What Women Want

Designing algorithms to seek and avoid pregnancy

SDS 23 June 2022
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Ava Women AG

Founded 2014

Our vision is to aid women throughout their lives with their reproductive health

Recognised with start-up, femtech, and medtech awards

Our products:

Wearable device collecting user physiological signals:

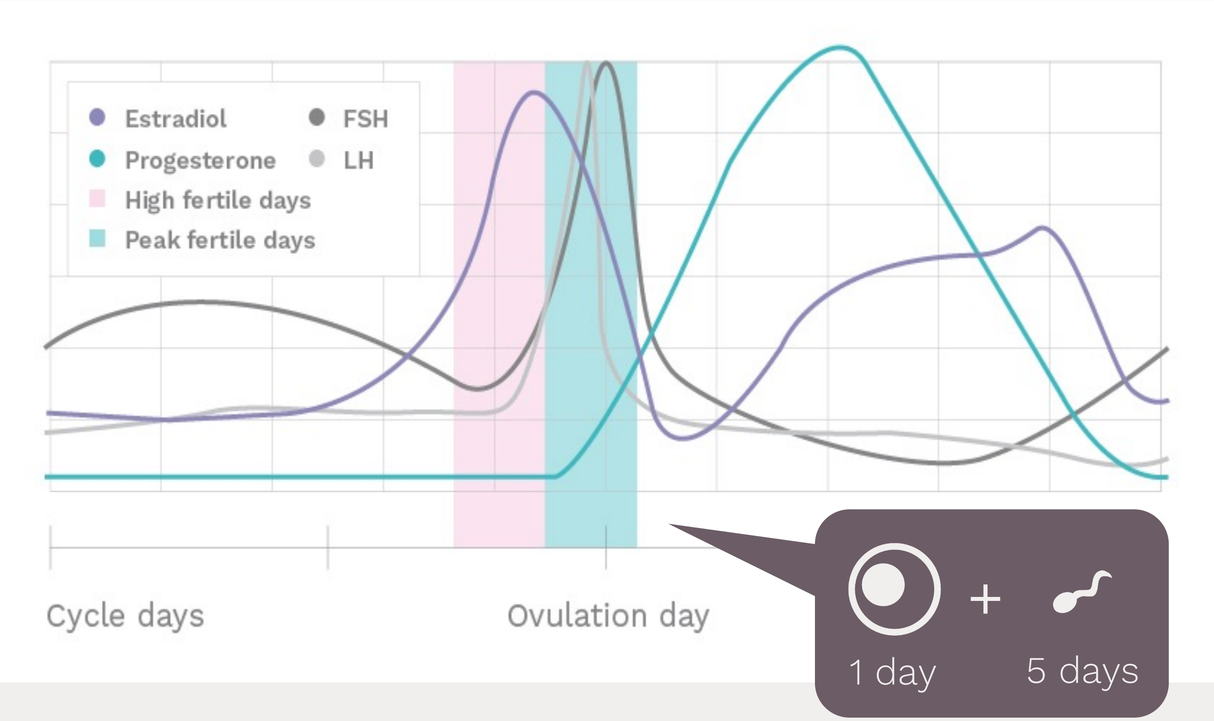
- Heart rate, HRV, temperature, breathing rate, perfusion
- 200,000 users each collecting 1m datapoints per night

Data-driven applications:

- Fertility app launched in 2016 (CE & FDA approved)
- Contraception app launching 2023 in Europe
- Early covid detection (research project)

