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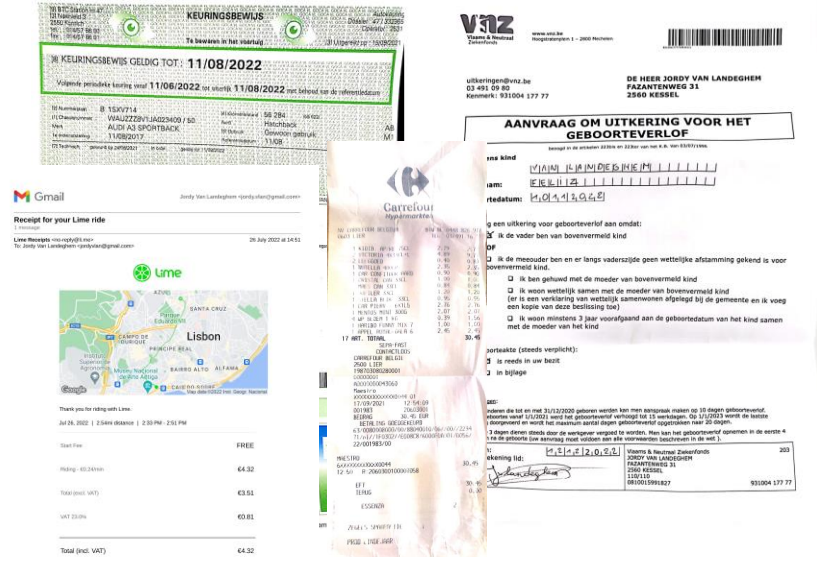
Intelligent Automation for AI-Driven Document Understanding

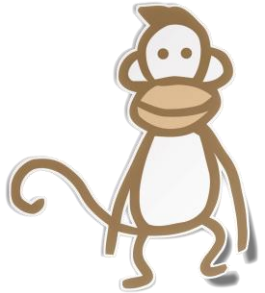
Jordy Van Landeghem

23/04/2024

VLAIO

The in the room: **documents** pervade our daily lives





Instant gratification monkey – Tim Urban

Humans and organizations are *drowning* under visually-rich documents…

Document-based communication facilitates crucial interactions, decisions and actions

Manual processing is inefficient

Technology assistance?

…yet organizations lag in adopting **automated document processing** solutions

Two primary challenges:

I. Complexity of processing, long multimodal documents algorithmically

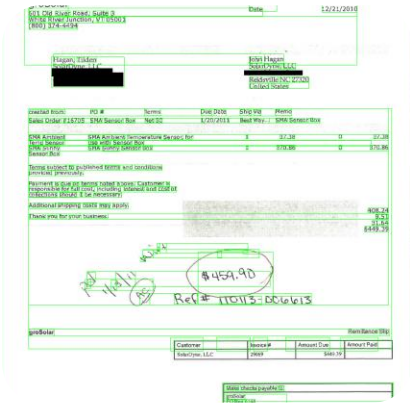
→ Document Understanding (DU)

II. Need for reliability, robustness and control over associated risks

→ Intelligent Automation (IA)

Document Understanding: the E2E process

Optical Character Recognition



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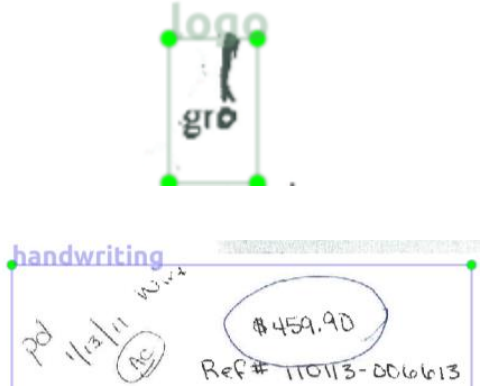
Document Layout Analysis / Document Object Detection

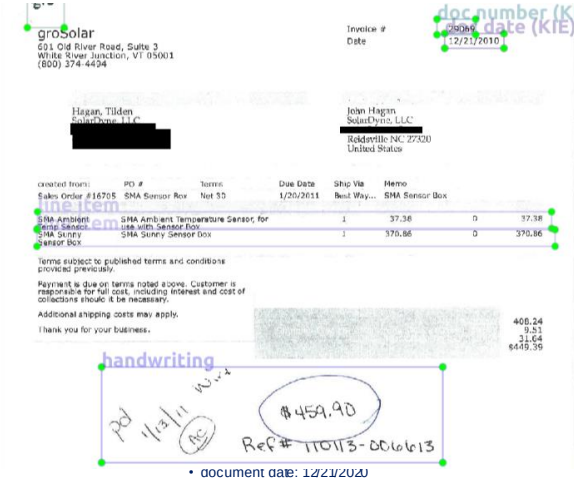


logo: *136,313; 313,432*
handwriting:
(493,2133; 2063,2523)

Document Classification

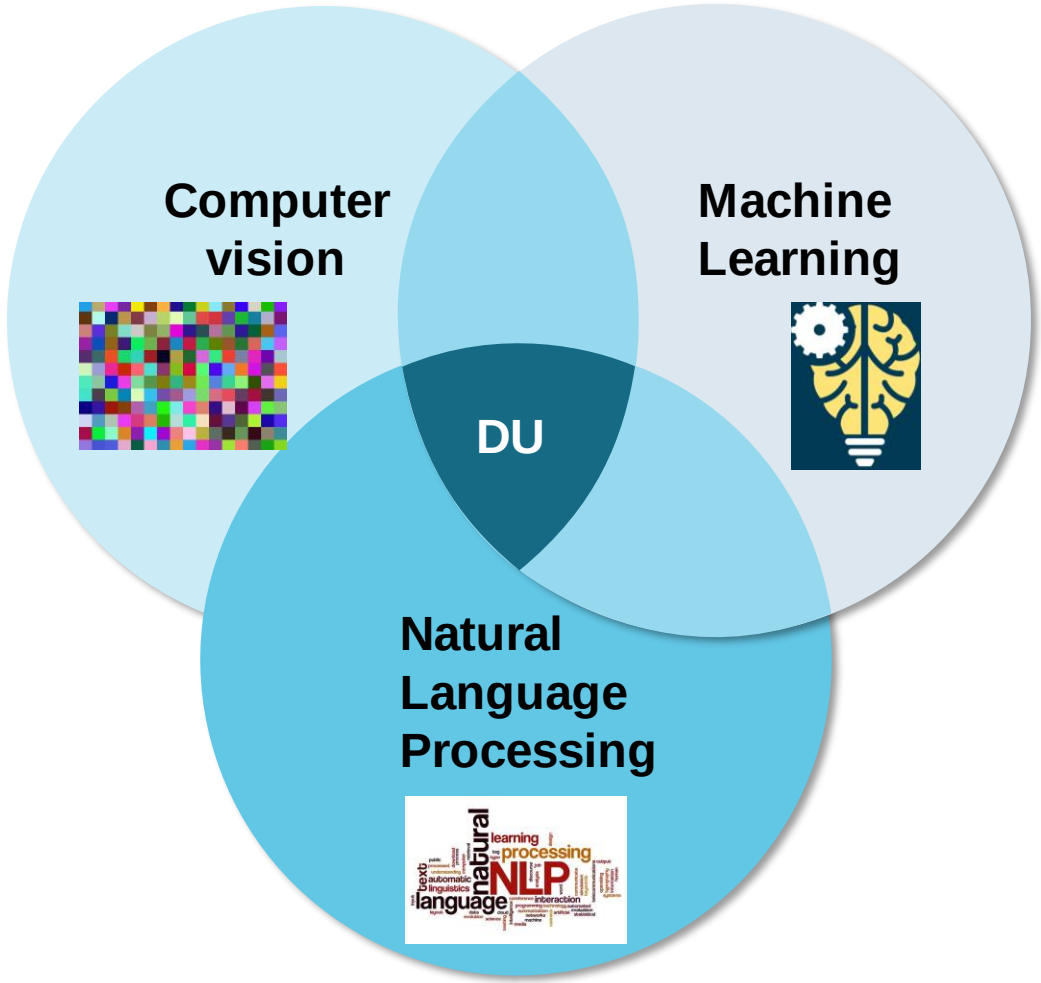
document type: invoice

Key Information Extraction



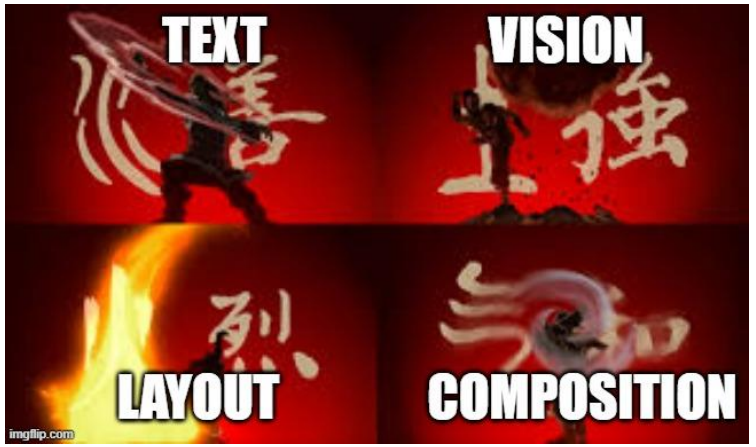
document number: 29069
document date:12/21/2020
…

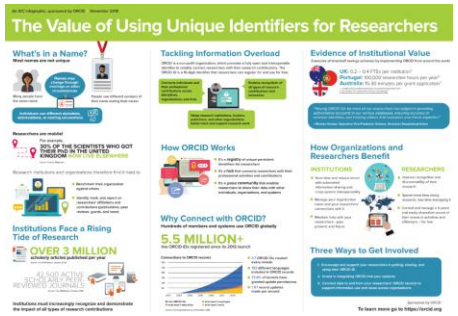
Document Understanding: the research field

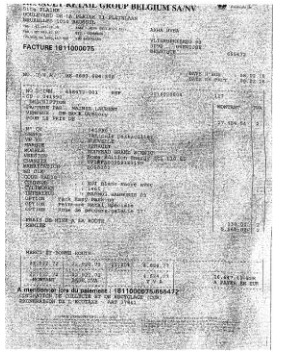


Deal with any subtasks and all complexities of documents

- **Multimodal**
- **Multipage**
- Channel
- Quality
- ...







Recent advances ❤ ***Large Language Models*** *(LLM)*

What is a (Large) Language Model?

The best thing about AI is its ability to

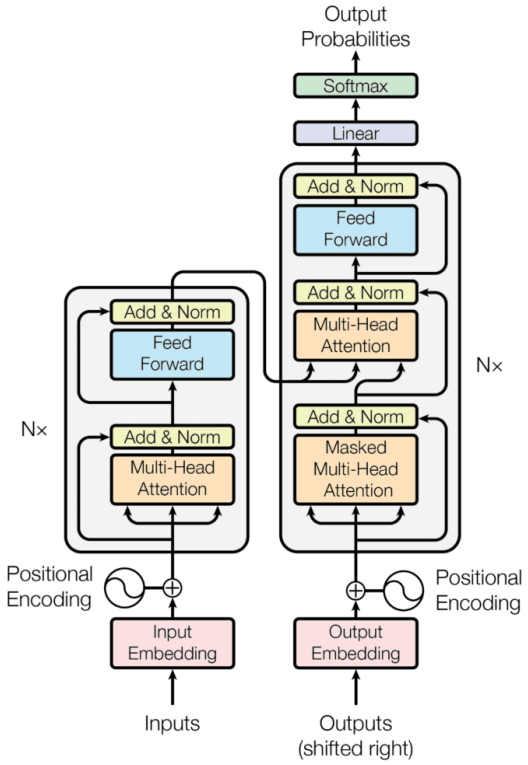
learn	4.5%
predict	3.8%
make	3.2%
understand	3.1%
do	2.8%

The best thing about AI is its ability to **learn**
The best thing about AI is its ability to learn **from**
The best thing about AI is its ability to learn from **experience …**

Slide adapted from link

How ChatGPT and LLMs are developed

Main architecture



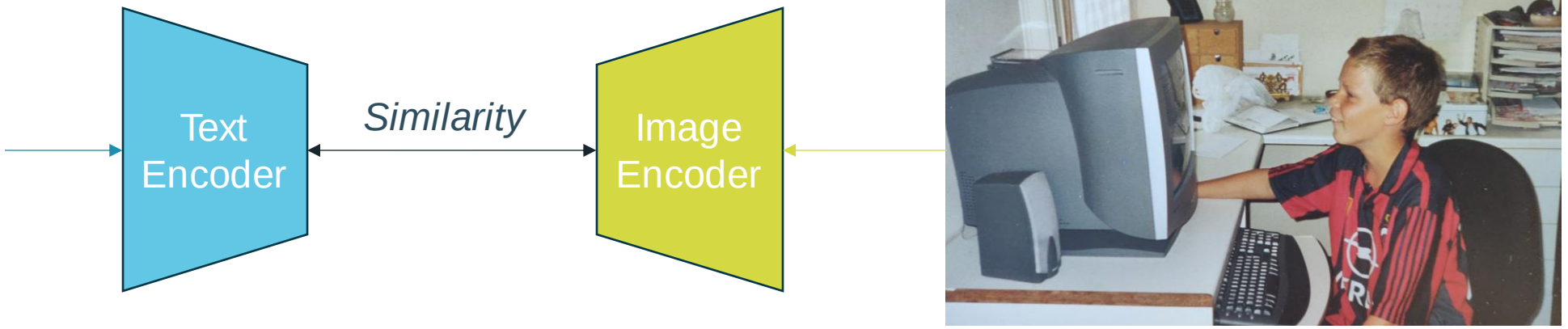
Training stages

1. **Pretraining** man's best friend is a <MASK>
2. **Alignment** D > A > B > C
3. **Instruction tuning / prompt engineering**

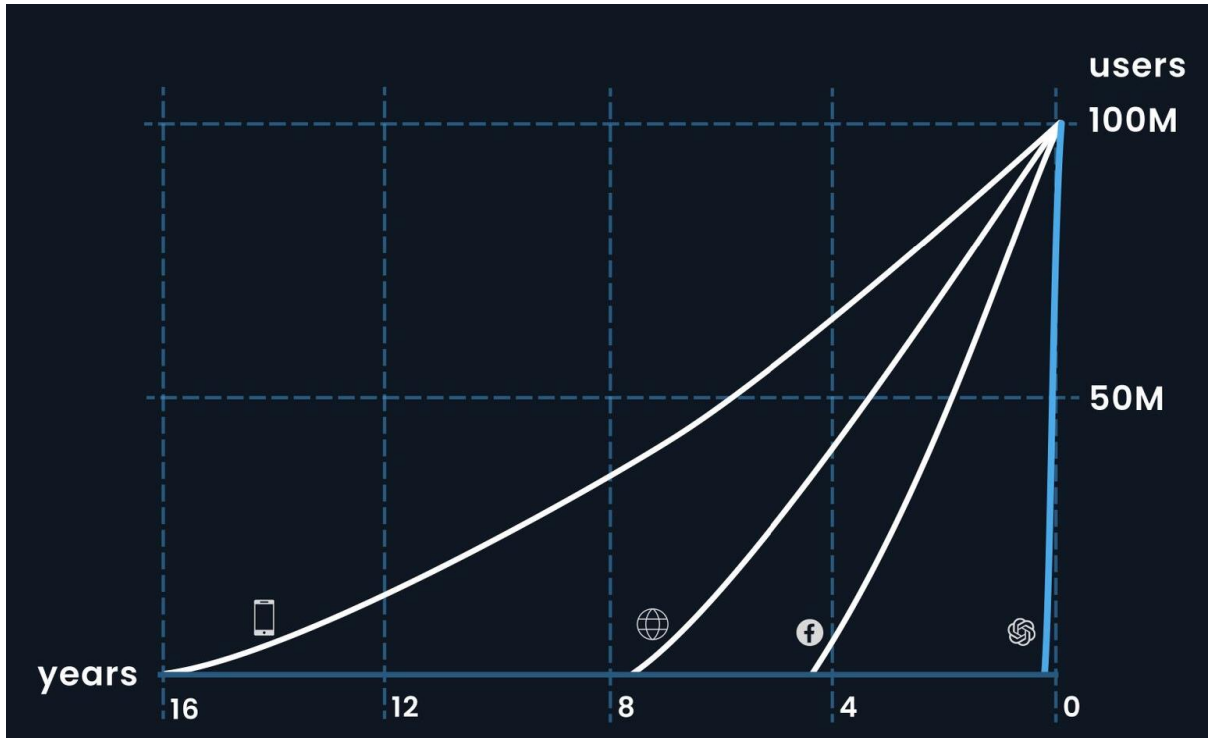
#1	Prompt
1	You are asked to answer questions asked on a document image.
2	The answers to questions are short text spans taken verbatim from the document.
3	This means that the answers comprise a set of contiguous text tokens present in the document.
4	Document:
5	{Layout Aware Document placeholder}
6	Question: {Question placeholder}
7	
8	Directly extract the answer to the question from the document with as few words as possible.
9	
10	Answer: {}

What is a (Large) Vision-Language Model?

