The Secret Life of Cells
(and how to uncover it)

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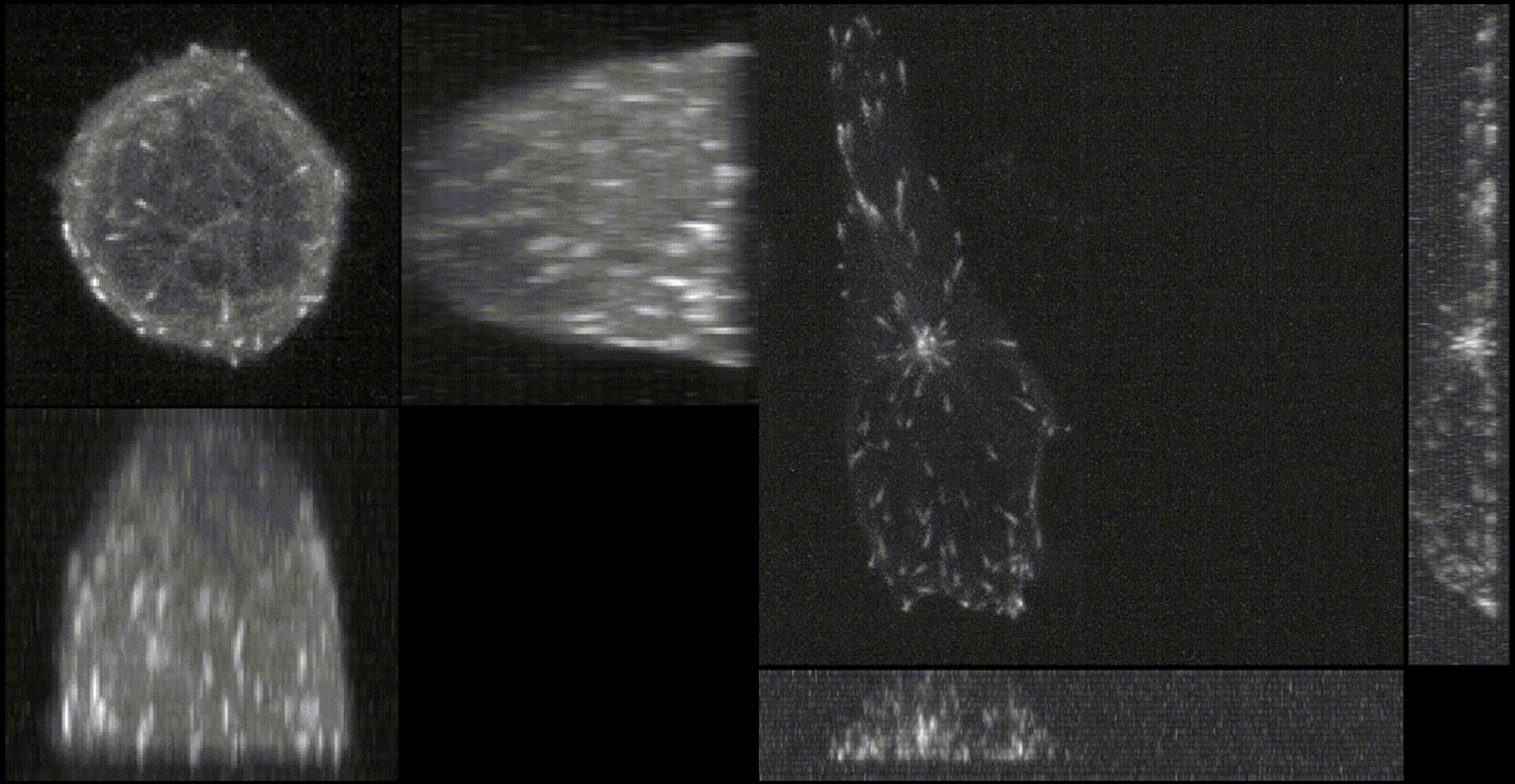
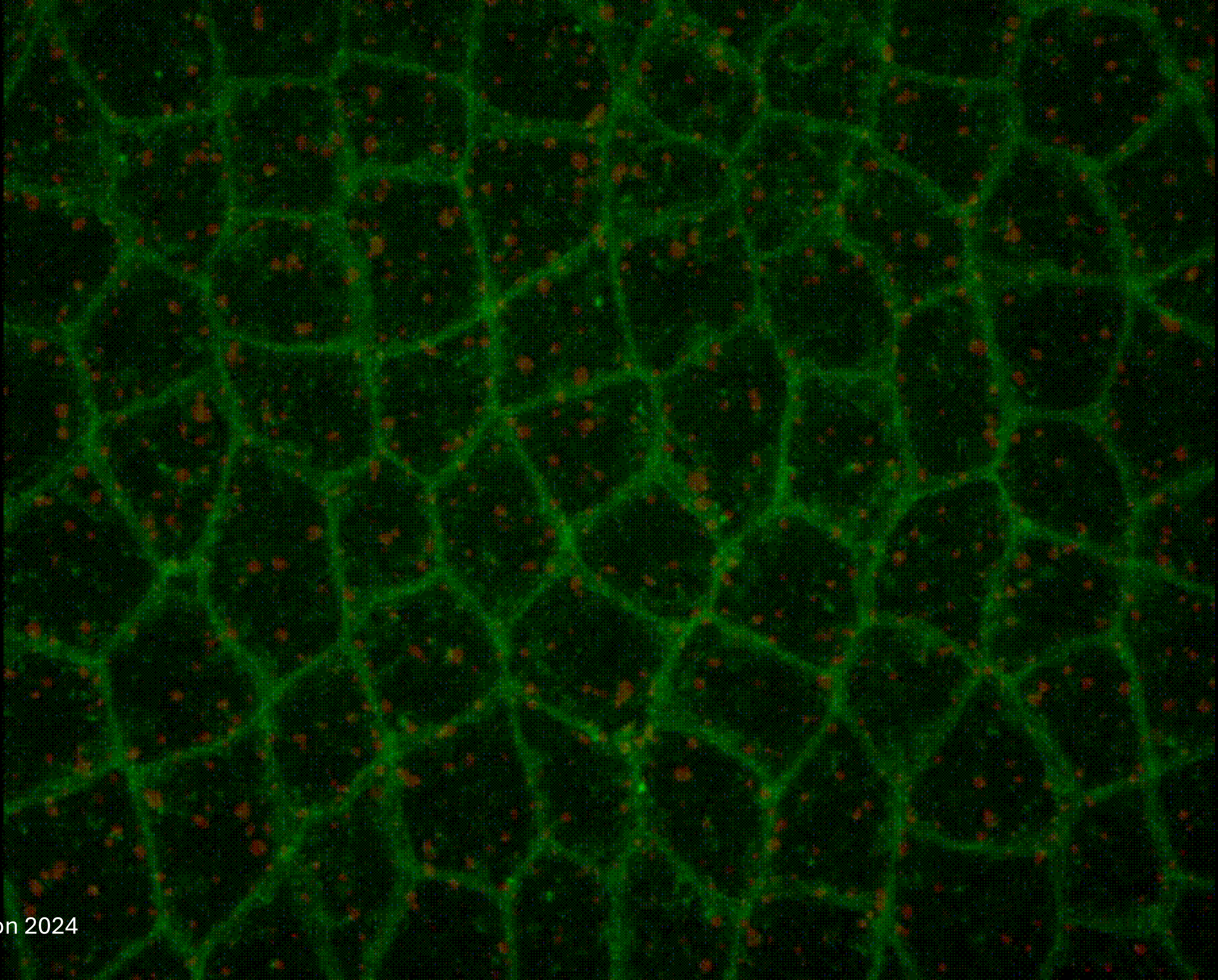
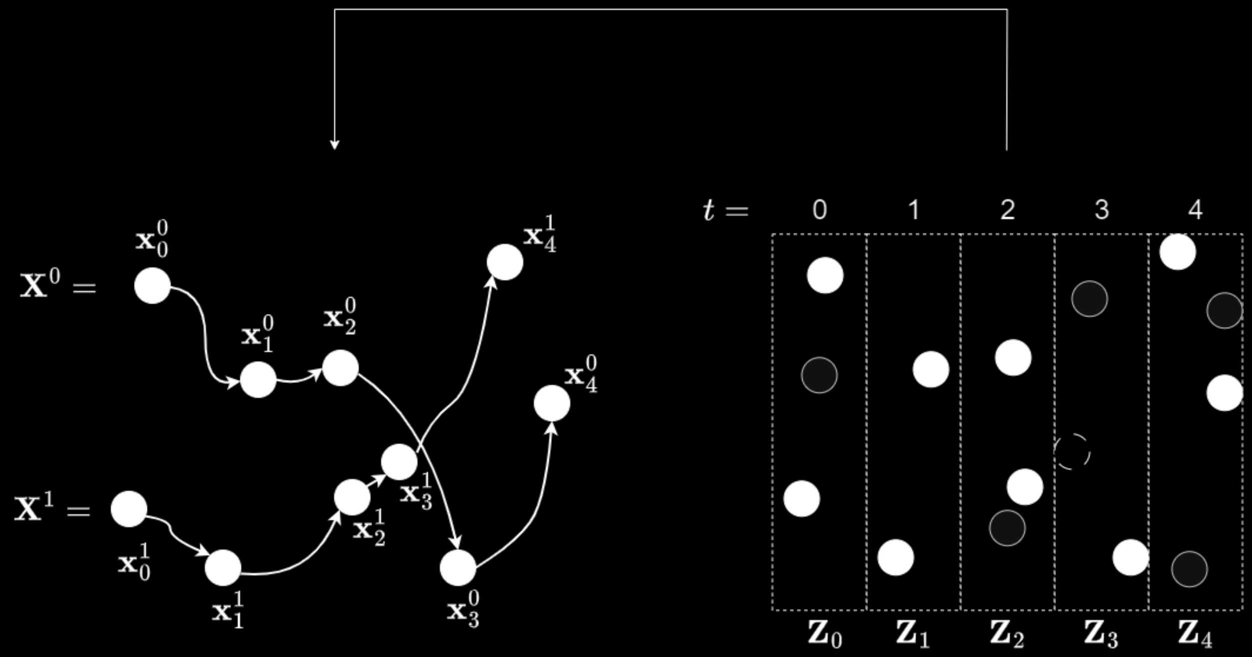


