Interpretability in NLP: Moving Beyond Vision

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Work done in collaboration with
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JOHNS HOPKINS
UNIVERSITY

Outline

- A Quick Tour of Interpretability
  - Model Transparency
  - Post-hoc Interpretations
- Moving Visual Interpretability to Language:
  - Word Alignment for NMT Via Model Interpretation
  - Benchmarking Interpretations Via Lexical Agreement
- Future Work

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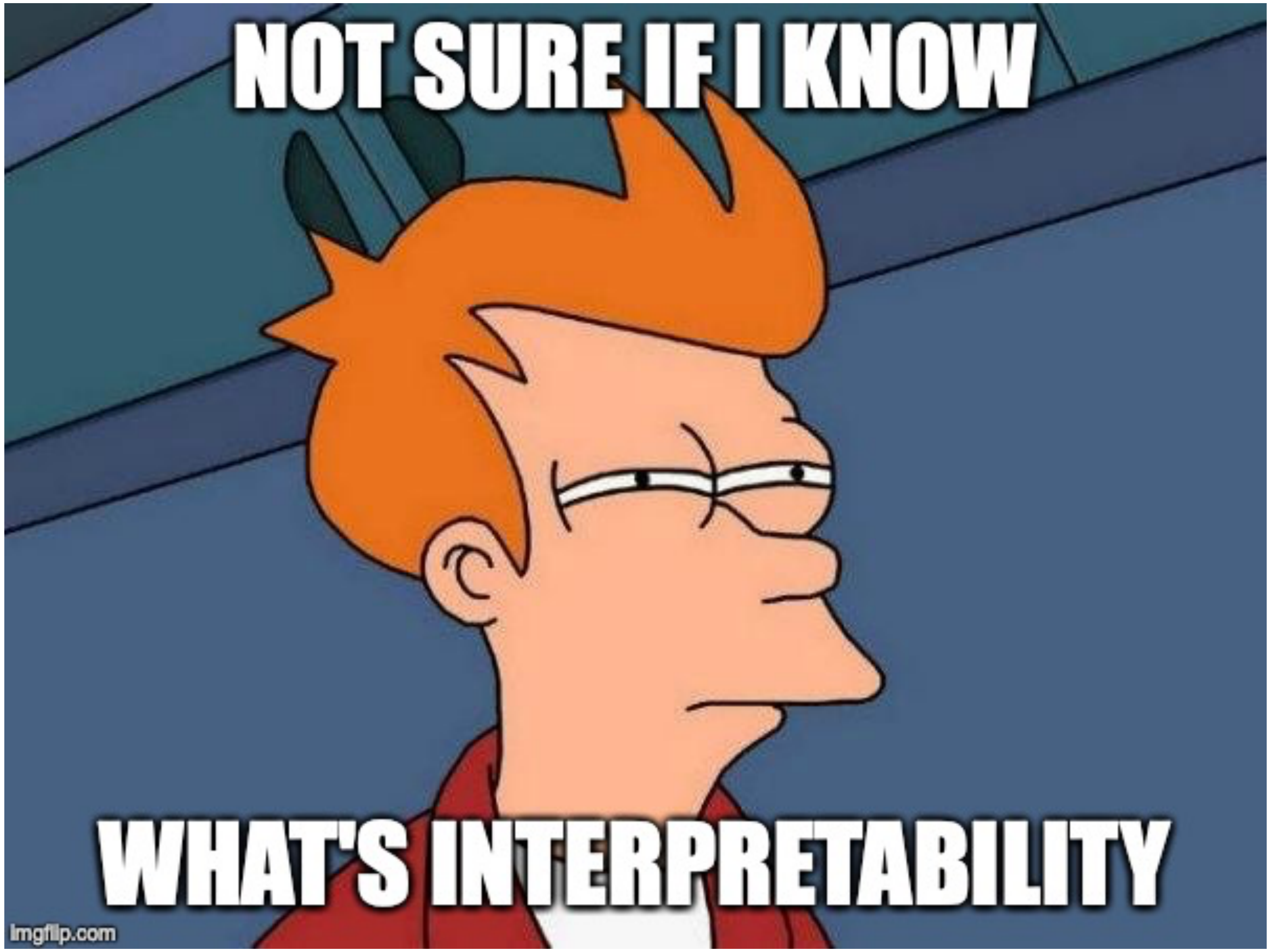
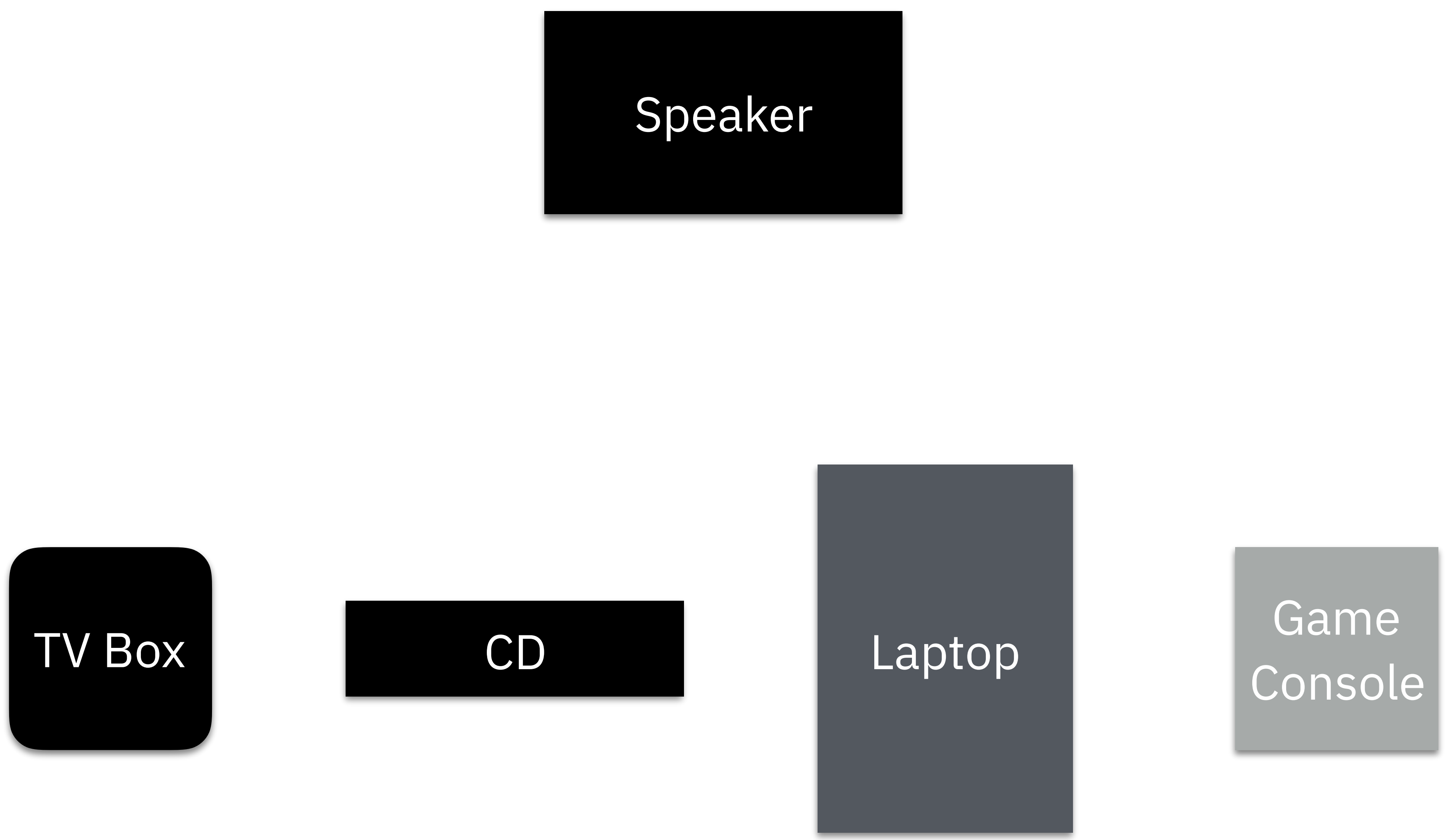

NOT SURE IF I KNOW
WHAT'S INTERPRETABILITY
imgflip.com

What is Interpretability?

- **No consensus!**
- Categorization proposed in [Lipton 2018]
  - **Model Transparency**
  - **Post-hoc Interpretation**

