

Forecasting Morphogenesis in Latent and Image Space

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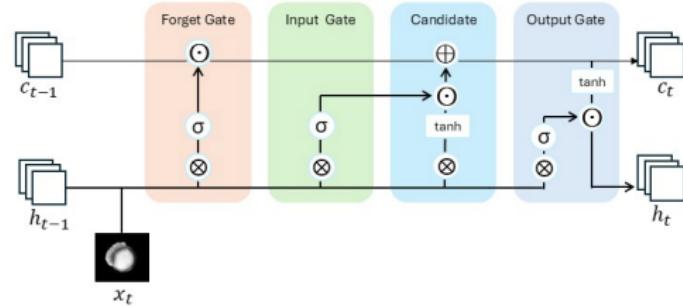
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1.- Forecasting Morphogenesis: ConvLSTM Model & Data

The Model:

- **Architecture:** ConvLSTM (Convolutional Long Short-Term Memory).
- **Complexity:** 70,000 parameters.

ConvLSTM Layer 1:



The Data:

- **Dataset:** 6 Embryos Types.
- **Controls:** Control1, Control2.
- **Mutants:** Mutant1, Mutant2, Mutant3, Mutant4.
- **Temporal Dimension:** 450 Frames per embryo.
- **Range:** $t = 120 \text{ min}$ to $t = 960 \text{ min}$ (16 hours of development).

2.- Experimental Setup

1. Data Split (Generalization Focus)

- **Train/Validation (90/10):** Trained on Control1, Mutant1, Mutant3.
- **Test (100%):** Evaluated on Control2, Mutant2, Mutant4 (Completely unseen subjects).

2. Loss Function

- **SSIM (Structural Similarity Index):** Prioritizes structural shape.

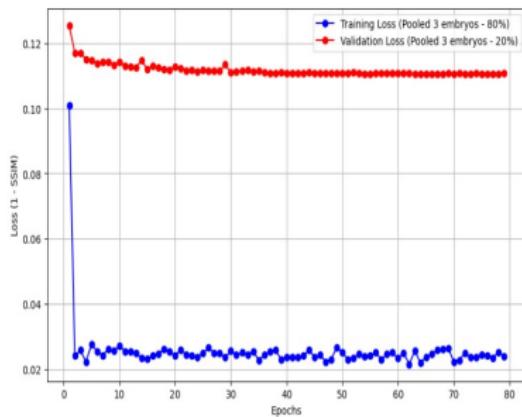
3. Robustness: Data Augmentation

Applied "On-the-fly" to the training set to teach spatial invariance.

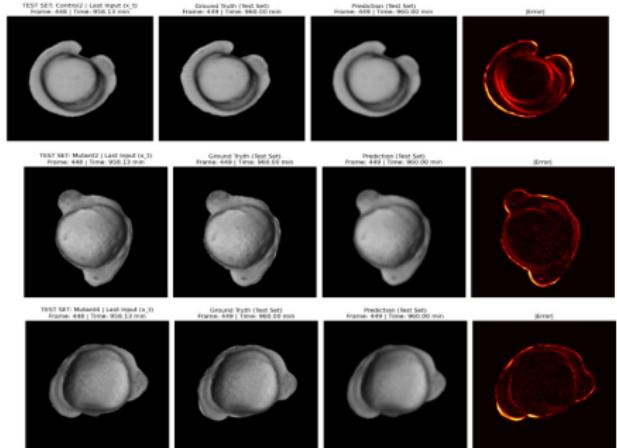
- **SSIM (Structural Similarity Index):** Prioritizes structural shape.
- **Transformations (Lock-Step):** Flips: Horizontal & Vertical.
 - Rotation (-180° to 180°)
 - Zoom ($\pm 5\%$)
 - Shift ($\pm 5\%$) (10 pixels approx)

3.- Model Performance on Unseen Data

Learning Curves



Blind Test Predictions



Quantitative Metrics:

Avg. Test Loss for Control2: 0.07159310

Avg. Test Loss for Mutant2: 0.09640111

Avg. Test Loss for Mutant4: 0.11105474

Observation: The model successfully predicts future morphology on embryos it has never seen before.