G.D.C. Ortega,
ETH Zurich, 2023



Team Endotrack,
Centuri Hackathon 2024

Mapping measurements to states is an inverse problem of data-association



$\mathbf{X} = \{\mathbf{X}^{\mathbf{P}}\}_{p=0:N-1}$

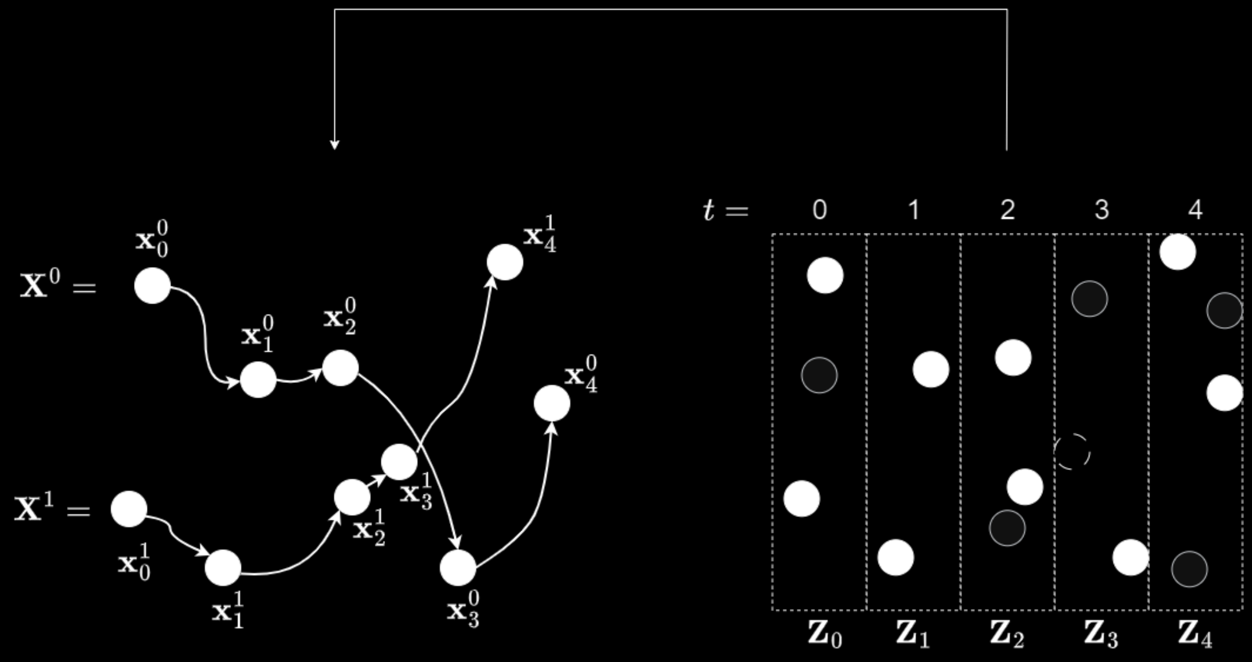
states

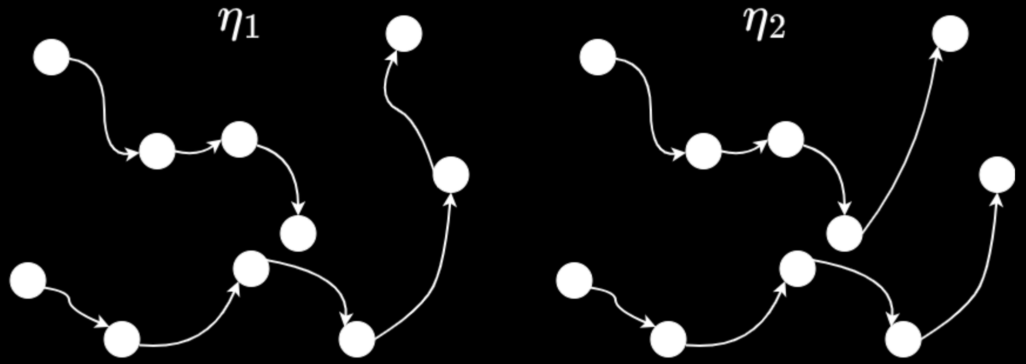
$\mathbf{Z} = \{\mathbf{Z}_t\}_{t=0:T-1}$

