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Data-consistent Approaches to Modeling Population Distributions of Parameters for Biomedical Systems

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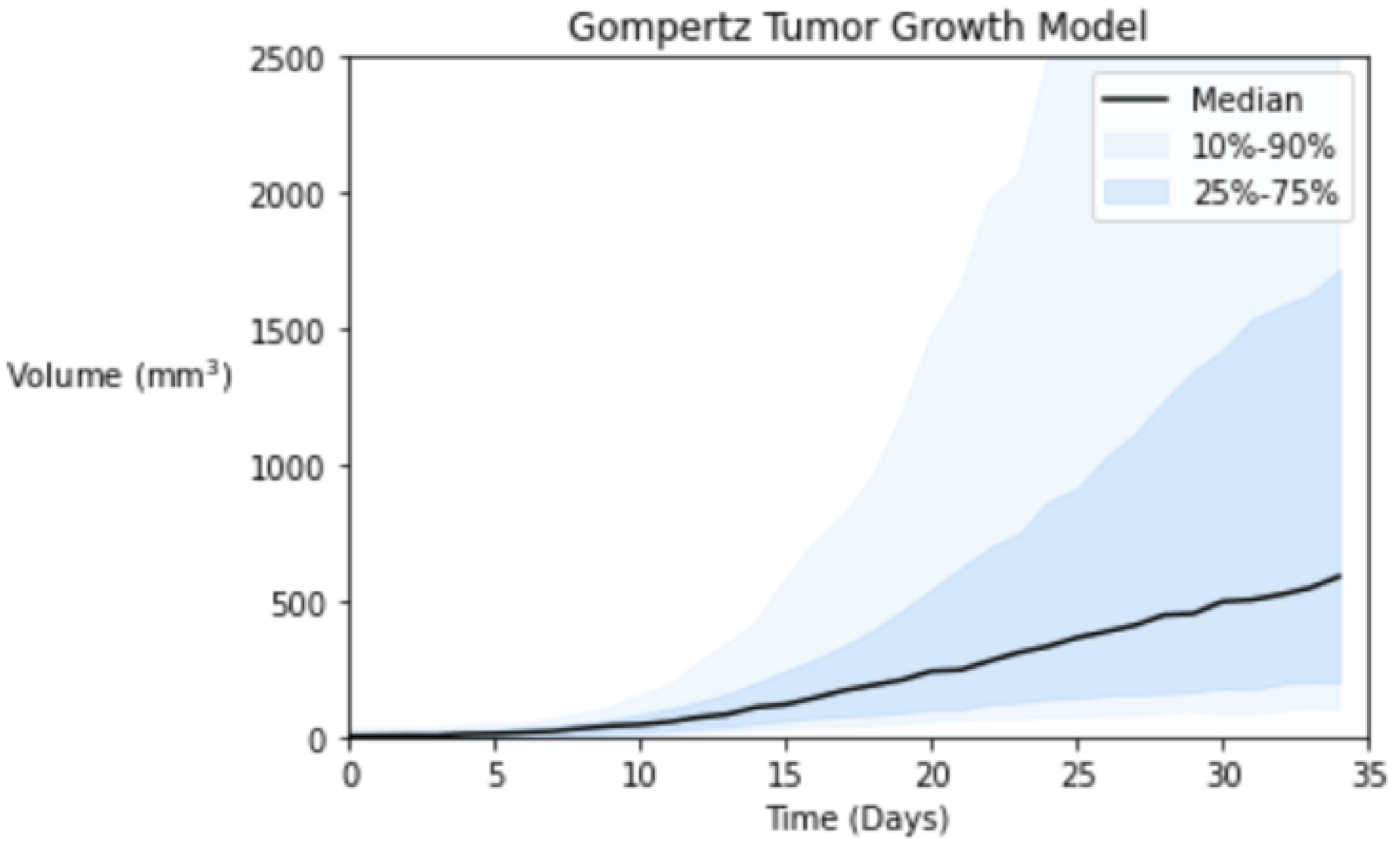
In many contexts, decision-making and "best practice" is guided by ***average*** or ***typical*** behavior…

