ML4Seismic Partners Meeting 2023

Effective Data Selection for Seismic Interpretation through Disagreement

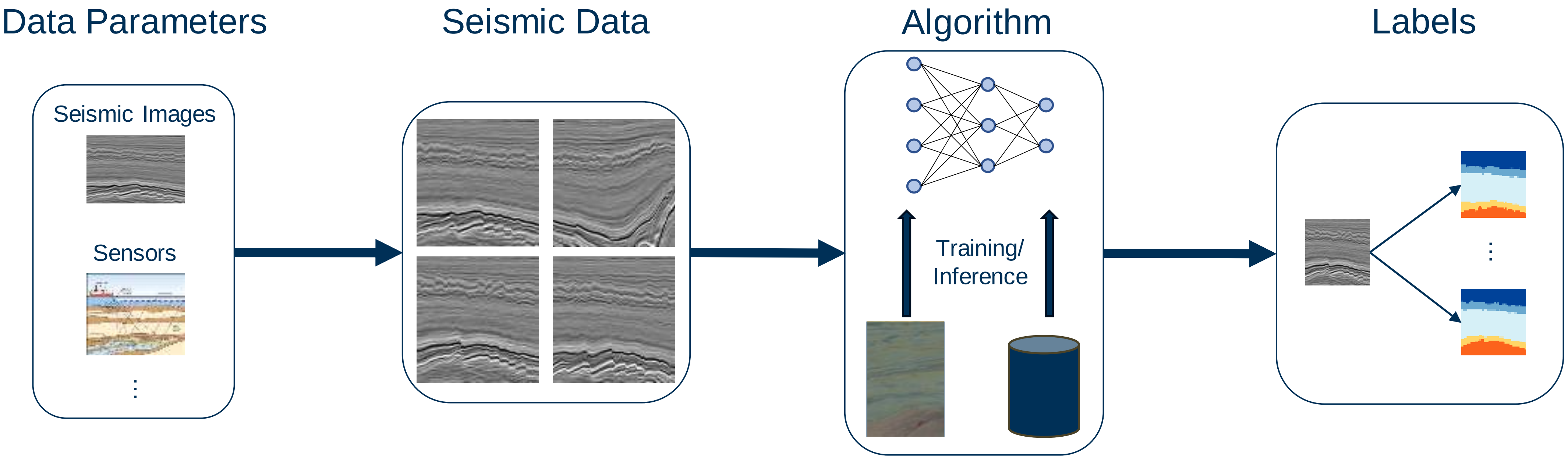
Ryan Benkert, Mohit Prabhushankar, and Ghassan AlRegib

Nov. 7th – Nov. 9th

Proposed Uncertainty Framework

Our Framework Reflects the Processing Steps of the Entire Interpretation Pipeline

Proposed Uncertainty Framework



Data ξ $\xrightarrow{p(X|\xi)}$ Images X $\xrightarrow{p(\alpha|X,W)}$ Interpretations $\boldsymbol{\alpha = Y}$

Data Uncertainty | **Model Uncertainty** | **Interpretational Uncertainty**

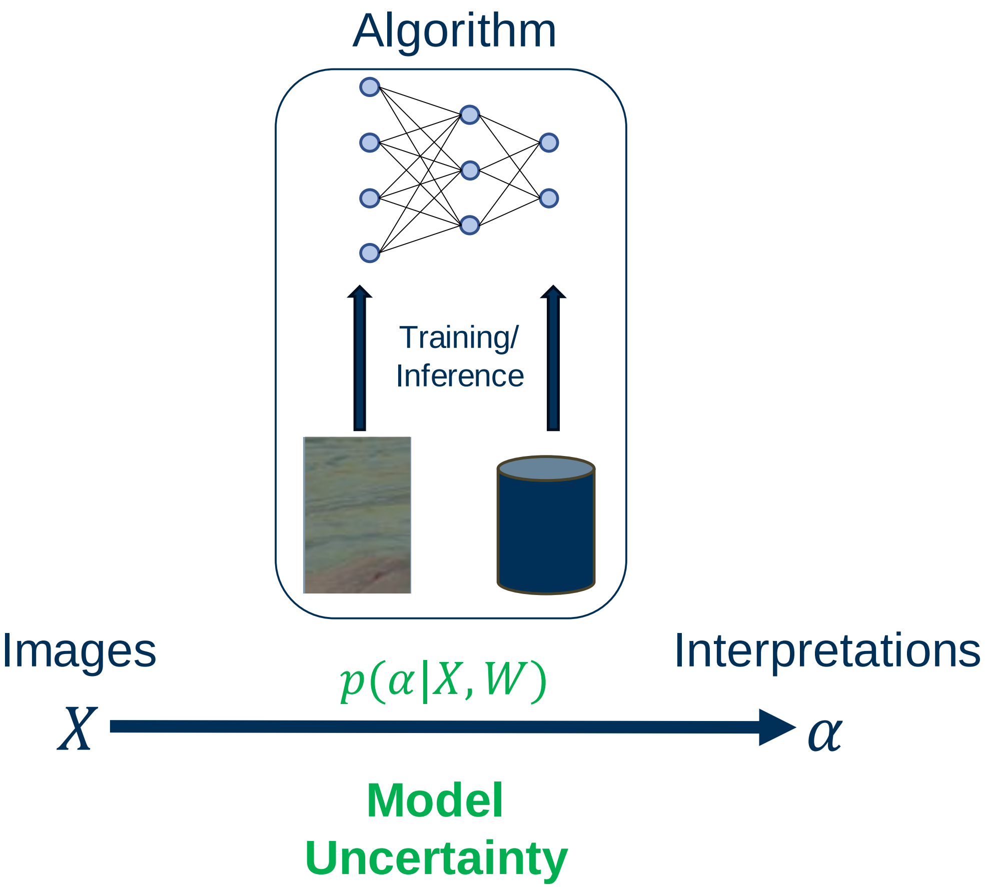
Proposed Uncertainty Framework

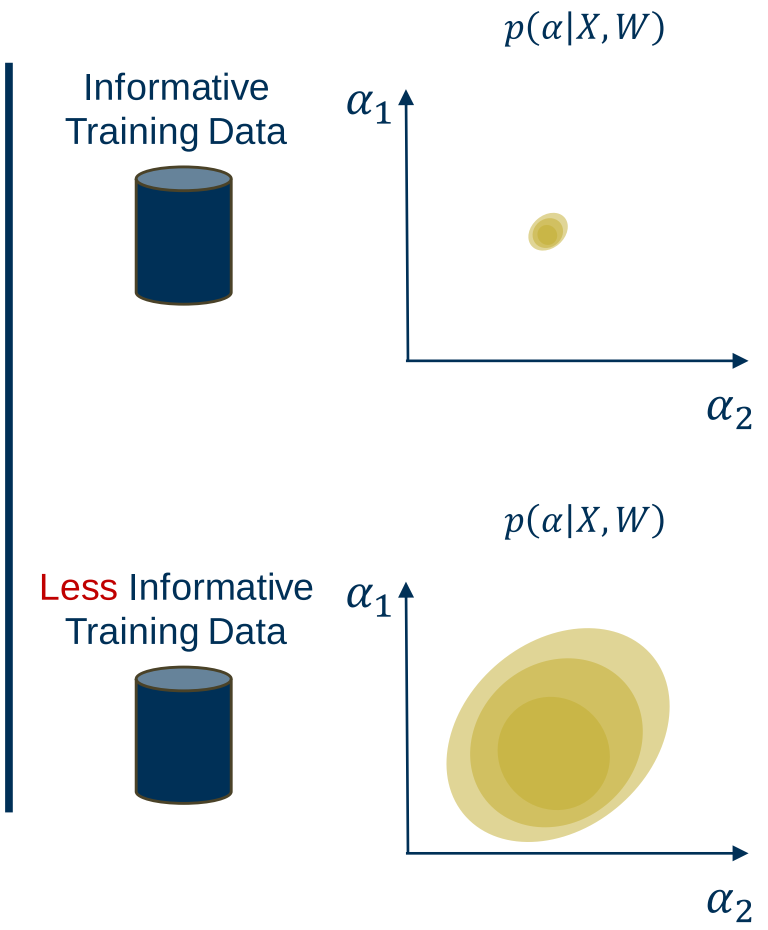
Our Framework Reflects the Processing Steps of the Entire Interpretation Pipeline

Proposed Uncertainty Framework

Model Uncertainty:

- Uncertainty in the **model parameters**
- Depends on the **information content** of the training data
- Heavily influenced by training **data selection**

