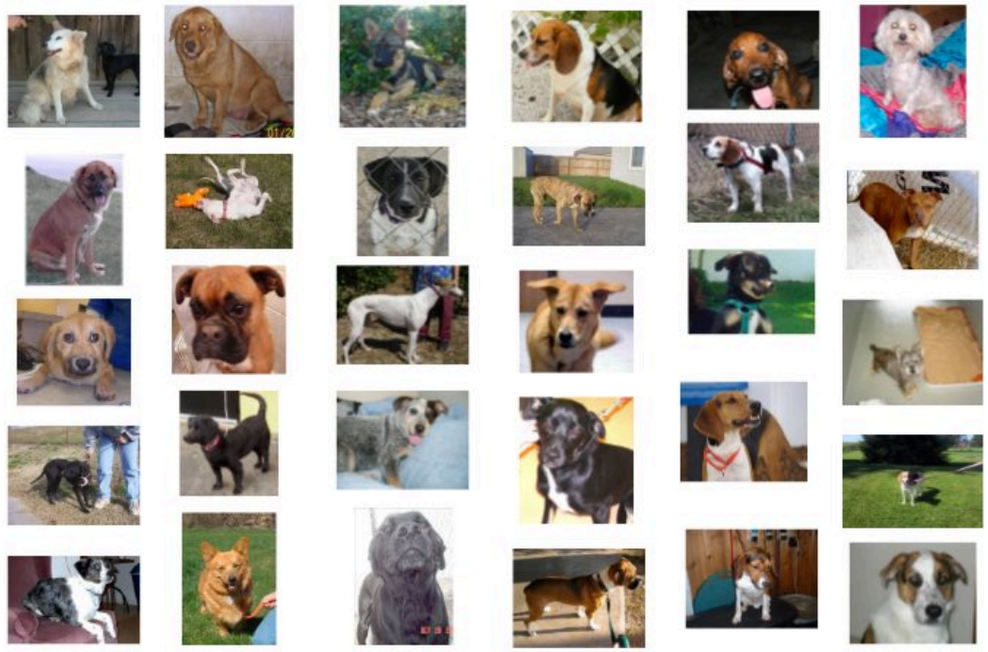

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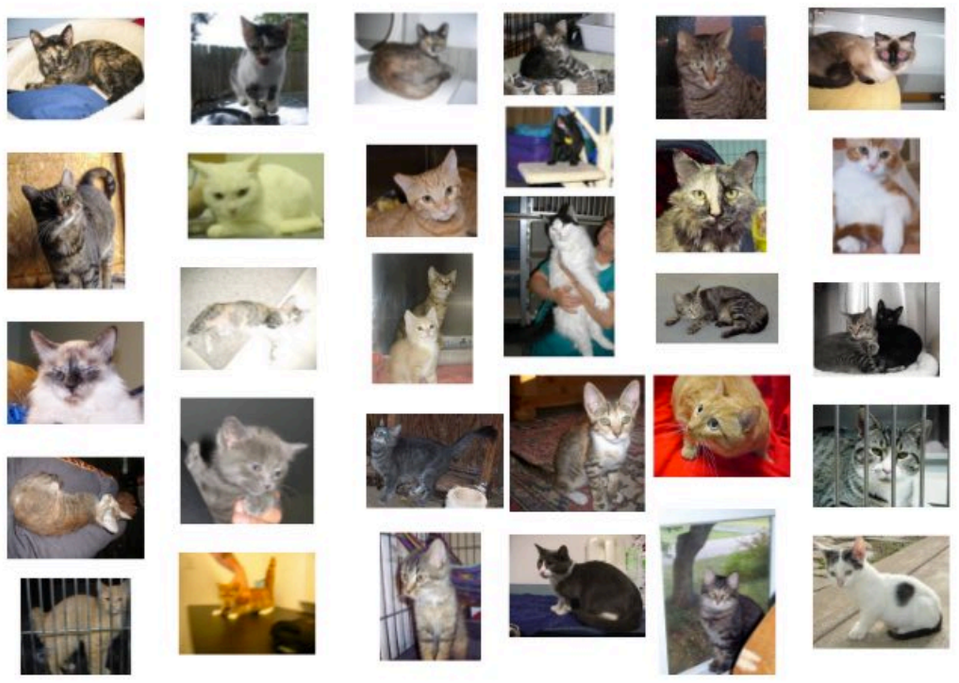

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Dogs

- 4 legged animals (mammals)
- Size: from ~20 cm to ~1m (large diversity in sizes)
- Hair type: short hair, long hair or fluffy curly hair
- Hair Color: mostly shades of brown, but also white or black
- Most dogs have long nose with black truffle
- Ears: mostly falling on the side of head, except when paying attention to smth

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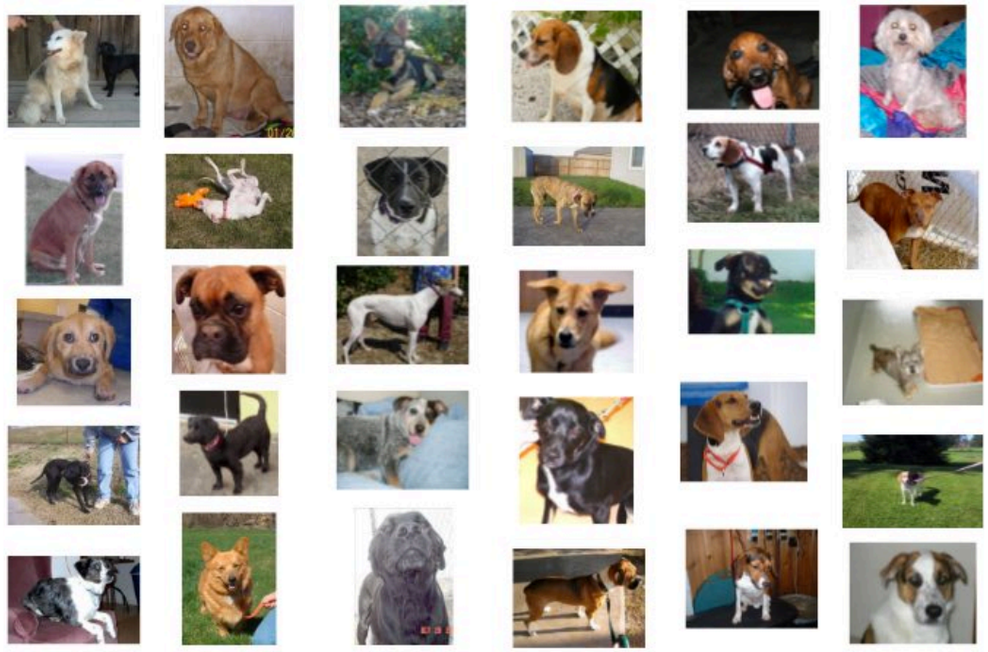

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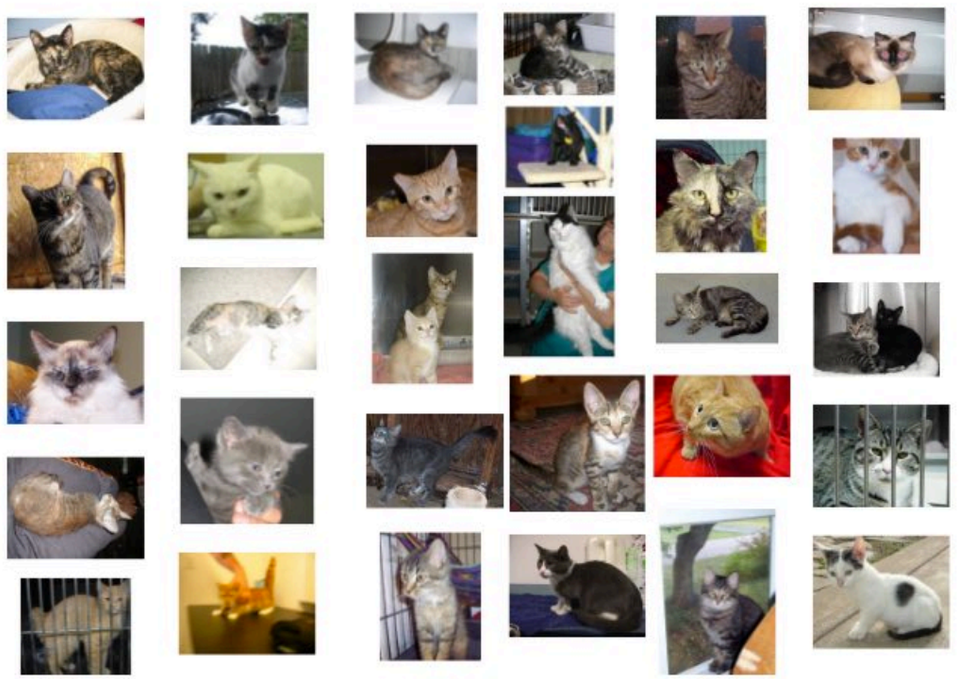

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- Size: 25cm ± 5cm (smaller variance in size than dogs)
- Hair type: mostly short hair, sometimes long, can be fluffy (but not curly)
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- Ears are pointy and mostly straight up.

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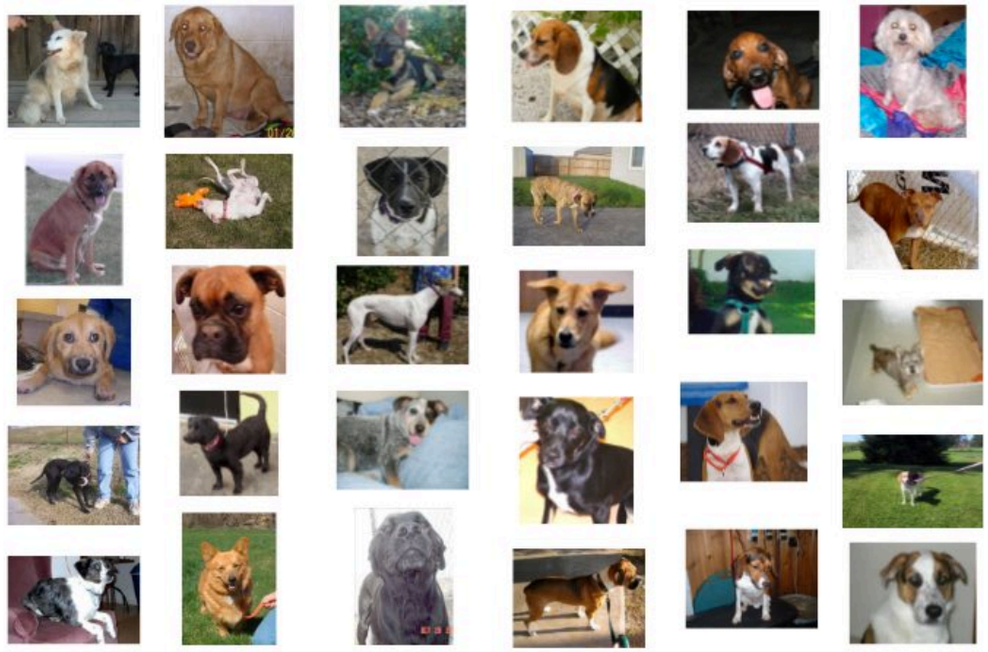

