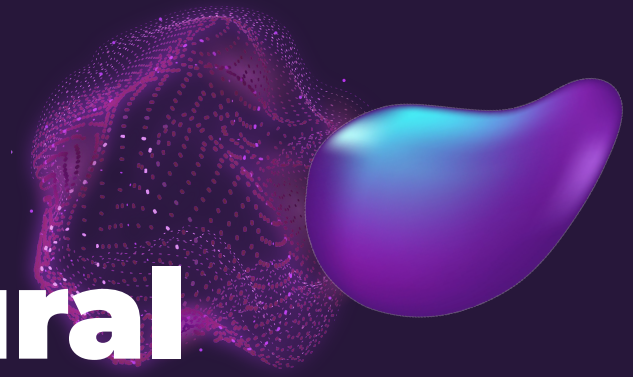


Applying Neural Networks to Galaxy Classification

Joel, Evan, James, Lily, Xavier, Haygen

What exactly is a Neural Network?

- **Input layer**, where data enters
- **Hidden layers,** where the “thinking” happens
- **Output Layer**, where the prediction comes out

- **Initial Guess**, random weights at first
- **Forward Pass,** data flows from input to output
- **Compare**, checks prediction against the correct answer and measures the difference (the **loss)**
- **Backpropagation,** network works backward, adjusting weights to minimize loss

Training the Model

Training Error - The error the model makes on the data it was trained on

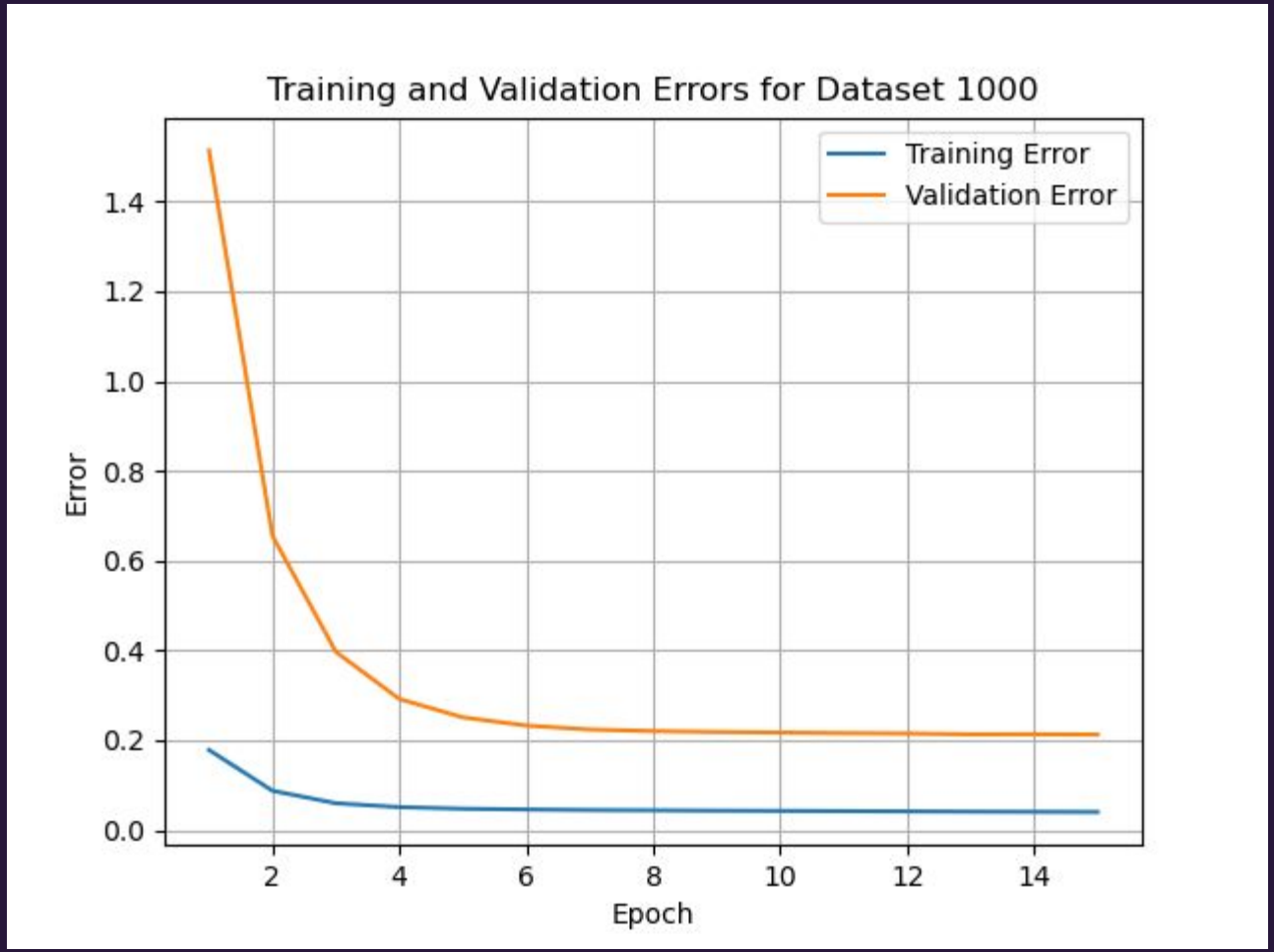
If training error is high, model hasn't learned pattern -> **Underfitting**