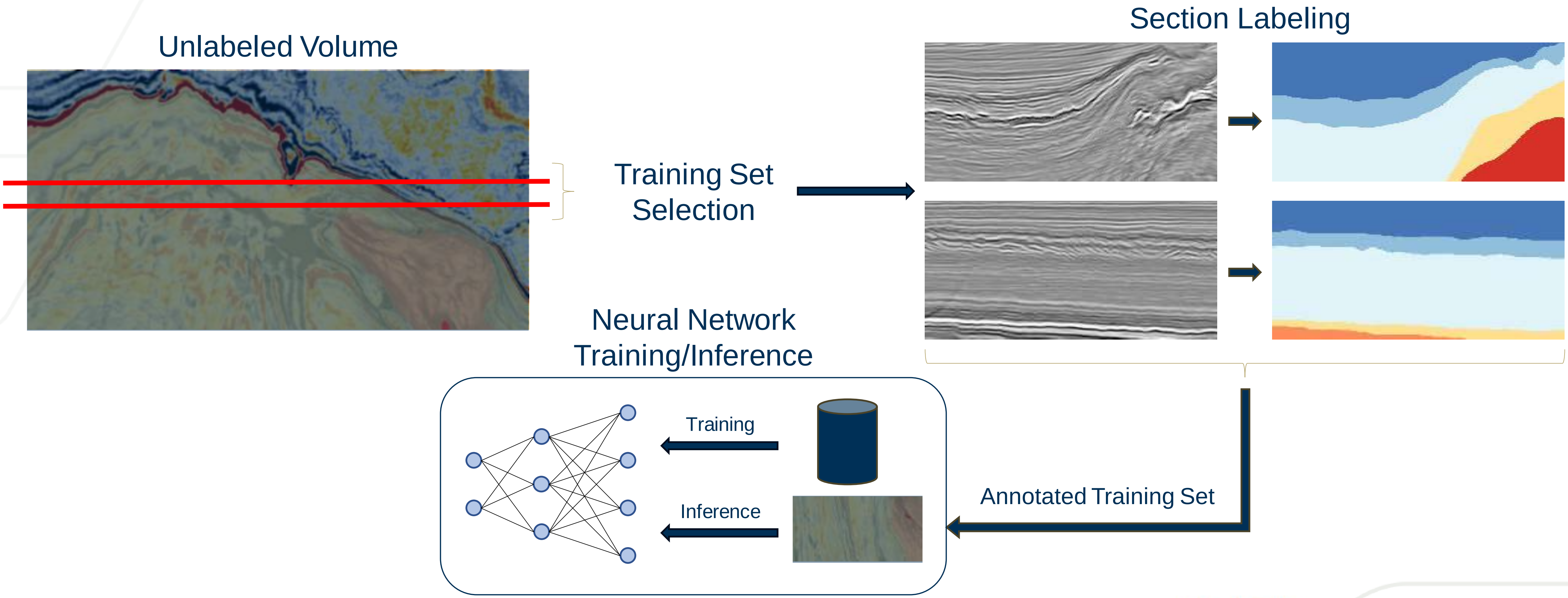




Dataset Selection for Seismic Interpretation

Training Set Selection Severely Impacts the Performance of Deep Neural Networks

Automated Seismic Interpretation Workflow



Dataset Selection for Seismic Interpretation

Training Set Selection Severely Impacts the Performance of Deep Neural Networks

Automated Seismic Interpretation Workflow

Which samples must be labeled to maximize the interpretation performance?

Dataset Selection for Seismic Interpretation
Training Set Selection Severely Impacts the Performance of Deep Neural Networks

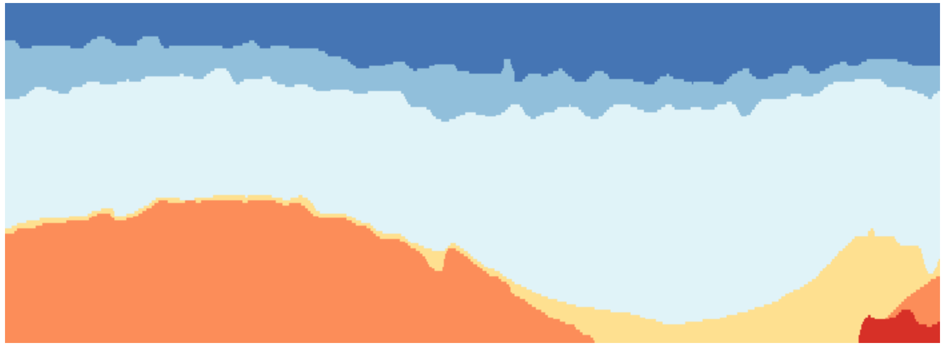
Training Set Selection is a Paramount Factor in Prediction Performance

Selected Training Samples (Toy)

- **Annotations are limited** in seismic datasets
- **Naively** selected training sets can result in **poor performance**

Test Set Prediction

Manual Interpretation

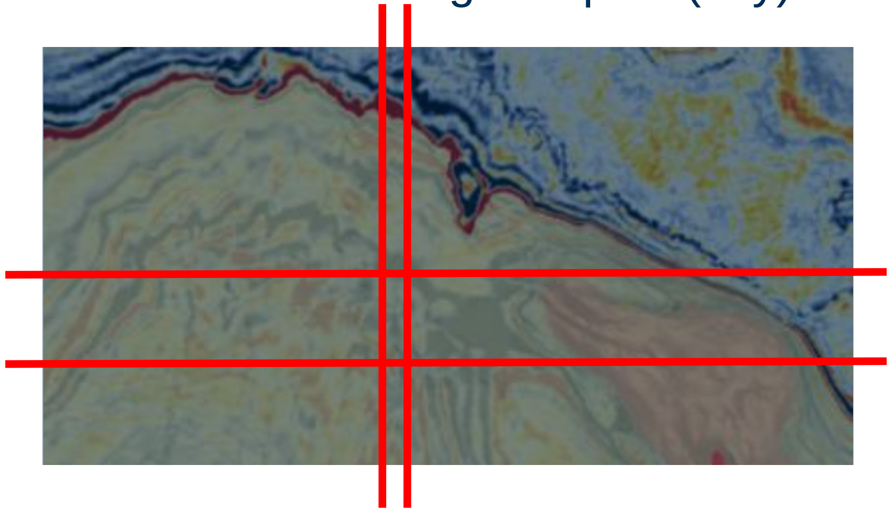


Dataset Selection for Seismic Interpretation

Training Set Selection Severely Impacts the Performance of Deep Neural Networks

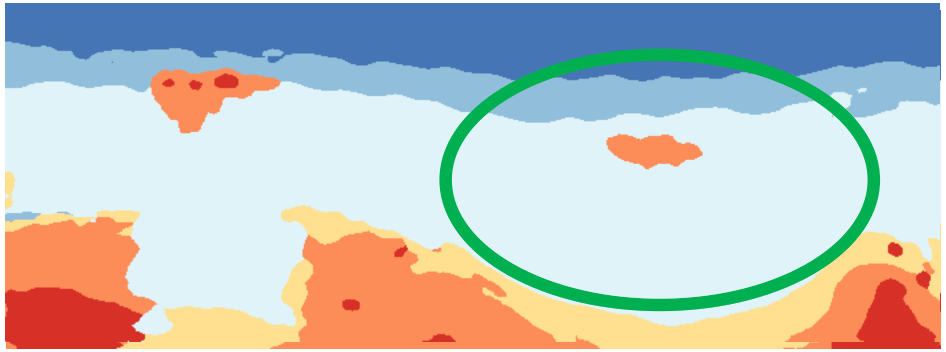
Training Set Selection is a Paramount Factor in Prediction Performance

Selected Training Samples (Toy)

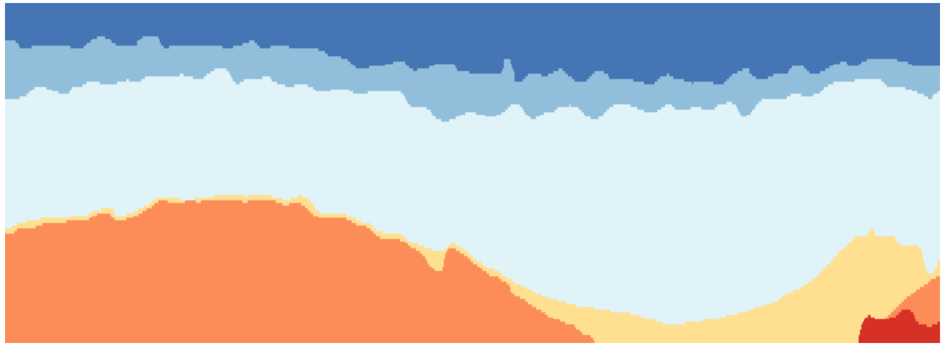


- **Annotations are limited** in seismic datasets
- **Selecting efficiently increases generalization**

