Concept Review

29 January 2026

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Schedule for Today

- Review some of concepts.
- Deep Learning teaser.
- Work a visual example on confusion matrixes and visualizing model error.
- Open Professor hours for last few minutes/leave early.

Principles

- Lots of the things that you're working on might not be something you do in your job (I don't remember the last time I trained a KNN classifier for research) BUT
- The principles of things you learn in this class will be super important. (Model evaluation and validation)
- Later topics (Neural networks, backpropagation, gradient descent, clustering) are all things I use in my life.
- The specific models you will work with might not exist yet!
- Focus on understanding principles.

Model Selection

- How do we know what model to choose?
- One issue is that we only know about 3 types of models. Next week we're doing regression, then trees, then SVMs, then Neural Networks.
- It's hard to fully get into model selection if we only know about 3 models.
- Imagine trying to do construction with a hammer, a screwdriver, and a pair of pliers. (No wrench or saw or power tools)
- Or draw with only 3 crayons!
- Unsatisfying answer – 'You'll understand it better later'

Metrics

- We've looked at a *lot* of metrics.
- Pretty much all of the metrics you need to know can be derived from the confusion matrix.
- Accuracy, Precision, Recall, F1, (Micro and Macro F1), F-Beta, ROC curves, and Precision-Recall curves.
- ***All*** of these are just fancy ways of counting up confusion matrix stuff.

ACTUAL VALUES	POSITIVE	NEGATIVE
POSITIVE	TP	FN
NEGATIVE	FP	TN

$$Precision = \frac{TP}{TP + FP} \qquad Recall = \frac{TP}{TP + FN}$$

$$Accuracy = \frac{TP + TN}{TP + FP + FN + TN}$$

$$F1\ Score = 2 \times \frac{Precision \times Recall}{Precision + Recall}$$

$$F_\beta = (1 + \beta^2) \cdot \frac{\text{Precision} \cdot \text{Recall}}{(\beta^2 \cdot \text{Precision}) + \text{Recall}}$$

$$\text{Macro F1} = \frac{F_1(A) + F_1(B) + F_1(C)}{3}$$

$$\text{Micro Precision} = \frac{\text{Total TP}}{\text{Total TP} + \text{Total FP}}$$

Models

- I want you to have a model-agnostic understanding of Machine Learning.
- A **model** is a mathematical function for describing the relationship between inputs and outputs and making predictions.
- If you can learn (approximate) the function between inputs and outputs, that can be useful in real life.
- We learn this function by tweaking **parameters** inside the model
- How do we know which direction to tweak the parameters? We try to minimize our **error**.

Fake Model Example

How Does a Model Learn?

- A **model** (usually) has trainable *parameters*.
- When training a model, we want to train the parameters using **data**.
- We do this by *minimizing* the error or loss.
- Imagine training a basketball-shooting cannon. You have 2 parameters:
  - Angle (x)
  - Angle (y)

How Does a Model Learn?

- You start with the cannon pointing in some direction.
- How do you know where the cannon will shoot?
- You have to try shooting the cannon.
- You miss. Now what?

How Does a Model Learn?

- You can see how far off you are.
- This is the error (related to loss)
- Then, you make a decision to try and minimize that error.
- In our case, we change our parameters (the x and y angles of the cannon) to try and make a better shot.

How Does a Model Learn?

- We repeat the process:
  - Shoot the cannon
  - Measure how far we missed by (error/loss)
  - Tweak the angle of the cannon (parameters)

until we're making all of our shots

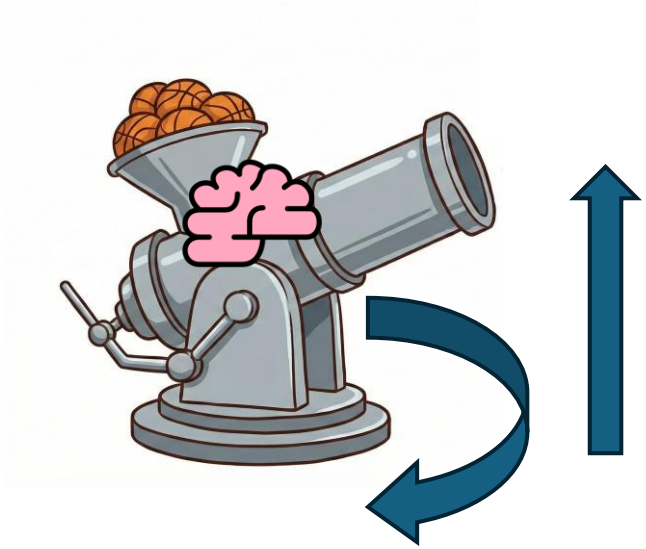
We can think of each time we shoot, measure, tweak as a training example.

How Does a Model Learn?

- But we don't want to have to tweak the parameters by ourselves.
- Instead, we create some sort of system that tries to minimize error **by itself** by tweaking its own parameters.
- That's the **machine** in **machine learning.**

How Does a Model Learn?

- So instead, we make a little mechanical brain for our cannon. (This is an abstraction). After each shot, we tell it its error, and allow it to tweak its own parameters.
- That's the basic idea of training a machine learning model.



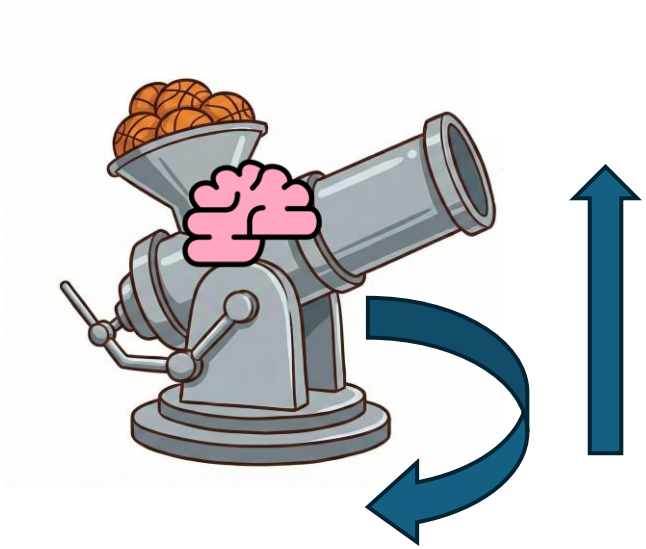
Parameters vs Hyperparameters

Parameters vs Hyperparameters

Feature	Parameters (Weights)	Hyperparameters (Settings)
Who decides?	The **Algorithm** (The Machine).	The **Engineer** (You).
When?	During Training (Learning).	**Before** Training starts.
Analogy	The internal gears of the engine.	The knobs on the dashboard.
Examples	w (Weights), Probabilities.	k (Neighbors), Learning Rate, Smoothing Count.

This Example Again

- Parameters: the X and Y angles of the cannon (chosen by the little mechanical brain)
- Hyperparameter: number of degrees to change at a time



Error/Loss

vs

Accuracy/Precision/Recall/F1

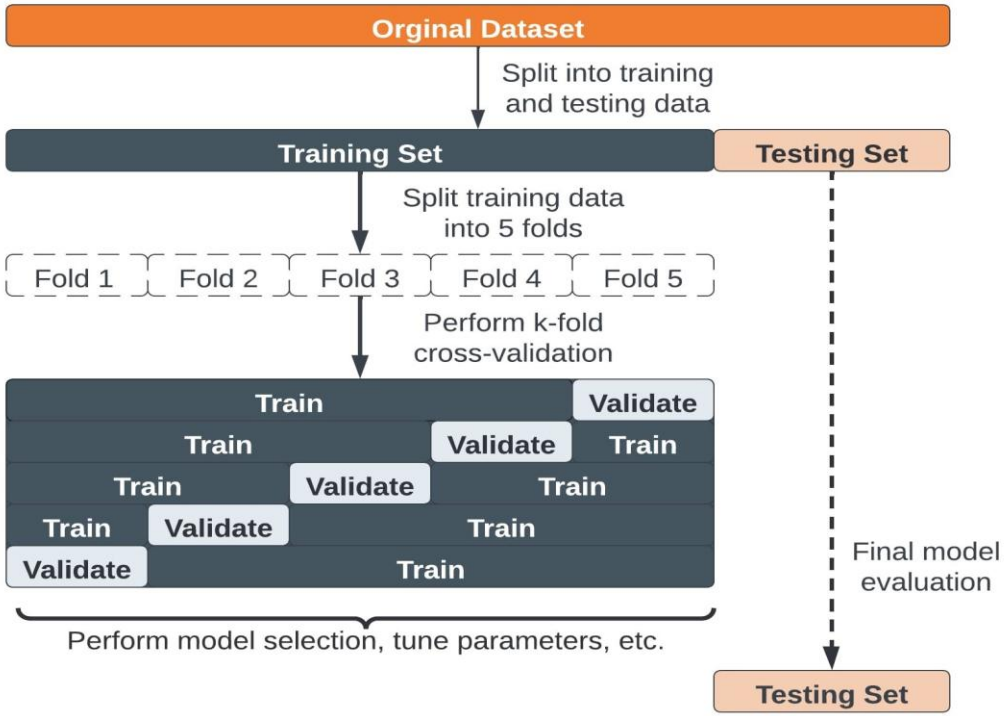
Error/Loss vs Accuracy/Precision/Recall/F1

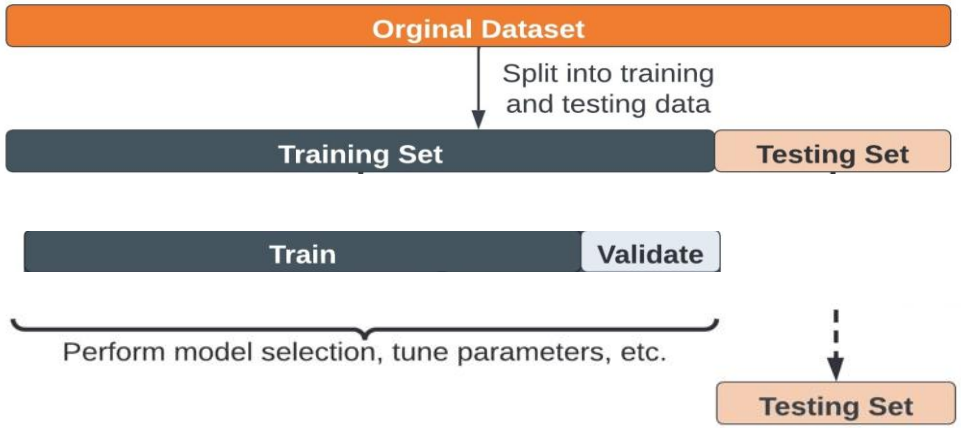
- We measure the performance of our model multiple times.
- When the model learns, it tries to minimize the difference between its predictions and actual values (the error). It minimizes the error by tweaking its own parameters. This is learning.
- Error and Loss describe the difference between the model's predictions and the targets while the model is training. The *model* cares about error/loss.
- The Confusion Matrix metrics we've talked so much about help us understand how well our model might do in the real world. The *ML Engineer* cares about these metrics.