Toy Example



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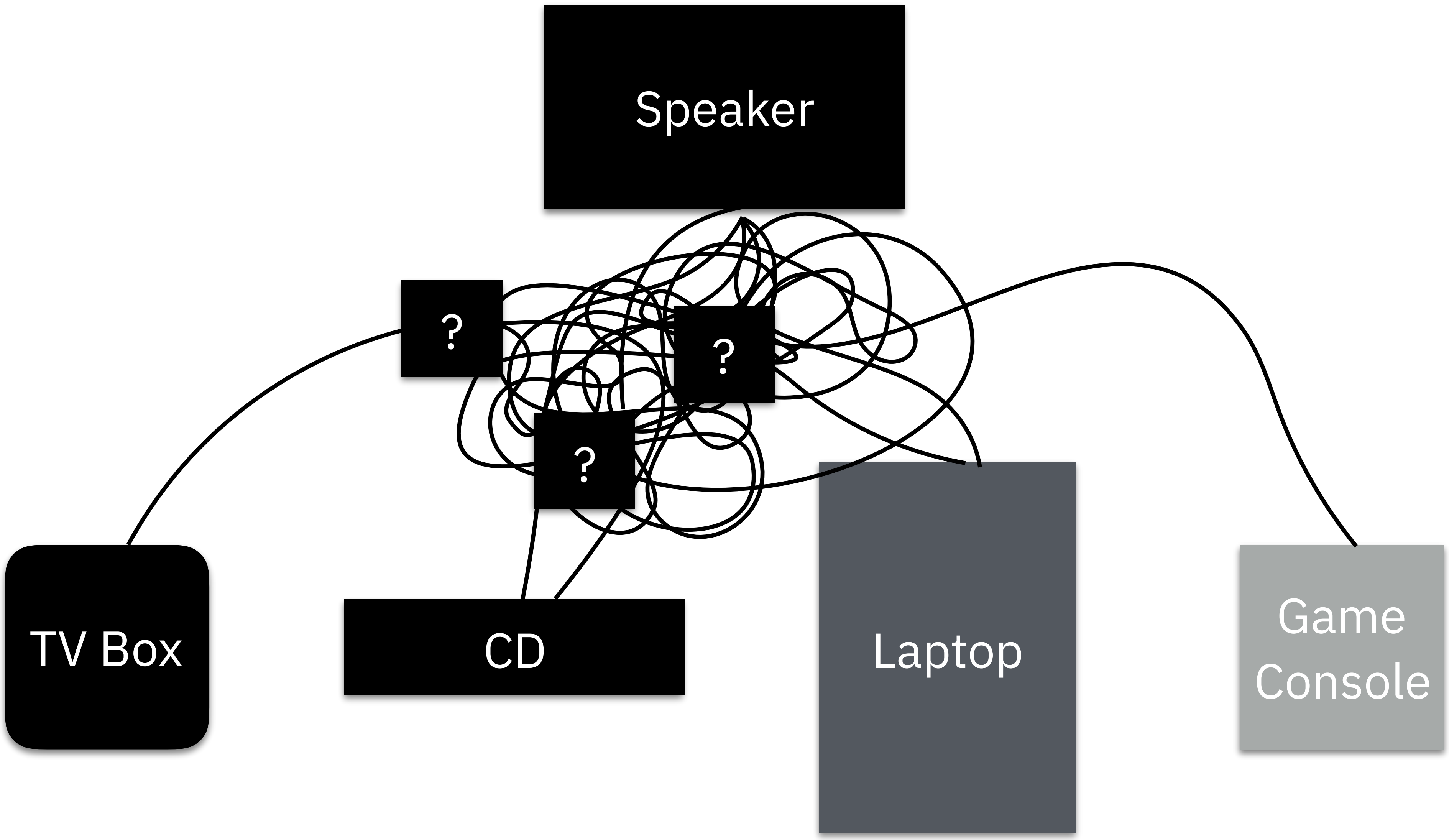
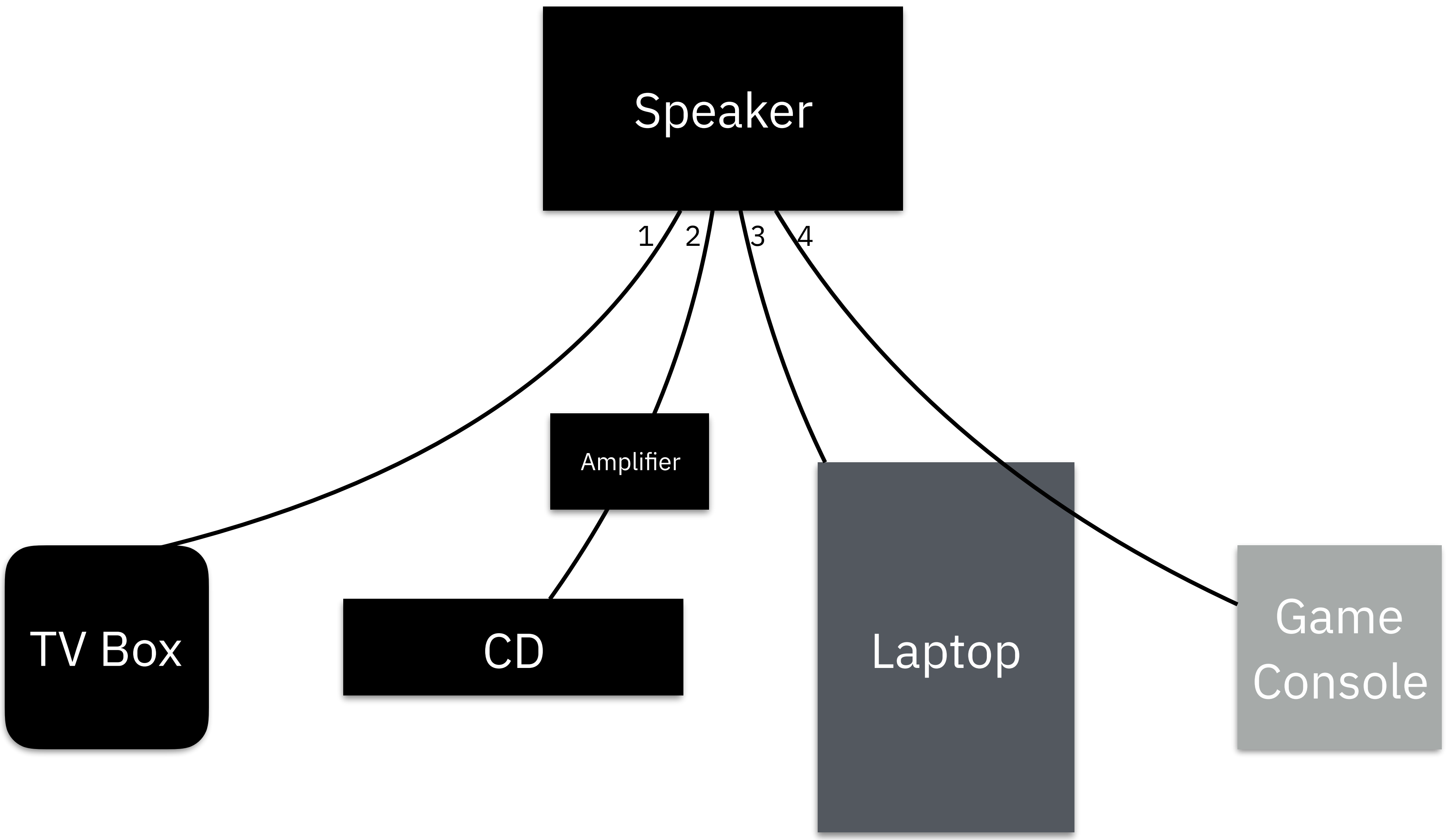


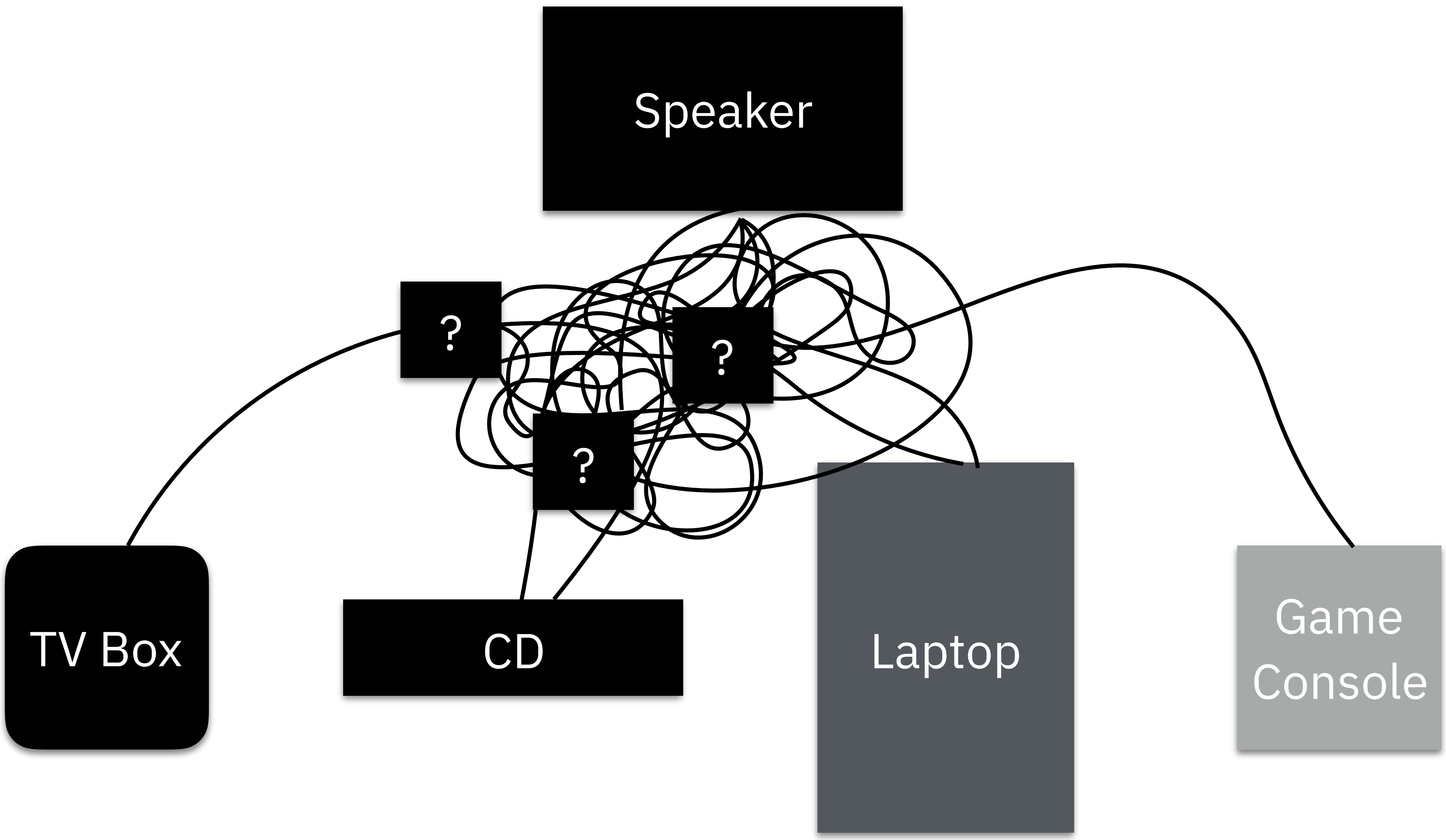
A Transparent Model



Transparent Models

- Build **another model** that accomplishes the **same task**, but with **easily explainable behaviors**
- Deep neural networks are **not** interpretable...
- So what models are? (Open question)
  - log-linear model?
  - attention model?

Meh. Too lazy for that!



Post-hoc Interpretation

- **Ask a human**
  - Interpretation with stand-alone model **(different task!)**
- **Jiggle the cable!**
  - Interpretation with sensitivity w.r.t. features

