

Initializing Kalman Filter for Visual Inspections of Bridge Network + Demo

Zachary Hamida Doctorant
James-A. Goulet Professeur



Polytechnique Montréal, Canada
Département des génies civil, géologique et des mines

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*Transports,
Mobilité durable
et Électrification
des transports*

Québec 

Partenaire



Outline

Context

Proposed Deterioration Model

Init. State Analyses with Synthetic Data

Data Navigation

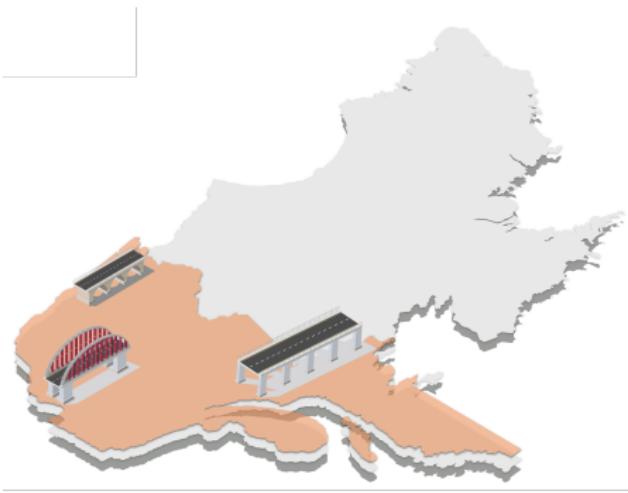
Progress & Next Steps

Context

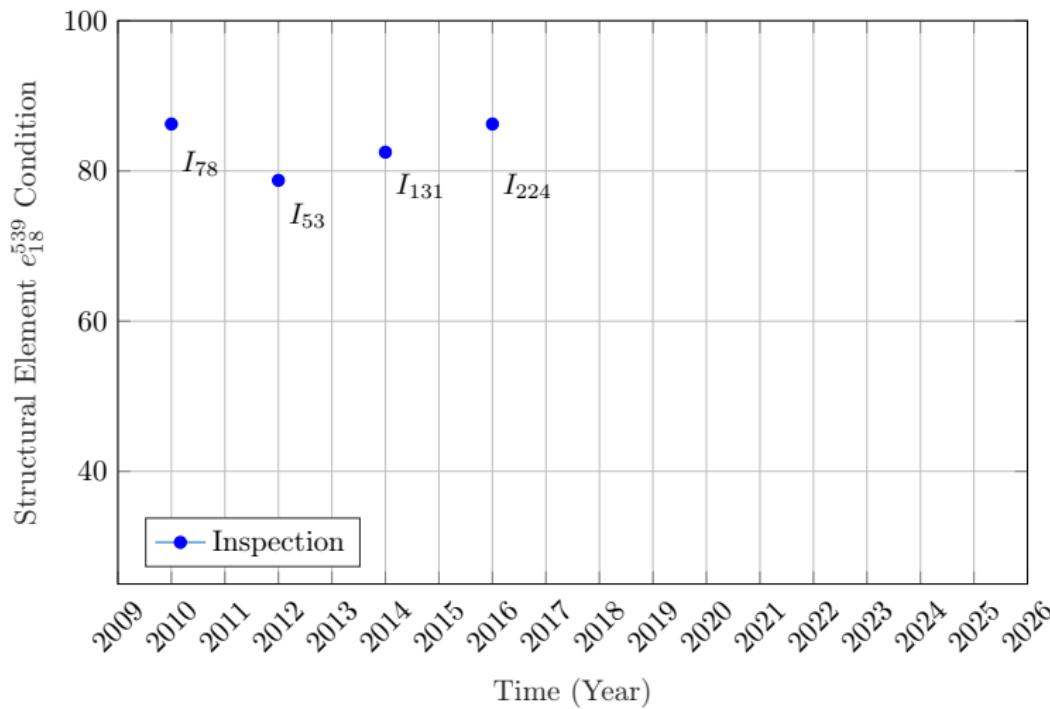
Visual Inspection
data of ~ 10K Bridge,

100's of Inspectors,

2-4 inspections/element,
1-4 years Inspection span,
~ 1.3M inspections reported.



Example: Series of Inspections on Structural Element



Objectives

- **Model the deterioration** behaviour based on the data from network of bridges

Deterioration Behaviour Described by Kinematics

Kinematic Equations

$$x_t = x_{t-1} + \dot{x}_{t-1} \Delta t + \frac{1}{2} \ddot{x}_{t-1} \Delta t^2 + w \quad (\text{Condition})$$

Deterioration Behaviour Described by Kinematics

Kinematic Equations

$$\overbrace{\begin{aligned}x_t &= x_{t-1} + \dot{x}_{t-1}\Delta t + \frac{1}{2}\ddot{x}_{t-1}\Delta t^2 + w && \text{(Condition)} \\ \dot{x}_t &= \dot{x}_{t-1} + \ddot{x}_{t-1}\Delta t + \dot{w} && \text{(Speed)}\end{aligned}}$$

Deterioration Behaviour Described by Kinematics

Kinematic Equations

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Deterioration Behaviour Described by Kinematics

$$\underbrace{\begin{bmatrix} x_t \\ \dot{x}_t \\ \ddot{x}_t \end{bmatrix}}_{\mathbf{x}_t} = \underbrace{\begin{bmatrix} 1 & \Delta t & \frac{\Delta t^2}{2} \\ 0 & 1 & \Delta t \\ 0 & 0 & 1 \end{bmatrix}}_A \cdot \underbrace{\begin{bmatrix} x_{t-1} \\ \dot{x}_{t-1} \\ \ddot{x}_{t-1} \end{bmatrix}}_{\mathbf{x}_{t-1}} + \underbrace{\begin{bmatrix} w_t \\ \dot{w}_t \\ \ddot{w}_t \end{bmatrix}}_{\mathbf{w}_t}$$

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Method: State-Space Model

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Method: State-Space Model

$$\underbrace{x_t = Ax_{t-1} + w_t}_{\text{transition model}}$$

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Method: State-Space Model

$$\underbrace{x_t = Ax_{t-1} + w_t}_{\text{transition model}}, \underbrace{w_t : W \sim \mathcal{N}(w; \mathbf{0}, Q_t)}_{\text{process error}}$$

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observation model

$$\underbrace{y_t = Cx_t + v_t}_{}$$

Deterioration Behaviour Described by Kinematics

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observation model

$$\underbrace{y_t = Cx_t + v_t}_{\text{observation error}}, \underbrace{v_t : V(l_i) \sim \mathcal{N}(v; 0, R_t(l_i))}_{l_i \in [l_1, l_2, \dots, l_I] = \mathcal{I}} \quad \text{inspectors}$$

Model Parameter Estimation

$$\mathcal{P} = \left\{ \underbrace{\sigma_v(l_1), \sigma_v(l_2), \dots, \sigma_v(l_I)}_{\text{Inspector std.}}, \underbrace{\sigma_w}_{\text{Process error std.}}, \underbrace{n}_{\text{Transform. Param.}}, \underbrace{, \dot{\mu}_0, \ddot{\mu}_0, \sigma_0^x, \sigma_0^{\dot{x}}, \sigma_0^{\ddot{x}}}_{\text{Initial state.}} \right\}$$

Model Parameter Estimation

Model Parameter Estimation

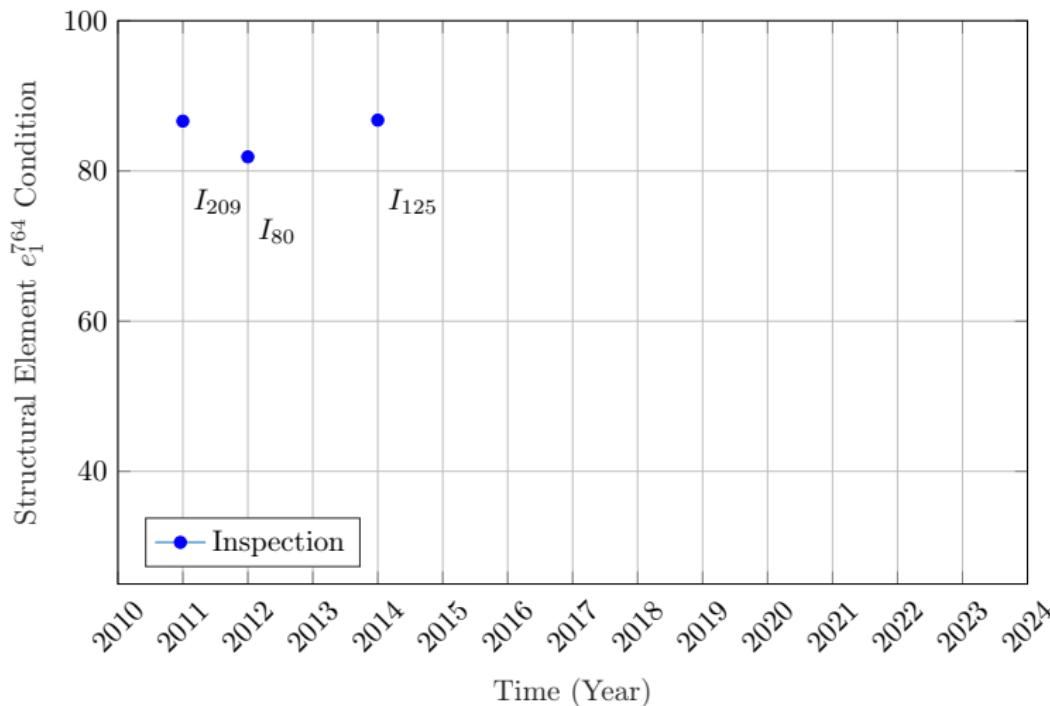
$$\mathcal{P} = \left\{ \underbrace{\sigma_v(l_1), \sigma_v(l_2), \dots, \sigma_v(l_I)}_{\text{Inspector std.}}, \underbrace{\sigma_w}_{\text{Process error std.}}, \underbrace{n}_{\text{Transform. Param.}}, \underbrace{, \dot{\mu}_0, \ddot{\mu}_0, \sigma_0^x, \sigma_0^{\dot{x}}, \sigma_0^{\ddot{x}}}_{\text{Initial state.}} \right\}$$

$$\mathcal{P}^* = \arg \max_{\mathcal{P}} \mathcal{L}(\mathcal{P}),$$

subject to: (parameters feasible domain)