Training, Validation, Testing

Training, Validation, Testing

- We train a model on data. How can we be sure it will generalize to new data?
- Overfitting (do we remember this?)
- We use an unseen (by the model) Test Set.
- We should ALWAYS use some sort of test set to ensure our model can generalize.
- But how can we make decisions about what hyperparameters to use? How can we decide which model would be best?
- To do that, we use a validation set.
- The validation set can be static, or not (cross-validation), depending on the context.


Orginal Dataset
Split into training and testing data
Training Set
Testing Set
Split training data into 5 folds
Fold 1
Fold 2
Fold 3
Fold 4
Fold 5
Perform k-fold cross-validation
Train
Validate
Final model evaluation
Perform model selection, tune parameters, etc.
Testing Set

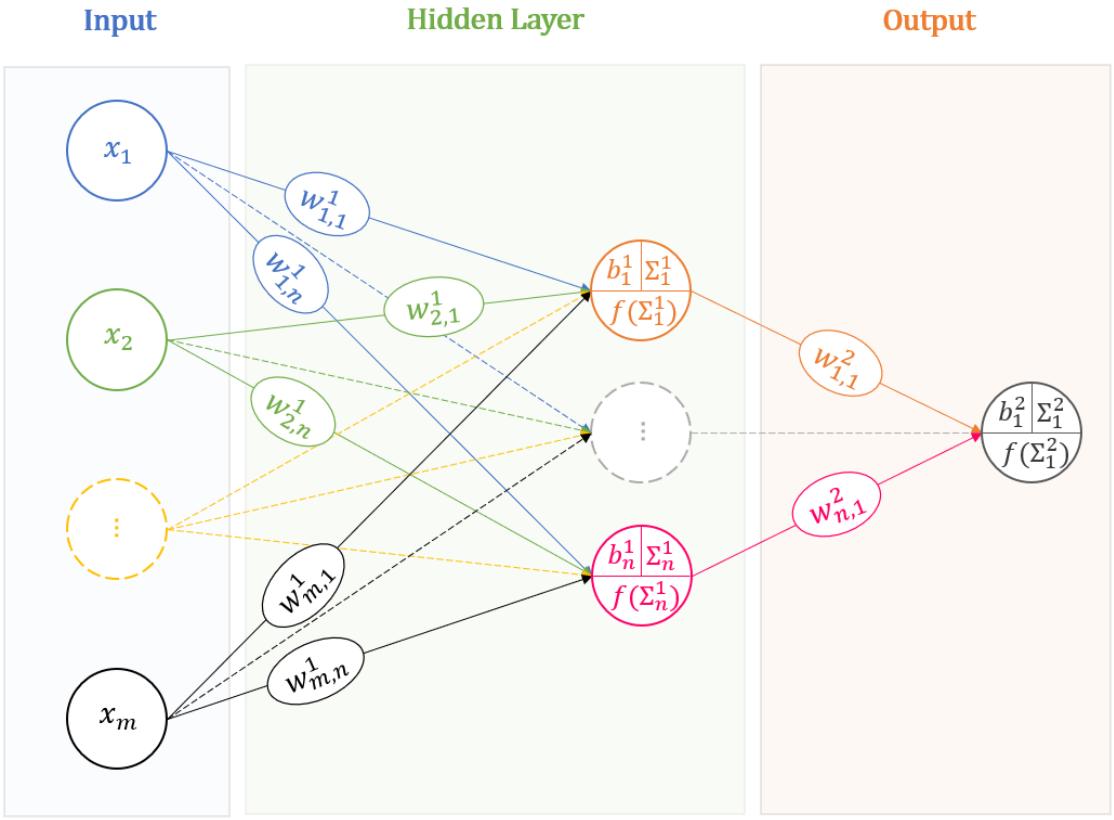

Orginal Dataset
Split into training and testing data
Training Set
Testing Set
Train
Validate
Perform model selection, tune parameters, etc.
Testing Set

Questions?

Pretraining and Fine Tuning

Deep Learning Basics

- For now, you are going to trust me that an artificial neural net has trainable *parameters* (weights) inside of it.
- You are also going to trust me that the neural net is doing something fancy (gradient descent via backpropagation) to minimize its error/loss.
- Deep learning is **much more computationally intense** than the other methods we will discuss in this class.



Pre-Training and Fine-Tuning

- Imagine if you had two people who had never played soccer before. They've never heard of soccer.
- Your goal is to teach one of them soccer.
- One is a baby and one is an athletic woman in her '20s.
- Who is going to have an easier time learning to play soccer?
- Obviously the woman. She can already run and kick and has coordination.
- The baby would need to learn all of those skills.

Pre-Training and Fine-Tuning

- Training an artificial neural network is a lot more work (computationally) than doing something like logistic regression or KNN.
- When we initialize a neural network, all of the parameters start out randomly initialized.
- The model has to learn the weights by minimizing error over a bunch of training examples.
- That's a lot of work!

Pre-Training and Fine-Tuning

- What if we could do a lot of the work up front one time?
- Pre-training a model involves training the model on generic data so it is capable, before fine-tuning for a specific task.

Pre-Training and Fine-Tuning Example

- Example: Middle English and Modern English are pretty different.
- (word order in line 70, vocab line 75)
- I wanted to make a translator to turn Modern English into Middle English.
- How could I do that?
- There's not enough training data!

70 **He nevere yet no vileynye ne sayde**
He never yet said any rude word
71 **In al his lyf unto no maner wight.**
In all his life unto any sort of person.
72 **He was a verray, parfit gentil knyght.**
He was a truly perfect, noble knight.
73 **But for to tellen yow of his array,**
But to tell you of his clothing,
74 **His hors were goode, but he was nat gay.**
His horses were good, but he was not gaily dressed.
75 **Of fustian he wered a gypon**
He wore a tunic of coarse cloth
76 **Al bismotered with his habergeon,**
All stained (with rust) by his coat of mail,
77 **For he was late ycome from his viage,**
For he was recently come (back) from his expedition,
78 **And wente for to doon his pilgrymage.**
And went to do his pilgrimage.

Pre-Training and Fine-Tuning

- We start with BART, a language model from Meta was trained to learn English from 160 GB of text including:
  - **BooksCorpus:** A large dataset of unpublished books.
  - **English Wikipedia:** The full English Wikipedia (excluding talk pages).
  - **News Data:** CC-NEWS, which is a collection of news articles.
  - **Web Text:** OpenWebText.
  - **Stories:** A dataset of stories
- The pre-training took 16 NVIDIA V100 GPUs (back in 2019 that was a lot).
- This would have cost them thousands of dollars and taken several days of continuous training.
- Then they made it available to the public for free!

Pre-Training and Fine-Tuning

- I gathered about 60,000 paired sentences (Modern and Middle English), taken from Chaucer's complete works, the Wycliffe Bible, and Sir Gwain and the Green Knight.
- Then, I fine-tuned the model on the paired sentences (one gpu, a few hours)


```
{ "en": "And God said, Let the earth put forth grass, herbs yielding seed, `and' fruit-trees bearing fruit after their kind, wherein is the seed thereof, upon the earth: and it was so.", "me": "and seide, The erthe brynge forth…
{ "en": "And the earth brought forth grass, herbs yielding seed after their kind, and trees bearing fruit, wherein is the seed thereof, after their kind: and God saw that it was good.", "me": "And the erthe brouyte forth greene…
{ "en": "And there was evening and there was morning, a third day.", "me": "And the euentid and morwetid was maad, the thridde dai." }
{ "en": "And God said, Let there be lights in the firmament of heaven to divide the day from the night; and let them be for signs, and for seasons, and for days and years:", "me": "Forsothe God seide, Liytis be maad in the firmament…
{ "en": "and let them be for lights in the firmament of heaven to give light upon the earth: and it was so.", "me": "and shyne tho in the firmament of heuene, and liytne tho the erthe; and it was doon so." }
{ "en": "And God made the two great lights; the greater light to rule the day, and the lesser light to rule the night: `he made' the stars also.", "me": "And God made twei grete liytis, the gretter liyt that it schulde be bifor…
{ "en": "And God set them in the firmament of heaven to give light upon the earth,", "me": "and God made sterris; and settide tho in the firmament of heuene, that tho schulden schyne on erthe," }
```

Pre-Training and Fine-Tuning

Break Time

Visualizing a Confusion Matrix With Image Classification

Magic: the Gathering

Magic: the Gathering

- **White** represents order and community, building large armies of small creatures and using protective magic to control the battlefield and enforce its laws.
- **Blue** embodies intellect and the pursuit of perfection, controlling the game by drawing extra cards to gain knowledge and canceling an opponent's spells before they can even take effect.
- **Black** is the color of ambition and amorality, achieving power by any means necessary, whether it's destroying opposing creatures, reanimating the dead, or sacrificing its own life for a winning advantage.
- **Red** channels passion and chaos to act on pure impulse, overwhelming opponents with fast, aggressive creatures and spells that deal direct damage to any target.
- **Green** is the color of nature and growth, embracing the law of the jungle by accelerating its resources to summon gigantic, powerful creatures that overpower the opposition.

Train Time!

White


Razor Rings
Instant
Razor Rings deals 4 damage to target attacking or blocking creature. You gain life equal to the excess damage dealt this way.
"There's someone in there! He's bending the vines!"
—Sokka
Revitalize
Instant
You gain 3 life.
Draw a card.
Esika alone knotes how to distill the essence of the World Tree into the Cosmos Elixir, a magical substance which grants the Skoti god-family immortality.
Scholar of New Horizons
Creature — Human Scout
Scholar of New Horizons enters the battlefield with a +1/+1 counter on it.
, Remove a counter from a permanent you control: Search your library for a Plains card and reveal it. If an opponent controls more lands than you, you may put that card onto the battlefield tapped. If you don't put the card onto the battlefield, put it into your hand. Then shuffle.
1/1
Scion of Vitu-Ghazi
Creature — Elemental
When Scion of Vitu-Ghazi enters the battlefield, if you cast it from your hand, put a 1/1 white Bird creature token with flying onto the battlefield, then populate. (Put a token onto the battlefield that's a copy of a creature token you control.)
4/4
Secret Rendezvous
Sorcery
You and target opponent each draw three cards.
Strixhaven's five colleges encourage natural rivalries among the students, but some bonds transcend all barriers.
Seized from Slumber
Instant
This spell costs 3 less to cast if it targets a tapped creature.
Destroy target creature.
Tyson tried to scream for help, but his lungs simply unraveled.
Seize the Initiative
Instant
Target creature gets +1/+1 and gains first strike until end of turn.
The time between spotting a leonin shikari and feeling its claws is just time enough to draw your last breath.
Serra Zealot
Summon Soldier
First strike
"The humans are useful in their way, but they must be commanded as the builder commands the stone. Be soft with them, and they will become soft."
—Radiant, archangel
1/1
Shahrazad
Sorcery
Players must leave game in progress as it is and use the cards left in their libraries as decks with which to play a subgame of Magic. When subgame is over, players shuffle these cards, return them to libraries, and resume game in progress, with any loser of subgame halving his or her remaining life points, rounding down. Effects that prevent damage may not be used to counter this loss of life. The subgame has no ante; using less than forty cards may be necessary.
Illus. © Kaja Foglio
Silent-Chant Zubera
Creature — Zubera Spirit
When Silent-Chant Zubera is put into a graveyard from play, you gain 2 life for each Zubera put into a graveyard from play this turn.
When the Honden of Cleansing Fire was abandoned, its attendants swarmed Kamigawa to erode mortal will.
Ben Thompson
1/2
Solstice Zealot
Creature — Rhino Cleric
When Solstice Zealot enters the battlefield, you get ⟨two energy counters⟩.
, Pay : Tap target creature.
"Embrace the light, or succumb to the shadows."
2/3
Spiritualize
Instant
Until end of turn, whenever target creature deals damage, you gain that much life.
Draw a card.
"There is purity in all things. Even hatred."
—Lieutenant Kirtar