If training error is too low, model may have memorized training data

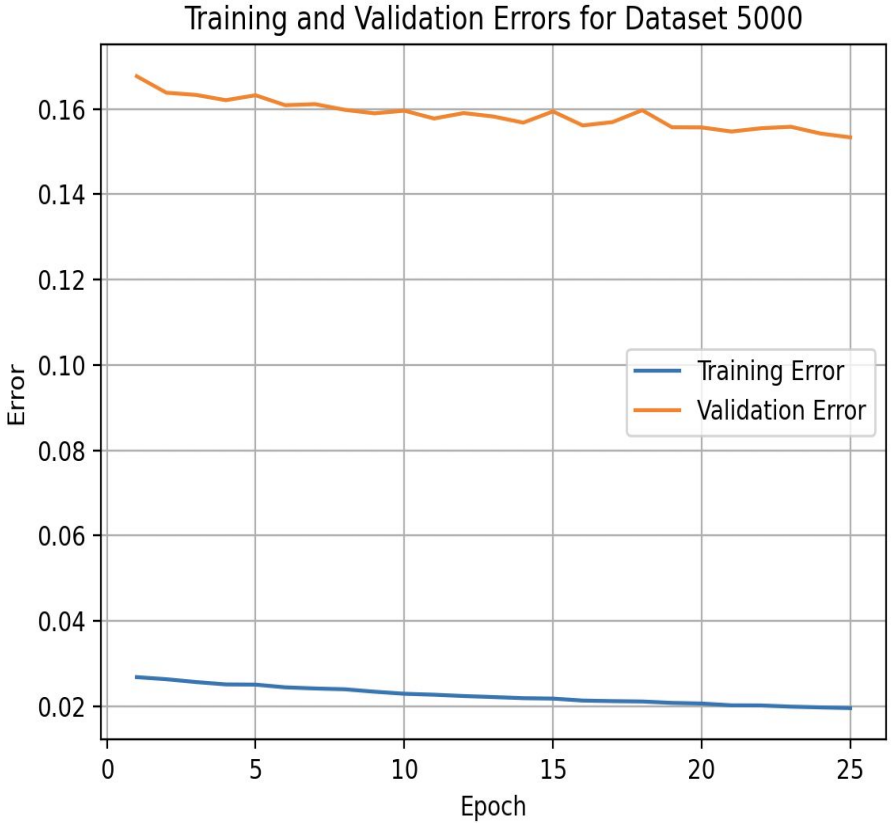
Validation Error - The error the model makes on new data it hasn't seen before

This tells if the model's learning generalizes to unseen images

Validation data does not update weights of the actual model, purely for testing


Training and Validation Errors for Dataset 1000
Training Error
Validation Error
Error
Epoch
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
2
4
6
8
10
12
14


Training and Validation Errors for Dataset 2500
Error
Epoch
Training Error
Validation Error
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0
5
10
15
20
25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Error
Epoch
Training Error
Validation Error
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0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
5
10
15
20
25


Training and Validation Errors for Dataset 10000
Training Error
Validation Error
0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
Error
2
4
6
8
10
12
14
Epoch

Probing the Model (not like that..)

Depth Sweeps

- Depth = number of layers between input and output
- Increasing depth can improve testing performance, or performance can stop improving/get worse
- Basically how well the **concept** was learned in different layers

Decision Tree

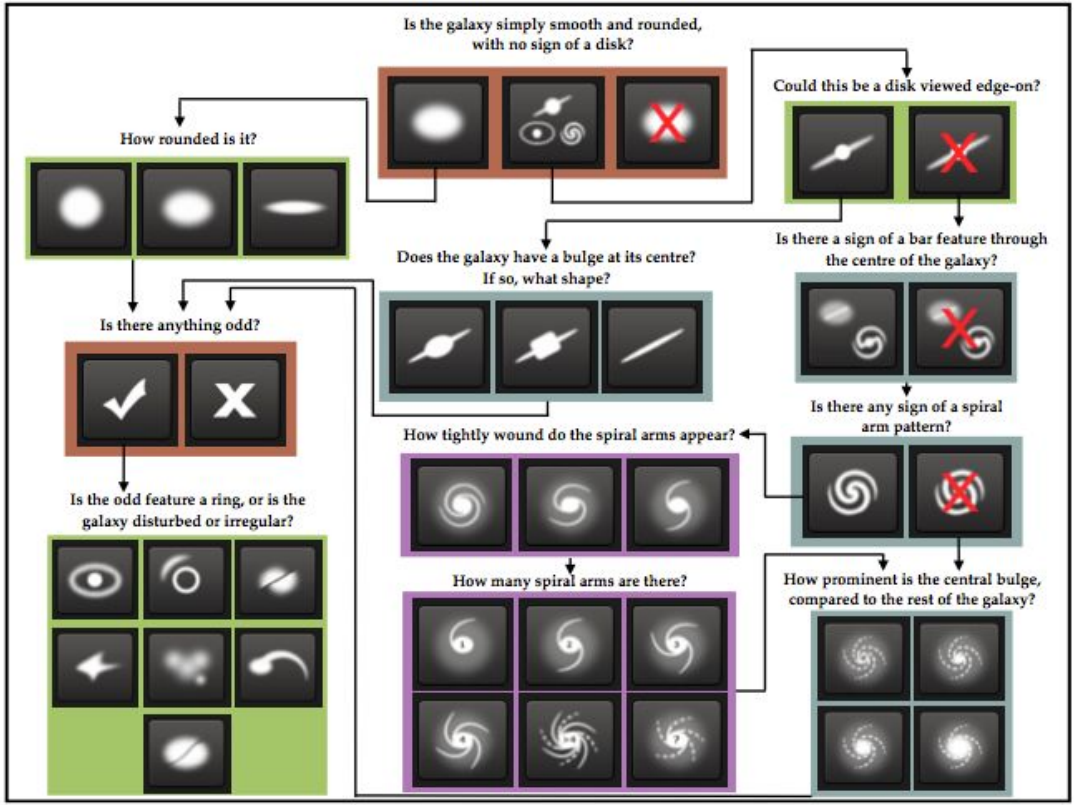
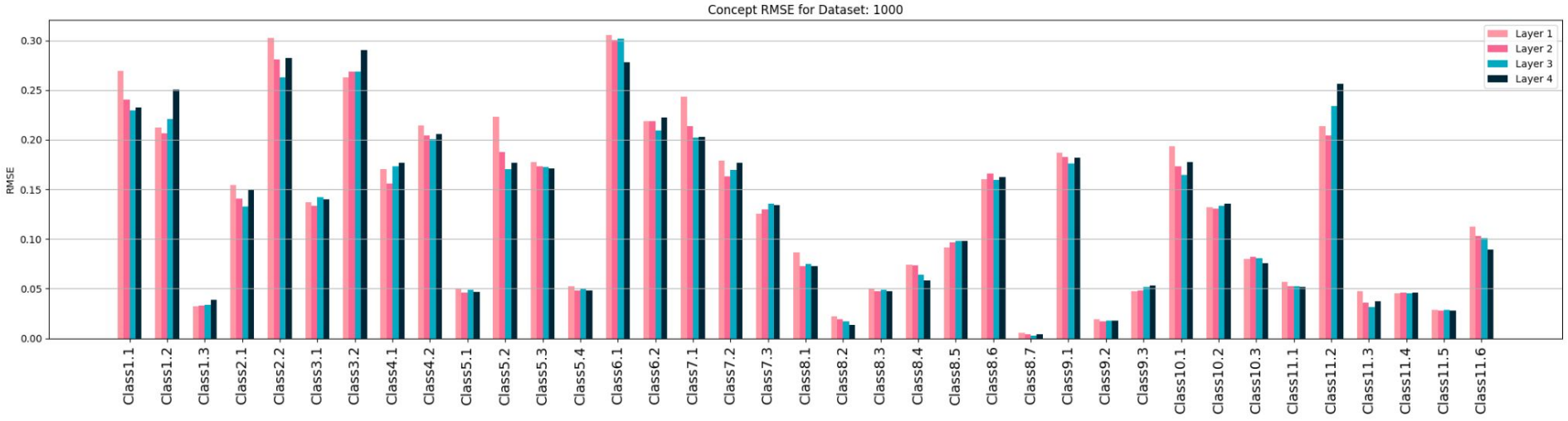
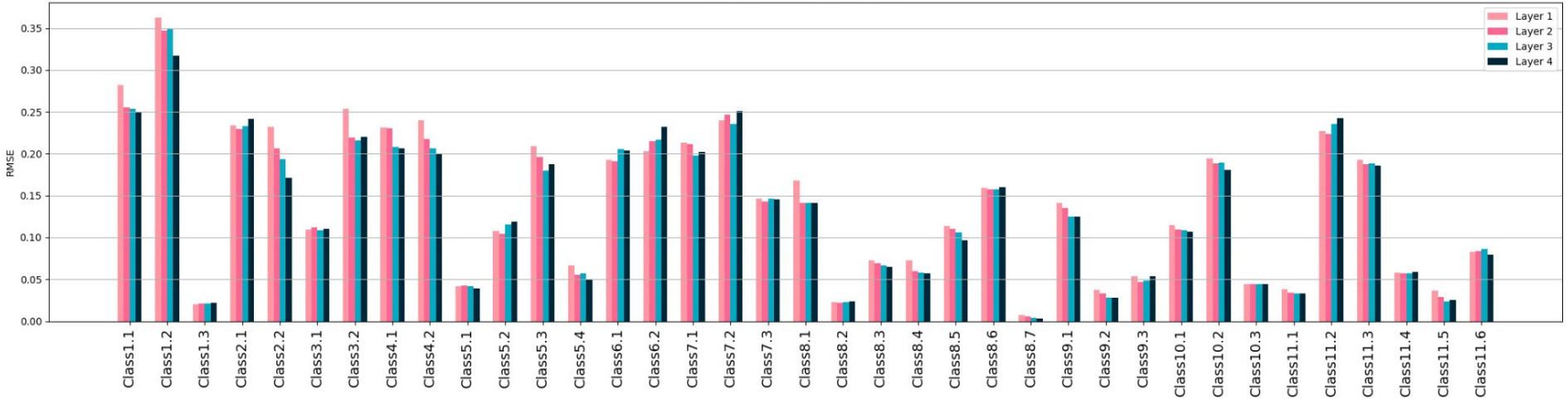