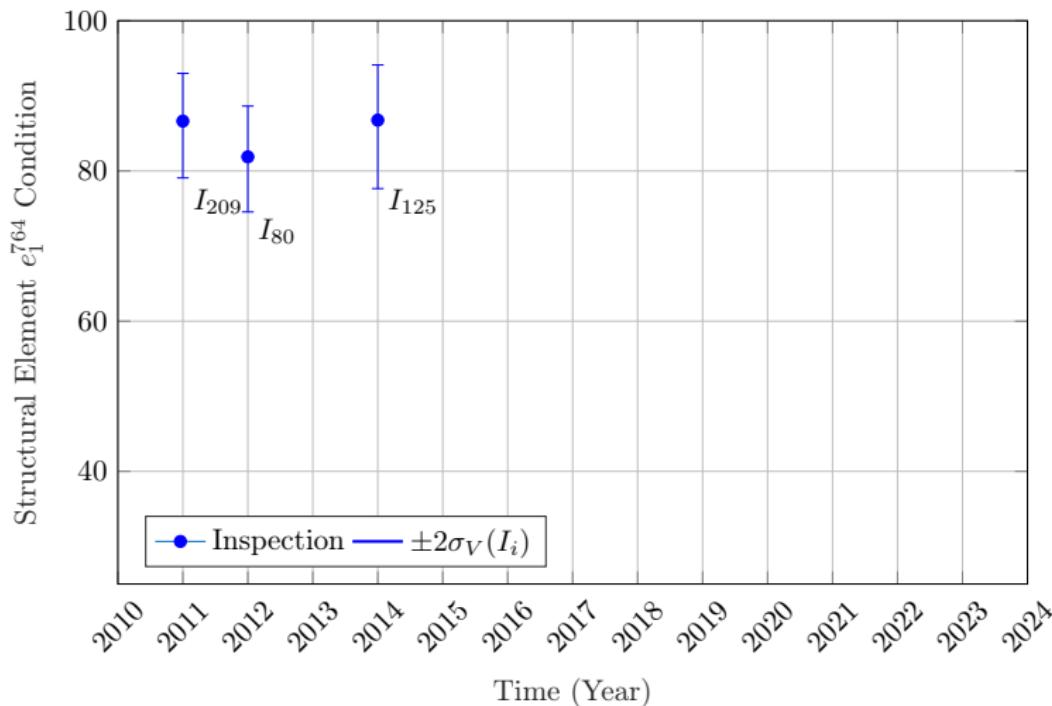
Overall Model Performance with Synthetic Data

Performance Verification



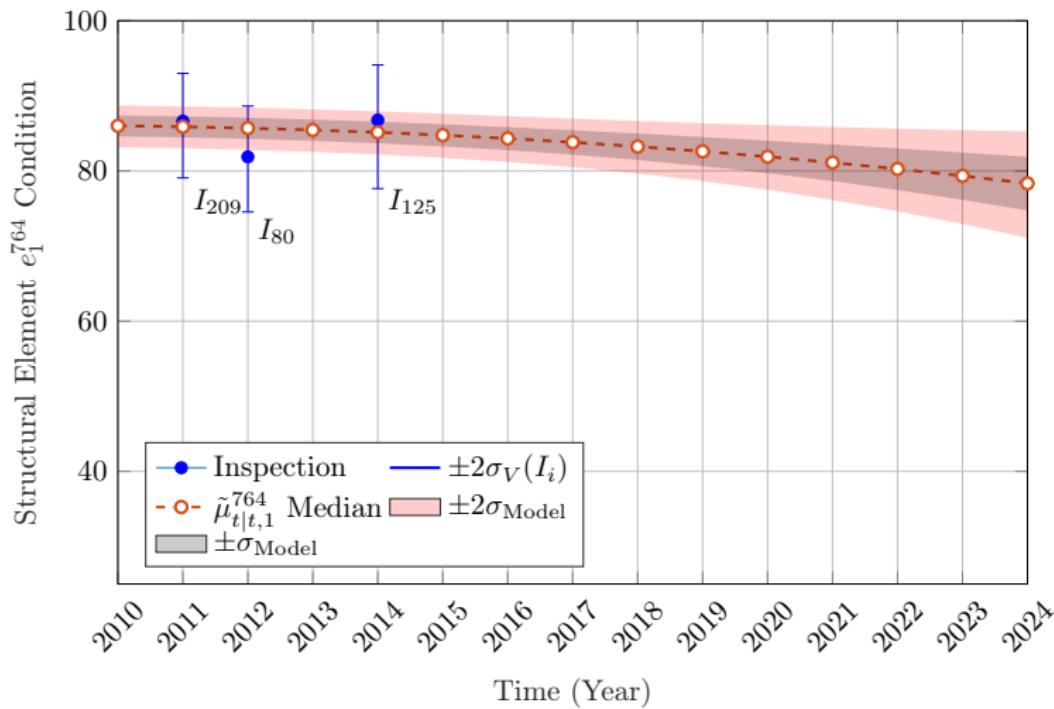
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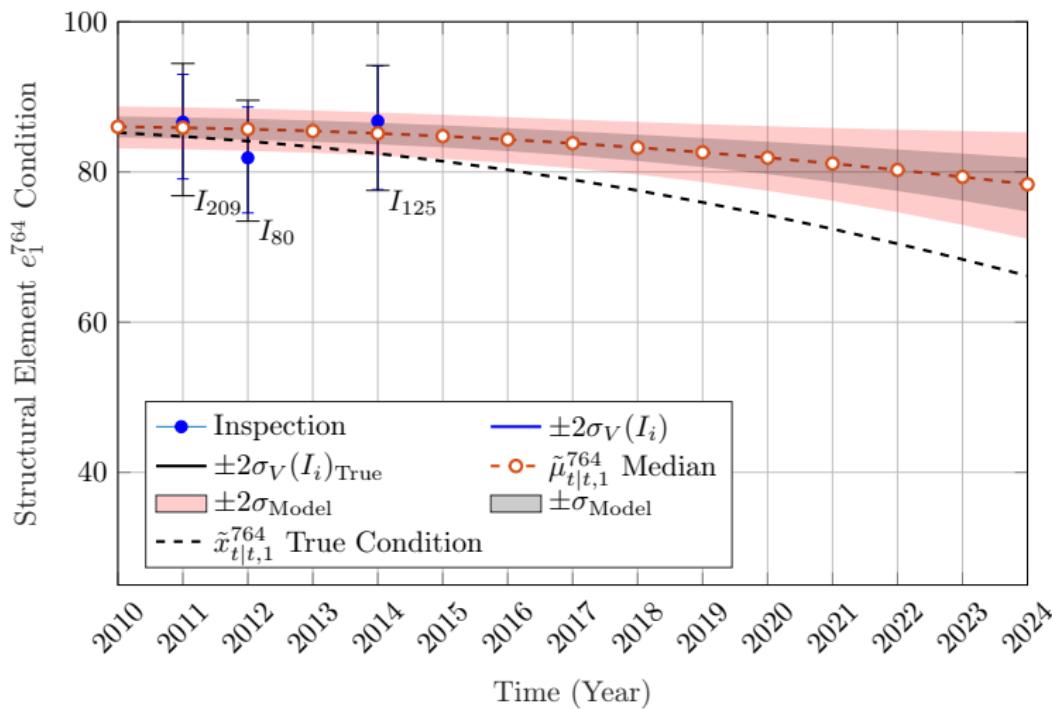
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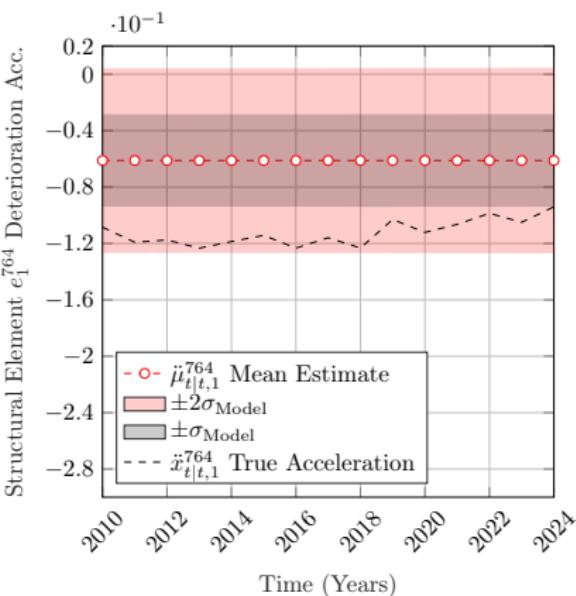
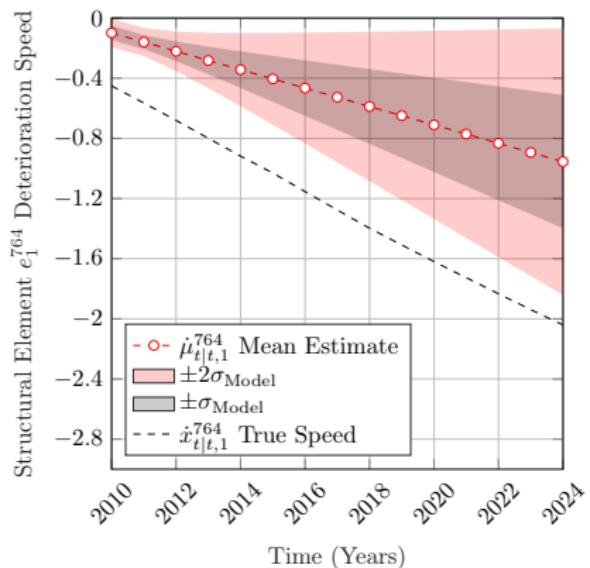
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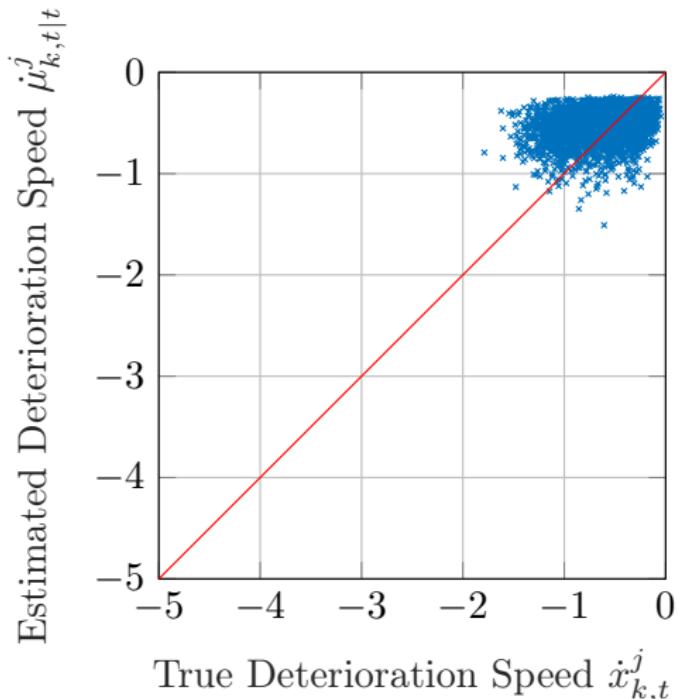