Oncology Example:

Tumor growth kinetics used to prescribe radiation treatment dosage and schedules



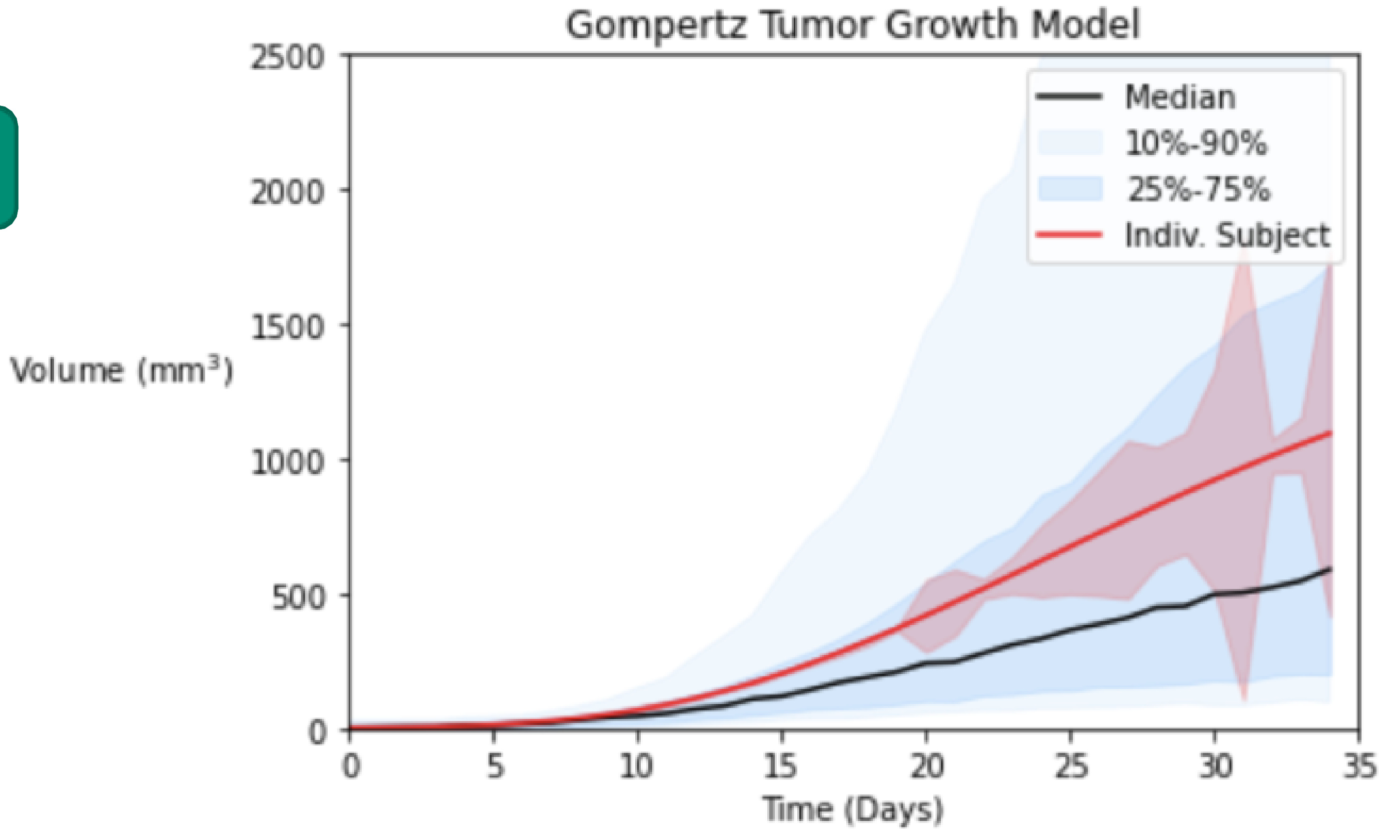
$$\frac{dV}{dt} = \left(\alpha - \beta \log\left(\frac{V}{V_{inj}}\right)\right)V$$