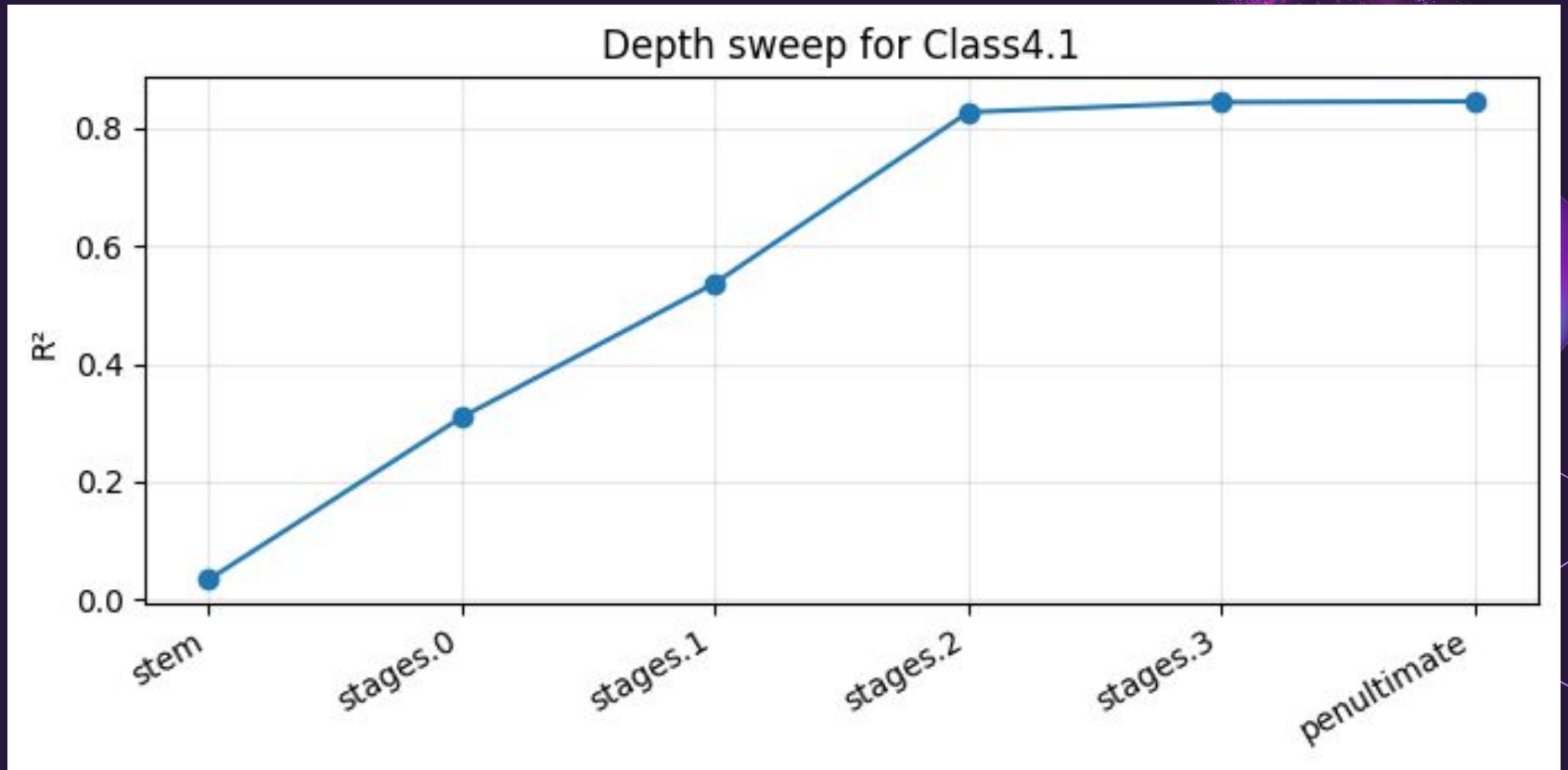
Figure 1. Flowchart of the classification tasks for GZ2, beginning at the top centre. Tasks are colour-coded by their relative depths in the decision tree. Tasks outlined in brown are asked of every galaxy. Tasks outlined in green, blue, and purple are (respectively) one, two or three steps below branching points in the decision tree. Table 2 describes the responses that correspond to the icons in this diagram.