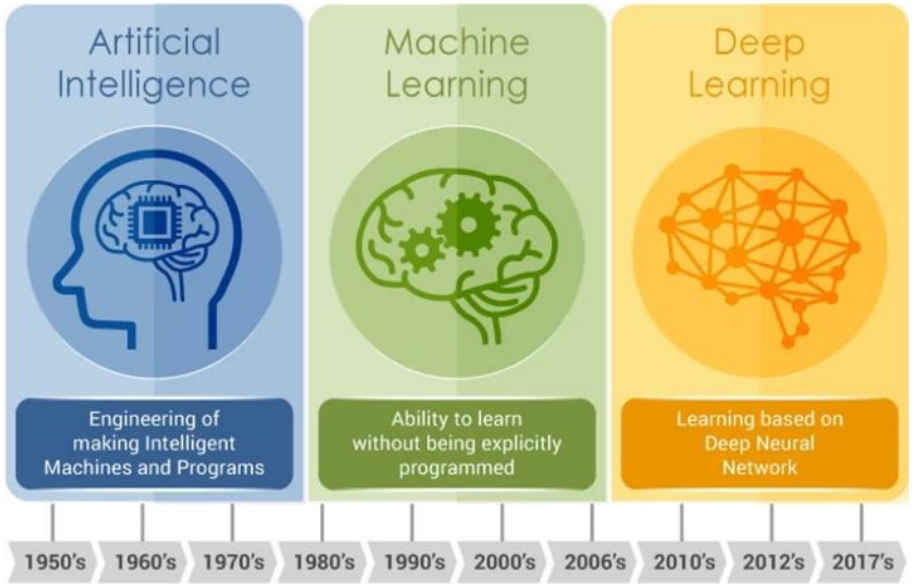
A child wearing an AC Milan 1999 shirt sitting at a desktop computer

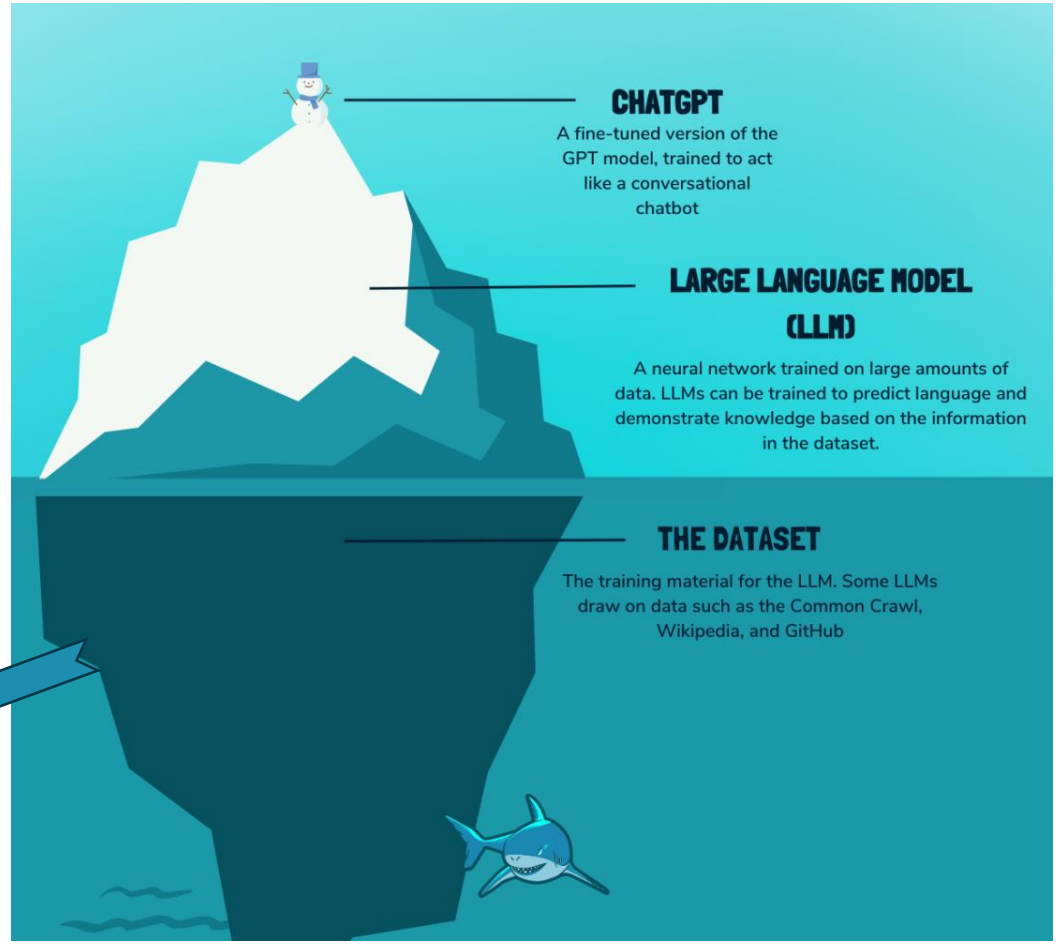


The success of ChatGPT and generative AI



What is fueling the GenAI boom?

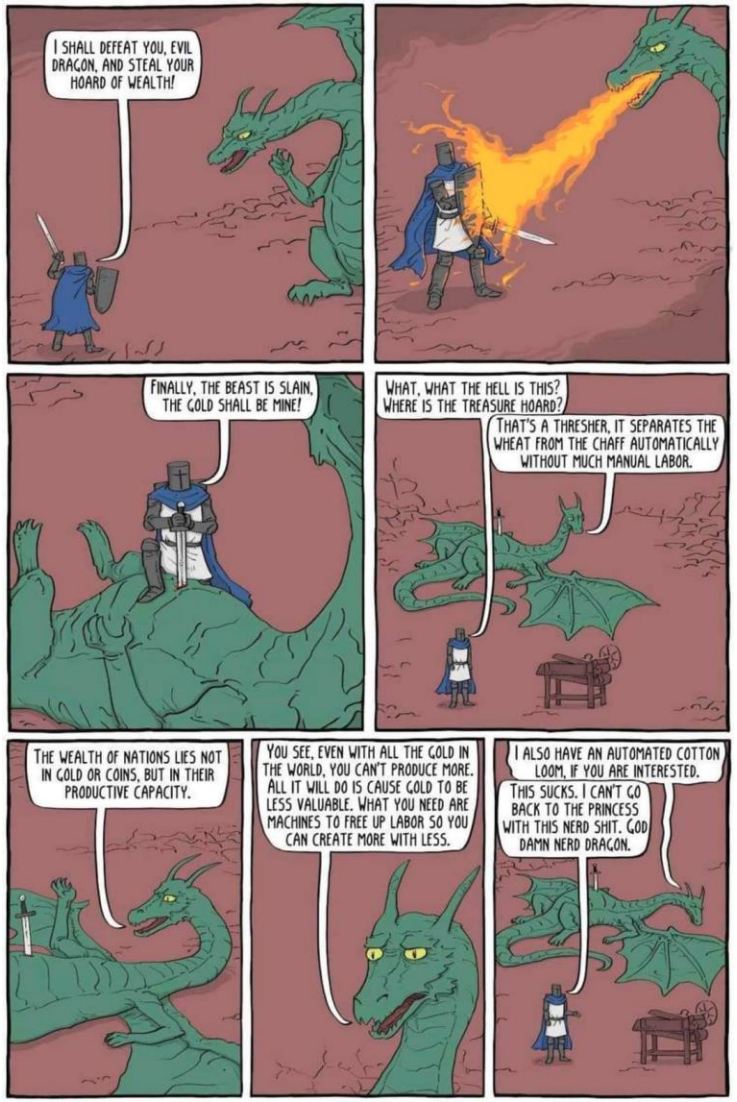


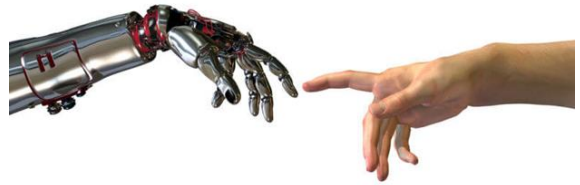


The role of data > algorithmic improvements

1. **Training:** new skills
2. **Evaluation**: track progress

From boom to A(G)I doom OR Intelligent Automation



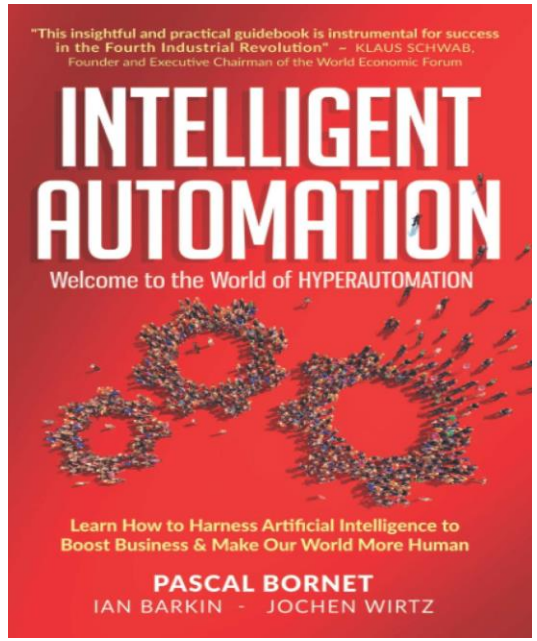


What makes automation intelligent?

Intelligent Automation (IA) = AI + RPA + BPM

- Mimic human capabilities required to perform **knowledge work**
- Capable of solving major world problems when combined with people & organizations

Goal: **Taking the robot out of the human**, not replacing human workers



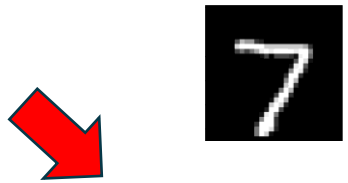
Pascal Bornet, Ian Barkin and Jochen Wirtz (2020)

Requirements

Confidence scoring
Failure prediction
Advanced evaluation

build **straight-through** business processes, which are more efficient (**productivity, processing speed, cost**) and often more effective (**quality and logic**).

How is the technology being evaluated?

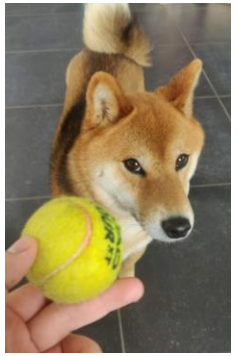


Accuracy-focus
Domain-specific
Public holdout set

Automation-focus
Multi-domain
Private holdout set

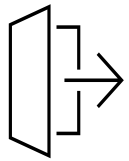
Automation-focus
Real-world usage, >i.i.d.
Human evaluation, Blind A/B testing

Overview of this presentation



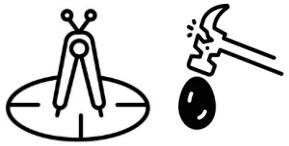
Reliable and **Robust** Deep Learning

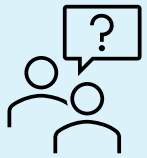
Realistic and **Efficient** Document Understanding



Conclusions and *Takeaway Messages*

Overview: publications and innovation scope





Predictive Uncertainty for Probabilistic Novelty Detection in Text Classification
ICML 2020

Benchmarking Scalable Predictive Uncertainty in Text Classification
IEEE Access 2022

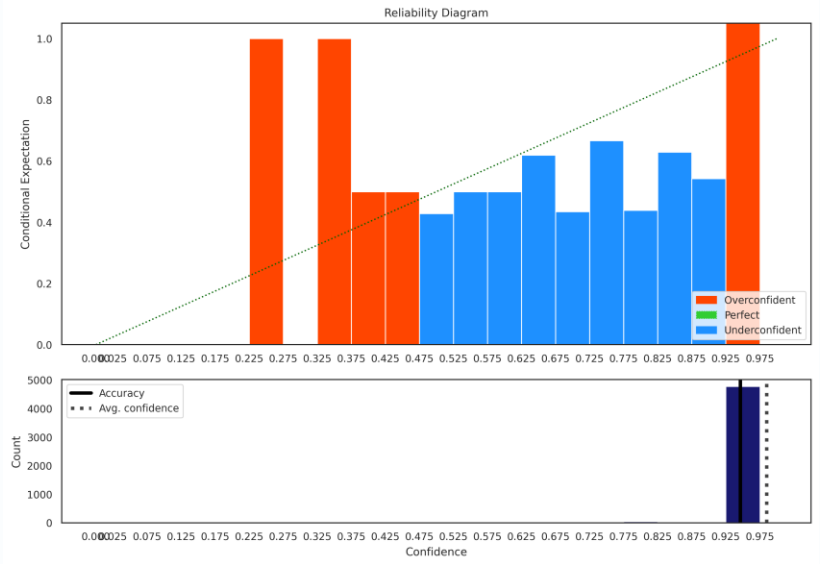
Beyond Document Page Classification: Design, Datasets, and Challenges
WACV 2024 *oral*

