

Document Analysis in the time of LLMs

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Talk Outline

- AI Revolution
- Three Types of Document Analysis Systems
- Documents as Sources of Facts for LLMs

REVOLUTION IN MACHINE LEARNING / AI

LLMs / VLMs Have been Eating Machine Learning

- tasks that used to require extensive, specialized training...
- ... are now handled by foundation models
- ... or with minimal fine tuning

Big Changes over the Last Decade

- broad, general models that work across many tasks and modalities
- very large scale unsupervised pretraining
- multitask training and multitask models
- efficient and simple fine-tuning on small datasets
- many problems solved with zero-shot or few-shot methods
- task specifications through natural language

Zero/Few Shot with LLMs and VLMs

LLMs	VLMs
Named Entity Recognition (NER)	Object Recognition/Classification
Document Categorization	Object Detection
Sentiment Analysis	Scene Understanding
Text Summarization	Action Recognition
Machine Translation	...
...	

Example: Zero-Shot VLM Tasks

- "Is there a dog in the image?"
- "What is the bounding box for the dog in the image?"
- "How many balls are there in the image?"
- "Is Marilyn Monroe in the picture?"
- "Caption the picture."
- "Is the picture in focus?"

Example: Zero-Shot Document Classification

```
prompt = """"  
### Instructions
```

```
You are given the text of the first page of a PDF document. Please extract the title,  
author, year, and abstract. Then assign a category to the document  
from the following list of categories:
```

- ocr: text recognition, layout analysis, page segmentation
- handwriting: handwriting recognition, handwriting synthesis, etc.
- scene-text: text recognition in natural images and scenes
- ... more categories ...
- other: anything else

```
You must return only a JSON format dictionary with fields of  
title, author, abstract, year, and category. Your output  
will be parsed by machine.  
"""
```

```
classifier = OpenAIClient(prompt)  
result = classifier.json_query(text)
```


Some Tasks Still Require Specialized Custom Models

(For now)

- Stereo -- two image input, specialized preprocessing
- Gaze Estimation -- high precision, specialized datasets
- Anomaly Detection -- specialized statistics
- 3D Pose Estimation for Articulated Objects -- complex structured outputs
- ...

