

Human vs. AI Text Classification

A 6-Metric Linguistic Baseline

Subject: SC203 - Scientific Method

Research Team: Sahur

Dataset: Roy et al. (2025) Subset

Agenda

1. **Motivation:** The "Arms Race" of Generative AI.
2. **The Dataset:** Roy et al. (2025) & Data Engineering.
3. **Pipeline Architecture:** From Ingestion to Parquet.
4. **The 6 Core Metrics:** Definitions & Calculation Logic.
5. **Lexical Analysis:** IRAL Log-Odds Ratio.
6. **Findings & Discussion:** Interpreting the "Human Fingerprint".

The Problem: AI is "More Human than Human"

- **Context:** Large Language Models (LLMs) like GPT-4 and Mistral produce highly coherent text.
- **The Challenge:** Distinguishing AI text is critical for academic integrity and preventing misinformation.
- **Current State:** "Zero-shot" black-box detectors often fail on domain-specific text (*Wu et al., 2024*).

“"The need to discriminate human writing from AI is now both critical and urgent." – *Desaire et al. (2023)*”

Beyond Detection: A Paradigm Shift

New Scientific Baseline: Zhu et al. (2025) (Computer Assisted Language Learning).

- **The Insight:** AI corpora are not just "cheat tools" but essential instruments for scaffolding L2 writing.
- **Our Goal:** We do not aim to merely *differentiate*; we aim to **point out differences** to find the "best of both worlds."
- **Application:** Teaching students genre awareness and structural comprehension by visualizing the "fingerprints" of both Human and AI text.

“"AI-powered corpora are essential instruments for scaffolding L2 writing." – Zhu et al. (2025)

”

Our Approach: Linguistic Analysis Pipeline

Instead of opaque neural networks, we propose a **Linguistic Baseline** using 6 explainable metrics.

Why Explainable Metrics?

1. **Explainability:** We can point to *why* a text differs (e.g., "Too repetitive", "Lack of hedging").
2. **Scientific Grounding:** Based on linguistic features proven to differentiate human/AI writing, such as lexical diversity and sentence complexity.

The Dataset: Roy et al. (2025)

We utilize the "**Comprehensive Dataset for Human vs. AI Generated Text Detection**".

- **Source Scale:** 58,000+ text samples (Full Dataset).
- **Our Focus: Training Split** (~7,300 rows) for deep linguistic analysis.
- **Human Baseline:** New York Times (NYT) articles (High-quality, edited journalism).
- **AI Contenders:** 6 Models generated from abstract prompts:
 - Gemma-2-9b, Mistral-7B, Qwen-2-72B
 - LLaMA-8B, Yi-Large, GPT-4o

Dataset Context & Research Goals

Source: *Defactify 4: Multimodal Fact-Checking* (Co-located with AAAI 2025).

Alignment with Research Objectives:

We fulfill the dataset's call for **Feature Engineering**:

“Investigate linguistic, stylistic, and semantic features that are indicative of AI generation... to capture nuanced patterns.” – *Roy et al. (2025)*”

Project Trajectory:

1. **Current Phase (SC203):** Feature Engineering (The Explainable Pipeline).
2. **Future Phase:** Developing Robust Classifiers (High-Ranked Research Goal).

Data Cleaning & Pipeline

Based on our project architecture:

1. **Ingestion:** Raw CSVs from Roy et al. loaded via `src.cli`.
2. **Curation:** Shortlisted **25 high-quality rows** per topic (for Balanced Benchmarking).
 - *Reasoning:* Ensures fair comparison between large shards (Tech: 1,459) and small shards (Environment: 40).
 - *Selection:* Long paragraphs rich in sentence structure (Manual + AI assisted).
3. **Sanitization:**
 - Removal of nulls and artifacts.
 - Alignment of `human_story` vs. `model_output` columns.
4. **Processing:** Sharded processing with `spaCy` and `DuckDB` (Parquet output).

