

# Optimizing the Labeling Process

Week 4 · CS 203: Software Tools and Techniques for AI

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# Part 1: The Labeling Cost Problem

*Why we need smarter approaches*

# Previously on CS 203...

**Week 1:** Collected movie data from APIs

**Week 2:** Validated and cleaned the data

**Week 3:** Learned how to label data with quality control

```
# We labeled 1,000 movies... but we need 100,000!
labeled_movies = 1000
total_needed = 100000
remaining = total_needed - labeled_movies # 99,000 more!
```

**Problem:** At \$0.30/movie and 5 min/movie, this would cost \$30,000 and 8,333 hours!

# The Labeling Bottleneck

## TRADITIONAL APPROACH

```
Unlabeled      Label      Labeled      Train  
Data    → ALL of   → Data    → Model  
(100,000)     them!      (100,000)  
  
Cost: $$$$$    Time: Months
```

Can we do better?

# Three Strategies to Reduce Labeling Cost

| ACTIVE LEARNING  | WEAK SUPERVISION                                   | LLM LABELING   |
|--|--|--|
| <b>Label SMARTER</b><br>Pick the most informative examples | <b>Label with CODE</b><br>Write rules & heuristics | <b>Label with AI</b><br>Use GPT/Claude as annotators |
| Human labels<br>fewer items                                | Noisy labels<br>many items                         | AI labels<br>many items                              |

# Today's Mission

Learn techniques to reduce labeling effort by 10x or more.

| Technique            | Effort Reduction | Best When                            |
|----------------------|------------------|--------------------------------------|
| Active Learning      | 2 - 10x          | Limited budget for human labels      |
| Weak Supervision     | 10 - 100x        | Patterns can be encoded as rules     |
| LLM Labeling         | 10 - 50x         | Task is well-defined, cost-sensitive |
| Noisy Label Handling | 1.5 - 2x         | Labels already exist but noisy       |

## Part 2: Active Learning

*Label smarter, not harder*

# What is Active Learning?

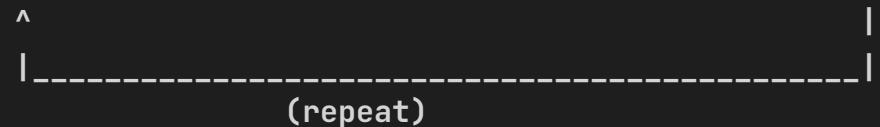
**Core Idea:** Let the model choose which examples to label.

## PASSIVE LEARNING (Traditional)

Random sample → Human labels → Train model

## ACTIVE LEARNING

Model picks "hard" examples → Human labels → Train model



**Why it works:** Not all examples are equally informative!

# The Teaching Analogy

Imagine you're learning to drive:

## PASSIVE LEARNING:

Instructor randomly picks roads

- 50 trips on straight highways (easy, repetitive)
- 3 trips in parking lots (never practiced!)
- 2 trips in rain (rare but important!)

## ACTIVE LEARNING:

You tell instructor what you struggle with

- 10 trips on straight highways (got it!)
- 20 trips in parking lots (need practice)
- 15 trips in rain (challenging!)

Active learning focuses effort where it helps most!

# Active Learning: The Intuition

Easy Examples  
(Model is confident)

"I loved this movie! Best film ever!"  
Model: 99% POSITIVE → Don't need to label this

Hard Examples  
(Model is uncertain)

"The movie was... interesting."  
Model: 48% POS, 52% NEG → LABEL THIS ONE!

Hard examples teach the model the most!

# Movie Review Example: Why Uncertainty Matters

```
# Our movie review classifier after training on 100 examples

reviews = [
    "Best movie ever! 10/10!",           # Model: 99% POS - Already knows this
    "Terrible waste of time.",          # Model: 98% NEG - Already knows this
    "It was okay, I guess.",           # Model: 52% POS - UNCERTAIN!
    "Interesting but flawed.",         # Model: 55% NEG - UNCERTAIN!
    "Not bad, not great.",            # Model: 49% POS - VERY UNCERTAIN!
]

# Which should we label next?
# The uncertain ones! They define the decision boundary.
```

The model already "knows" extreme reviews. Label the ambiguous ones!

# The Decision Boundary Intuition

| Positive Reviews | Negative Reviews |
|------------------|------------------|
| +                | -                |
| +++              | ---              |
| +++++            | - - -            |
| ++++++           | - - - -          |
| +++++            | - - - -          |
| +++              | - - -            |
| +                | -                |

Easy to classify      THE BOUNDARY  
(don't need labels)    (need labels!)

Easy to classify  
(don't need labels)

Active learning samples from the decision boundary where the model is confused!