Overall Model Performance with Synthetic Data

Performance Verification



Model Weak-Spots



- 1. Examine the deterioration speed.

 Plan de la section

Init. State Analyses with Synthetic Data

- 3.1 Synthetic Data Characteristics
 - 3.2 Generating Synthetic Data
 - 3.3 Synthetic Data Old Hypothesis
 - 3.4 Synthetic Data New Hypothesis
 - 3.5 Initial State Analyses
 - 3.6 Condition vs. Speed
 - 3.7 Condition vs. Acc.
 - 3.8 Initial State Parameters
 - 3.9 Results
-

Synthetic Data Characteristics

Synthetic Inspection Data

Inspections réelles



Inspections synthétiques



- 1. Same number of structural elements.

Synthetic Data Characteristics

Synthetic Inspection Data

Inspections réelles



Inspections synthétiques



- 1. Same number of structural elements.
- 2. Same number of inspectors.

Synthetic Data Characteristics

Synthetic Inspection Data

Inspections réelles



Inspections synthétiques



- 1. Same number of structural elements.
- 2. Same number of inspectors.
- 3. Same number of inspections per-structural element.

Generating Synthetic Data

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Method: Transition & Observation Models

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$$\overbrace{\mathbf{x}_t = \mathbf{A}\mathbf{x}_{t-1} + \mathbf{w}_t}^{\text{transition model}}$$

Generating Synthetic Data

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Generating Synthetic Data

Method: Transition & Observation Models

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transition model

$$\underbrace{\mathbf{y}_t = \mathbf{C}\mathbf{x}_t + \mathbf{v}_t, \quad \mathbf{v}_t : \mathcal{V} \sim \mathcal{N}(\mathbf{v}; \mathbf{0}, \mathbf{R}_t)}_{\text{observation error}}$$

observation model

Generating Synthetic Data

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observation model

Generating Synthetic Data

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Method: Transition & Observation Models

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$$\underbrace{l_i \in [l_1, l_2, \dots, l_I] = \mathcal{I}}_{\text{inspectors}}$$

Synthetic Data Old Hypothesis

Initial State Hypothesis:

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$$\mathbf{x}_0 = \begin{bmatrix} \mu_0 \\ \dot{\mu}_0 \\ \ddot{\mu}_0 \end{bmatrix} \quad \begin{aligned} \mu_0 &\sim \mathcal{U}(a = 70, b = 100) \\ \dot{\mu}_0 &\sim \mathcal{U}(a = -0.2, b = -0.0001) \\ \ddot{\mu}_0 &\sim \mathcal{U}(a = -0.1, b = -0.0001) \end{aligned}$$

Initial State Hypothesis:

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Problem: the combinations among the condition, the speed and the acceleration are too random to be real.

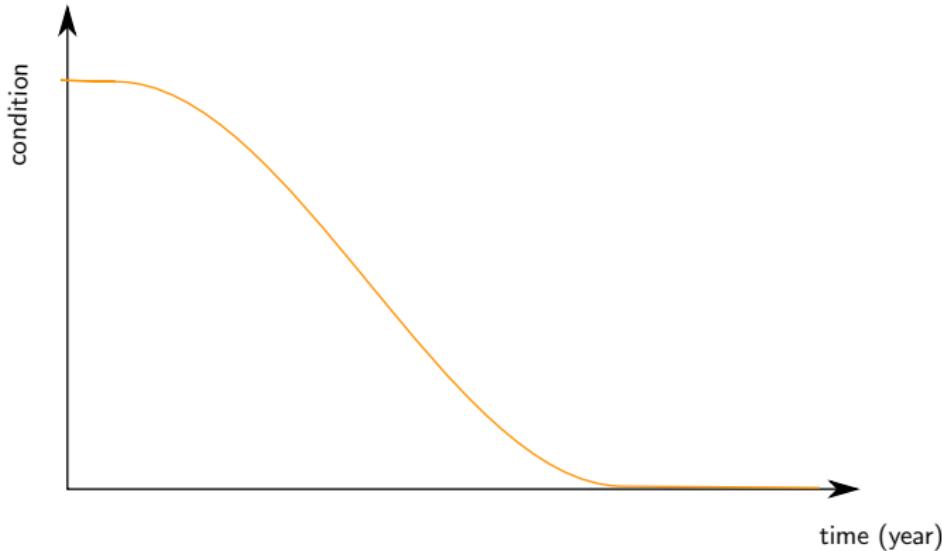
Synthetic Data New Hypothesis

$$\begin{aligned}\mu_0 &= 100, \\ \dot{\mu}_0 &\sim \text{InN}(\lambda, \zeta) ; \mathbb{E}[\dot{\mu}_0] = -0.05, \text{ var}[\dot{\mu}_0] = 0.015^2, \\ \ddot{\mu}_0 &\sim \mathcal{N}(-0.001, 0.005^2)\end{aligned}$$



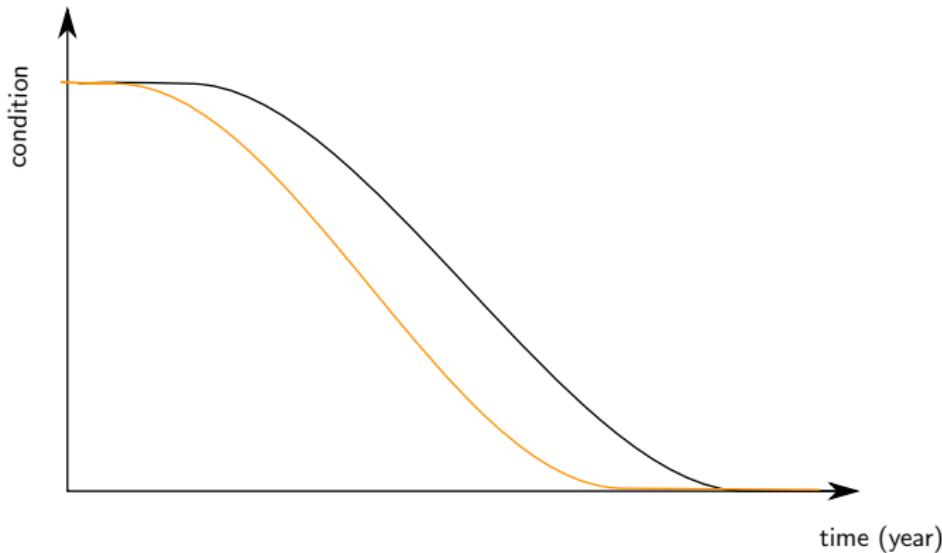
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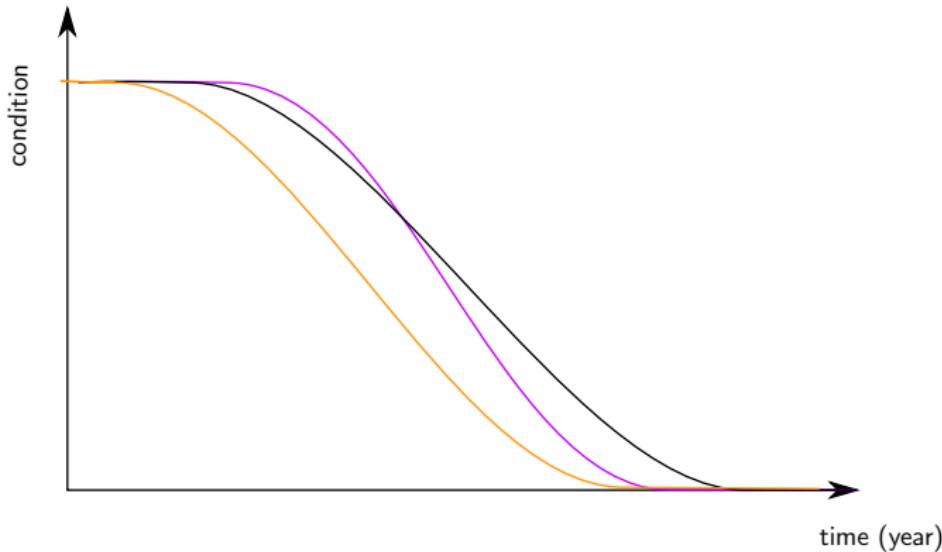
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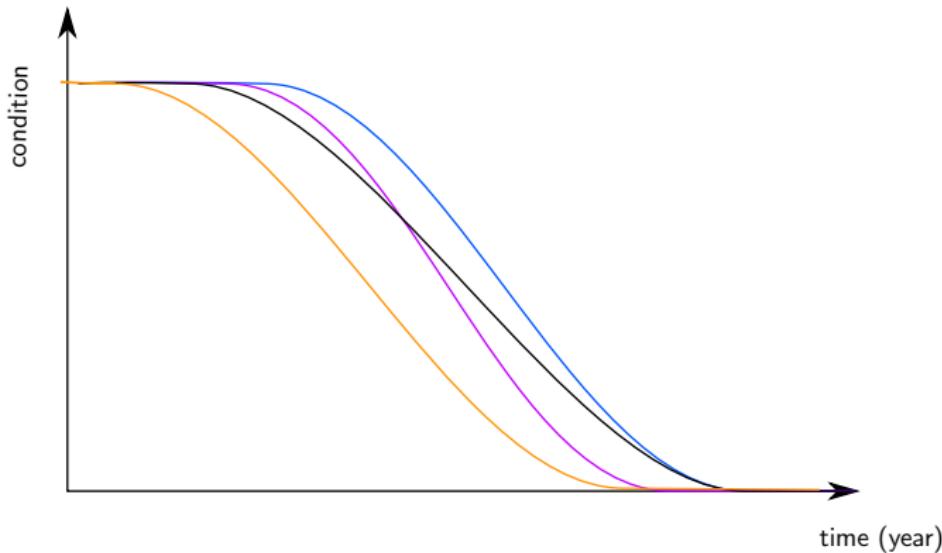
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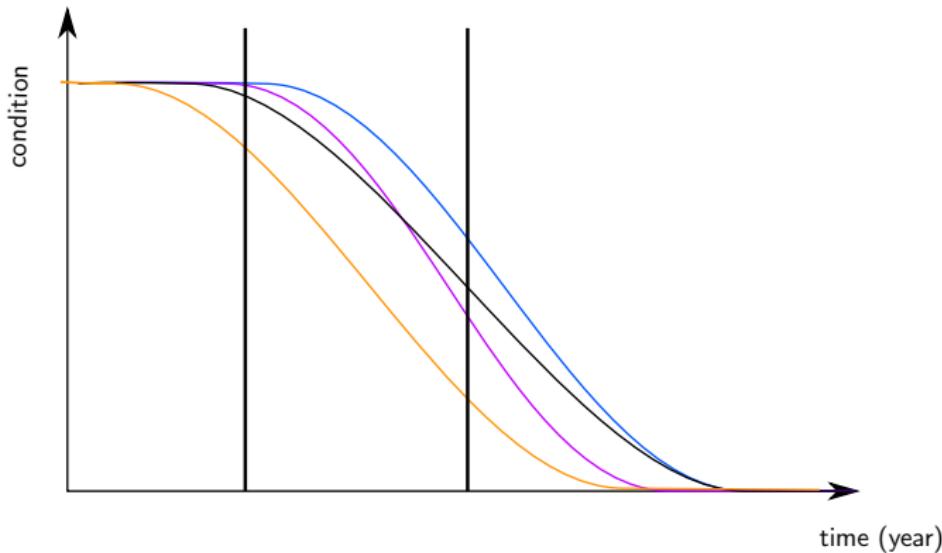