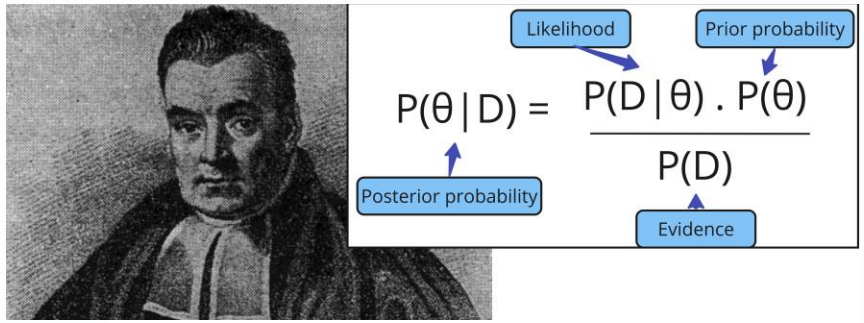
Competition on Document UnderstanDing of Everything
ICDAR 2023 *oral*

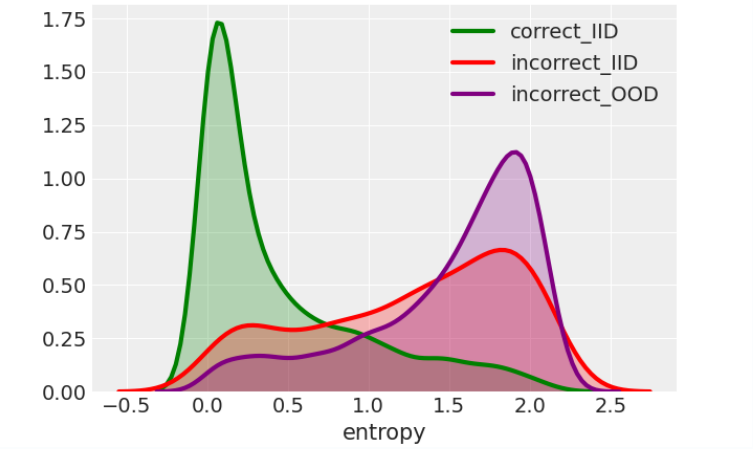
Document Understanding Dataset and Evaluation
ICCV 2023

Knowledge Distillation for Visually-Rich Document Applications
ICDAR 2024

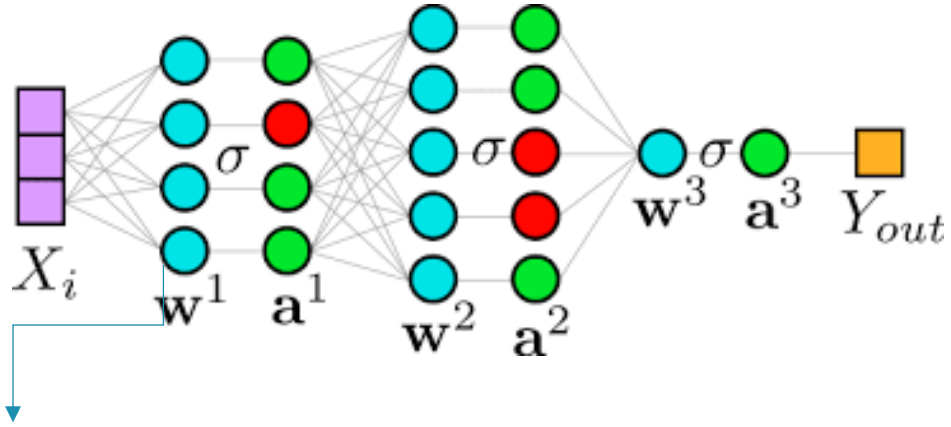
I. **Reliable** and **Robust** Deep Learning



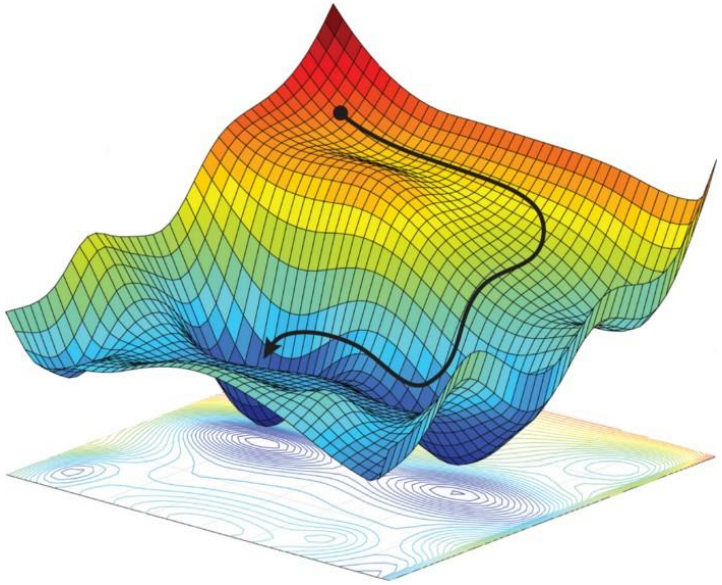


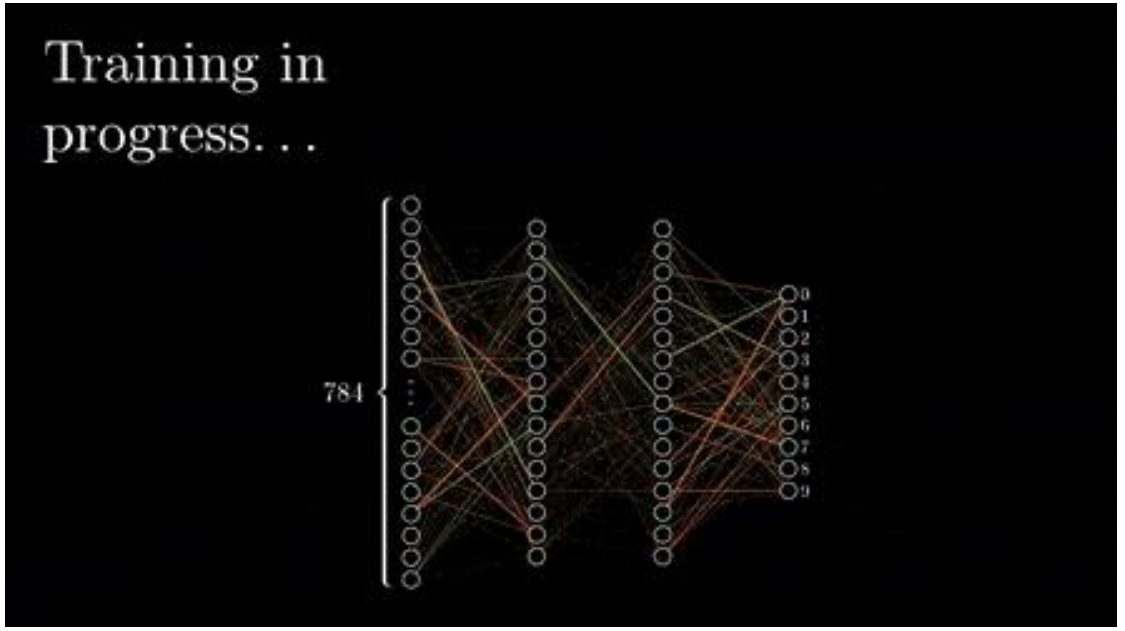


The foundations of Deep Learning



$y = wx + b$

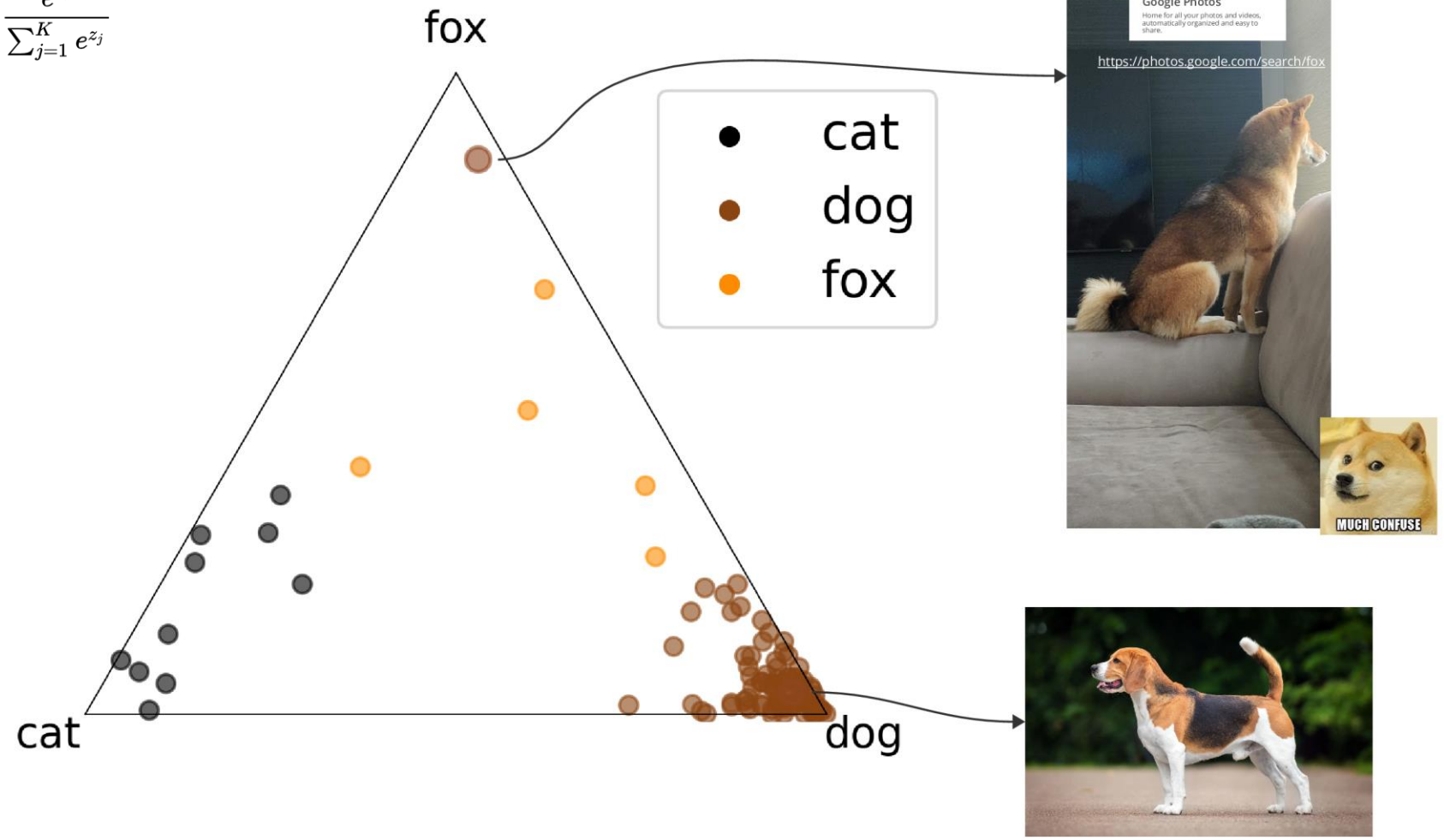




"Neurons that 🔥 together, 📝 together"

Deterministic NNs output unreliable uncertainty

$$\sigma(\vec{z})_i = \frac{e^{z_i}}{\sum_{j=1}^{K} e^{z_j}}$$

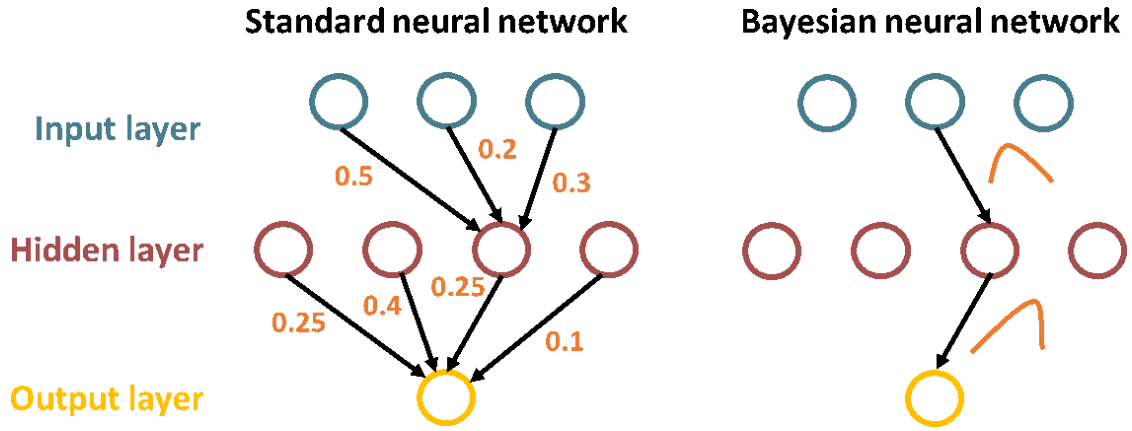


Alternative confidence scoring functions?

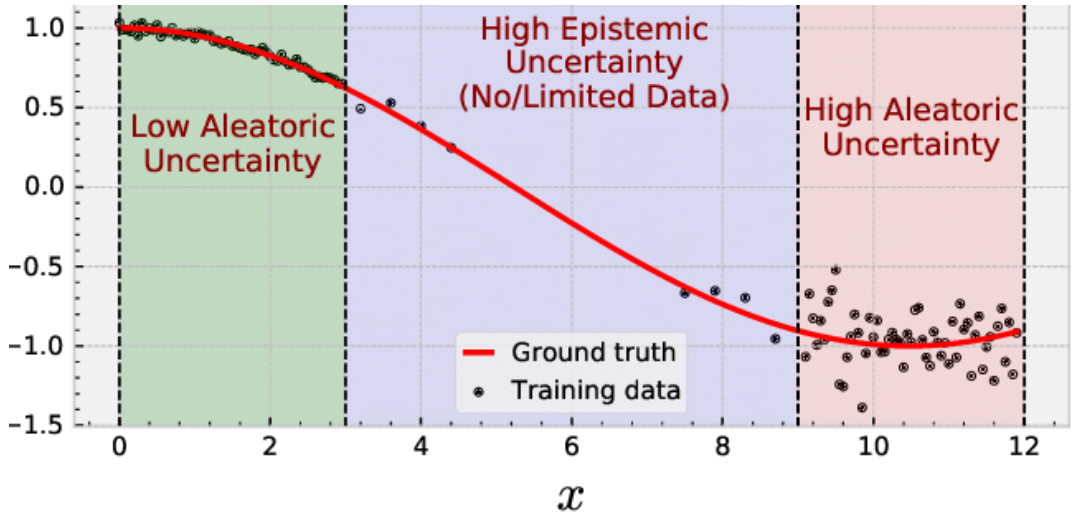
Bayesian Deep Learning

→ Modern DNNs are underspecified by the data, capable of representing many compelling parameterized solutions

→ Investigate parameter uncertainty vs. deterministic NNs



Predictive Uncertainty Quantification:
Disentangle sources of uncertainty



What does uncertainty mean for language tasks?