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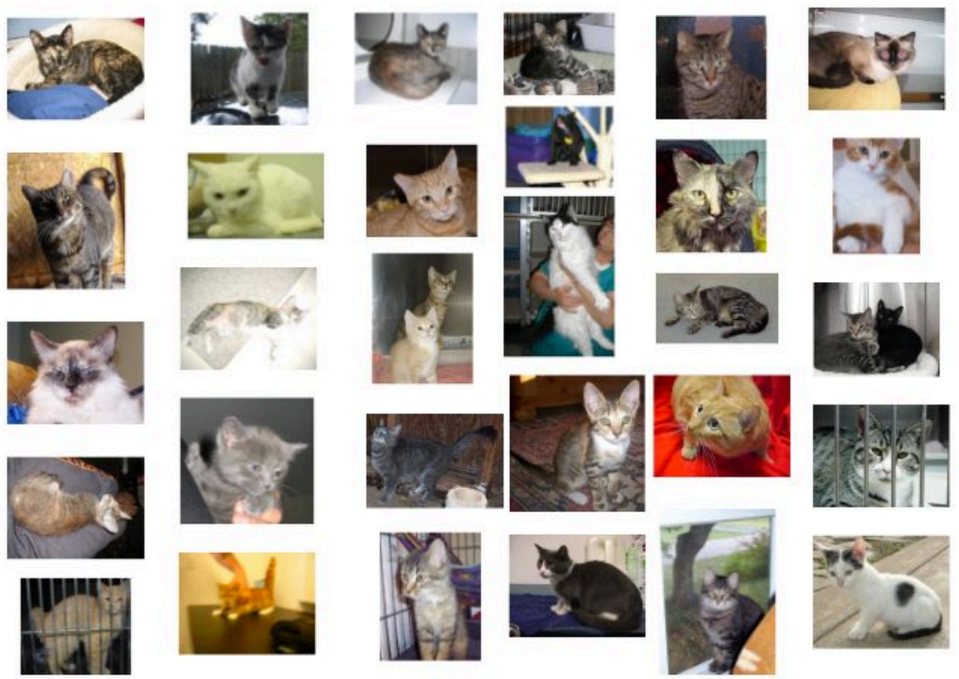

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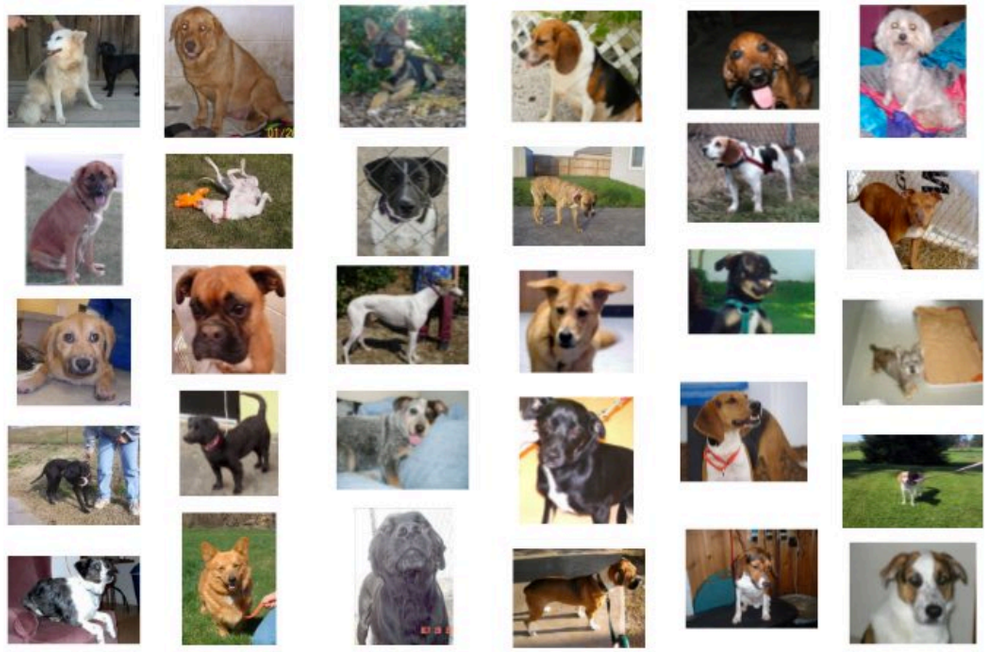

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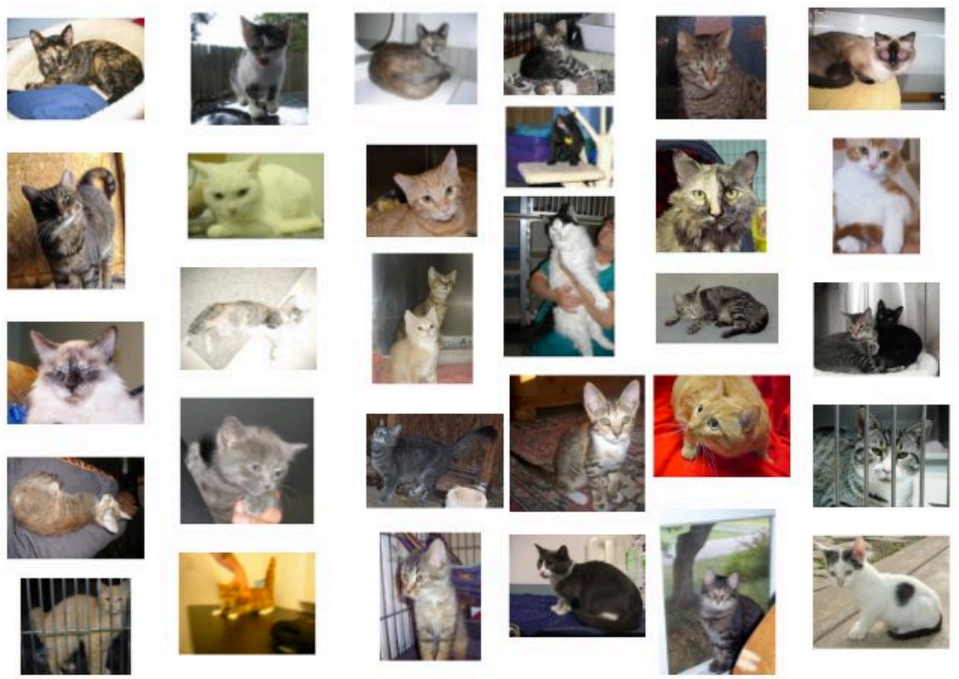

