Bayesian Visual Analytics (BaVA): A Formal Visual Updating Procedure

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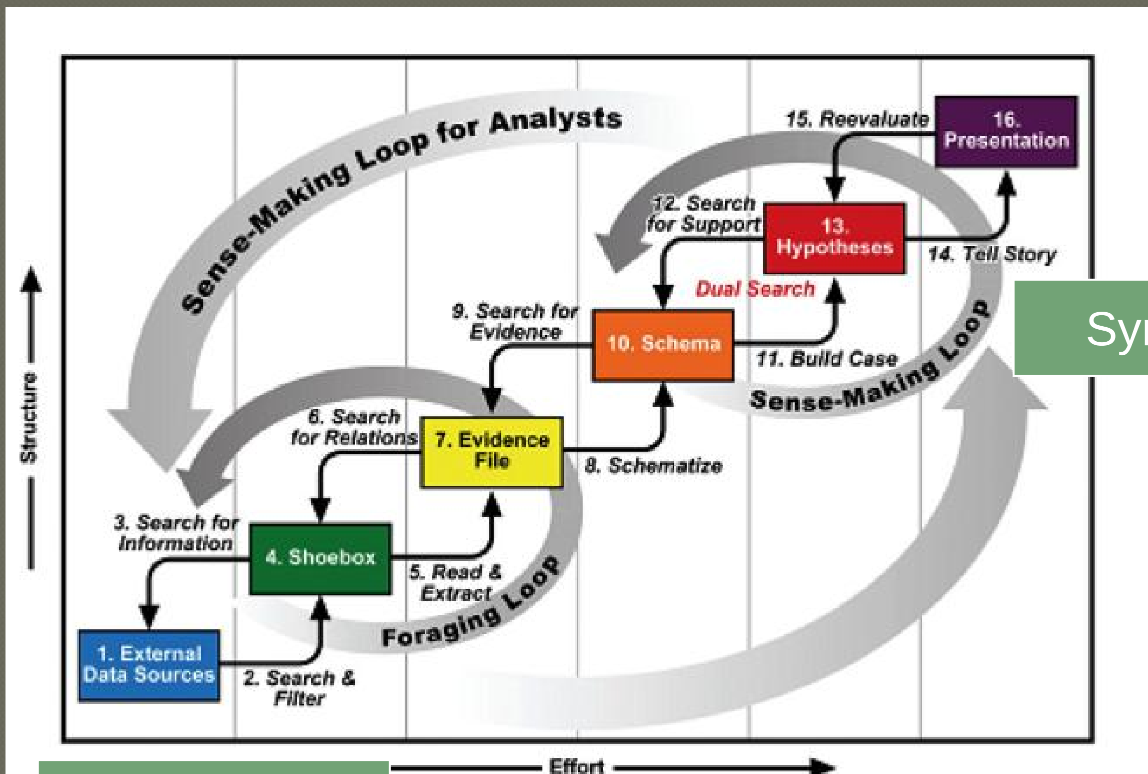
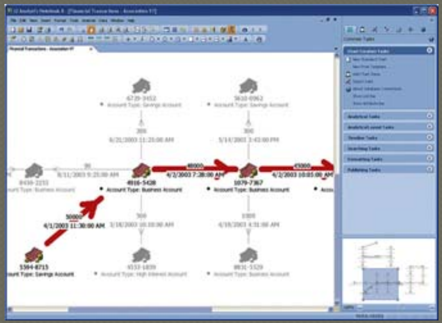
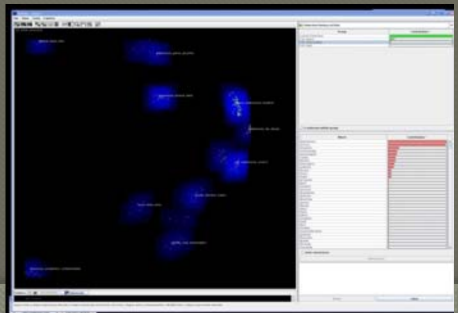
Foraging + Sensemaking