Task	Question	Responses	Next
01	*Is the galaxy simply smooth and rounded, with no sign of a disk?*	smooth features or disk star or artifact	07 02 **end**
02	*Could this be a disk viewed edge-on?*	yes no	09 03
03	*Is there a sign of a bar feature through the centre of the galaxy?*	yes no	04 04
04	*Is there any sign of a spiral arm pattern?*	yes no	10 05
05	*How prominent is the central bulge, compared with the rest of the galaxy?*	no bulge just noticeable obvious dominant	06 06 06 06
06	*Is there anything odd?*	yes no	08 **end**
07	*How rounded is it?*	completely round in between cigar-shaped	06 06 06
08	*Is the odd feature a ring, or is the galaxy disturbed or irregular?*	ring lens or arc disturbed irregular other merger dust lane	**end** **end** **end** **end** **end** **end** **end**
09	*Does the galaxy have a bulge at its centre? If so, what shape?*	rounded boxy no bulge	06 06 06
10	*How tightly wound do the spiral arms appear?*	tight medium loose	11 11 11
11	*How many spiral arms are there?*	1 2 3 4 more than four can't tell	05 05 05 05 05 05

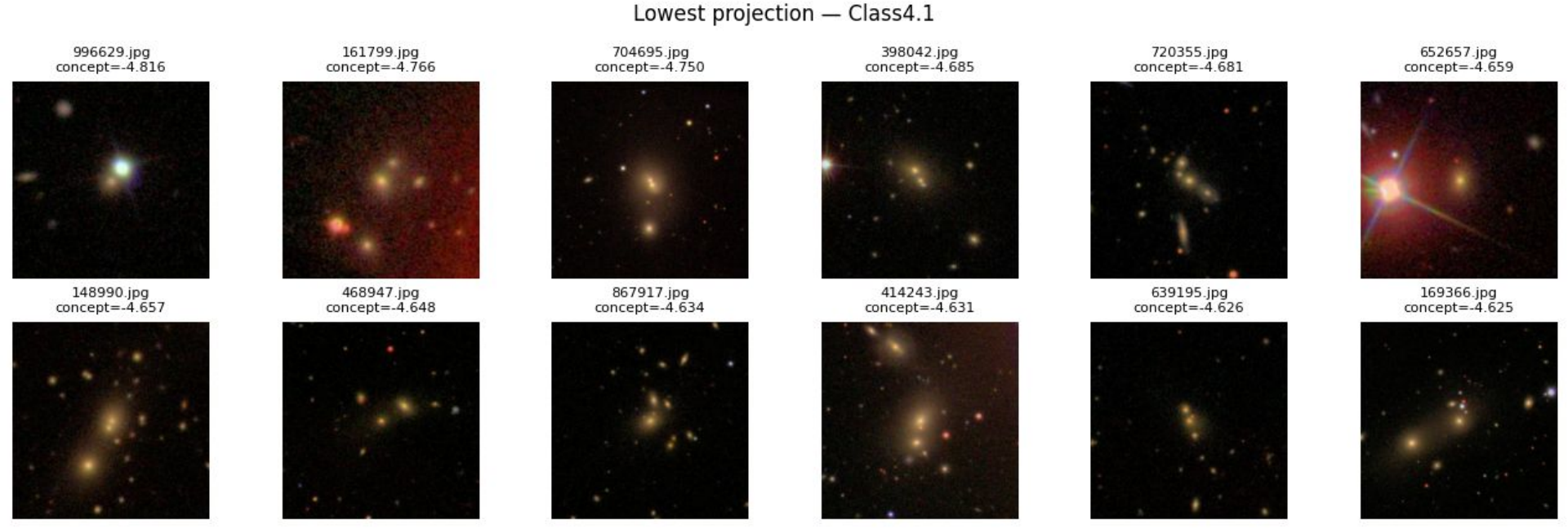

Concept RMSE for Dataset: 1000
RMSE
Layer 1
Layer 2
Layer 3
Layer 4
0.00
0.05
0.10
0.15
0.20
0.25
0.30
Class1.1
Class1.2
Class1.3
Class2.1
Class2.2
Class3.1
Class3.2
Class4.1
Class4.2
Class5.1
Class5.2
Class5.3
Class5.4
Class6.1
Class6.2
Class7.1
Class7.2
Class7.3
Class8.1
Class8.2
Class8.3
Class8.4
Class8.5
Class8.6
Class8.7
Class9.1
Class9.2
Class9.3
Class10.1
Class10.2
Class10.3
Class11.1
Class11.2
Class11.3
Class11.4
Class11.5
Class11.6


Concept RMSE for Dataset: 50000
RMSE
Layer 1
Layer 2
Layer 3
Layer 4
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
Class1.1
Class1.2
Class1.3
Class2.1
Class2.2
Class3.1
Class3.2
Class4.1
Class4.2
Class5.1
Class5.2
Class5.3
Class5.4
Class6.1
Class6.2
Class7.1
Class7.2
Class7.3
Class8.1
Class8.2
Class8.3
Class8.4
Class8.5
Class8.6
Class8.7
Class9.1
Class9.2
Class9.3
Class10.1
Class10.2
Class10.3
Class11.1
Class11.2
Class11.3
Class11.4
Class11.5
Class11.6