Test Set Prediction

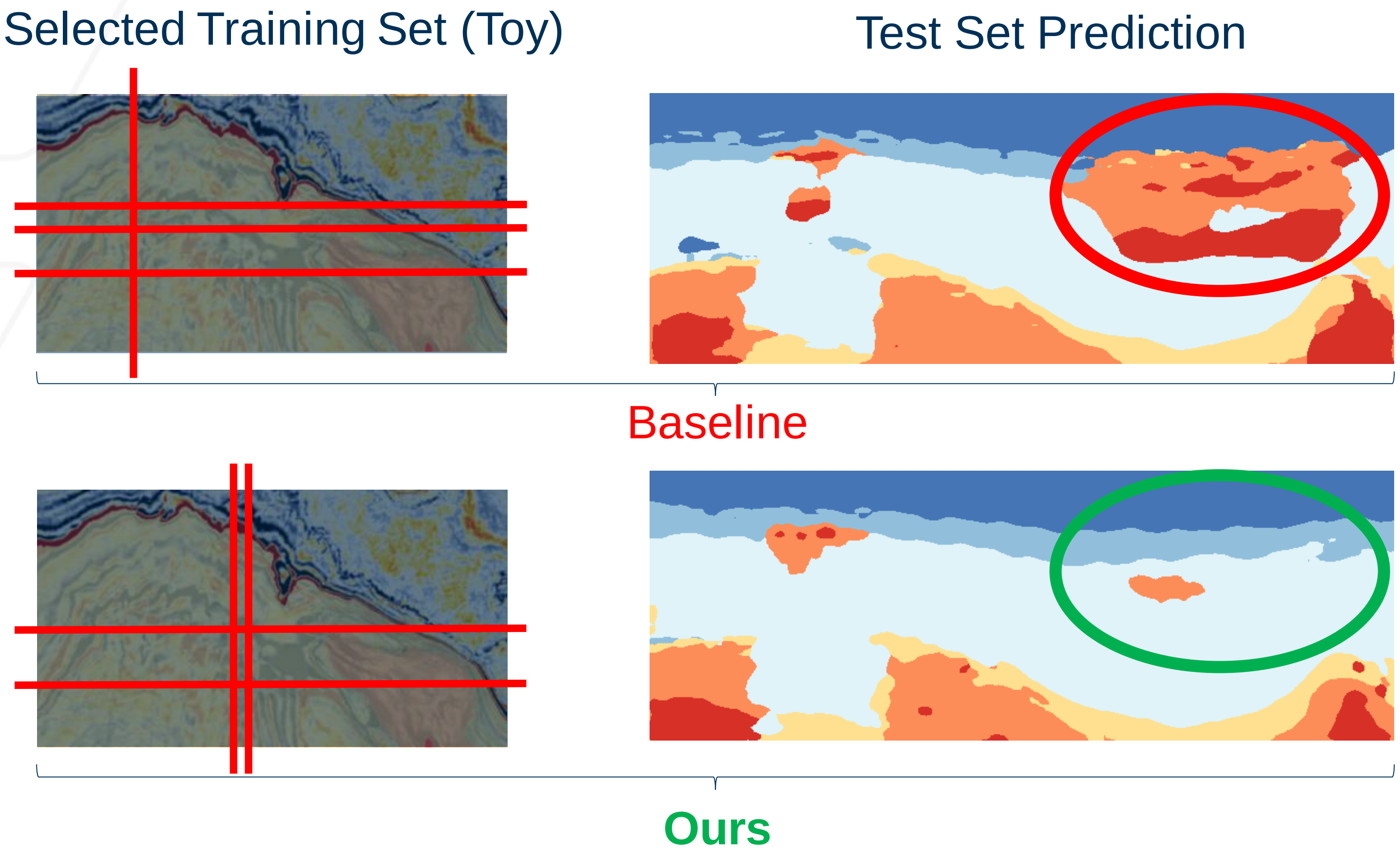


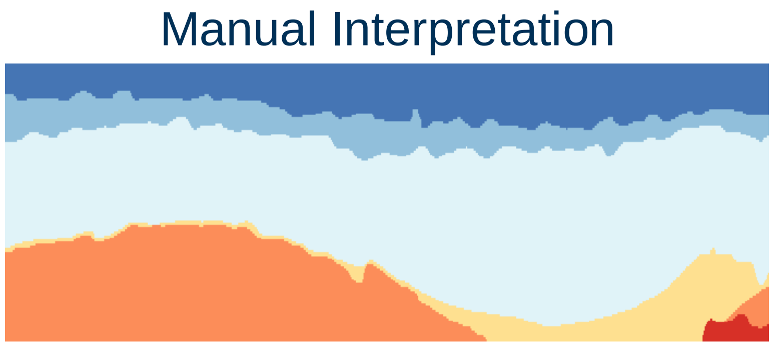
Manual Interpretation



We Integrate Disagreement into Data-Selection for Seismic Interpretaion

Contributions: Integrating Disagreement in Data-Selection for Seismic Interpretation





Contributions:

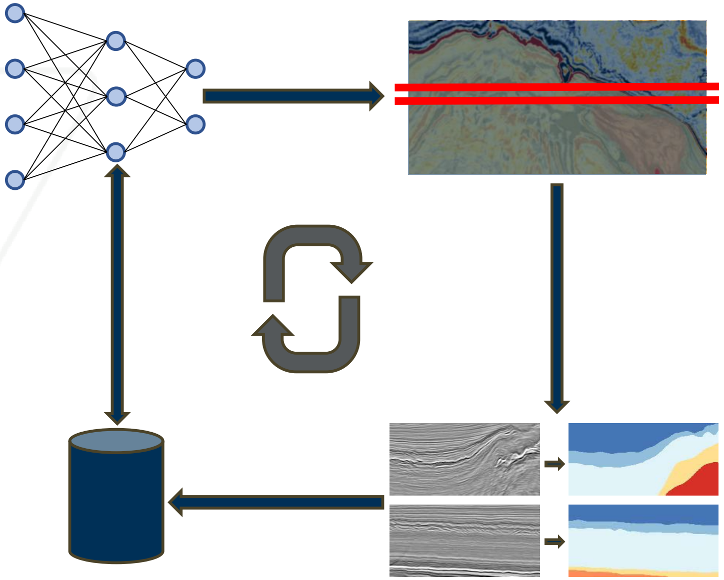
- Discuss **disagreement** as a method to **reduce model uncertainty**
- A theoretically grounded **definition** of disagreement **for neural networks**
- An **automated selection framework** for seismic interpretation

Presentation Structure and Outline

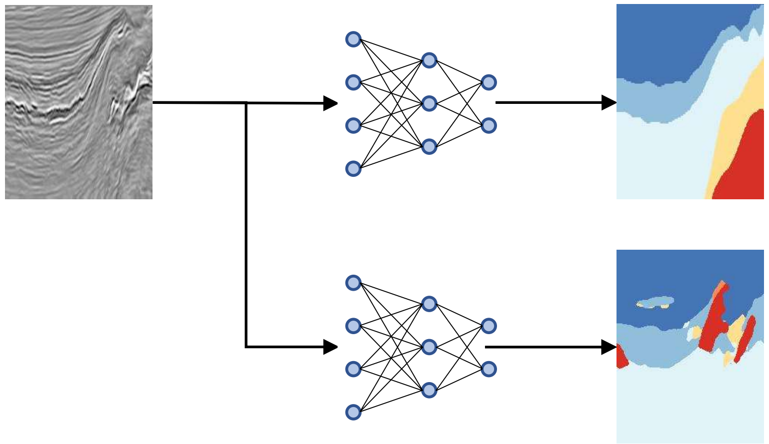
Discussion Topics are Active Learning, ATLAS, and Results

Contributions: Integrating Disagreement in Data-Selection for Seismic Interpretation

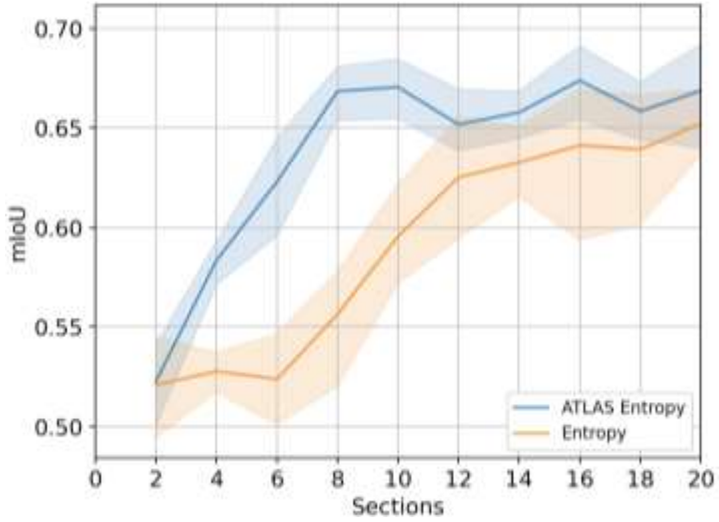
Background: Active Learning



Method: Disagreement



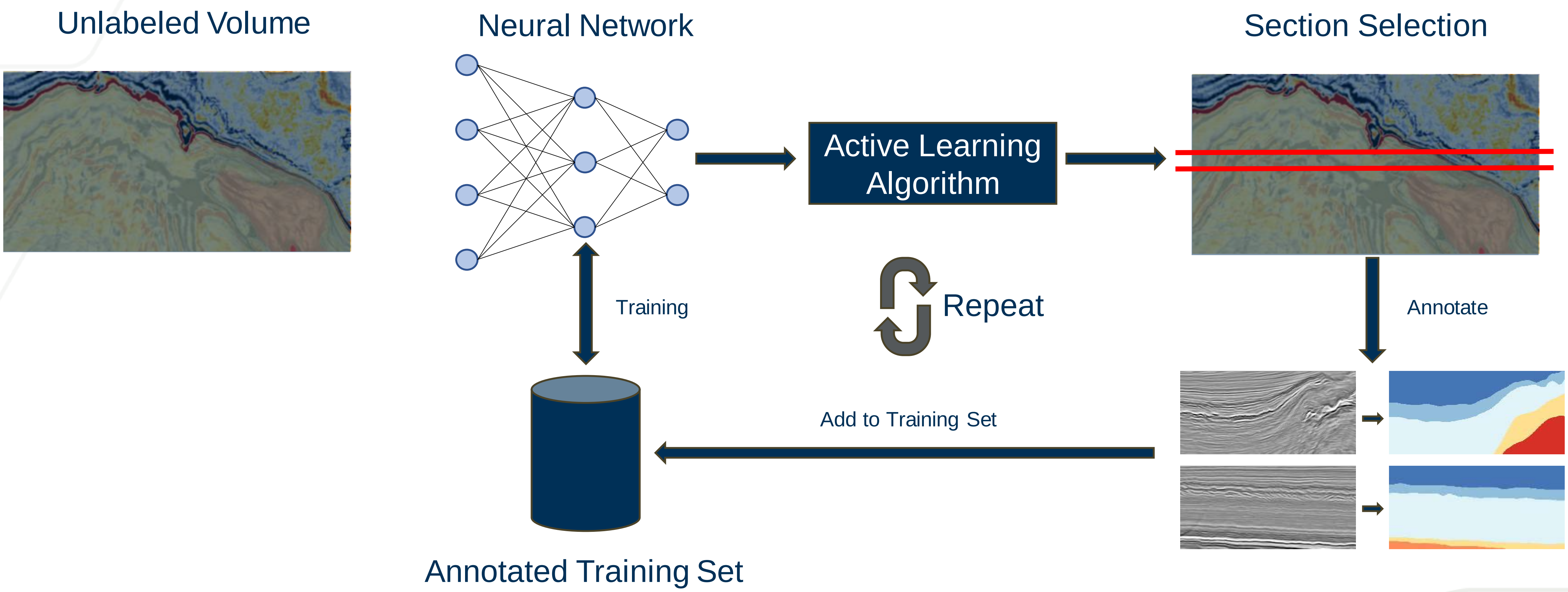
Results: Disagreement



Background: Active Learning

Active Learning is a Machine Learning Paradigm for Efficient Data Selection

Conventional Active Learning Workflow



Cohn, David A., Zoubin Ghahramani, and Michael I. Jordan. "Active learning with statistical models." *Journal of artificial intelligence research* 4 (1996): 129-145.