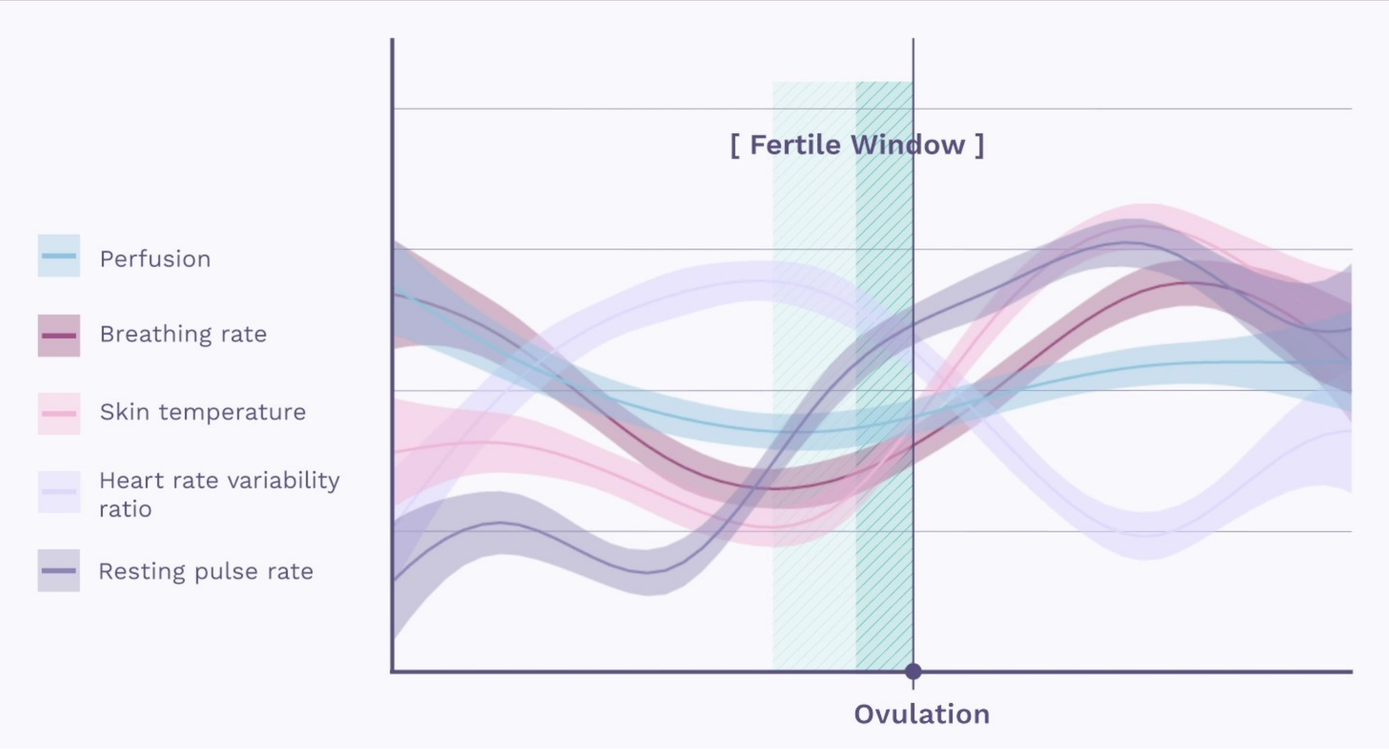
The fertile window

Each cycle contains a 6-day *fertile window* …



Many fertility detection methods identify ovulation when it occurs – almost too late to be useful!

Do better with sensors and data science



physiological signals

differentiate cycle phases
statistically significant differences
measurable

data science

time-series signals data
+ ML & probabilistic models
= real-time fertility prediction

advantages

accuracy without the overhead
unobtrusive
convenient

Fertility prediction model

+

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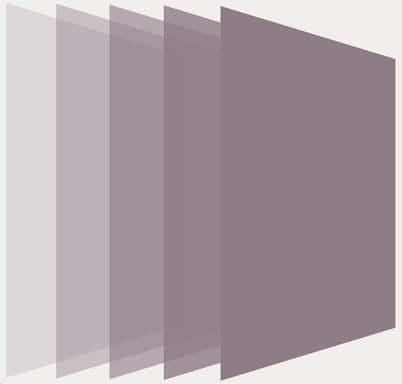
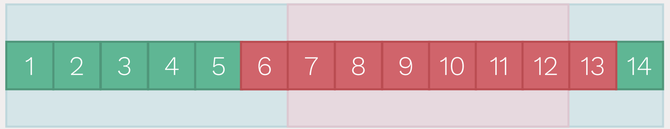