Synthesis

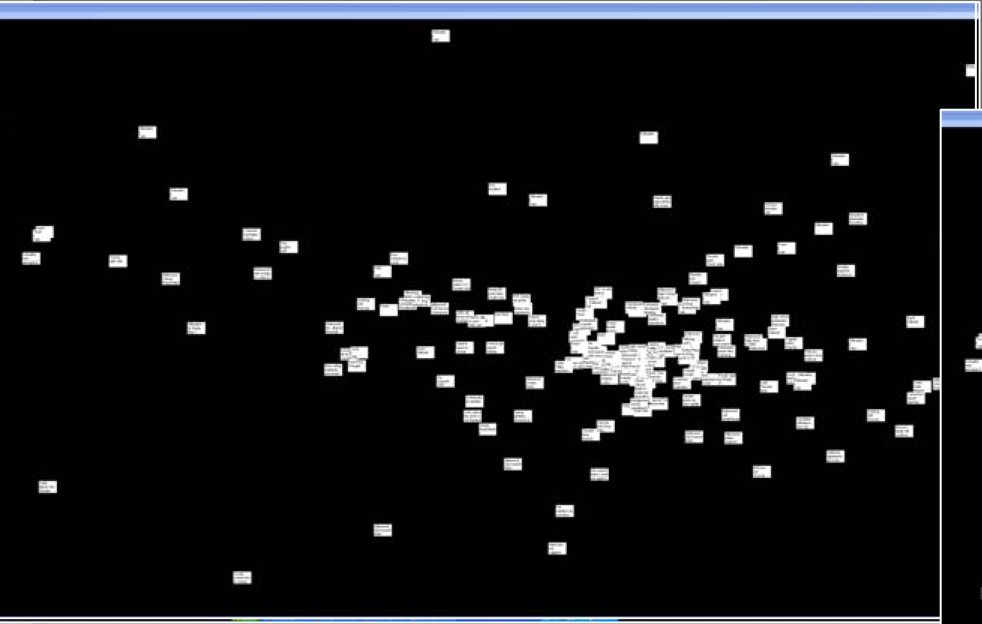


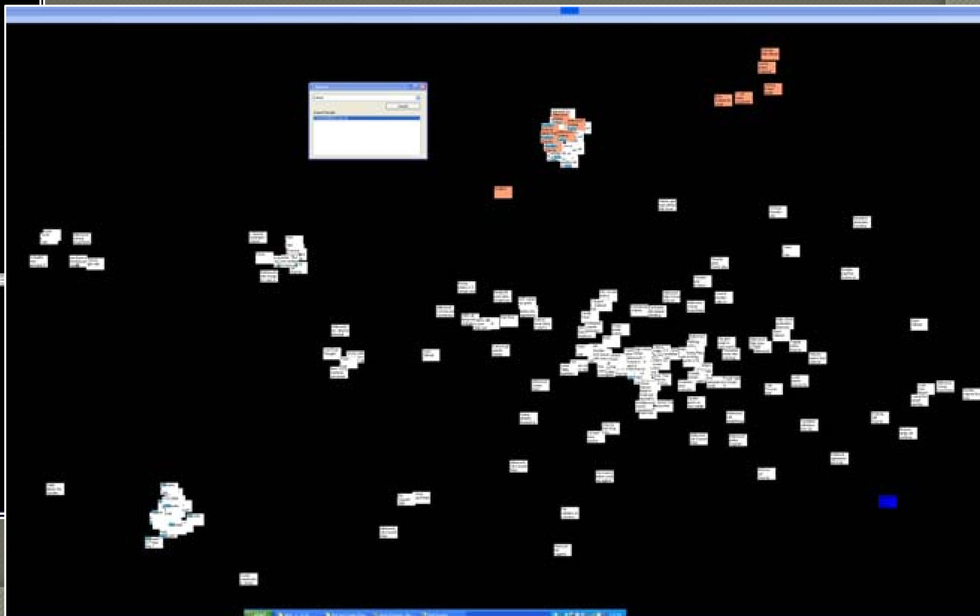
Extraction



Deep Interaction

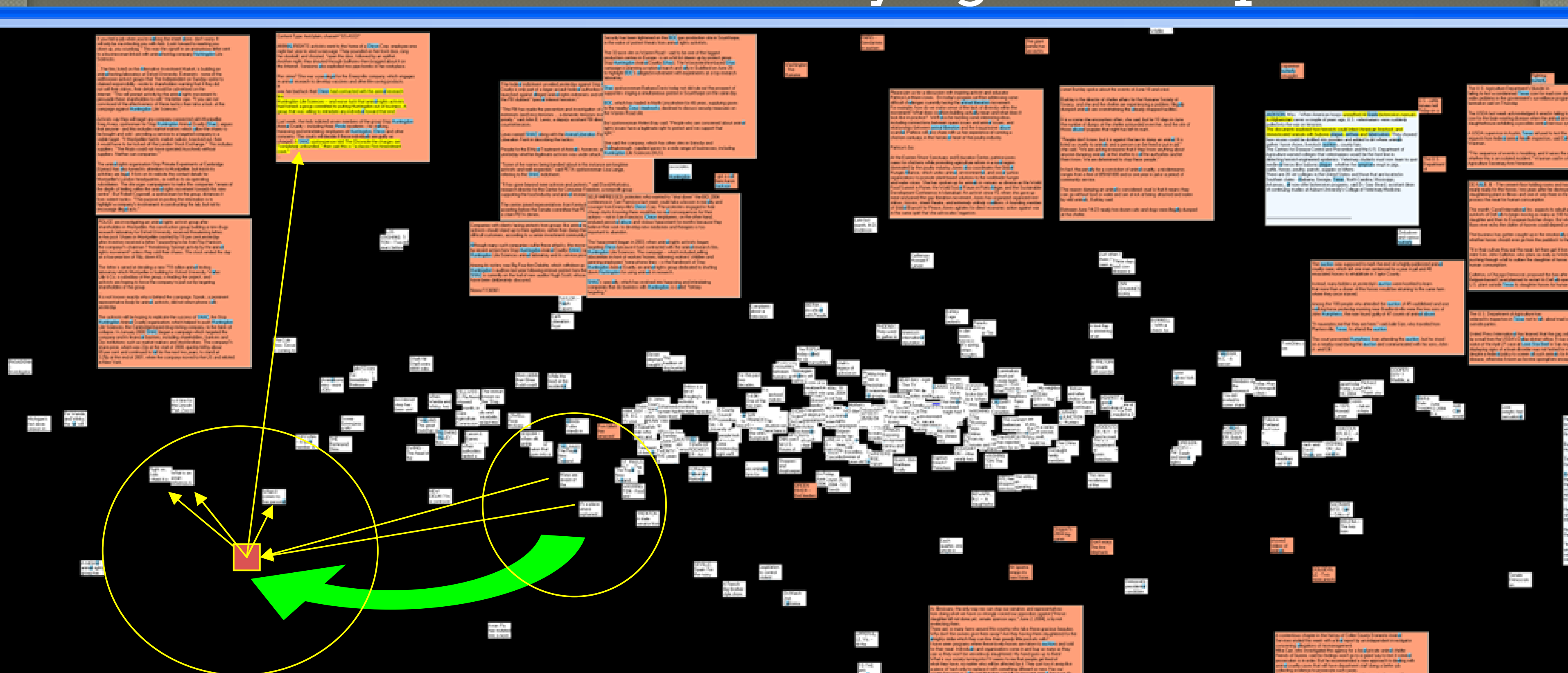
- User guided modeling, via direct manipulation
- Analyst injects domain knowledge into the visualization
- The visualization responds meaningfully





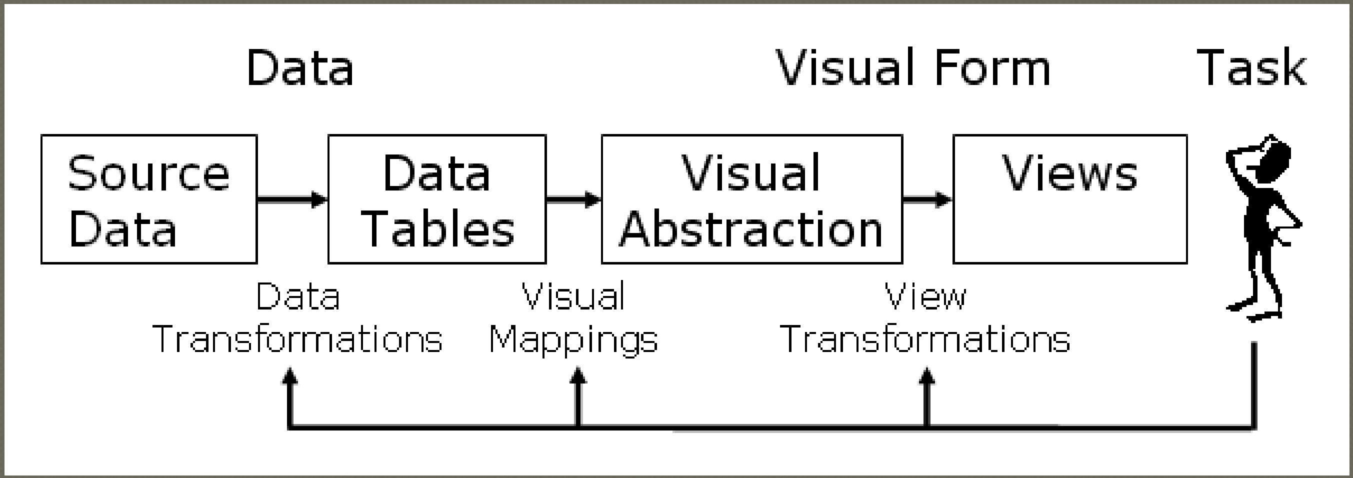
Mapping Visual to Model

- Natural interaction within the visual metaphor
- Level of detail of interactive input control
- Visual feedback of underlying model updates



A New Framework…

- Beyond the Visualization Pipeline



Outline

1. The BaVA process of incorporating visualizable feedback.
2. A Cartoon Illustration of the BaVA process
3. Formalities
4. Insights

The BaVA Process

The BaVA paradigm is a hierarchical process, entailing 5 layers. Some of these layers will rely on stochastic models, while others might utilize deterministic transformations.