Blue


Deep Freeze
Enchantment — Aura
Enchant creature
Enchanted creature has base power and toughness 0/4, has defender, loses all other abilities, and is a blue Wall in addition to its other colors and types.
For cryomancers, studying the Ice Age isn't just an academic exercise.
Dematerialize
Sorcery
Return target permanent to its owner's hand.
Flashback (You may play this card from your graveyard for its flashback cost. Then remove it from the game.)
Denizen of the Deep
Creature — Serpent
When Denizen of the Deep enters the battlefield, return each other creature you control to its owner's hand.
According to merfolk legend, a denizen of the deep swallows the horizon at the end of each day, bringing on the cold blanket of night.
11/11
Desynchronization
Instant
Return each nonland permanent that's not historic to its owner's hand. (Artifacts, legendaries, and Sagas are historic.)
History cannot be changed, and the Animus is not kind to those who try.
Desynchronize
Instant
Target nonland permanent's owner puts it on the top or bottom of their library. Scry 2.
Before Kaya could pull Teferi's spirit back, the overloaded temporal anchor failed, and he was set adrift in the currents of time.
Divide by Zero
Instant
Return target spell or permanent with mana value 1 or greater to its owner's hand.
Learn. (You may reveal a Lesson card you own from outside the game and put it into your hand, or discard a card to draw a card.)
"Misery. Inadequacy. Failure. The common denominator is you."
Dizzy Spell
Instant
Target creature gets -3/-0 until end of turn.
Transmute (Discard this card: Search your library for a card with the same converted mana cost as this card, reveal it, and put it into your hand. Then shuffle your library. Play only as a sorcery.)
Dormant Gomazoa
Creature — Jellyfish
Flying
Dormant Gomazoa enters the battlefield tapped.
Dormant Gomazoa doesn't untap during your untap step.
Whenever you become the target of a spell, you may untap Dormant Gomazoa.
5/5
Downsize
Instant
Target creature you don't control gets -4/-0 until end of turn.
Overload (You may cast this spell for its overload cost. If you do, change "target" in its text to "each.")
Electrozoa
Creature — Jellyfish
Flash
Flying
When Electrozoa enters the battlefield, you get (two energy counters).
At the beginning of your precombat main phase, tap Electrozoa unless you pay .
3/1
Ertai, Wizard Adept
Summon Legend
Ertai, Wizard Adept counts as a Wizard.
: Counter target spell. Play this ability as an interrupt.
"Was that it?"
—Ertai, wizard adept
1/1
Erudite Wizard
Creature — Human Wizard
Whenever you draw your second card each turn, put a +1/+1 counter on this creature.
"Pretty baubles and gilded palaces may appeal to the egotist, but true wealth comes only through knowledge."
2/3

Black


Ashen-Skin Zubera
Creature — Zubera Spirit
When Ashen-Skin Zubera is put into a graveyard from play, target opponent discards a card for each Zubera put into a graveyard from play this turn.
When the Honden of Night's Reach began to crumble, its attendants swarmed Kamigawa to haunt mortal dreams.
1/2
Azra Smokeshaper
Creature — Azra Ninja
Ninjutsu
When Azra Smokeshaper enters the battlefield, target creature you control gains indestructible until end of turn.
3/3
Azula Always Lies
Instant — Lesson
Choose one or both —
• Target creature gets -1/-1 until end of turn.
• Put a +1/+1 counter on target creature.
Azula is a skilled and deadly warrior, but her true passion is emotional torment.
Azula, On the Hunt
Legendary Creature — Human Noble
Firebending 2
Whenever Azula attacks, you lose 1 life and create a Clue token.
"You can run, but I'll catch you."
4/3
Azula, Ruthless Firebender
Legendary Creature — Human Noble
Firebending 1
Whenever Azula attacks, you may discard a card. Then you get an experience counter for each player who discarded a card this turn.
: Until end of turn, Azula gets +1/+1 for each experience counter you have and gains menace.
3/3
Baron Helmut Zemo
Legendary Creature — Human Noble Villain
Whenever you cast a black spell from your hand, Baron Helmut Zemo connives.
Boast — Exile any number of black cards from your graveyard with fifteen or more black mana symbols among their mana costs: Copy those exiled cards. You may cast up to three of the copies without paying their mana costs.
3/3
Bartizan Bats
Creature — Bat
Flying
At night, bats will feast on whatever is drawn to lanterns and streetlights.
3/1
Blacksnag Buzzard
Creature — Bird
Flying
Blacksnag Buzzard enters the battlefield with a +1/+1 counter on it if a creature died this turn.
Plot
2/1
Black Sun's Zenith
Sorcery
Put X -1/-1 counters on each creature. Shuffle Black Sun's Zenith into its owner's library.
"Under the suns, Mirrodin kneels and begs us for perfection."
—Geth, Lord of the Vault
Blessing of Belzenlok
Instant
Target creature gets +2/+1 until end of turn. If it's legendary, it also gains lifelink until end of turn.
"My heart is not mine, it is Belzenlok's. All hearts are his, and all blood."
—"Rite of Belzenlok"
Blind Zealot
Creature — Human Cleric
Intimidate
Whenever Blind Zealot deals combat damage to a player, you may sacrifice it. If you do, destroy target creature that player controls.
2/2
Blitz Leech
Creature — Leech
Flash
When Blitz Leech enters the battlefield, target creature an opponent controls gets -2/-2 until end of turn. Remove all counters from that creature.
"Fools wear armor against it as if the worst it could take is your blood."
—Gavi, nest warden
5/2

Red


Hazoret's Favor
Enchantment
At the beginning of combat on your turn, you may have target creature you control get +2/+0 and gain haste until end of turn. If you do, sacrifice it at the beginning of the next end step.
Hazoret's gift is bestowed only once.
Hazoret's Undying Fury
Sorcery
Shuffle your library, then exile the top four cards. You may cast any number of nonland cards with converted mana cost 5 or less from among them without paying their mana costs. Lands you control don't untap during your next untap step.
Hazoret the Fervent
Legendary Creature — God
Indestructible, haste
Hazoret the Fervent can't attack or block unless you have one or fewer cards in hand.
, Discard a card: Hazoret deals 2 damage to each opponent.
5/4
Heiko Yamazaki, the General
Legendary Creature — Human Samurai
Trample
Whenever a Samurai or Warrior you control attacks alone, you may cast target artifact card from your graveyard this turn.
"I prefer to let my sword do the talking."
3/3
Iizuka the Ruthless
Legendary Creature — Human Samurai
Bushido 2 (When this blocks or becomes blocked, it gets +2/+2 until end of turn.)
, Sacrifice a Samurai: Samurai you control gain double strike until end of turn.
3/3
Ilharg, the Raze-Boar
Legendary Creature — Boar God
Trample
Whenever Ilharg, the Raze-Boar attacks, you may put a creature card from your hand onto the battlefield tapped and attacking. Return that creature to your hand at the beginning of the next end step.
When Ilharg, the Raze-Boar dies or is put into exile from the battlefield, you may put it into its owner's library third from the top.
6/6
Inescapable Blaze
Instant
This spell can't be countered.
Inescapable Blaze deals 6 damage to any target.
"The Izzet are blamed for every little disaster, which is unfair because we only cause most of them."
—Mizzix of the Izmagnus
Ironclaw Buzzardiers
Creature — Orc Scout
Ironclaw Buzzardiers can't block creatures with power 2 or greater.
: Ironclaw Buzzardiers gains flying until end of turn.
They warn the army of danger as they squawk past in swift retreat.
2/2
Iron-Fist Pulverizer
Creature — Giant Warrior
Reach
Whenever you cast your second spell each turn, Iron-Fist Pulverizer deals 2 damage to target opponent. Scry 1. (Look at the top card of your library. You may put that card on the bottom.)
"The 3:10 to Omenport will be delayed."
—Prosperity Station announcement
4/5
Izzet Chemister
Creature — Goblin Wizard
Haste
, : Exile target instant or sorcery card from your graveyard.
, , Sacrifice Izzet Chemister: Cast any number of cards exiled with Izzet Chemister without paying their mana costs.
1/3
Kari Zev's Expertise
Sorcery
Gain control of target creature or Vehicle until end of turn. Untap it. It gains haste until end of turn.
You may cast a card with converted mana cost 2 or less from your hand without paying its mana cost.
"I was made for this!"
Kari Zev, Skyship Raider
Legendary Creature — Human Pirate
First strike, menace
Whenever Kari Zev, Skyship Raider attacks, create Ragavan, a legendary 2/1 red Monkey creature token. Ragavan enters the battlefield tapped and attacking. Exile that token at end of combat.
Aboard her ship, the Dragon's Smile, Kari follows no one's rules but her own.
1/3