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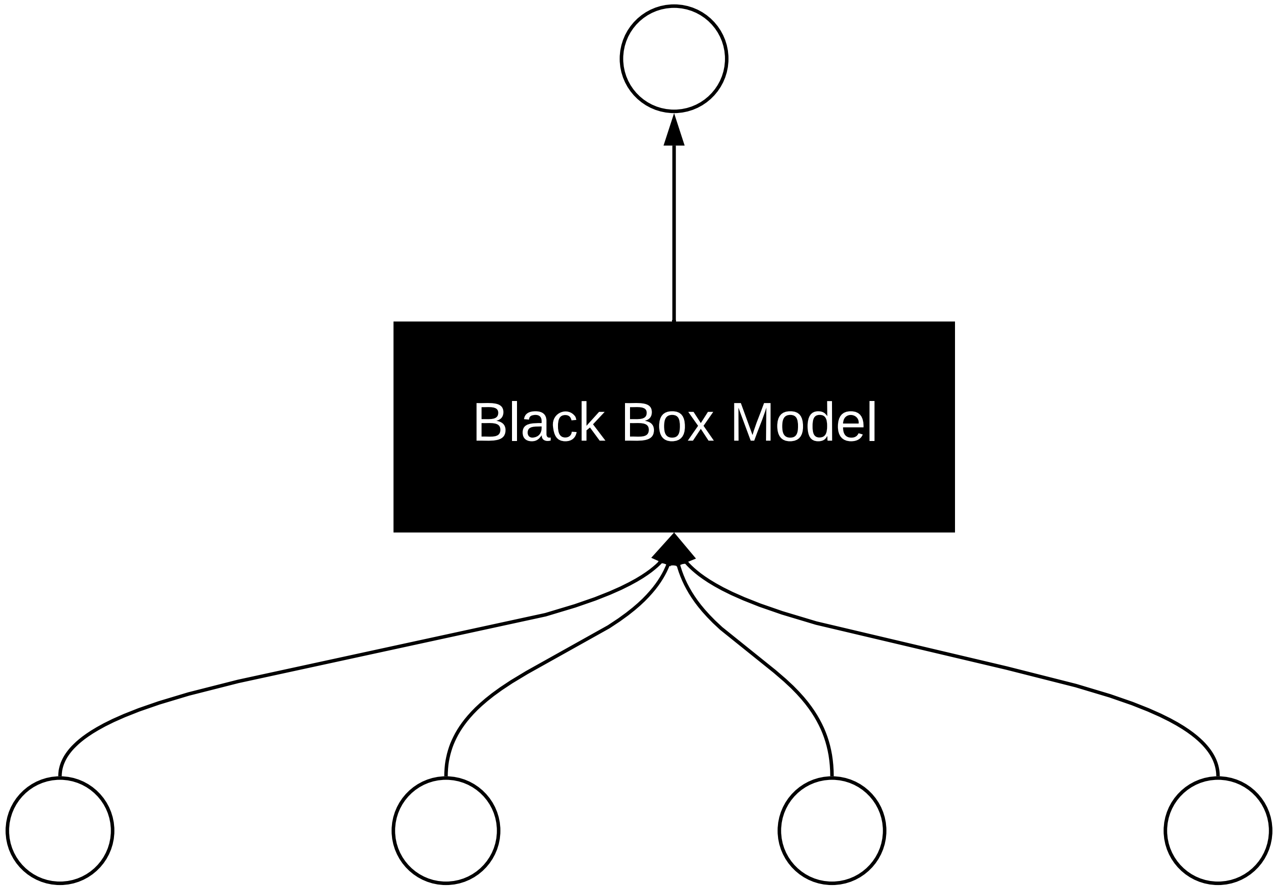
A Little Abstraction...



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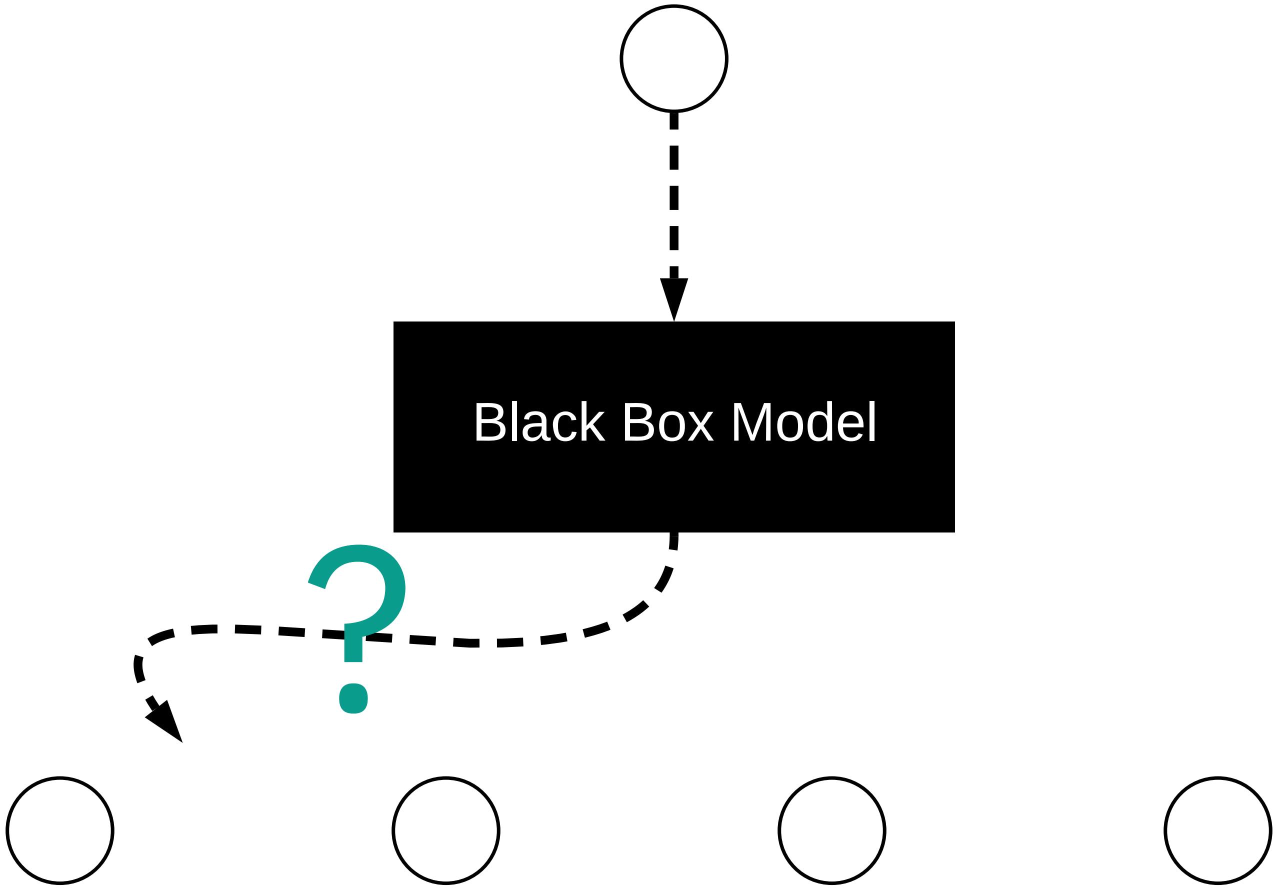

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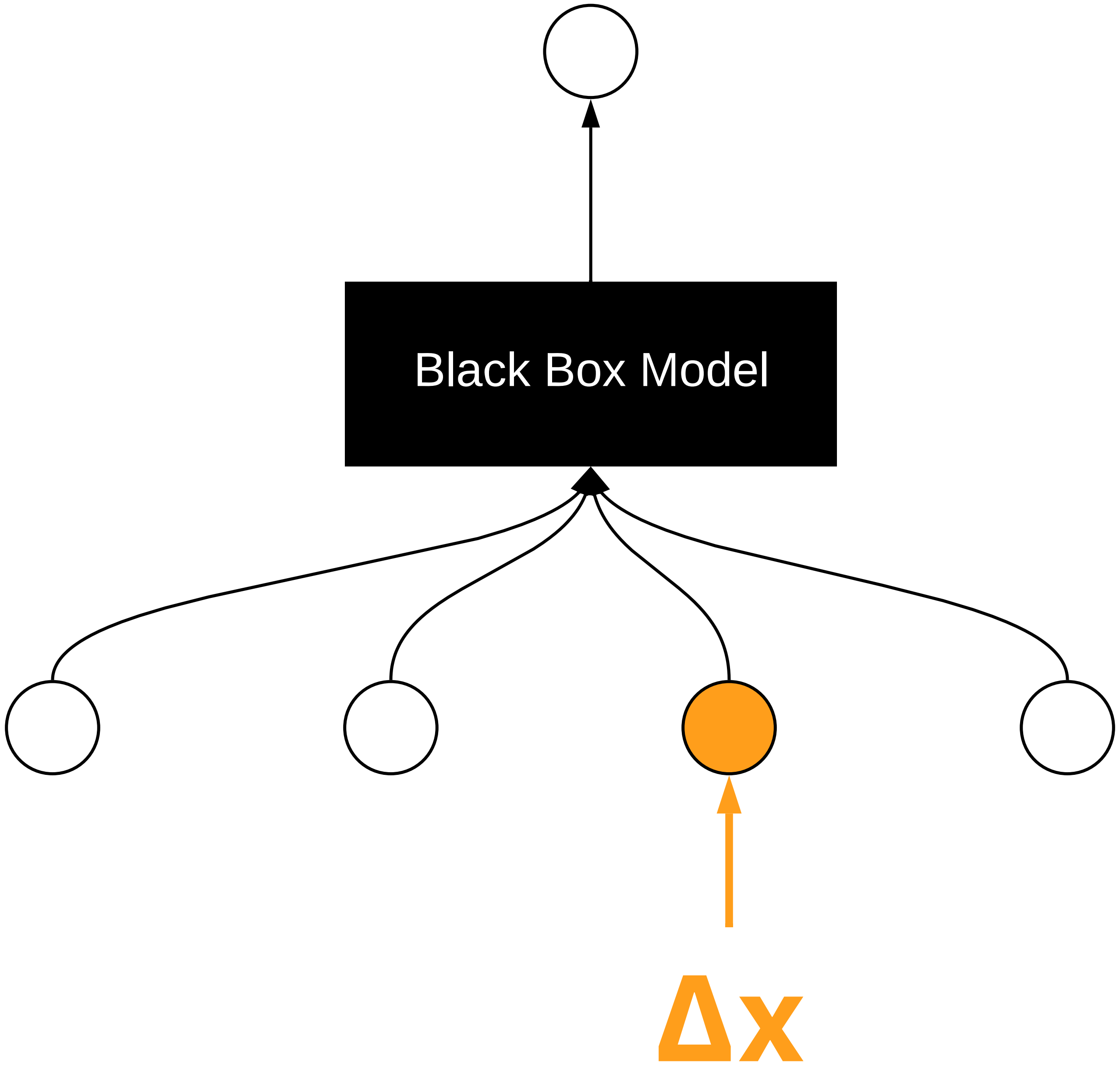