Current State of OCR

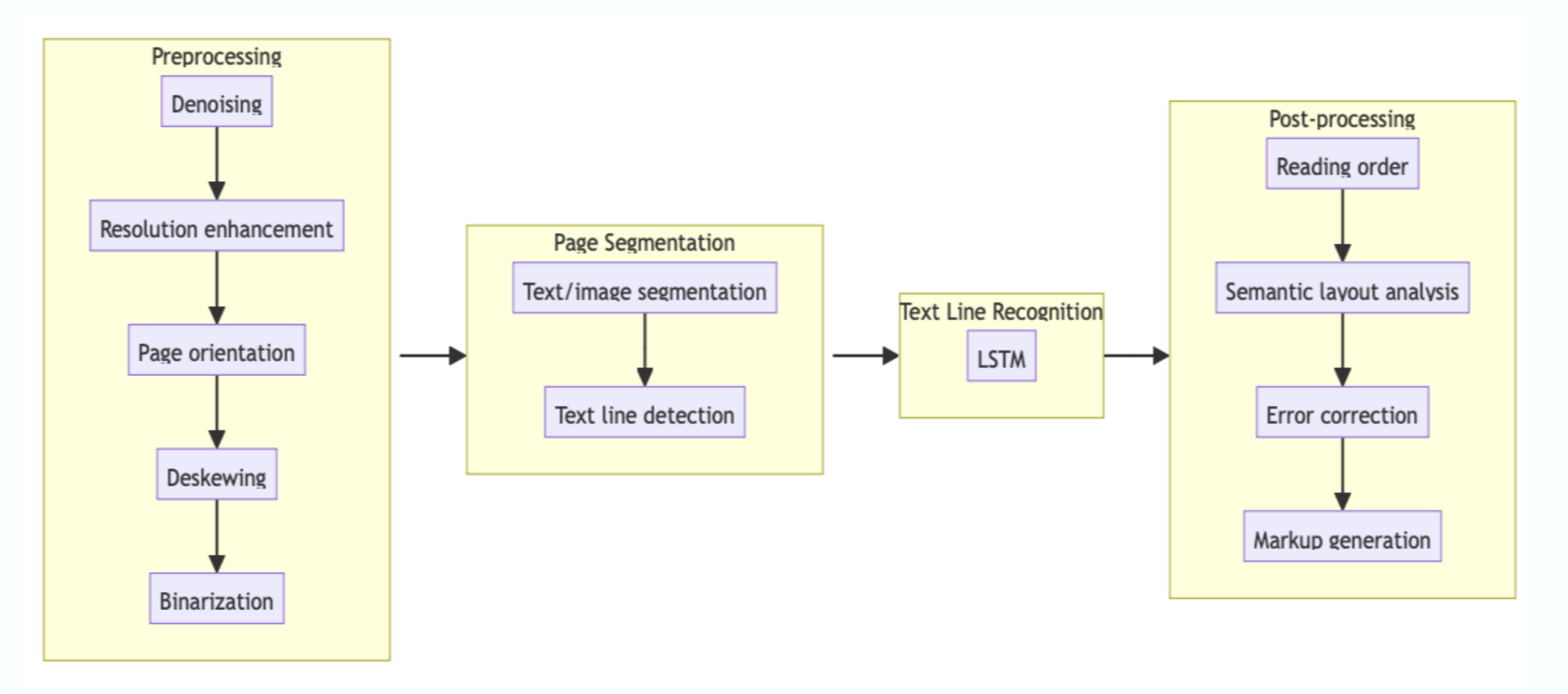
Users & Use Cases

- Personal Library of Biomedical Researcher ($>10^6$ users)
 - Digital PDFs, some scanned.
 - Use LLMs for categorization, retrieval; not high accuracy.
 - Combo of OCR, pdf2text, and existing LLMs adequate.
- Financial Data Services Provider (<1000 users)
 - Native digital PDFs; specialized layouts
 - Avoids image-based OCR, prefers text extraction
 - Mix of manual keying, OCR, digital formats; incremental improvements possible.

Users & Use Cases (2)

- Large Academic/Non-Profit Archives (<100 users)
 - Large diverse collections of scanned docs
 - Requires low error, high quality markup, reading order.
 - Often used by academics interested in the details of the text.
 - Not currently well-served.
- Companies Training Foundation Models (<100 users)
 - Large, scanned datasets for LLM training.
 - Unclear how much OCR errors affect LLM quality.