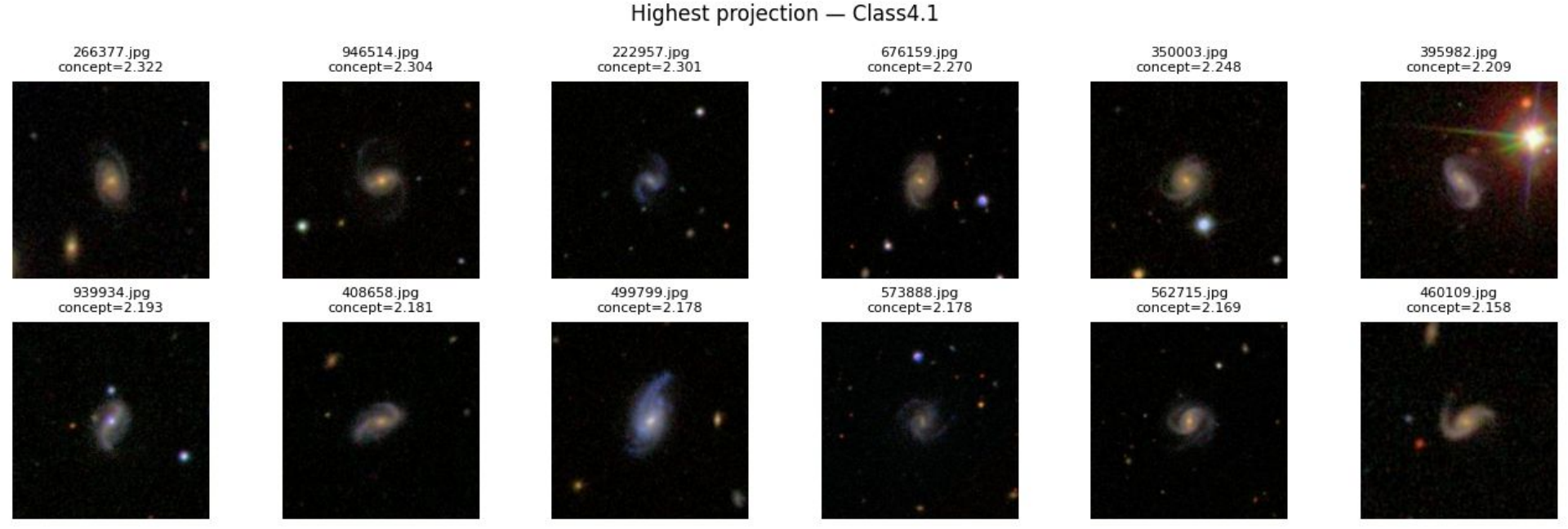
Depth Sweeps: Application



Depth Sweeps: Application



Depth Sweeps: Application



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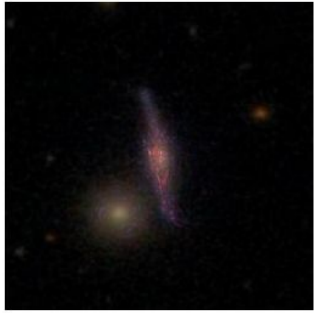
185377.jpg
concept=-2.023

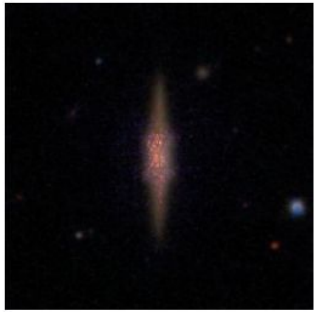


317340.jpg
concept=-1.963

601935.jpg
concept=-1.925

404423.jpg
concept=-1.918

837501.jpg
concept=-1.918

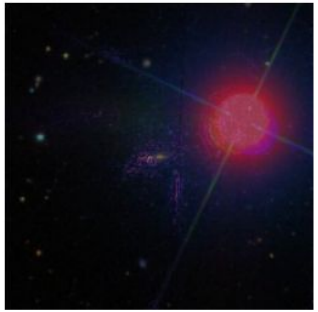


356310.jpg
concept=8.998

955102.jpg
concept=8.264

126783.jpg
concept=8.142

515600.jpg
concept=7.232



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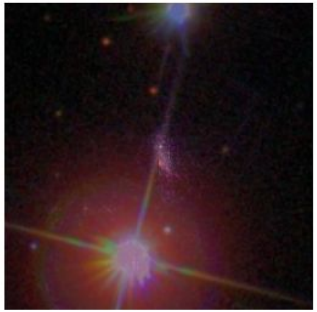
concept=6.824

809801.jpg
concept=6.684



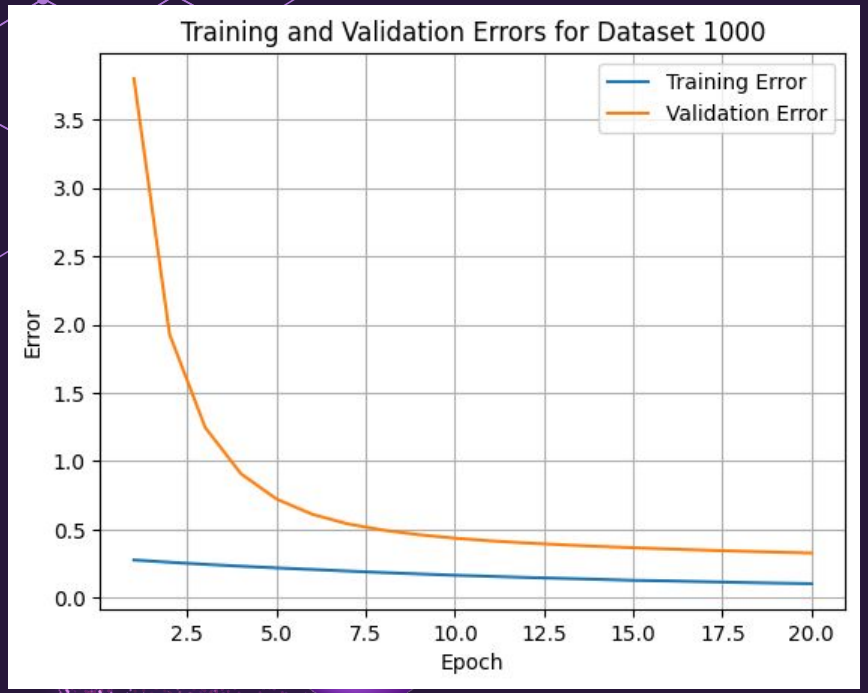
Optimization Functions

Mathematical algorithms that use a combination of past network decision data, labels placed on target data, and calculus to determine whether an AI is improving and tweak parameters based on its processing.