Background: Active Learning

Active Learning is a Machine Learning Paradigm for Efficient Data Selection

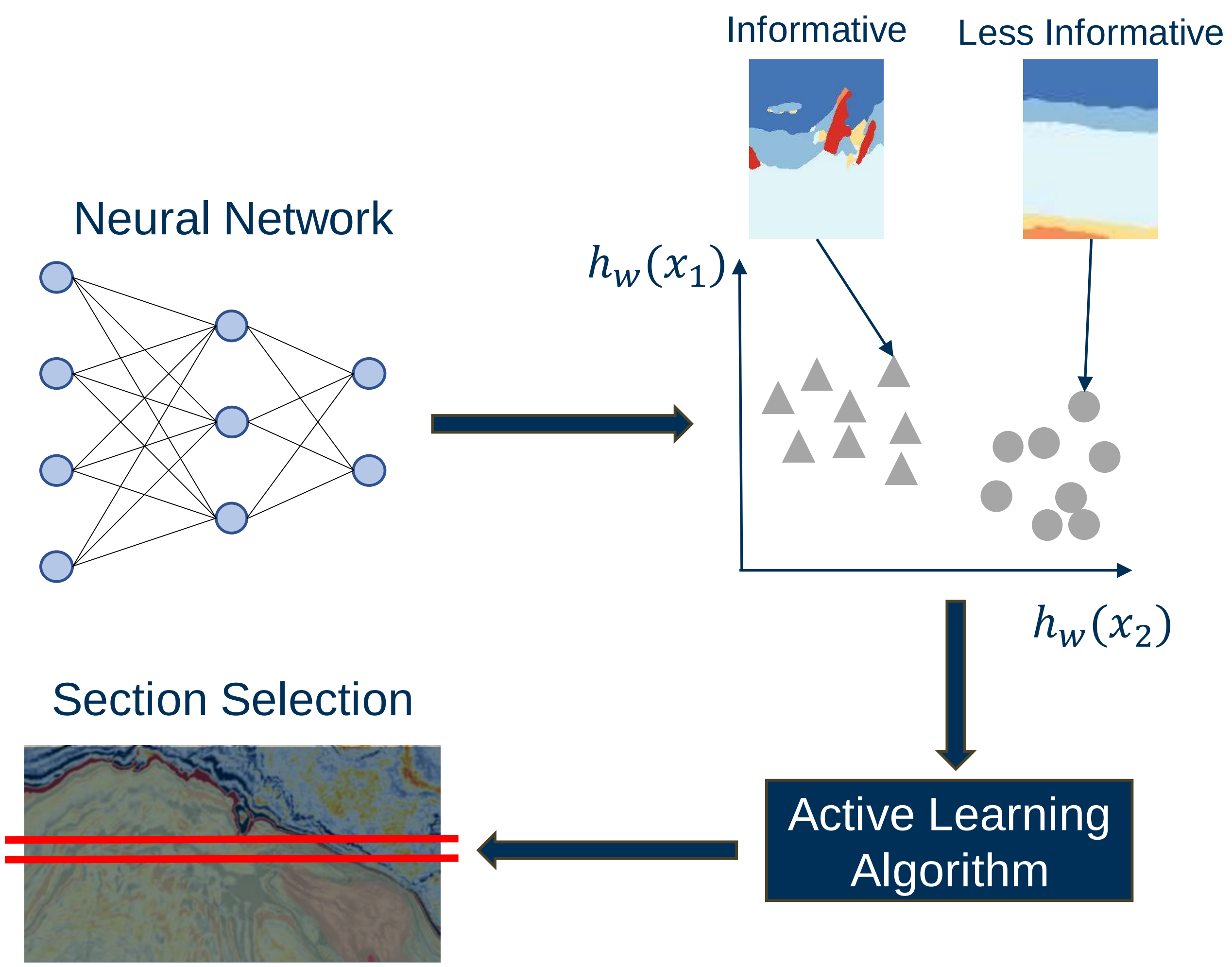
Conventional Active Learning Workflow

- Active learning selects samples using an acquisition function to rank representations

$$\underset{x_1,\ldots,x_b \in D_{pool}}{\operatorname{argmax}} \; a(x_1,\ldots,x_b|h_w)$$

- For an effective selection, the input **representations must be separable** based on their information content

- **Interesting geological** regions are frequently **underrepresented** and **collapse** to single data-points



Background: Active Learning

Active Learning is a Machine Learning Paradigm for Efficient Data Selection

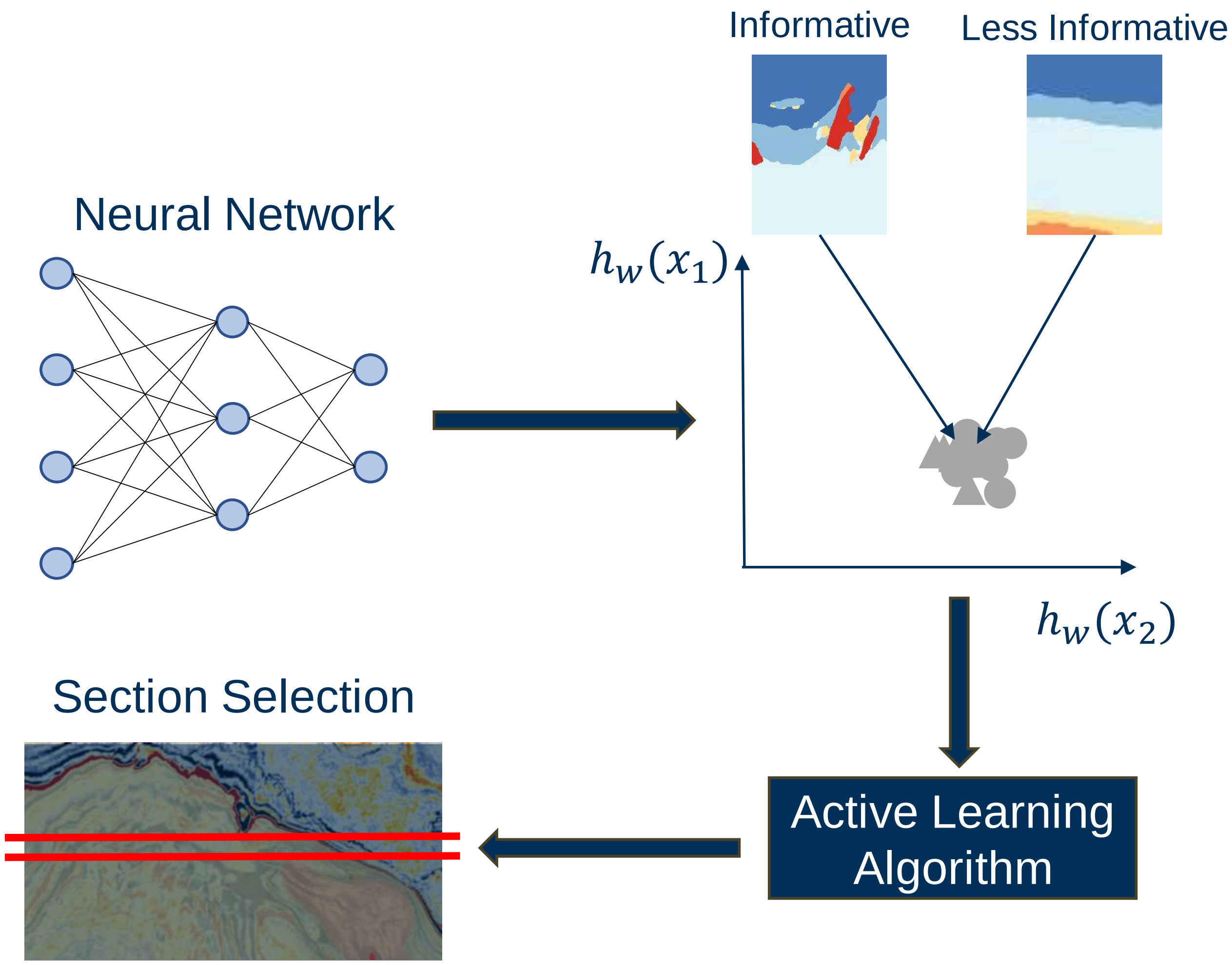
Conventional Active Learning Workflow

- Active learning selects samples using an acquisition function to rank representations

$$\underset{x_1,\ldots,x_b \in D_{pool}}{\operatorname{argmax}} \; a(x_1, \ldots, x_b | h_w)$$

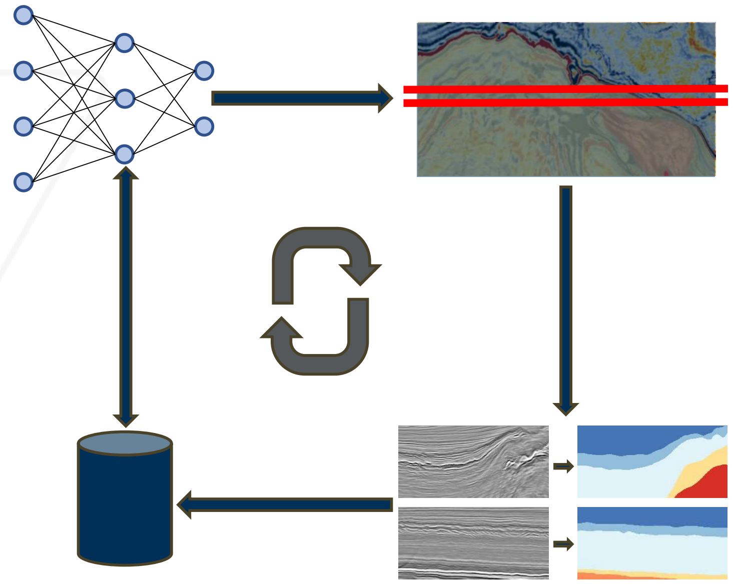
- For an effective selection, the input **representations must be separable** based on their information content

- **Interesting geological** regions are frequently **underrepresented** and **collapse** to single data-points

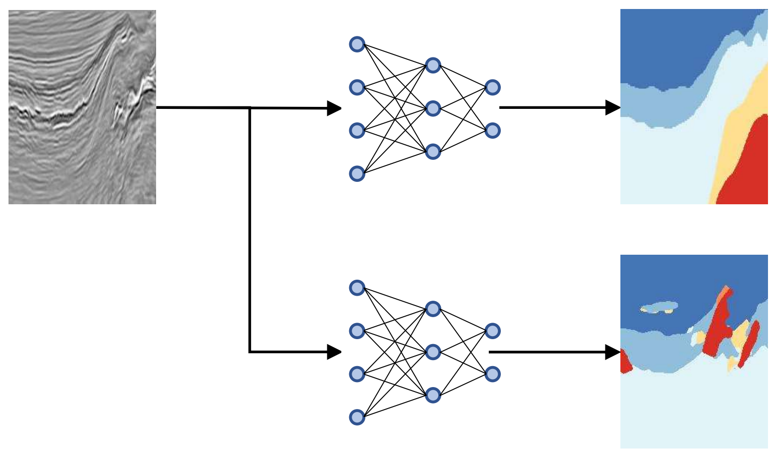


Contributions: Integrating Disagreement in Data-Selection for Seismic Interpretation