# The Active Learning Loop

1. Start with small labeled set (seed data)  
v
2. Train model on labeled data  
v
3. Model scores unlabeled examples  
v
4. Select most informative examples (query strategy)  
v
5. Human labels selected examples  
v
6. Add to labeled set, repeat from step 2

# Query Strategies: How to Pick Examples

## 1. Uncertainty Sampling - Pick examples where model is least confident

```
# For classification, pick where max probability is lowest  
uncertainty = 1 - max(model.predict_proba(x))
```

## 2. Margin Sampling - Pick where top two classes are closest

```
probs = sorted(model.predict_proba(x), reverse=True)  
margin = probs[0] - probs[1] # Small margin = uncertain
```

## 3. Entropy Sampling - Pick where prediction distribution is most spread

```
entropy = -sum(p * log(p) for p in model.predict_proba(x))
```

# Query Strategy Comparison

## UNCERTAINTY SAMPLING

Probs: [0.34, 0.33, 0.33]

Max: 0.34 (low confidence)

Both would select this example - very uncertain!

## MARGIN SAMPLING

Probs: [0.50, 0.49, 0.01]

Margin: 0.50 - 0.49 = 0.01

Very uncertain between top 2 classes

## ENTROPY SAMPLING

Probs: [0.34, 0.33, 0.33]

Entropy =  $-3 * (0.33 * \log(0.33)) = 1.58$  (high)

Probs: [0.98, 0.01, 0.01]

Entropy =  $-(0.98 * \log(0.98) + 2 * 0.01 * \log(0.01)) = 0.12$  (low)

# Active Learning with modAL

```
from modAL.models import ActiveLearner
from modAL.uncertainty import uncertainty_sampling
from sklearn.ensemble import RandomForestClassifier

# Start with small seed set
X_initial, y_initial = X_labeled[:10], y_labeled[:10]
X_pool = X_unlabeled

# Create active learner
learner = ActiveLearner(
    estimator=RandomForestClassifier(),
    query_strategy=uncertainty_sampling,
    X_training=X_initial,
    y_training=y_initial
)
```

# Active Learning Loop in Practice

```
n_queries = 100

for i in range(n_queries):
    # Query for the most uncertain example
    query_idx, query_instance = learner.query(X_pool)

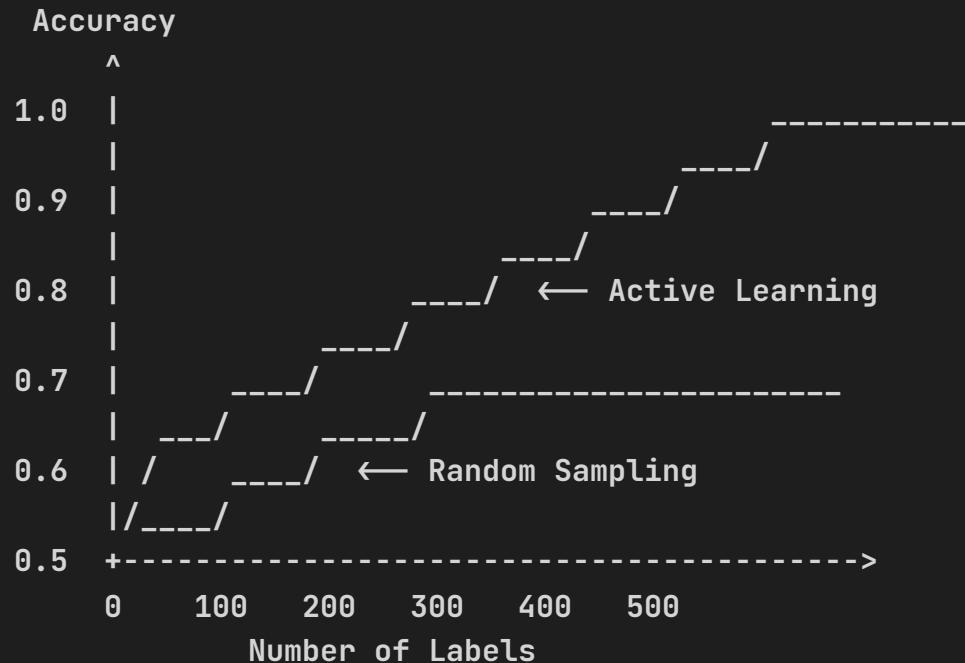
    # Get label from human (or oracle in experiments)
    y_new = get_human_label(query_instance)

    # Teach the model
    learner.teach(query_instance, y_new)

    # Remove from pool
    X_pool = np.delete(X_pool, query_idx, axis=0)

    # Track performance
    accuracy = learner.score(X_test, y_test)
    print(f"Query {i+1}: Accuracy = {accuracy:.2f}")
```

# Active Learning: Typical Results



Active learning reaches 90% accuracy with 200 labels

Random sampling needs 400+ labels for same accuracy

# Batch Active Learning

**Problem:** Querying one example at a time is slow.

**Solution:** Select a batch of examples at once.

```
from modAL.batch import uncertainty_batch_sampling

learner = ActiveLearner(
    estimator=RandomForestClassifier(),
    query_strategy=uncertainty_batch_sampling,
    X_training=X_initial,
    y_training=y_initial
)

# Query 10 examples at once
query_idx, query_instances = learner.query(X_pool, n_instances=10)
```