Synthetic Data New Hypothesis

$$\mu_0 = 100,$$

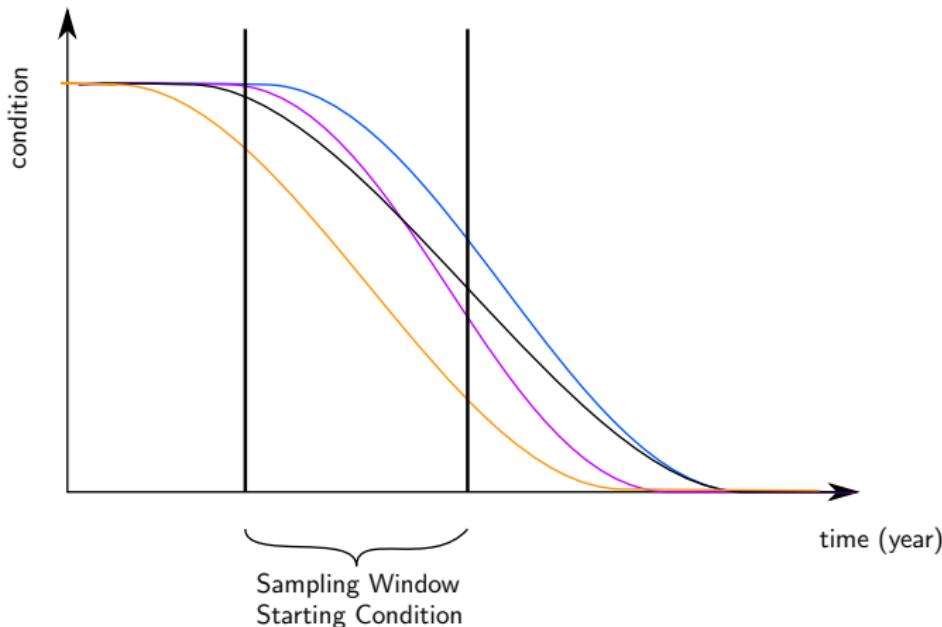
$$\dot{\mu}_0 \sim \ln\mathcal{N}(\lambda, \zeta) ; \mathbb{E}[\dot{\mu}_0] = -0.05, \text{var}[\dot{\mu}_0] = 0.015^2,$$