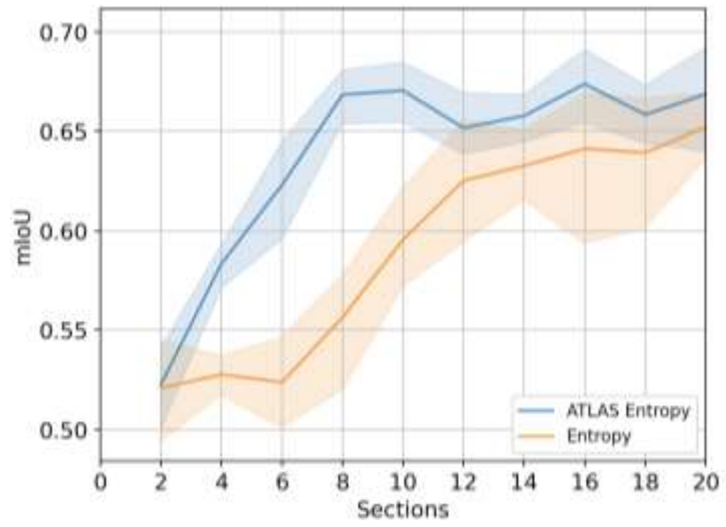
Background: Active Learning



Method: Disagreement



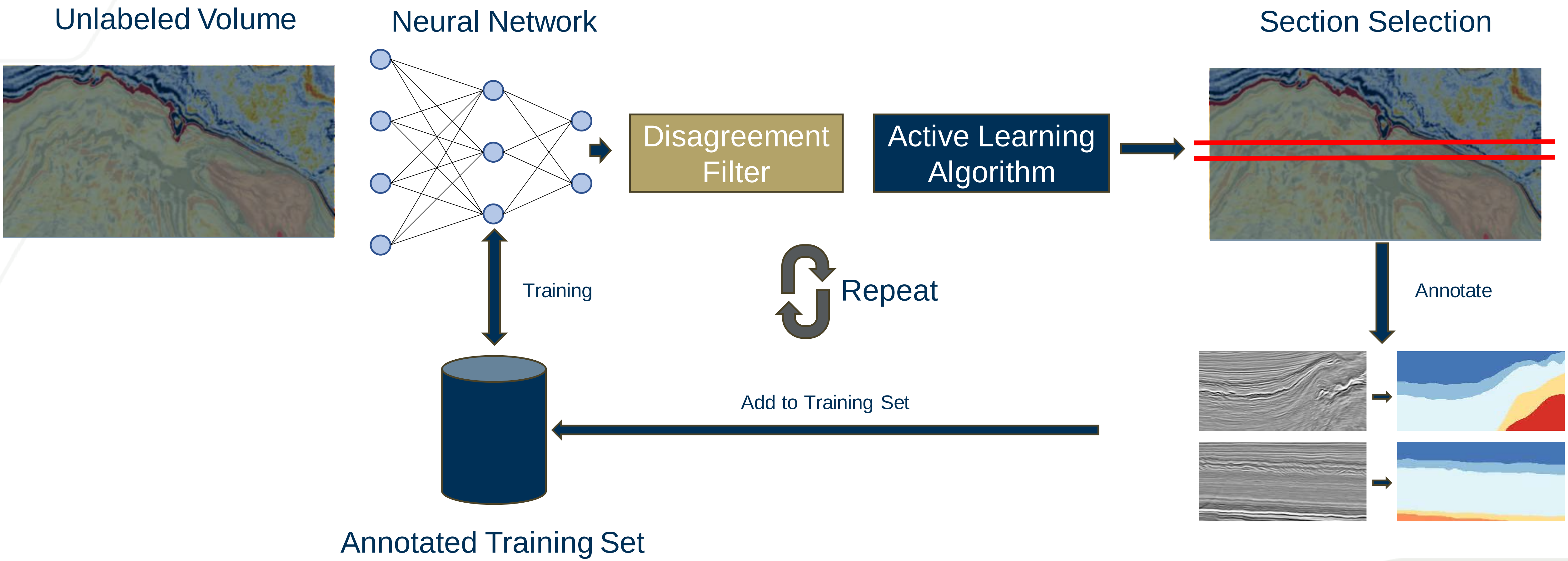
Results: Disagreement



Method: Spatially-Aware Active Learning

Seismic Interpretation Requires Spatial Awareness in Data Selection

Spatially-Aware Active Learning Workflow



Method: Spatially-Aware Active Learning

Active Learning is a Machine Learning Paradigm for Efficient Data Selection

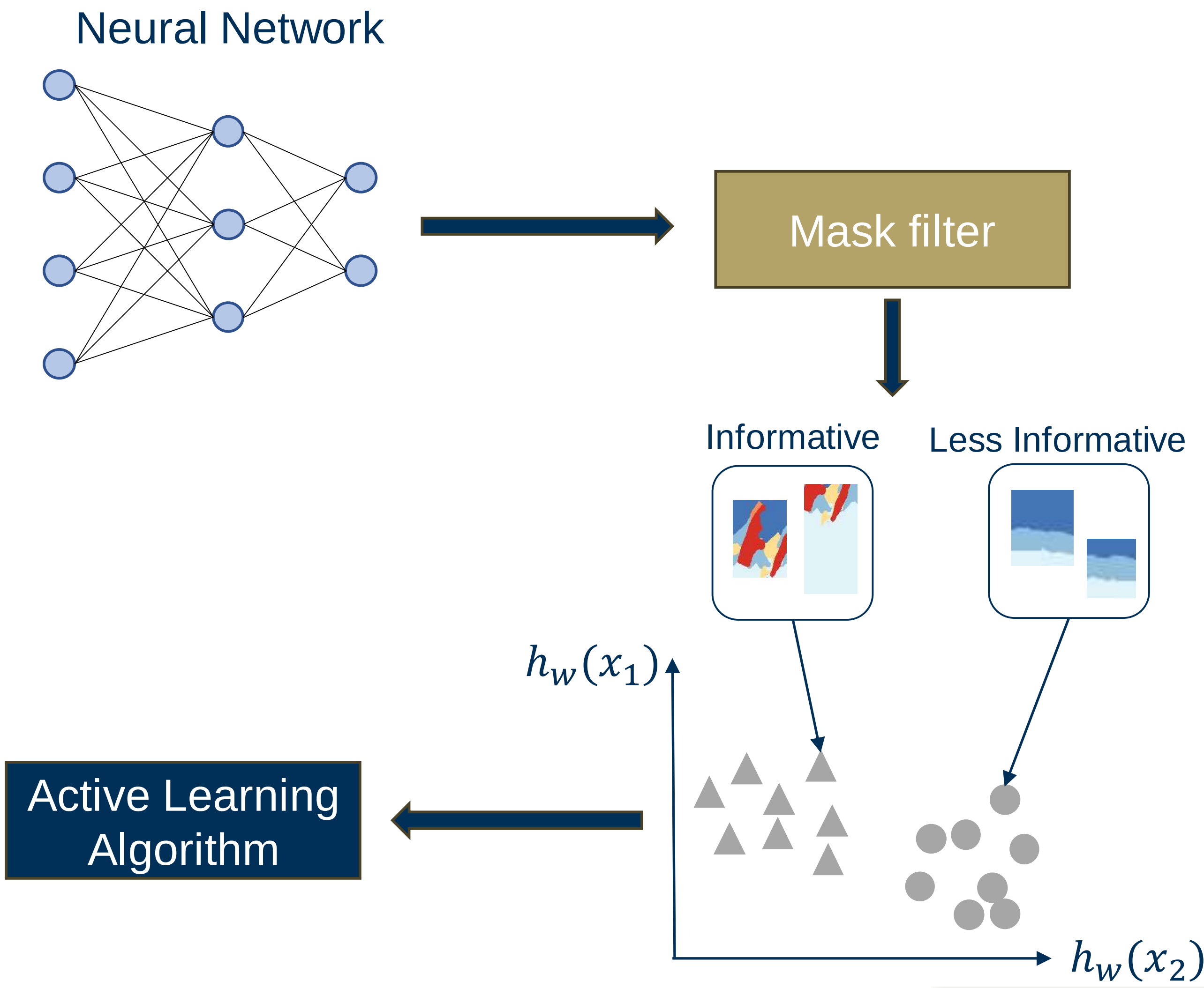
Spatially-Aware Active Learning Workflow

- **Spatially-Aware Active Learning** uses a modified acquisition function

$$\underset{x_1,\ldots,x_b \in D_{pool}}{\operatorname{argmax}} \; a(\boldsymbol{\phi}(x_1, h_w), \ldots, \boldsymbol{\phi}(x_b, h_w) | h_w)$$

where the input is a mask filter

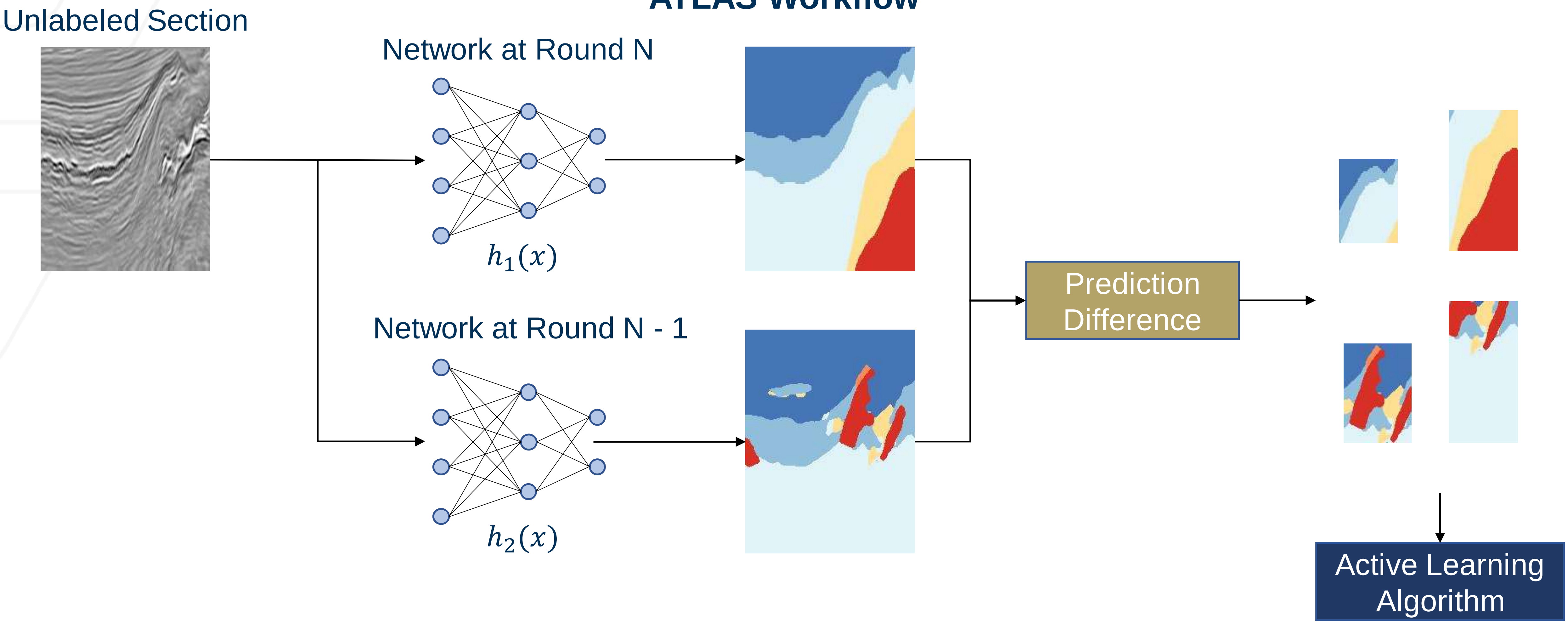
$$\phi(x, h_w) = x * m(x, h_w)$$



Method: Active Transfer Learning for Attention Sensitivity (ATLAS)