Data Engineering: Topic Sharding

To ensure metrics hold true across diverse contexts, we implemented a rigorous **16-shard strategy**:

- **Major Shards (Raw):** Technology (1,459), Politics (1,187), Entertainment (806).
- **Niche Shards (Raw):** Environment (40), Travel (61), Science (88).

Processing Statistics:

Stage	Count	Notes
Input	7,321	Raw rows (Training Set)
Filtered	1,744	Removed (Timeouts/Errors)
Final	5,577	High-fidelity rows

The 6 Core Metrics

We extract these features to capture the "fingerprint" of human writing:

1. **MTLD** (Lexical Diversity)
2. **Nominalization Density** (Academic formality)
3. **Modal/Epistemic Rate** (Hedging/Equivocal language)
4. **Clause Complexity** (Syntactic depth)
5. **Passive Voice Ratio** (Stylistic preference)
6. **S2S Cosine Similarity** (Semantic repetition)

Metric 1: MTLD (Lexical Diversity)

Definition: *Measure of Textual Lexical Diversity.* It measures vocabulary richness by calculating the mean length of sequential word strings that maintain a Type-Token Ratio (TTR) above a threshold (0.72).

Relevance:

- Humans generally use more varied, context-rich vocabulary tied to personal experience (*Zhang & Crosthwaite, 2025*).
- AI tends to be "safe" and repetitive, leading to lower diversity scores in long texts.

Metric 1: Calculation Logic

Algorithm:

1. Initialize `TTR = 1.0`, `count = 0`, `factors = 0`.
2. Iterate through tokens. Update TTR (Unique/Total).
3. If `TTR < 0.72` :
 - Increment `factors`.
 - Reset TTR.
4. Final Score: `Total Words / Factors`.

Example:

- **Human:** "The feline slept. The pet rested." (High MTLD → TTR stays high).
- **AI:** "The cat sat. The cat sat." (Low MTLD → TTR drops fast).

Metric 2: Nominalization Density

Definition: The frequency of nouns derived from verbs or adjectives (e.g., *implement* → *implementation*).

Relevance:

- A marker of **formal, academic human writing** (Zhang & Crosthwaite, 2025).
- AI models often simplify phrasing for clarity, reducing nominalization density.

Formula:

$$D_{nom} = \frac{\text{Count}(\text{suffix} \in \{-\text{tion}, -\text{ment}, -\text{ness}, -\text{ity}\}) \times 1000}{\text{Total Words}}$$

Metric 2: Calculation Example

Compare:

“**Human (High Density):** "The **implementation** of the **regulation** caused **frustration**."
3 nominalizations per 7 words.

”

“**AI (Low Density):** "People were frustrated because they implemented the rule."
0 nominalizations.

”

Metric 3: Modal & Epistemic Rate

Definition: The frequency of "hedging" words (modals) and contrastive conjunctions.

Relevance:

- Desaire et al. (2023) found scientists have a penchant for **equivocal language** (*however, although*).
- AI tends to be declarative and confident.

Target Tokens:

[might, may, could, perhaps, possible, unlikely, however, although, but]

Metric 3: Calculation Example

Formula:

$$R_{modal} = \frac{\text{Count}(\text{Target Tokens}) \times 100}{\text{Total Words}}$$

Example:

“**Human:** “These results **suggest** that it **may** be possible, **although** further study is needed.”
High Epistemic Rate.”

“**AI:** “This proves that it is possible. Future studies are needed.”
Low Epistemic Rate.”

Metric 4: Clause Complexity

Definition: The average depth of the syntactic dependency tree.

Relevance:

- Humans exhibit "Burstiness": a mix of simple and deeply complex sentences.
- *Desaire et al. (2023)* noted that sentence length diversity is a key feature of human writing.

Calculation:

Using `spaCy` dependency parsing, we calculate the maximum depth from the `ROOT` verb to the furthest leaf node.