The promise of ”precision medicine” requires effective uncertainty quantification…

Personalized care and effective decision-making needs to account for uncertainty…

Bayesian Analysis:

$$\pi^{post}(\alpha,\beta) \propto \pi^{prior}(\alpha,\beta) \cdot \pi^{like}\,(d|\alpha,\beta)$$

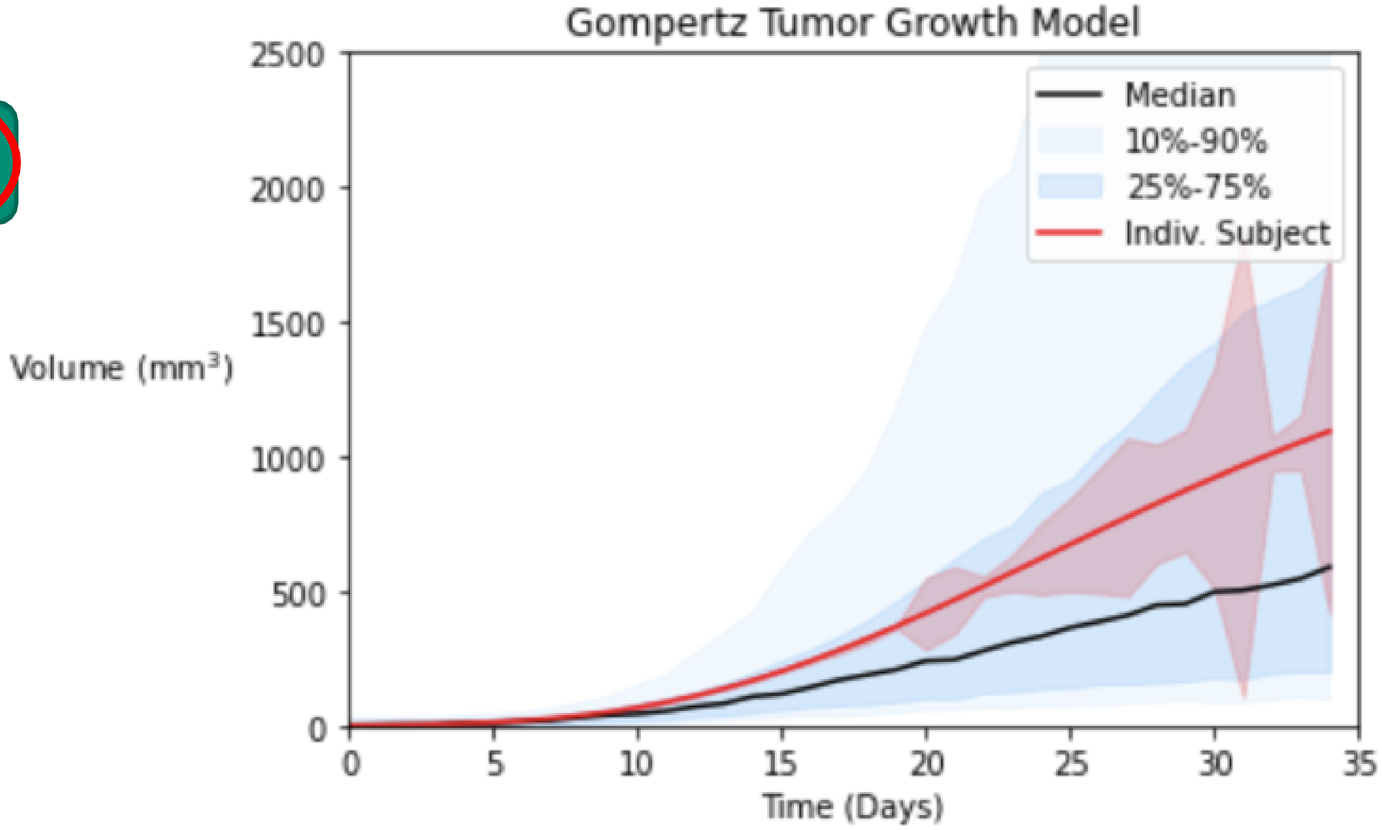


Bayesian approach to personalized uncertainty will be strongly influenced by “population” prior distributions…