Image Segmentation

Uncertainty (entropy of class probs)

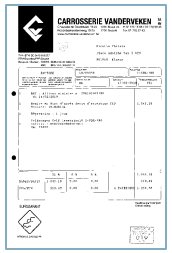
(By Roman Bachmann) 46

Knowledge gaps:

- Missing evaluation of PUQ in NLP
  - Applicability and scalability?
- Architecture, prior and hyperparameter influences on uncertainty quality

Distribution shift is an unavoidable failure source

ID

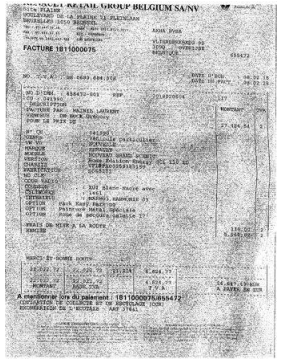


Repair invoice

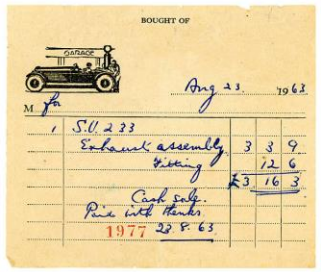
Hardware invoice

Car invoice

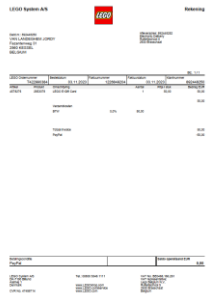
OOD



Covariate shift

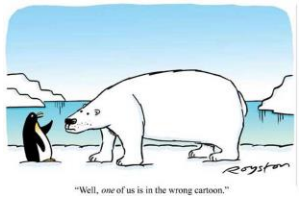


Concept drift



Subclass shift

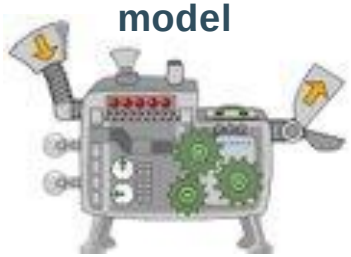
Near OOD

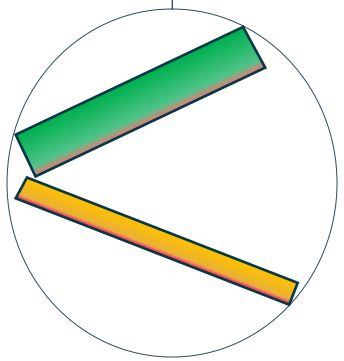


Far OOD

Decision-making under Predictive Uncertainty

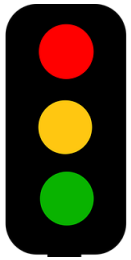
model





Automated

Manual review



Wrong triage

Correct triage

Automated

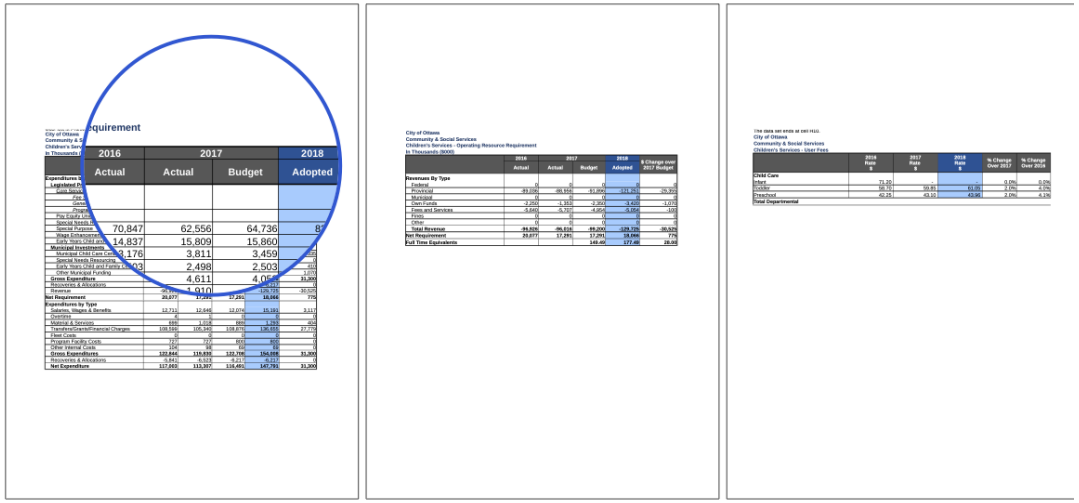
Hallucination, control and the evaluation problem

DALL·E

A little girl in standing next to a shiba inu next to a pond, the girl is holding a lucky clover in her left hand, the dog sits next to her, black and white

Hallucinations in generative modelling emphasizes the need for uncertainty quantification

As I explained in my previous email, I am not considering relocation because I have just started building my family with a little baby girl of ly old, and I am not willing to move her away from her grandparents. I am also not willing to move my wife away from her family, as she is a very family-oriented person. I am also not willing to move away from my family, as I am a very family-oriented person. I am also not willing to move away from my friends, as I am a very social person. I am also not willing to move away from my country, as I am a very patriotic person. I am also not willing to move away from my city, as I am a very city-oriented person. I am also not willing to move away from my neighborhood, as I am a very neighborhood-oriented person. I am also not willing to move away from my house, as I am a very house-oriented person. I am also not willing to move away from my room as I am a very room-oriented person. I am also not willing to move away from my bed, as I am a very bed-oriented person. I am also not willing to move away from my pillow, as I am a very pillow-oriented person. I am also not willing to move away from my blanket, as I am a very blanket-oriented person. I am also not willing to move away from my computer, as I am a very computer-oriented person. I am also not willing to move away from my desk, as I am a very desk-oriented person. I am also not willing to move away from my chair, as I am a very chair-oriented person. I am also not willing to move away from my keyboard, as I am a very keyboard-oriented person. I am also not willing to move away from my mouse, as I am a very mouse-oriented person. I am also not willing to move away from my monitor, as I am a very monitor-oriented person. I am also not willing to move away from my headphones, a I am a very headphones-oriented person. I am also not willing to move away from my coffee mug, as I am a very coffee mug-oriented person. I am also not willing to move away from my coffee machine, as I am a very coffee machine-oriented person. I am also not willing to move away from my coffee beans, as I am a very coffee beans-oriented person. I am also not willing to move away from my coffee grinder, as I am a very coffee grinder-oriented person. I am also not willing to move away from my coffee filter, as I am a



Non-Answerable Question: In what year does the Net Requirement exceed 25,000?

ChatGPT: 2016/2017/2018/…

Contributions: **Reliable** and **Robust**

Predictive Uncertainty for Probabilistic Novelty Detection in Text Classification
ICML UDL 2020

Benchmarking Scalable Predictive Uncertainty in Text Classification
IEEE Access 2022

- BDL survey and literature review
- PUQ methods NLP benchmark

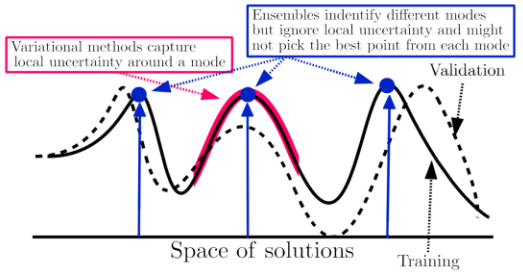
⇨

- Novel hybrid PUQ methods
- Real-world evaluation setups
- Take-home guidelines for PUQ

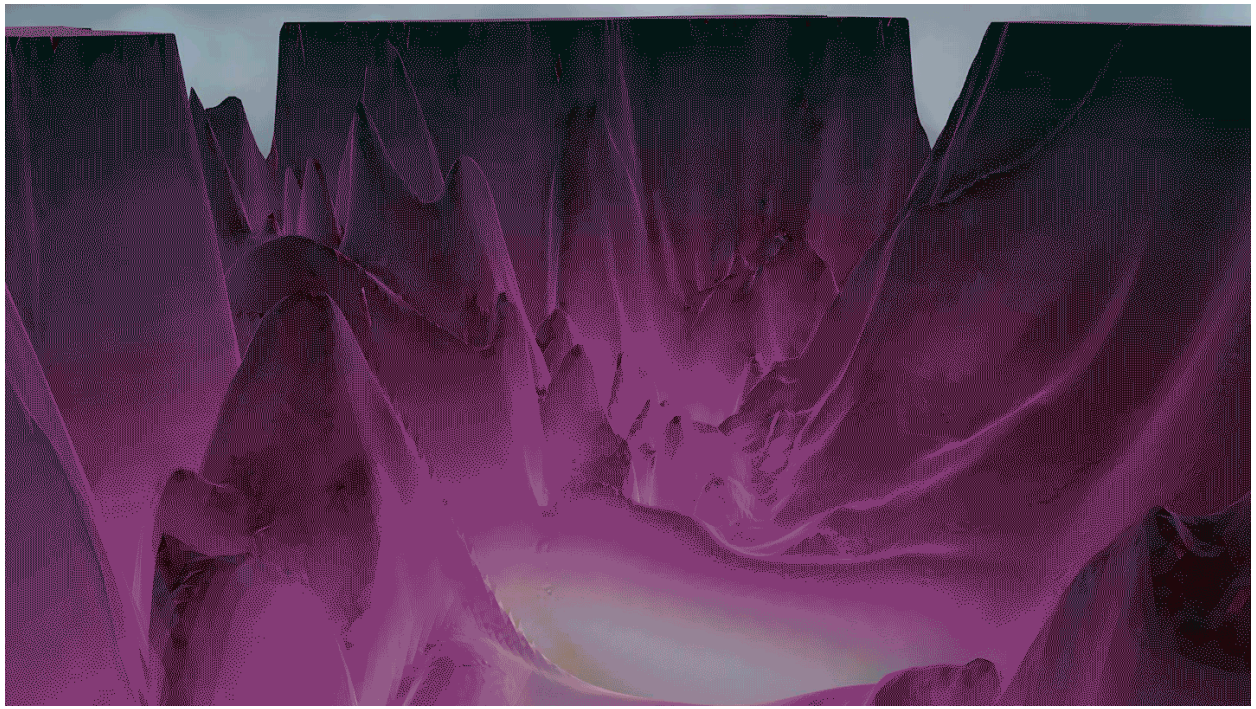
Presenting the first, comprehensive benchmark for scalable PUQ in NLP

- ✓6 text classification datasets
- ✓2 neural network architectures
- ✓6 unique, 28 total uncertainty methods
- ✓5 uncertainty measures
- ✓3 experiment setups
- ✓5 random seeds
- ✓4 hyperparameter ablations

Proposing novel, hybrid PUQ methods from complementarity in function space



Deep Ensemble (*Lakshminarayanan 2017)*



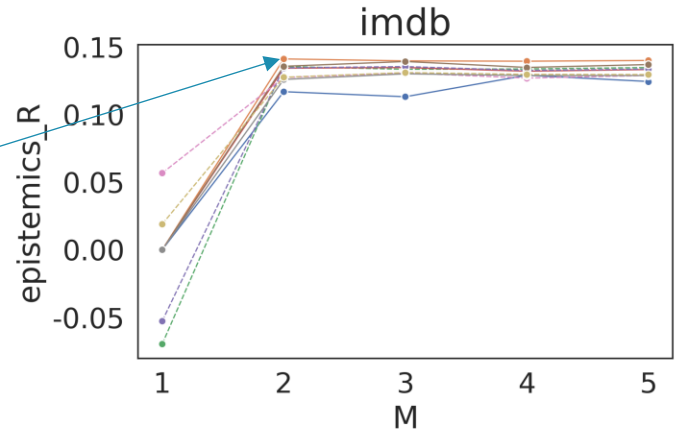
Variational Inference (MC Dropout (*Gal 2016*))

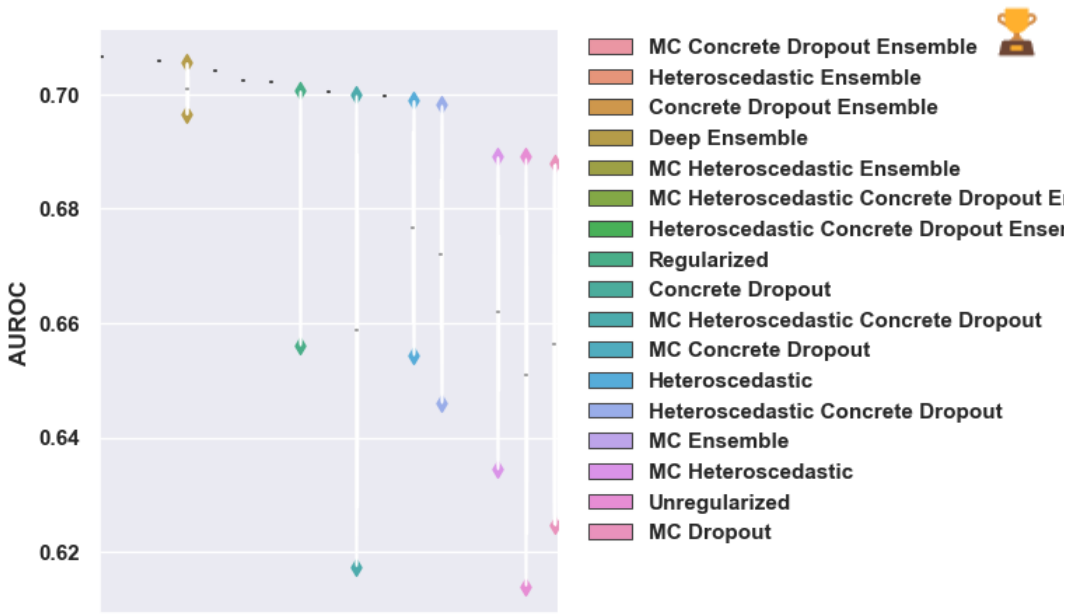
Credit: *Bryan Van Hauwaert*
Source: https://losslandscape.com/explorer

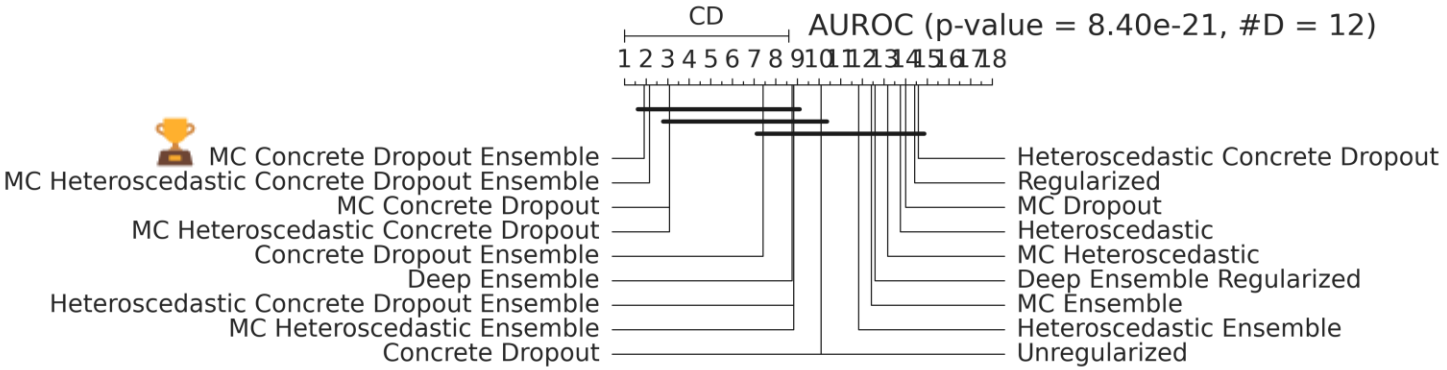
Finding 1: Proposed hybrid method is superior, at higher efficiency

MC Concrete Dropout Ensemble:

- Presented empirical evidence for theory of complementarity in function space
- Superior at novel class robustness and out-of-domain detection, even at a lower ensemble size

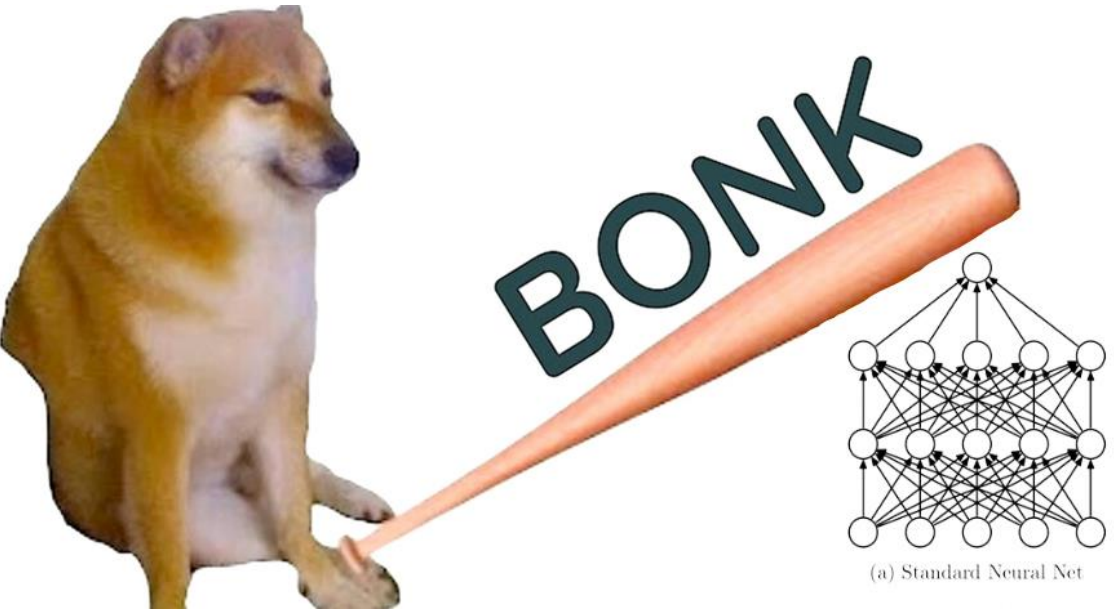




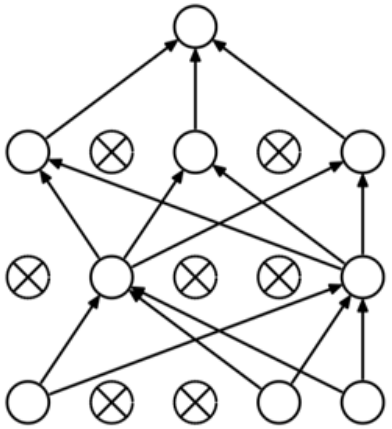


Decomposing Monte Carlo Concrete Dropout Ensemble

Randomly set a % *p* of neurons/weights to 0



(a) Standard Neural Net



(b) After applying dropout.

Algorithm 1: MCdropout

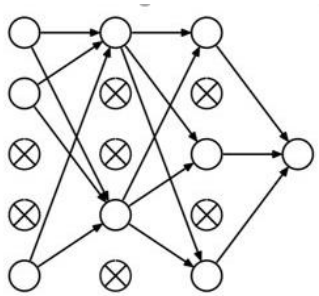
Input: data x^*, encoder $g(\cdot)$, prediction network $h(\cdot)$, dropout probability p, number of iterations B

Output: prediction $\hat{y}^*_{mc}$, uncertainty η_1

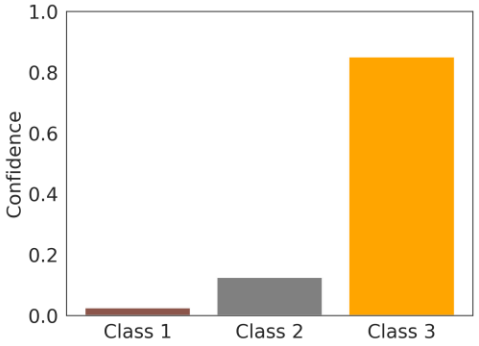
for $b = 1$ to B **do**
  $e^*_{(b)} \leftarrow \textit{VariationalDropout}(g(x^*), p)$
  $z^*_{(b)} \leftarrow \text{Concatenate}(e^*_{(b)}, \text{extFeatures})$
  $\hat{y}^*_{(b)} \leftarrow \textit{Dropout}\ (h(z^*_{(b)}), p)$
end for
// prediction
$\hat{y}^*_{mc} \leftarrow \frac{1}{B}\sum_{b=1}^{B} \hat{y}^*_{(b)}$
// model uncertainty and misspecification
$\eta_1^2 \leftarrow \frac{1}{B}\sum_{b=1}^{B}(\hat{y}^*_{(b)} - \hat{y}^*)^2$
return $\hat{y}^*_{mc}$, η_1

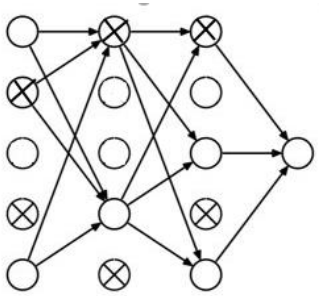
Gal and Ghahramani 2016; Lakshminarayanan 2017; Gal 2017

MC dropout: low uncertainty

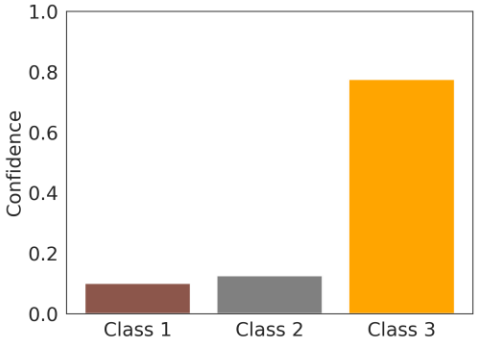


Sample 1





Sample 2



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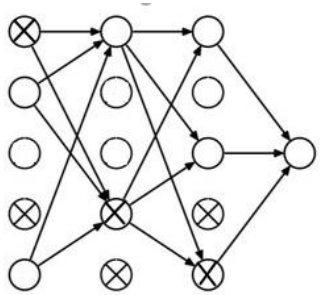
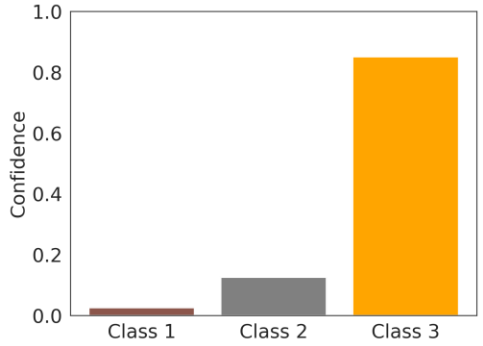
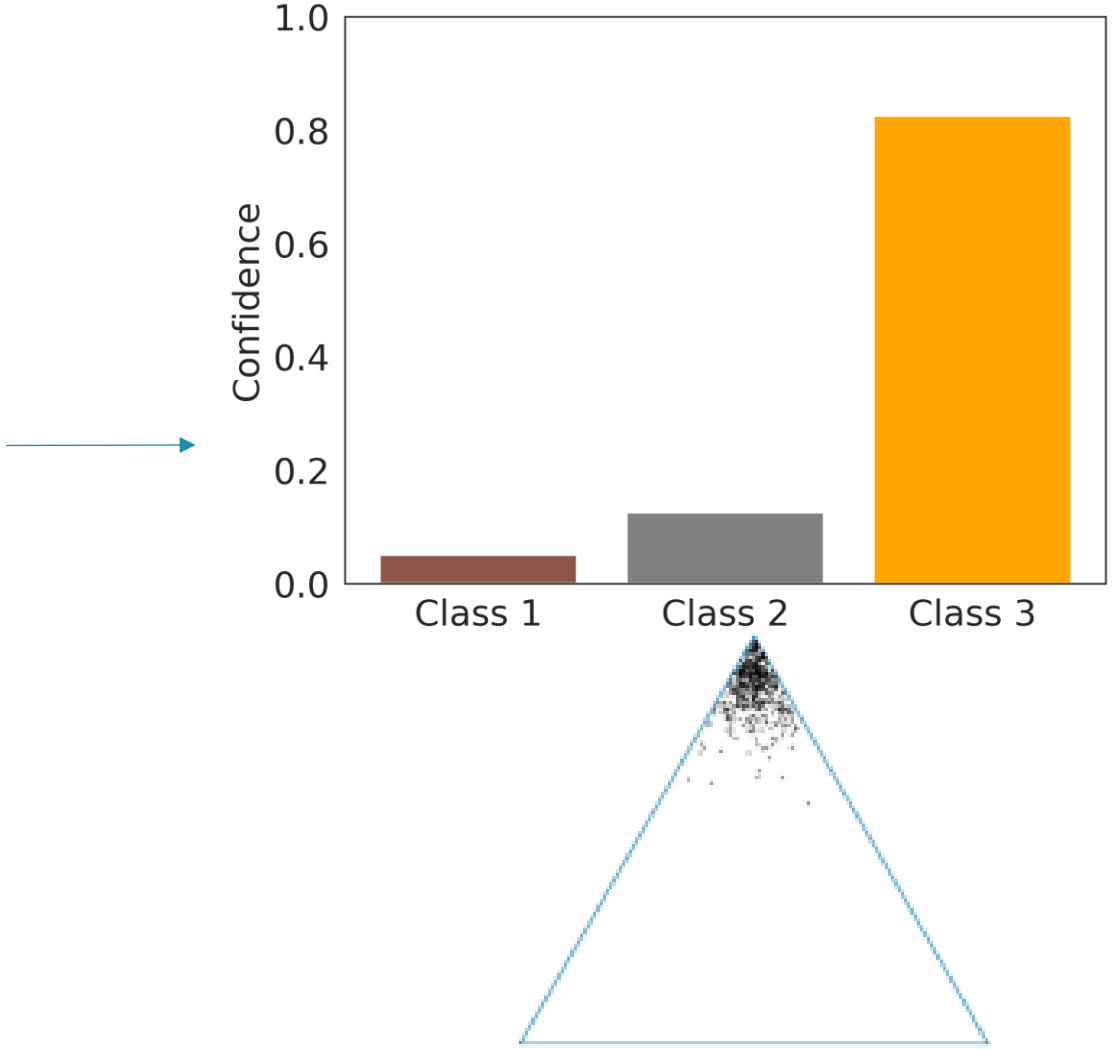


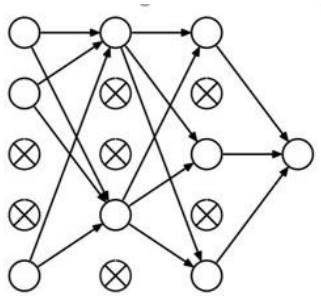
Sample T

...

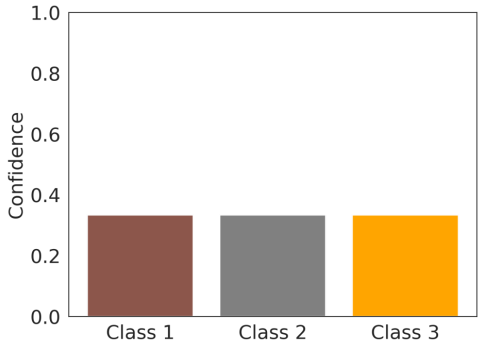


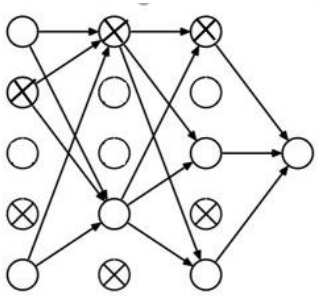


MC dropout: max *data* uncertainty

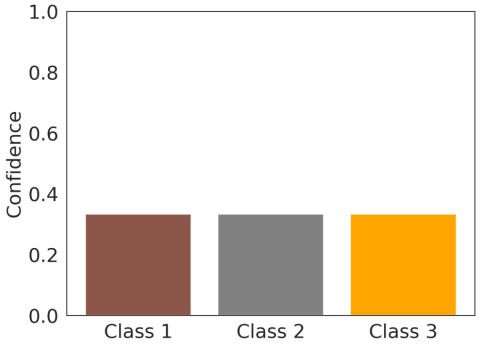


Sample 1





Sample 2



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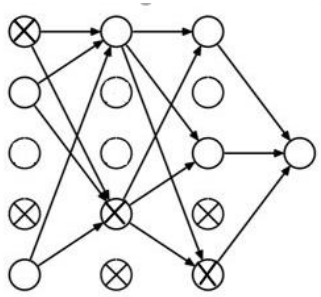
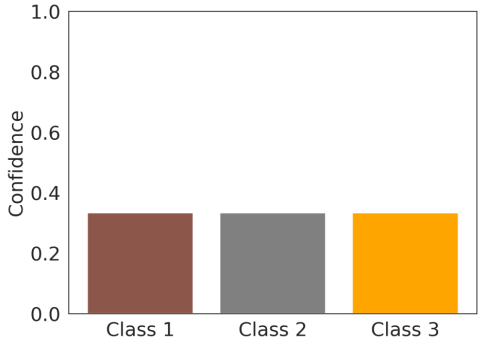
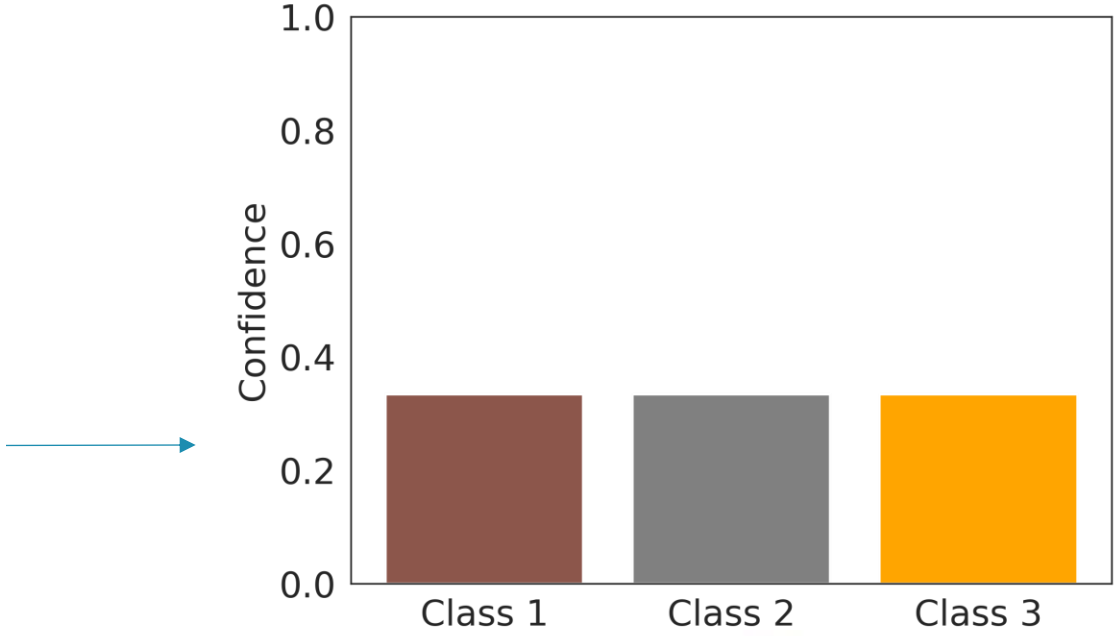
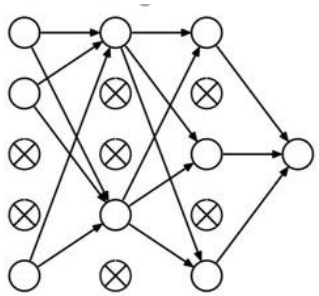