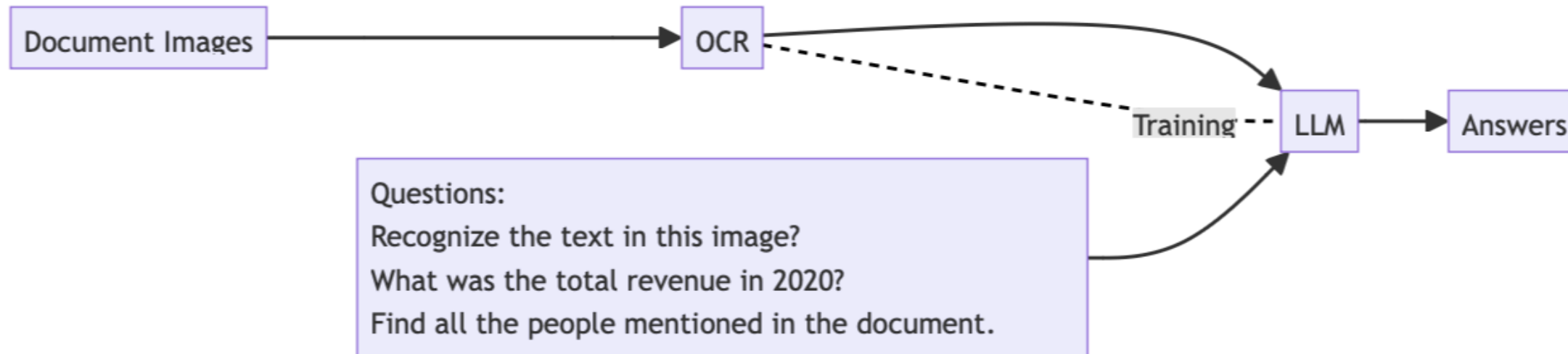
"Traditional" OCR Pipeline



OCR

- high accuracy scanned-to-text conversion
- fast on high resolution images
- < 0.5 character error
- substantial problems with reading order, logical layout !
- ideally, recover markup (LaTeX, etc.)

OCR + LLM



OCR + LLM

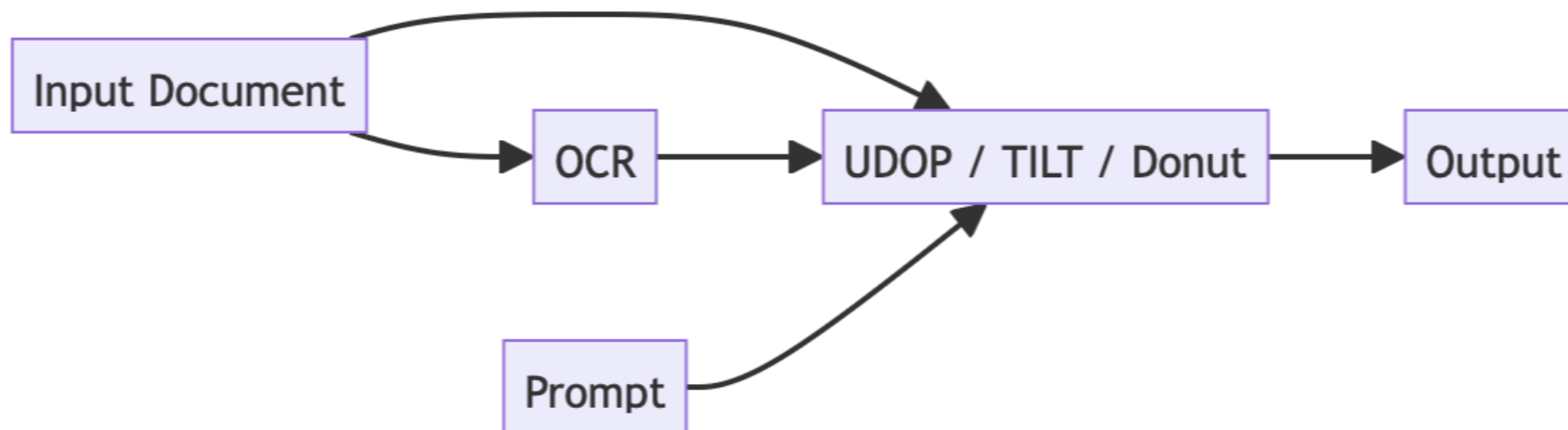
- LLMs can solve many traditional retrieval and information extraction tasks
- LLMs are remarkably robust to OCR errors and layout errors
- LLMs also are good at OCR error correction ("correct the OCR errors in this text")
- combination of Traditional OCR + LLM works pretty well
- e.g. Tesseract + GPT-4o

OCR + Multimodal Model

- substantial information is contained in the visual layout of documents
- traditional OCR systems are not very good at high level layout analysis

Examples: LayoutLMv3, UDOP, TILT, DocFormer, StrucText, ...