input : γ (lr), β_1, β_2 (betas), θ_0 (params), $f(\theta)$ (objective)
λ (weight decay), *amsgrad*, *maximize*, ϵ (epsilon)
initialize : $m_0 \leftarrow 0$ (first moment), $v_0 \leftarrow 0$ (second moment), $v_0^{max} \leftarrow 0$

---

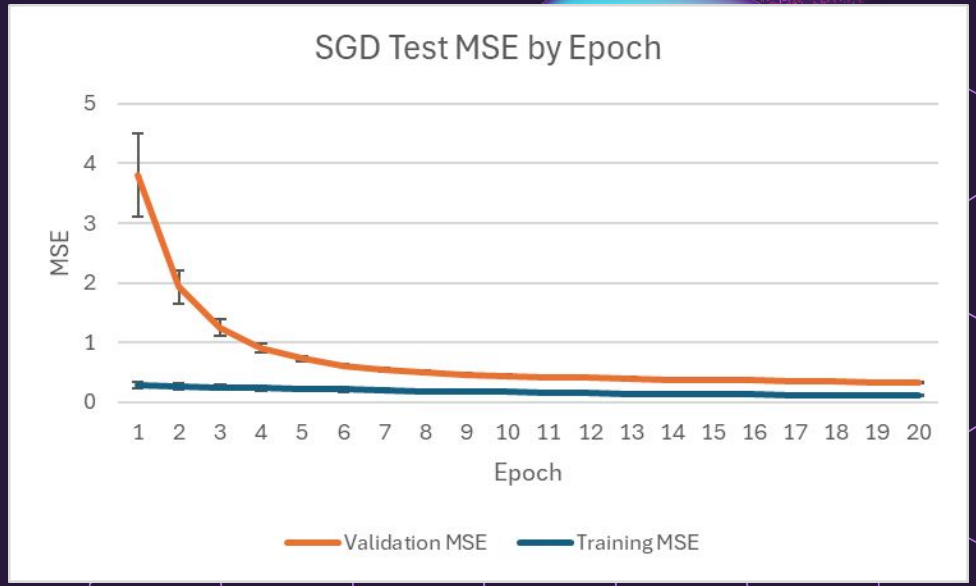
for $t = 1$ **to** $\ldots$ **do**
  if *maximize* :
    $g_t \leftarrow -\nabla_\theta f_t(\theta_{t-1})$
  else
    $g_t \leftarrow \nabla_\theta f_t(\theta_{t-1})$
  if $\lambda \neq 0$
    $g_t \leftarrow g_t + \lambda\theta_{t-1}$
  $m_t \leftarrow \beta_1 m_{t-1} + (1-\beta_1) g_t$
  $v_t \leftarrow \beta_2 v_{t-1} + (1-\beta_2) g_t^2$
  $\widehat{m_t} \leftarrow m_t / \left(1-\beta_1^t\right)$
  if *amsgrad*
    $v_t^{max} \leftarrow \max(v_{t-1}^{max}, v_t)$
    $\widehat{v_t} \leftarrow v_t^{max} / \left(1-\beta_2^t\right)$
  else
    $\widehat{v_t} \leftarrow v_t / \left(1-\beta_2^t\right)$
  $\theta_t \leftarrow \theta_{t-1} - \gamma \widehat{m_t} / \left(\sqrt{\widehat{v_t}} + \epsilon\right)$