**Challenge:** Top-10 uncertain examples might be very similar!

# Diversity in Batch Selection

```
from modAL.batch import ranked_batch

def diversity_uncertainty_sampling(classifier, X_pool, n_instances=10):
    # Get uncertainty scores
    uncertainty = 1 - np.max(classifier.predict_proba(X_pool), axis=1)

    # Cluster similar examples
    from sklearn.cluster import KMeans
    kmeans = KMeans(n_clusters=n_instances).fit(X_pool)

    # Pick most uncertain from each cluster
    selected = []
    for cluster_id in range(n_instances):
        cluster_mask = kmeans.labels_ == cluster_id
        cluster_uncertainty = uncertainty[cluster_mask]
        best_idx = np.argmax(cluster_uncertainty)
        selected.append(np.where(cluster_mask)[0][best_idx])

    return selected
```

# Active Learning: Practical Considerations

## 1. Cold Start Problem

- Initial model is bad, uncertainty estimates unreliable
- Solution: Start with diverse random sample or stratified sample

## 2. Stopping Criteria

- When to stop labeling?
- Options: Budget exhausted, accuracy plateau, uncertainty threshold

## 3. Class Imbalance

- Uncertainty sampling may neglect rare classes
- Solution: Add diversity constraint or stratified sampling

## 4. Batch vs Sequential

- Sequential: More efficient per label
- Batch: Faster in practice (parallel labeling)

# Active Learning Tools

| Tool            | Description                          | Best For              |
|-----------------|--------------------------------------|-----------------------|
| modAL           | Python library, sklearn-compatible   | Research, prototyping |
| Label Studio ML | ML backend for Label Studio          | Production annotation |
| Prodigy         | Commercial, built-in active learning | NLP tasks             |
| BaaL            | Bayesian active learning             | Deep learning         |

```
# Install modAL
pip install modAL-python

# Install Label Studio with ML backend
pip install label-studio
pip install label-studio-ml
```

# Part 3: Weak Supervision

*Label with code, not clicks*

# What is Weak Supervision?

**Core Idea:** Write labeling functions (code) instead of labeling examples.

```
# Traditional: Label 10,000 examples by hand

# Weak Supervision: Write 10 labeling functions
def lf_contains_love(text):
    return "POSITIVE" if "love" in text.lower() else None

def lf_contains_terrible(text):
    return "NEGATIVE" if "terrible" in text.lower() else None

def lf_exclamation_count(text):
    if text.count("!") > 3:
        return "POSITIVE"
    return None
```

**Trade-off:** Labels are noisier, but you get many more of them!

# The Expert Knowledge Intuition

You're a movie critic. How do you know a review is positive?

## YOUR BRAIN'S "LABELING FUNCTIONS":

1. Contains "amazing", "loved", "masterpiece" → Positive
2. Contains "boring", "waste", "terrible" → Negative
3. Rating mentioned > 8/10 → Positive
4. Multiple exclamation marks → Probably positive
5. Mentions "Oscar" or "award" → Probably positive
6. Very short review → Often negative (rant)

Weak supervision = encoding your expert intuition as code!

# Labeling Functions: Netflix Movie Example

```
# Real labeling functions for our Netflix movie dataset

@labeling_function()
def lf_high_rating(movie):
    """Movies rated > 8 on IMDB are usually good."""
    if movie.imdb_rating and movie.imdb_rating > 8.0:
        return POSITIVE
    return ABSTAIN

@labeling_function()
def lf_oscar_winner(movie):
    """Oscar winners are good movies."""
    if "Oscar" in str(movie.awards) and "Won" in str(movie.awards):
        return POSITIVE
    return ABSTAIN

@labeling_function()
def lf_low_box_office(movie):
    """Very low box office often means bad movie."""
    if movie.box_office and movie.box_office < 1_000_000:
        return NEGATIVE
    return ABSTAIN

@labeling_function()
def lf_sequel_fatigue(movie):
    """Sequels numbered > 3 are often worse."""
    if re.search(r'\b[4-9]\b|10|11|12', movie.title):
        return NEGATIVE
    return ABSTAIN
```

# Labeling Functions: Characteristics

## COVERAGE vs ACCURACY

High Coverage,  
Low Accuracy

^

|

Keyword  
Match  
  
"good"  
in text  
→ POS

Low Coverage,  
High Accuracy

^

|

Pattern  
Match  
  
rating  
> 9/10  
→ POS

Matches 40%  
of data

70% accurate

Matches 5%  
of data

95% accurate

# Labeling Functions: Types

## 1. Keyword/Pattern-based

```
def lf_keyword_positive(text):
    keywords = ["amazing", "excellent", "loved", "great"]
    return "POS" if any(k in text.lower() for k in keywords) else None
```

## 2. Heuristic-based

```
def lf_short_reviews_negative(text):
    # Short reviews tend to be complaints
    return "NEG" if len(text.split()) < 10 else None
```

## 3. External Knowledge

```
def lf_known_good_movie(text, movie_title):
    top_movies = load_imdb_top_250()
    return "POS" if movie_title in top_movies else None
```

# Labeling Function Conflicts

**Problem:** LFs often disagree!

```
text = "I love how terrible this movie is!"  
  
lf_contains_love(text)      # Returns: "POSITIVE"  
lf_contains_terrible(text) # Returns: "NEGATIVE"  
  
# Which one is right?
```