OCR + Multimodal Model



OCR + Multimodal Model

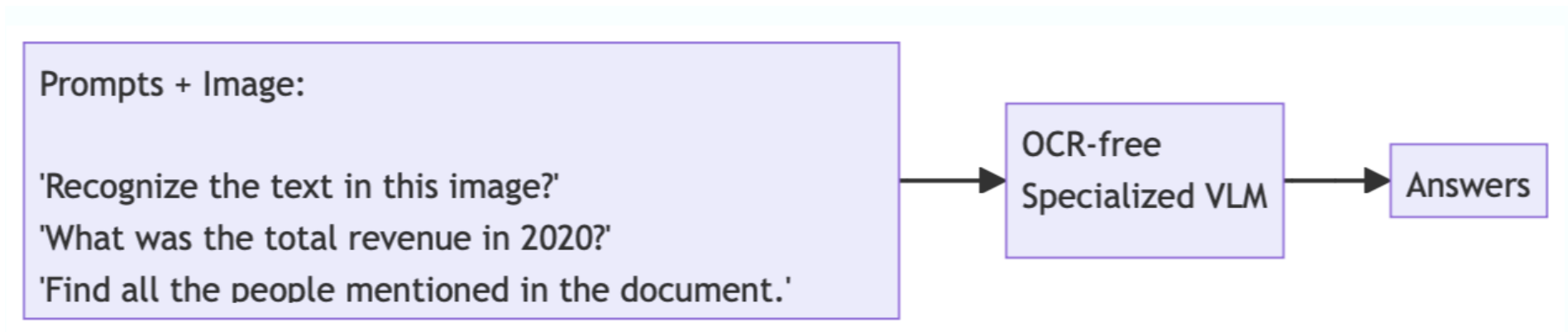
- OCR system can operate efficiently at high image resolutions
- multimodal model can handle layout analysis, reading order, etc.
- modularity of the system makes training, testing, and fine-tuning easier
- currently the most popular approach

OCR-Free Approaches

- attempt to solve document understanding tasks without separate OCR step
- usually, a single transformer model performs both text recognition and layout analysis
- may perform full page recognition

Examples: Donut, DAN, TrOCR, ...

OCR-Free



Transformer-Based "Traditional" OCR

Most "OCR-free" transformers cannot perform full OCR. A few can:

- TrOCR (CER 2.89% handwriting only)
- UDOP (CER 2.56%, IOU 91.62%)
- Nougat (CER 25.5%)
- Kosmos 2.5 (CER 9.2%, IOU 82.1%)

Note:

- These are not particularly good results by OCR standards.
- Unknown how much is due to language modeling and even memorization.

Current Benchmarks and Leaderboards

- text localization (receipts, etc)
- page segmentation and reading order (PubLayNet, PubTables-1M)
- visual question answering (VQA, DocVQA)
- key information extraction (KIE on SROIE)
- no widely used end-to-end OCR benchmarks

NVIDIA OCR Efforts and Foundation Models

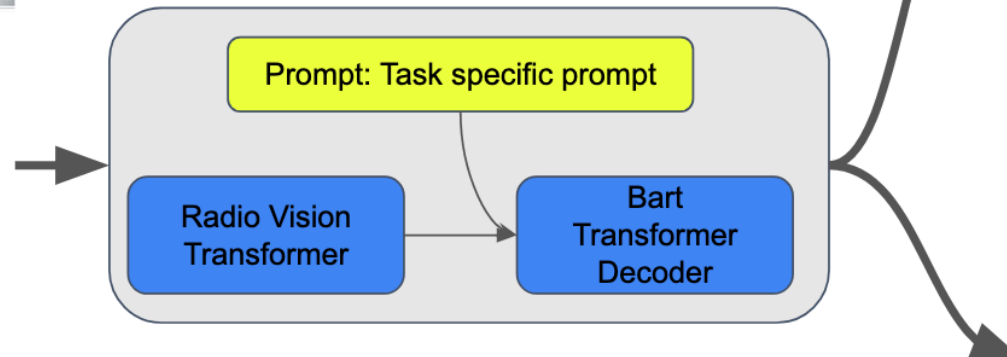
Ambitious all-in-one effort:

- VLMs that handle vision, scenes, and documents
- prompted responses
- document capabilities:
 - high accuracy image-to-text for books, articles
 - outputs logical and physical markup (headers, footnotes, etc.)
 - handles math and other special content
- massive training and data management effort due to generality of model