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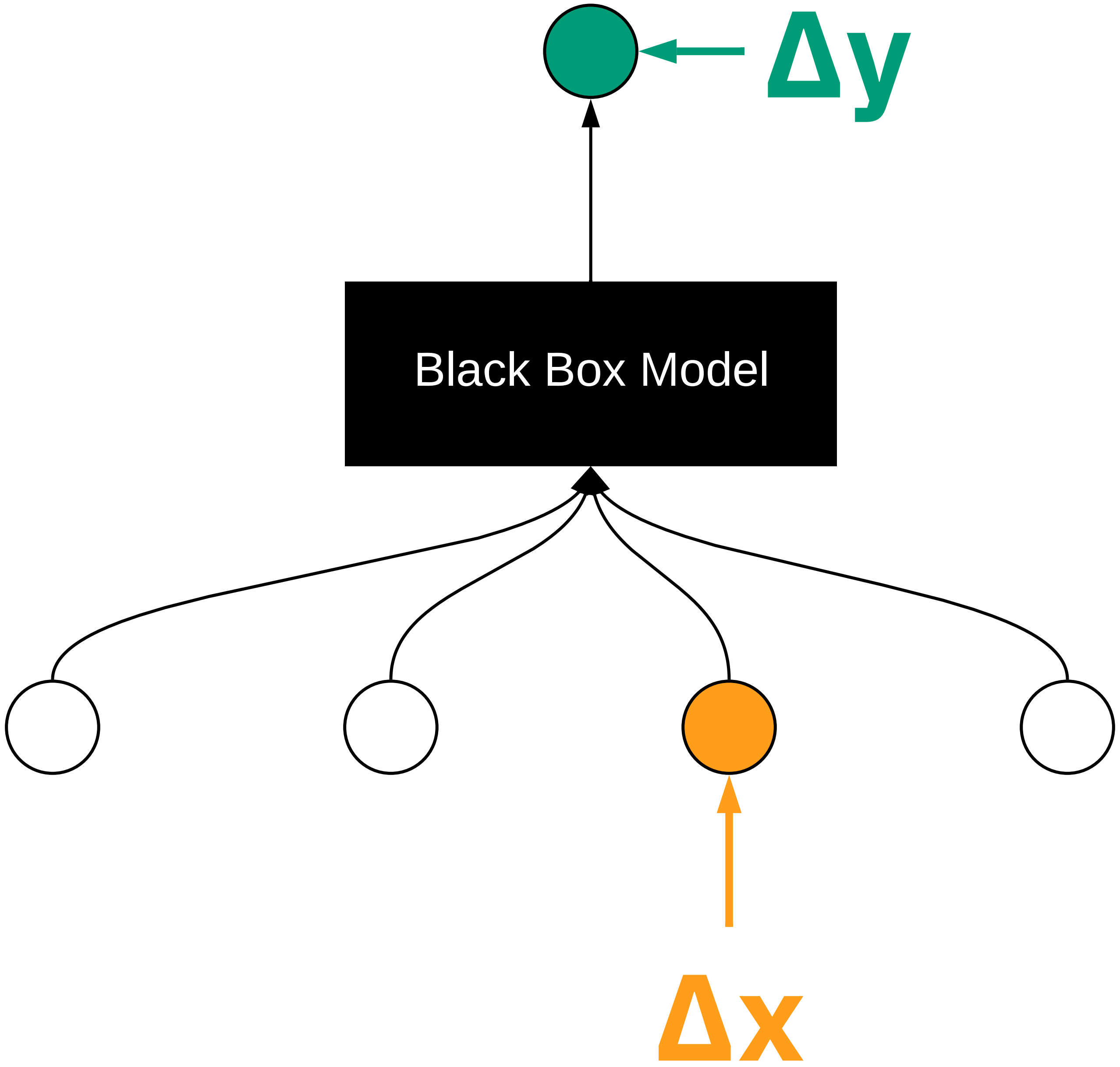


Relative Sensitivity…?

$$\frac{\Delta y}{\Delta x}$$

Relative Sensitivity...?

$$\frac{\Delta y}{\Delta x}$$

when $\Delta x \longrightarrow 0$ **:**

$$\frac{\Delta y}{\Delta x} \longrightarrow \frac{\partial y}{\partial x}$$

Saliency

$$\frac{\partial y}{\partial x}$$

What's good about this?

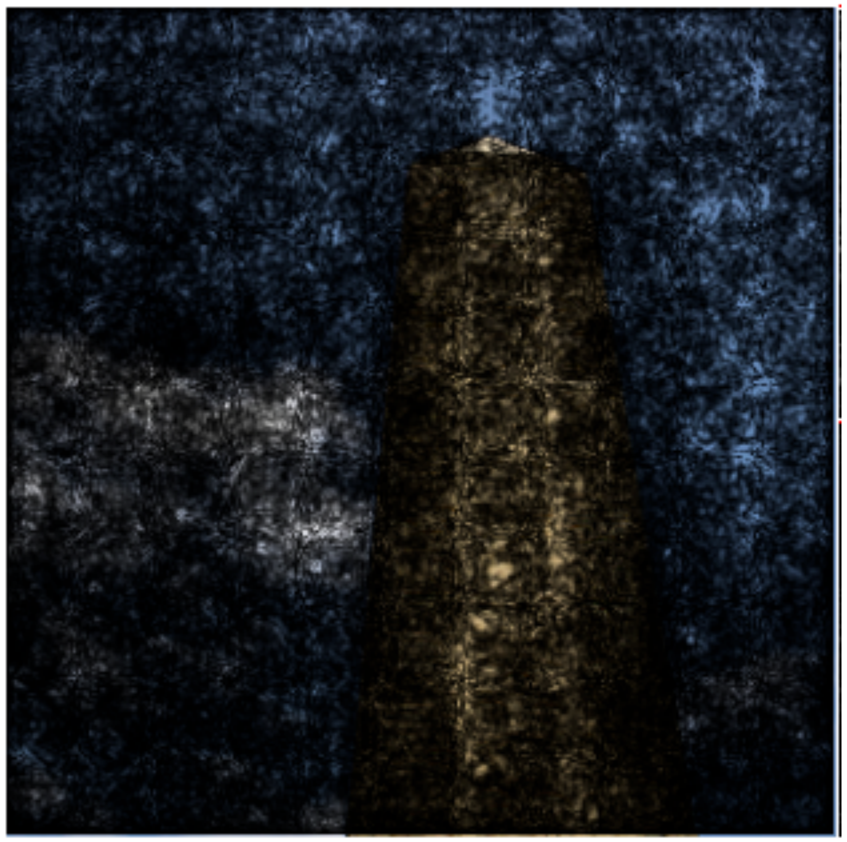
1. **Model-agnostic**, and yet with **some exposure** to the interpreted model