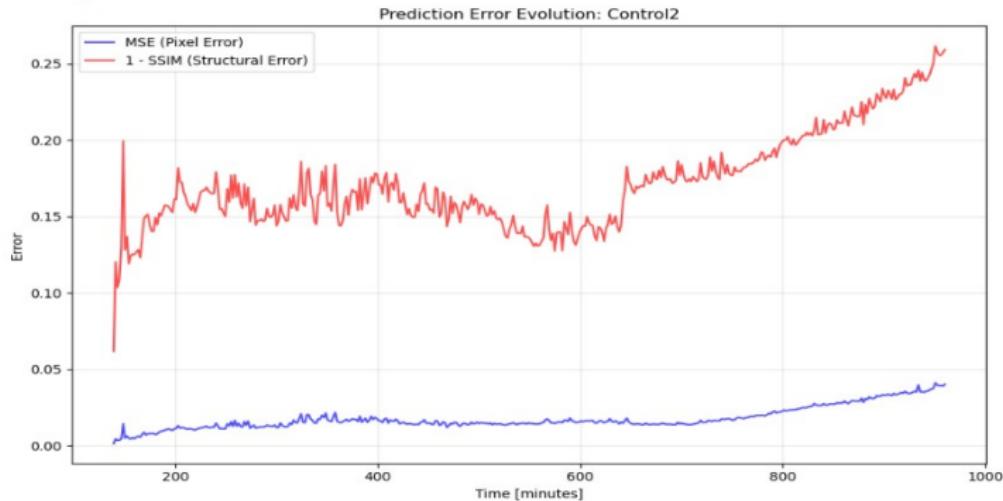
4.- Long-term Recursive Forecasting

The Challenge

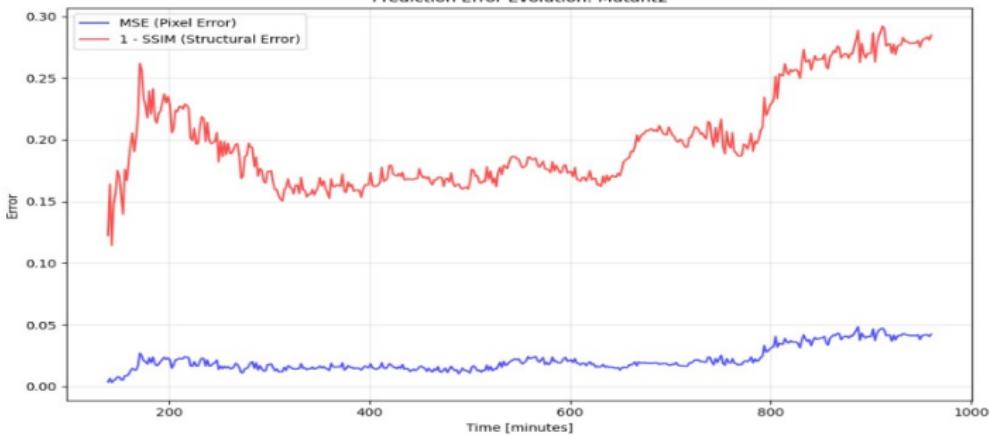
One-Step Prediction: Uses real ground truth to predict $t + 1$ (Easy).

Recursive Prediction: Uses its own previous predictions to forecast 400+ frames into the future (Hard).

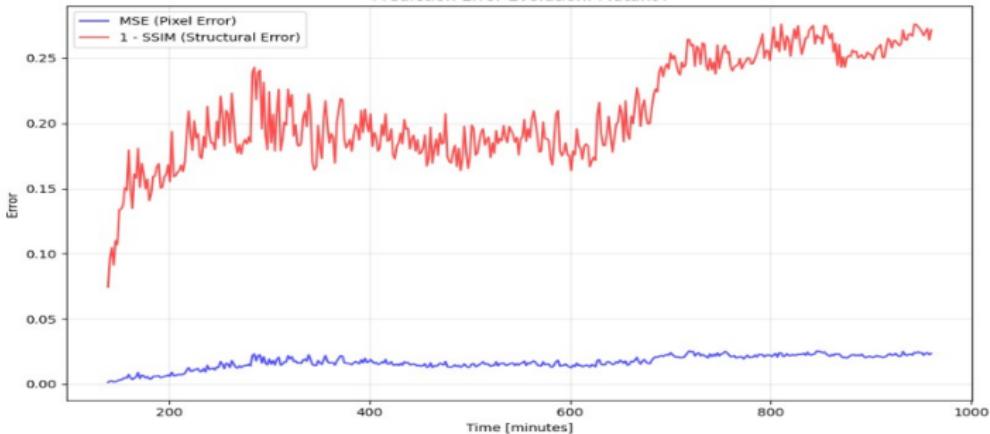
Results:

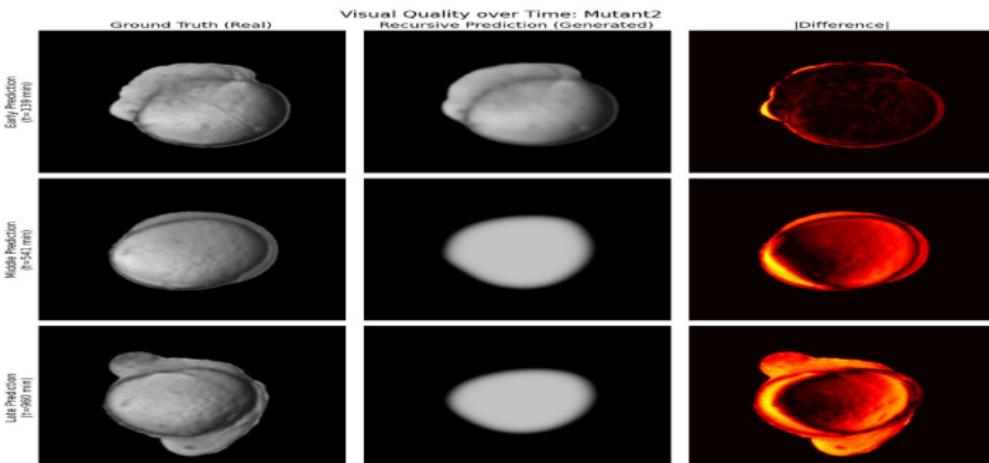
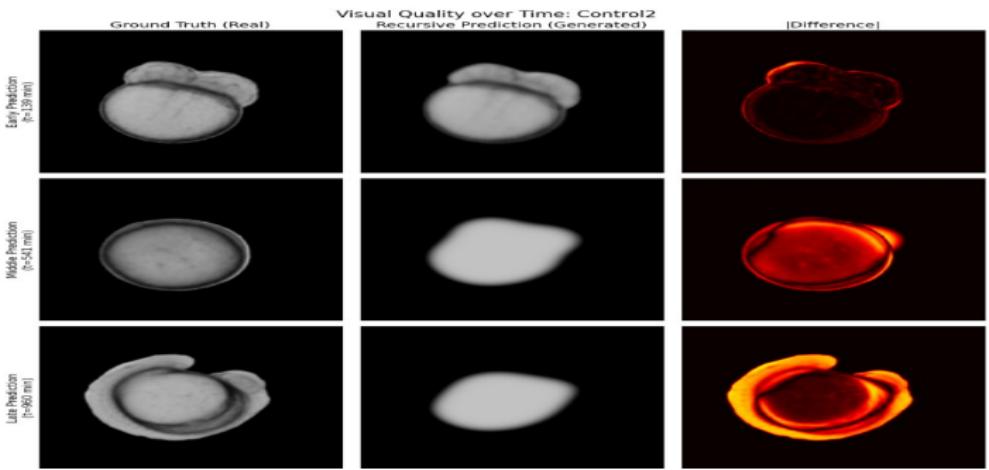


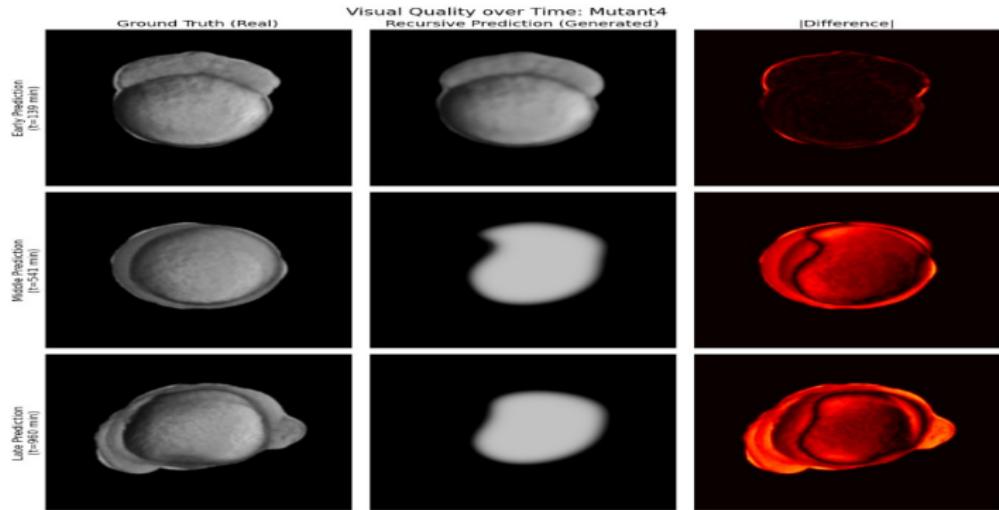
Prediction Error Evolution: Mutant2



Prediction Error Evolution: Mutant4







Insights

Decay in SSIM reflects the "blurring" effect common in long-term recursive loops.

- Event Detection: Spikes in the error curve correlate with complex biological events.

5.- Future Work & Next Steps

1. Scaling the Dataset

- **Objective:** Incorporate more biological samples into the training set.
- **Hypothesis:** Increasing the number of training subjects will generalize better to new geometries and significantly improve sharpness in long-term predictions.

2. Scheduled Sampling

- **Objective:** Train the model using its own predictions.
- **Methodology:** Instead of always feeding the Ground Truth, we will gradually introduce the model's own previous outputs as inputs during training.