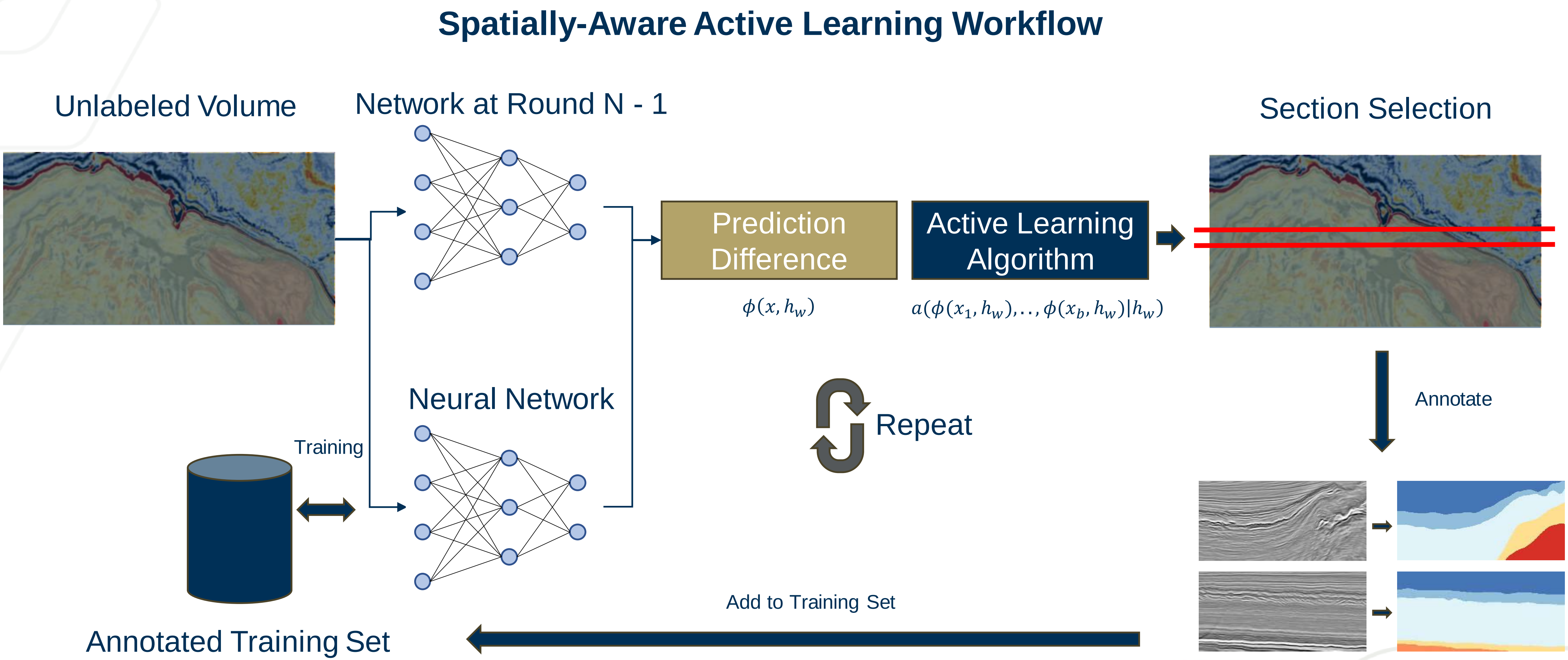
ATLAS is a Simple Implementation of Spatially-Aware Active Learning with Prediction Switches

ATLAS Workflow



Method: ATLAS – Full Workflow

ATLAS is a Simple Implementation of Spatially-Aware Active Learning with Prediction Switches

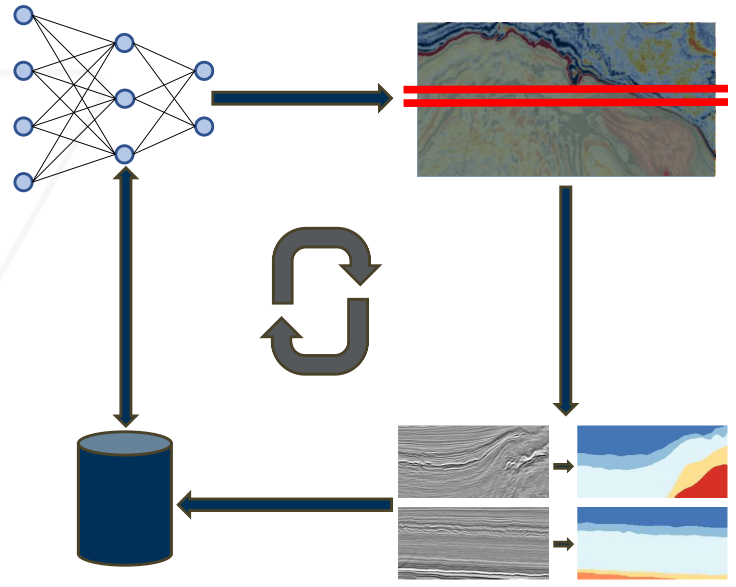


Presentation Structure and Outline

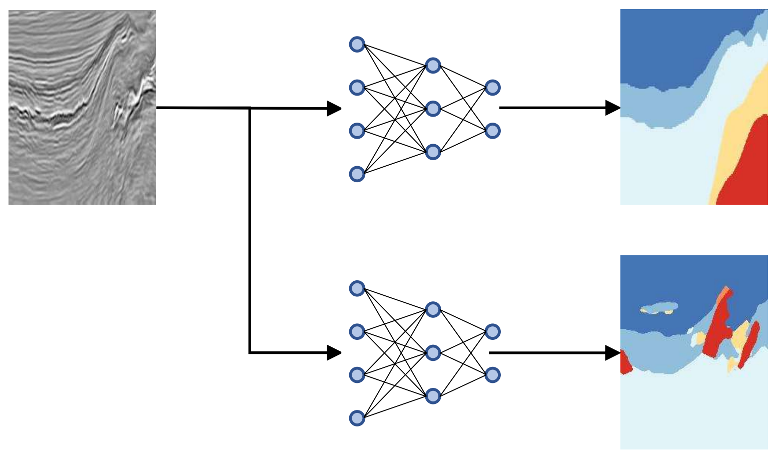
Discussion Topics are Active Learning, ATLAS, and Results

Contributions: Integrating Disagreement in Data-Selection for Seismic Interpretation

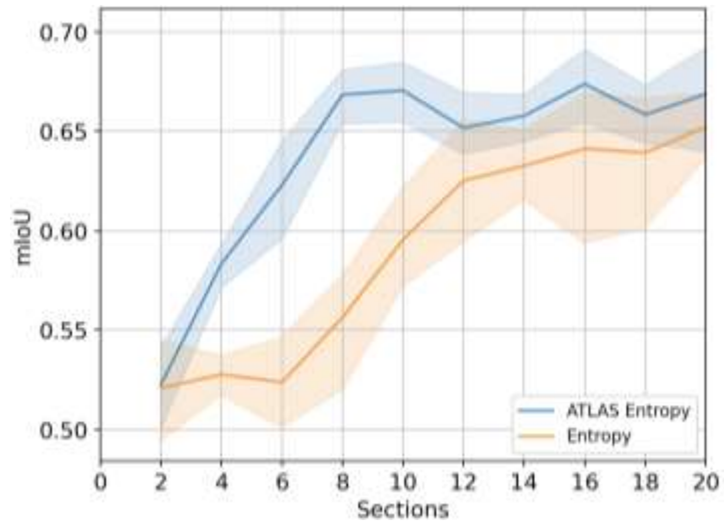
Background: Active Learning



Method: Disagreement



Results: Disagreement

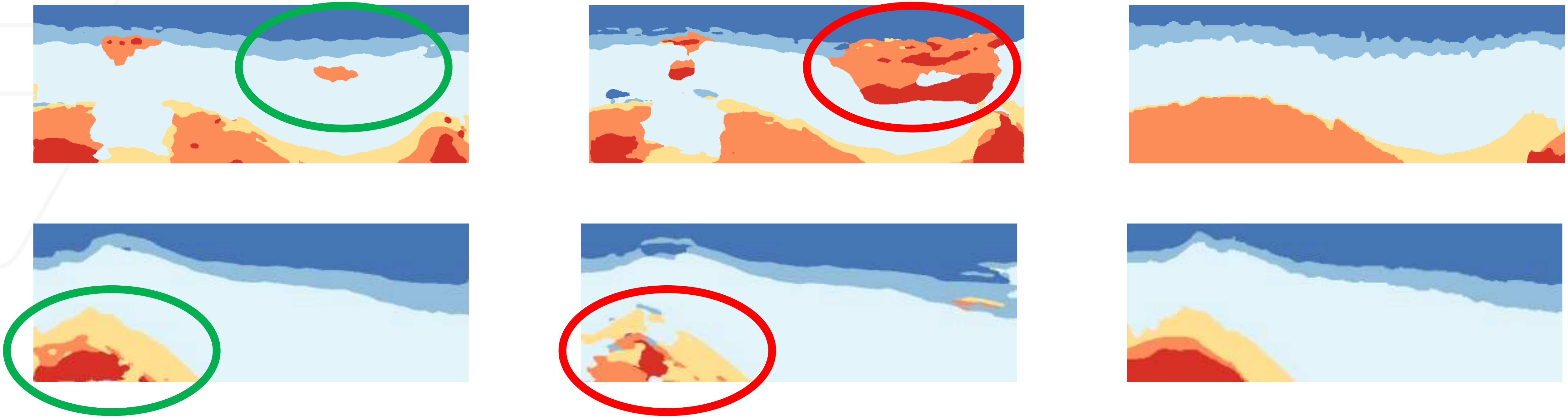


Results: ATLAS – Qualitative Results

ATLAS Matches or Outperforms the Baseline

Qualitative Results – Least Confidence Predictions with or without ATLAS

ATLAS Least Confidence | Least Confidence | Manual Interpretation



ATLAS matches or improves over conventional Active Learning.