2. Derivatives are **easy to obtain** for any DL toolkit

Saliency in Computer Vision

Image

Saliency



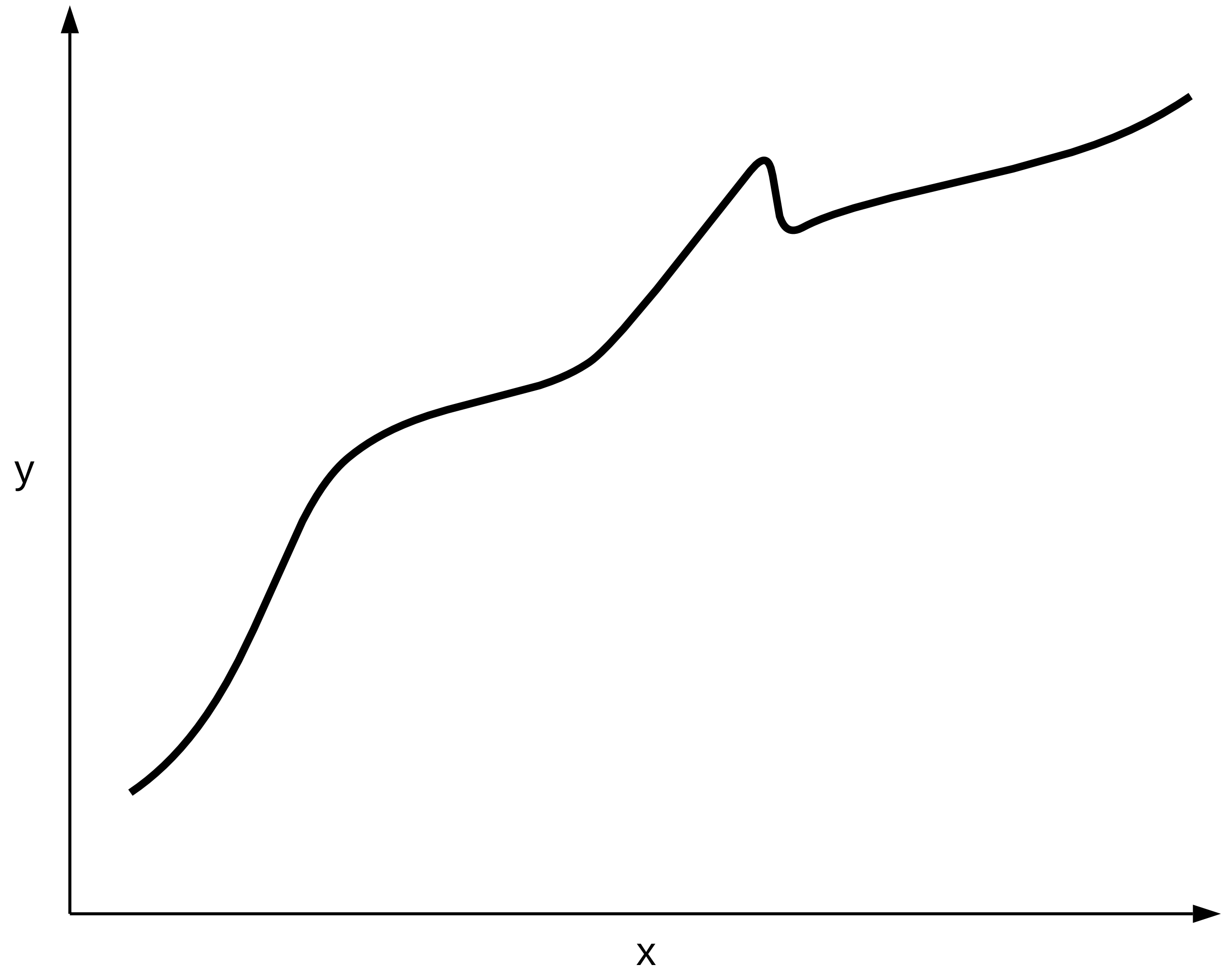
https://pair-code.github.io/saliency/

SmoothGrad

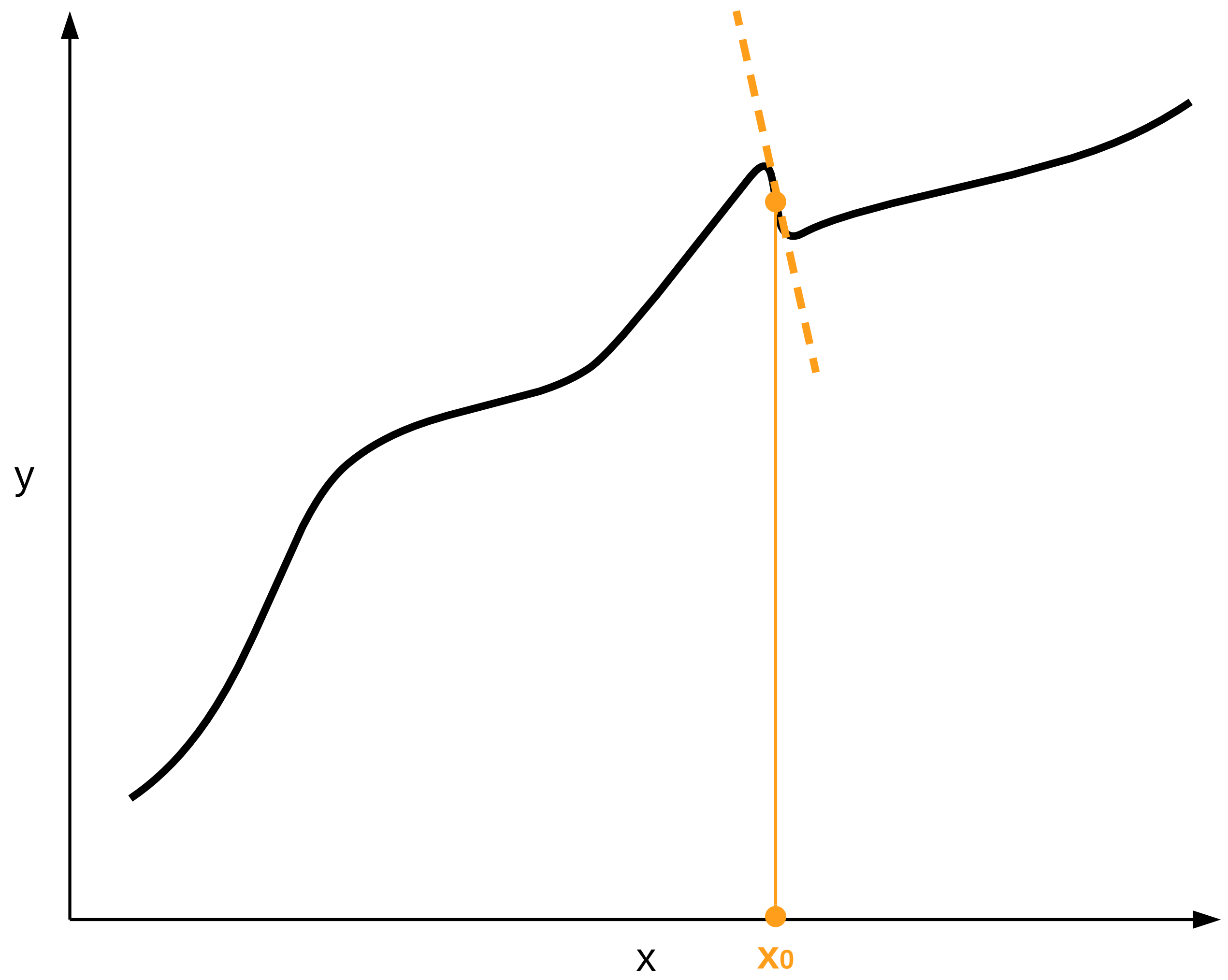
- Gradients are very **local** measure of sensitivity.
- Highly non-linear models may have pathological points where the gradients are **noisy**.

[Smilkov et al. 2017]

SmoothGrad



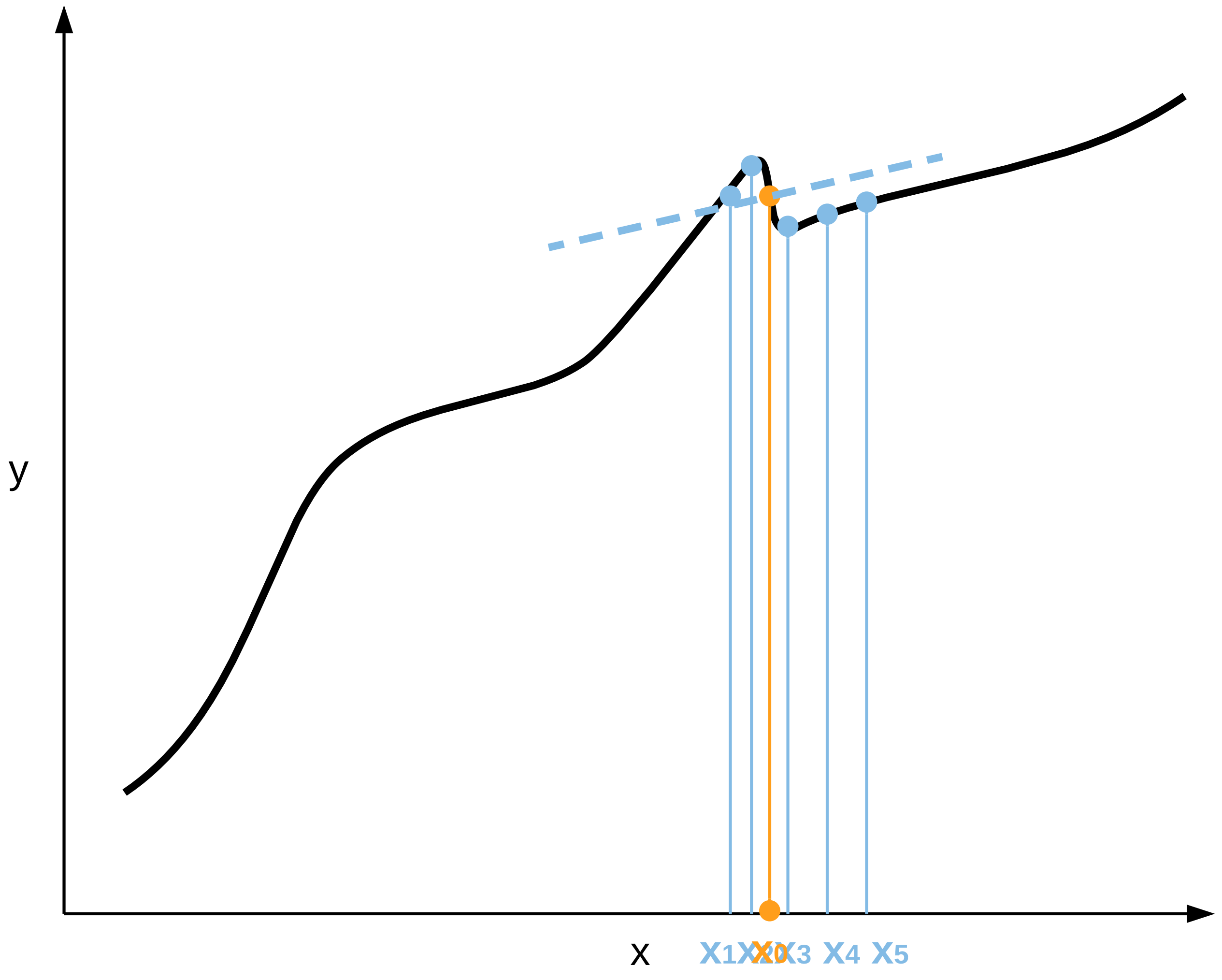
SmoothGrad



SmoothGrad

- Solution: calculate saliency for **multiple copies of the same input** corrupted with **gaussian noise**, and **average** the saliency of copies.