measurements

$$\mathbf{Z} = \mathbf{\Lambda} \cdot \mathbf{X} + \epsilon$$

Data-association is a combinatorially hard problem





$$|\eta_i| \propto N!^t$$

$$\mathbf{X} = \{\mathbf{X}^{\mathrm{p}}\}_{p=0:N-1}$$

states

$$\mathbf{Z} = \{\mathbf{Z}_t\}_{t=0:T-1}$$

measurements

hypotheses

$$\mathbf{Z} = \mathbf{\Lambda} \cdot \mathbf{X} + \epsilon$$

Conventional methods use an iterative estimator as a suboptimal solution

$$p(\mathbf{X}_t|\mathbf{Z}_{1:t}) = p(\mathbf{Z}_t|\mathbf{X}_t) \int p(\mathbf{X}_t|\mathbf{X}_{t-1}) p(\mathbf{X}_{t-1}|\mathbf{Z}_{1:t-1}) d\mathbf{X}$$

association — prediction — a priori

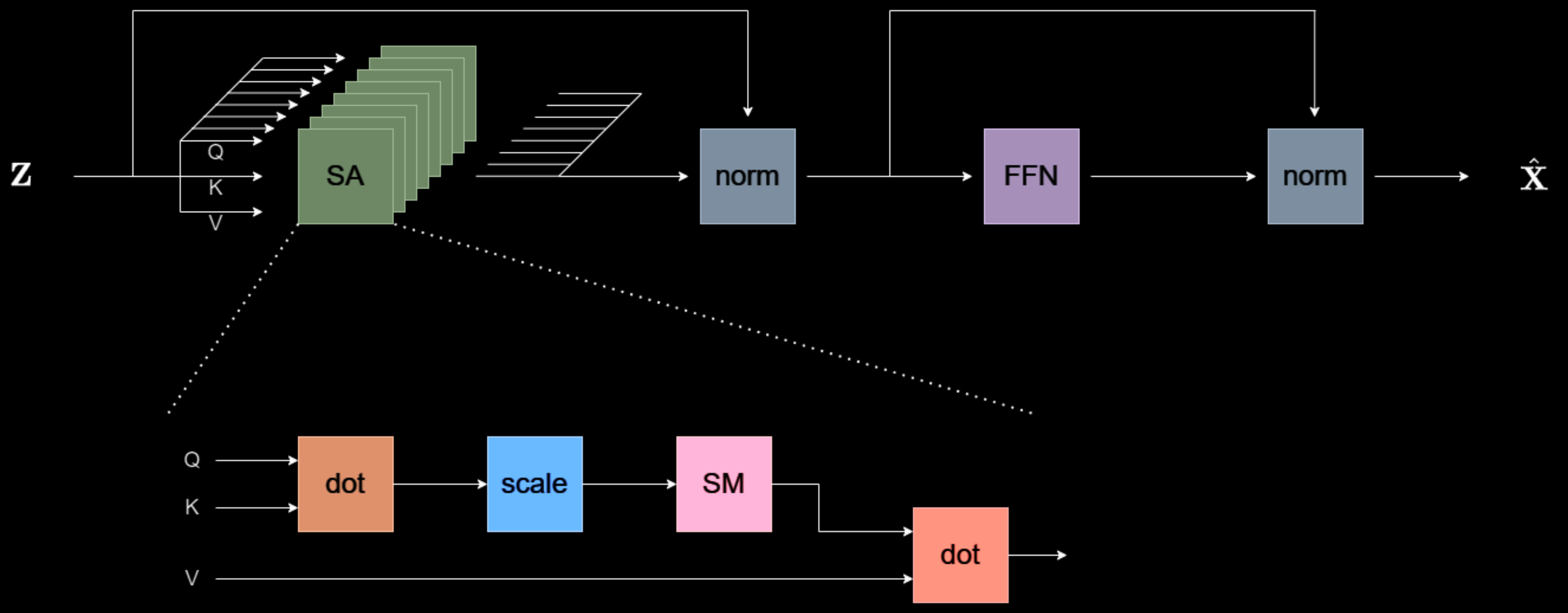
Conventional methods must prematurely prune hypotheses based on priors

$$p(\mathbf{X}_t|\mathbf{Z}_{1:t}) = p(\mathbf{Z}_t|\mathbf{X}_t) \int p(\mathbf{X}_t|\mathbf{X}_{t-1}) p(\mathbf{X}_{t-1}|\mathbf{Z}_{1:t-1}) d\mathbf{X}$$

association   prediction   a priori

$$= \sum_{\boldsymbol{\eta}_p^t \in \mathbf{H}_t'} p(\mathbf{Z}_t|\mathbf{X}_t, \boldsymbol{\eta}_p^t) p(\boldsymbol{\eta}_p^t|\mathbf{X}_t) \int p(\mathbf{X}_t|\mathbf{X}_{t-1}) p(\mathbf{X}_{t-1}|\mathbf{Z}_{1:t-1}) d\mathbf{X}$$

Attention can be used to make decisions on both states & hypotheses



$$\hat{\mathbf{X}} = \mathrm{concat}\left(\mathrm{softmax}\left(\frac{\mathbf{Z}_m \mathbf{W}_{q,m} (\mathbf{Z}_m \mathbf{W}_{k,m})^T}{\sqrt{d_k}}\right) \mathbf{Z}_m \mathbf{W}_{v,m}, \forall m \in \left[1, \frac{h}{n_h}\right] \subset \mathbb{N}\right) \cdot \mathbf{W}_l$$

A simple experimental setup for proof-of-concept

$$y^{t,p} = y^{t-1,p} + \varepsilon^{t,p} + \delta^{p}$$

drift

randomness
with process
noise

$$z^{t,p} = y^{t,p} + \omega^{p}$$

measurement noise

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Similarity between ground-truth and prediction is given by Jaccard coefficient