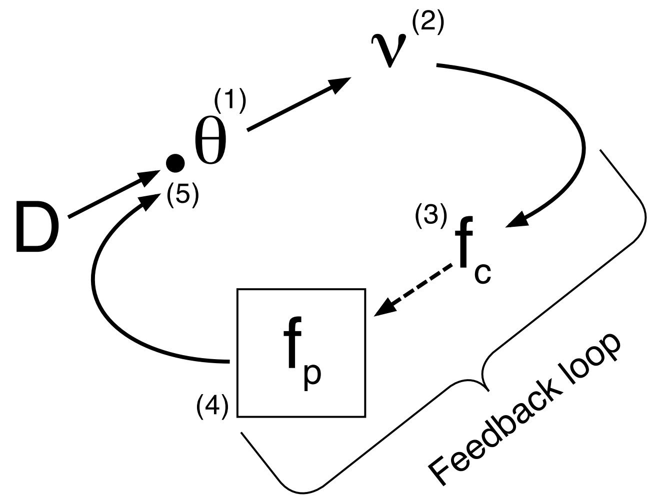


Figure 1: Schematic illustration of the BaVA process.

The BaVA Process

Preliminary: Obtain data $\boldsymbol{D}$, which will in general be high dimensional, and massive in size. Like most analyses, our objective is to find hidden structure, and associations within the data.

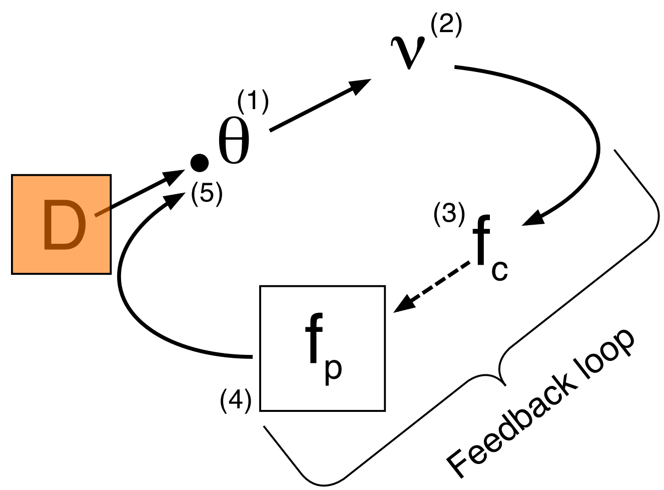


Figure 2: Schematic illustration of the BaVA process.

The BaVA Process

Step 1: From a parameterized mathematical model, $\pi(\boldsymbol{D}|\boldsymbol{\theta})$, which relates relevant unknowns $(\boldsymbol{\theta})$ to the data $\boldsymbol{D}$, obtain inferences about $\boldsymbol{\theta}$ using Bayes' Theorem: $\pi(\boldsymbol{\theta}|\boldsymbol{D}) = \pi(\boldsymbol{D}|\boldsymbol{\theta})\pi(\boldsymbol{\theta})/\int \pi(\boldsymbol{D}|\boldsymbol{\theta})\pi(\boldsymbol{\theta})d\boldsymbol{\theta}$.

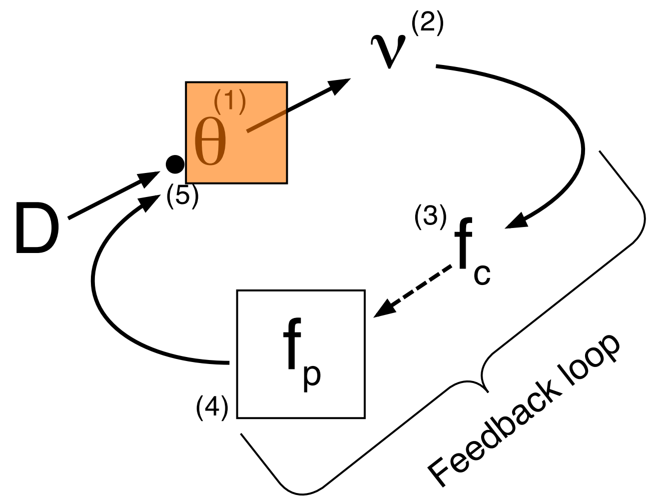


Figure 3: Schematic illustration of the BaVA process.

The BaVA Process

Step 2: Visualize both data $(\boldsymbol{D})$ and inferences $(\boldsymbol{\theta})$ (perhaps only a summary: $\hat{\boldsymbol{\theta}}$) in a *meaningful way*.

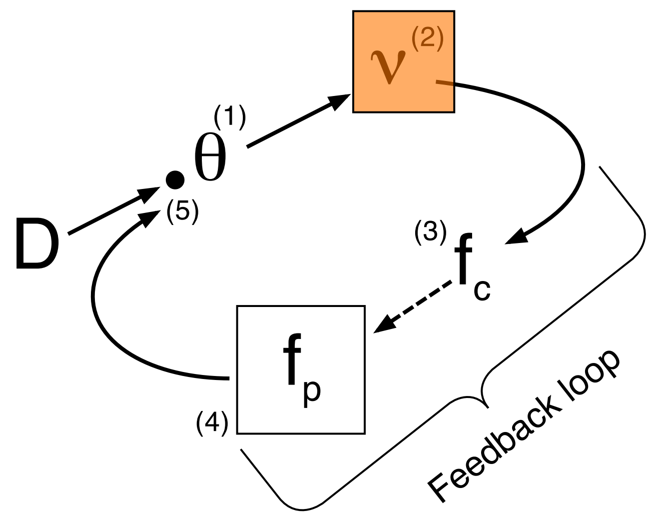


Figure 4: Schematic illustration of the BaVA process.

The BaVA Process

Step 3: Allow the user to reconfigure the visualization, in order to express relationships between a small set of objects. We refer to this as *cognitive feedback*.

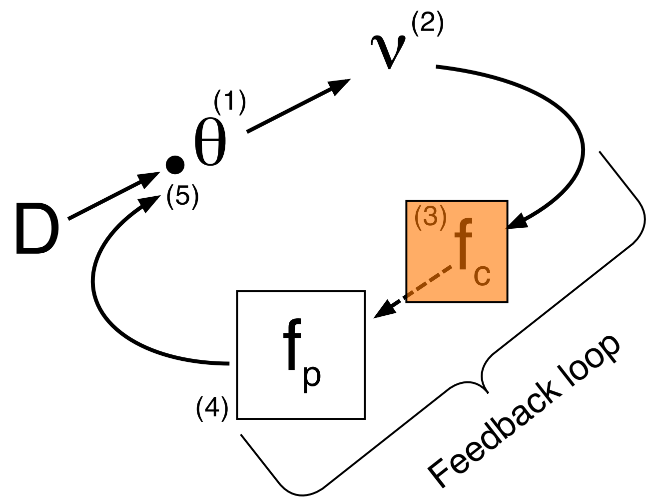


Figure 5: Schematic illustration of the BaVA process.

The BaVA Process

Step 4: The information contained in the cognitive feedback is translated (parameterized) back into model parameters (θ). This is referred to as *parametric feedback*, and usually invokes a black-box layer, which does not involve the user.