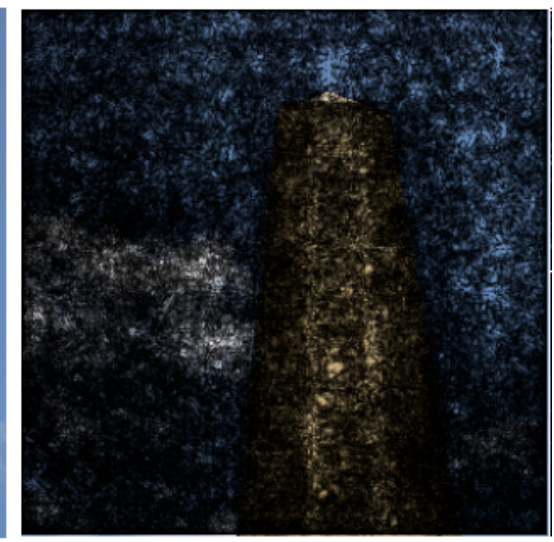
SmoothGrad



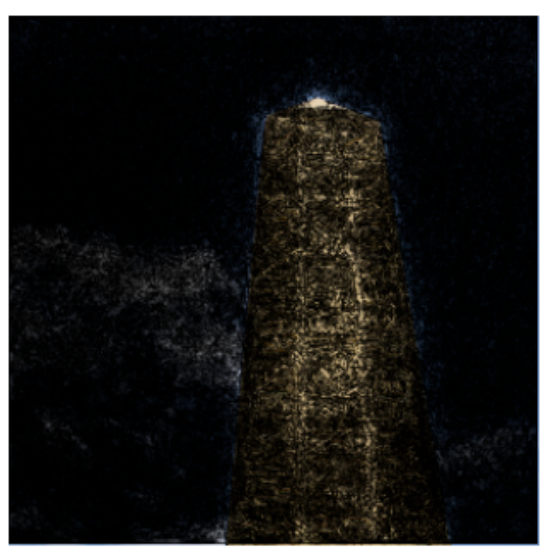
SmoothGrad in Computer Vision

Original Image

Vanilla



SmoothGrad



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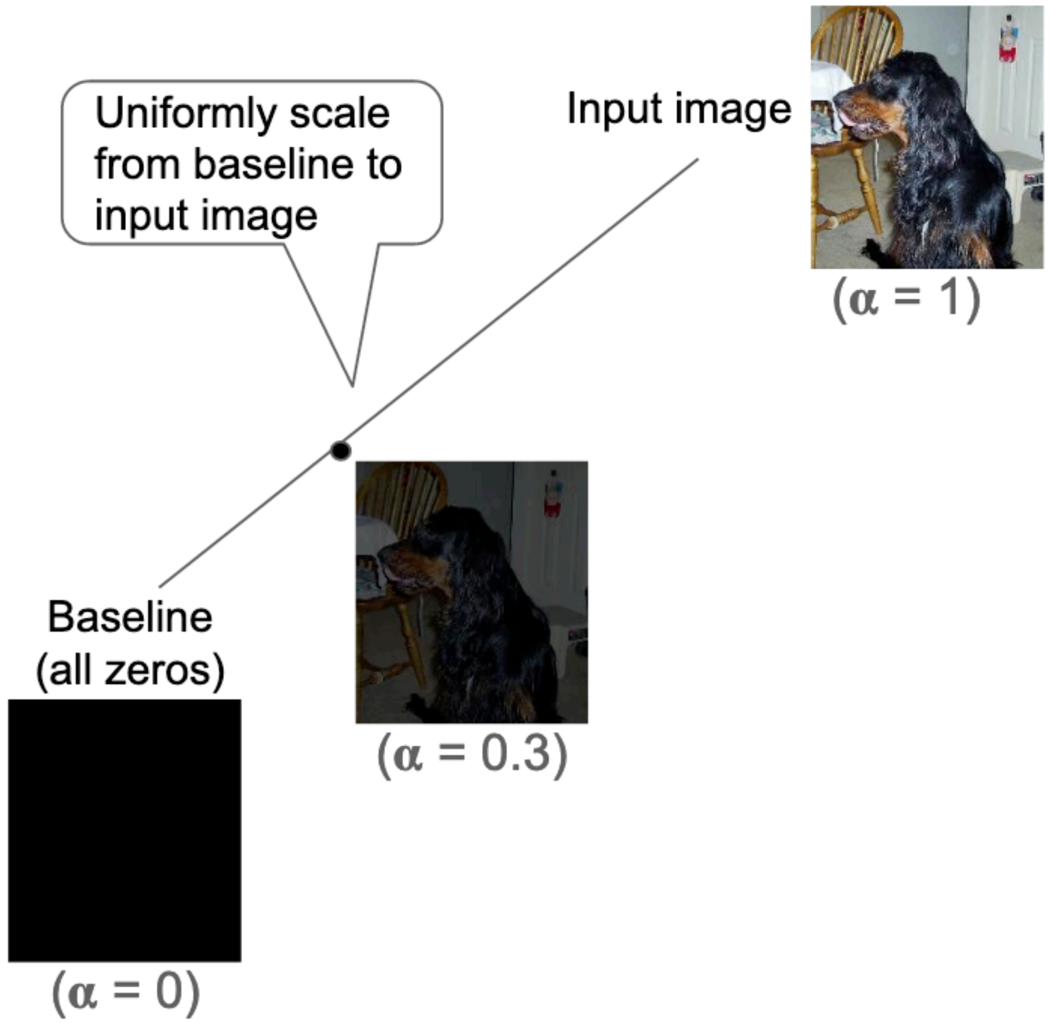
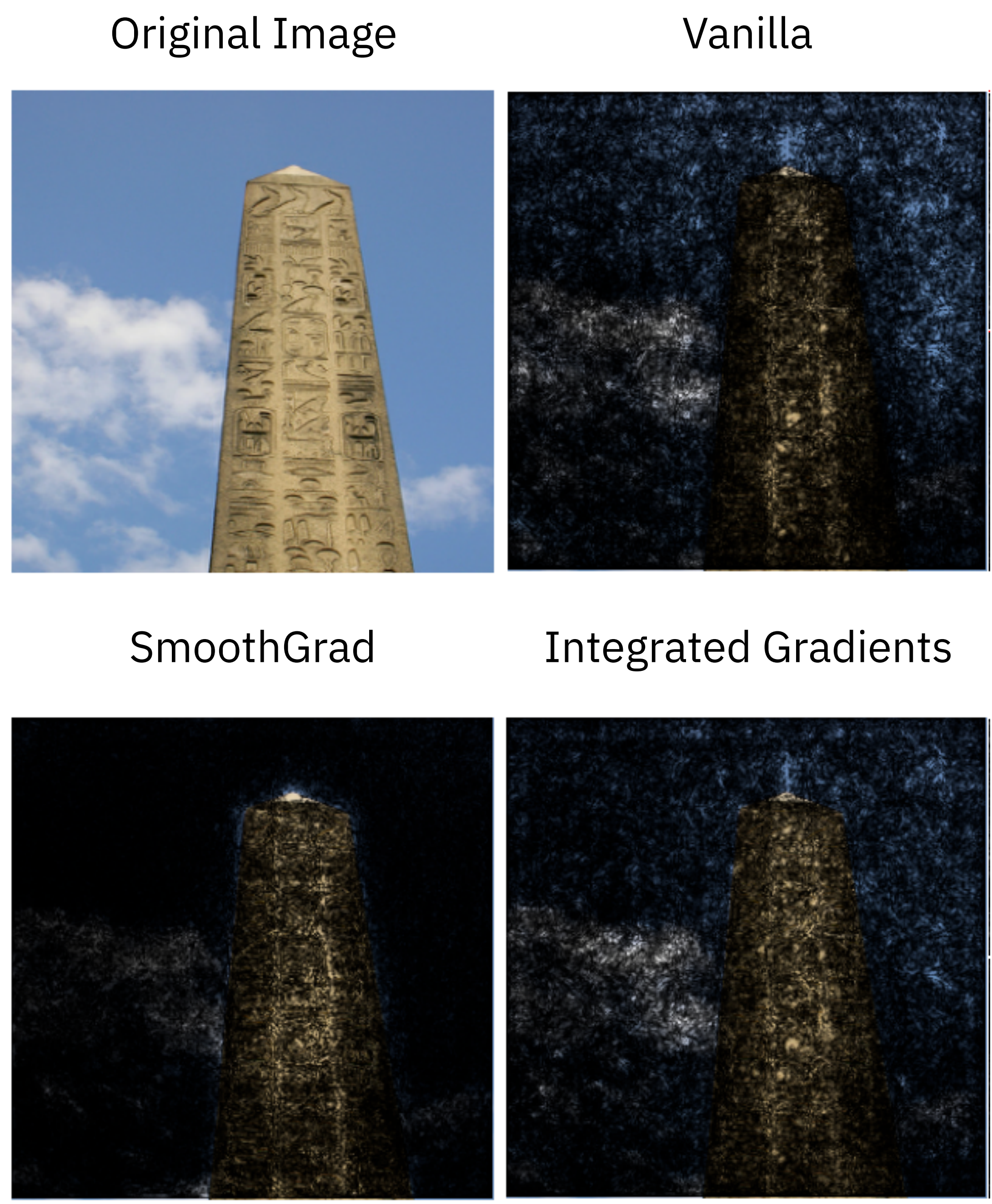
Integrated Gradients (IG)



- Proposed to solve **feature saturation**
- ***Baseline***: an input that carries no information
- Compute gradients on **interpolated** baseline & input and average by integration

[Sundararajan et al. 2017]

IG in Computer Vision



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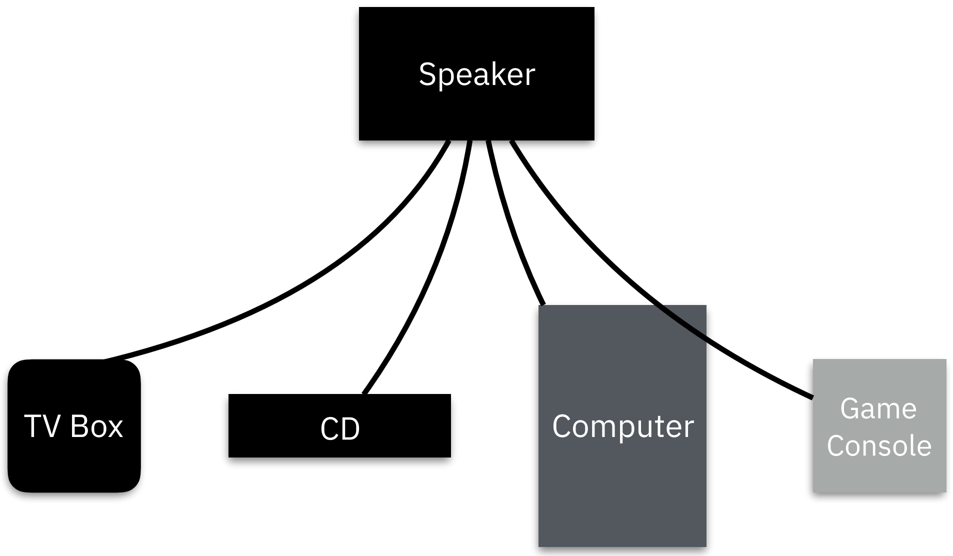
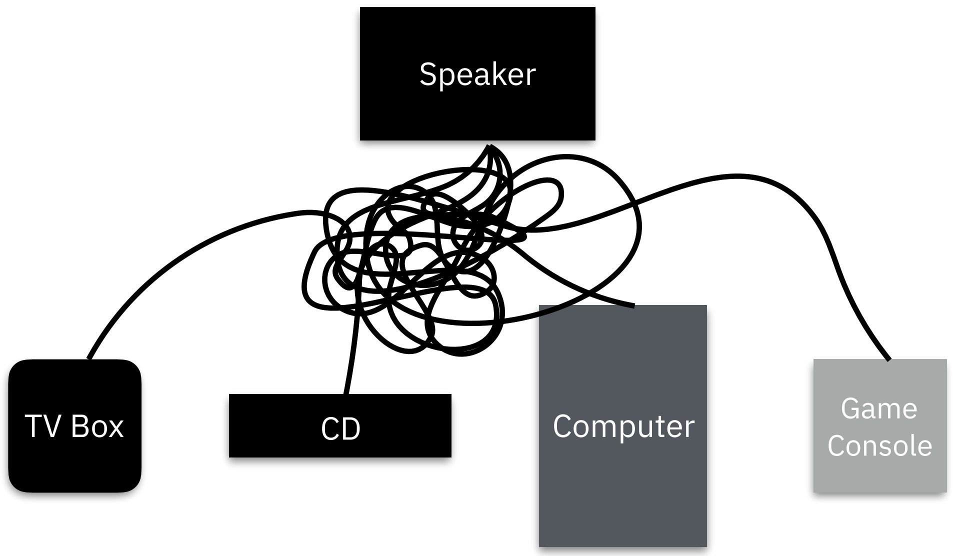
Summary





Model Transparency:
- Build model that operates in an explainable way
- Interpretation does not depend on output

Post-hoc interpretation:
- Keep the original model intact
- Interpretation depends on specific output

Summary

- How is this related to what I'm talking about next?
- *Word Alignment for NMT Via Model Interpretation*
    - **transparent models vs. post-hoc interpretations**
- *Benchmarking Interpretations Via Lexical Agreement*
    - **different post-hoc interpretation methods**

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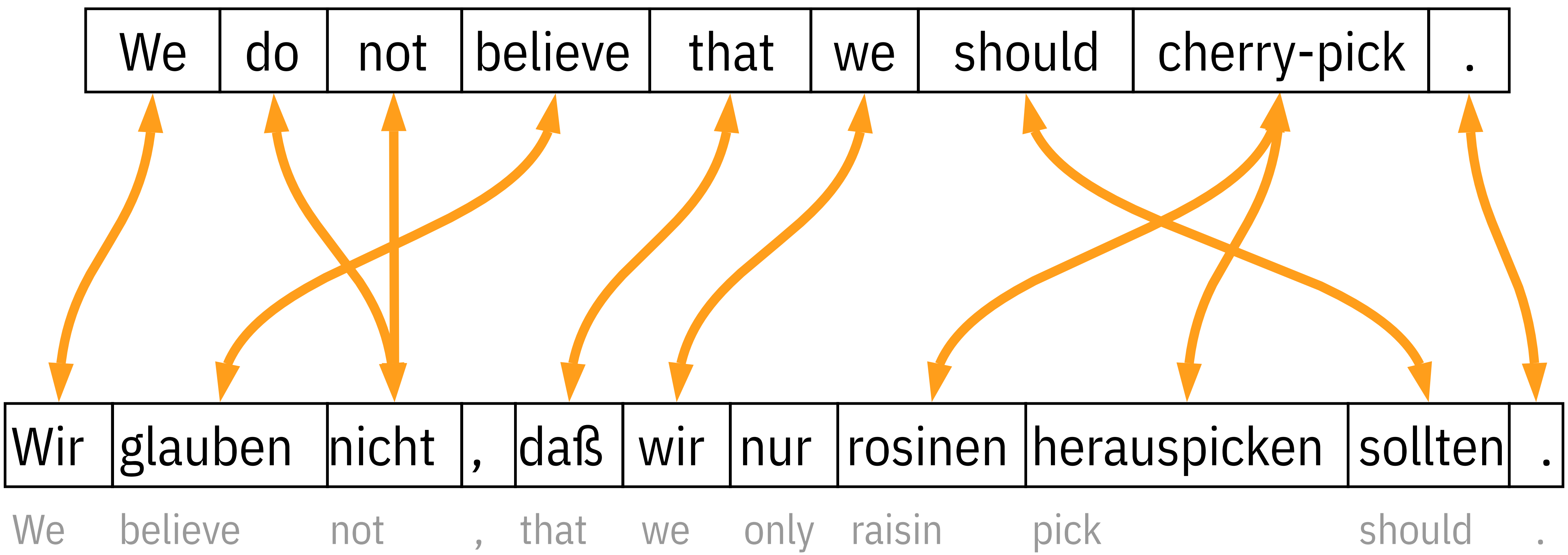
Word Alignment