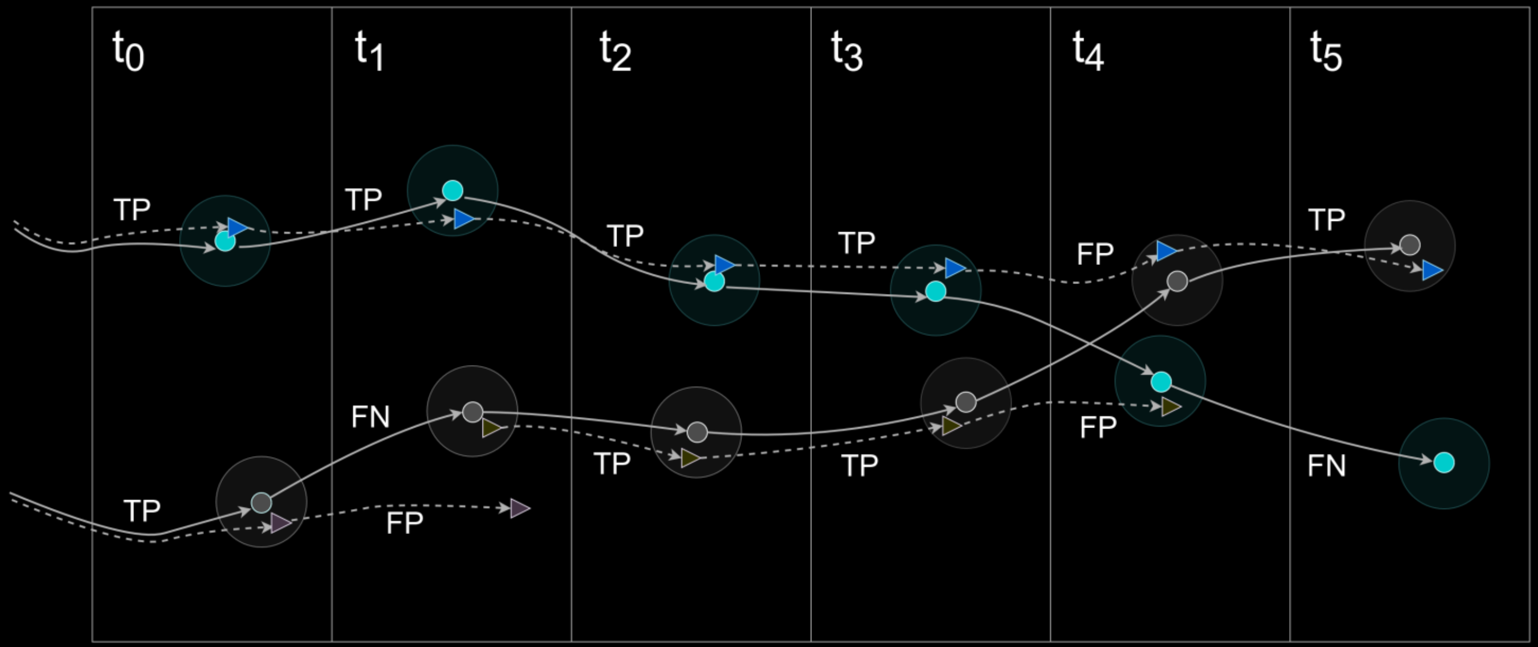
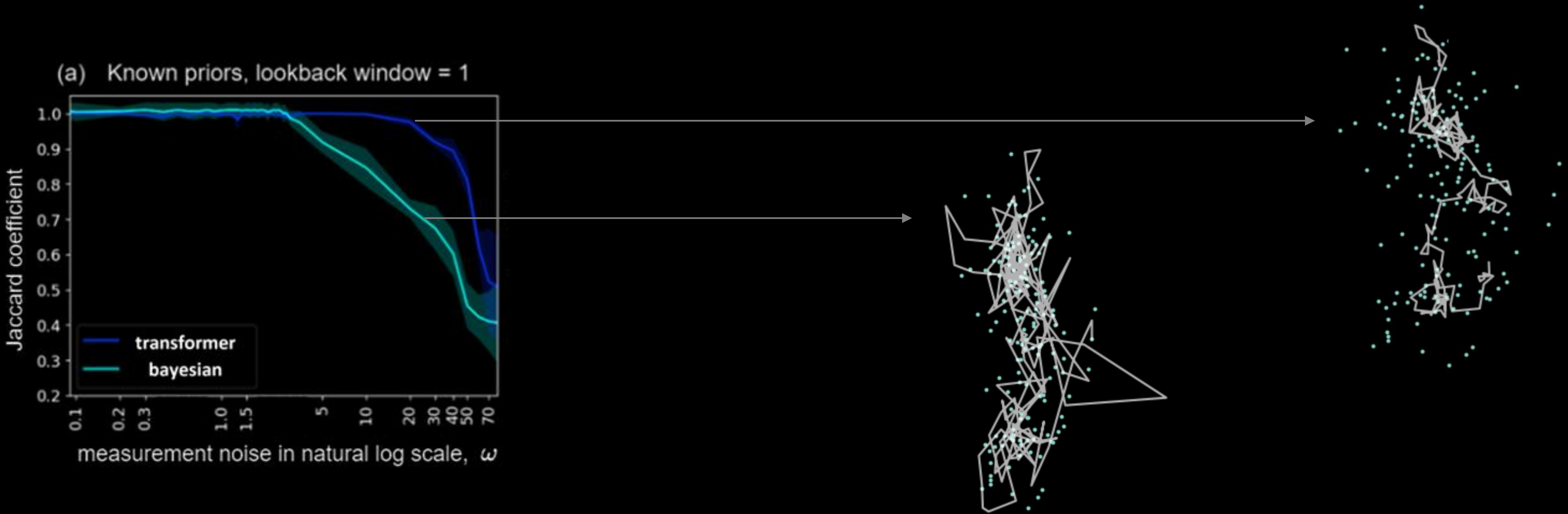


Illustration by Laura Neschen

Attention is robust to increasing noise in long sequences



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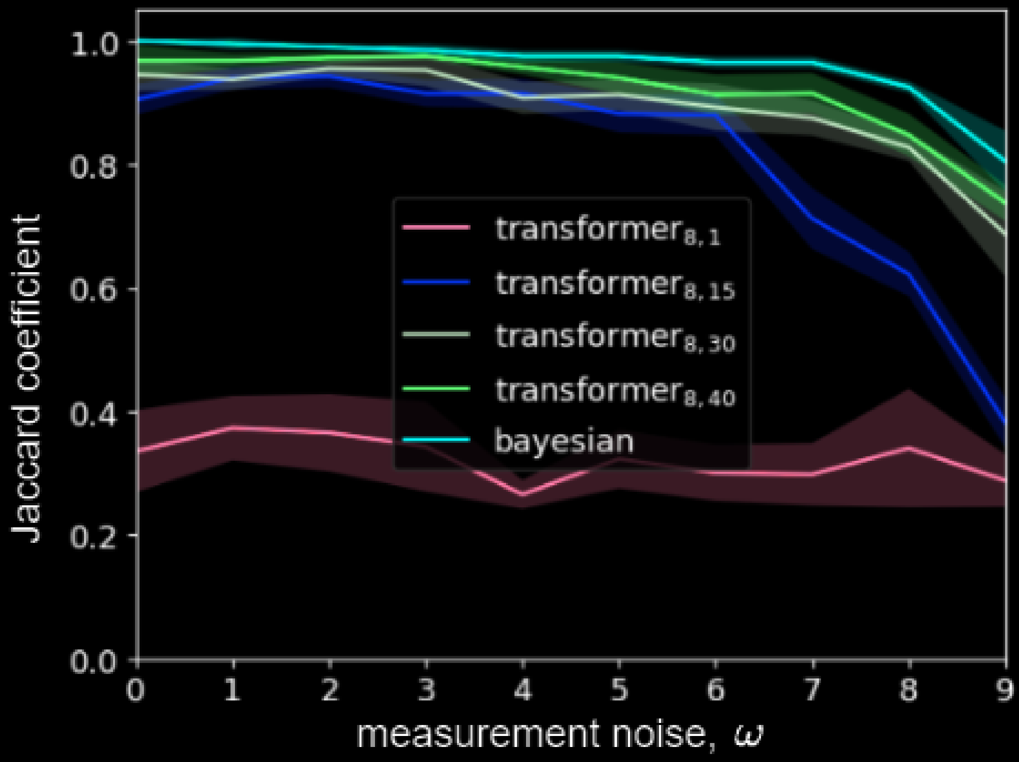
When Bayesian filtering is optimal, attention is suboptimal