Limited data on individuals ⇒ *Population prior* will bias decisions…

Bayesian Analysis:

$$\pi^{post}(\alpha,\beta) \propto \pi^{prior}(\alpha,\beta) \cdot \pi^{like}(d|\alpha,\beta)$$



Data-consistent inversion may be a powerful tool to obtaining suitable prior distributions for Bayesian analyses.

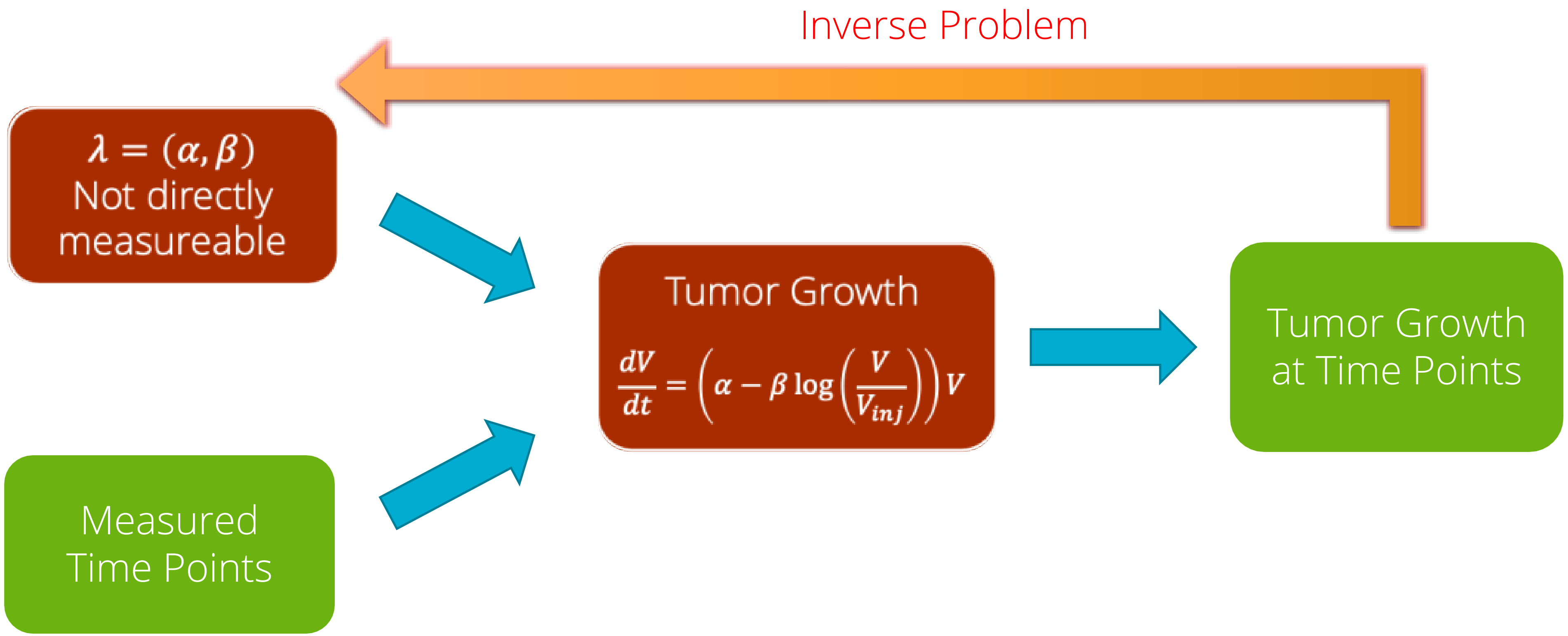
Data-consistent inversion is a measure-theoretic framework for stochastic inversion.