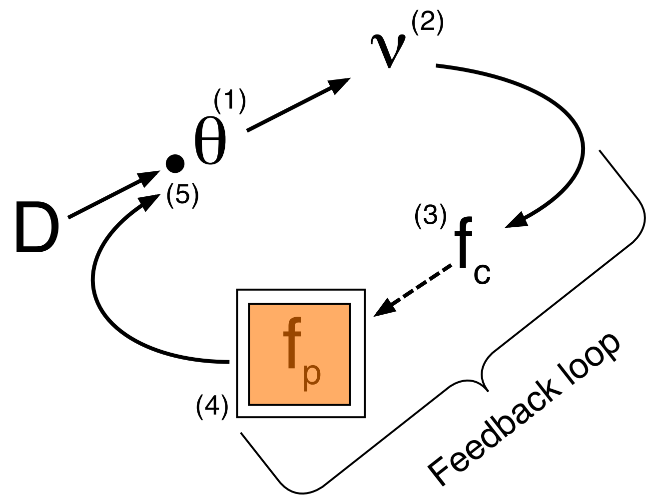


Figure 6: Schematic illustration of the BaVA process.

The BaVA Process

Step 5: The parameterized feedback is injected into the system, to provide updated parameter assessments, and subsequently updated visualizations. This relies on the a new iteration of Bayes' Theorem:
$\pi(\boldsymbol{\theta}|f, v, \boldsymbol{D}) = \pi(f|v, \boldsymbol{\theta})\pi(\boldsymbol{\theta}|\boldsymbol{D})/\int \pi(f|v, \boldsymbol{\theta})\pi(\boldsymbol{\theta}|\boldsymbol{D})d\boldsymbol{\theta}$, where $f = \{f_p, f_c\}$

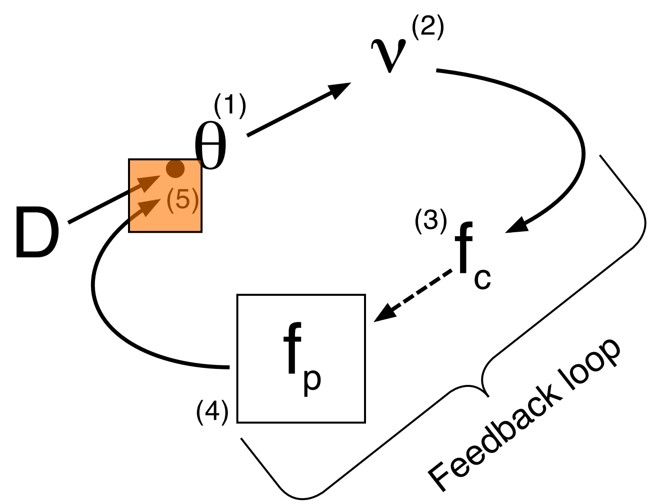


Figure 7: Schematic illustration of the BaVA process.

A Cartoon Illustration

Step 1: Perform Bayesian analysis to obtain model inferences. For this example, we will focus on projection based clustering (PCA), but will rely on its model based variant Probabilistic-PCA (PPCA) (Tipping and Bishop, 1999).

A Cartoon Illustration

Step 1: Perform Bayesian analysis.
Step 2: Visualize the inferences. (Project through principal subspace)

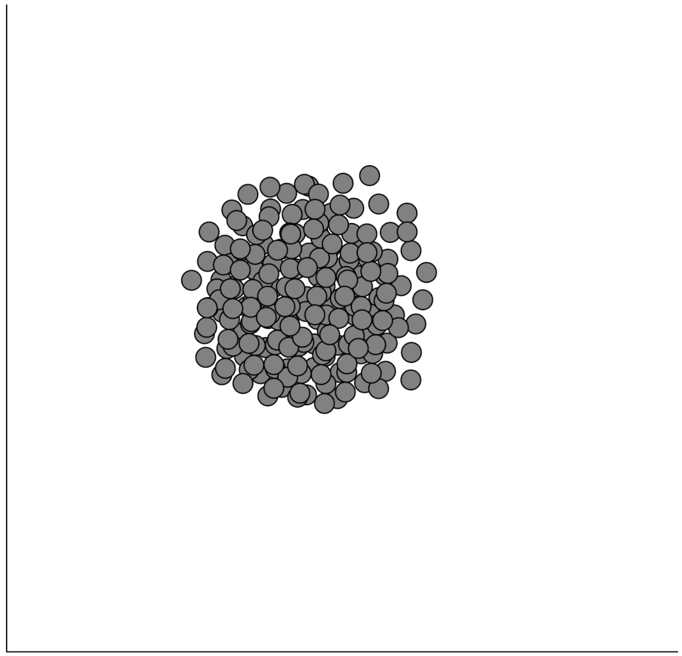


Figure 8: RAW PCA projection

A Cartoon Illustration

Step 2: Visualize the inferences. (Project through principal subspace)

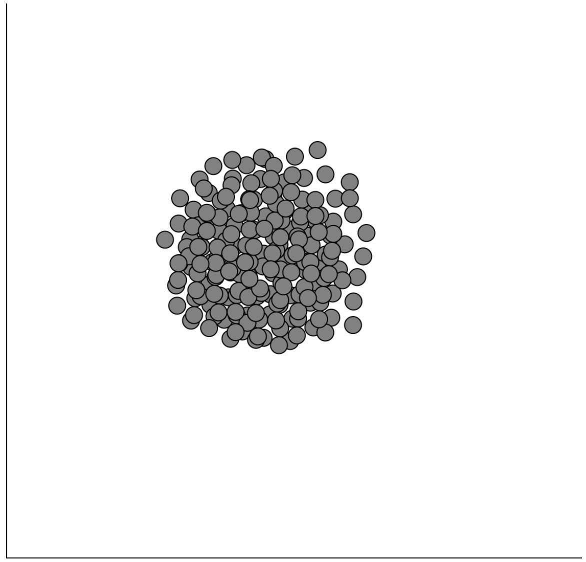


Figure 9: RAW PCA projection

This is really pretty uninformative, but is not unlikely to occur in real applications.

A Cartoon Illustration

Step 2: Visualize the inferences.
Step 3: Identify anomalous structure in the visual display.

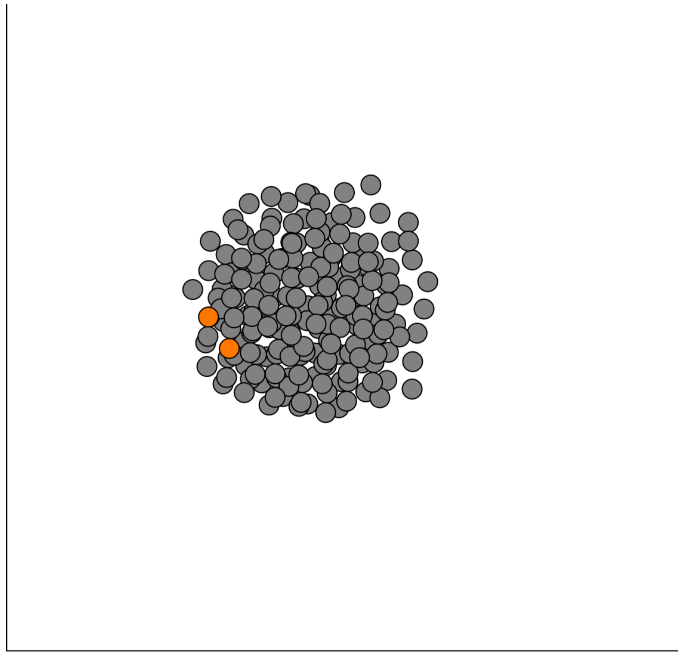


Figure 10: Identify odd structure

A Cartoon Illustration

Step 2: Visualize the inferences.
Step 3: Identify anomalous structure in the visual display.