**Solution:** Use a [Label Model](#) to combine LF outputs.

# Snorkel: The Weak Supervision Framework

```
from snorkel.labeling import labeling_function, LFAnalysis

@labeling_function()
def lf_contains_good(x):
    return 1 if "good" in x.text.lower() else -1 # 1=POS, 0=NEG, -1=ABSTAIN

@labeling_function()
def lf_contains_bad(x):
    return 0 if "bad" in x.text.lower() else -1

@labeling_function()
def lf_rating_based(x):
    if hasattr(x, 'rating') and x.rating is not None:
        return 1 if x.rating > 7 else 0
    return -1
```

# Applying Labeling Functions

```
from snorkel.labeling import PandasLFApplier

# Define all LFs
lfs = [lf_contains_good, lf_contains_bad, lf_rating_based]

# Apply to data
applier = PandasLFApplier(lfs=lfs)
L_train = applier.apply(df_train)

# L_train is a matrix: (n_examples, n_lfs)
# Each cell is 1 (POS), 0 (NEG), or -1 (ABSTAIN)

print(L_train[:5])
# [[-1,  0, -1],   # Only lf_contains_bad fired → NEG
#  [ 1, -1,  1],   # lf_contains_good and lf_rating agree → POS
#  [-1, -1, -1],   # No LF fired → unlabeled
#  [ 1,  0, -1],   # Conflict! good vs bad
#  [-1, -1,  0]]  # Only lf_rating → NEG
```

# Analyzing Labeling Functions

```
from snorkel.labeling import LFAnalysis  
  
analysis = LFAnalysis(L=L_train, lfs=lfs).lf_summary()  
print(analysis)
```

| LF               | Polarity | Coverage | Overlaps | Conflicts |
|------------------|----------|----------|----------|-----------|
| If_contains_good | [1]      | 0.25     | 0.12     | 0.05      |
| If_contains_bad  | [0]      | 0.18     | 0.08     | 0.05      |
| If_rating_based  | [0, 1]   | 0.60     | 0.15     | 0.02      |

**Coverage:** Fraction of data the LF labels

**Overlaps:** Fraction where LF agrees with another

**Conflicts:** Fraction where LF disagrees with another

# The Label Model

**Goal:** Combine noisy LF outputs into probabilistic labels.

```
from snorkel.labeling.model import LabelModel

# Train label model
label_model = LabelModel(cardinality=2, verbose=True)
label_model.fit(L_train=L_train, n_epochs=500)

# Get probabilistic labels
probs = label_model.predict_proba(L_train)
# probs[i] = [P(NEG), P(POS)] for example i

# Get hard labels (for training downstream model)
preds = label_model.predict(L_train)
```

# How the Label Model Works

| LF Outputs<br>(noisy votes) | Label Model<br>(learns weights) | Probabilistic<br>Labels                  |
|-----------------------------|---------------------------------|--|
| lf_good: [1, -1, 1, 0]      |                                 | [0.85, 0.2, 0.9, 0.3]                    |
| lf_bad: [0, -1, 0, 1]       | → Learns which →                |  |
| lf_rating:[1, -1, 1, 1]     | LFs are accurate                | $P(\text{POSITIVE}   \text{LF outputs})$ |

**Key Insight:**

- LFs that often agree are probably accurate
- LFs that often conflict might be noisy
- Model learns accuracy WITHOUT ground truth labels!

# The Voting Intuition

Think of LFs as a jury voting on each example:

Movie: "The Godfather" (1972)

```
LF_high_rating:    POSITIVE (IMDB: 9.2)
LF_oscar_winner:  POSITIVE (Won Best Picture)
LF_classic_year:  POSITIVE (Before 1980, acclaimed)
LF_sequel_fatigue: ABSTAIN (Not a sequel)
LF_low_budget:    ABSTAIN (No data)
```

Jury Vote: 3 POSITIVE, 0 NEGATIVE, 2 ABSTAIN

Label Model Output: 95% POSITIVE

LFs that agree with each other get higher weight!

# When LFs Disagree: The Label Model Resolves

Movie: "Sharknado 5" (2017)

```
LF_high_rating: NEGATIVE (IMDB: 3.5)
LF_cult_classic: POSITIVE (Has devoted fanbase)
LF_sequel_fatigue: NEGATIVE (5th sequel!)
LF_social_buzz: POSITIVE (Trending on Twitter)
```

Jury Vote: 2 POSITIVE, 2 NEGATIVE

But LF\_high\_rating has 90% accuracy historically  
And LF\_cult\_classic only has 60% accuracy

Label Model Output: 65% NEGATIVE  
(Weighs LFs by learned accuracy)

The label model learns which LFs to trust!