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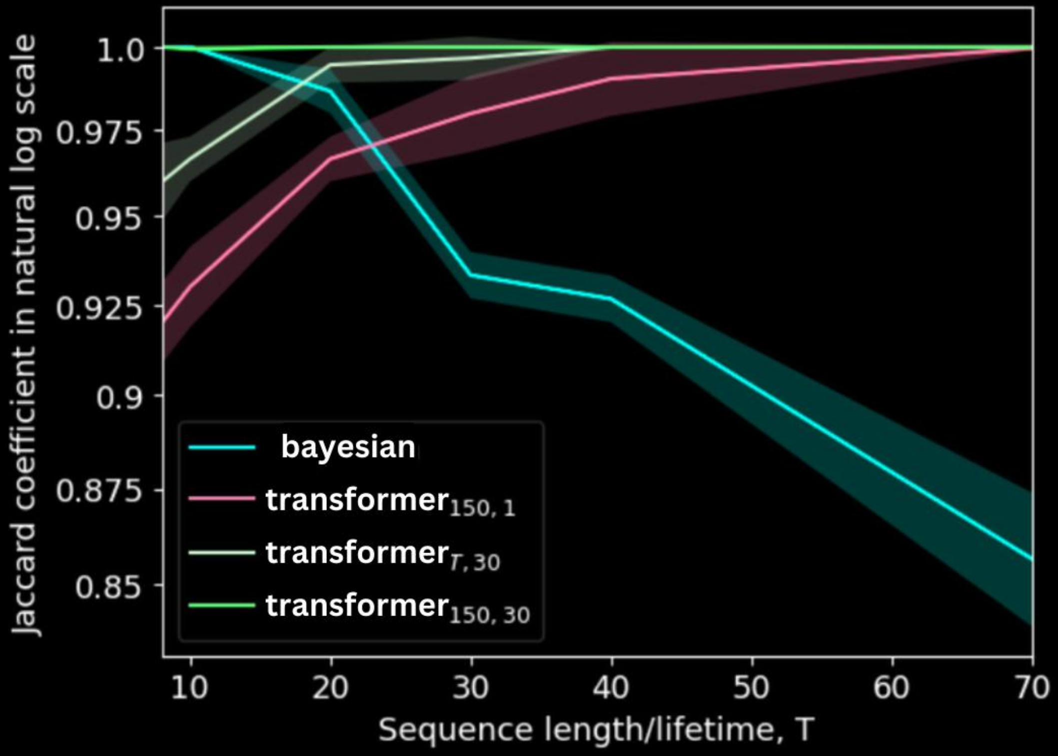
Attention is robust to increasing sequence length



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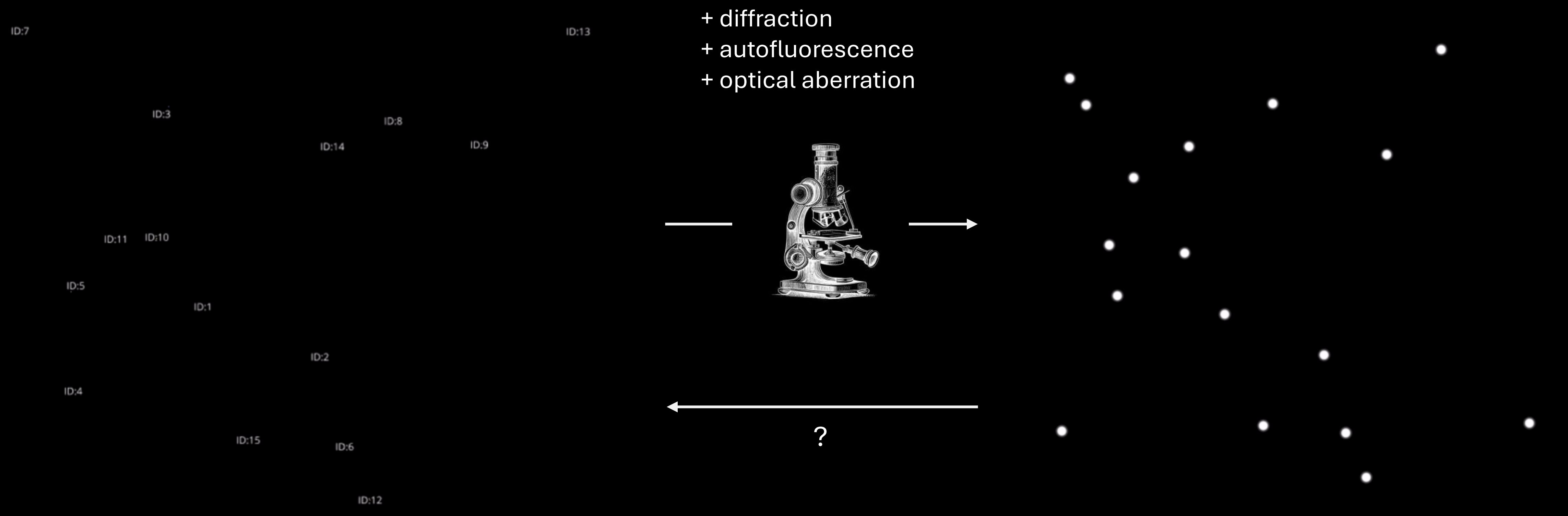
Ongoing work: A frugal tracking strategy that uses attention to build global priors

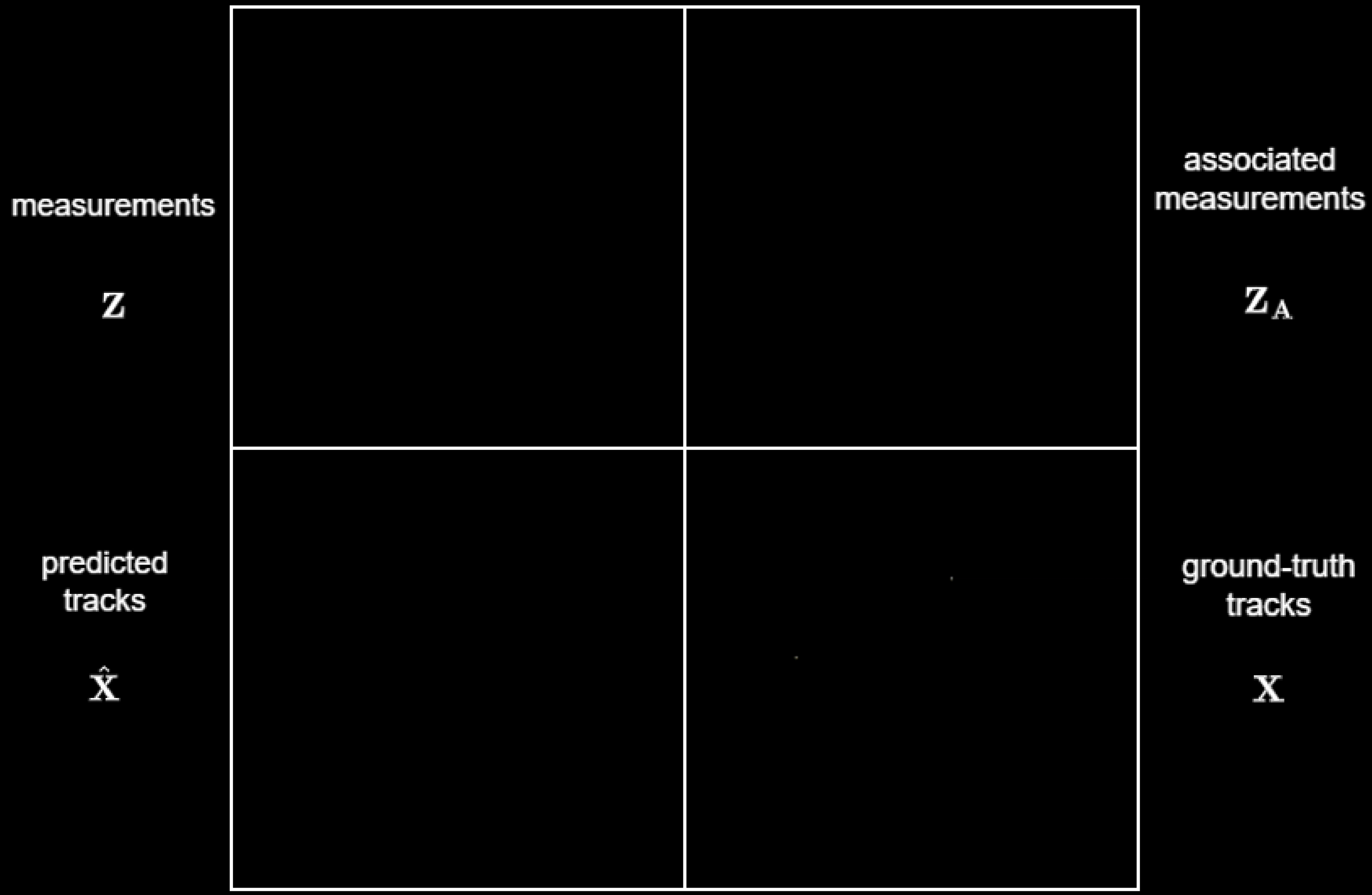
Application: Tracking particles for microscopy