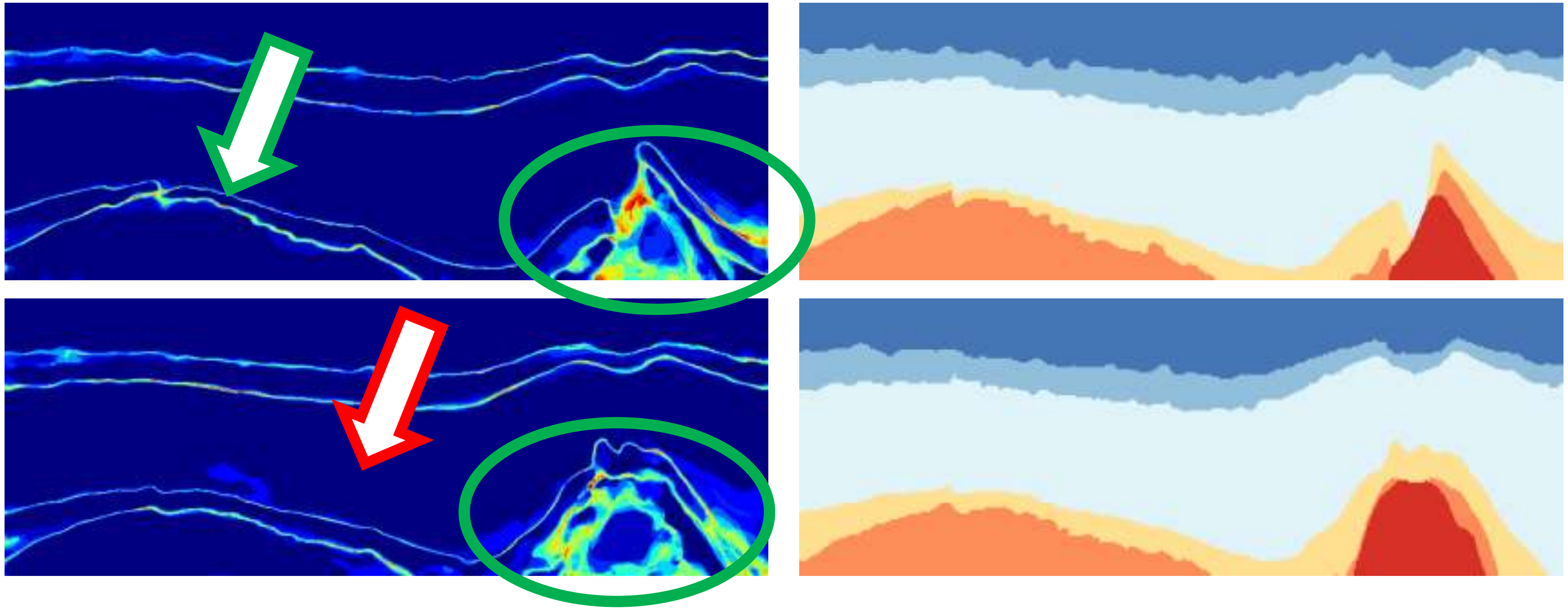
Results: ATLAS – Qualitative Results
ATLAS Matches or Outperforms the Baseline

Qualitative Results – Areas ATLAS Focuses On

Regions **ATLAS Filters**:
- Class **boundaries**
- Difficult **structures**
- **Underrepresented** classes
- …

Regions **ATLAS Ignores**:
- **Well-represented** facies
- **Monotonous** structures
- …

Filtered Regions Across All Rounds | Manual Interpretation

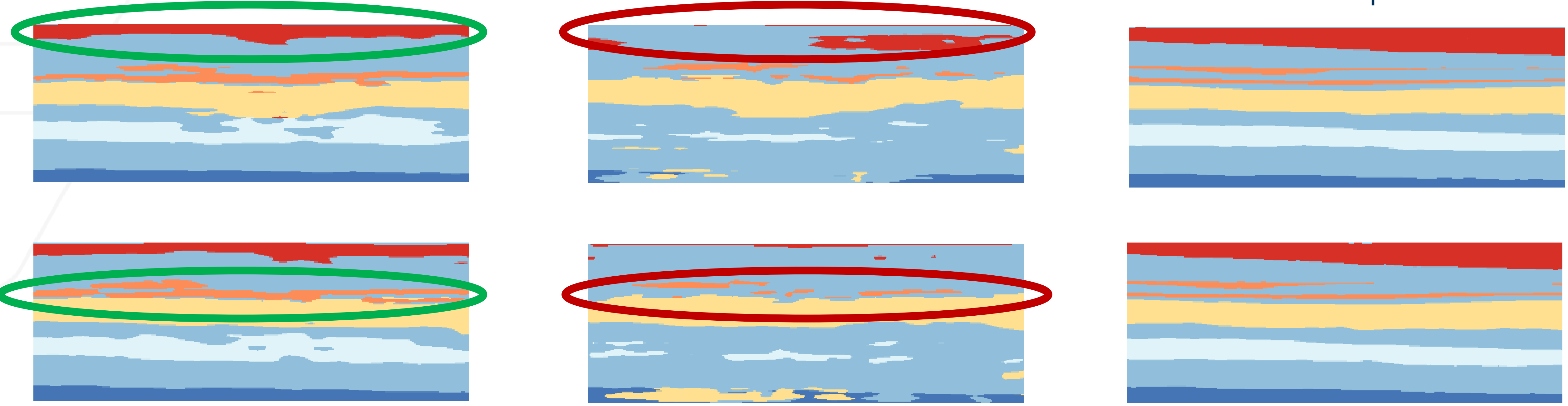


Results: ATLAS – Qualitative Results

ATLAS Matches or Outperforms the Baseline

Qualitative Results – Least Confidence Predictions with or without ATLAS

ATLAS Least Confidence | Least Confidence | Manual Interpretation



ATLAS performs especially well on class boundaries

OLIVES @GeorgiaTech

Georgia Tech

Results: ATLAS – Numerical Results

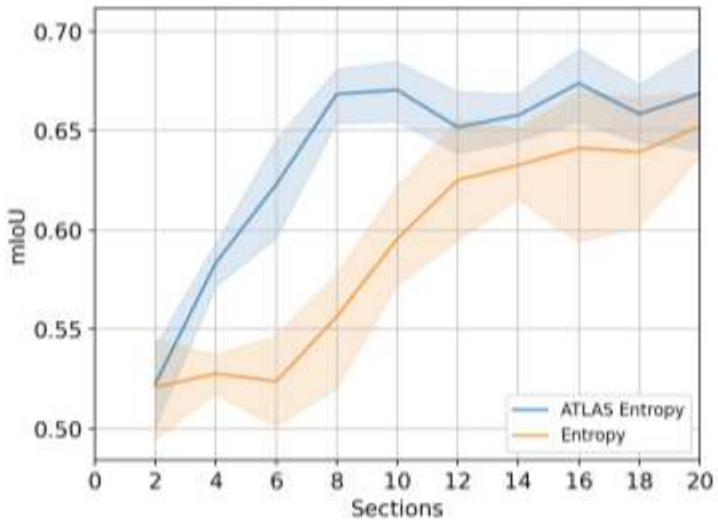
ATLAS Matches or Outperforms the Baseline

Numerical Results

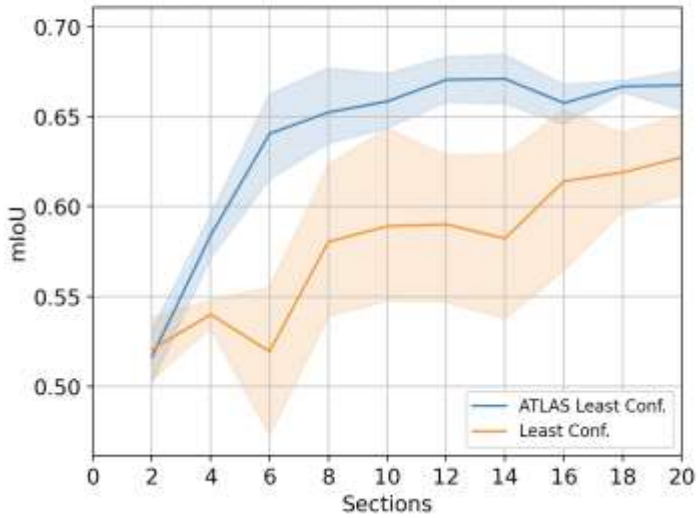
Experimental Details:

Dataset: F3 block
Initial training size: 2 Sections
Query Size: 2 Sections

Entropy



Least Confidence



Algorithm	mIoU	Upper N.S.	Mid. N.S.	Lower N.S.	Chalk	Scruff	Zechstein
Entropy	0.591	0.975	0.846	0.950	0.636	0.373	**0.461**
ATLAS Entropy	**0.620**	**0.976**	**0.872**	**0.957**	**0.651**	**0.495**	0.417
Least Conf.	0.575	0.970	0.808	0.944	0.637	0.388	0.430
ATLAS Least Conf.	**0.619**	**0.974**	**0.869**	**0.956**	**0.653**	**0.480**	**0.459**

Thanks for Listening

Questions?