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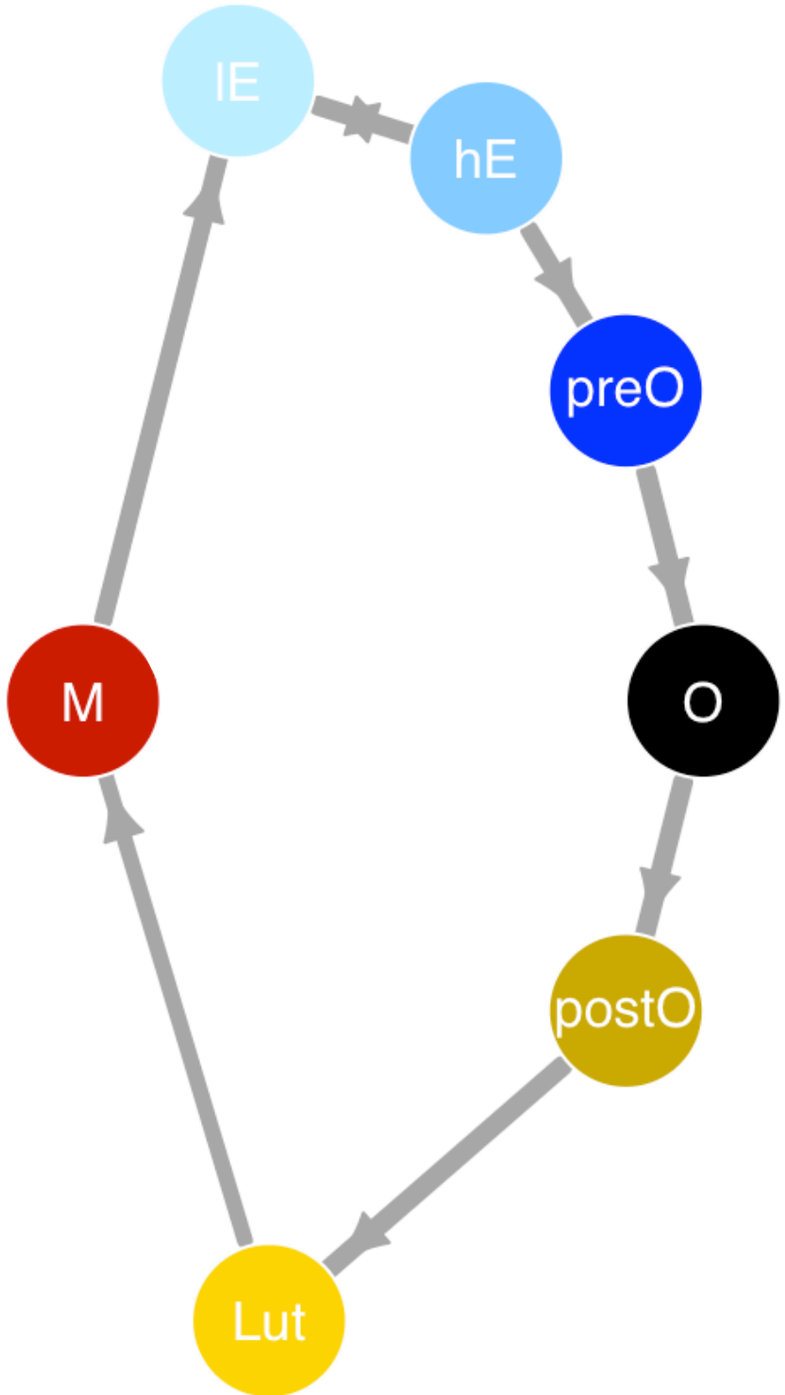
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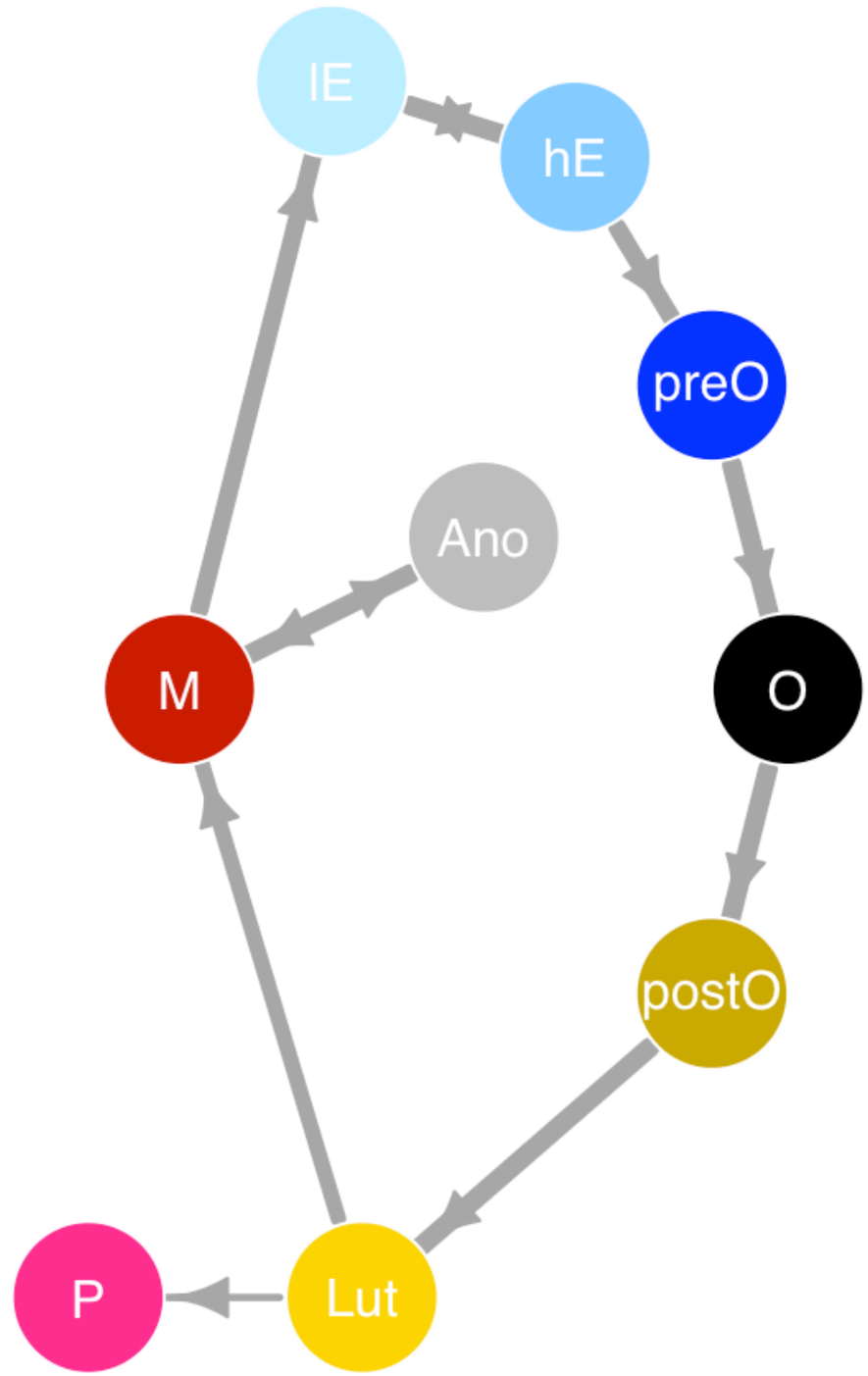
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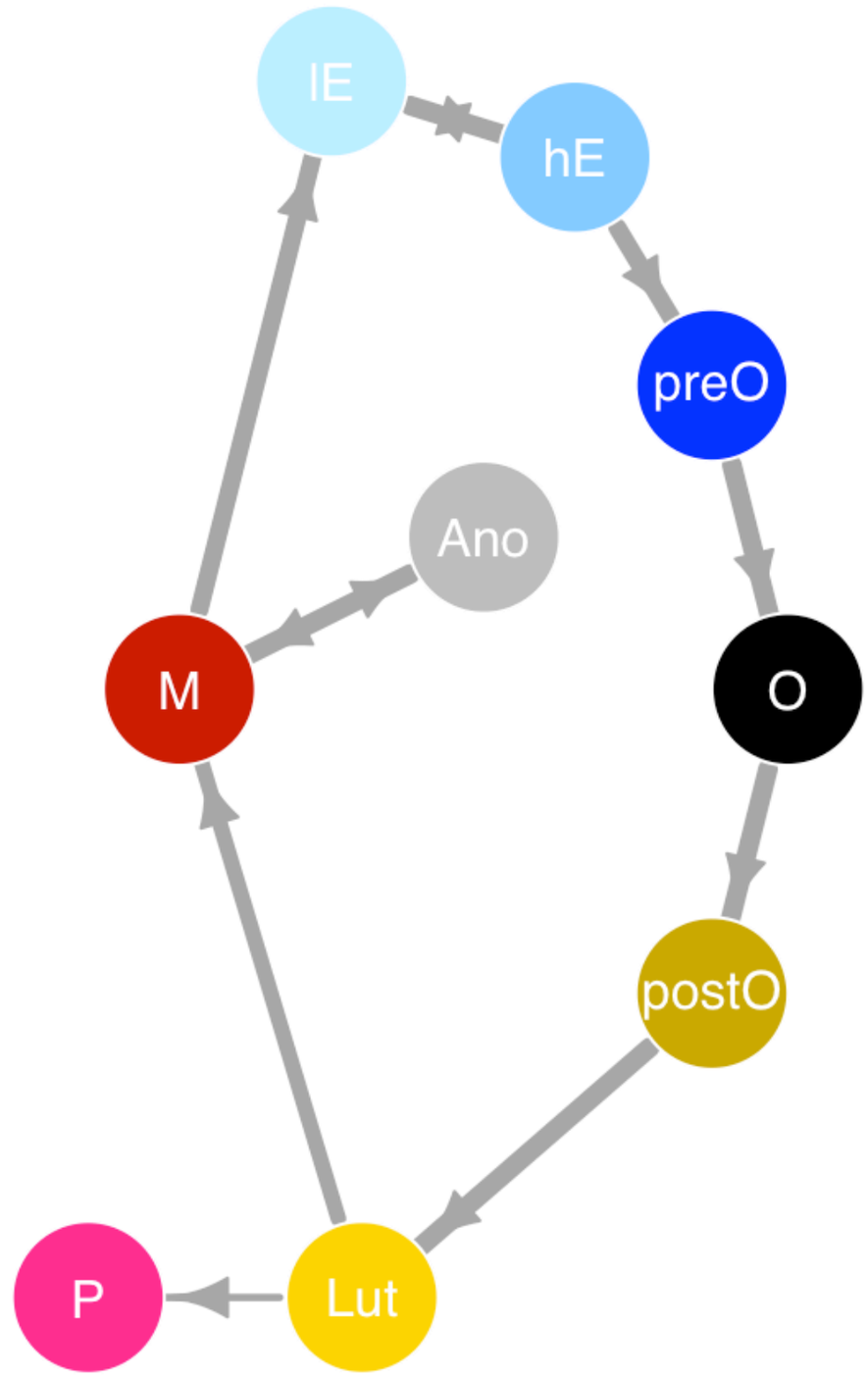
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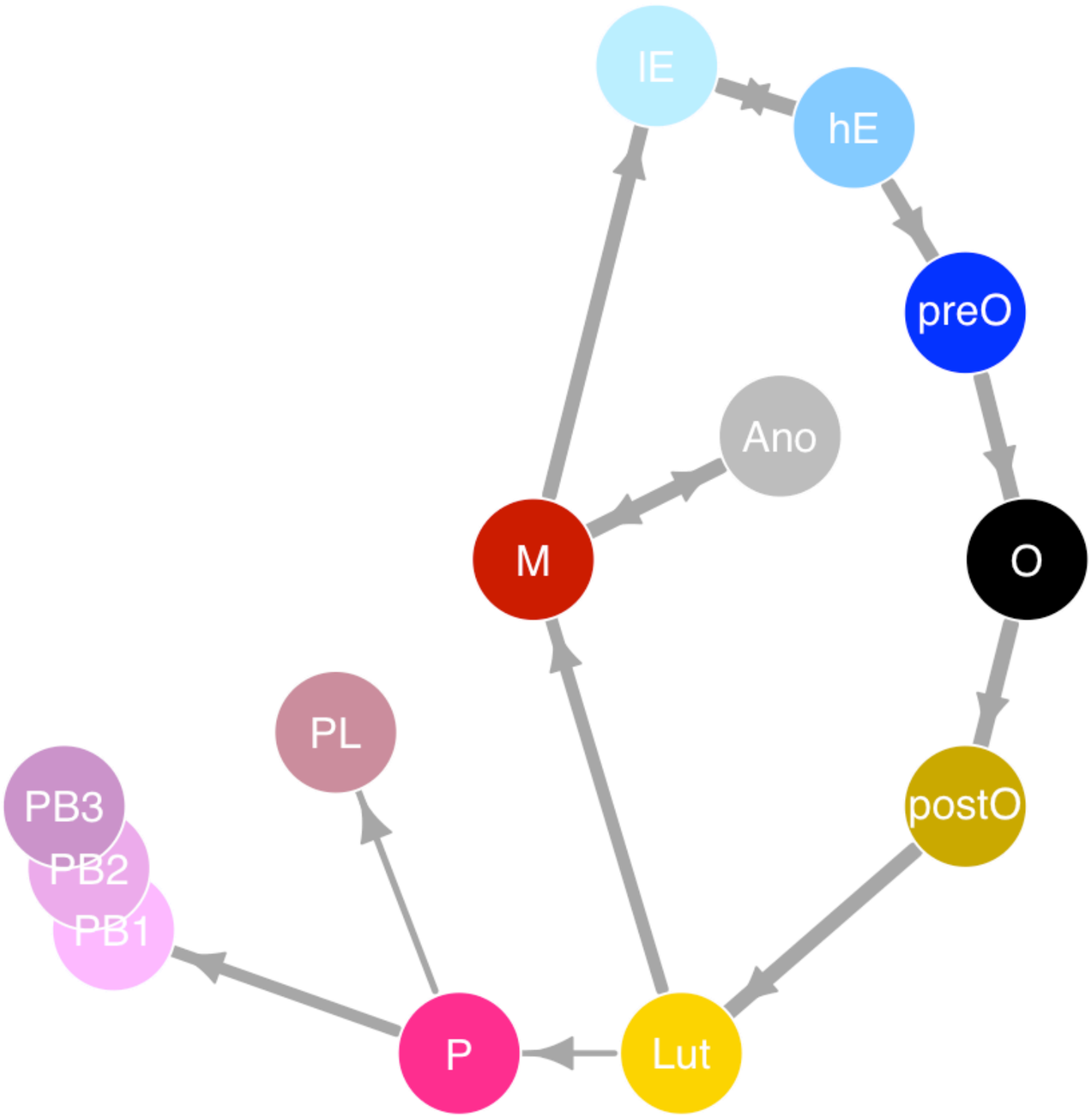