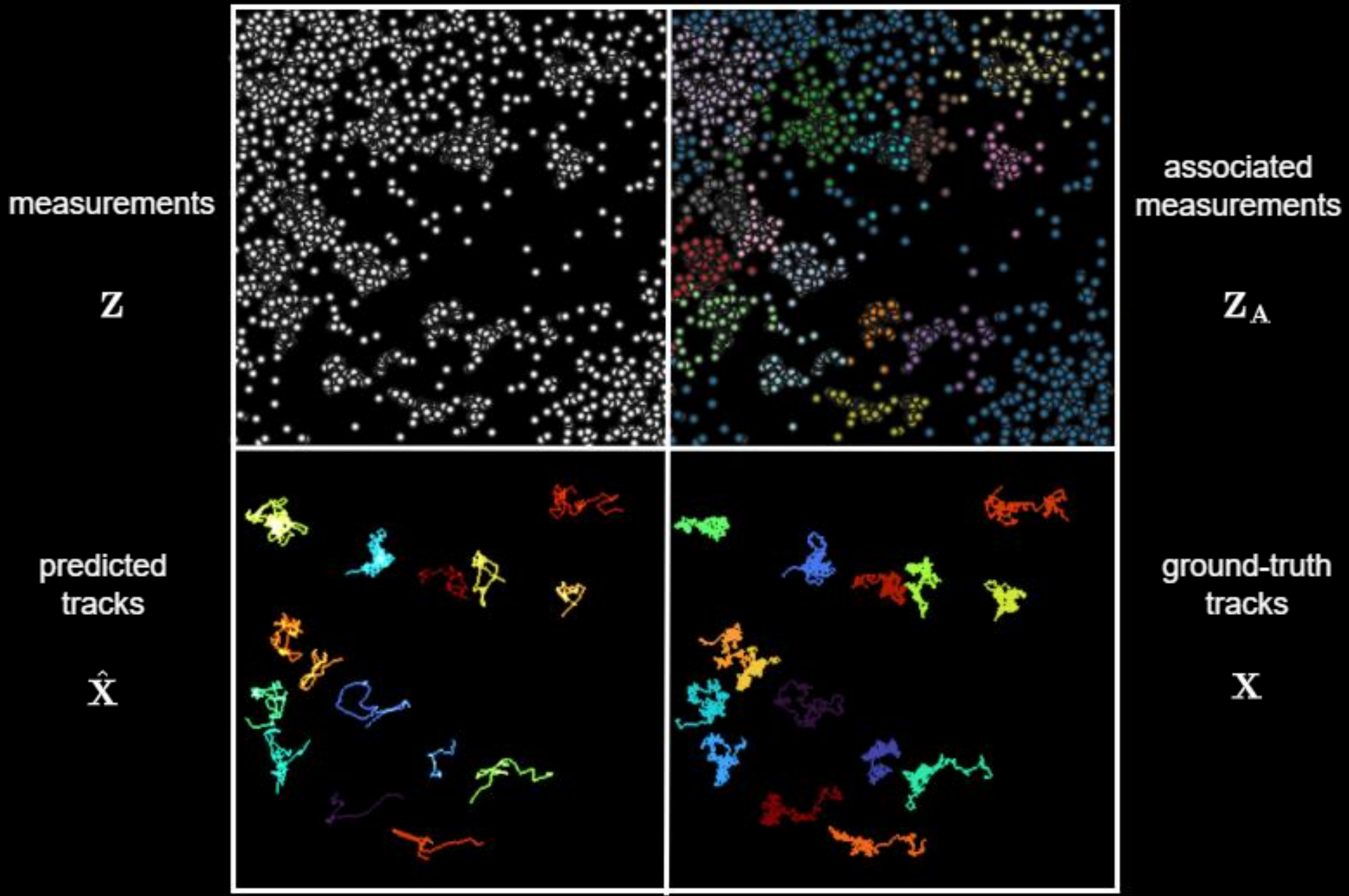
simulation of real dynamics

detections / measurements

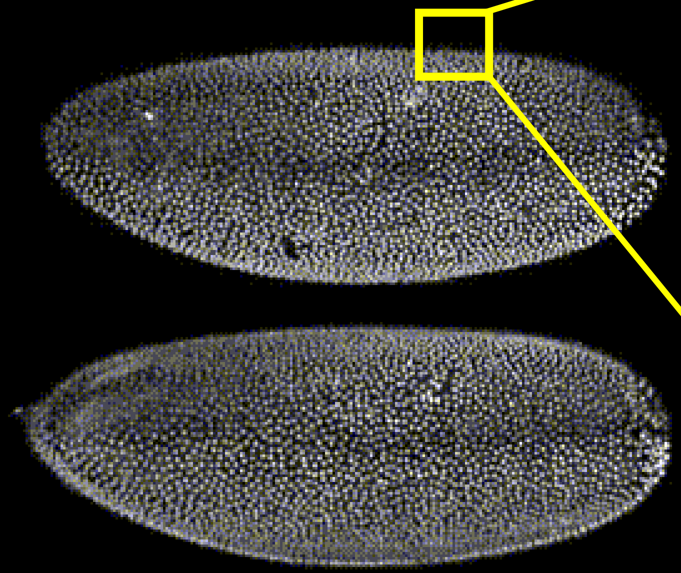
Application: Tracking particles for microscopy