- The updated "population" parameter distribution is ***consistent*** with observed variation
- The updates from data-consistent inversion occur ***only influence data-informed*** directions
- The update is a ***non-parametric*** density estimate
- Generally, ***less computationally expensive*** than hierarchical Bayesian methods

$$\pi_{update}(\lambda) = \pi_{init}(\lambda)\frac{\pi_{obs}(Q(\lambda))}{\pi_{predict}(Q(\lambda))}$$

Brief Overview of Data-consistent Inversion

The goal of an inverse problem with ***a known dynamics model*** is to obtain a better characterization of ***input parameters***.

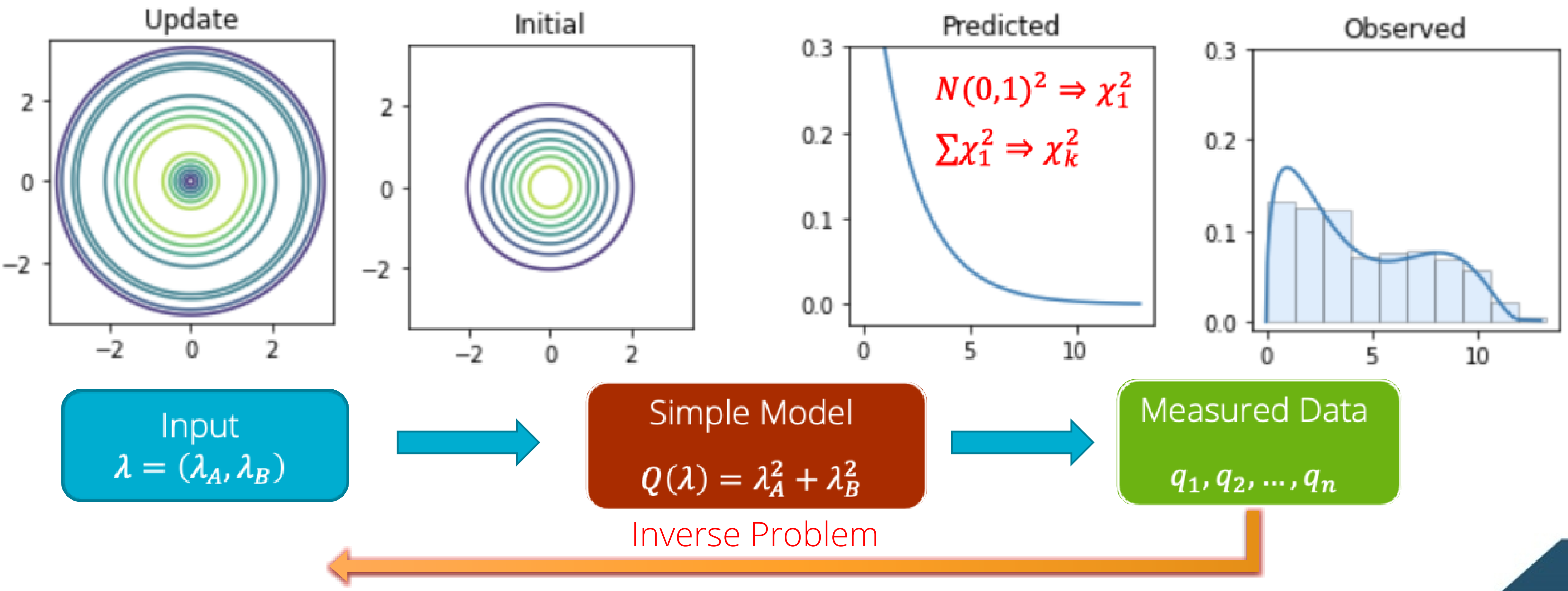


Key Point: In our *stochastic* inverse problem, we want to find the population *distribution* of λ !