NVIDIA Architecture

- Single monolithic autoregressive VLM
- We train our models using bf16 + 128xH100 in 2 days with x million pages with Energon
- 3-5 pages/sec using TRT LLM on H100 + fp16 without any focus on optimization

Document image

[illegible]

<https://github.com/NVIDIA/Megatron-Engine>

<https://github.com/NVlabs/RADIO>

BBOX Output

<p>PROPERTY TRANSACTIONS Property transactions, not consisted of the following:</p>		<p>Other: including, during 2003, The amount of the net proceeds for targeted assets as determined based on the net book value of the assets and engineering unit's transactions with the related development agreement is 2,000, the Company's net loss of 111 million, which was the net book value of previously acquired development units abandoned in compliance with the reforming program on July 20, 2003, after previously several allocations to improve regional value of the related development project in 2003. Also, in 2002, the Company recorded write-downs and impairment losses of assets abandoned in compliance with the reforming program.</p>	
<p>THE EFFECT OF FINANCIAL TRANSACTIONS Assets (Increase/Decrease in thousands)</p>		<p>Assets (Increase/Decrease in thousands)</p>	
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NVIDIA Results

Internal Test Set		
	Word Error Rate	Passed Pages (F1 > 0.75)
ECLAIR	6.0%	99.1%
(commercial hosted OCR)	8.4%	96.4%
Kosmos-2.5	15.9%	91.2%
PyMuPDF	22.9%	94.75%

What's Missing

- Need better end-to-end OCR benchmarks, not just task-specific benchmarks.
- Need more dense and diverse annotated dataset and benchmarks with complete annotation
- Better coverage (training+benchmarks) of mathematical equations, chemistry, etc.
- More diversity: different set of layout, languages, fonts, etc.
- Better coverage of uncommon layouts.

OCR Future

Two different OCR approaches:

- High performance self-contained OCR as input to LLMs and multimodal models
- Multimodal models that perform basic OCR/layout and invoke specialized agents.

Both will likely co-exist for some time.

What do we need OCR for?

What do we need OCR for?

- largely already converted (e.g. Gutenberg)
 - important pre-1924 books
 - important scientific papers
- good alternatives to OCR / good custom solutions
 - business, legal, government communications
 - scene text (camera based translation, self-driving cars, etc.)
- largely available in digital format
 - open source textbooks and other publications
 - scientific publications (tagged PDF/A will have large impact)

Objective?

We are trying to translate texts into *facts*

Types of Tasks involved in LLM Answers

- knowledge of facts ("Lincoln was president")
- knowledge of meta-facts ("this fact is true according to...")
- ability to reason ("Lincoln was a US citizen because he was president.")
 - reasoning can be imitated with factual knowledge
- ability to recall verbatim ("please quote ...")

MMLU Examples of Multiple-Choice Questions

Biology Example: (fact, knowledge)

What is the powerhouse of the cell?

(A) Nucleus (B) Mitochondria (C) Ribosome (D) Endoplasmic Reticulum

Mathematics Example: (inference)

If 4 daps = 7 yaps, and 5 yaps = 3 baps, how many daps equal 42 baps?