Green


Ezekiel Sims, Spider-Totem
Legendary Creature — Spider Human Advisor
Reach
At the beginning of combat on your turn, target Spider you control gets +2/+2 until end of turn.
For all his wealth and power, there is a fear deep inside Ezekiel that spurs him to train others.
3/5
Ezuri, Renegade Leader
Legendary Creature — Elf Warrior
: Regenerate another target Elf.
: Elf creatures you control get +3/+3 and gain trample until end of turn.
Great hero or grand betrayer? The truth of Ezuri's legacy is clouded by the fog of legend.
2/2
Ezuri's Archers
Creature — Elf Archer
Reach
Whenever Ezuri's Archers blocks a creature with flying, Ezuri's Archers gets +3/+0 until end of turn.
Eyes and arrows trained ever skyward.
1/2
Ezuri's Brigade
Creature — Elf Warrior
Metalcraft — As long as you control three or more artifacts, Ezuri's Brigade gets +4/+4 and has trample.
Riding ravenous, ever-growing vorracs is almost as dangerous as fitting them with saddles.
4/4
Ezuri's Predation
Sorcery
For each creature your opponents control, create a 4/4 green Phyrexian Beast creature token. Each of those tokens fights a different one of those creatures.
"Slaughter the weak ones. They are unworthy of the gift of compleation."
Ezzaroot Channeler
Creature — Treefolk Druid
Reach
Creature spells you cast cost X less to cast, where X is the amount of life you gained this turn.
: You gain 2 life.
4/6
Ferocious Zheng
Creature — Cat Beast
Known for their glowing horn and stone-rattling roar, zheng are the fiercest predators in the forest. Few survived before Jiang Yanggu came.
4/4
Floral Spuzzem
Summon Spuzzem
If Floral Spuzzem attacks an opponent and is not blocked, then Floral Spuzzem may choose to destroy a target artifact under that opponent's control and deal no damage.
Illus. © 1994 Rob Alexander
2/2
Foe-Razer Regent
Creature — Dragon
Flying
When Foe-Razer Regent enters the battlefield, you may have it fight target creature you don't control.
Whenever a creature you control fights, put two +1/+1 counters on it at the beginning of the next end step.
4/5
Frenzied Baloth
Creature — Beast
This spell can't be countered.
Trample, haste
Creature spells you control can't be countered.
Combat damage can't be prevented.
Not all species on Evendo welcomed the thawing of the ice.
3/2
Gemrazer
Creature — Beast
Mutate 1
(If you cast this spell for its mutate cost, put it over or under target non-Human creature you own. They mutate into the creature on top plus all abilities from under it.)
Reach, trample
Whenever this creature mutates, destroy target artifact or enchantment an opponent controls.
4/4
Ghazbán Ogre
Summon Ogre
During your upkeep, if a player has more life than any other, he or she gains control of Ghazbán Ogre.
"We were holding our own—until the ogre guiding us suddenly grinned and turned on our commander."
—Tova Jursdotter, Sarpadian mercenary
Illus. Mike Raabe
2/2

Test Time!

Test #1


Cavalier of Flame
Creature — Elemental Knight
M20
1 : Creatures you control get +1/+0 and gain haste until end of turn.
When Cavalier of Flame enters the battlefield, discard any number of cards, then draw that many cards.
When Cavalier of Flame dies, it deals X damage to each opponent and each planeswalker they control, where X is the number of land cards in your graveyard.
6/5
125/280 M
M20 • EN
Wesley Burt
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Test #2


Aggressive Urge
1
Instant
Target creature gets +1/+1 until end of turn.
Draw a card.
The power of the wild, concentrated in a single charge.
374 C
JMP • EN
Christopher Moeller
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Test #3


Arborea Pegasus
3
Creature — Pegasus
Flying
When Arborea Pegasus enters the battlefield, target creature gets +1/+1 and gains flying until end of turn.
The noble steeds of the elven gods can sometimes be persuaded to allow mere mortals on their backs.
2/3
002/281 C
AFR • EN
Justyna Gil
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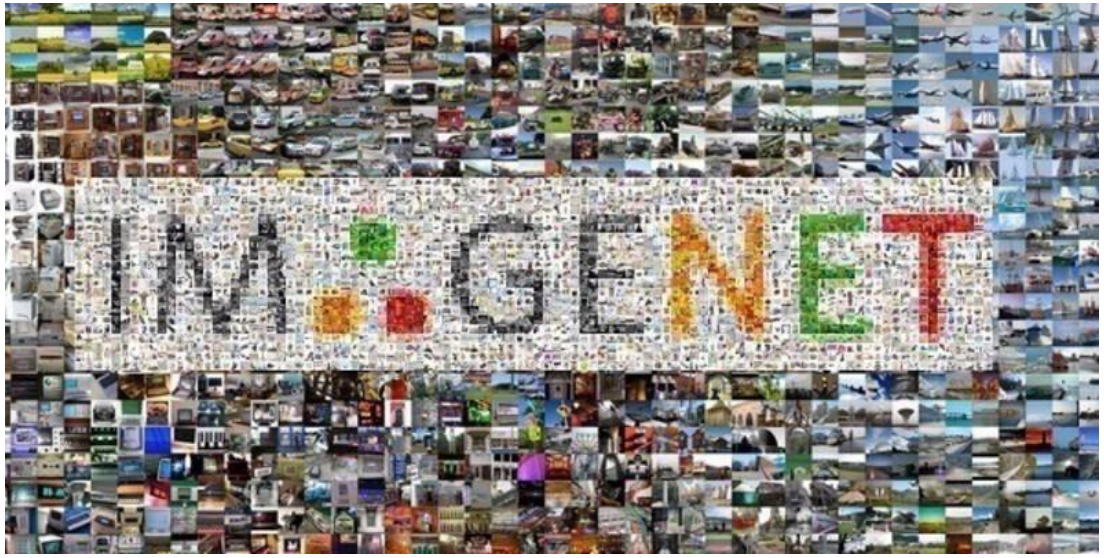
Start with a Pretrained Model

- Resnet-18 (special type of neural network specifically for image classification)
- Pre-trained on ImageNet-1k (Over 1 million examples from 1,000 classes



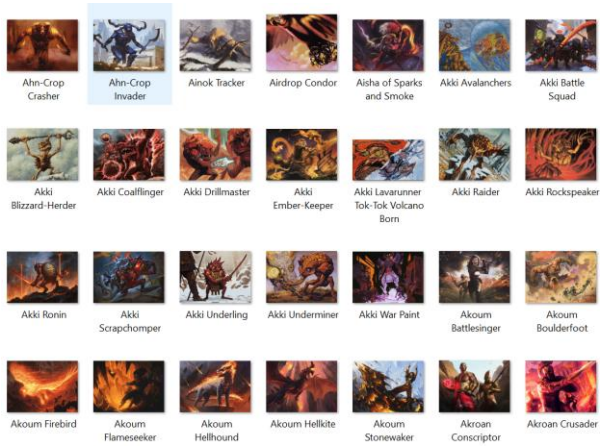

```
# Setup Model
model = models.resnet18(weights=models.ResNet18_Weights.IMAGENET1K_V1)
```

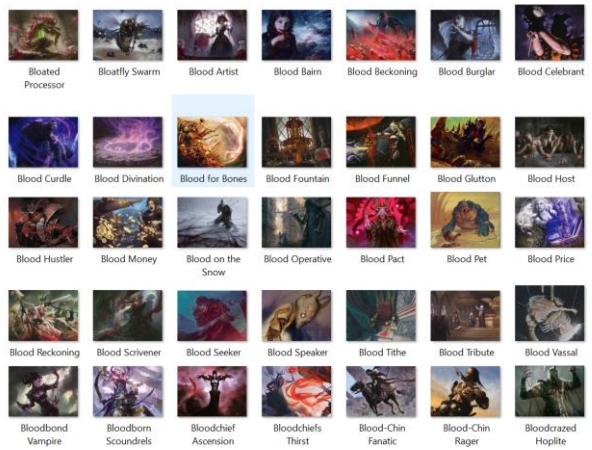
Create a Dataset

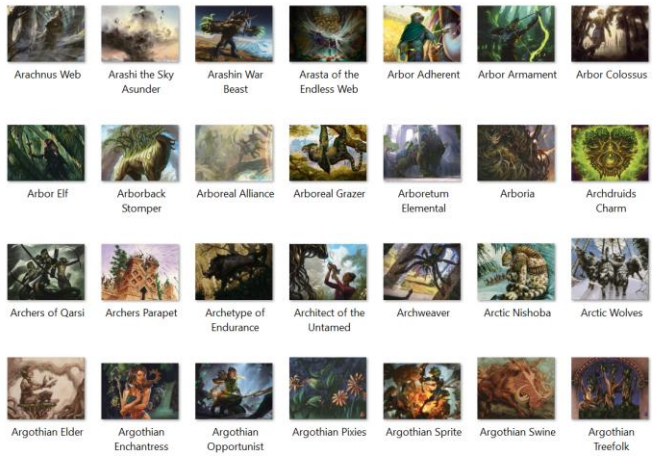
- Scryfall API
- Get 500 random cards in each color
- 80-20 train/test split (we should get about 100 cards from each color in the test set).

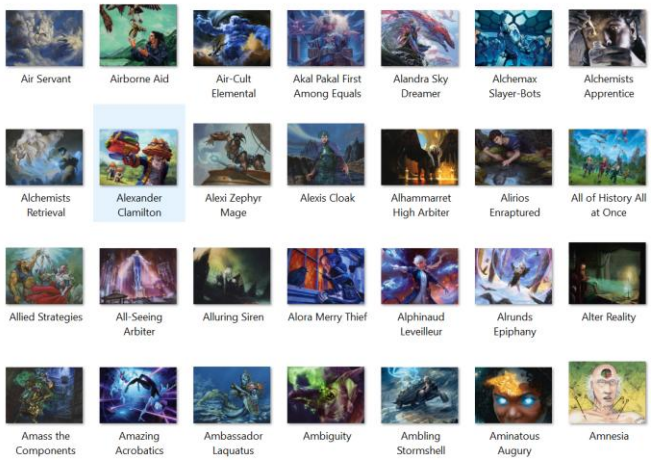
```python
# 1. DOWNLOADER FUNCTION
def download_dataset():
    if os.path.exists(DATA_DIR):
        print(f"Directory {DATA_DIR} exists. Skipping download.")
        return

    os.makedirs(DATA_DIR, exist_ok=True)

    for color in CLASSES:
        # Create class subfolder (e.g., ./mtg_data/W)
        class_dir = os.path.join(DATA_DIR, color)
        os.makedirs(class_dir, exist_ok=True)

        print(f"Fetching {color} cards...")

        # Scryfall query: Single color, not digital, has art
        query = f"c={color} -c:m is:spell -is:digital"
        api_url = "https://api.scryfall.com/cards/search"

        count = 0
        page = 1

        while count < SAMPLES_PER_CLASS:
            params = {'q': query, 'page': page, 'format': 'json'}
            resp = requests.get(api_url, params=params)

            if resp.status_code != 200:
                break

            data = resp.json()
            if 'data' not in data: break

            for card in data['data']:
                if count >= SAMPLES_PER_CLASS: break

                # Safety check for image dict
                if 'image_uris' in card and 'art_crop' in card['image_uris']:
                    img_url = card['image_uris']['art_crop']
                    # Sanitize filename
                    safe_name = "".join([c for c in card['name'] if c.isalnum() or c in (' ','-')]).strip()
                    save_path = os.path.join(class_dir, f"{safe_name}.jpg")

                    try:
                        img_data = requests.get(img_url).content
                        with open(save_path, 'wb') as f:
                            f.write(img_data)
                        count += 1
                    except Exception as e:
                        print(f"Failed {safe_name}: {e}")

            page += 1
            time.sleep(0.1) # Respect API limits
```