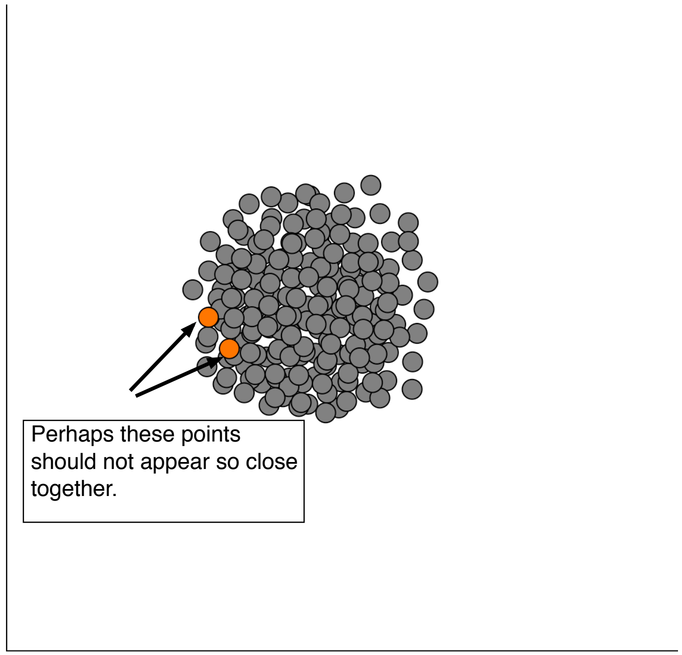


Figure 11: Identify odd structure

A Cartoon Illustration

Step 3: Identify anomalous structure in the visual display.
Supply feedback by adjusting the display

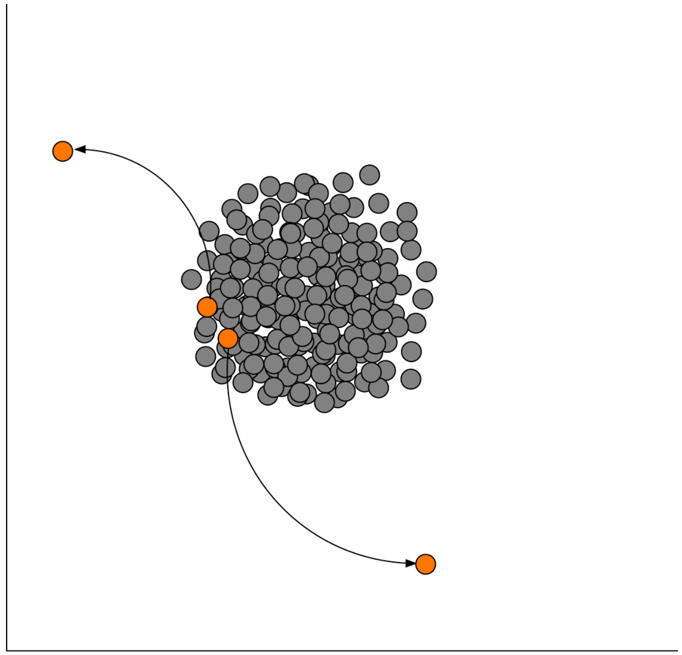


Figure 12: Supply Feedback (Cognitive)

A Cartoon Illustration

Step 3: Supply feedback by adjusting the display

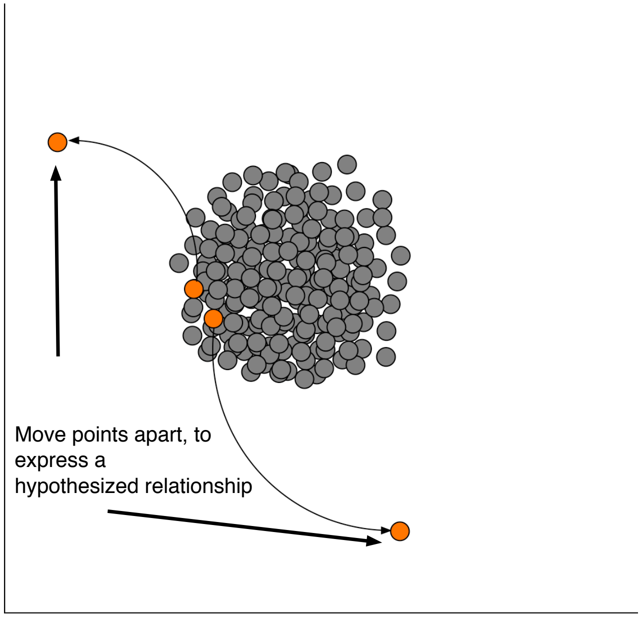


Figure 13: Supply Feedback (Cognitive)

Given the visualization, the user is defining a random variable, governed by a *cognitive distribution:* $\pi(f_c|v)$.

A Cartoon Illustration

Step 3: Supply feedback by adjusting the display (Cognitive Feedback)
Step 4: Parameterize the feedback

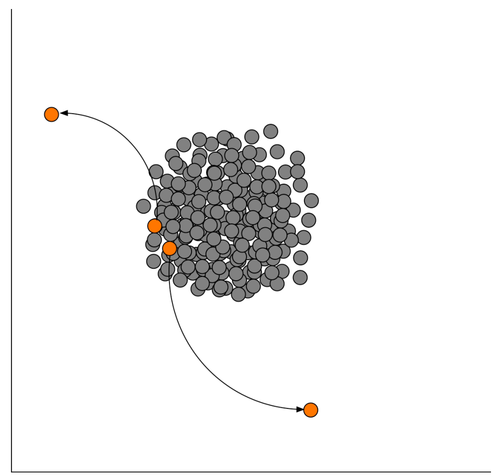


Figure 14: Supply Feedback (Cognitive)

Express a mathematical relationship, between feedback, and parameters: $g(f_p|f_c, \boldsymbol{\theta})$.

A Cartoon Illustration

Step 4: Parameterize the feedback
Step 5: Update the display.