physiological data

skin temperature
heart rate
breathing rate
HRV
skin perfusion

LH-labelled menstrual phases

0 – out of cycle
1 – follicular phase
2 – fertile phase
3 – luteal phase

ML architecture

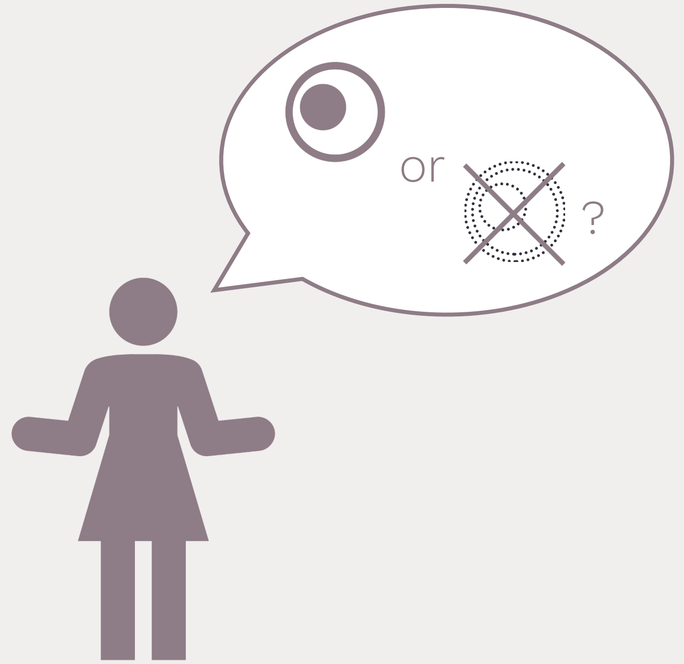
per-day fertility prediction

within fertile window
out of fertile window

“fertile” prediction
“not fertile” prediction

So it’s just a binary classification problem

… right?



But it’s a bit more complex...

Not all fertile days are equal:

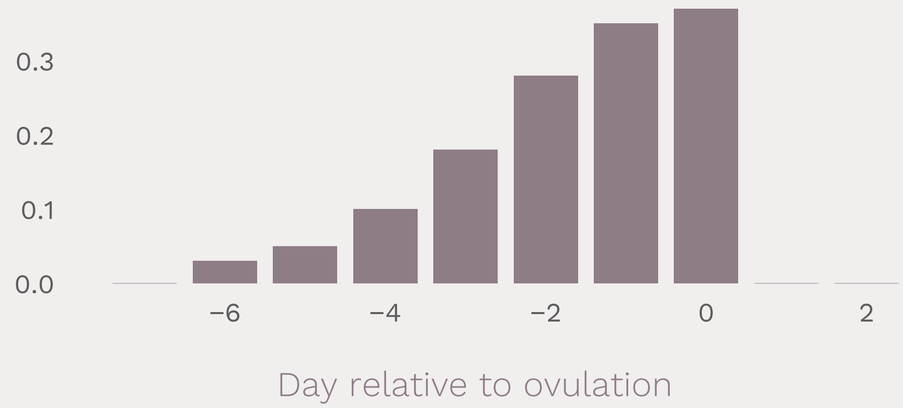
conception probability varies within fertile window

It’s a fertile *window*:

we expect at least 6 consecutive “fertile” days

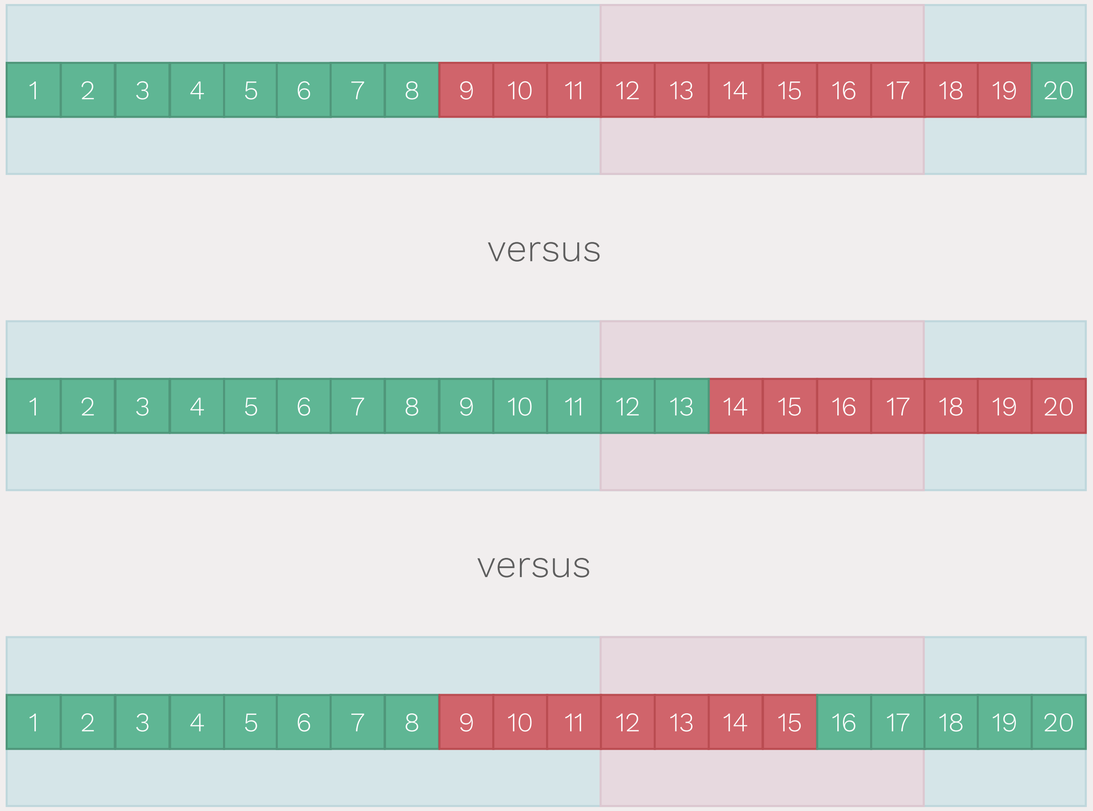
How precise are our training labels?

LH tests are not 100% accurate at indicating ovulation



*Ferreira-Poblete A. *The probability of conception on different days of the cycle with respect to ovulation an overview*. Advances in Contraception. 1997 Jun 1;13(2-3):83-95

Setting thresholds for contraception



When is the fertile window opened? When is it closed?

ROC curve analysis ignores structure in the data and the problem:

- Some days are more fertile than others
- Better to have FNs at fertile window start

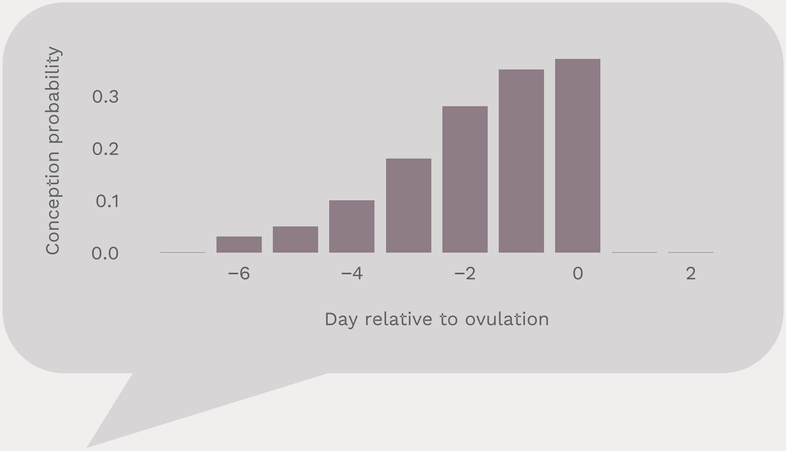
Sensitivity is not a good enough metric!

Threshold calibration scores

Estimated cumulative pregnancy rate

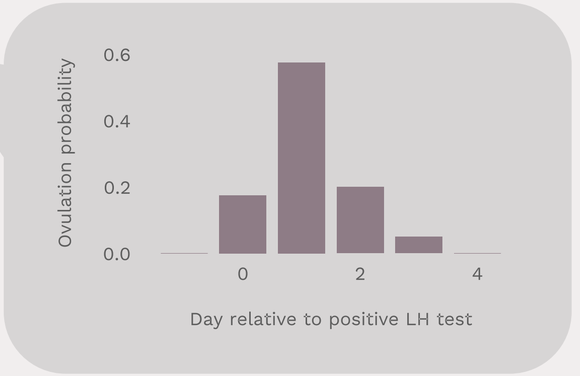
Fixing open and close thresholds...