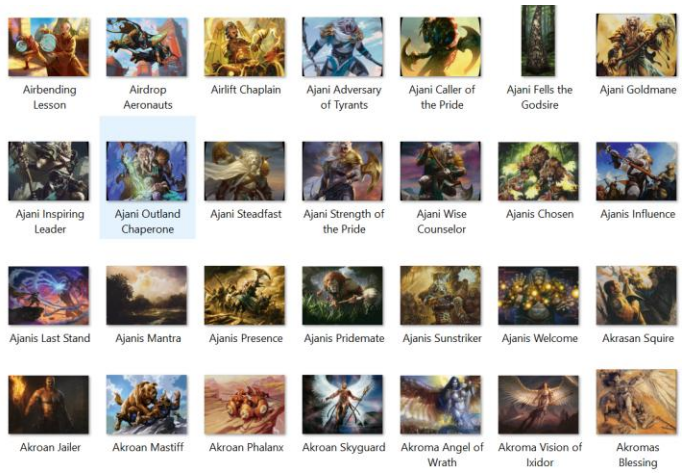
Look at the Dataset











Train the Model

- We train the model on the train set.
- As the model trains, it tweaks its own weights to learn to classify Magic card art based on color.
- Hey look! We're using Cross Entropy Loss! We've heard of that.

```
criterion = nn.CrossEntropyLoss()
optimizer = optim.Adam(model.fc.parameters(), lr=0.001)

print("Training model...")
for epoch in range(5): # 5 epochs is plenty for this
    model.train()
    running_loss = 0.0
    for inputs, labels in tqdm(loader, desc=f"Epoch {epoch+1}"):
        inputs, labels = inputs.to(device), labels.to(device)
        optimizer.zero_grad()
        outputs = model(inputs)
        loss = criterion(outputs, labels)
        loss.backward()
        optimizer.step()
        running_loss += loss.item()

# Save Model
torch.save(model.state_dict(), MODEL_PATH)
print(f"Model saved to {MODEL_PATH}")
```

Test the Model

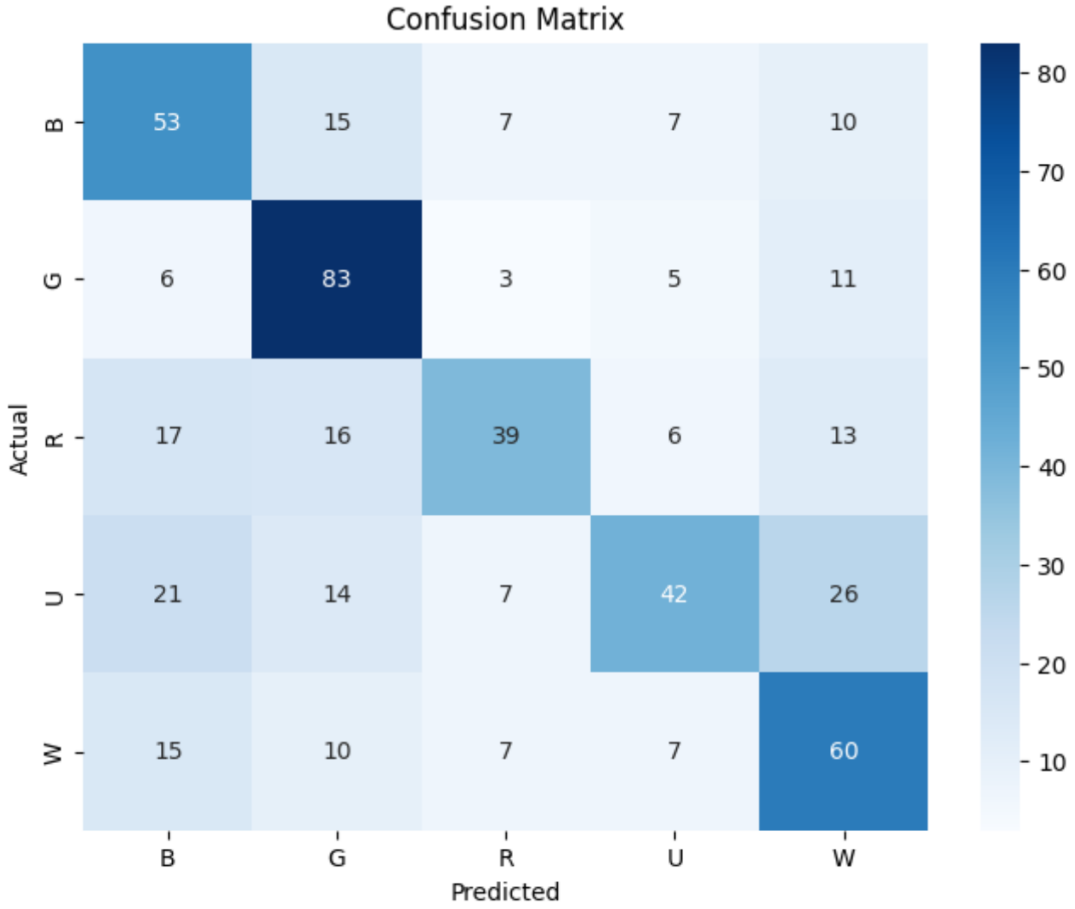
- We test the model on the test set.
- How well did we do?
- What is random chance?
- How balanced are our classes?
- How well did we do on each class?

Classification Report:

	precision	recall	f1-score	support
B	0.47	0.58	0.52	92
G	0.60	0.77	0.67	108
R	0.62	0.43	0.51	91
U	0.63	0.38	0.47	110
W	0.50	0.61	0.55	99
macro avg	0.56	0.55	0.54	500
weighted avg	0.57	0.55	0.55	500

Test the Model – Confusion matrix

- Which color was our model best at?
- Worst?
- What kind of errors did the model make?



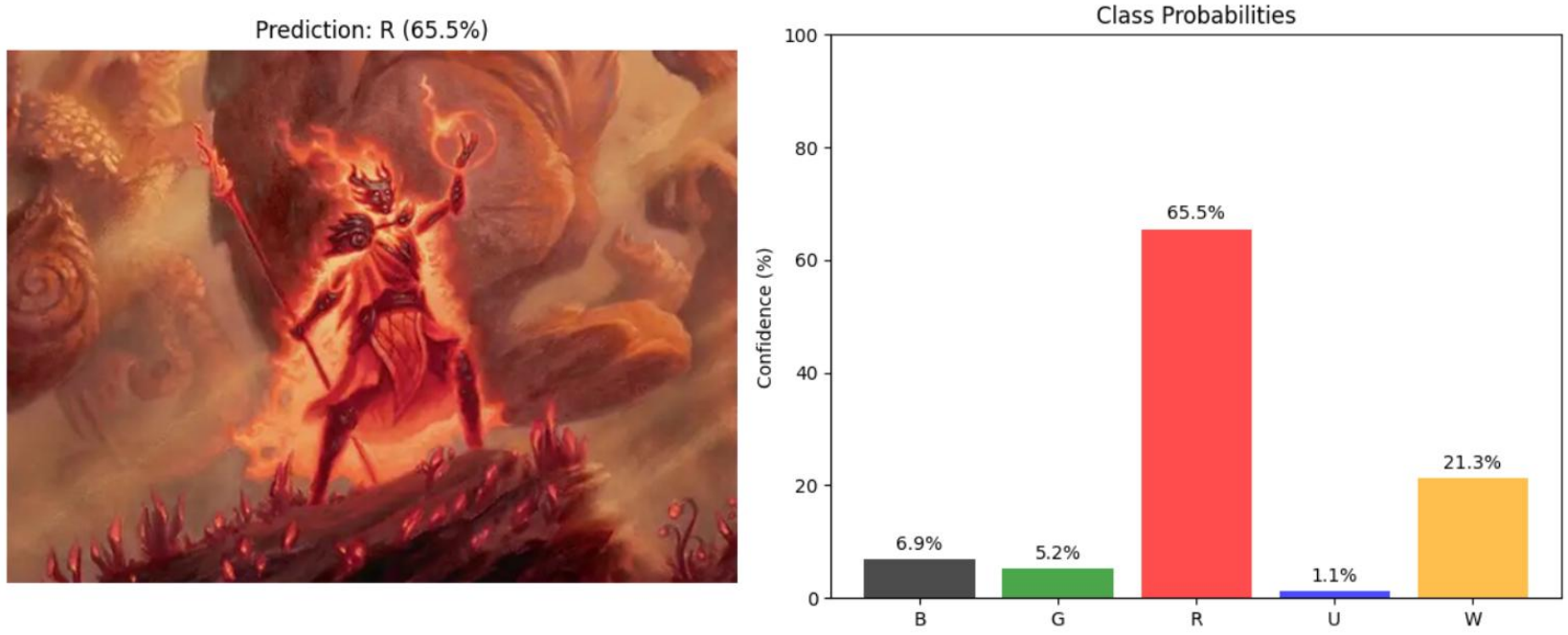
Test the Model – Look at Good/Bad Classifications

- Models can do poorly for a couple of reasons:
  - The model didn't learn what it was supposed to.
  - The task it was learning was messy. (Noice/Variance)
- If our model is failing, but we can be more confident that it is failing for the second reason, that's good.

Let's look at some examples of good and bad classifications by our model:

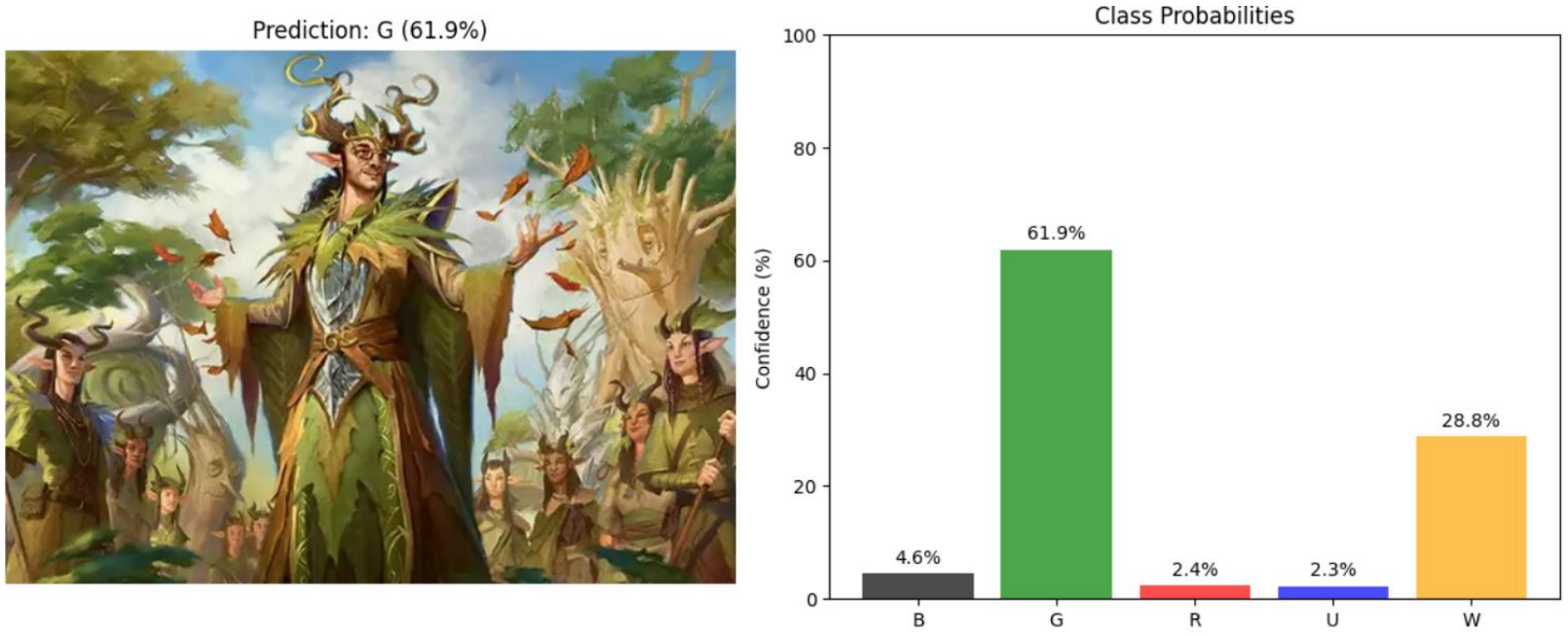
Quick Reminder About Classification

- Classification models don’t just output a guess, they output a probability distribution across all classes.
- Example:



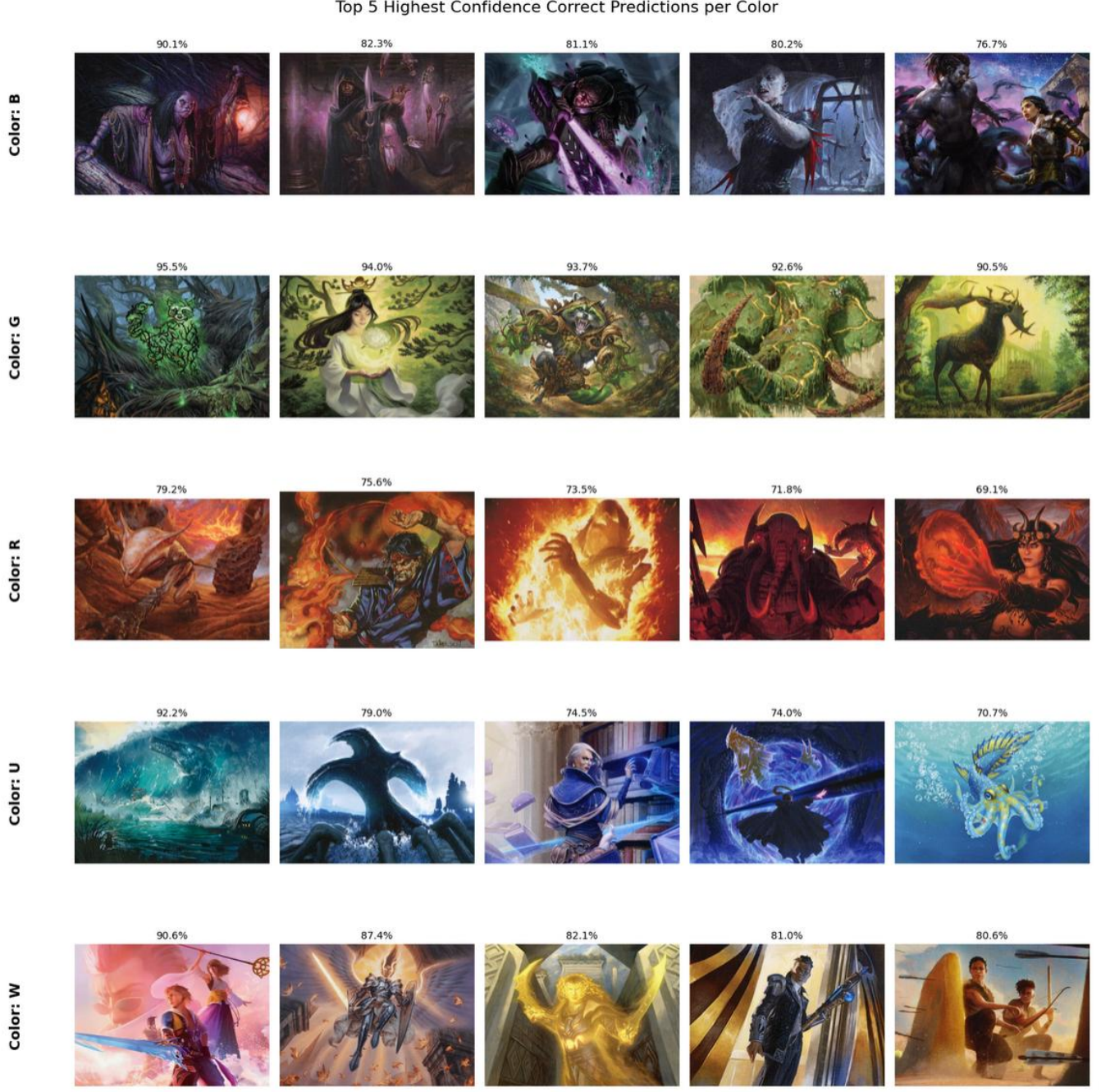
Quick Reminder About Classification

- Models don’t just output a guess, they output a probability distribution across all classes.
- Example 2:

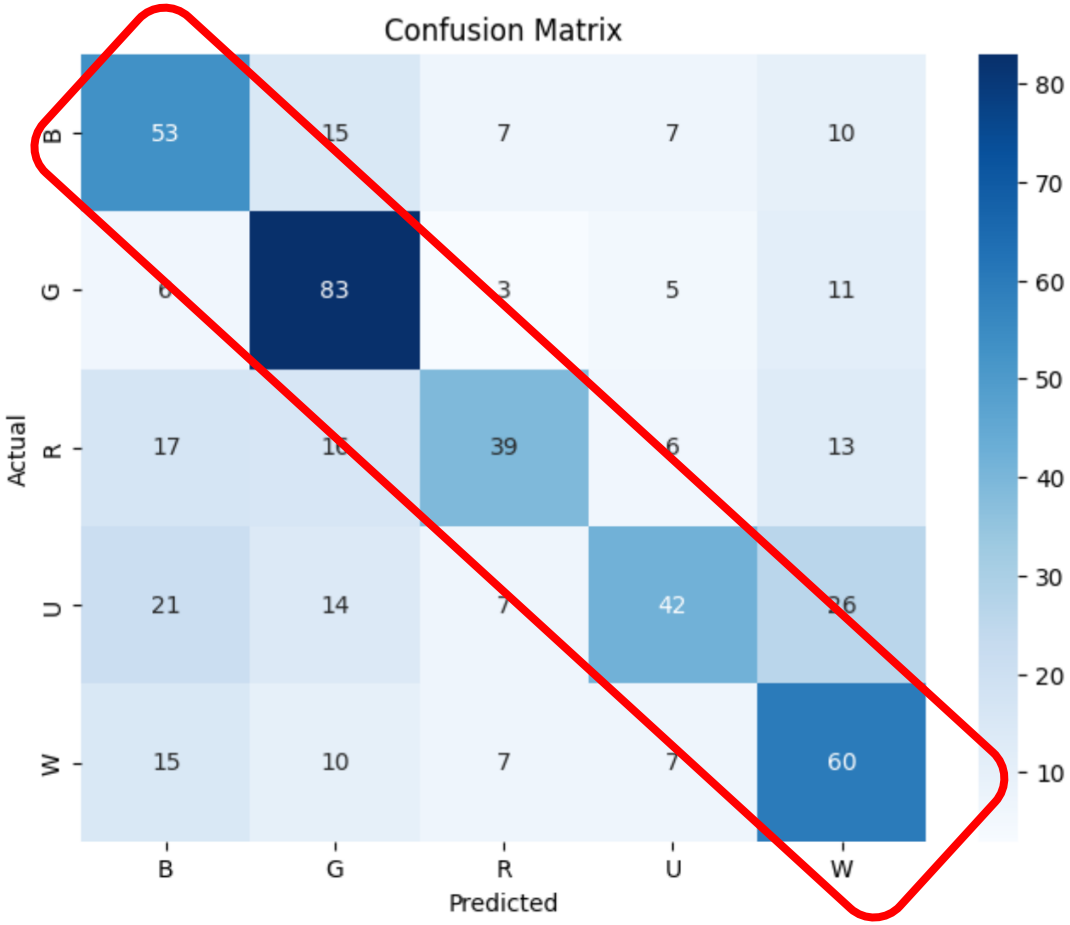


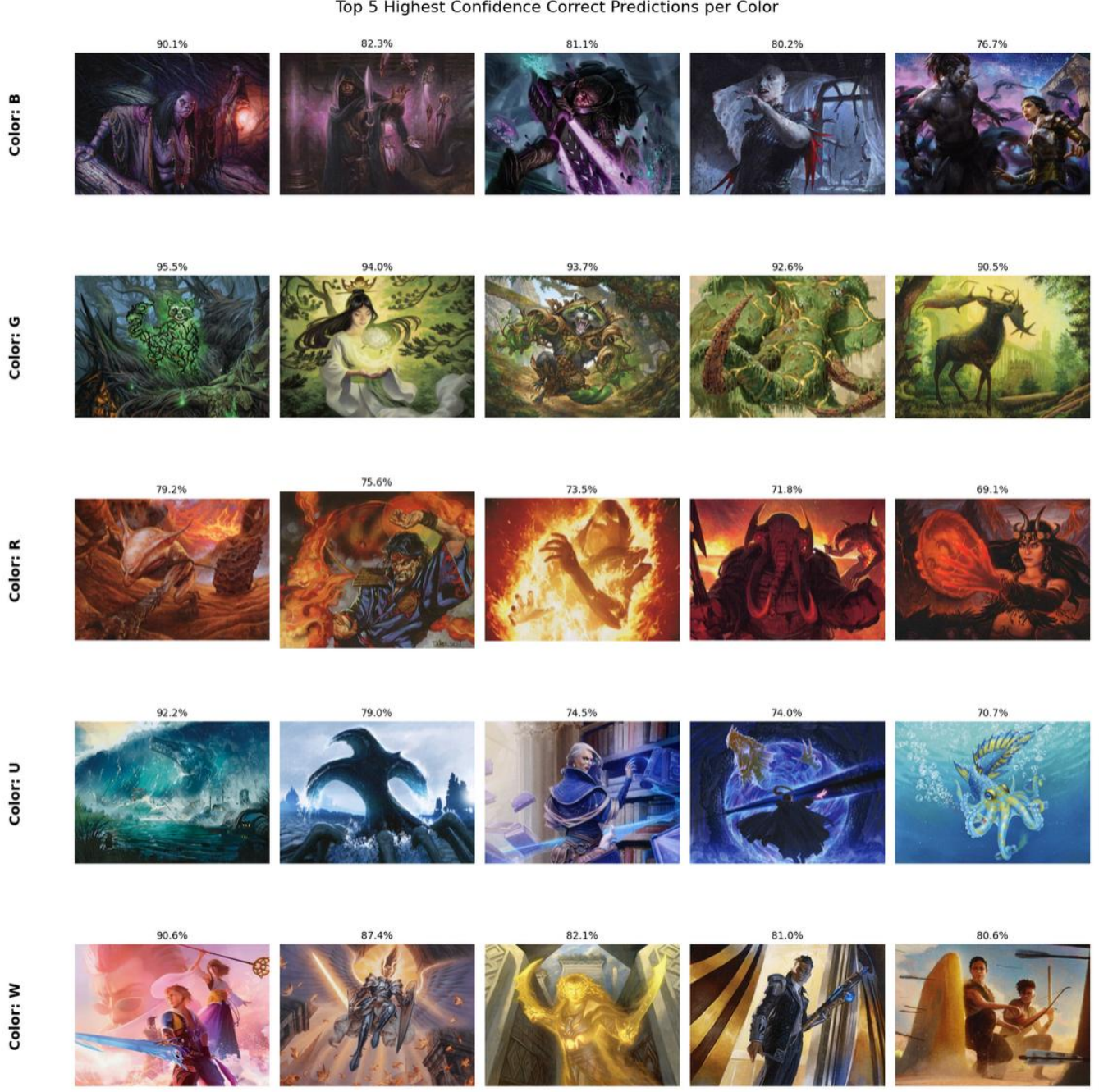
Correct Classifications

- We can look at the images our model classified correctly with the highest confidence (assigned the most probability to the correct class)
- What does this tell us about our model?