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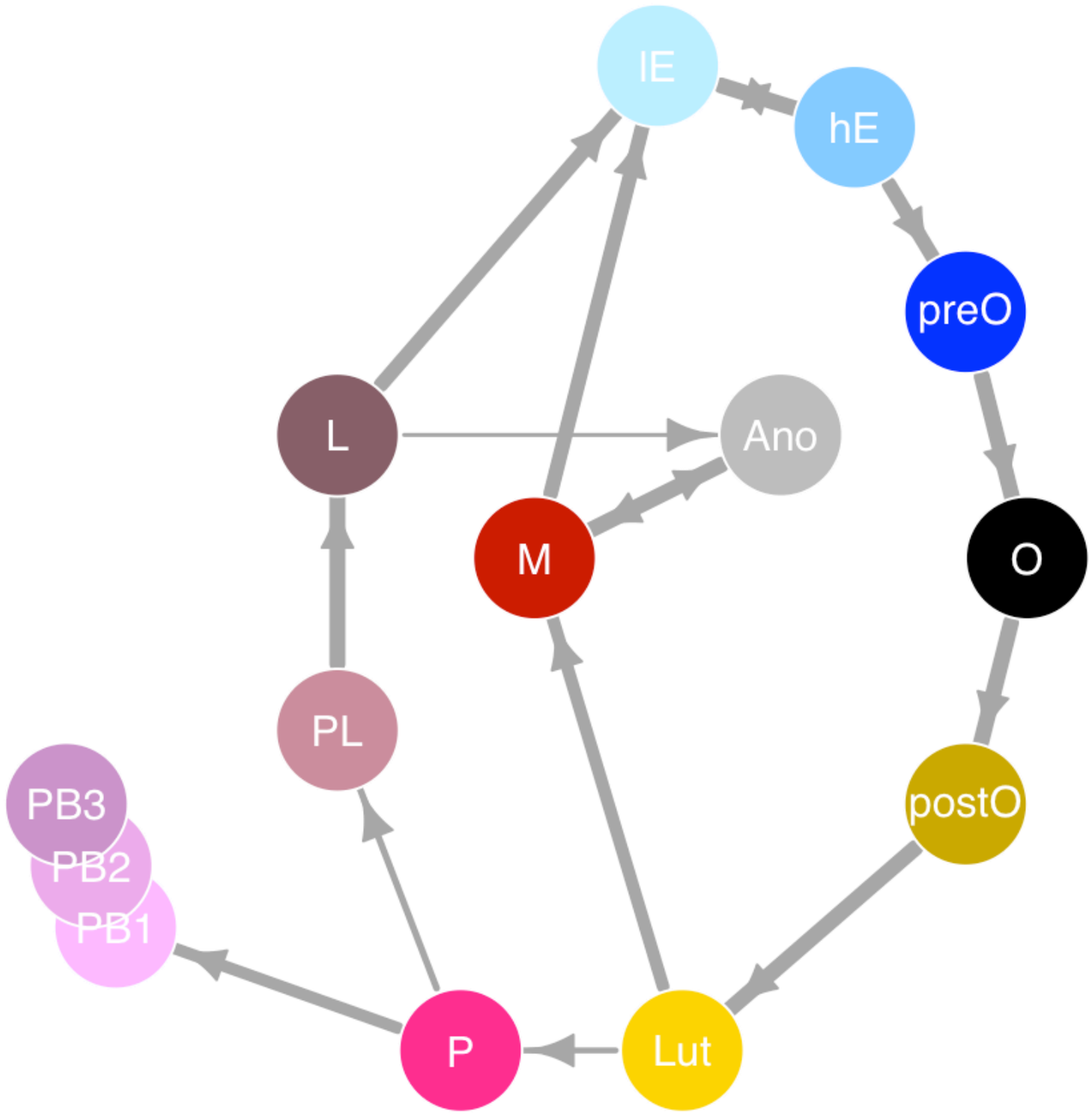
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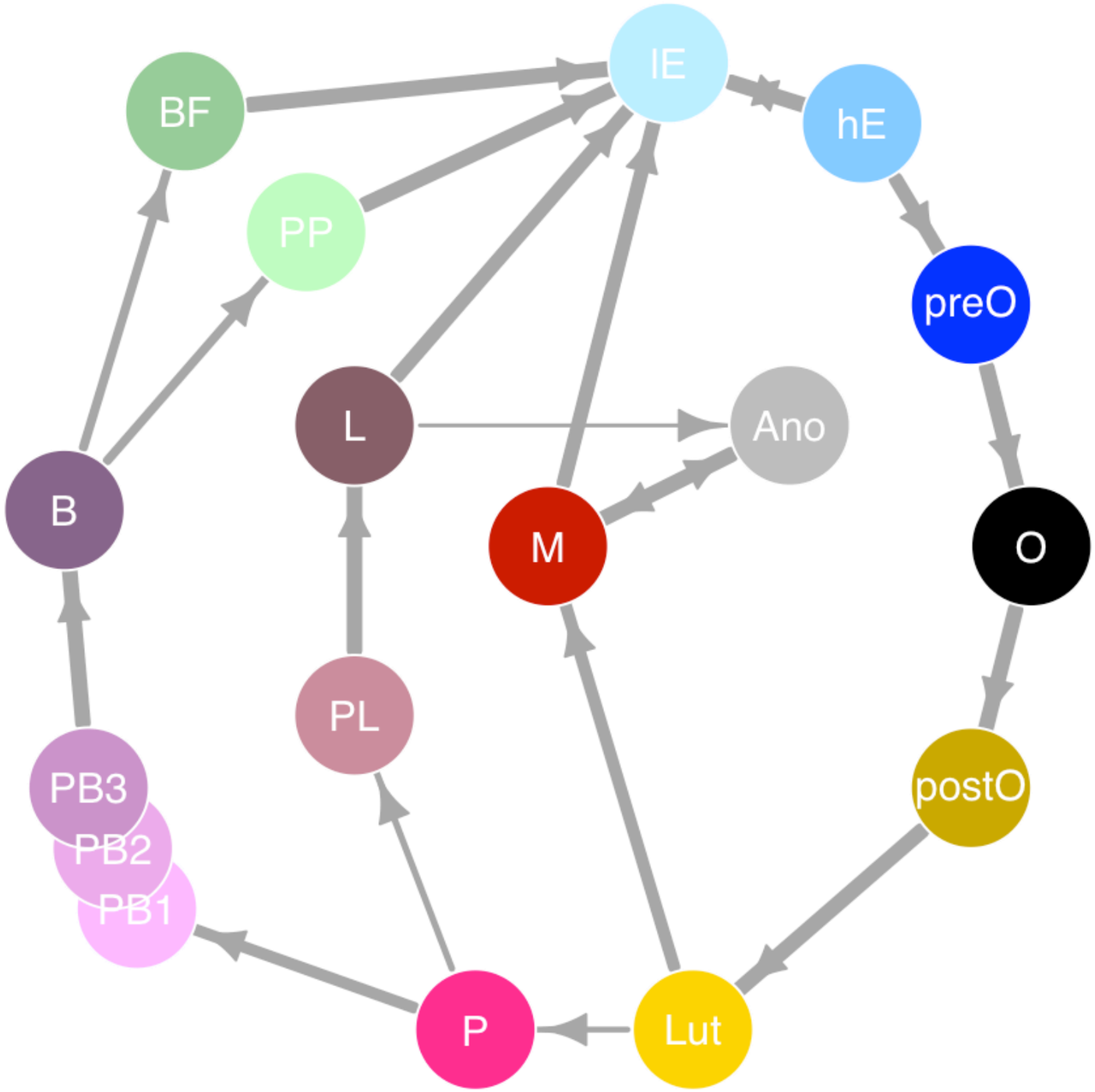
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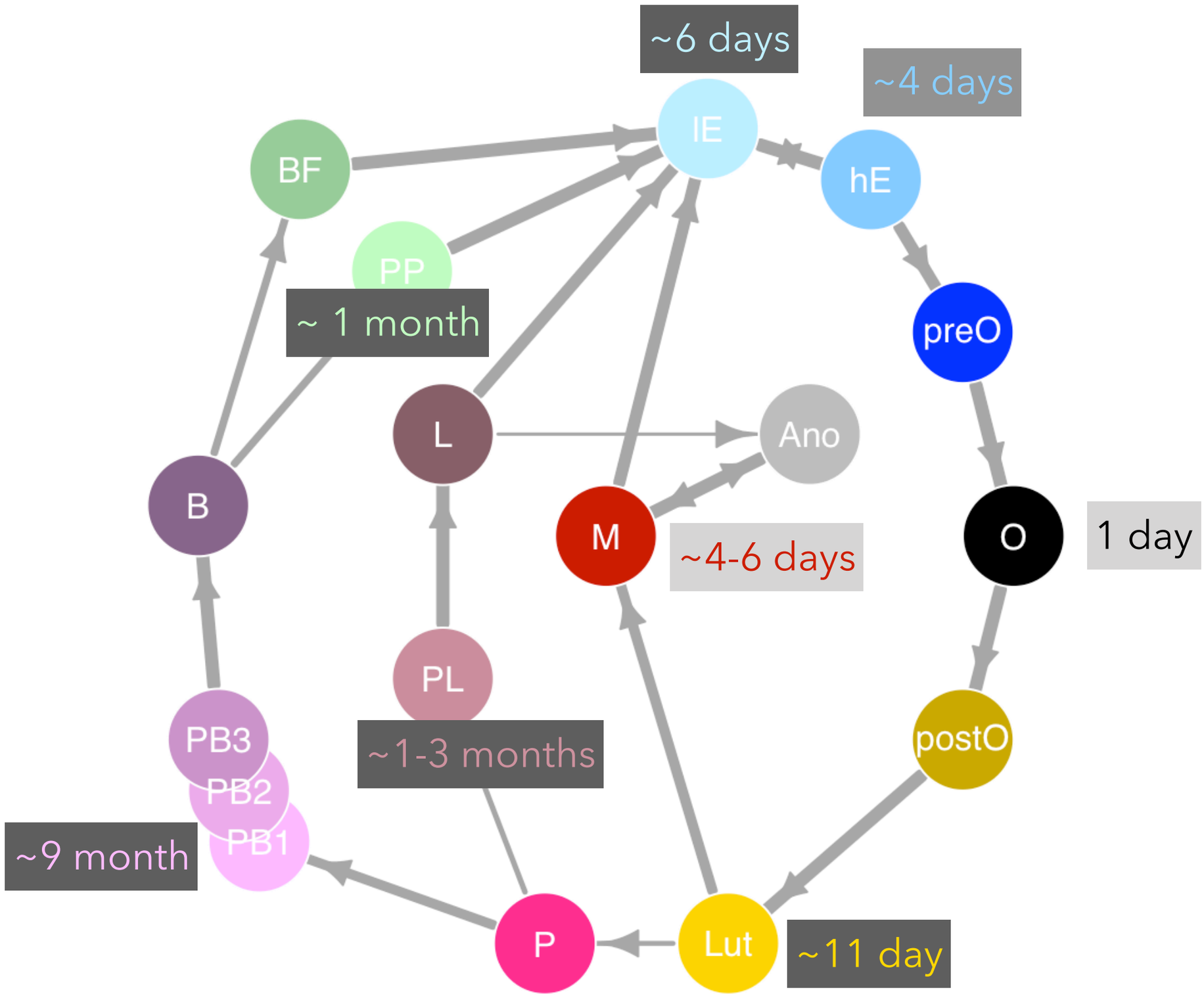
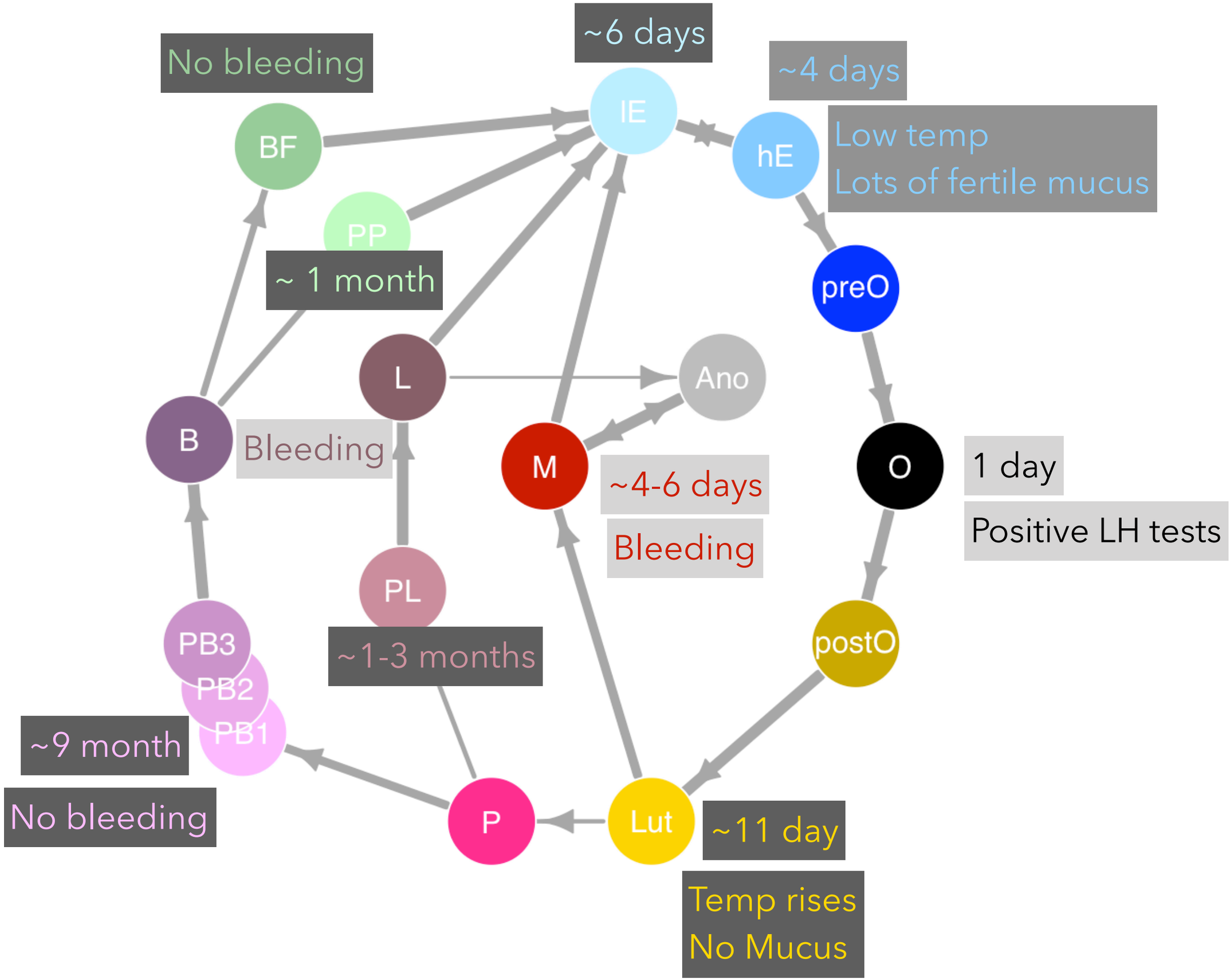
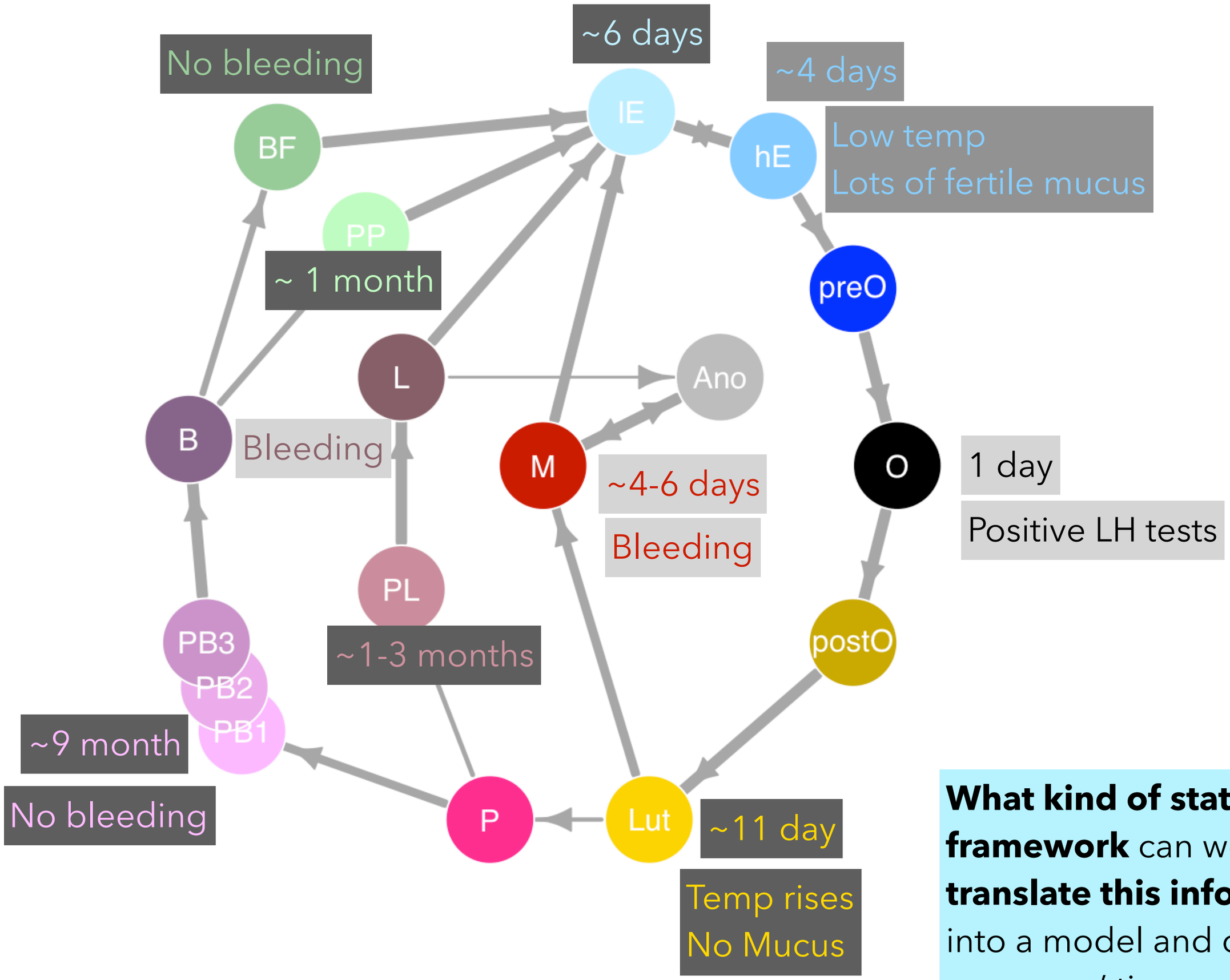