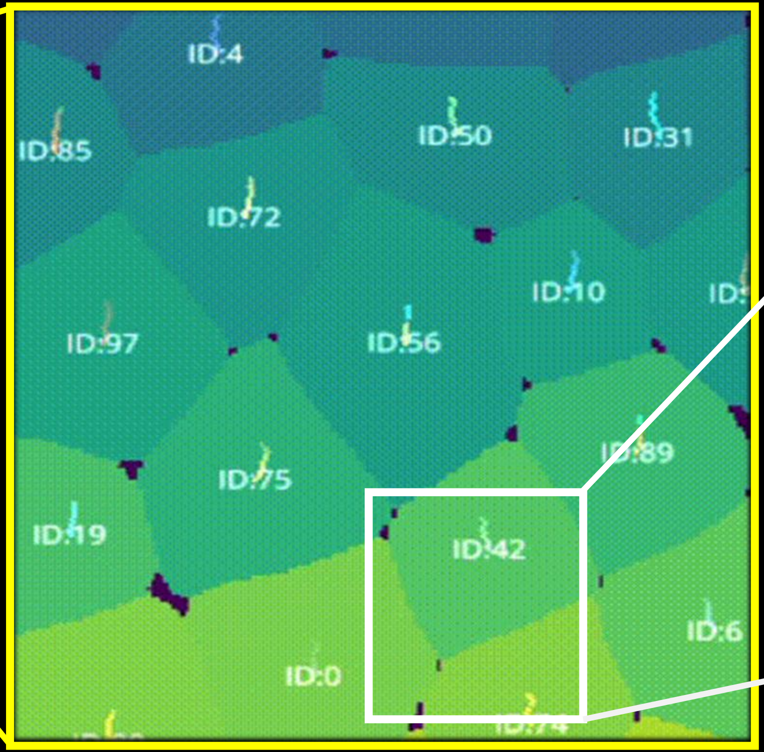
Application: Tracking particles for microscopy



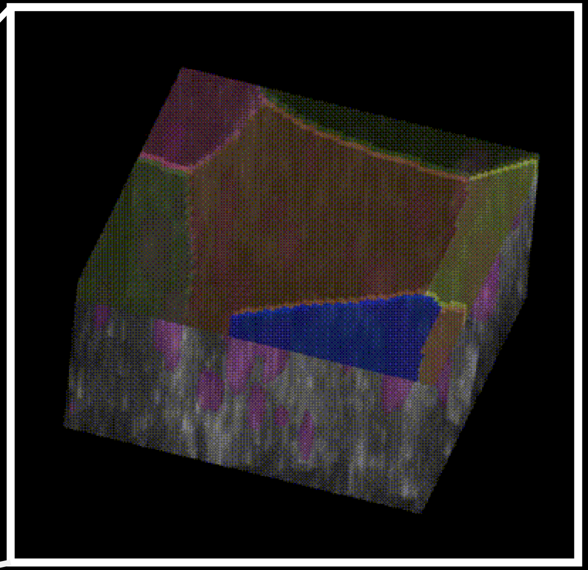
Application: Stand on a moving cell



Microscopy images
of fruitfly embryo,
C. Collinet, IBDM



Tracking cells using
the Bayesian-Attention
hybrid strategy



Stabilised region of interest
Team Endotrack
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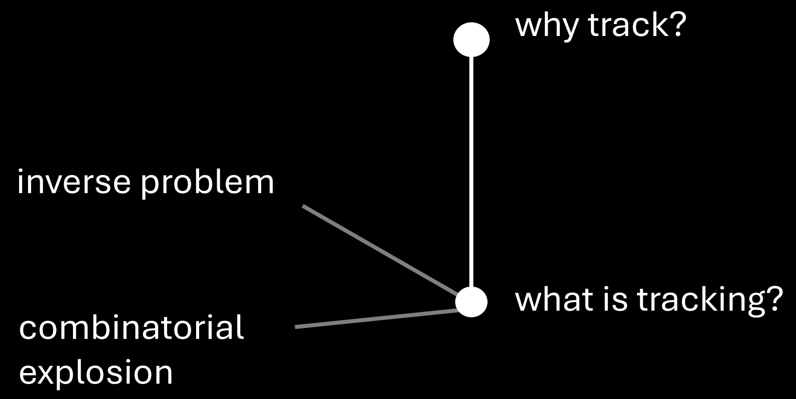
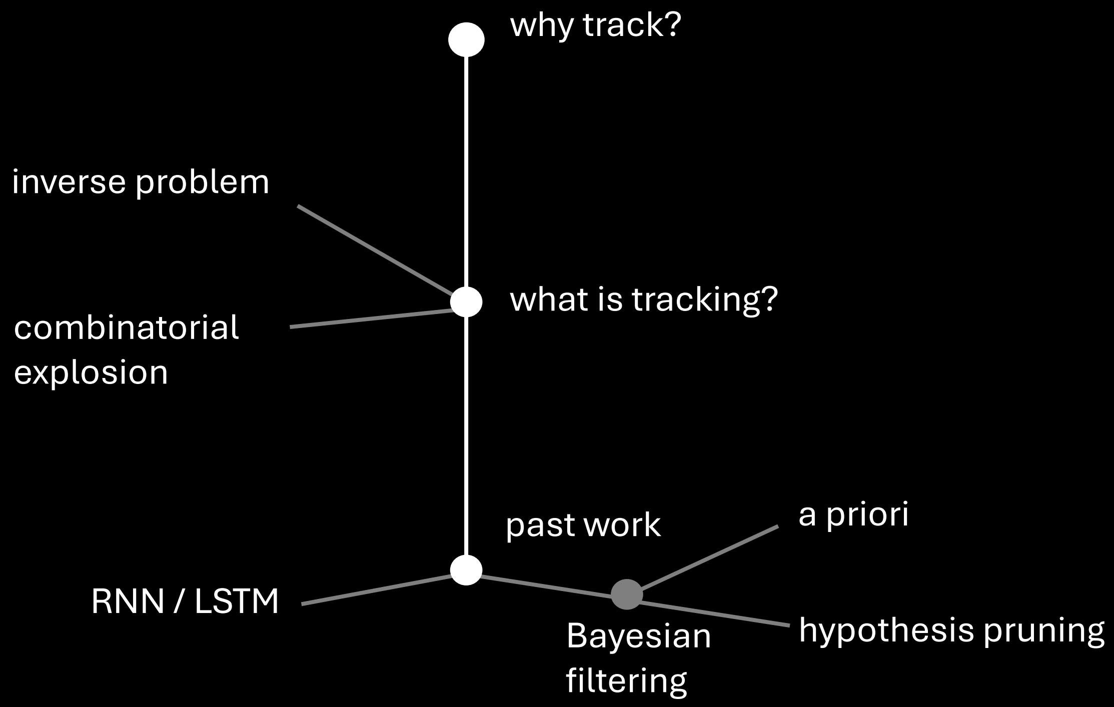
- why track?