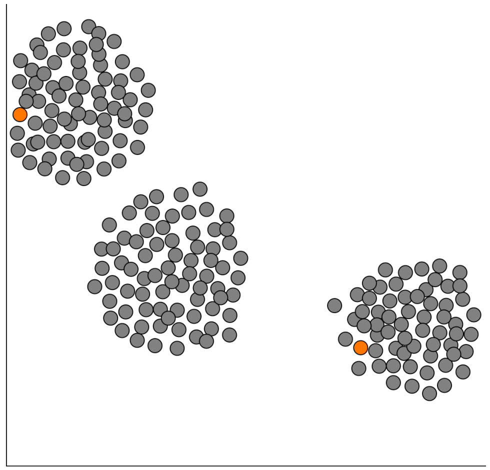


Figure 15: Sequentially update

Formalities

Core BaVA steps:

1. Posterior inferences: $\pi(\boldsymbol{\theta}|\boldsymbol{D}) = \pi(\boldsymbol{D}|\boldsymbol{\theta})\pi(\boldsymbol{\theta})/\int \pi(\boldsymbol{D}|\boldsymbol{\theta})\pi(\boldsymbol{\theta})d\boldsymbol{\theta}$.
2. Visualize: $g(v|\hat{\boldsymbol{\theta}}, \boldsymbol{D})$, or $g(v|\boldsymbol{D}) = \int g(v|\boldsymbol{\theta}, \boldsymbol{D})d\boldsymbol{\theta}$.
3. Supply Cognitive Feedback: $\pi(f_c|v)$.
4. Parameterize Feedback: $g(f_p|f_c, v)$.
5. Sequentially update using Bayes' Sequential updating formula:

$$\begin{aligned}
\pi(\boldsymbol{\theta}|f, v, \boldsymbol{D}) &= \pi(f|v, \boldsymbol{\theta})\pi(\boldsymbol{\theta}|\boldsymbol{D})/\int \pi(f|v, \boldsymbol{\theta})\pi(\boldsymbol{\theta}|\boldsymbol{D})d\boldsymbol{\theta} \\
&\propto \pi(f|v, \boldsymbol{\theta})\pi(\boldsymbol{\theta}|\boldsymbol{D}) \\
&= g(f_p|f_c, \boldsymbol{\theta})\pi(f_c|v)\pi(\boldsymbol{\theta}|\boldsymbol{D}),
\end{aligned}$$

where $f = \{f_p, f_c\}$

Insights

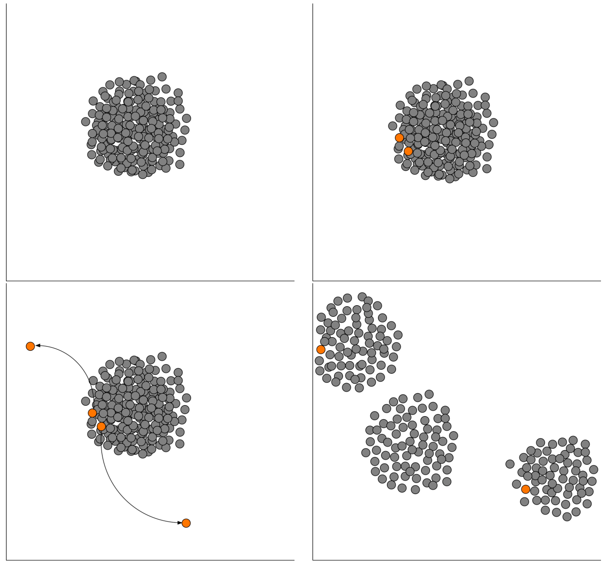


Figure 16: a cartoon illustration of the BaVA process

Insights

The mathematics suggests an uninteresting projection.

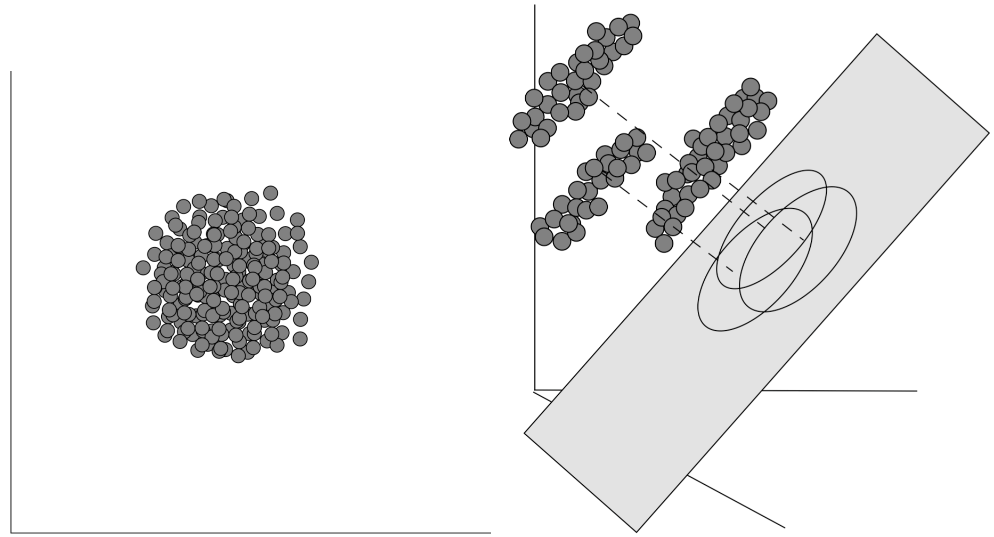


Figure 17: An uninteresting projection

Insights

A user keys into interesting structure.

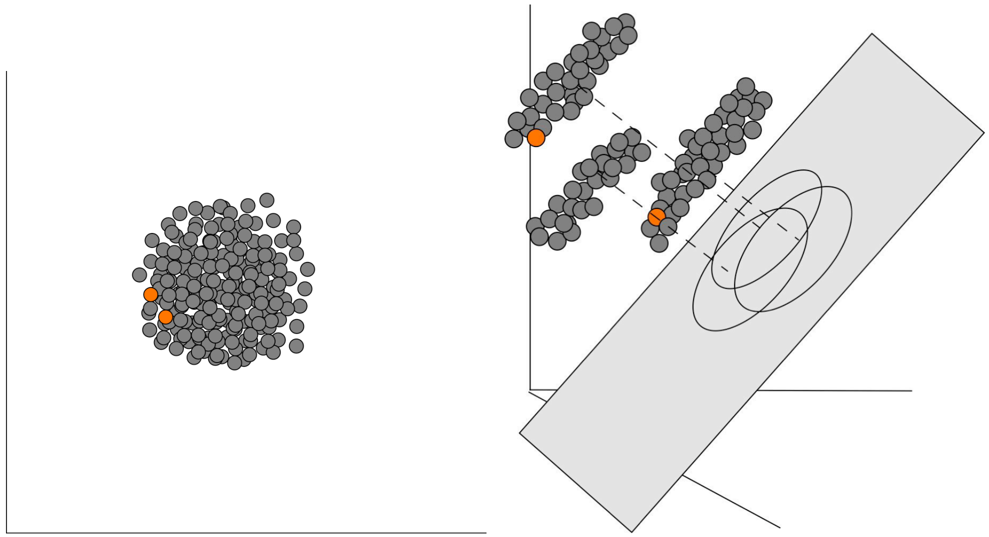


Figure 18: An uninteresting projection

Insights

A user keys into interesting structure and provides feedback.