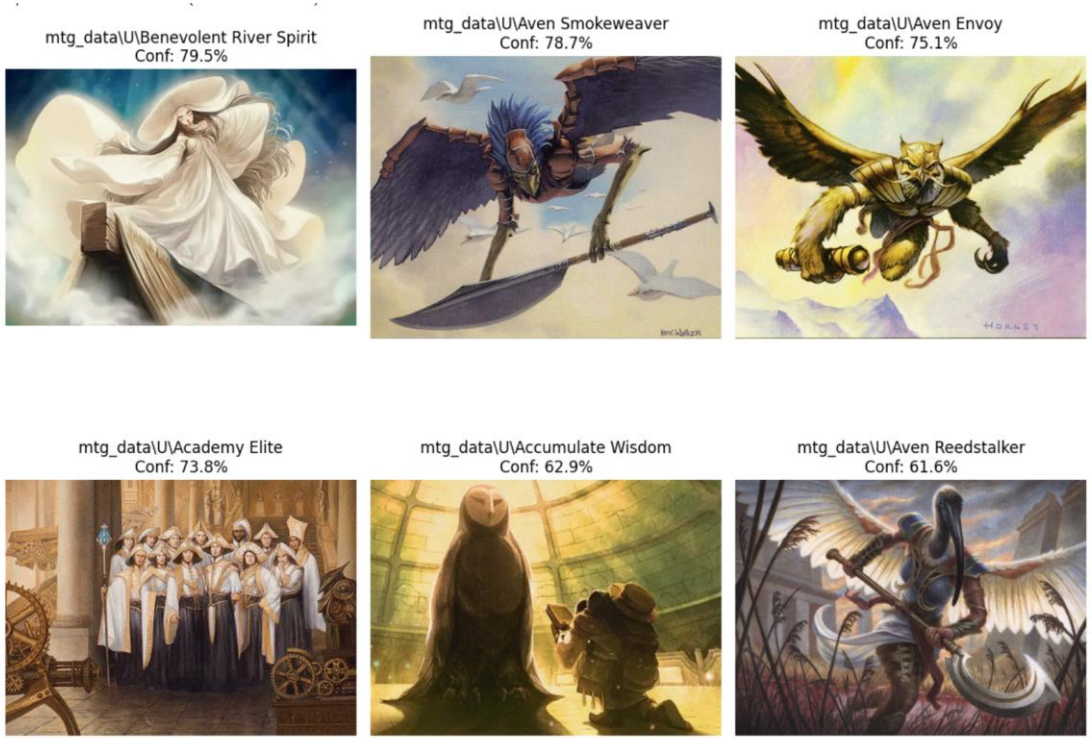


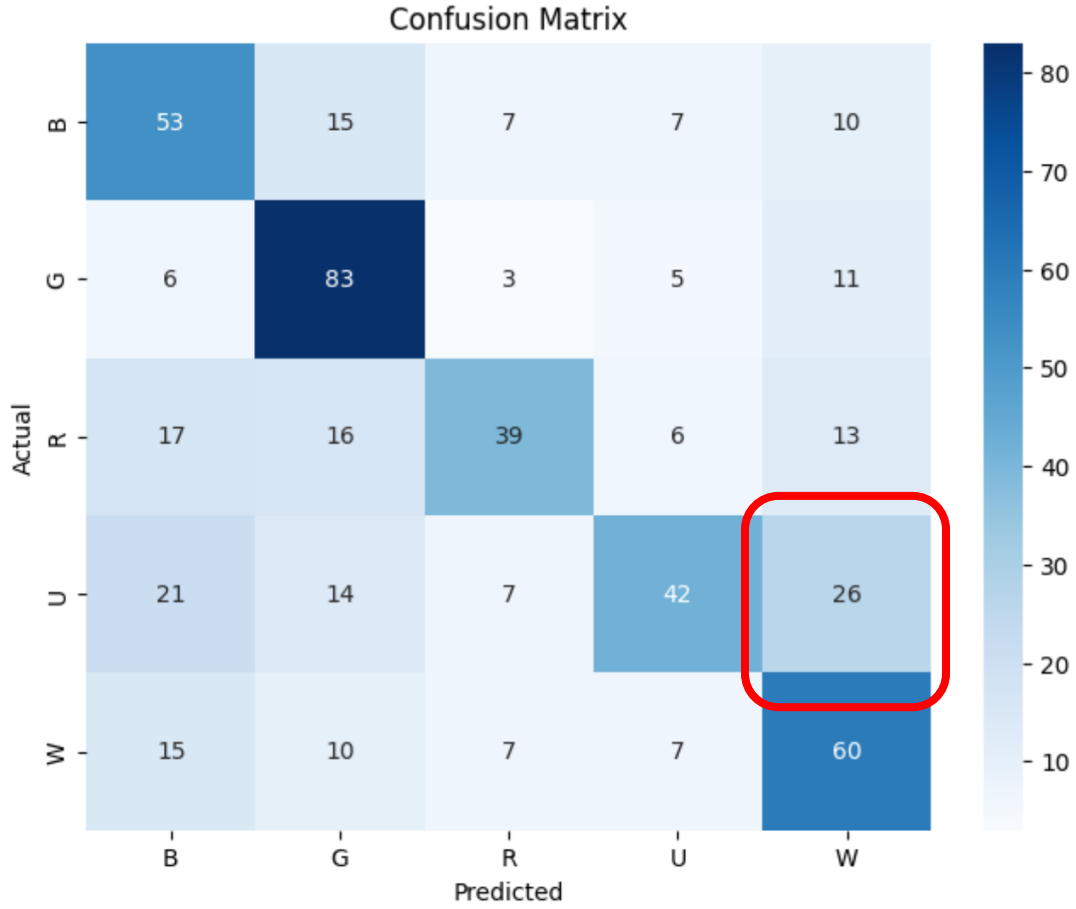
Correct Classifications



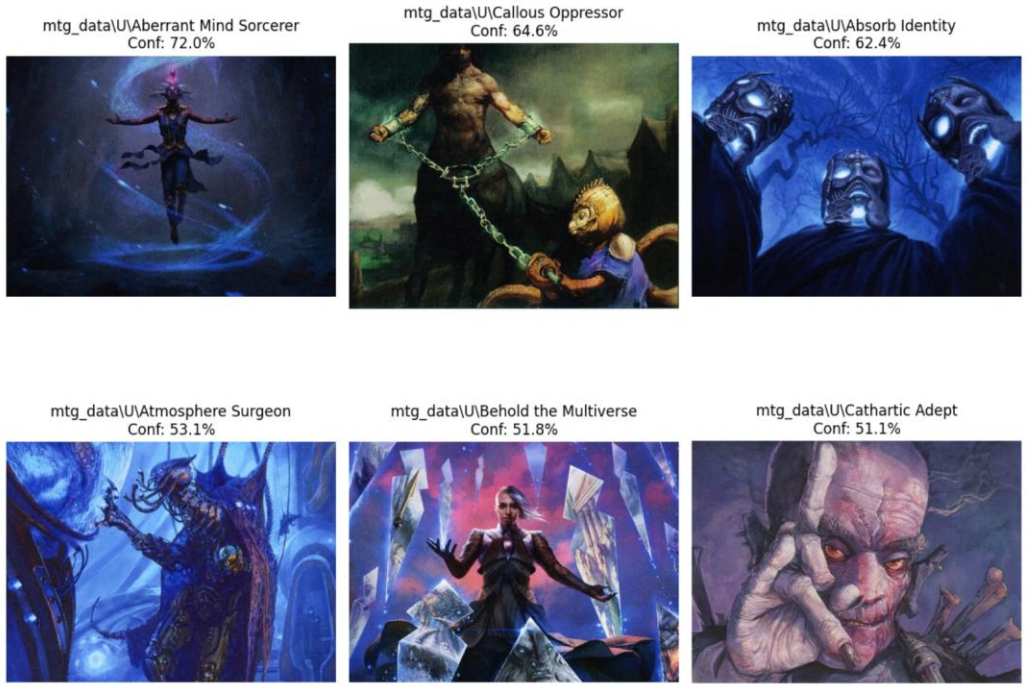


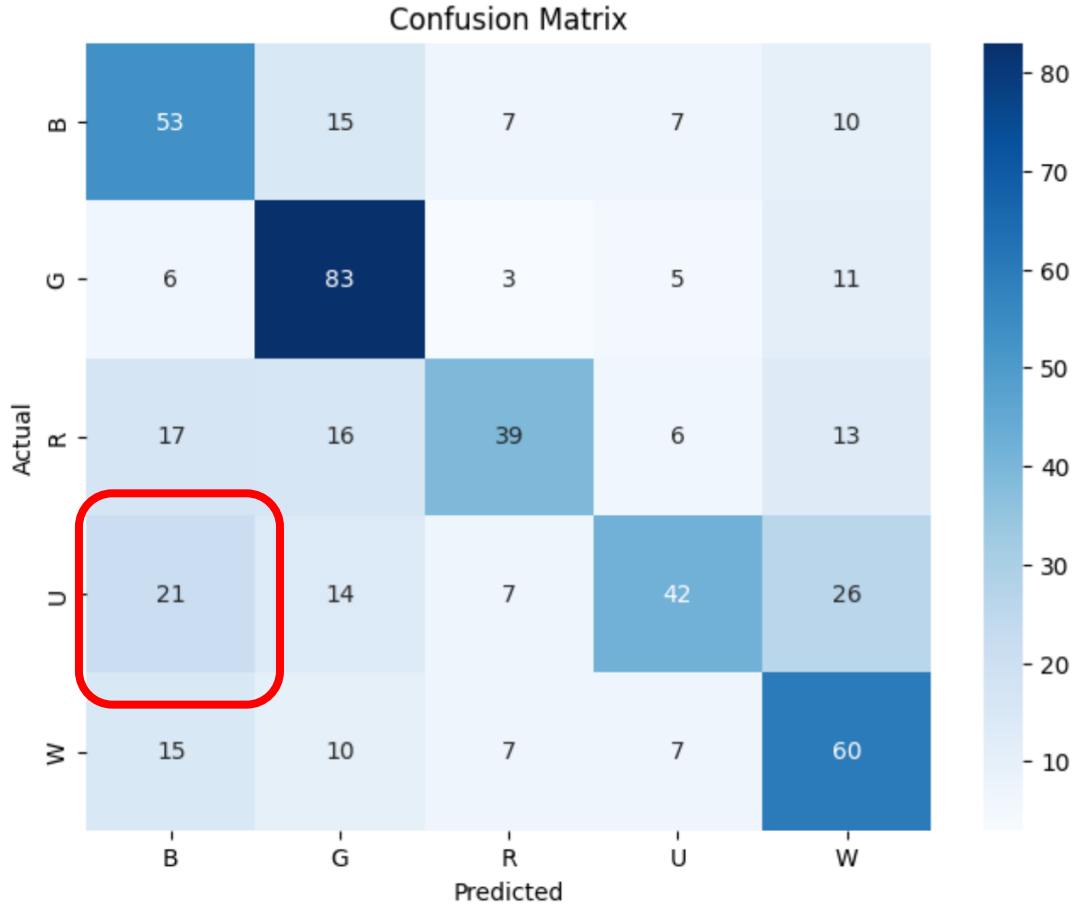
Confusion Matrix Revisited



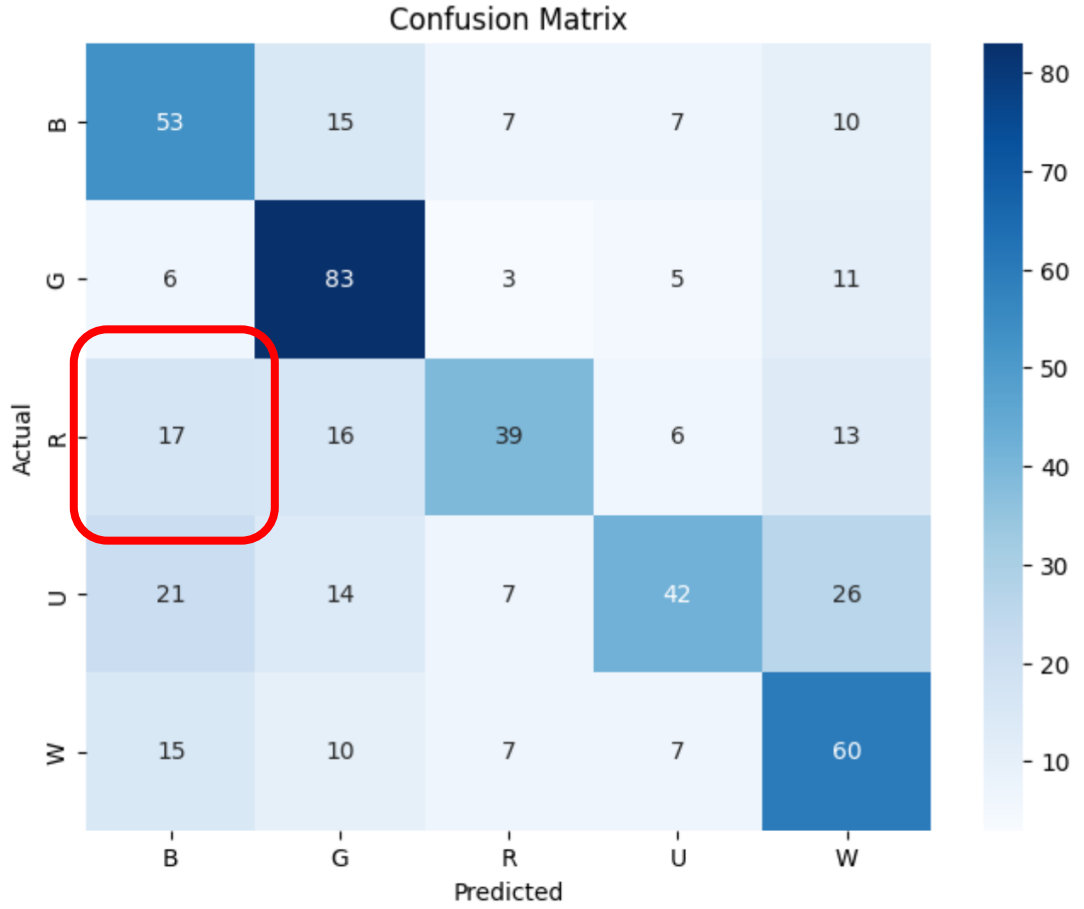


Confusion Matrix Revisited

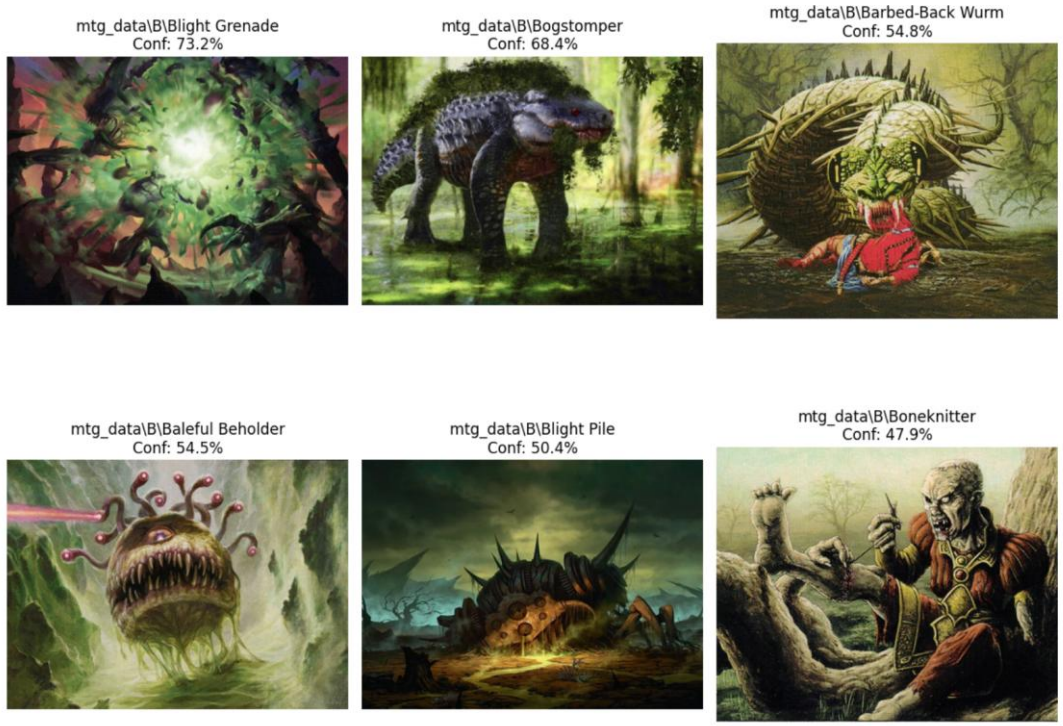