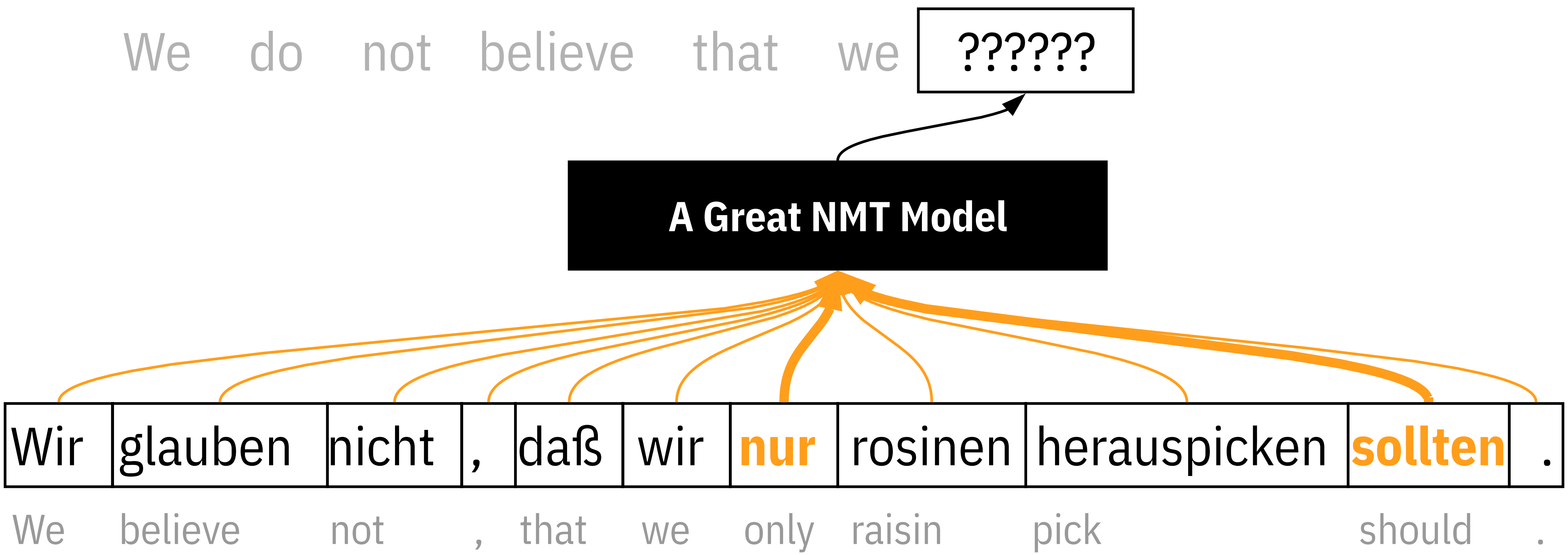
We do not believe that we should cherry-pick .

Wir	glauben	nicht	,	daß	wir	nur	rosinen	herauspicken	sollten	.
We	believe	not	,	that	we	only	raisin	pick	should	.

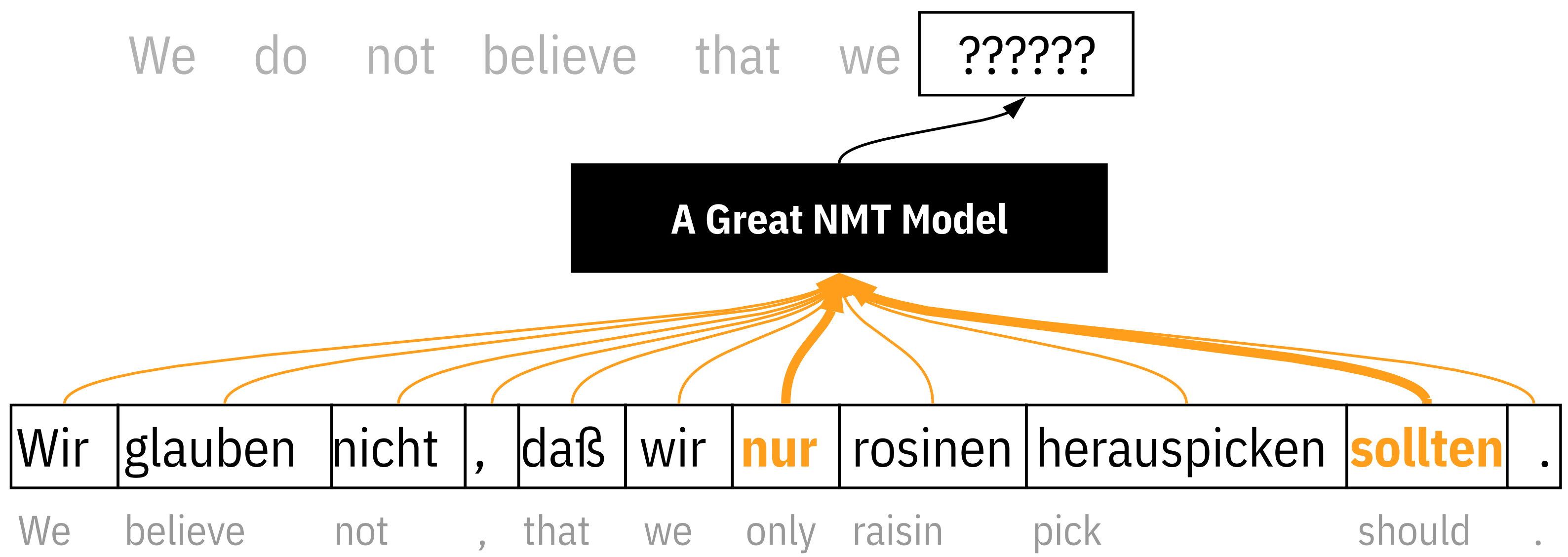
Word Alignment



Model Transparency?

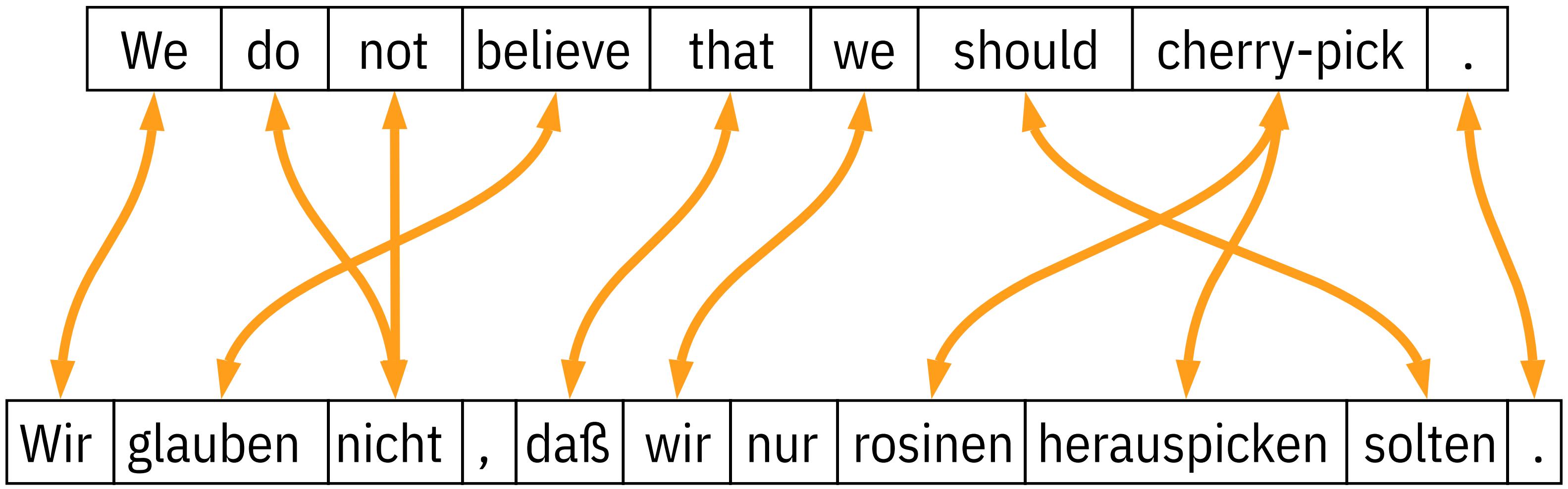


Model Transparency?



Wait... word alignments should be aware of the output!

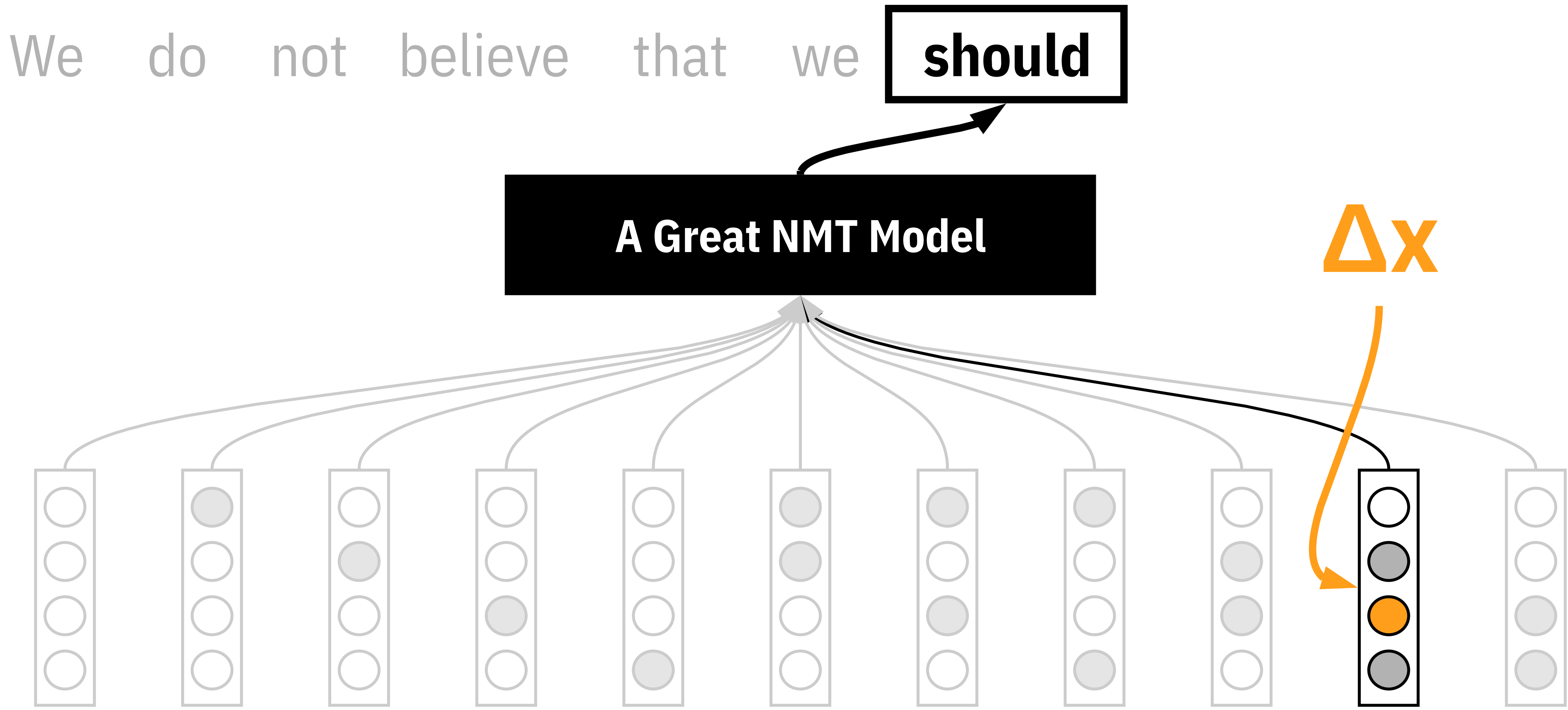
Post-hoc Interpretations with Stand-alone Models?