$$\ddot{\mu}_0 \sim \mathcal{N}(-0.001, 0.005^2)$$



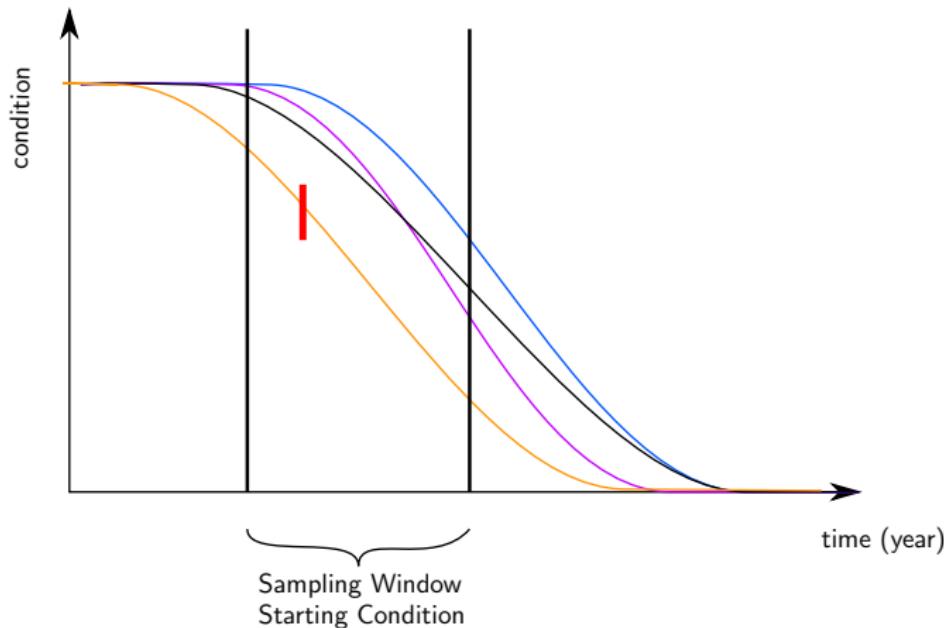
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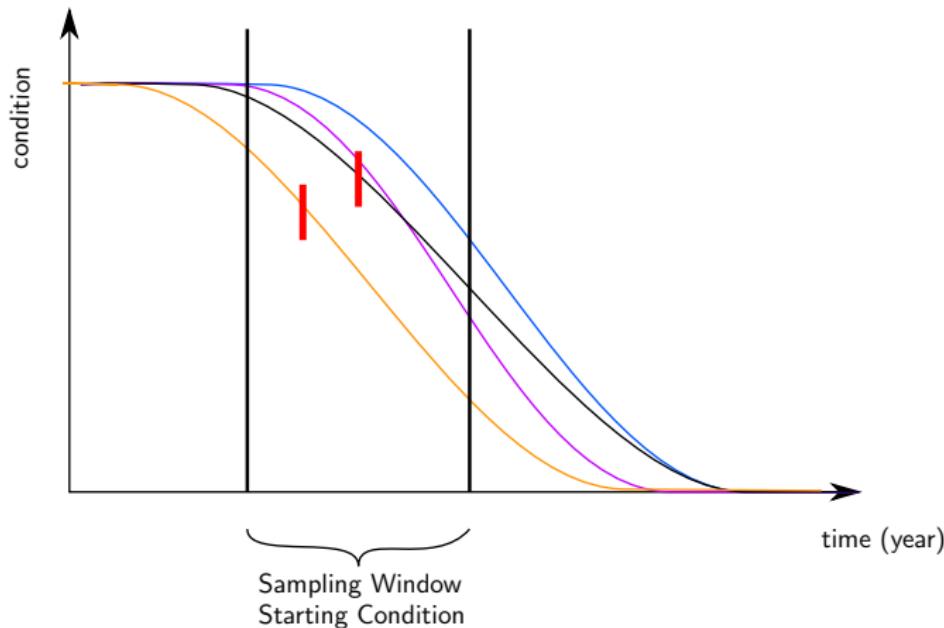
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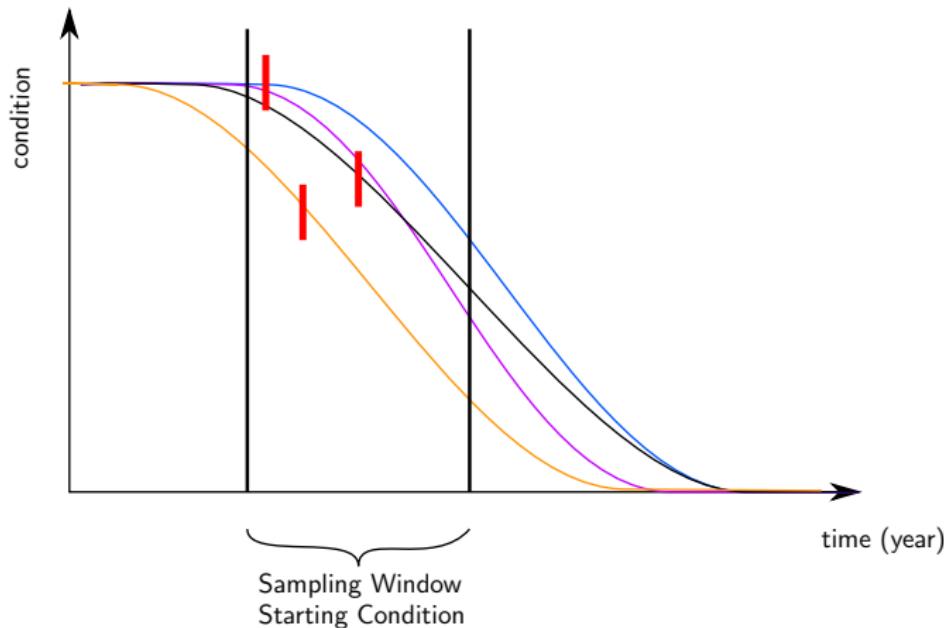
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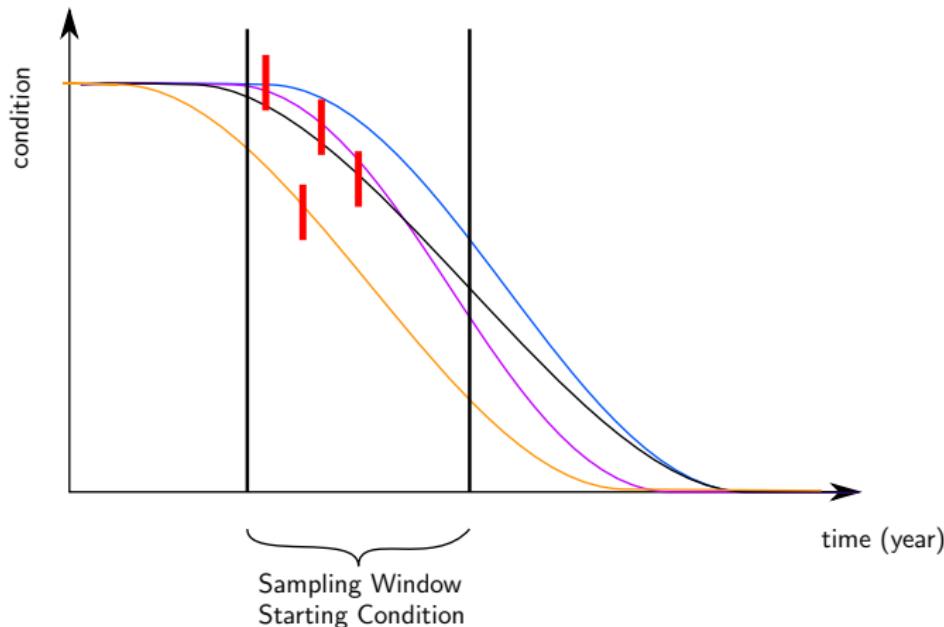
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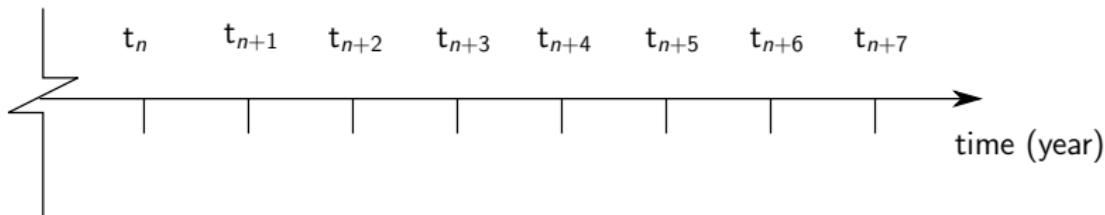
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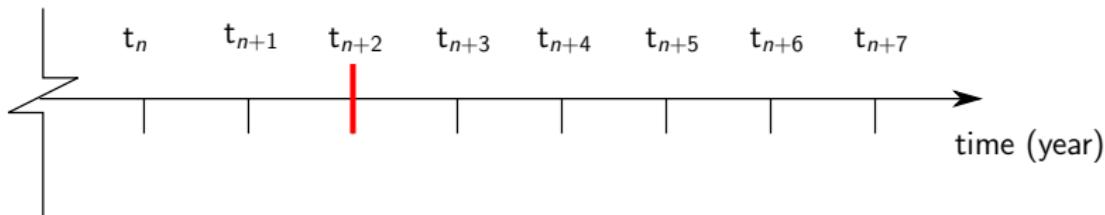
Initial State Analyses

Proposition



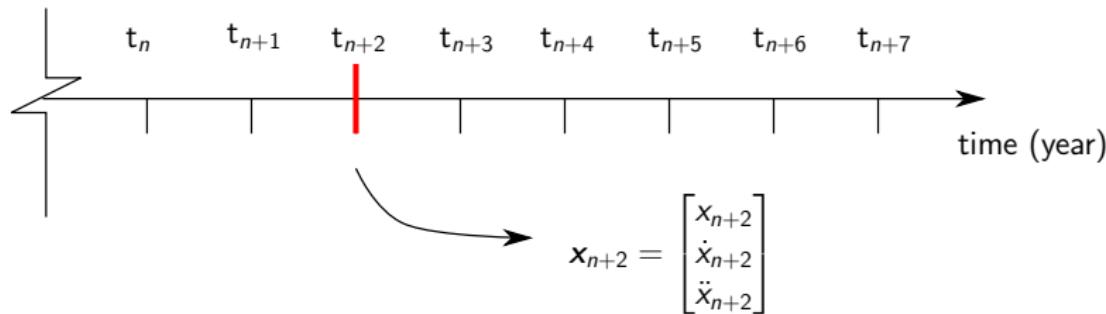
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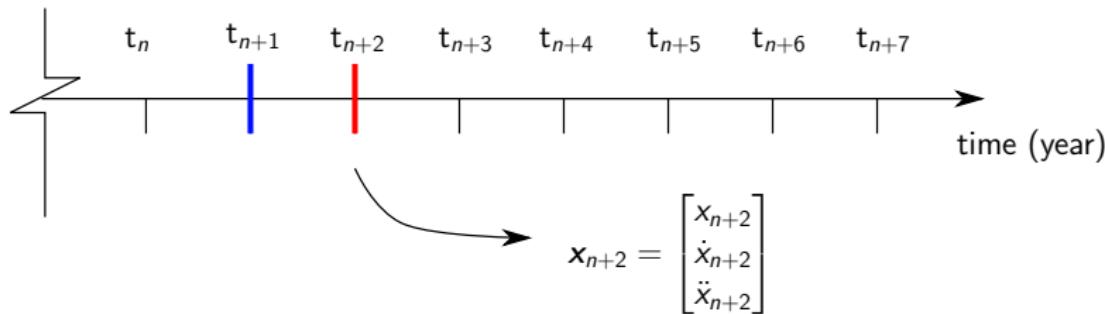
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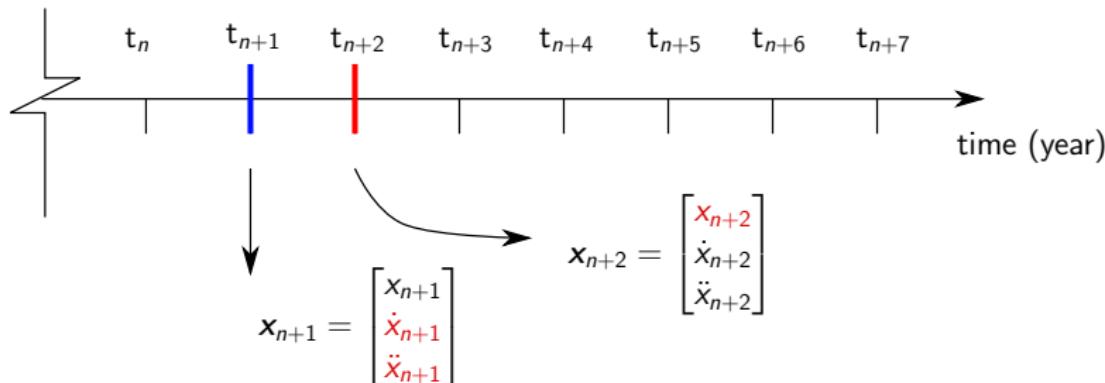
Initial State Analyses

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A timeline diagram showing time points $t_n, t_{n+1}, t_{n+2}, t_{n+3}, t_{n+4}, t_{n+5}, t_{n+6}, t_{n+7}$ along a horizontal axis labeled "time (year)". A vertical arrow points down from t_{n+1} to a state vector $x_{n+1} = \begin{bmatrix} x_{n+1} \\ \dot{x}_{n+1} \\ \ddot{x}_{n+1} \end{bmatrix}$. Another vertical arrow points down from t_{n+2} to a state vector $x_{n+2} = \begin{bmatrix} x_{n+2} \\ \dot{x}_{n+2} \\ \ddot{x}_{n+2} \end{bmatrix}$. A curved arrow points from x_{n+1} to x_{n+2} .