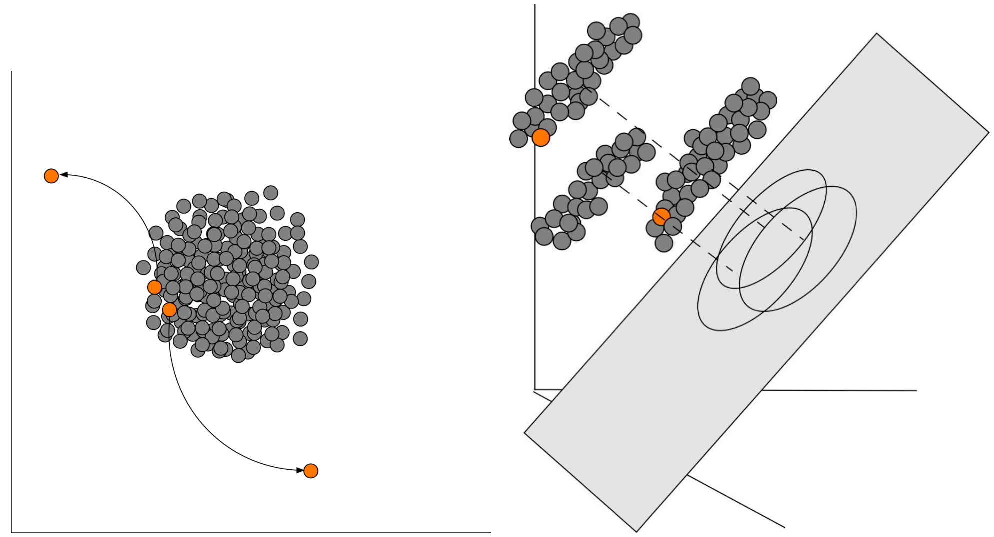


Figure 19: User provides cognative feedback

Insights

This feedback is parameterized, using information in both the low and high dimensional feature spaces.

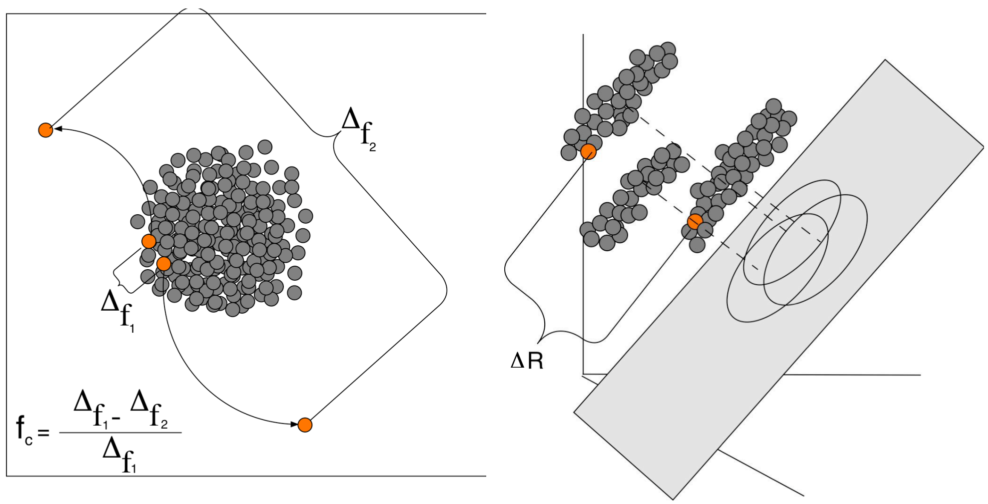
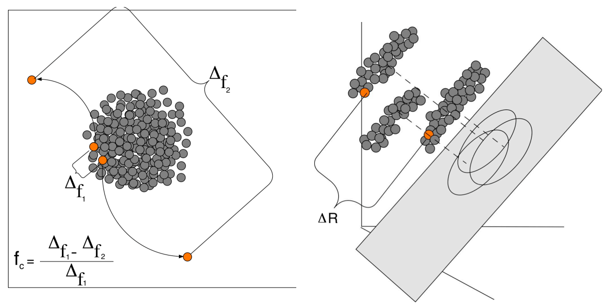


Figure 20: Feedback is parameterized

$\Delta_R^t = [\Delta_{R_x}, \Delta_{R_y}, \Delta_{R_z}]$, is the vector of residues in the high dimensional feature space.

Insights

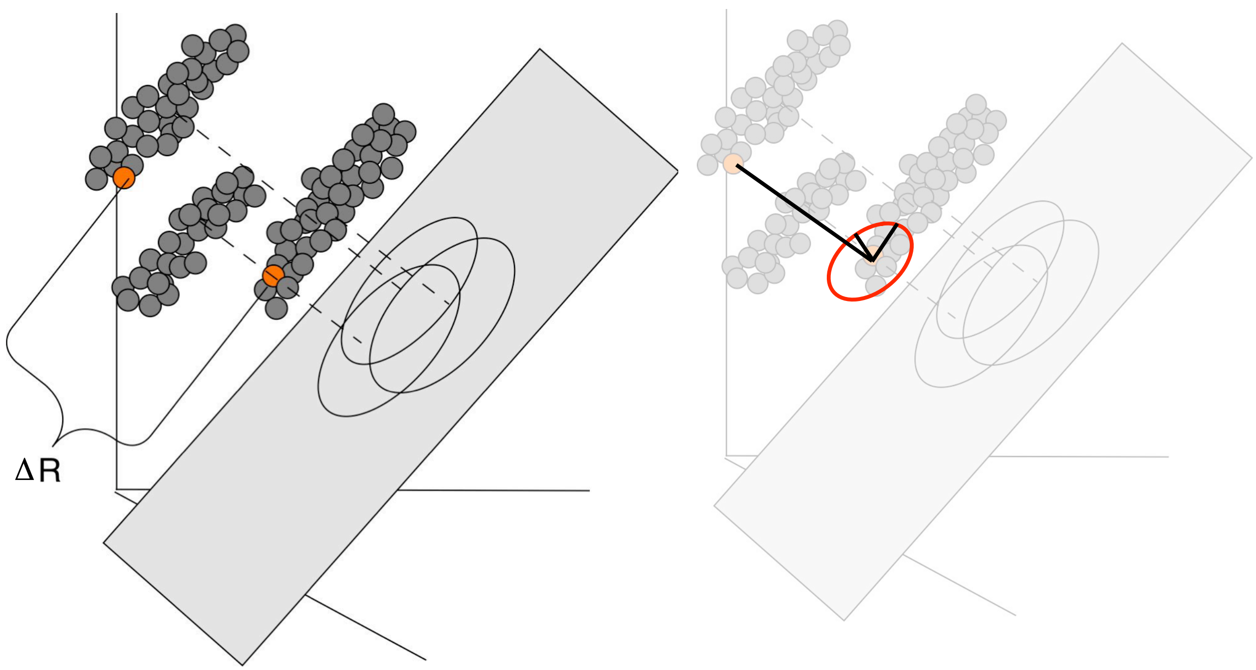


$$
\begin{aligned}
f_p &= \\
(\Delta_R \Delta_R^t)^{[-f_c]} &= \begin{pmatrix} (\Delta_{R_x})^{-2f_c} & (\Delta_{R_x}\Delta_{R_y})^{-f_c} & (\Delta_{R_x}\Delta_{R_z})^{-f_c} \\ (\Delta_{R_y}\Delta_{R_x})^{-f_c} & (\Delta_{R_y})^{-2f_c} & (\Delta_{R_y}\Delta_{R_z})^{-f_c} \\ (\Delta_{R_z}\Delta_{R_x})^{-f_c} & (\Delta_{R_z}\Delta_{R_y})^{-f_c} & (\Delta_{R_z})^{-2f_c} \end{pmatrix}
\end{aligned}
$$

$$g(f_p|\Sigma, f_c) = \text{Inv-Wish}(f_p|\Sigma)$$

Insights

The new principal directions corresponding to the parameterized feedback matrix $f_p = (\Delta_R \Delta_R^t)^{[-f_c]}$ are displayed.