# Training Downstream Model

```
from snorkel.labeling import filter_unlabeled_dataframe

# Filter out examples where no LF fired
df_train_filtered, probs_filtered = filter_unlabeled_dataframe(
    df_train, probs, L_train
)

# Train your actual model on probabilistic labels
from sklearn.linear_model import LogisticRegression

# Use soft labels (probabilistic)
model = LogisticRegression()
model.fit(
    df_train_filtered['text_features'],
    probs_filtered[:, 1] # P(POSITIVE)
)

# Or use hard labels
hard_labels = (probs_filtered[:, 1] > 0.5).astype(int)
model.fit(df_train_filtered['text_features'], hard_labels)
```

# Weak Supervision: Complete Example

```
import pandas as pd
from snorkel.labeling import labeling_function, PandasLFApplier
from snorkel.labeling.model import LabelModel

# 1. Load unlabeled data
df = pd.read_csv("movie_reviews.csv")

# 2. Define labeling functions
@labeling_function()
def lf_awesome(x):
    return 1 if "awesome" in x.text.lower() else -1

@labeling_function()
def lf_boring(x):
    return 0 if "boring" in x.text.lower() else -1

lfs = [lf_awesome, lf_boring, ...] # Add more LFs
```

# Weak Supervision: Complete Example (cont.)

```
# 3. Apply LFs to data
applier = PandasLFApplier(lfs=lfs)
L_train = applier.apply(df)

# 4. Train label model
label_model = LabelModel(cardinality=2)
label_model.fit(L_train, n_epochs=500)

# 5. Get probabilistic labels
probs = label_model.predict_proba(L_train)

# 6. Train downstream model
from sklearn.feature_extraction.text import TfidfVectorizer
from sklearn.naive_bayes import MultinomialNB

vectorizer = TfidfVectorizer()
X = vectorizer.fit_transform(df['text'])
model = MultinomialNB()
model.fit(X, (probs[:, 1] > 0.5).astype(int))
```

# When to Use Weak Supervision

## Good candidates:

- Patterns can be encoded as rules
- You have domain knowledge
- Labels have clear heuristics
- Data is too large for manual labeling

## Bad candidates:

- Task requires human judgment (e.g., humor detection)
- No clear patterns or heuristics
- Very small dataset (just label it manually)
- High precision required (weak labels are noisy)

## Part 4: LLM-Based Labeling

*AI labeling your data*

# The LLM Labeling Revolution

**2022-2024:** Large Language Models became viable annotators.

```
# Before: Hire annotators
cost_per_label = 0.30 # USD
human_labels = 10000
total_cost = 3000 # USD

# Now: Use GPT-4 / Claude
cost_per_label = 0.002 # USD (roughly)
llm_labels = 10000
total_cost = 20 # USD

# 150x cost reduction!
```

**But:** Are LLM labels as good as human labels?

# Why LLMs Can Label Data

LLMs are trained on the entire internet - they've "seen" everything:

GPT-4 has read:

- Millions of movie reviews
- IMDB, Rotten Tomatoes, Metacritic
- Professional film criticism
- Reddit discussions about movies
- Academic papers on sentiment analysis

So when you ask: "Is this review positive or negative?"

It can often answer correctly!

LLMs = Crowdsourced human knowledge, distilled into a model

# LLM Labeling: Movie Review Example

```
import openai

def label_movie_review(review):
    response = openai.ChatCompletion.create(
        model="gpt-4",
        messages=[
            {"role": "system", "content": """
                You are a movie critic. Classify reviews as:
                - POSITIVE: Reviewer enjoyed the movie
                - NEGATIVE: Reviewer did not enjoy the movie
                - NEUTRAL: Mixed feelings or no clear opinion
            """,},
            {"role": "user", "content": f'Review: "{review}"\n\nClassification:'}
        ]
    )
    return response.choices[0].message.content

# Examples from our Netflix dataset
print(label_movie_review("Mind-blowing visuals! Nolan does it again!"))
# Output: POSITIVE

print(label_movie_review("Meh. Seen better, seen worse."))
# Output: NEUTRAL

print(label_movie_review("Two hours of my life I'll never get back."))
# Output: NEGATIVE
```

# LLM Labeling: Basic Approach

```
import openai

def label_with_gpt(text, task_description):
    response = openai.ChatCompletion.create(
        model="gpt-4",
        messages=[
            {"role": "system", "content": task_description},
            {"role": "user", "content": f"Text: {text}\n\nLabel:"}
        ],
        max_tokens=10
    )
    return response.choices[0].message.content.strip()

# Example
task = "Classify movie reviews as POSITIVE or NEGATIVE."
label = label_with_gpt("This movie was incredible!", task)
print(label) # "POSITIVE"
```

# Prompt Engineering for Annotation

**Bad Prompt:**

Classify this: "The movie was okay I guess"

**Good Prompt:**

You are an expert movie critic annotating reviews for sentiment.

Task: Classify the sentiment of movie reviews.

Labels:

- POSITIVE: The reviewer liked the movie
- NEGATIVE: The reviewer disliked the movie
- NEUTRAL: The reviewer has mixed or no strong feelings

Review: "The movie was okay I guess"

Classification (respond with only the label):

# Few-Shot Prompting

```
prompt = """Classify movie review sentiment.  
  
Examples:  
Review: "Absolutely loved it! Best movie of the year!"  
Label: POSITIVE  
  
Review: "Waste of time. Don't bother watching."  
Label: NEGATIVE  
  
Review: "It was fine. Nothing special but not bad."  
Label: NEUTRAL  
  
Review: "{review_text}"  
Label:"""  
  
label = label_with_gpt(prompt.format(review_text=text))
```

Few-shot examples significantly improve accuracy!