~6 days
~4 days
IE
BF
hE
PP
~ 1 month
preO
L
Ano
B
M
~4-6 days
O
1 day
PL
~1-3 months
PB3
PB2
PB1
~9 month
postO
P
Lut
~11 day


~6 days
No bleeding
~4 days
IE
BF
hE
Low temp
Lots of fertile mucus
PP
~ 1 month
preO
L
Ano
B
Bleeding
M
O
1 day
~4-6 days
Positive LH tests
Bleeding
PL
PB3
~1-3 months
postO
PB2
PB1
~9 month
No bleeding
P
Lut
~11 day
Temp rises
No Mucus



What kind of statistical/ML framework can we use to **translate this information** into a model and decode app users' time-series?

Short introduction to **hidden semi-Markov models** (hsMm)

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Hidden Markov Models

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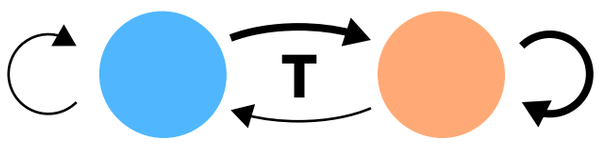

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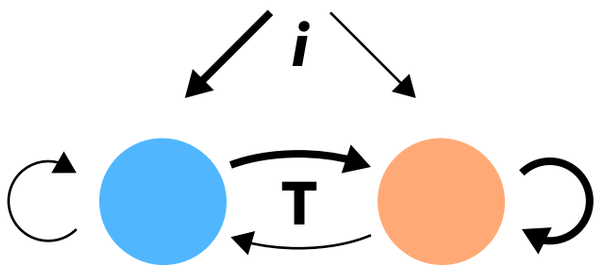

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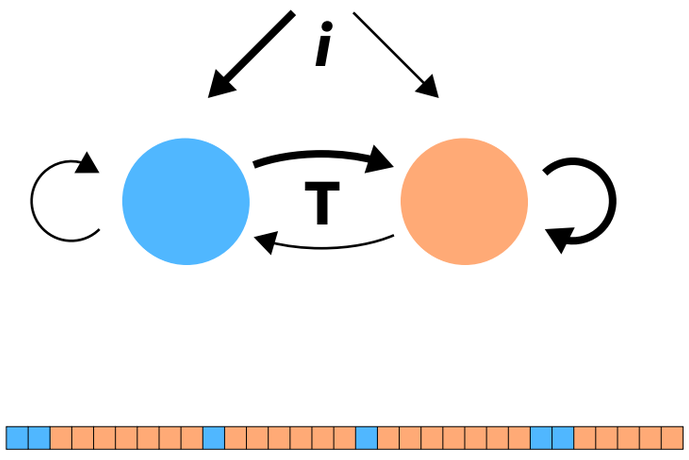

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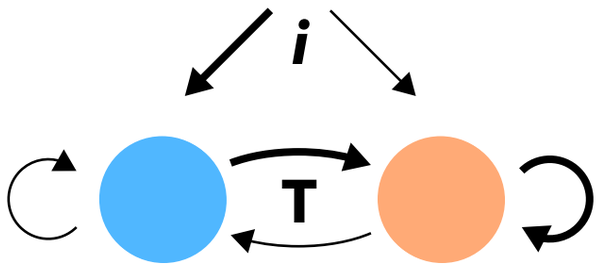

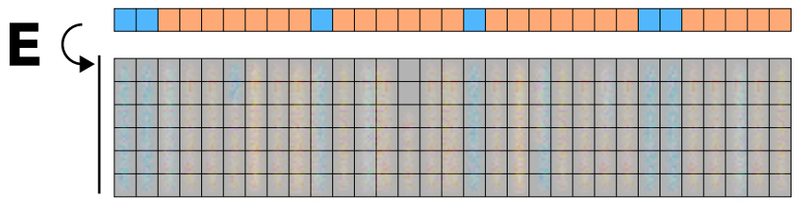

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- **Emission probabilities** for the observed variables

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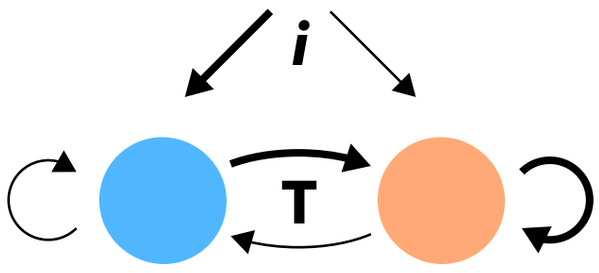

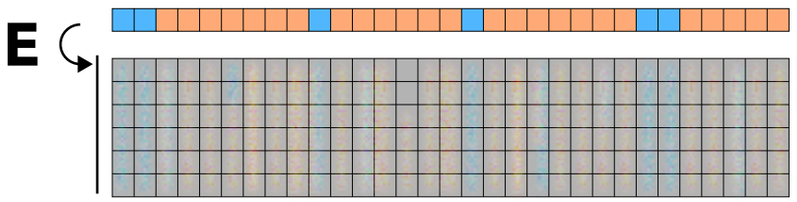

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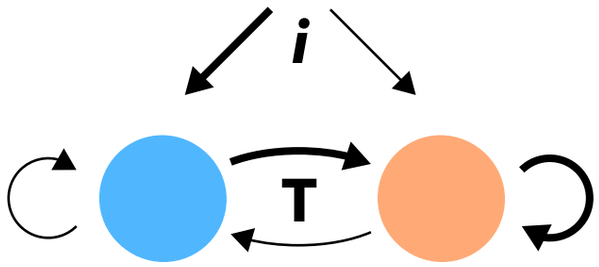
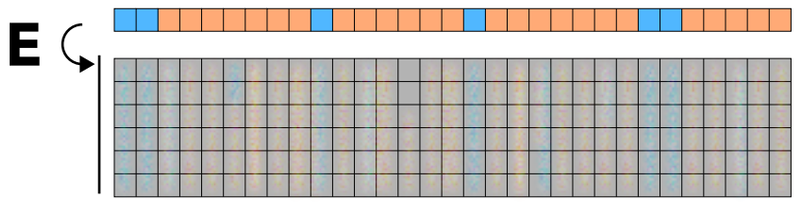
Hidden Markov Models





- **Transition** probabilities (matrix)
  - To switch states
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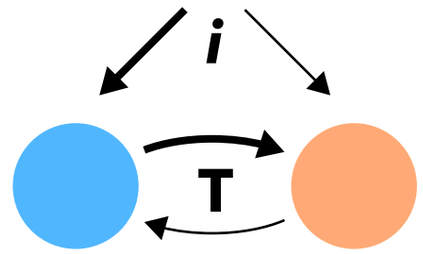
- **Initial state** probability vector
- **Emission probabilities** for the observed variables