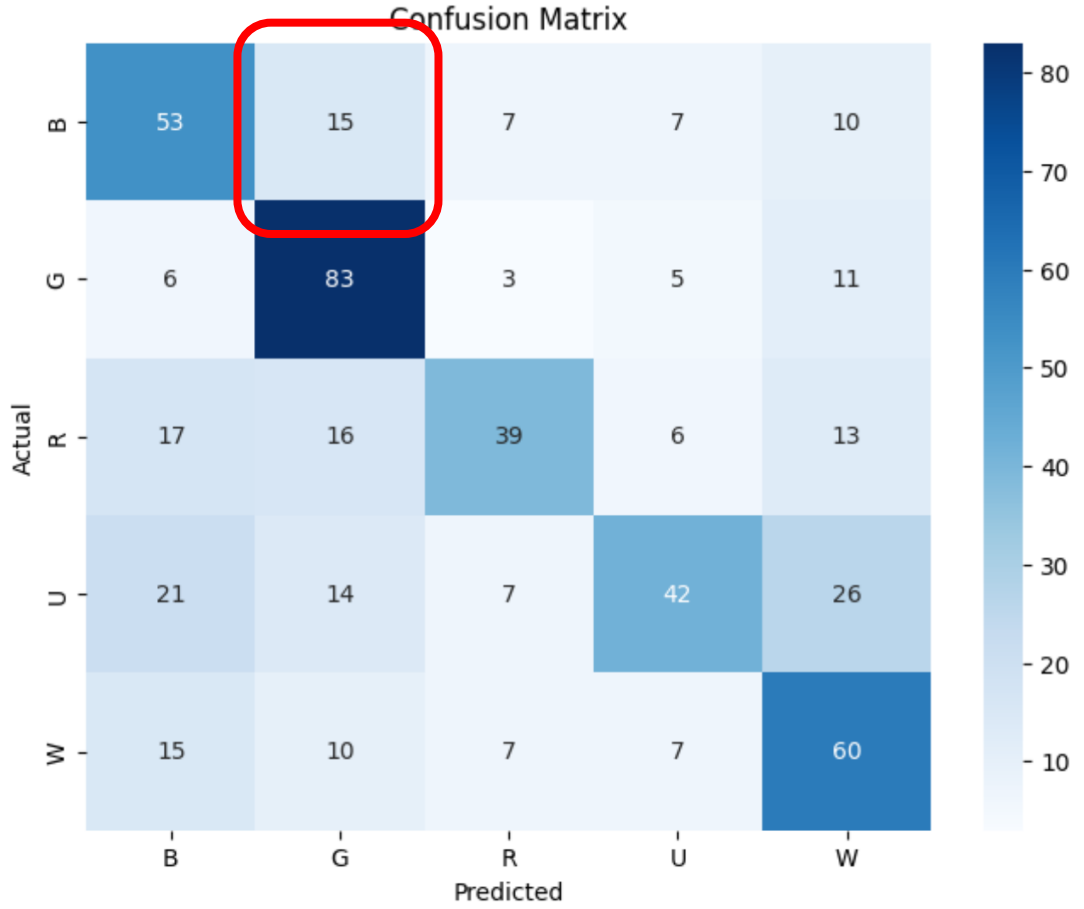


Confusion Matrix Revisited



Confusion Matrix Revisited





Test the Model – Confusion matrix

- What does the confusion matrix tell us about how our model is doing?
- How did inspecting individual examples help us understand our confusion matrix/model?