The per-day conception probability is:



Conception probability on day x, given ovulation on day z

$$\underbrace{P(\text{conc. } x \mid \text{LH } y)}_{\text{Conception probability on day x, given positive LH test on day y}} = \sum_z \overbrace{P(\text{conc. } x \mid \text{OV } z)} \cdot \underbrace{P(\text{OV } z \mid \text{LH } y)}_{\text{Probability of ovulation on day z, given positive LH test on day y}}$$



Threshold calibration scores

Estimated cumulative pregnancy rate

Fixing open and close thresholds...

The per-day conception probability is:

$$P(\text{conc. } x \,|\, \text{LH } y) = \sum_z P(\text{conc. } x \,|\, \text{OV } z) \cdot P(\text{OV } z \,|\, \text{LH } y)$$

Assuming:

- Intercourse does not occur on days labelled “fertile” by the model
- Intercourse certainly occurs on all other days

The per-cycle conception probability is:

$$P(\text{conc. in cycle with LH } y) = 1 - \underbrace{\prod_{\text{‘not fertile’ } x_i} (1 - P(\text{conc. } x_i | \text{LH } y))}$$

Probability of *not* conceiving on any day on which intercourse occurs, given positive LH test on day y

Threshold calibration scores

Estimated cumulative pregnancy rate

Fixing open and close thresholds...

The per-day conception probability is:

$$P(\text{conc. } x \,|\, \text{LH } y) = \sum_{z} P(\text{conc. } x \,|\, \text{OV } z) \cdot P(\text{OV } z \,|\, \text{LH } y)$$

The per-cycle conception probability is:

$$P(\text{conc. in cycle with LH } y) = 1 - \prod_{\text{`not fertile'} \; x_i} (1 - P(\text{conc. } x_i | \text{LH } y))$$

Combining these per-cycle probabilities we get an *estimated cumulative pregnancy rate*

Threshold calibration scores

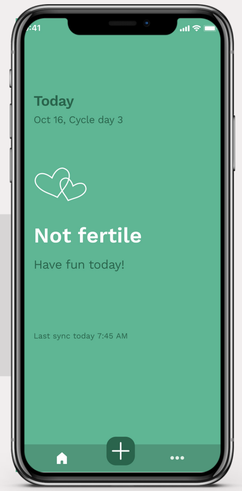
Estimated per-cycle green day ratio

Fixing open and close thresholds...

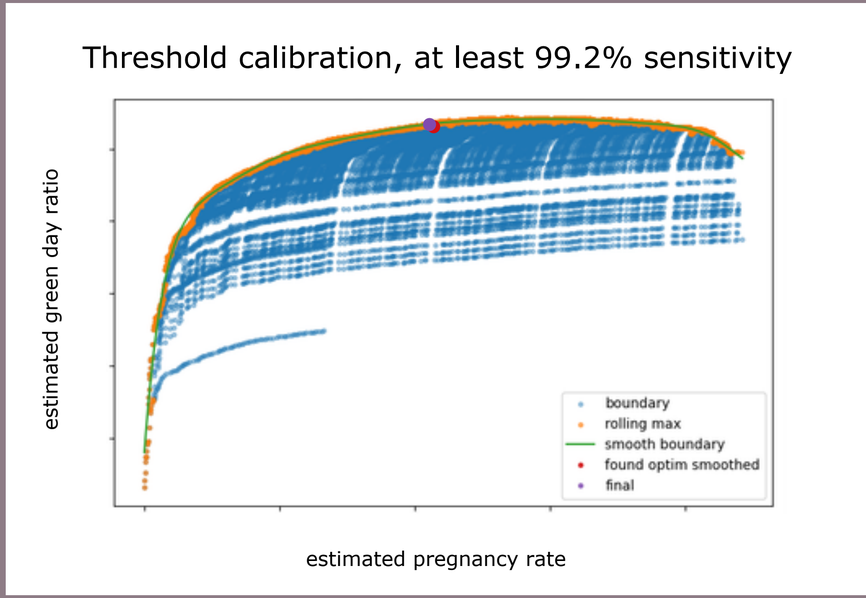
We wish to strike the optimal balance between estimated cumulative pregnancy rate and *estimated green day ratio*:

$$\mathbf{E}[\mathrm{GDR}] = \frac{1}{\#\mathrm{cycles}} \sum_{\mathrm{cycles}} \frac{\#\text{“not fertile” days}}{\text{cycle length}}$$