Hidden semi-Markov Models



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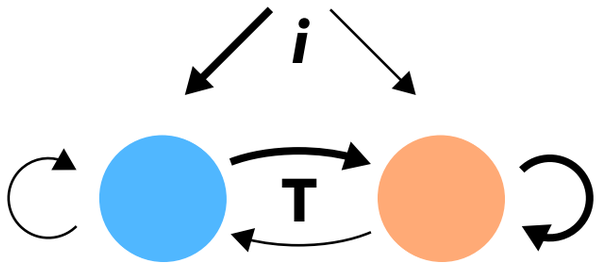

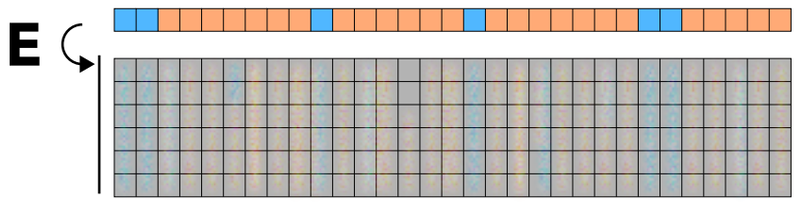

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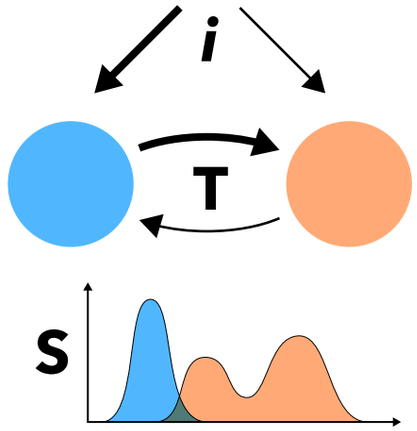

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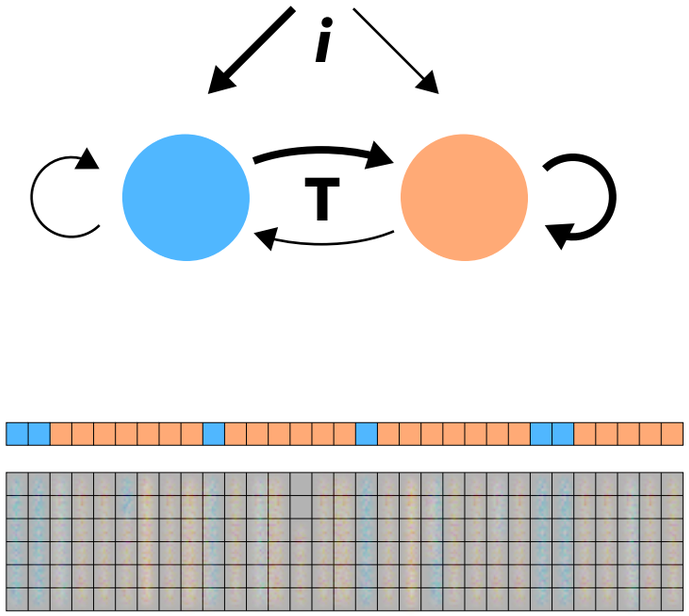

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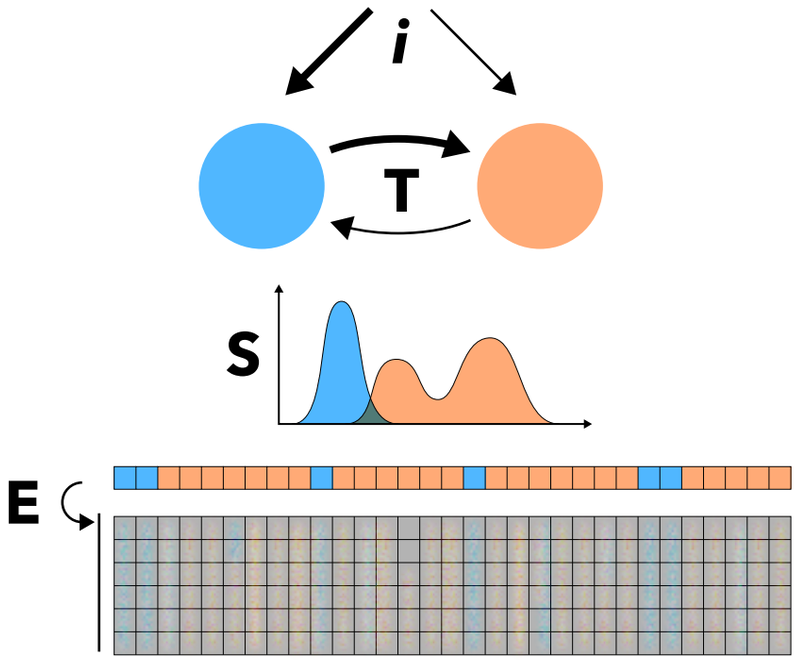

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Workflow

Workflow

- Initialize the model architecture
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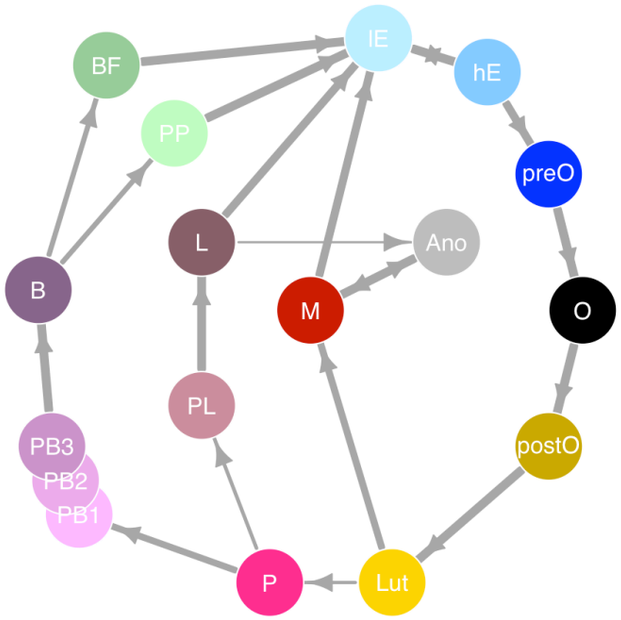

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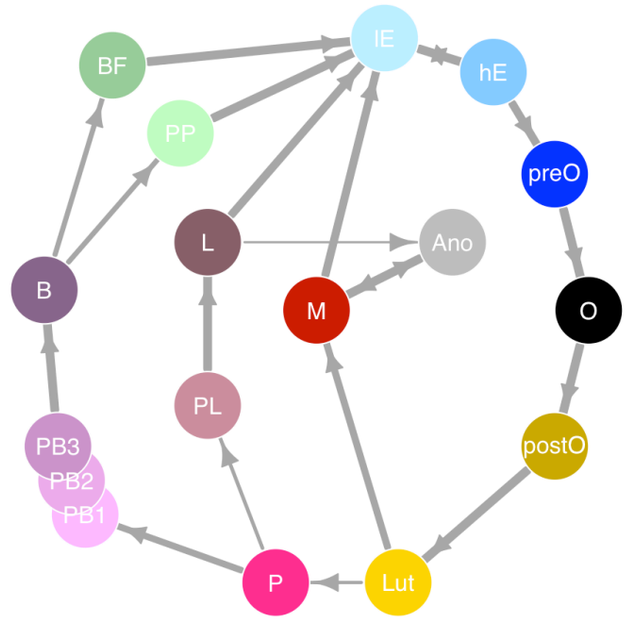

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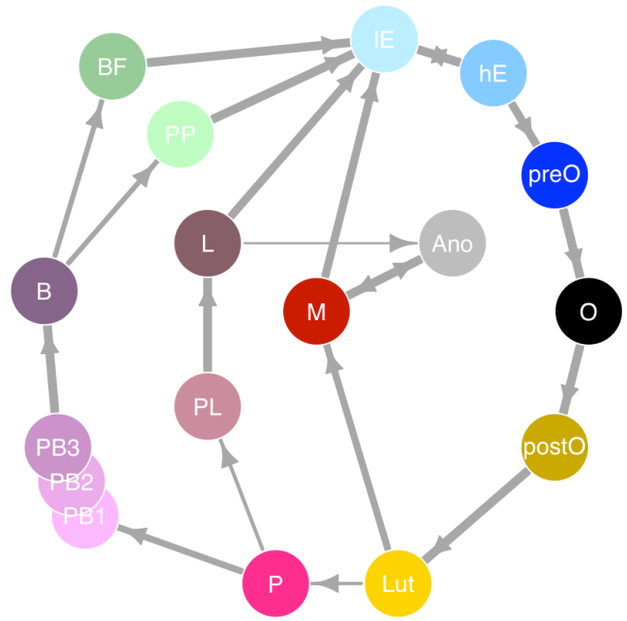

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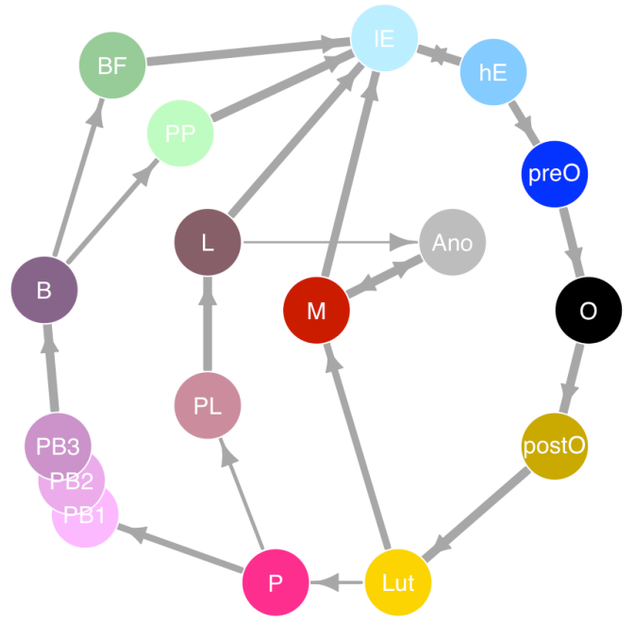

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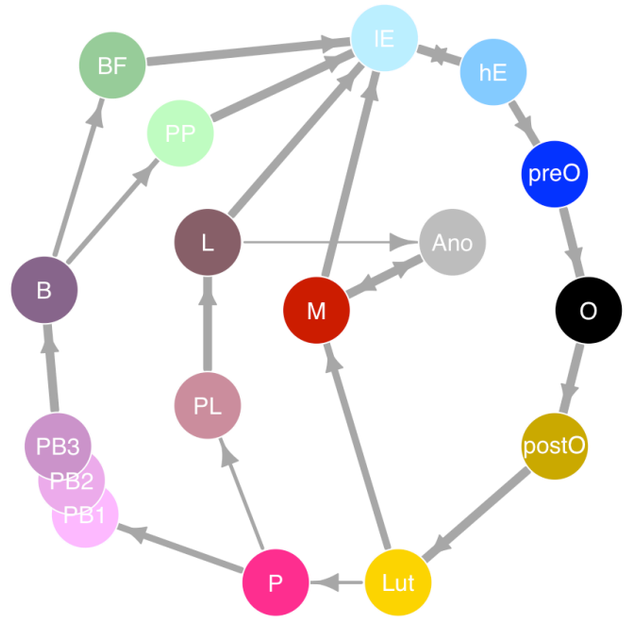

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- Decode all user's time-series