Metric 4: Calculation Example

Sentence: "*The dog that chased the cat, which was fast, barked.*"

Tree:

1. **barked** (ROOT, Depth 0)
2. → **dog** (nsubj, Depth 1)
3. → → **chased** (relcl, Depth 2)
4. → → → **cat** (dobj, Depth 3)
5. → → → → **was** (relcl, Depth 4)

Human: Mean Depth 4.5 | **AI:** Mean Depth 3.0 (Flatter trees).

Metric 5: Passive Voice Ratio

Definition: The percentage of sentences utilizing passive voice construction.

Relevance:

- Stylistic fingerprint. Scientific humans prefer Passive; Journalism prefers Active (*Desaire et al., 2023*).
- AI generally defaults to Active voice unless prompted otherwise.

Extraction Logic:

Locate dependency tag `nsubjpass` (nominal subject passive) + `auxpass`.

Metric 5: Calculation Example

Check:

$$\text{Ratio} = \frac{\text{Count(Passive Sentences)}}{\text{Total Sentences}}$$

Example:

"

1. "The decision **was made** by the committee." (✓ Passive)
2. "The committee made the decision." (✗ Active)

"

Metric 6: S2S Cosine Similarity

Definition: *Sentence-to-Sentence Semantic Similarity.* Using Sentence-Transformers (Embeddings) to measure semantic overlap between adjacent sentences.

Relevance:

- AI optimizes for "coherence," leading to high similarity (repetitiveness).
- Humans make "semantic jumps" (introducing new ideas).
- *Technical Basis:* Efficient sentence embeddings via DCT (*Almarwani et al.*).

Formula:

$$S_{sim} = \cos(\vec{v}_n, \vec{v}_{n+1}) = \frac{\vec{v}_n \cdot \vec{v}_{n+1}}{\|\vec{v}_n\| \|\vec{v}_{n+1}\|}$$

Evolution from Baseline (Herbold et al., 2023)

Article: "A large-scale comparison of human-written versus ChatGPT-generated essays"

Authors: Steffen Herbold et al.

Source: *Scientific Reports* (Nature Portfolio, Q1 | Impact Factor ~3.9).

Strategy: Moving from "Counting" to "Semantic" analysis.

Feature	Herbold (Baseline)	Our Expansion
Coherence	Word Counts (e.g., "however")	S2S Embeddings (Semantic Flow)
Style	Not Measured	Passive Voice (Academic vs. AI)
Complexity	Tree Depth	Clause Density (Unified metric)

“**Why?** We measure *meaning* and *structure*, not just surface-level keywords.”

Technical Deep Dive: Nominalization

The Baseline Flaw (Herbold et al.):

- Simple suffix counting (e.g., words ending in *-tion*).
- **Risk:** False positives like "Station" or "Lion".

Our Improvement (Lemma Verification):

- We check if the **Lemma** (root) differs from the **Surface Form**.

```
# Logic in metrics_core.py
if lemma_lower != text_lower:
    return True # It's a derived noun (e.g., Create -> Creation)
```

Reimplementation of the IRAL Research

Source: Zhang & Crosthwaite (2025) - "More human than human?" (IRAL).

Methodological Divergence:

Feature	Original Paper	Our Implementation (iral_lexical.py)
Metric	Z-score & Lambda	PMI (Pointwise Mutual Information)
Goal	Balance frequency & strength.	Measure predictive association.
Bias	Favors High-Frequency pairs.	Favors Low-Frequency pairs.

“**Why?** PMI allows us to detect highly specific "hallucinations" or rare token bindings that act as strong model signatures, even if they appear infrequently.”

Methodology Upgrade: From R to Python

The Original Baseline:

- The IRAL paper relied on **R** (R Studio, `quanteda` package).
- **Limitation:** Often designed for smaller, static datasets; harder to integrate into real-time production pipelines.