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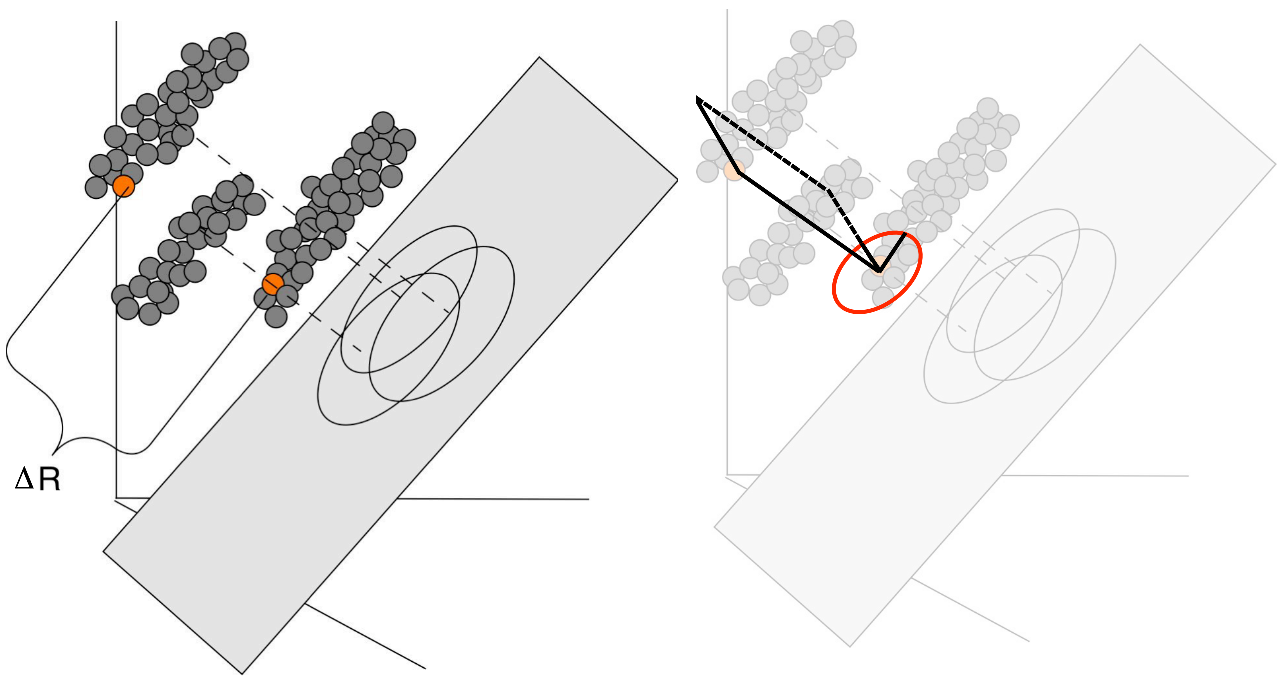

Insights

The system is sequentially updated

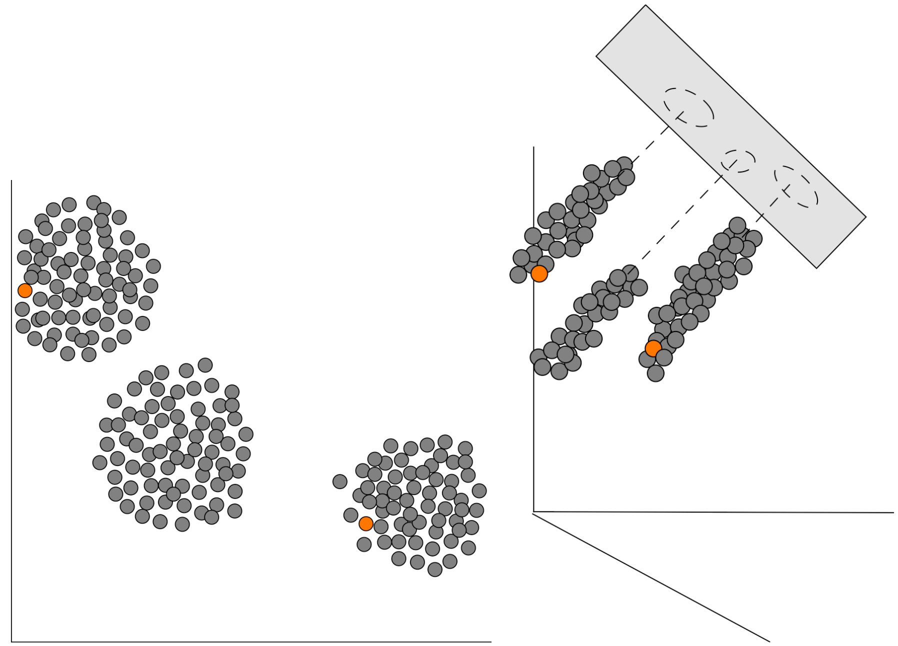

Figure 21: Feedback is parameterized

Insights

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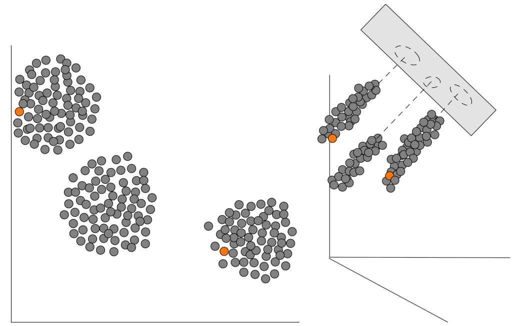

Figure 22: Feedback is parameterized

$$
\begin{aligned}
\pi(\boldsymbol{\theta}|f, v, \boldsymbol{D}) &= \pi(f|v, \boldsymbol{\theta})\pi(\boldsymbol{\theta}|\boldsymbol{D}) / \int \pi(f|v, \boldsymbol{\theta})\pi(\boldsymbol{\theta}|\boldsymbol{D}) d\boldsymbol{\theta} \\
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&= g(f_p|f_c, \boldsymbol{\theta})\pi(f_c|v)\pi(\boldsymbol{\theta}|\boldsymbol{D}),
\end{aligned}
$$

where $f = \{f_p, f_c\}$.

Demonstration

Enough already. Does this actually work??

Conclusion

- Summary:
  - Motivation (Chris)
  - BaVA process (Scotland)
  - Proof of concept by demo (Leanna)

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  - Develop BaVA methods for different types of models e.g., tree diagrams, graphical models
  - Develop meaningful visualizations that relate to update-able parameters
  - Test our tool at PNNL with real analysts

Thank you very much