a day labelled as “not fertile” is a green light for unprotected sex



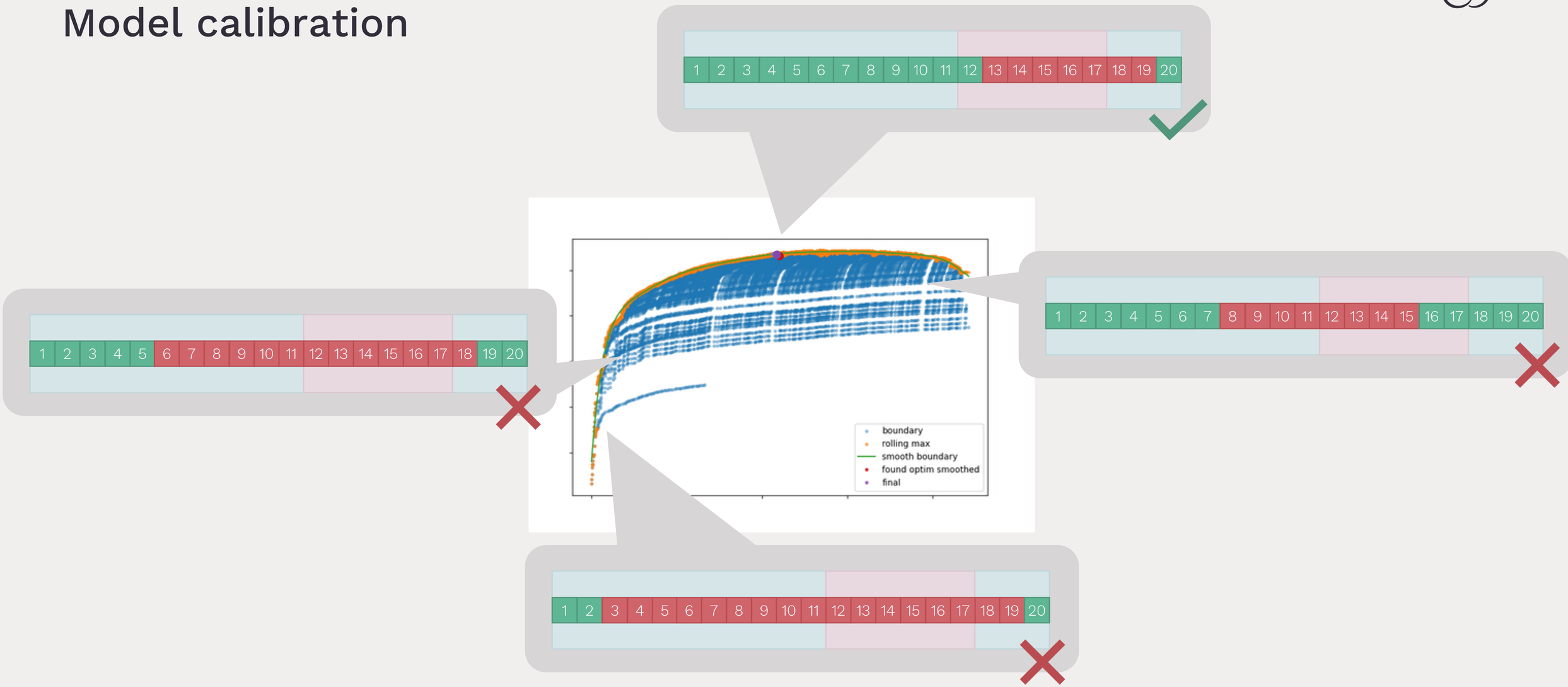
Model calibration



Our calibration recipe:

- Perform separate ROC analyses on open & close thresholds to obtain threshold pairs of interest
- Restrict to those threshold pairs with a sensitivity of at least 99.2%
- For each threshold pair, estimate *pregnancy rate* and *green day ratio*
- Plot pregnancy rates against green day ratio
- Select threshold pair with maximum green day ratio for minimum pregnancy rate

Model calibration



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Outlook

What have we learned?

- Take advantage of the structure in your data
- Ground truth is not always true
- Targeted metrics are more informative

Of course, there are many other challenges that we had to face.

Some we are still grappling with…

Thank you!