Our Contribution (SC203):

- **Complete Reimplementation:** We ported the statistical logic to **Python**.
- **Tech Stack:**
 - **Logic:** `iral_lexical.py` for Log-Odds and collocation extraction.
 - **Orchestration:** `iral_orchestrator.py` for batch processing 58k samples.
 - **Visualization:** `iral_plots.py` for automated figure generation.

IRAL Lexical Analysis (Log-Odds)

Inspired by *Zhang & Crosthwaite (2025)*, we identify "giveaway" words.

Method (Log-Odds Ratio):

$$\text{Log Odds} = \ln \left(\frac{\text{Freq}(W)_{\text{AI}} + 0.5}{\text{Freq}(W)_{\text{Human}} + 0.5} \right)$$

Interpretation:

- **Positive Score:** Strongly associated with AI.
- **Negative Score:** Strongly associated with Human.

Inside `iral_lexical.py`: The Reimplementation of the Baseline

We implemented the **Log-Odds Ratio with Informative Dirichlet Prior** directly in Python.

The Algorithm:

1. **Tokenization:** Clean tokens using the shared `spacy` pipeline.
2. **Counting:** Efficient frequency counts for Human corpus (y_{human}) vs. AI corpus (y_{ai}).
3. **Smoothing:** Apply statistical smoothing to handle zero-frequency words.
4. **Z-Score Calculation:** Compute the z-score for each word to determine significance ($z > 1.96$).

“**Result:** A statistically robust list of "Giveaway Words" generated automatically for every model.”

Inside `iral_plots.py`: Automated Insights

Instead of manual plotting in R Studio, our pipeline automatically generates:

1. **Log-Odds Charts:** Visualizing the "fight" between Human words (negative) and AI words (positive).
2. **Collocation Clouds:** Extracting bigrams (e.g., "climate change", "vital role") that appear significantly more often in AI text.

Outcome:

We moved from "analyzing a CSV" to a **push-button explainability engine** that instantly visualizes the linguistic divergence of any new model we test.

Lexical Findings (Hypothesized)

Based on IRAL literature:

Category	Human Words	AI Words
Themes	<i>Leaders, Food, Career, Youtube</i>	<i>Sustainable, Educational, Technical</i>
Style	<i>Said, Reported, Years</i>	<i>Delve, Landscape, Crucial, Pivotal</i>
Type	Concrete Entities	Abstract Concepts

Preliminary Findings: Complexity

Hypothesis:

Human text (NYT) will exhibit higher **Standard Deviation** in sentence length compared to AI.

Evidence:

- Desaire et al. found humans vary sentence length significantly more than AI.
- **Why?** AI generates tokens based on probability, favoring "average" sentence structures.
Humans write for impact (Burstiness).

Preliminary Findings: Hedging

Hypothesis:

Humans will have a higher **Modal/Epistemic Rate**.

Evidence:

- Humans use "maybe", "suggest", "however" to denote scientific or journalistic caution.
- AI outputs are often designed to be helpful and authoritative, reducing uncertainty markers.

Cross-Topic Analysis & Synthesis

Interpreting the Heatmaps

- **Variance Analysis:**
 - *Question:* Do we observe clearer differentiation in **Specialized Sectors** (Tech/Health) compared to **Lifestyle** topics?
 - *Hypothesis:* Technical vocabulary may limit the "creativity" of LLMs, making them easier to differentiate or attribute.
- **Model-Specific Patterns:**
 - *Observation:* Which model (Gemma, Mistral, Qwen, etc.) shows the most consistent heatmap signature across all 3 clusters?
- **Outliers:**
 - *Note:* Identify any topic (e.g., **Fashion**) where the heatmap significantly deviates from the average baseline accuracy.

Interpretation of the Numbers

GPT-4o	Human Writing	Llama-8B
The "Sophisticated" Mimic	The Baseline	The Outlier
Max vocabulary diversity & nominalization .	Distinct for low nominalizations .	Uses more passive voice .
Mimics human active voice .	Lower similarity (High uniqueness).	Slightly more complex clauses .

Discussion: The "Human Fingerprint"

What makes text "Human"?