Initial State Analyses

Proposition



Initial State Analyses

Proposition

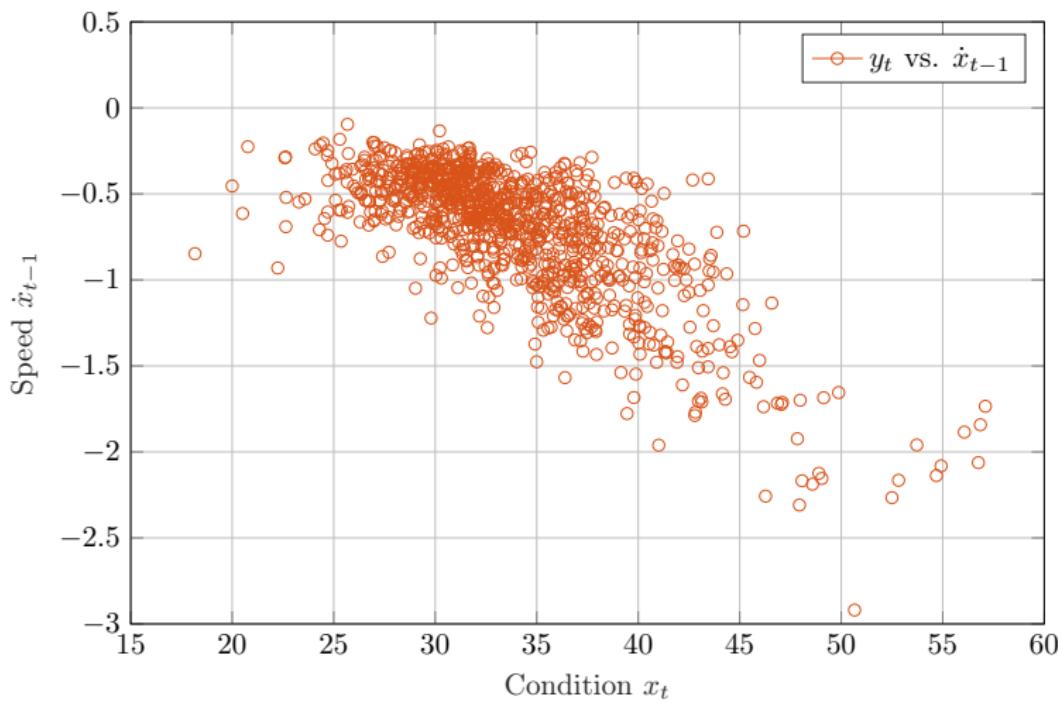
$$x_{n+1} = \begin{bmatrix} x_{n+1} \\ \dot{x}_{n+1} \\ \ddot{x}_{n+1} \end{bmatrix} \quad x_{n+2} = \begin{bmatrix} x_{n+2} \\ \dot{x}_{n+2} \\ \ddot{x}_{n+2} \end{bmatrix}$$

observation model

$$\overbrace{\mathbf{y}_t = \mathbf{C}\mathbf{x}_t + \boldsymbol{\nu}_t, \quad \boldsymbol{\nu}_t : \mathbf{V}(l_i) \sim \mathcal{N}(\boldsymbol{\nu}; \mathbf{0}, \mathbf{R}_t(l_i))}^{\text{observation error}}$$

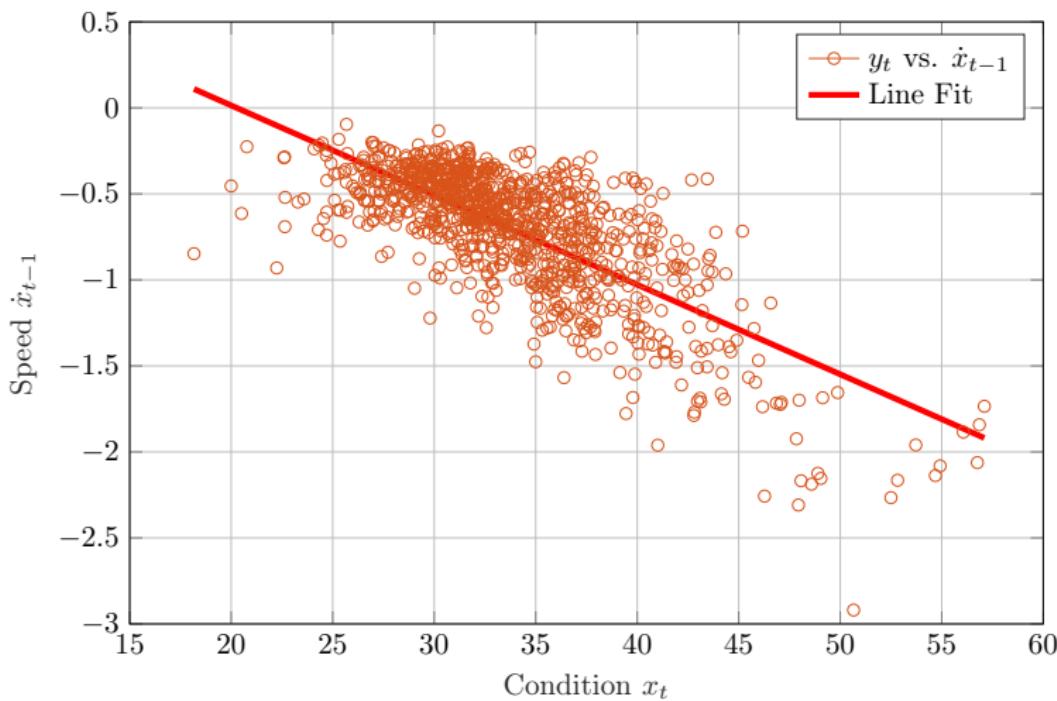
Condition vs. Speed

Initial Speed & Condition:



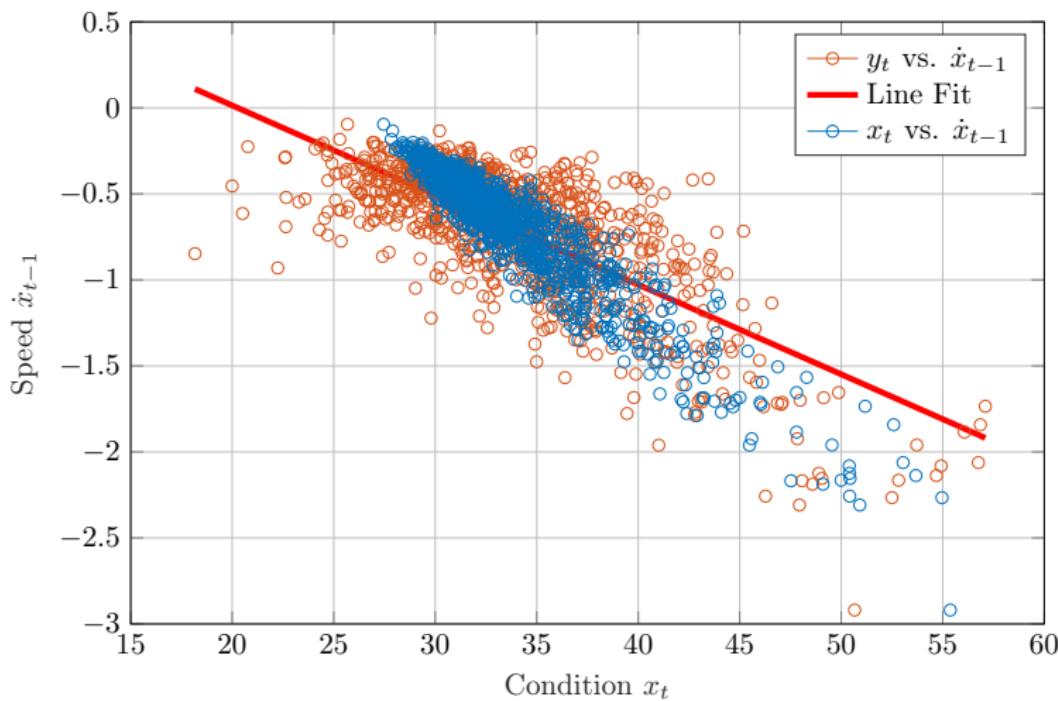
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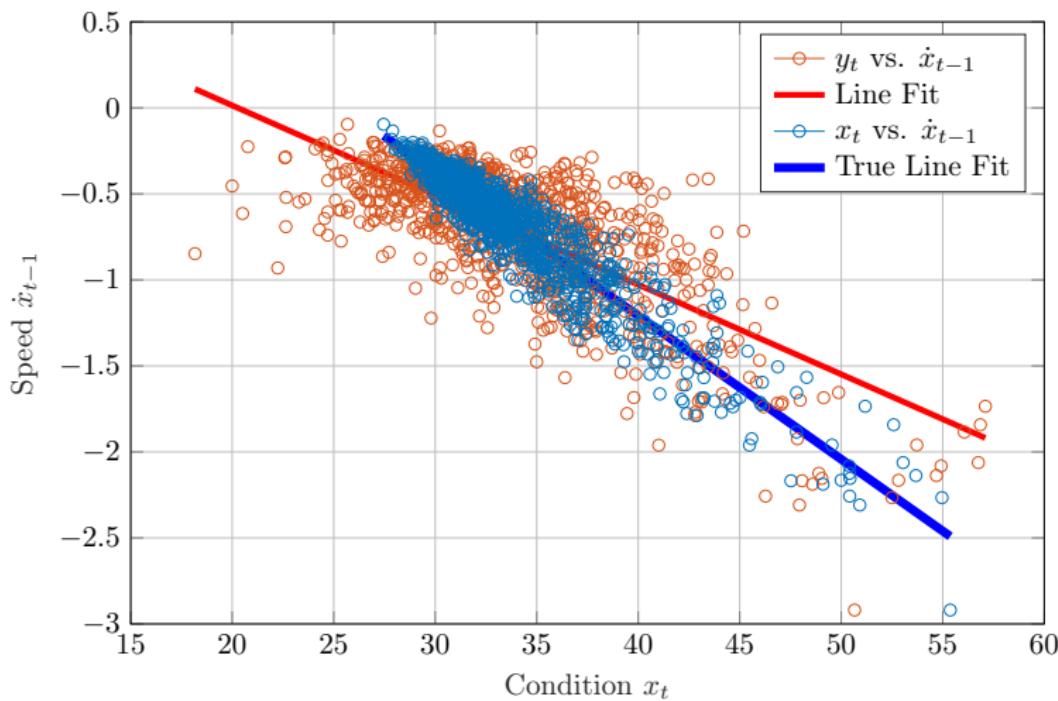
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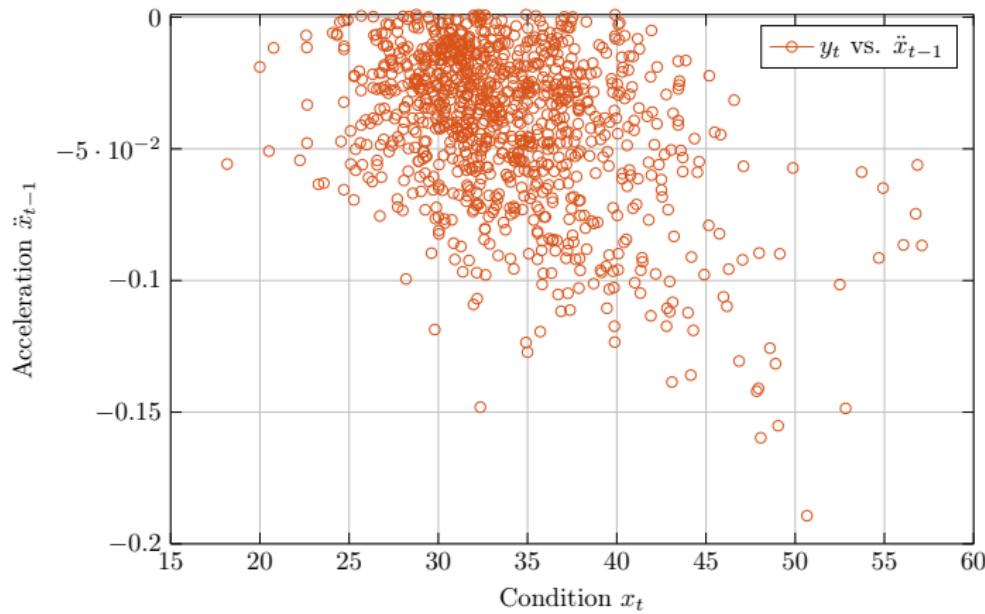
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Initial Speed & Condition:



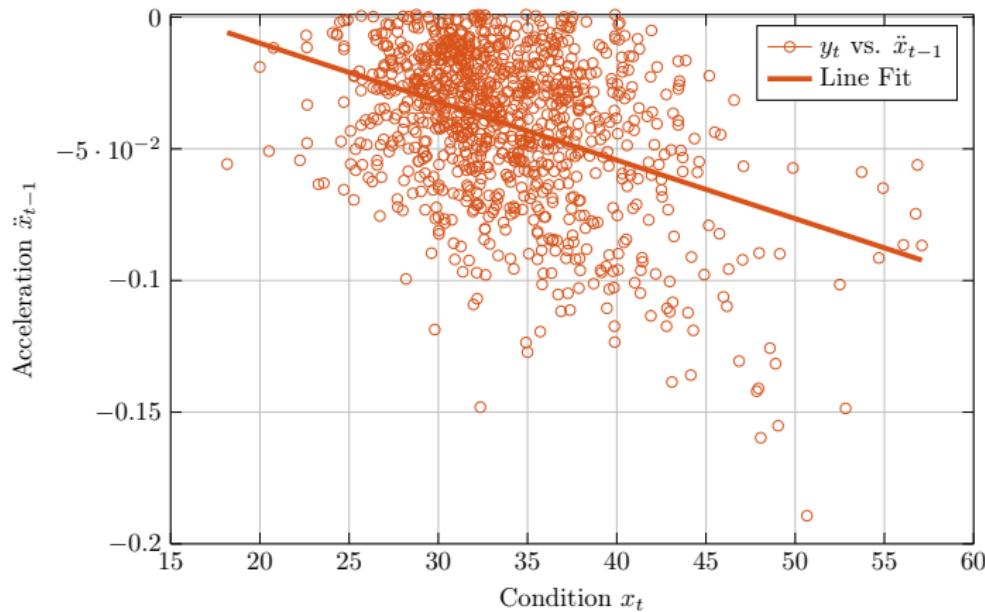
Condition vs. Acc.

Initial Acc. Analyses:



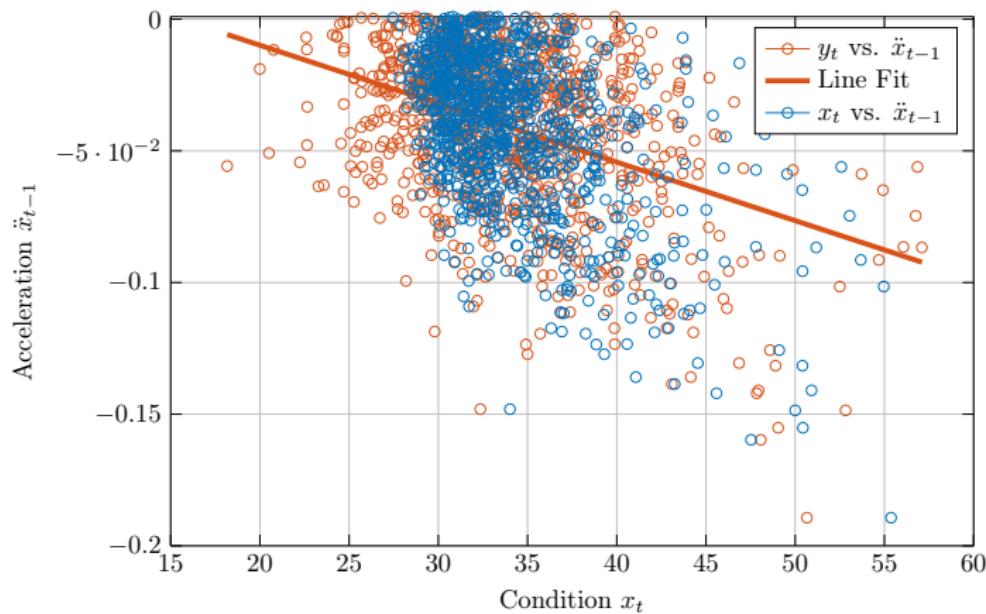
Condition vs. Acc.

Initial Acc. Analyses:



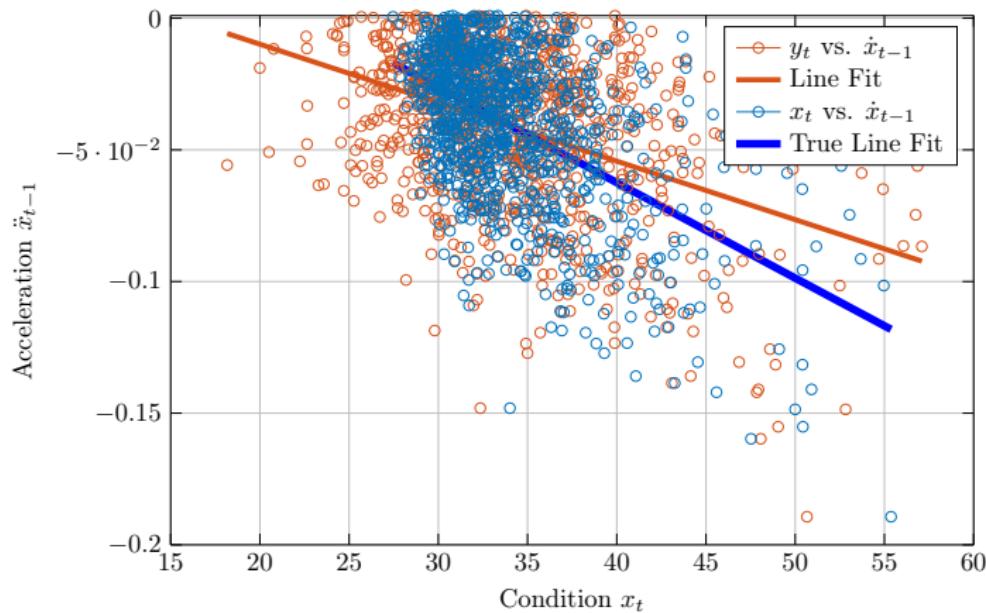
Condition vs. Acc.

Initial Acc. Analyses:



Condition vs. Acc.

Initial Acc. Analyses:



Initial State Parameters

Estimating Initial Speed & Acc.:

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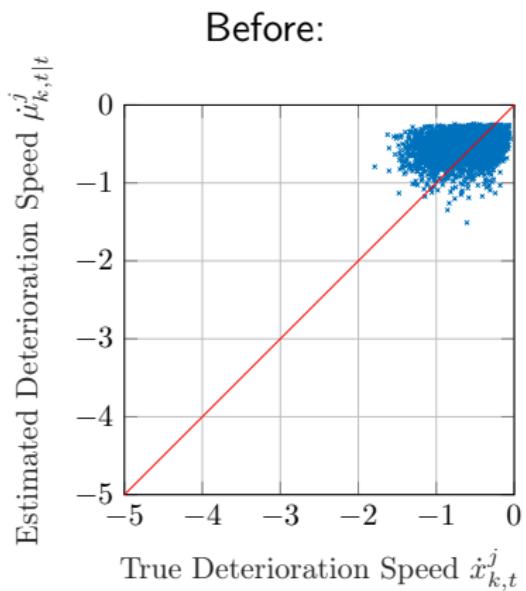
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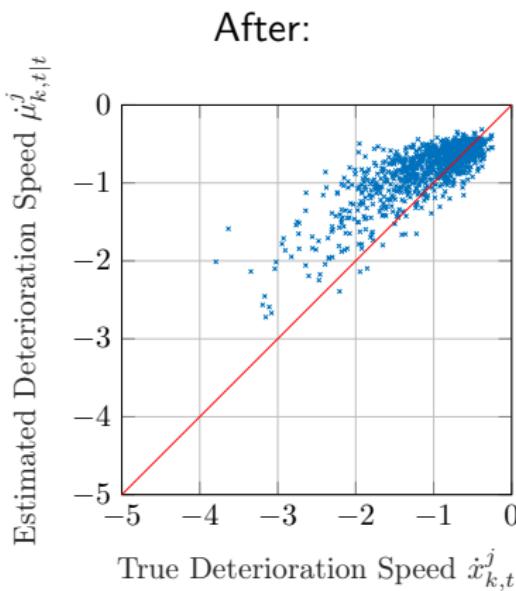
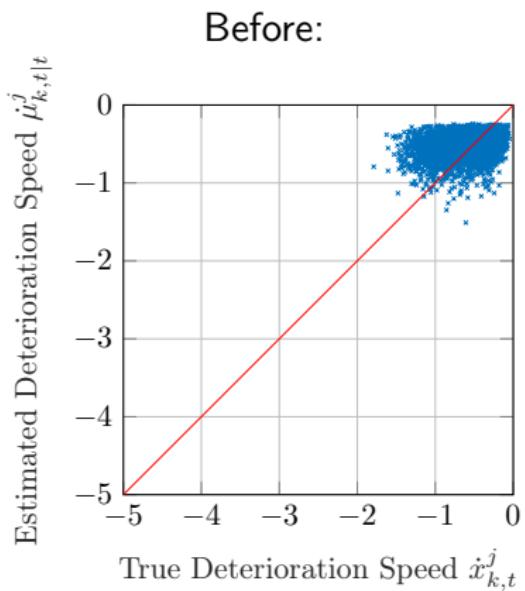
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Condition: $\begin{cases} y_1 \\ x_{0|\tau} \text{ (Smoothed State)} \end{cases}$

Estimating Speed after the First Observation:



Estimating Speed after the First Observation:



 Plan de la section

Data Navigation

- 4.1 Limitations in User Experience
 - 4.2 Solution
-

Limitations in User Experience

User - Model - Data



User



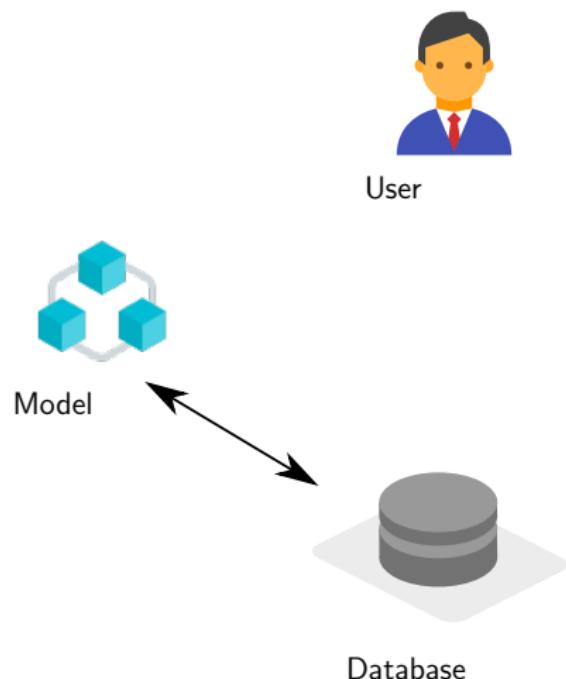
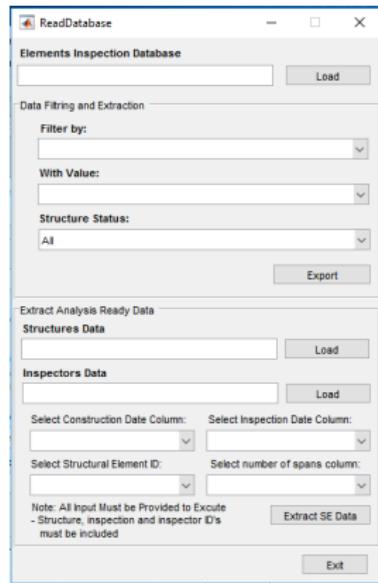
Model



Database

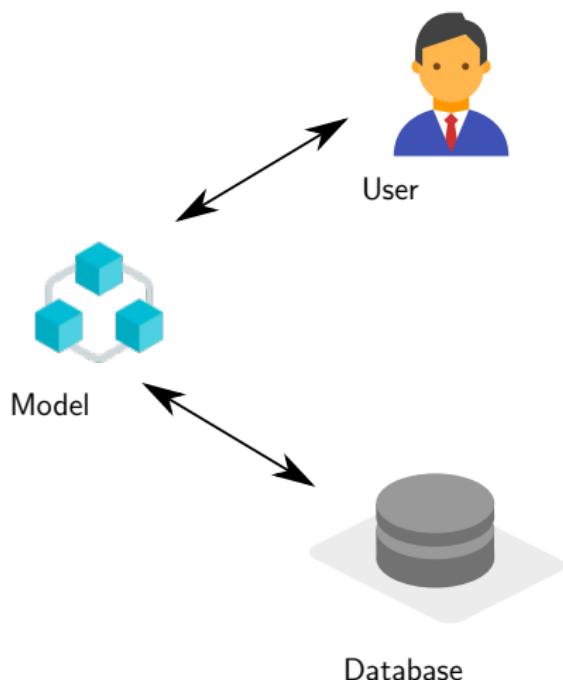
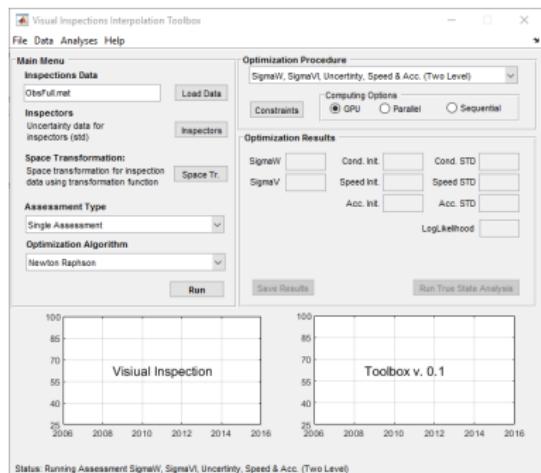
Limitations in User Experience

User - Model - Data



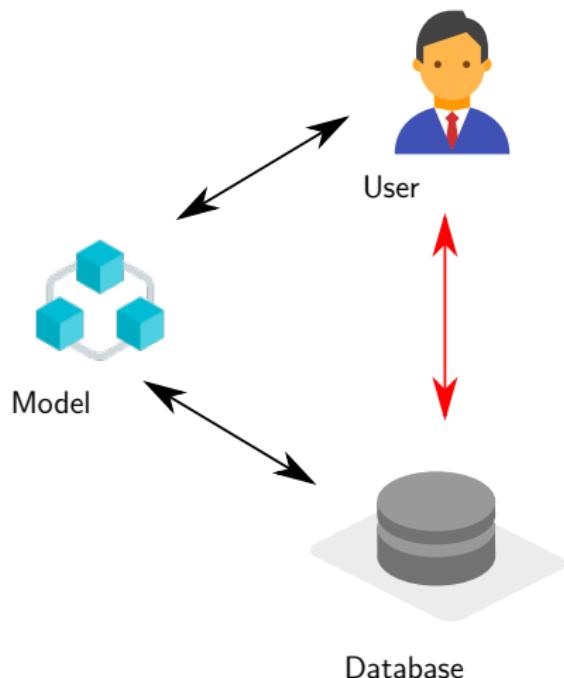
Limitations in User Experience

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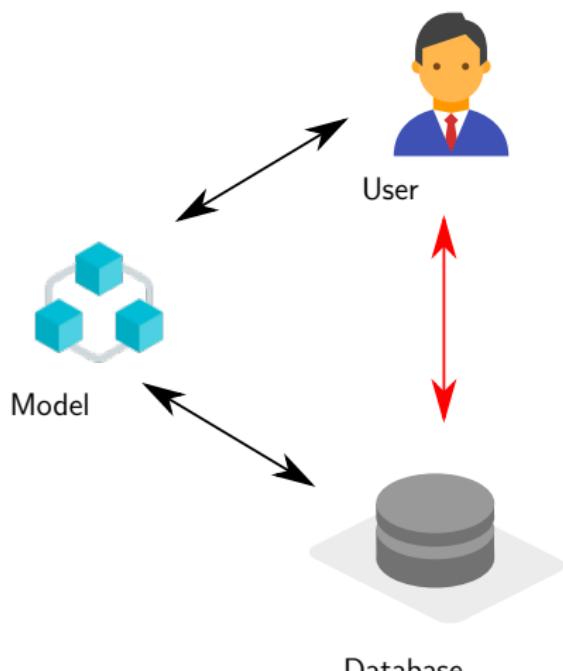
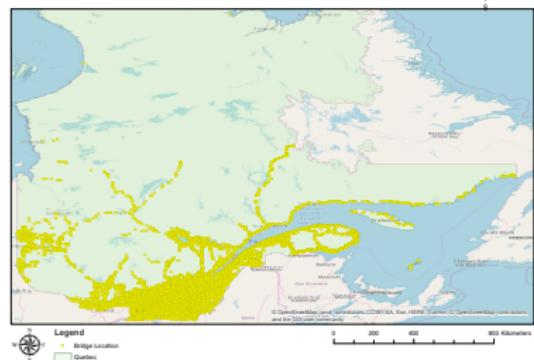
Limitations in User Experience

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Limitations in User Experience

User - Model - Data





Build a solution from Scratch!

Interactive Bridge Network Map

(Demo)

📍 Plan de la section

Progress & Next Steps

- 5.1 Project Progress
 - 5.2 Next Steps
-

Advancement Summary

1. Run analyses on GPU/CPU (+code optimization).

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7. Build Interactive Bridge Network Map.
8. Access All toolboxes from one place.

Next Steps

Next:

1. Code Optimization.

Next Steps

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1. Code Optimization.
2. Test different optimization frameworks.