ML4SEISMIC

OLIVES
@GeorgiaTech

Publications **Code**

Active Learning is a Machine Learning Paradigm for Efficient Data Selection

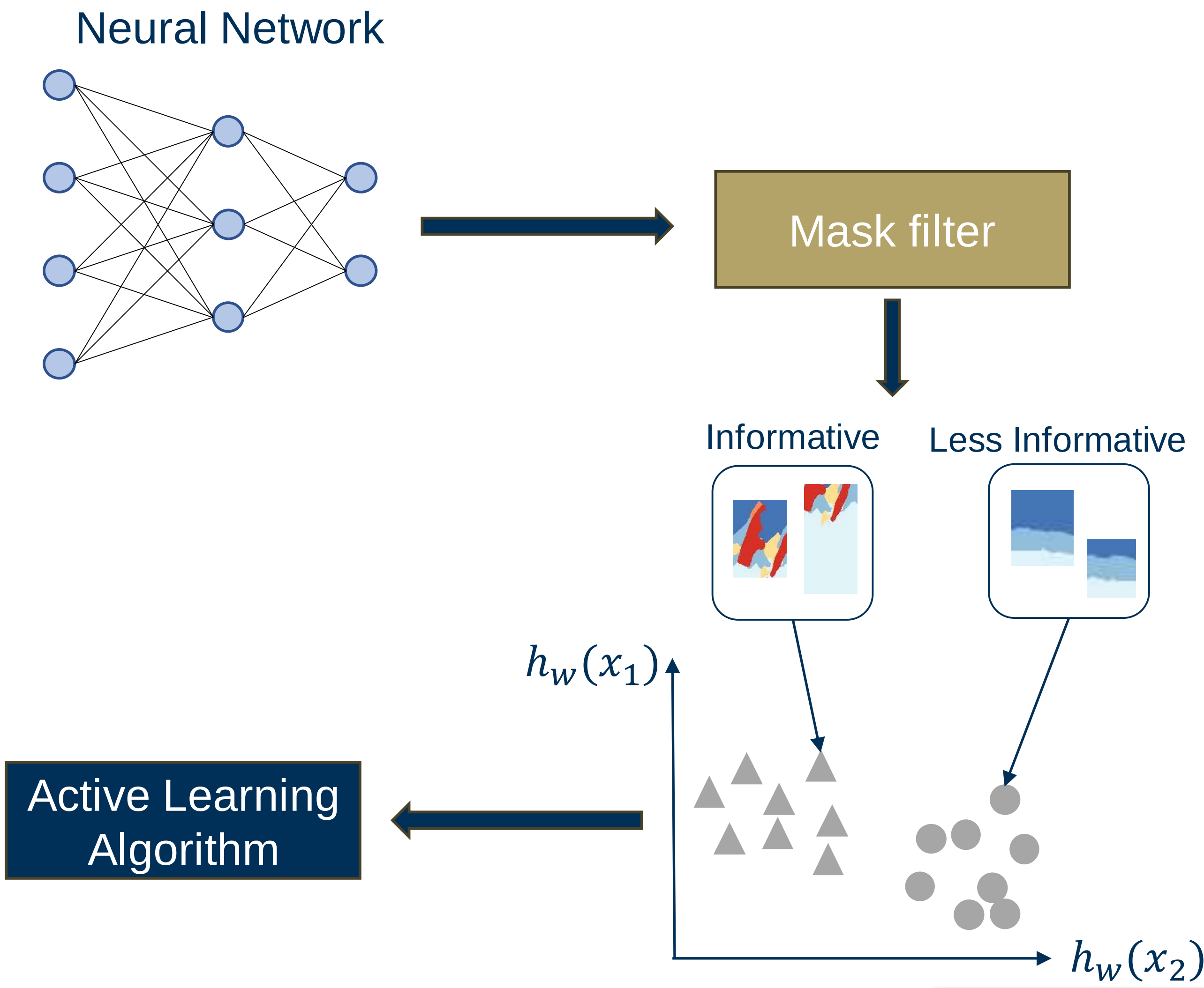
Spatially-Aware Active Learning Workflow

- **Spatially-Aware Active Learning** uses a modified acquisition function

$$\underset{x_1,\ldots,x_b \in D_{pool}}{\operatorname{argmax}} \; a(\boldsymbol{\phi}(x_1, h_w), \ldots, \boldsymbol{\phi}(x_b, h_w) | h_w)$$

where the input is a mask filter

$$\phi(x, h_w) = x * m(x, h_w)$$



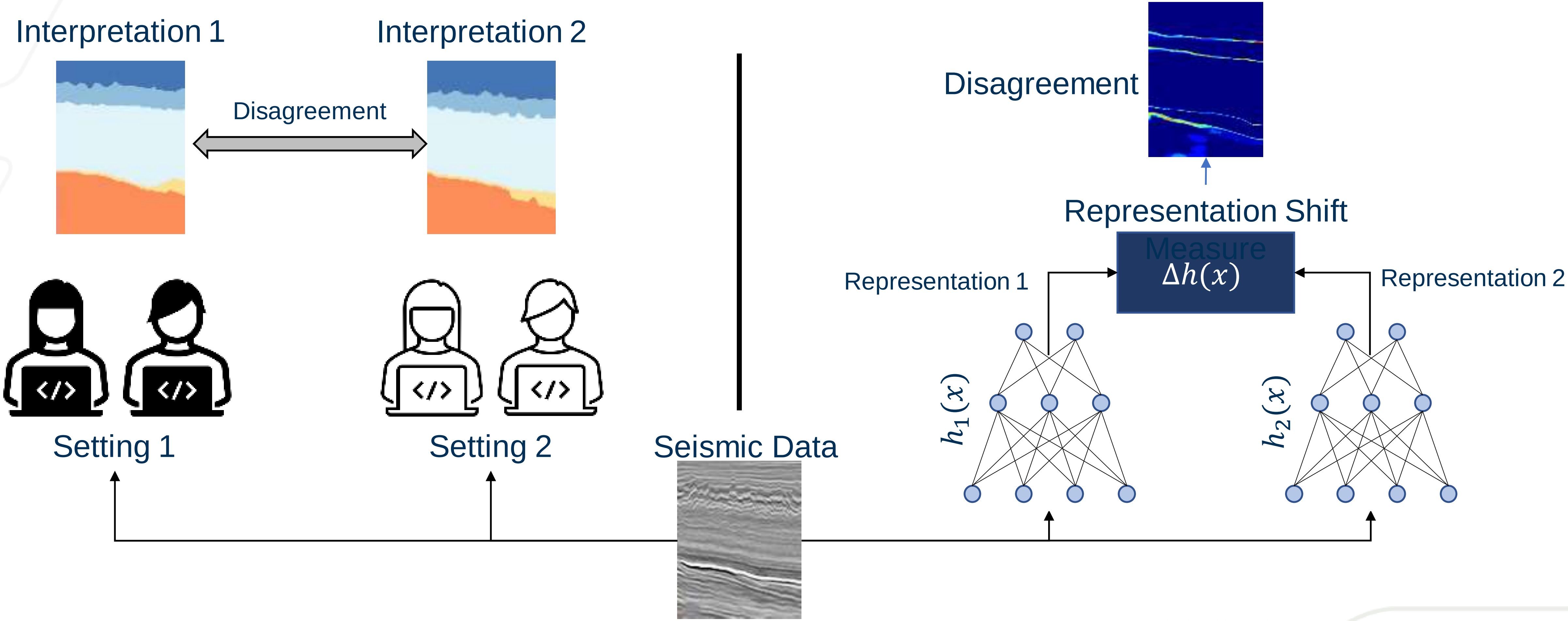
We model geological interest as interpretation disagreement.

Method: Geological Interest as Disagreement

Disagreement Mimics the Manual Interpretation Process and is Beneficial for Data Selection

Interpretation Disagreement

Representation Disagreement



OLIVES @GeorgiaTech

Georgia Tech

Method: Geological Interest as Disagreement

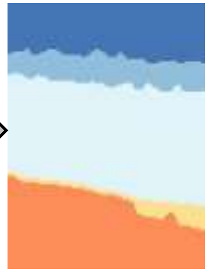
Disagreement Mimics the Manual Interpretation Process and Measures Information Content

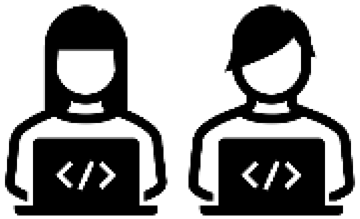
Interpretation Disagreement

Interpretation 1

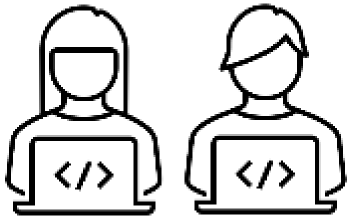
Disagreement

Interpretation 2





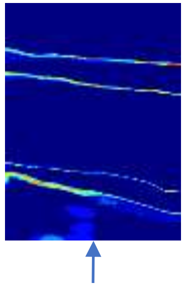
Setting 1



Setting 2

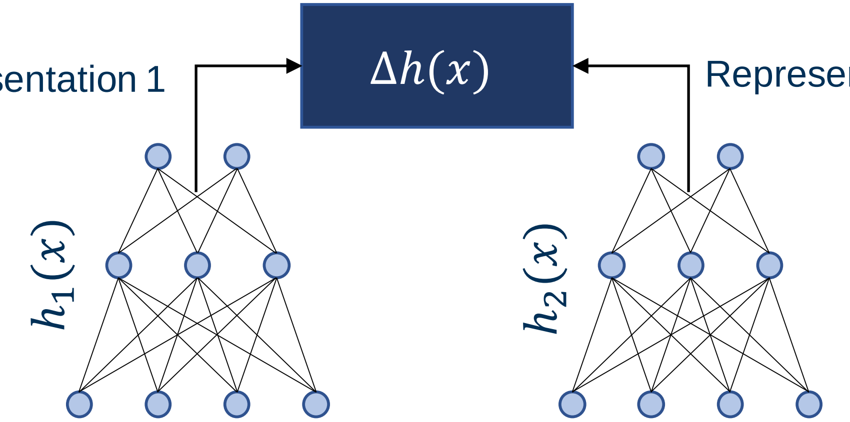
Representation Disagreement

Disagreement



Representation Shift

Representation 1



Representation 2

Disagreement **mimics manual interpretation** and **measures information content** of a section