Sample T

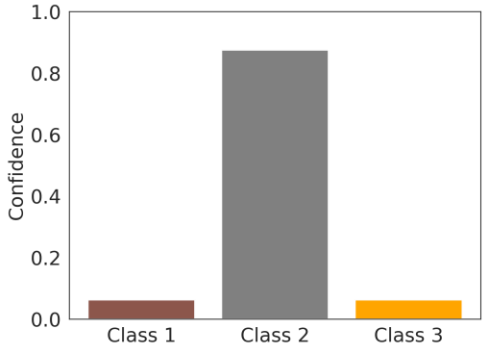


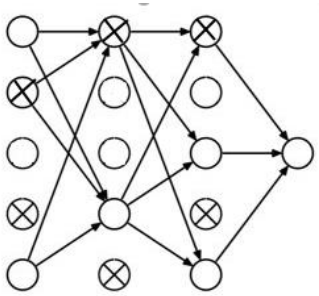


MC dropout: max *model* uncertainty

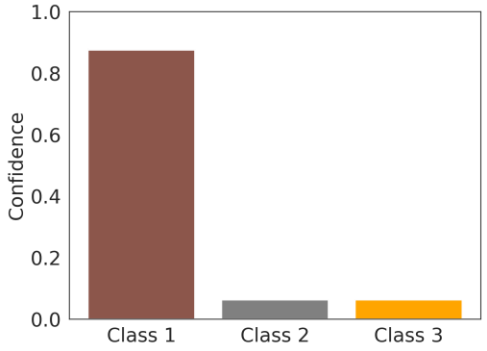


Sample 1





Sample 2



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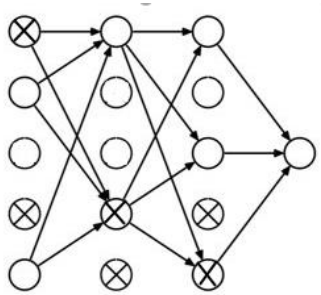
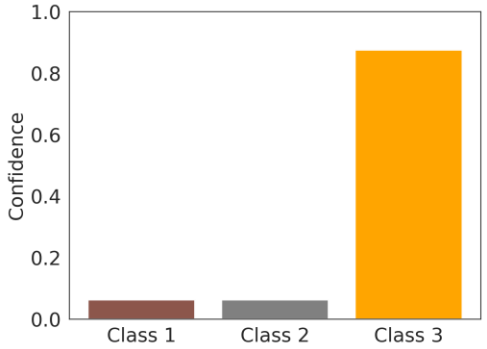


Sample T



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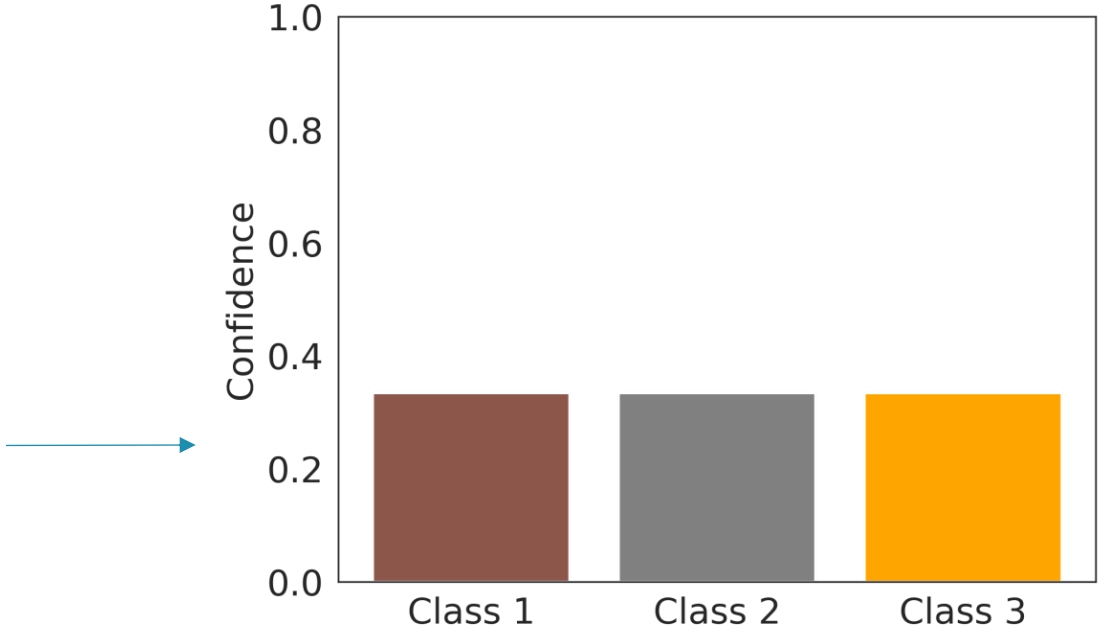
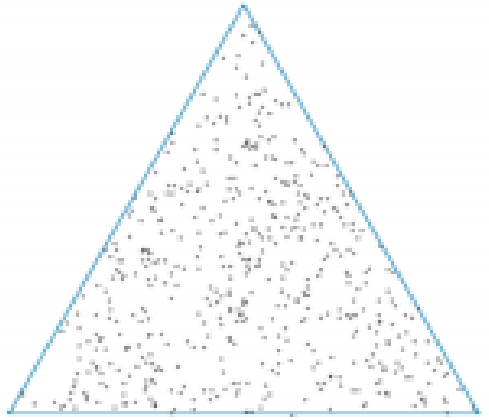
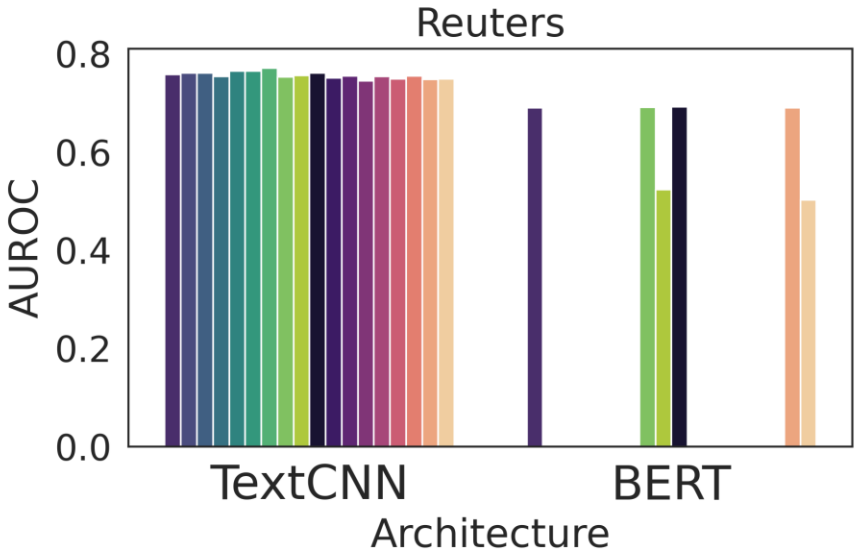
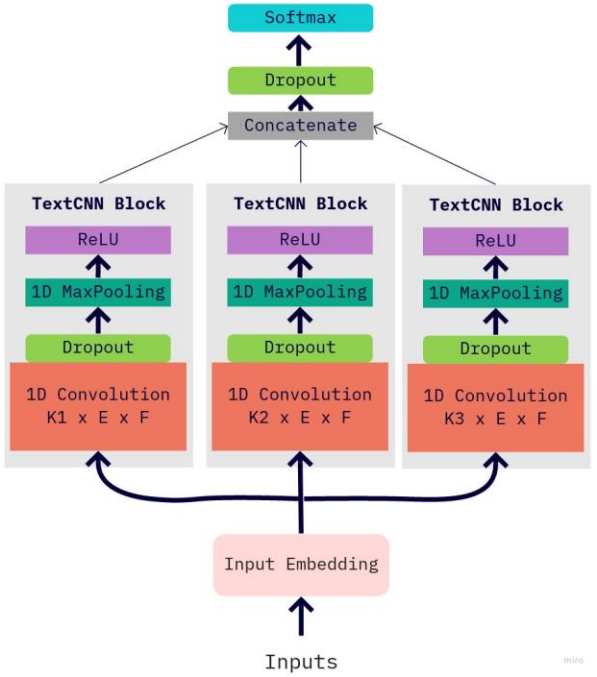


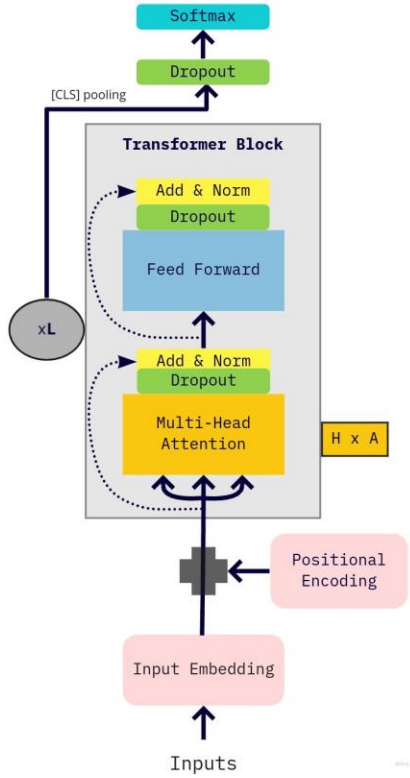


Finding 2: BERT underperforms in novel class detection





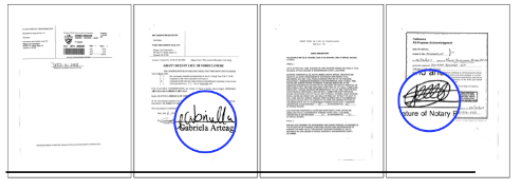
TextCNN (6M params)



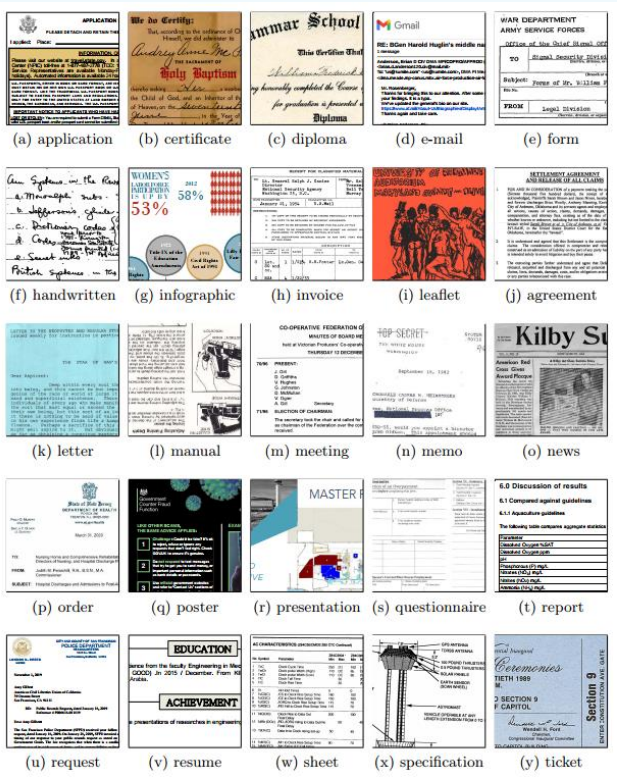
$BERT_{base}$ (110M params)

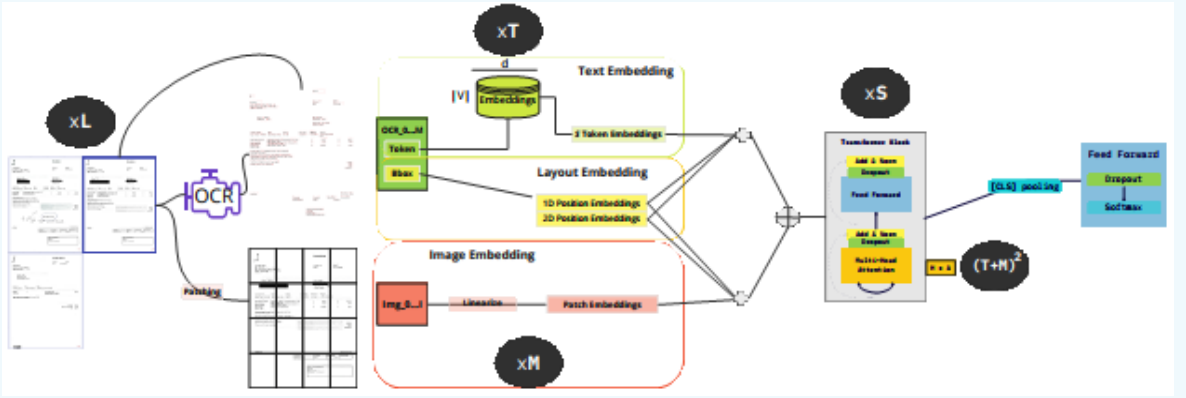
II. Realistic and **Efficient** Document Understanding

Requires counting. *How many pages have a signature?*
The question requires visual comprehension (recognition of signature), knowledge about layout, and counting.