why track?
inverse problem
what is tracking?
combinatorial explosion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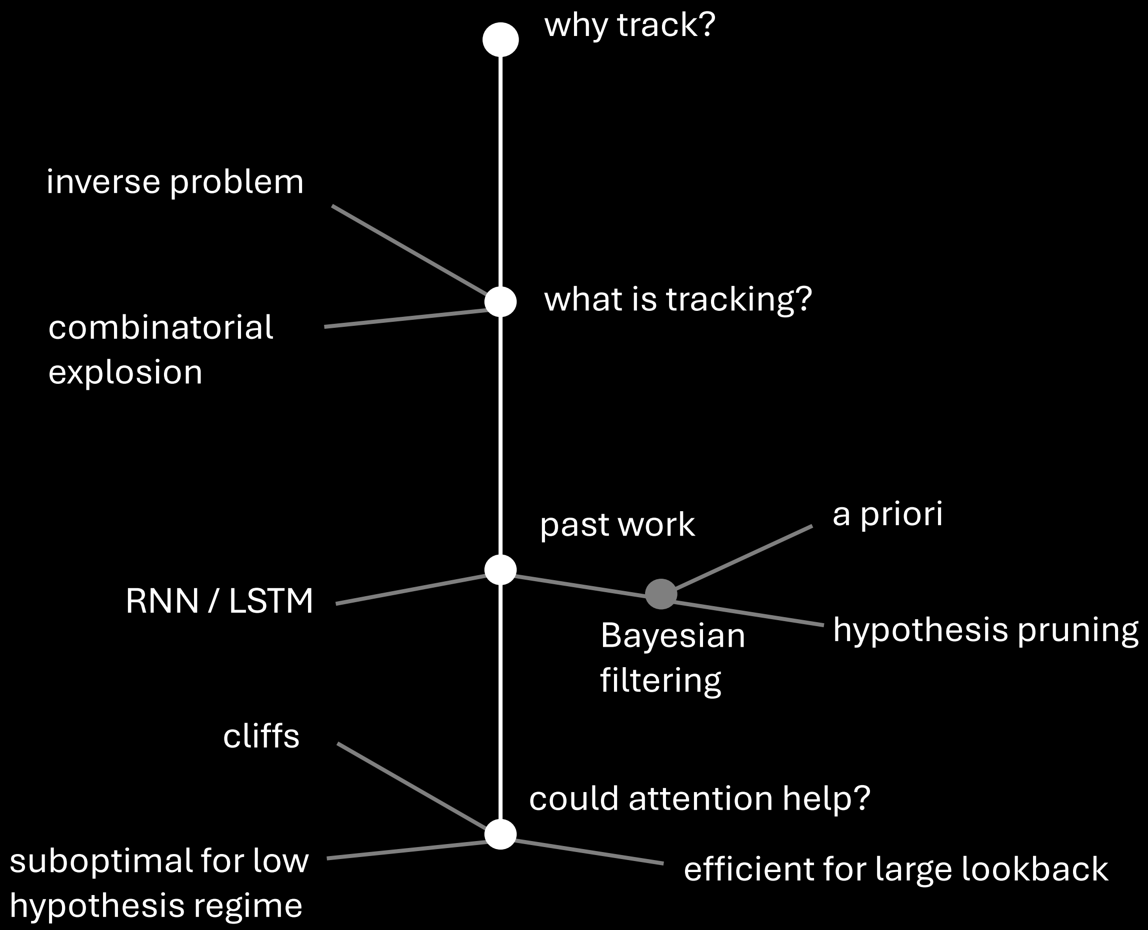
past work
a priori
RNN / LSTM
hypothesis pruning
Bayesian filtering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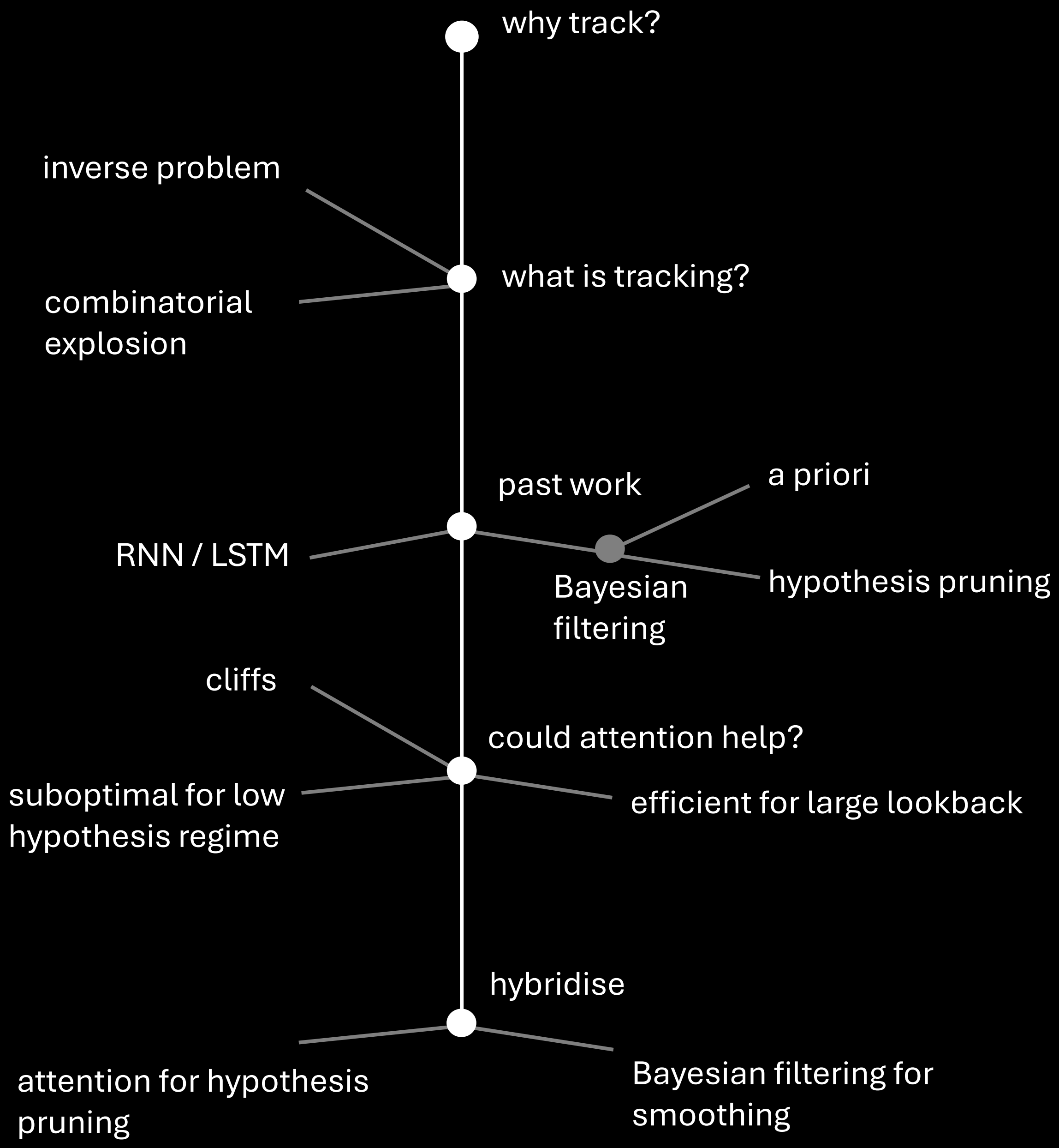
filtering
hypothesis pruning
cliffs
could attention help?
suboptimal for low
hypothesis regime
efficient for large lookback



why track?
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Bayesian filtering
hypothesis pruning
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suboptimal for low hypothesis regime
efficient for large lookback
hybridise
attention for hypothesis pruning
Bayesian filtering for smoothing

Thank you for your attention ☺

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