(A) 28 (B) 21 (C) 40 (D) 30

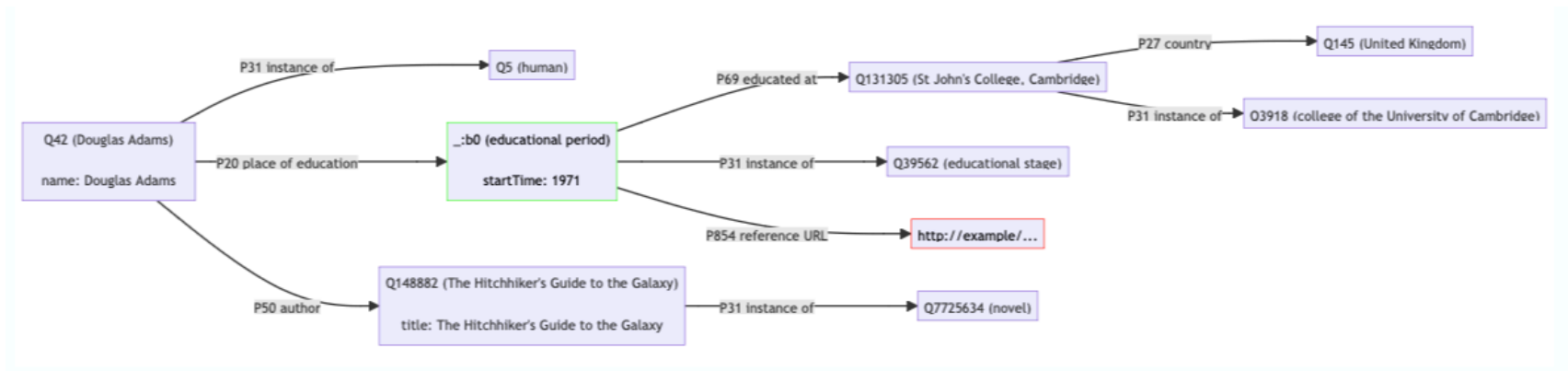
What do Facts Look Like?

```
wikidata_item:
  item_id: Q42 # Unique identifier
  labels: "Douglas Adams" # Main name
  descriptions: "English writer and humorist" # Short description
  aliases: ["Douglas Noël Adams"] # Alternative names
  sitelinks: ["https://en.wikipedia.org/wiki/Douglas_Adams"] # Wikipedia link

  statements:
    - property: Height
      property_id: P2048
      value: "185 cm" # Simple property example

    - property: Educated at
      property_id: P69
      value: {item: "St John's College, Cambridge", item_id: Q691283} # Statement pointing to another Q item
      qualifiers:
        - {qualifier: Start date, qualifier_id: P580, value: 1971}
        - {qualifier: End date, qualifier_id: P582, value: 1974}
      references:
        - {reference_property: Reference URL, reference_property_id: P854, value: "https://source.link"} # Reference URL
```

What do Facts Look Like?



What do Facts Look Like?

```
<"Q42 (Douglas Adams)", "name", "Douglas Adams">
<"Q42 (Douglas Adams)", "alias", "Douglas Noel Adams">
<"Q42 (Douglas Adams)", "P31 (instance of)", "Q5 (human)">
<"Q42 (Douglas Adams)", "P22 (father)", "_:b0 (educational period)">
<"Q42 (Douglas Adams)", "P50 (author)", "Q148882 (The Hitchhiker's Guide to the Galaxy)">

<"_:b0 (educational period)", "startTime", "1971">
<"_:b0 (educational period)", "endTime", "1974">
<"_:b0 (educational period)", "P69 (educated at)", "Q131305 (St John's College, Cambridge)">
<"_:b0 (educational period)", "P31 (instance of)", "Q39562 (educational stage)">
<"_:b0 (educational period)", "P854 (reference URL)", "http://example/...">

<"Q131305 (St John's College, Cambridge)", "P27 (country)", "Q145 (United Kingdom)">
<"Q131305 (St John's College, Cambridge)", "P31 (instance of)", "Q3918 (college of the University of Cambridge)">

<"Q148882 (The Hitchhiker's Guide to the Galaxy)", "title", "The Hitchhiker's Guide to the Galaxy">
<"Q148882 (The Hitchhiker's Guide to the Galaxy)", "firstPublished", "1979">
<"Q148882 (The Hitchhiker's Guide to the Galaxy)", "P31 (instance of)", "Q7725634 (novel)">
```

What do facts look like?

Douglas Adams, also known as Douglas Noel Adams, was a human. He authored the novel "The Hitchhiker's Guide to the Galaxy", first published in 1979. From 1971 to 1974, he was educated at St John's College, Cambridge, which is a college of the University of Cambridge in the United Kingdom.