The data-consistent approach finds a ***consistent*** update to the initial using the discrepancy between observations and predictions.

1. Propose initial distribution
2. Determine the predicted distribution
3. Compare predictions to observations
4. Re-weight initial distribution by ratio of pdfs

$$\pi_{update}(\lambda) = \pi_{init}(\lambda)\,\frac{\pi_{obs}(Q(\lambda))}{\pi_{predict}(Q(\lambda))}$$



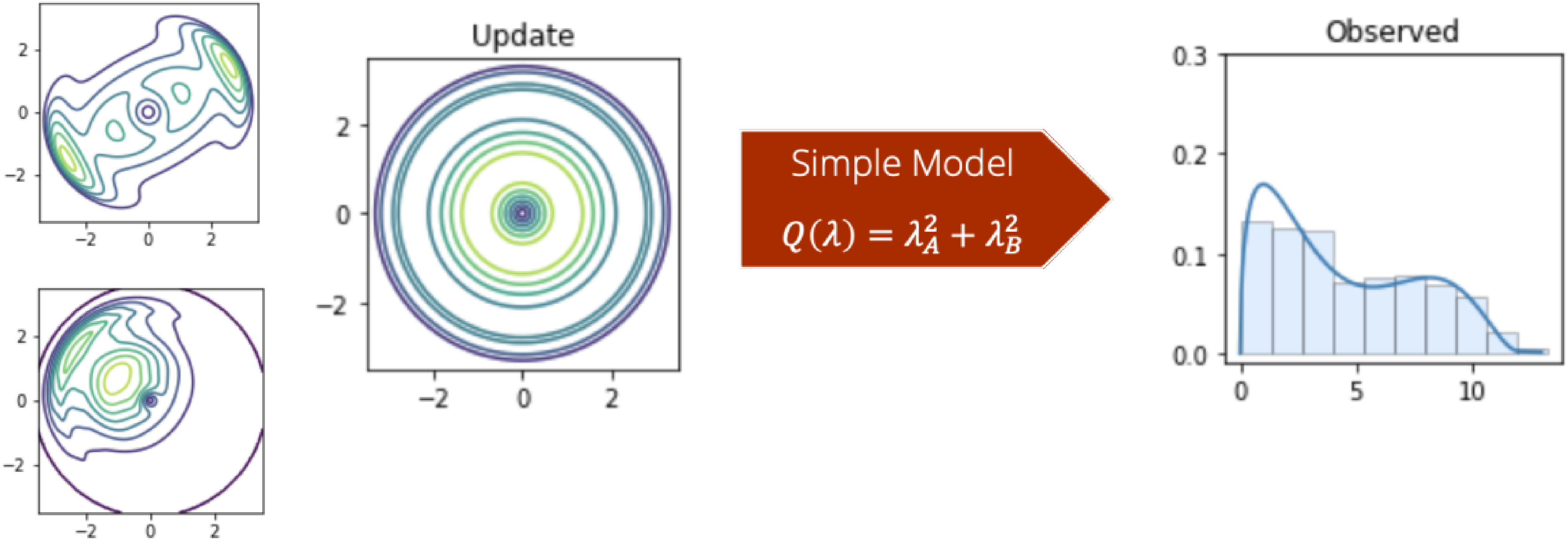
Features of Data-consistent Approach

The update is **consistent** with the observed distribution.

The data-consistent approach is **non-parametric**.

The update ***only influences data-informed*** directions and it is ***unbiased*** in these directions.