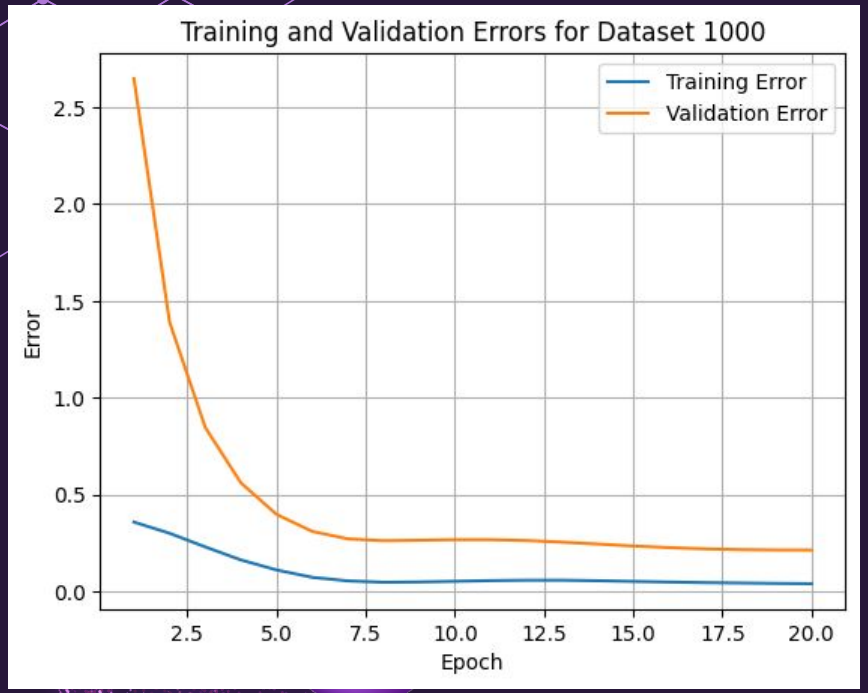


SGD

Average Best Validation MSE: 0.34346525

Average Best Training MSE: 0.121789928

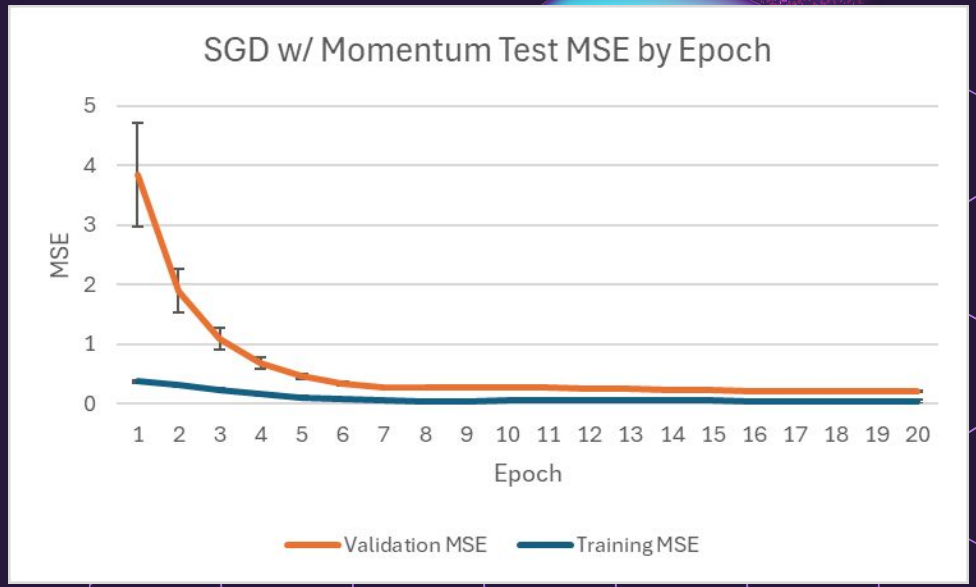


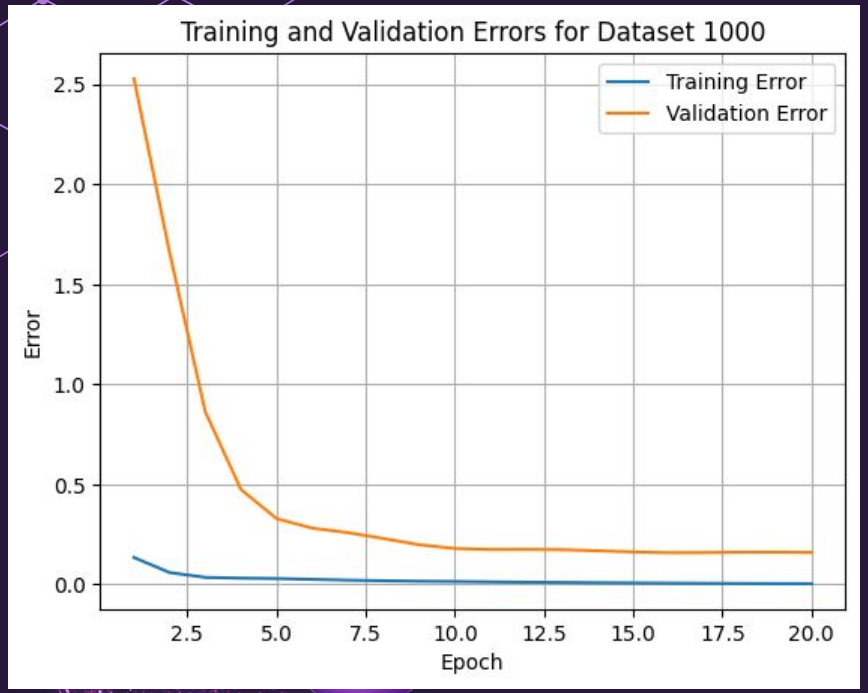


SGD w/ Momentum

Average Best Validation MSE: 0.20691055

Average Best Training MSE: 0.04042595

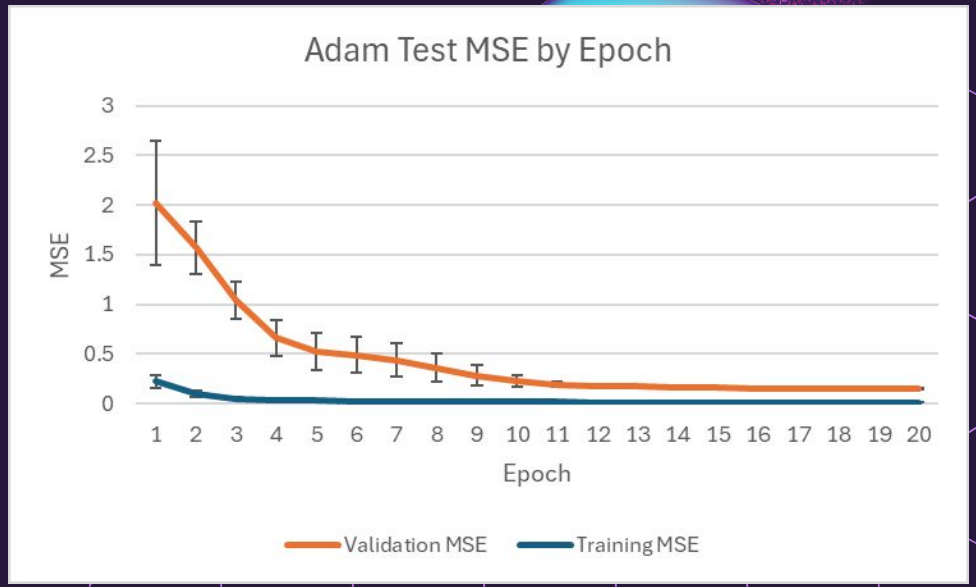


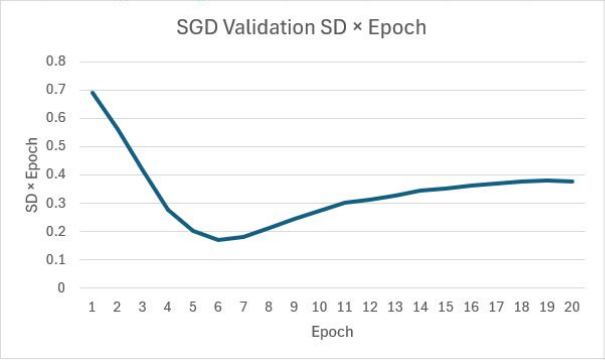


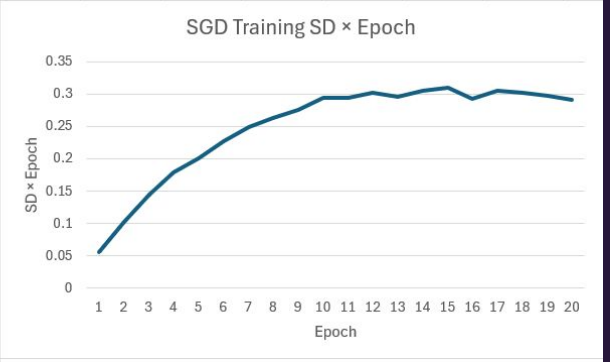
Adam

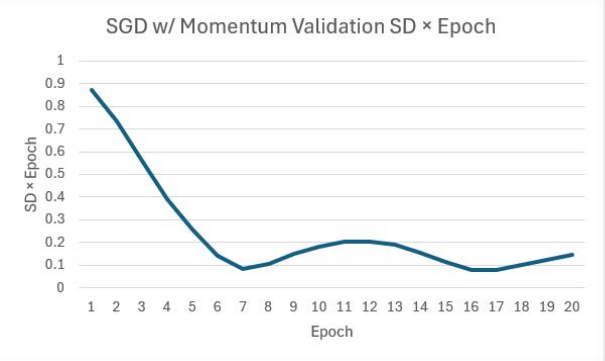
Average Best Validation MSE: 0.15251103

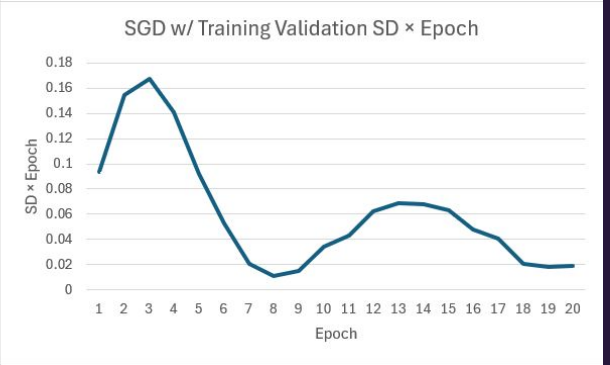
Average Best Training MSE: 0.007409483

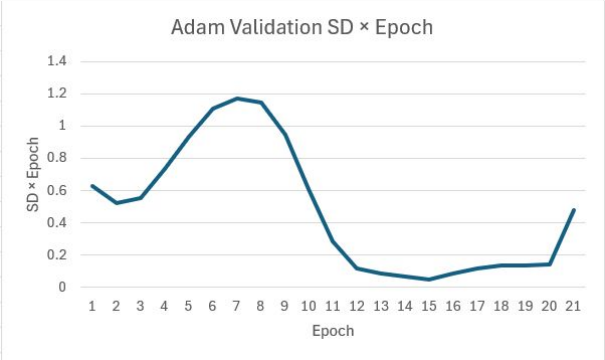


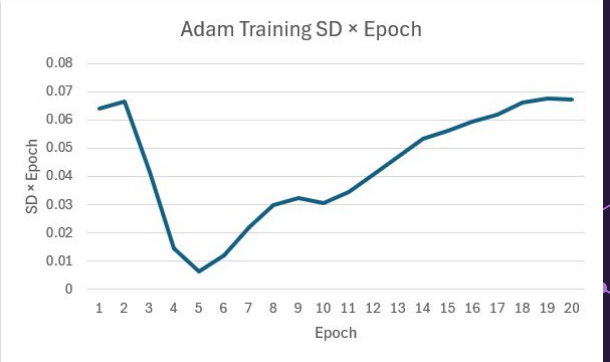












×

These graphs represent the Standard Deviation times the Epoch number of a given deep learning model. This should be mostly linear, as while a model is trained, it converges closer to an optimal value for the model. This does not become linear on the small scale, and the different shapes likely have to do with the element of momentum being present in the bottom 4 graphs.

Testing Models w/ Seed Variation

What are Seeds?

- Specific, consistent set of random numbers
- Seed = 50 will be one list of random numbers. Seed = 55 will be another list of random numbers
- No seed means the number will be randomly generated each time (think Minecraft!)

How Do Seeds Affect Models?