# Getting Confidence Scores

```
def label_with_confidence(text):
    prompt = f"""Classify the sentiment and provide confidence.

Text: {text}

Respond in JSON format:
[{"label": "POSITIVE/NEGATIVE/NEUTRAL", "confidence": 0.0-1.0}]
"""

    response = openai.ChatCompletion.create(
        model="gpt-4",
        messages=[{"role": "user", "content": prompt}]
    )

    import json
    result = json.loads(response.choices[0].message.content)
    return result["label"], result["confidence"]

label, conf = label_with_confidence("Great movie!")
print(f"Label: {label}, Confidence: {conf}")
# Label: POSITIVE, Confidence: 0.95
```

# Batch Processing for Cost Efficiency

```
import asyncio
import aiohttp

async def batch_label(texts, batch_size=10):
    results = []

    for i in range(0, len(texts), batch_size):
        batch = texts[i:i+batch_size]

        # Format as single prompt
        prompt = "Classify each review:\n\n"
        for j, text in enumerate(batch):
            prompt += f"{j+1}. {text}\n"
        prompt += "\nRespond with labels (one per line):"

        response = await async_gpt_call(prompt)
        labels = response.strip().split('\n')
        results.extend(labels)

    return results
```

# LLM Labeling Quality Control

```
def validate_llm_labels(texts, llm_labels, sample_size=100):
    # Random sample for human validation
    indices = random.sample(range(len(texts)), sample_size)

    human_labels = []
    for idx in indices:
        print(f"Text: {texts[idx]}")
        print(f"LLM Label: {llm_labels[idx]}")
        human = input("Your label (or 'agree'): ")
        if human.lower() == 'agree':
            human_labels.append(llm_labels[idx])
        else:
            human_labels.append(human)

    # Calculate agreement
    agreement = sum(h == llm_labels[i] for i, h in
                    zip(indices, human_labels)) / sample_size
    print(f"LLM-Human Agreement: {agreement:.1%}")

    return agreement
```

# When LLMs Struggle

## 1. Subjective Tasks

"This movie is so bad it's good"  
LLM: NEGATIVE (wrong - it's ironic praise!)

## 2. Domain-Specific Knowledge

"The mise-en-scene was pedestrian but the diegetic sound..."  
LLM: ? (needs film theory knowledge)

## 3. Nuanced Categories

5-point scale: Very Negative, Negative, Neutral, Positive, Very Positive  
LLM accuracy drops significantly with more categories

## 4. Ambiguous Guidelines

What exactly counts as "slightly negative"?

# Hybrid Approach: LLM + Human

```
def hybrid_labeling(texts, confidence_threshold=0.8):
    llm_labels = []
    human_queue = []

    for i, text in enumerate(texts):
        label, confidence = label_with_confidence(text)

        if confidence >= confidence_threshold:
            llm_labels.append((i, label, "llm"))
        else:
            human_queue.append(i)

    print(f"LLM labeled: {len(llm_labels)}")
    print(f"Need human: {len(human_queue)}")

    # Send human_queue to annotation platform
    return llm_labels, human_queue
```

Use LLMs for easy examples, humans for hard ones!

# LLM Labeling: Cost Comparison

| Method          | Cost/1000      | Quality  | Speed     |
|-----------------|----------------|----------|-----------|
| Expert humans   | \$300-500      | Highest  | Slow      |
| Crowdsourcing   | \$50-100       | Medium   | Medium    |
| GPT-4           | \$20-50        | Good     | Fast      |
| GPT-3.5         | \$2-5          | Moderate | Very Fast |
| Claude Haiku    | \$1 - 3        | Moderate | Very Fast |
| Open source LLM | ~\$0 (compute) | Varies   | Depends   |

**Sweet spot:** GPT-3.5/Claude for first pass, humans for validation

## Part 5: Handling Noisy Labels

*Garbage in, garbage out?*

# Sources of Label Noise

## LABEL NOISE SOURCES

### 1. ANNOTATOR ERROR

- Fatigue, lack of attention
- Misunderstanding guidelines

### 2. TASK AMBIGUITY

- Inherently subjective tasks
- Unclear category boundaries

### 3. WEAK SUPERVISION

- Noisy labeling functions
- Heuristic errors

### 4. DATA ENTRY ERRORS

- Mislabeled due to typos
- Wrong column/field mapping

# Detecting Label Errors

## Approach 1: Confident Learning

```
from cleanlab import Datalab

# Your data with possibly noisy labels
X, y = load_data()

# Find label issues
lab = Datalab(data={"X": X, "y": y}, label_name="y")
lab.find_issues(features=X)

# Get indices of likely mislabeled examples
issues = lab.get_issues()
mislabeled = issues[issues['is_label_issue'] == True].index
print(f"Found {len(mislabeled)} potential label errors")
```

# Confident Learning: How It Works

Model predicts  $P(\text{class}|x)$  for each example

Example: Label = "POSITIVE"  
 $P(\text{NEGATIVE}|x) = 0.92$   
 $P(\text{POSITIVE}|x) = 0.08$

This is likely mislabeled!