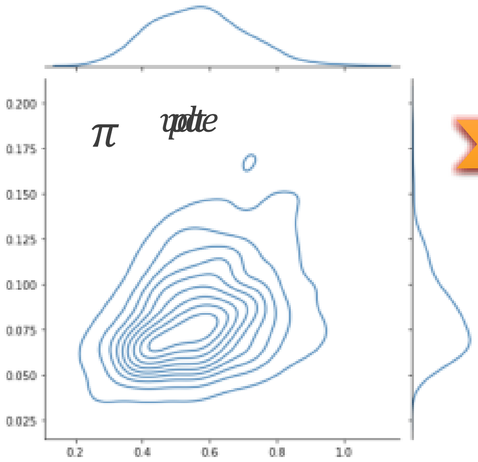
Generally, ***less computationally expensive*** than hierarchical Bayesian methods.

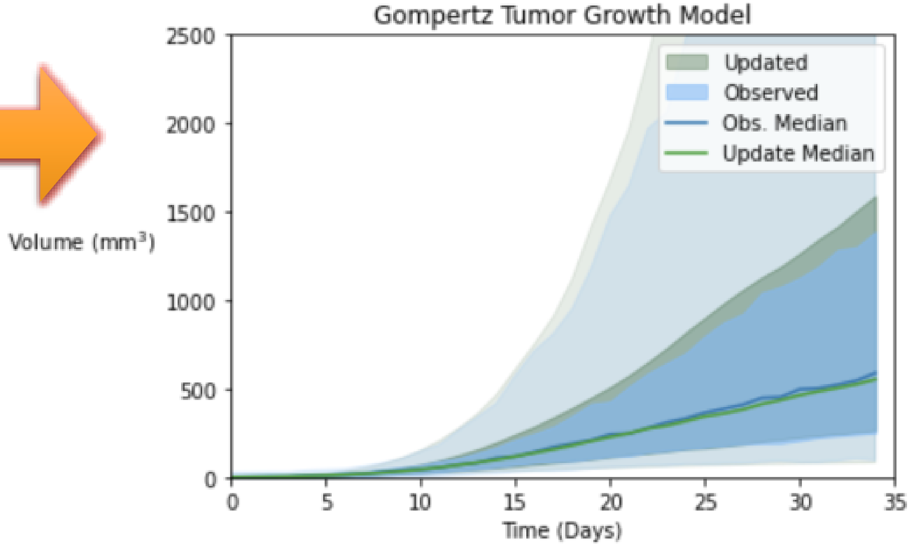


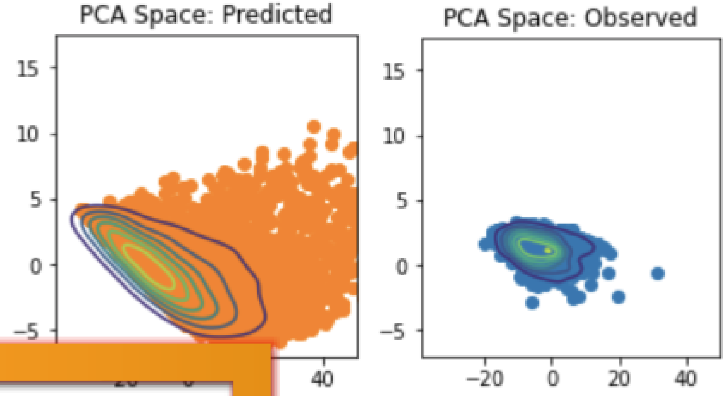
Data-consistent Inversion for Tumor Growth

A Data-consistent Approach to an Oncology Example

Goal: Obtain a *population* distribution of tumor growth parameters that is *consistent* with observed tumor growth curves.







$\lambda = (\alpha, \beta)$
Not directly measureable

Measured Time Points

Tumor Growth

$$\frac{dV}{dt} = \left(\alpha - \beta \log\left(\frac{V}{V_{inj}}\right)\right) V$$

Tumor Growth at Time Points

Conclusion: I am looking for collaborators…

Data-consistent inversion is a ***powerful*** new approach to stochastic inversion…

- Implementing data-consistent inversion is ***straightforward***…
- Applying the data-consistent approach requires the ***right perspective***…

The data-consistent approach may be particularly suited for estimating ***population*** distributions for use in precision medicine!

Interested? Reach out!
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