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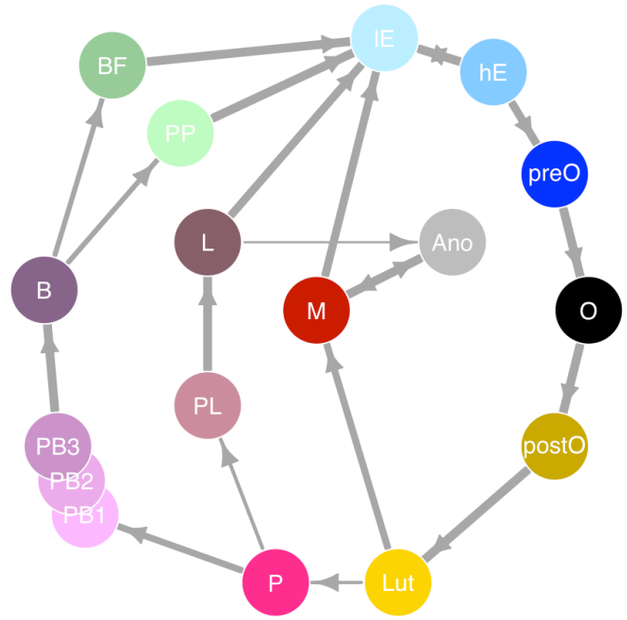

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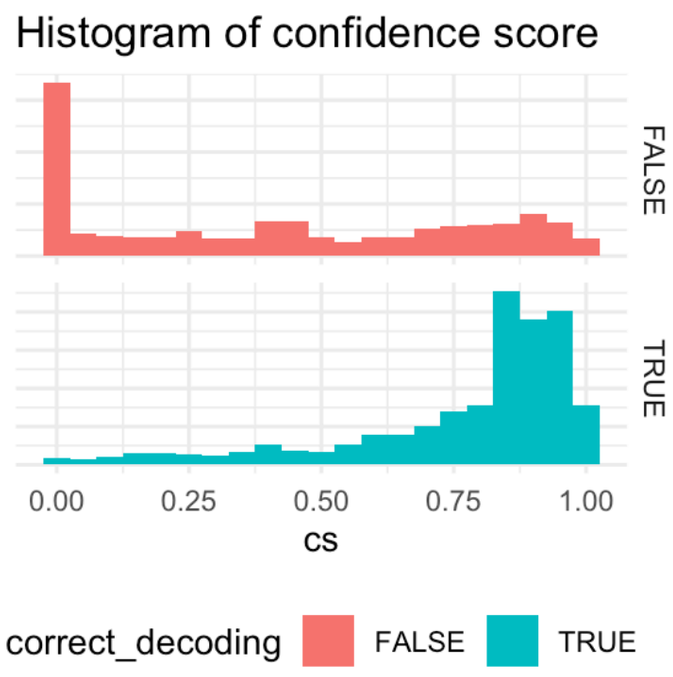
Epidemiological studies

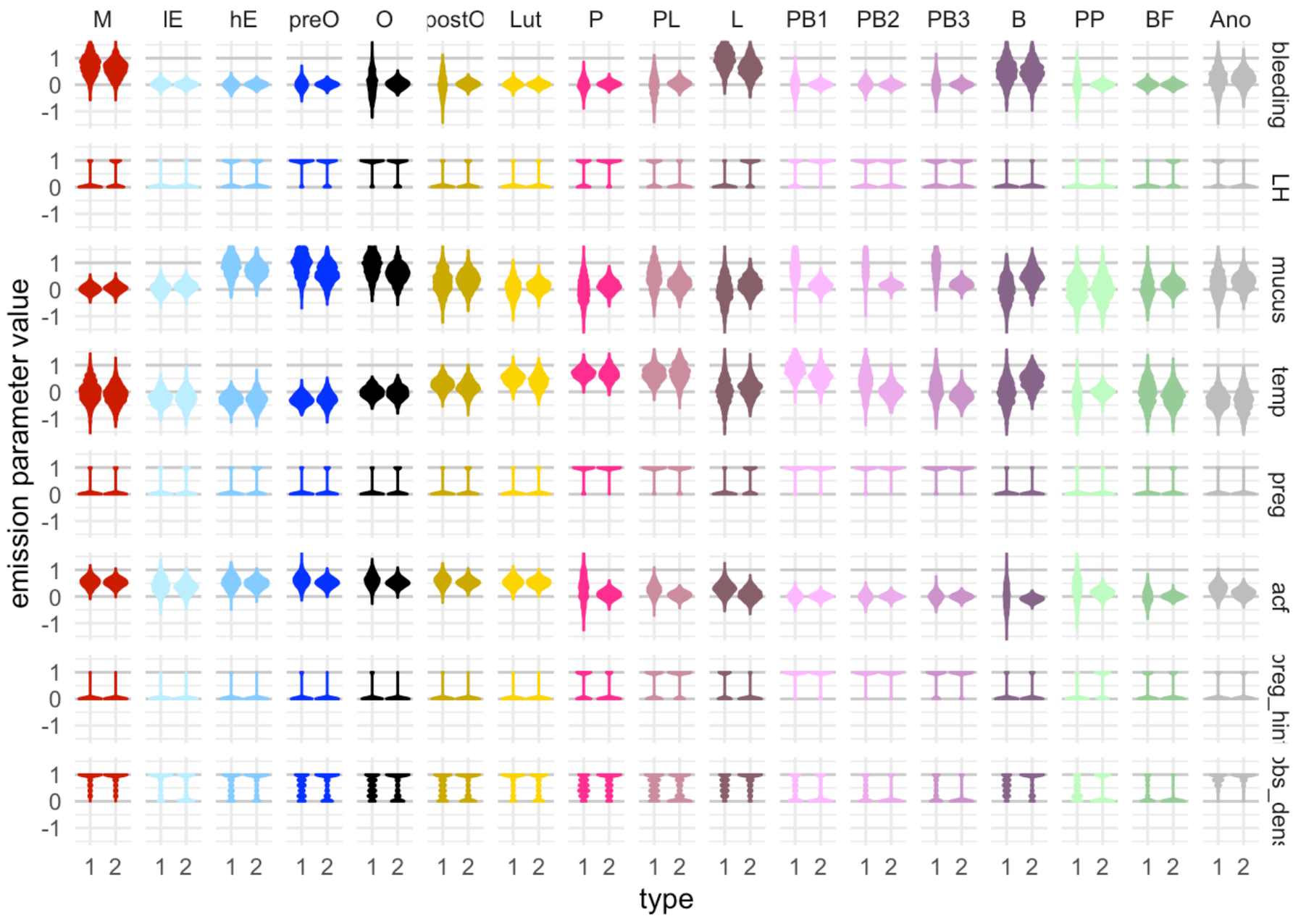
Results

Confidence in the decoded sequences



Accuracy ~80%

Emission parameters



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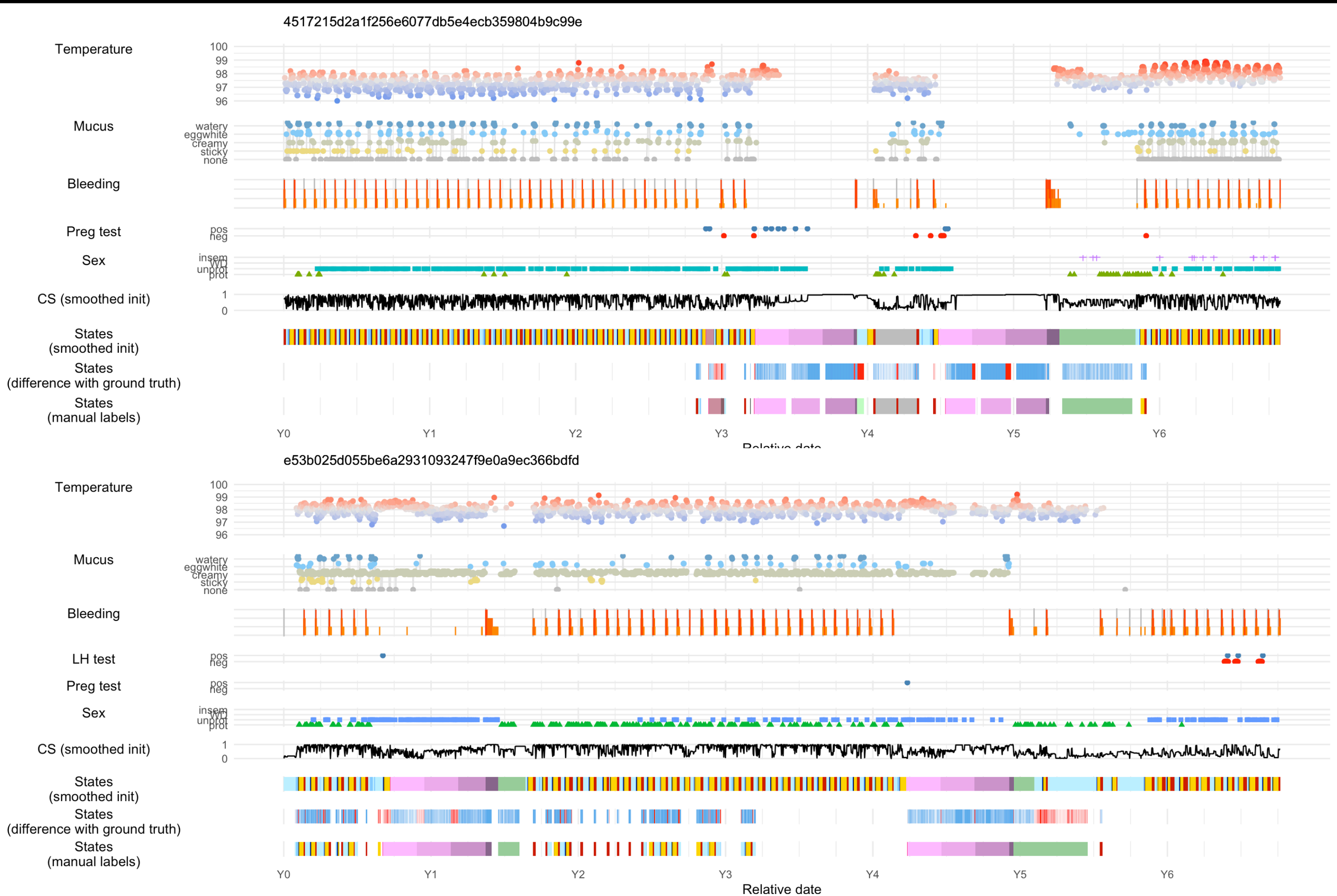
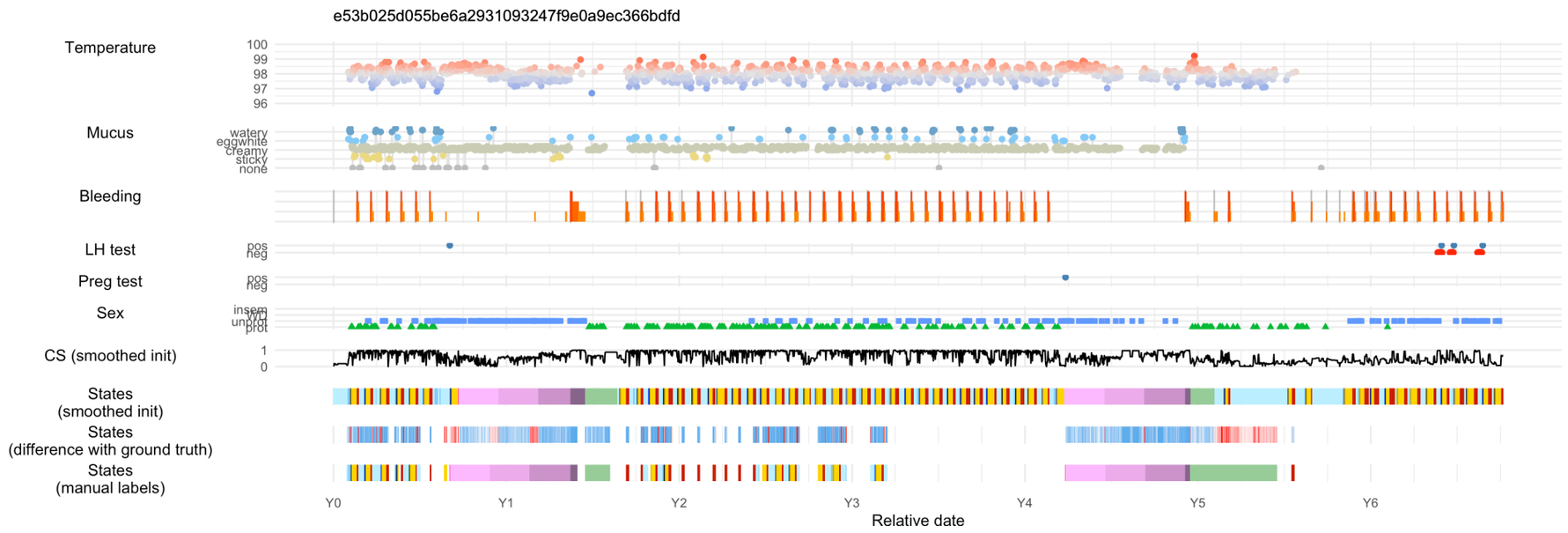