High confidence predictions that  
disagree with given labels = suspicious

# The Wisdom of the Crowd Intuition

Imagine 100 students grade an essay. 95 say "B", 5 say "A".

If the official grade is "A"... something's wrong!

Either:

1. The grading key was wrong
2. The teacher made a mistake
3. Those 5 students are unusually generous

Confident Learning = Train a model on all data

Model becomes the "crowd"

When crowd disagrees with label = suspicious

The model learns the data distribution and spots outliers!

# Real Example: Catching Label Errors

```
# Our Netflix movie reviews - some were mislabeled by tired annotators

review = "This movie was not good. I didn't enjoy it at all."
original_label = "POSITIVE" # Annotator mistake!

# Model prediction after training
model_prediction = {
    "POSITIVE": 0.05,
    "NEGATIVE": 0.95 # Model is VERY confident this is negative
}

# cleanlab flags this as a likely error
# Confidence of label being wrong: 95%

# Upon review: Yes, this was mislabeled!
corrected_label = "NEGATIVE"
```

Cleanlab found the annotator's mistake automatically!

# Cleanlab: Practical Example

```
from cleanlab import Datalab
from sklearn.ensemble import RandomForestClassifier
from sklearn.model_selection import cross_val_predict

# Get out-of-fold predictions
clf = RandomForestClassifier()
pred_probs = cross_val_predict(clf, X, y, cv=5, method='predict_proba')

# Find label issues using predictions
lab = Datalab(data={"features": X, "labels": y}, label_name="labels")
lab.find_issues(pred_probs=pred_probs)

# Examine issues
print(lab.get_issue_summary())
print(lab.get_issues().head(10))

# Get clean indices
clean_indices = lab.get_issues()[
    lab.get_issues()['is_label_issue'] == False
].index
```

# What to Do With Noisy Labels?

## Option 1: Remove them

```
clean_X = X[clean_indices]
clean_y = y[clean_indices]
model.fit(clean_X, clean_y)
```

## Option 2: Re-label them

```
for idx in mislabeled_indices:
    new_label = get_human_label(X[idx])
    y[idx] = new_label
```

## Option 3: Train with noise-robust methods

```
# Use label smoothing, mixup, or noise-robust losses
```

# Learning With Noisy Labels

**Label Smoothing:** Soften hard labels

```
# Instead of y = [1, 0, 0] (one-hot)
# Use y = [0.9, 0.05, 0.05] (smoothed)

def label_smoothing(y, num_classes, epsilon=0.1):
    smoothed = np.full((len(y), num_classes), epsilon / num_classes)
    for i, label in enumerate(y):
        smoothed[i, label] = 1 - epsilon + epsilon / num_classes
    return smoothed
```

**Mixup:** Interpolate between examples

```
# Create synthetic training examples
alpha = np.random.beta(0.2, 0.2)
x_mixed = alpha * x1 + (1 - alpha) * x2
y_mixed = alpha * y1 + (1 - alpha) * y2
```

# Noise Transition Matrix

Idea: Model how labels get corrupted

True Label → Observed Label

|          | POS           | NEG                             |  |
|----------|---------------|---------------------------------|--|
| True POS | [ 0.85 0.15 ] | 15% of true POS are labeled NEG |  |
| True NEG | [ 0.10 0.90 ] | 10% of true NEG are labeled POS |  |

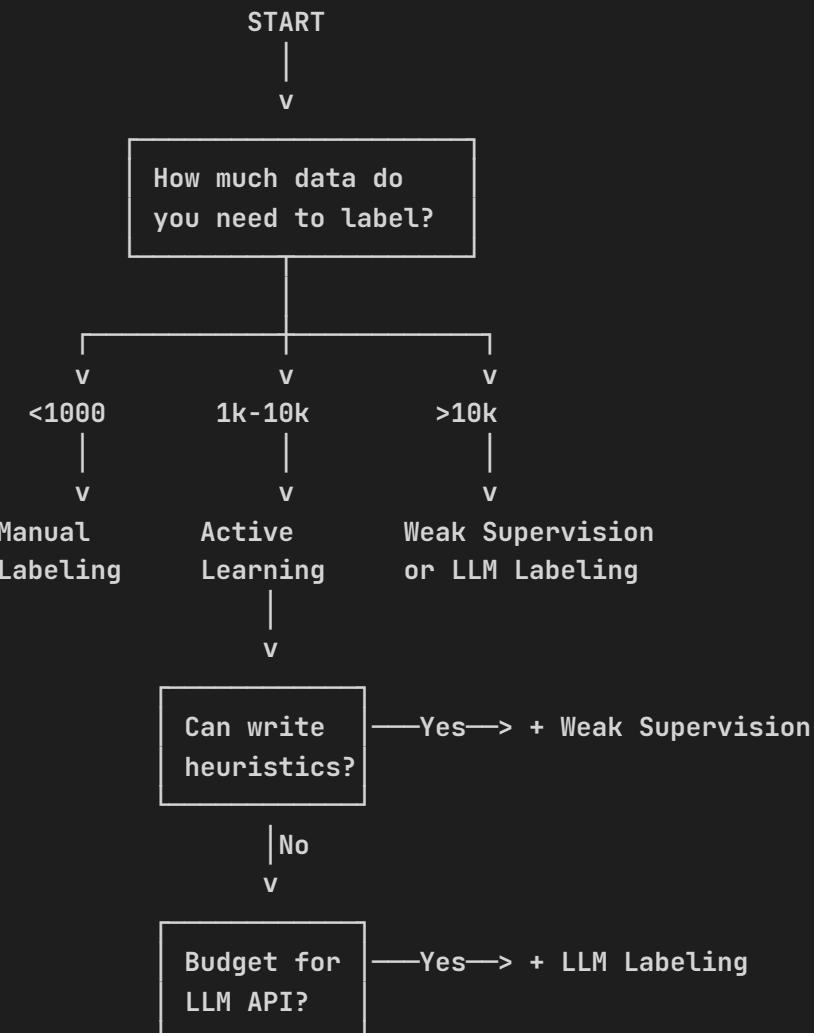
```
# Estimate transition matrix from data
from cleanlab.count import estimate_cv_predicted_probabilities
from cleanlab.count import compute_confident_joint

pred_probs = estimate_cv_predicted_probabilities(X, y, clf)
confident_joint = compute_confident_joint(labels=y, pred_probs=pred_probs)
transition_matrix = confident_joint / confident_joint.sum(axis=1, keepdims=True)
```