Classical Problems with Symbolic AI

- term resolution
 - "Douglas Adams" - "Douglas Noel Adams"
- disambiguation
 - "John Smith (actor)" vs "John Smith (politician)"
- ontology mapping
 - Wikidata "educated at" vs. DBpedia "alma mater"
- LLMs are good at resolving these problems

Facts and Documents

Documents can be understood as collections of facts:

- simple statements of facts ("Hydrogen is the lightest element")
- context-dependent facts ("Lincoln was president from 1861 to 1865")
- meta-facts ("According to ... Lincoln was president from 1861 to 1865")
- textual facts ("'Shall I compare thee to a summer's day?' is the first line of a sonnet by Shakespeare")

A Statistical Model of Facts

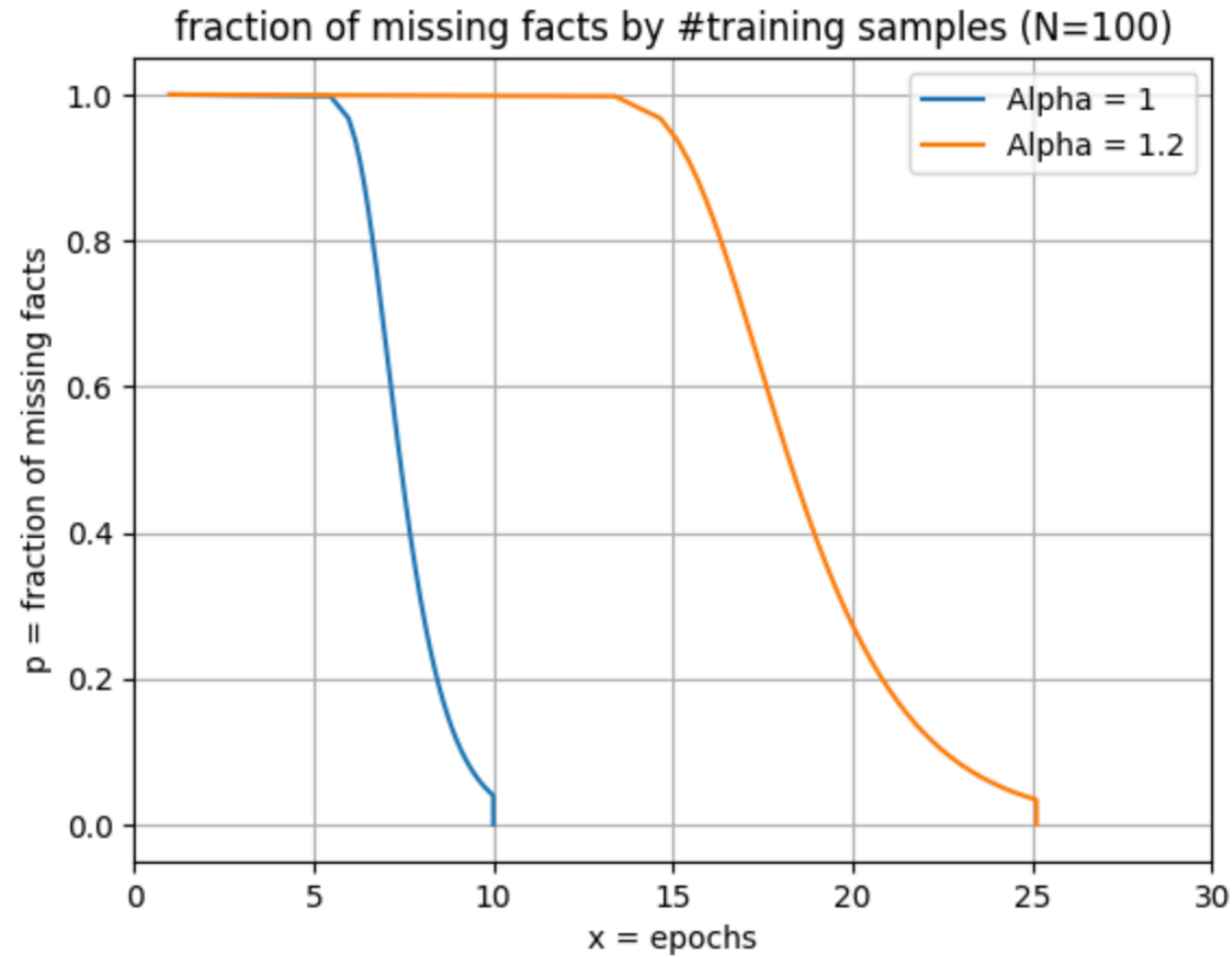
Model:

- facts are distributed across texts in a power law distribution
- LLMs need to be exposed to each fact approximately k times to learn it
- performance on fact-based benchmarks reflects the percentage of facts learned

Prediction:

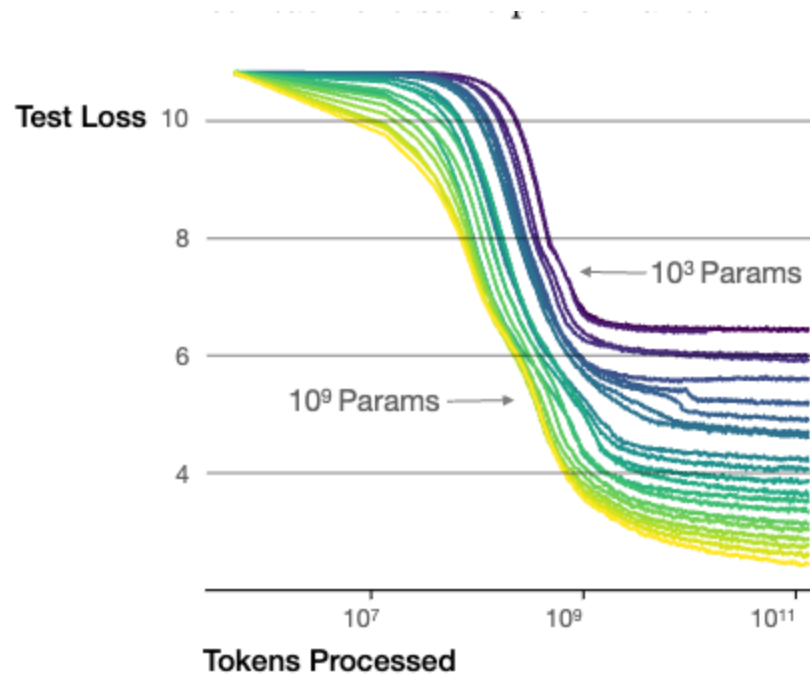
- how long does it take to learn $x\%$ of facts in a corpus?

Predictions of Learning Behavior



Actual Observations

Scaling Laws for Neural Language Models



Kaplan et al. 2021

Observations

- learning itself is a power law process
- the exponent of the power law is critical in determining learning time
- we can potentially achieve great improvements by achieving a more uniform distribution of facts

Approaches to Achieving Uniform Fact Distribution

- machine learning approaches
 - use umbrella sampling of documents
 - use boosting
- data driven approaches
 - careful manual selection of training data (e.g., textbooks)
 - small LLMs + utilize facts directly during inference
 - train directly on facts instead of documents

Summary

State of OCR

- Traditional OCR: high text accuracy, layout issues
- Three approaches: OCR+LLM, OCR+VLM, OCR-free
- Likely will continue to co-exist: different strengths/weaknesses.
- High performance image-to-markup desirable for many applications.
- Need:
 - Improve coverage: diverse layouts, math, formulas, etc.
 - Better end-to-end OCR benchmarks

State of Knowledge and Reasoning

- LLMs learn and reason from facts
- LLMs are primarily benchmarked on facts and inference
- Making facts explicit helps with acquisition, testing, reasoning
- Power law governs learning efficiency
- Scaling laws crucial for fact acquisition
- Uniform fact distribution potentially improves learning