4517215d2a1f256e6077db5e4ecb359804b9c99e
Temperature
100
99
98
97
96
Mucus
watery
eggwhite
creamy
sticky
none
Bleeding
Preg test
pos
neg
Sex
insem
unprot
prot
CS (smoothed init)
1
0
States (smoothed init)
States (difference with ground truth)
States (manual labels)
Y0
Y1
Y2
Y3
Y4
Y5
Y6
e53b025d055be6a2931093247f9e0a9ec366bdfd
LH test
Relative date

Conclusions



Upgraded `'hsmm'` R package that

- **can deal with high level of data missingness** (as found in any digital health project)
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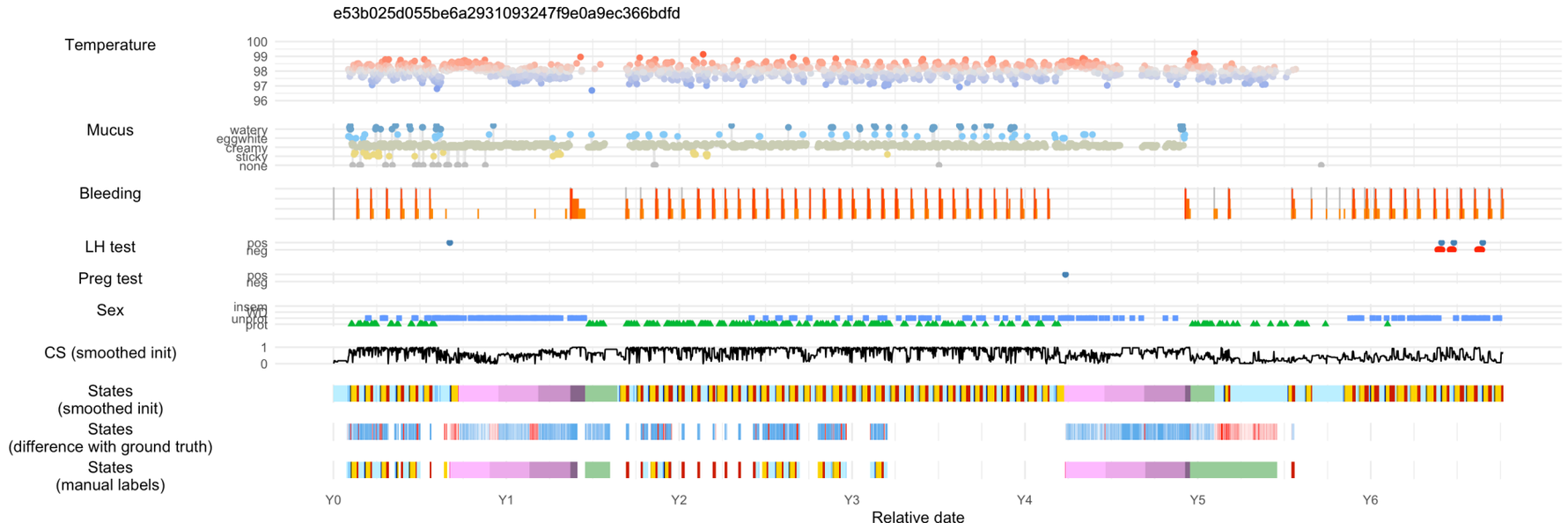

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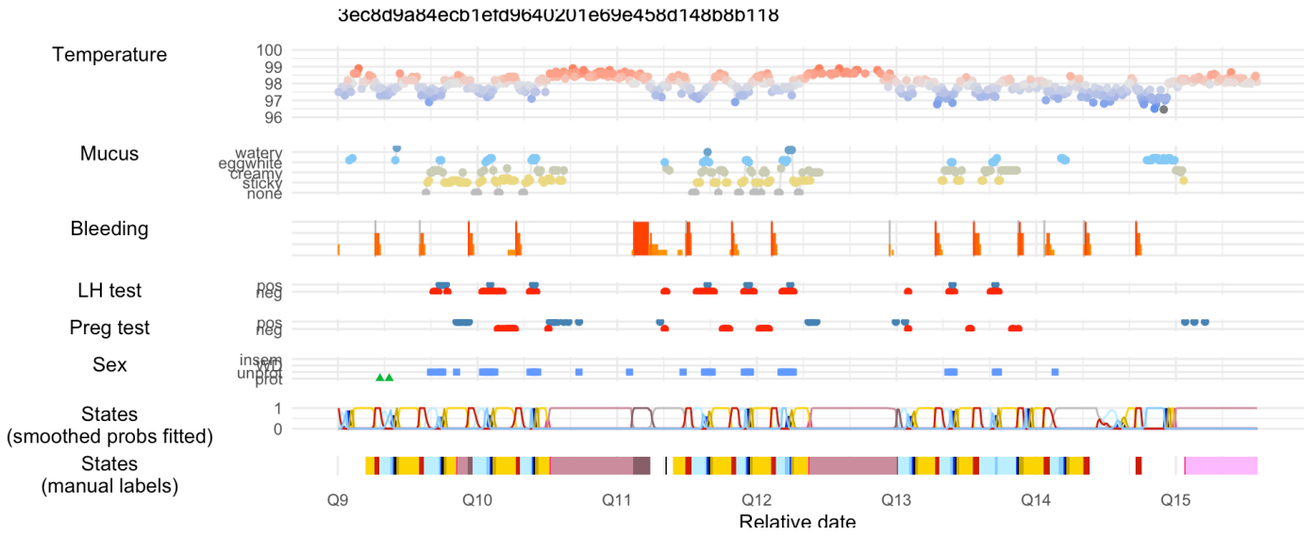
A statistical model that can accurately decode menstrual/fertility app data at different time-scale:



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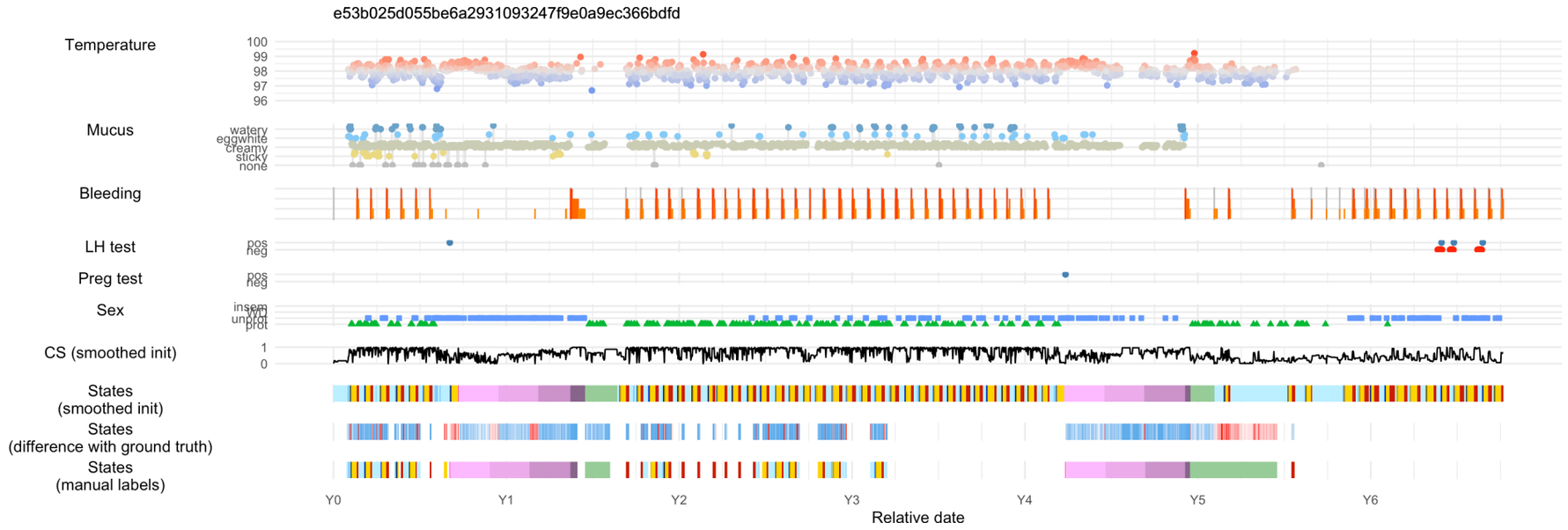

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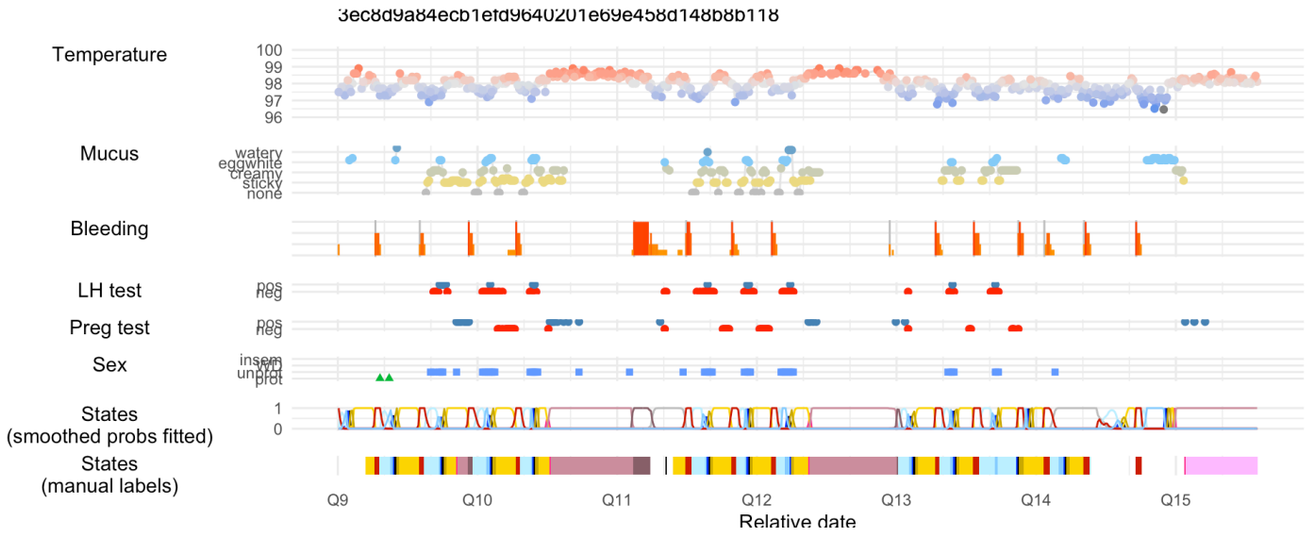
> **About 200k users time-series labelled.**
Now we can interrogate these data.



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KINDARA

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SCHWEIZERISCHER NATIONALFONDS
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