Source	Answer	ANLS	Conf.
Ground truth	*2*		
Human	*2*	1.0	—
T5	*1*	0.0	0.01
ChatGPT	*4*	0.0	—
GPT3	*[Not-answerable]*	0.0	—
T5-2D	*4*	0.0	0.69
HiVT5	*4*	0.0	0.41





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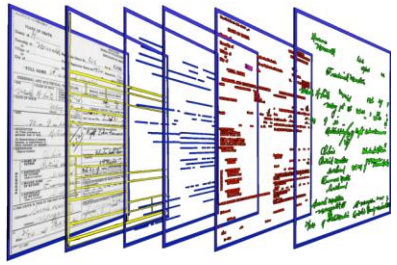
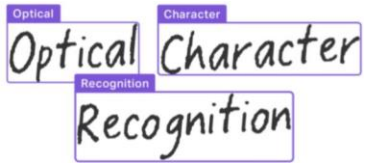
Shifting the focus to Document Understanding

Focus of the field





Document Understanding

Document data unavailability

- Datasets lacking variety, scale and multipage documents
- Current benchmarks evaluation does not transfer downstream

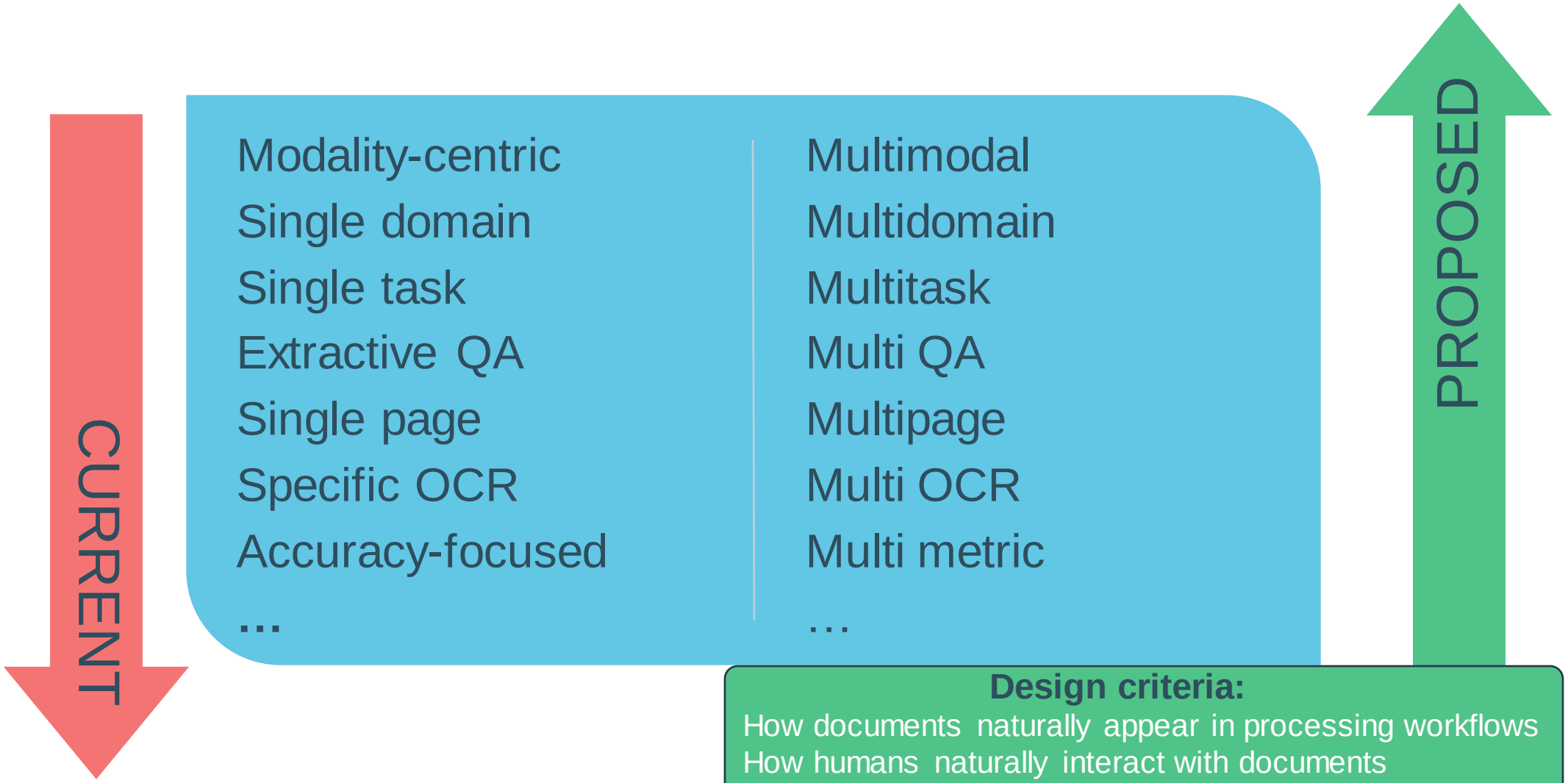
Pretrain-finetune | Foundation models

- Text-only LLMs for any document task?
- Foundation models more powerful, yet also more cumbersome

Objectives

- More generally applicable, embrace real-world complexity
- More efficient at modeling the multimodality of documents
- Evaluation more in sync with downstream requirements

What are DU benchmarks missing?



Design criteria:

How documents naturally appear in processing workflows

How humans naturally interact with documents

Contributions: Realistic

Beyond Document Page Classification: Design, Datasets, and Challenges
WACV 2024 *oral

- Formalization of multi-page DC
- Construction of two novel datasets
- Survey and recommendations:
  - Complete DC methodology
  - Dataset construction efforts

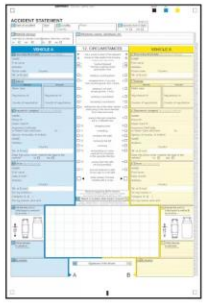
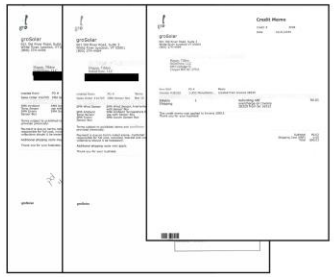
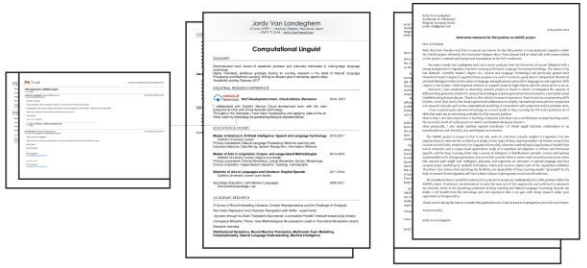
Document Understanding Dataset and Evaluation
ICCV 2023

Competition on Document UnderstanDing of Everything (DUDE)
ICDAR 2023 *oral

- Design of multi-faceted dataset
- Comprehensive evaluation of SOTA
- Baseline and competition results
- Calibrated, selective generation

Document classification is more complex than reported

Covered in public research benchmarks

	Page f_p	Document f_d	Document bundle f_b	Page stream f_s	Page splits f_m
INPUT TASK					
LABELS	collision form	purchase invoice	email; resume; application letter	wage slip, wage_slip; bank statement; id_back, id_front; wage_slip	ticket_1, ticket_2, ..., ticket_9
USE-CASE	*Insurance claims*	*Robotic accounting*	*HR job screening*	*Loan application*	*Expenditure*

A multi-faceted benchmark for generic DU challenges the state-of-the-art

Document UnderstanDing of Everything

#non-answerable

Q: In which year does the Net Requirement exceed 25,000?

A: *None*

#abstractive #counting

Q: How many attorneys are listed for the plaintiffs?

A: Two

#layout-navigating #graphic-intensive

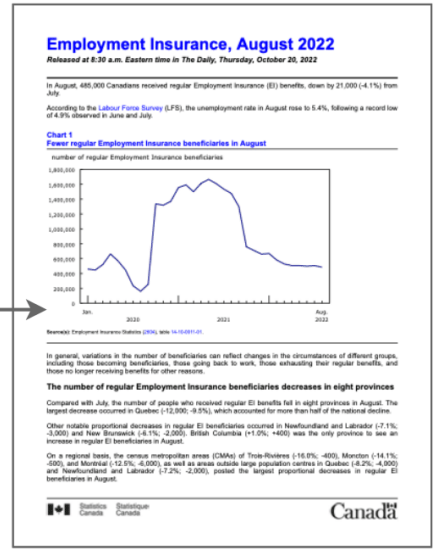
Q: Are the margins of the page uniform on all pages?

A: Yes

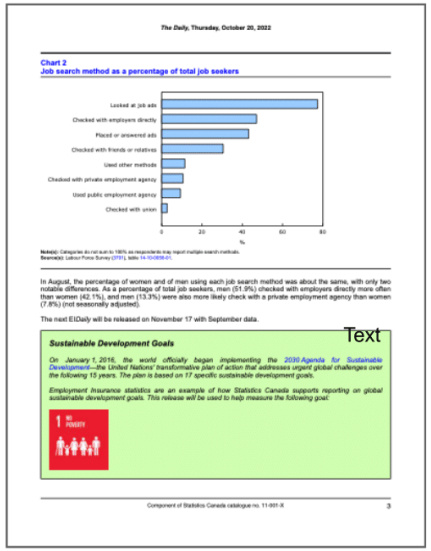
#extractive #list

Q: What are the Years mentioned in Chart 1?

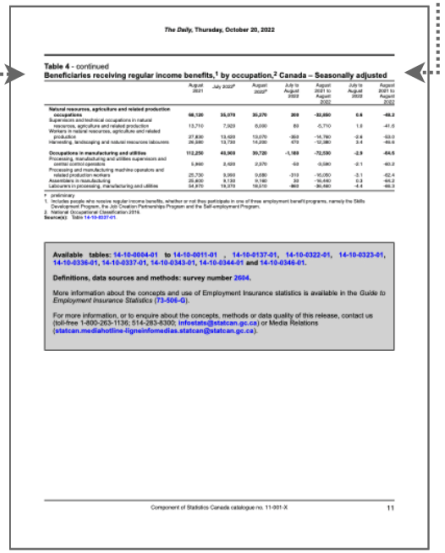
A: [2020, 2021, 2022]



Page 1



Page 2



Page *N*

#multi-hop #layout-navigating

Q: From the list of Top 10 Key Recovery Components, which is the last component listed on the second page?

A: Hope

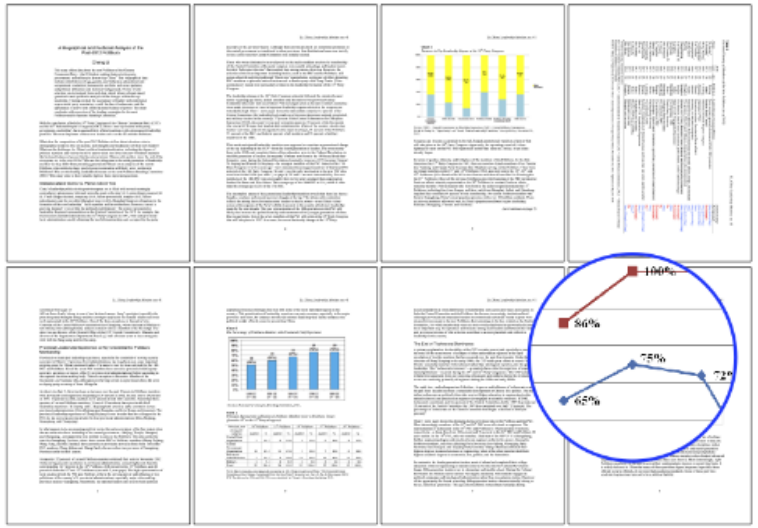
#abstractive #graphic-intensive

Q: Does this document contain any checkboxes?

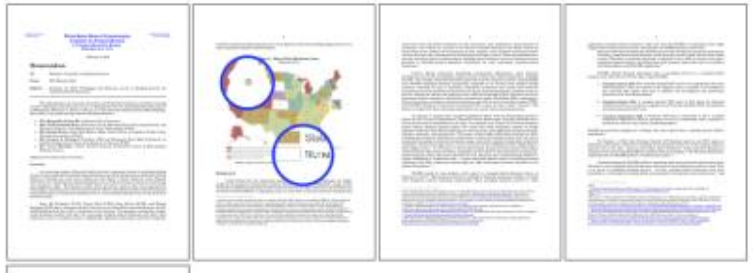
A: No

-Everything-, you mean?

Visual evidence (chart). *What is the maximum percentage of the blue graph line on page 8?* A highly demanding question that requires simultaneous competency of visual comprehension (locating chart and line color), navigating through layout (determining adequate page), and numerical comparison (deciding on the highest value).

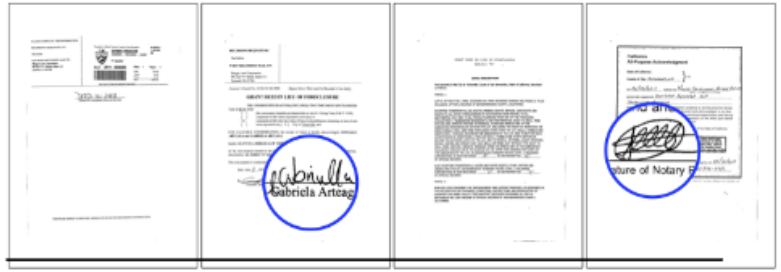


Visual evidence (map), multi-hop. *Which states don't have any marijuana laws?* The multi-hop question requires visually comprehending the map and linking knowledge from its legend with depicted regions.



Requires arithmetic. *What is the difference between how much Operator II and Operator III makes per hour?* The question requires table comprehension, determining relevant values, dividing extracted integers, and correcting the subject-verb agreement.

Requires counting. *How many pages have a signature?* The question requires visual comprehension (recognition of signature), knowledge about layout, and counting.



Source	Answer	ANLS	Conf.
Ground truth	*2*		
Human	*2*	1.0	—
T5	*1*	0.0	0.01
ChatGPT	*4*	0.0	—
GPT3	*[Not-answerable]*	0.0	—
T5-2D	*4*	0.0	0.69
HiVT5	*4*	0.0	0.41