Seeds make predictable and consistent behavior for the model

Data gets shuffled during training, so seeds allow that shuffling to be reproduced

Our Models

Tested 4 models with the same parameters except for seed

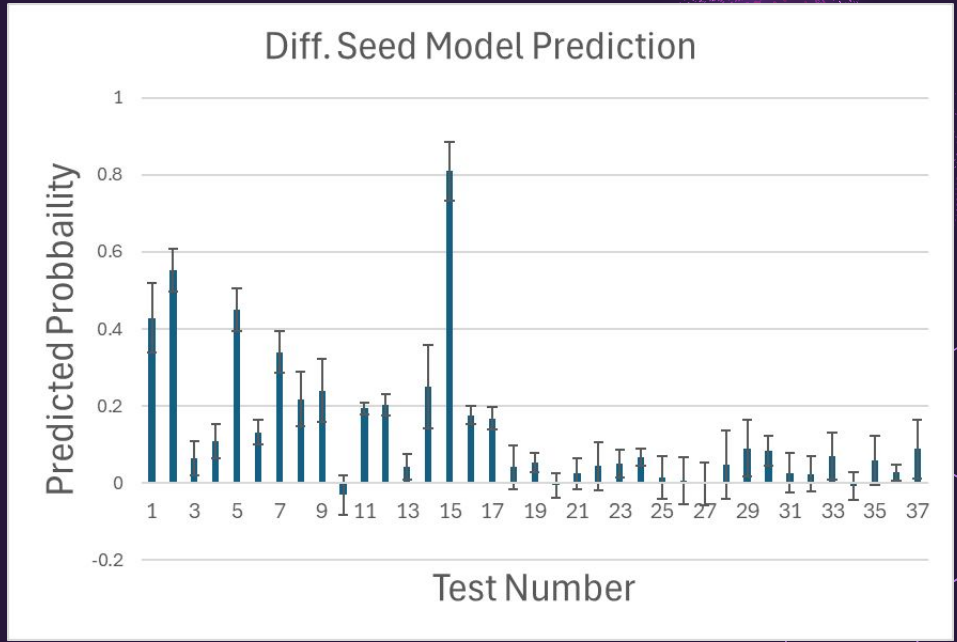
- Adam
- Regnet
- 1000 image set
- 0.1 LR
- 50 Epochs

Seeds: 10; 28; 420; 627

Seed Variation Results

Result Interpretation

- Model is becoming less confident as test number increases
- Could be due to harder content
- Could be getting more “realistic”
- Seeds are not directly affecting trendline, just keeping consistency for future testing
- More time could give more conclusive results



Avg. Pred: 0.13878

Standard Dev.: 0.17559

Applying New Data to the Model

- To further evaluate the model's ability to classify galaxies, we split the dataset from Galaxy Zoo into testing and training datasets. This was done so that we could feature imagery outside of the training dataset, evaluating the model on "new" data.
- After applying this new dataset, we noted that **the models did a great job identifying galaxy characteristics.**

While the model did well with the Galaxy Zoo dataset, we can further refine the model's abilities by:

- Increasing training time.
- Giving the model totally new data pulled off the internet that is not associated with galaxy zoo.
- Reducing bugs within code that are not allowing for the proper processing of images outside of the team's resources..