1. **Inconsistency:** We are "messy." We mix 5-word sentences with 50-word sentences.
2. **Uncertainty:** We use hedging to show nuance.
3. **Specificity:** We reference real-world entities (*Japan, YouTube*) more than abstract categories ("Social Media").

The "Hidden" Challenge: Data Hygiene

Reality: The raw dataset was not analysis-ready.

- **Source:** Scraped web data (PDF-to-Text artifacts).
- **Noise:**
 - "Page X" headers and footers breaking sentence flow.
 - Markdown symbols (#, *) and "source: [x]" citations embedded in text.
 - Non-narrative paragraphs (e.g., copyright notices).

“**Impact:** Raw noise artificially inflates "complexity" metrics, distorting the baseline for Human vs. AI comparison.”

Engineering Solution: Robust Ingestion

We implemented a custom sanitization module (`src.ingest`) to recover pure text.

Key Cleaning Steps:

1. **Regex Filtration:** Removing PDF artifacts (e.g., `^source: \d+ , --- PAGE \d+ ---`).
2. **Structural Cleaning:** Stripping Markdown formatting to isolate pure prose.
3. **Noise Rejection:** Discarding rows where text is too short or clearly navigational.
4. **Column Alignment:** Ensuring `human_story` and `model_output` align perfectly for paired T-tests.

Pipeline Architecture (Modular Design)

Our `src` codebase is built for reproducibility and scalability:

- `ingest.py` : Sanitizes raw CSVs and aligns columns.
- `parse_and_cache.py` : Runs `spacy` NLP processing once and caches to disk (Parquet).
- `metrics_core.py` : Stateless functions to calculate the 6 linguistic features.
- `stats_analysis.py` : Automated Welch's t-tests and Cohen's d calculation.

“**Why this matters:** Modular design allowed us to rapidly swap out metrics and upgrade the IRAL component without breaking the ingestion logic.”

Tools & Technologies

We leveraged a modern Python ecosystem to build a scalable, reproducible pipeline.

Core Libraries:

- **NLP & Parsing:** `spaCy` (Dependency Trees), `lexicalrichness` (MTLD).
- **S2S Extraction:** `sentence-transformers` (Model: `all-MiniLM-L6-v2`).
 - *Why?* High speed/accuracy balance for semantic similarity.
- **Data & Stats:** `pandas`, `scipy`, `statsmodels` (Welch's T-test).
- **Visualization:** `seaborn`, `matplotlib`.

“**Infrastructure:** The pipeline processes the dataset locally using efficient Parquet storage (`pyarrow`). ”

Limitations & Challenges

1. **Preprocessing Complexity:** NLP sanitization was extremely difficult. We relied on AI assistance to navigate the noise in raw web-scraped text.
2. **Tooling Constraints:** While `spaCy` is powerful, achieving full control over the dataset's linguistic nuances requires more time than available.
3. **Dataset Selection:** We discarded two cleaner datasets because they used older AI models. We chose *Roy et al. (2025)* to benchmark against modern LLMs (GPT-4o), accepting the trade-off of "noisier" data.
4. **Genre Bias:** Our baseline is Journalism (NYT). Scientific papers might differ (e.g., higher passive voice).
5. **Modeling Scope:** Our current focus is **Feature Engineering**. Expanding to production-grade ML classifiers requires further expertise.

Conclusion & Next Steps

1. **Conclusion:** An explainable pipeline offers a transparent baseline, not just for differentiation, but for **education**.
2. **Future Application:** Developing a **Hybrid Writing Tool** for Educational Technology.
 - *Goal:* Retain the writer's original **effort, style, and tone**.
 - *Benefit:* Help L2 writers reduce errors and sound more academic without losing their voice.
3. **The Vision:** Bridging the gap between **AI efficiency** and **Human creativity**.

References

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10. **Project Code:** AIvsHuman Pipeline README.

Thank You

Questions?

SC203 Research Team