Meet the DUDEs







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INSTABASE

Our Baselines vs. Competition

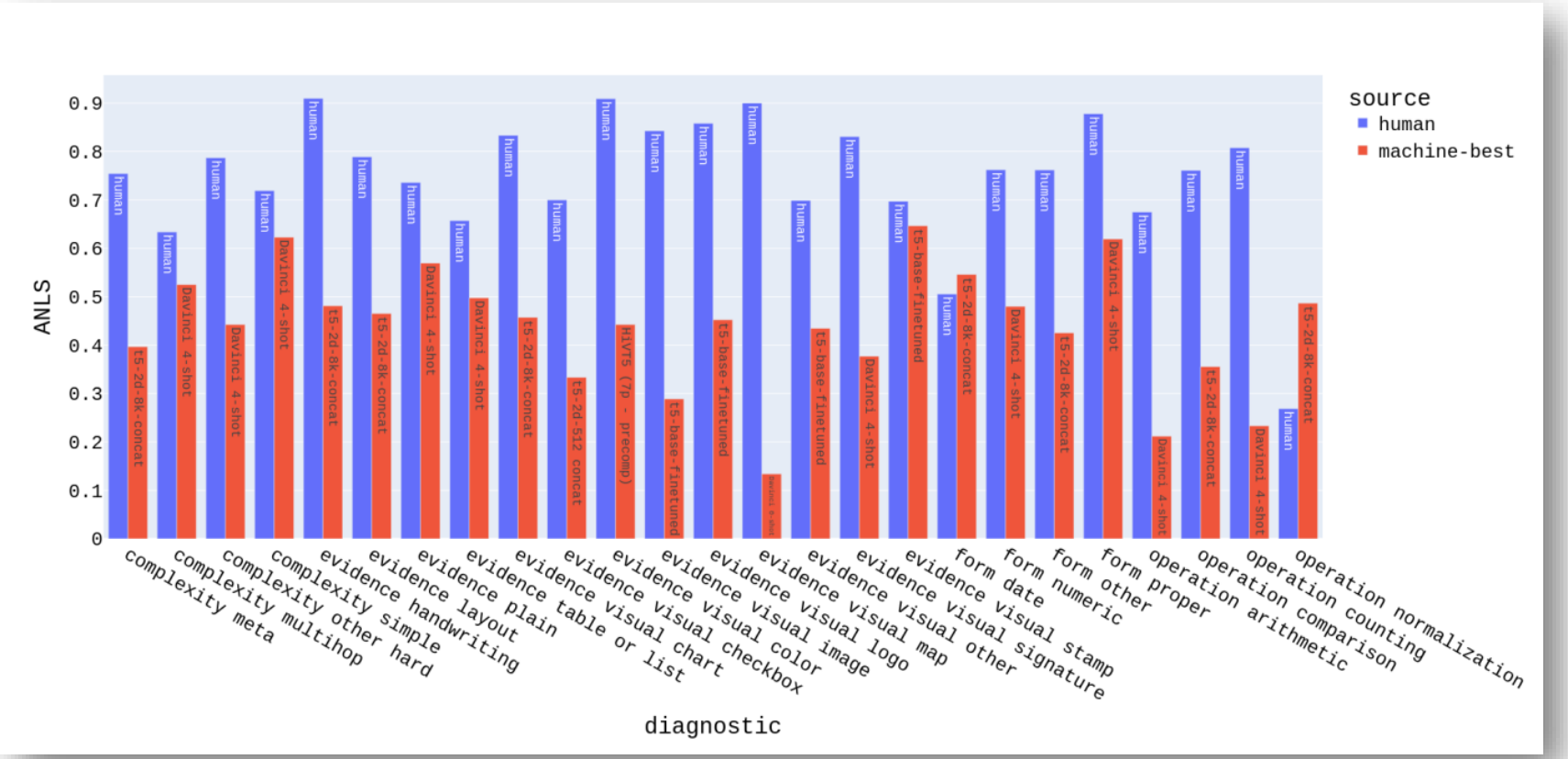
Model	Init.	Params	Max Seq. Length	Test Setup	$ANLS_{all}$ ↑	ECE_{all} ↓	$AURC_{all}$ ↓	$ANLS_{do}$	$ANLS_{do}$ Abs	$ANLS_{do}$ Ex	$ANLS_{do}$ NA	$ANLS_{do}$ Li
text-only Encoder-based models												
Big Bird	MPDocVQA	131M	4096	Concat*	26.27	30.14	44.22	30.67	7.11	40.26	12.75	8.46
BERT-Large	MPDocVQA	334M	512	Max Conf.*	25.48	34.06	48.60	32.18	7.28	42.23	5.88	11.13
Longformer	MPDocVQA	148M	4096	Concat*	27.14	27.59	44.59	33.45	8.55	43.58	10.78	10.62
text-only Encoder-Decoder based models												
T5	base	223M	512	Concat-0*	19.65	19.14	48.83	25.62	5.24	33.91	0	7.31
T5	MPDocVQA	223M	512	Max Conf.*	29.48	27.18	43.06	37.56	21.19	44.22	0	10.56
T5	base	223M	512	Concat+FT	37.41	**10.82**	41.09	40.61	42.61	48.20	53.92	16.87
T5	base	223M	8192	Concat+FT	41.80	17.33	49.53	44.95	47.62	50.49	63.72	7.56
text-only Large Language models (LLM)												
ChatGPT	gpt-3.5-turbo	20B	4096	Concat-0	-	-	-	35.07	16.73	42.52	70.59	15.97
				Concat-4	-	-	-	41.89	22.19	49.90	**77.45**	17.74
GPT3	davinci3	175B	4000	Concat-0	-	-	-	43.95	18.16	54.44	73.53	36.32
				Concat-4	-	-	-	47.04	22.37	**57.09**	63.73	**40.01**
text+layout Encoder-Decoder based models												
T5-2D	base	223M	512	Concat+FT	37.10	10.85	41.46	40.50	42.48	48.62	52.94	3.49
T5-2D	base	223M	8192	Concat+FT	42.10	17.00	48.83	45.73	48.37	52.29	63.72	8.02
T5-2D	large	770M	8192	Concat+FT	**46.06**	14.40	**35.70**	**48.14**	**50.81**	55.65	68.62	5.43
text+layout+vision models												
HiVT5		316M	20480	Hierarchical+FT	23.06	11.91	54.35	22.33	33.94	17.60	61.76	6.83
LayoutLMv3	MPDocVQA	125M	512	Max Conf.*	20.31	34.97	47.51	25.27	8.10	32.60	8.82	7.82
Human baseline								74.76	81.95	67.58	83.33	67.74

	Answer	Calibration		OOD Detection	ANLS / answer type			
Method	ANLS ↑	ECE ↓	AURC ↓	AUROC ↑	*Ex*	*Abs*	*Li*	*NA*
UDOP+BLIP+GPT	**50.02**	**22.40**	**42.10**	**87.44**	**51.86**	**48.32**	**28.22**	**62.04**
MMT5	37.90	59.31	59.31	50.00	41.55	40.24	20.21	34.67
HiVT5+modules	35.59	28.03	46.03	51.24	30.95	35.15	11.76	52.50

i. Generative = must
ii. LLMs are performant
iii. Outperformed by models
+layout understanding
++longer sequence length

SOTA ANLS <= 50%!

Diagnostic categories shed more light on what models have most difficulty with



Diagnostic categories with

- visual evidence
- reasoning operations

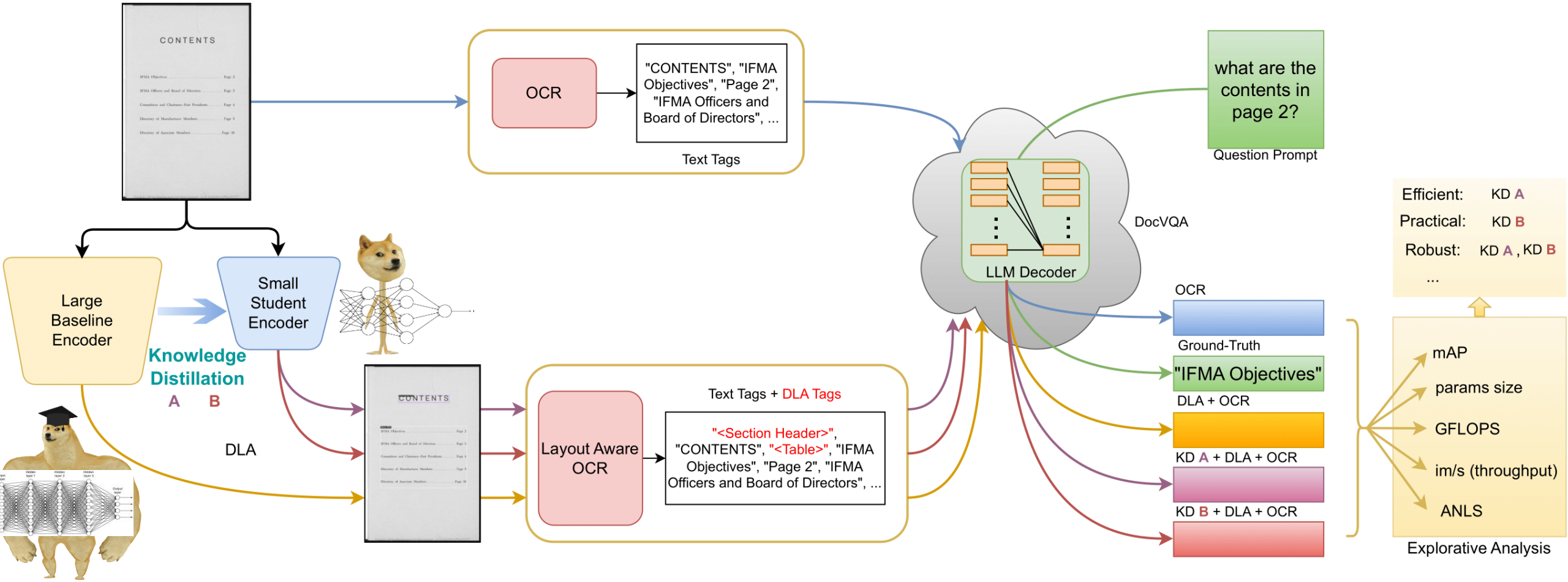
Baselines lagging far behind **human baseline**

Contributions: **Efficient** 

DistilDoc: Knowledge Distillation for Visually-Rich Document Applications
ICDAR 2024

- KD benchmark on VDU tasks
- Novel downstream evaluation
- Enrich LLMs with semantic layout

Knowledge distillation facilitates small, specialized task modules that enrich downstream representations



DistilDoc streamlines research on compression tailored to VDU tasks

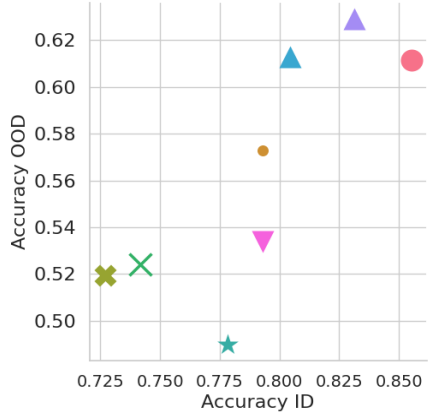
1. *Best KD method*
   - SimKD > vanilla KD, on par with teacher, **+** under covariate shift

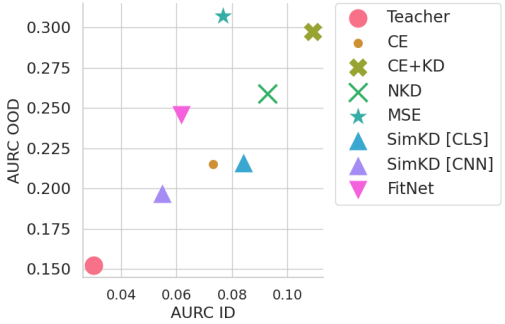
2. *Teacher-Student capacity gap*
   - ViT-Tiny SimKD →16x smaller model retains 90% rel. accuracy

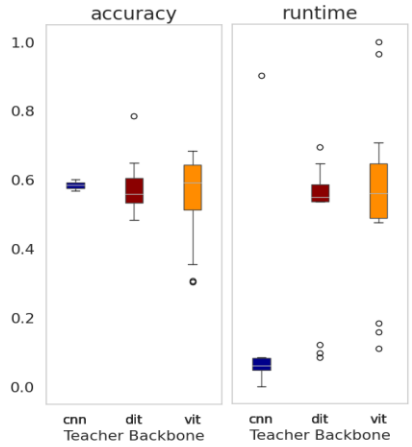
3. *Impact of Pretraining on KD*
   - ViT2ViT > DiT2ViT, **-** under covariate shift

4. *Architecture influence*
   - Random initialization & DLA-KD: CNN > ViT

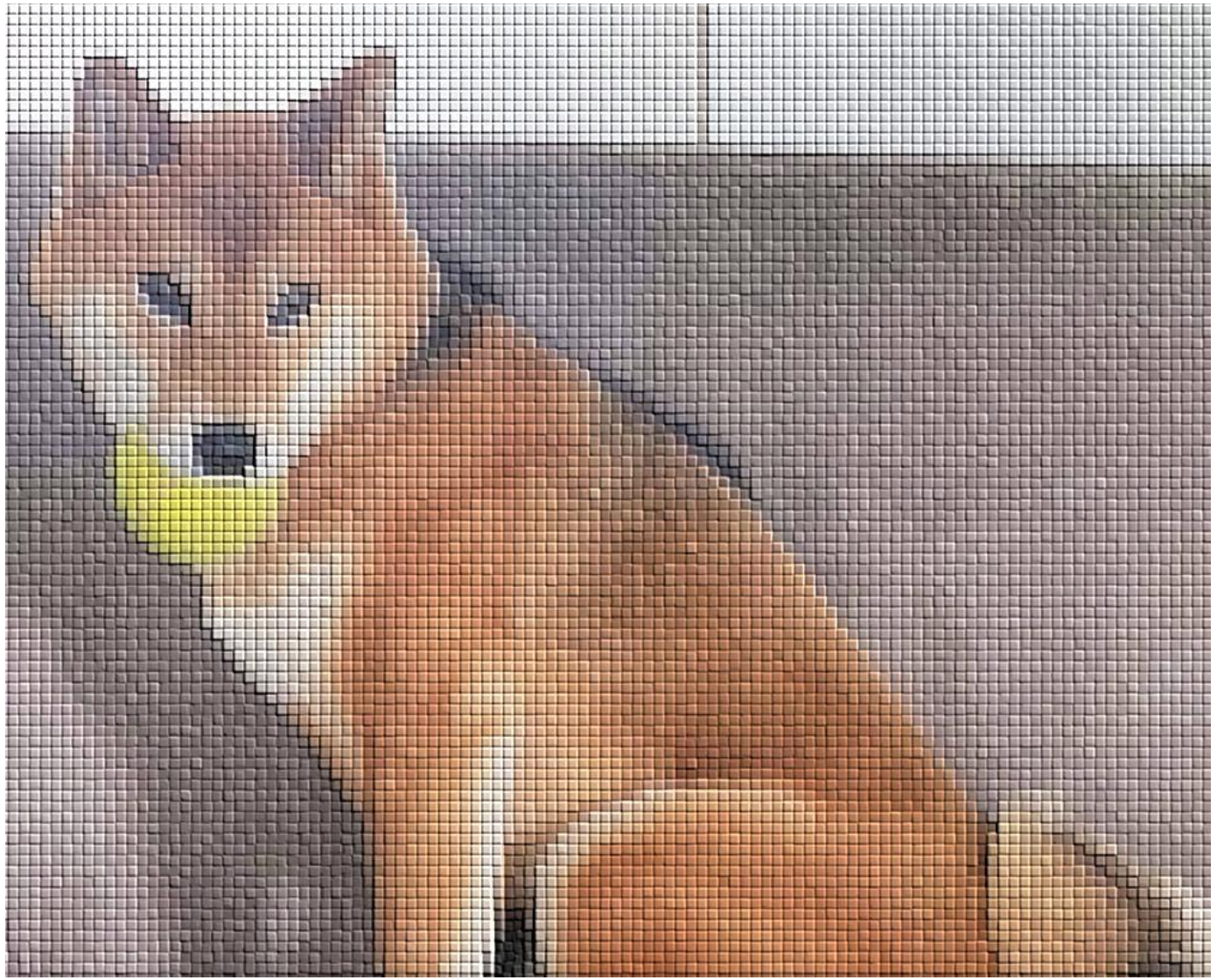
5. *Applicability for downstream tasks*
   - DLA-enriched ~~spacing~~ prompting contributes positively to DocVQA







Conclusions



Conclusions

My dissertation addresses gaps, proposes methodologies opening new opportunities:

1. Limited research on scalable uncertainty quantification in NLP
   -  Comprehensive survey and benchmark
   -  Design of hybrid PUQ methods, offering better robustness and scalability

2. Disconnect DU research and applications
   -  Complete redefinition of document classification and methodology

3. Unpredictable performance of SOTA for generic DU
   -  Multi-faceted benchmark and competition incorporating all document modalities
   -  Promote the layout modality and how to obtain it efficiently

Takeaway messages

1. Evaluate AI capability, without forgetting about reliability and robustness
2. Need increasingly complex real-world benchmarks to track DU progress
3. Moving the goalpost to complete documents will drive efficiency research
4. A long way to understanding: *multimodality, compositionality and memory*

A striking, ultra-realistic poster featuring a heartfelt "Thank You" message spelled out in a modern, bold font. The background is a visual representation of a million business documents, with different colors, patterns, and textures, creating a dynamic and visually rich atmosphere., poster @ Ideogram

DEMO: ask my thesis

Q&A