# Part 6: Combining Approaches

*The best of all worlds*

# Decision Tree: Which Technique?



# Hybrid Pipeline Example

```
# Step 1: Weak supervision for bulk labels
weak_labels = apply_labeling_functions(unlabeled_data)

# Step 2: LLM for high-uncertainty examples
uncertain = get_low_confidence_examples(weak_labels)
llm_labels = batch_label_with_gpt(uncertain)

# Step 3: Active learning for remaining hard cases
learner = ActiveLearner(estimator=model)
for round in range(n_rounds):
    query_idx = learner.query(hard_examples)
    human_labels = get_human_labels(hard_examples[query_idx])
    learner.teach(hard_examples[query_idx], human_labels)

# Step 4: Clean noisy labels
all_labels = combine_labels(weak_labels, llm_labels, human_labels)
clean_labels = cleanlab_filter(all_labels)

# Step 5: Train final model
model.fit(data, clean_labels)
```

# Cost-Benefit Analysis

| Approach           | Setup Cost | Per-Label Cost | Quality     |
|--------------------|------------|----------------|-------------|
| Manual only        | Low        | \$0.30         | High        |
| + Active Learning  | Medium     | \$0.30 (fewer) | High        |
| + Weak Supervision | High       | ~\$0           | Medium      |
| + LLM Labeling     | Low        | \$0.002        | Medium-High |
| + Noise Cleaning   | Medium     | ~\$0           | Improved    |

**Typical savings:** 5-20x cost reduction with hybrid approach

## Part 7: Key Takeaways

# Key Takeaways

1. **Active Learning** - Let model pick what to label (2-10x savings)
2. **Weak Supervision** - Write labeling functions (10-100x savings)
3. **LLM Labeling** - Use GPT/Claude as annotators (10-50x cost reduction)
4. **Noisy Labels** - Detect and handle with cleanlab
5. **Combine approaches** - Hybrid pipelines give best results
6. **Quality matters** - Validate with human spot-checks
7. **Tools exist** - modAL, Snorkel, cleanlab, OpenAI API

## Part 8: Lab Preview

*What you'll build today*

# This Week's Lab

## Hands-on Practice:

### 1. Active Learning with modAL

- Implement uncertainty sampling
- Compare to random sampling
- Visualize learning curves

### 2. Weak Supervision with Snorkel

- Write labeling functions
- Train label model
- Analyze LF quality

### 3. LLM Labeling

- Prompt engineering for annotation
- Compare GPT-3.5 vs GPT-4 quality
- Calculate cost savings

# Lab Setup Preview

```
# Install required packages
pip install modAL-python
pip install snorkel
pip install cleanlab
pip install openai

# Verify installations
python -c "import modAL; print('modAL OK')"
python -c "import snorkel; print('Snorkel OK')"
python -c "import cleanlab; print('cleanlab OK')"
```

You'll implement a complete labeling optimization pipeline!

# Next Week Preview

## Week 5: Data Augmentation

- Why augmentation improves models
- Text augmentation techniques
- Image augmentation with Albumentations
- Audio and video augmentation
- When (not) to augment

**More data from existing data - without labeling!**

# Resources

## Libraries:

- modAL: <https://modal-python.readthedocs.io/>
- Snorkel: <https://snorkel.ai/>
- cleanlab: <https://cleanlab.ai/>
- OpenAI API: <https://platform.openai.com/>

## Papers:

- "Data Programming" (Snorkel paper)
- "Confident Learning" (cleanlab paper)

## Reading:

- Snorkel tutorials: <https://www.snorkel.org/use-cases/>

# Questions?

# Thank You!

See you in the lab!