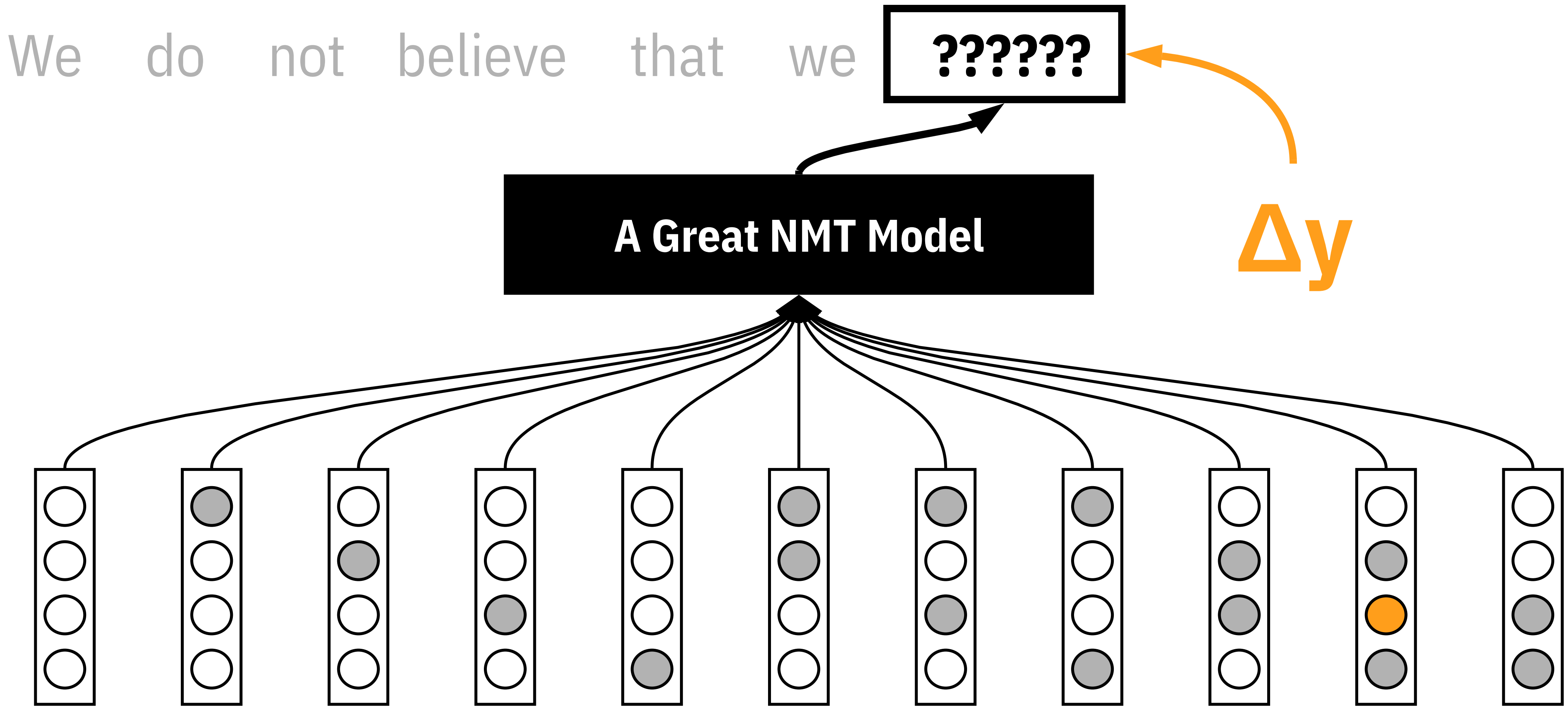
$$p(a_{ij} \mid e, f)$$

Hint: GIZA++, fast-align, etc.

Post-hoc Interpretations with Perturbation/Sensitivity?



Post-hoc Interpretations with Perturbation/Sensitivity?



“Feature” in Computer Vision

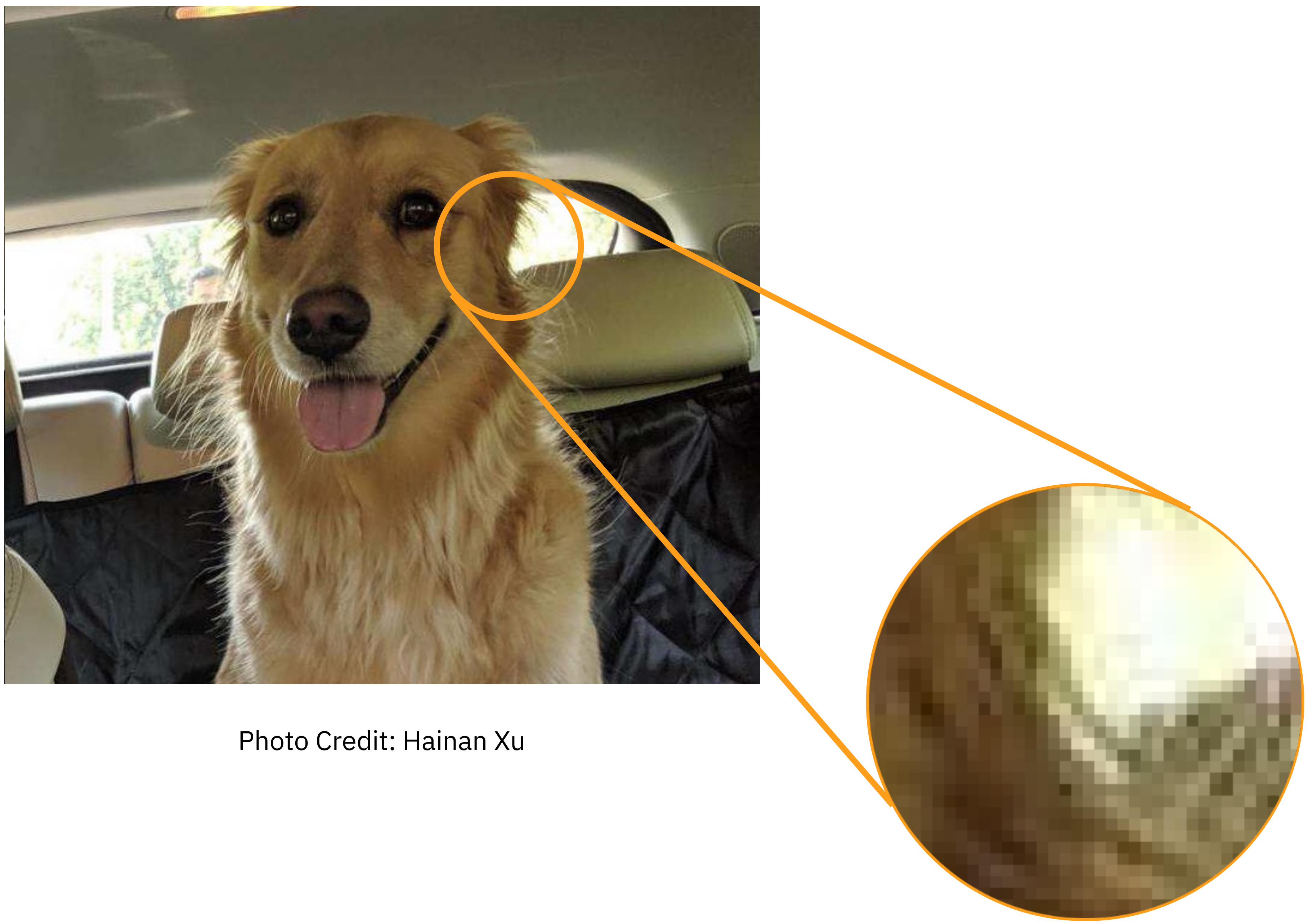
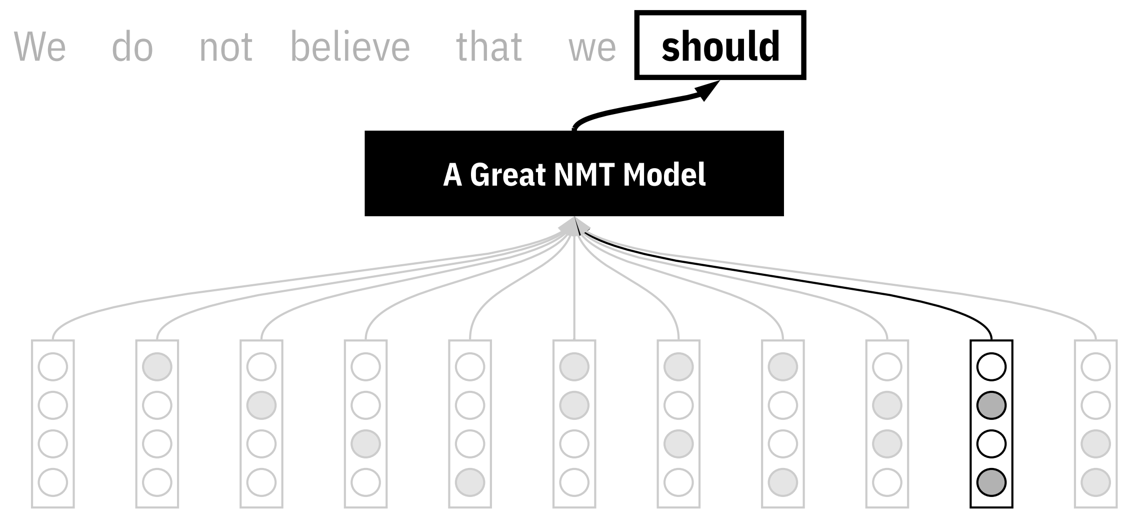


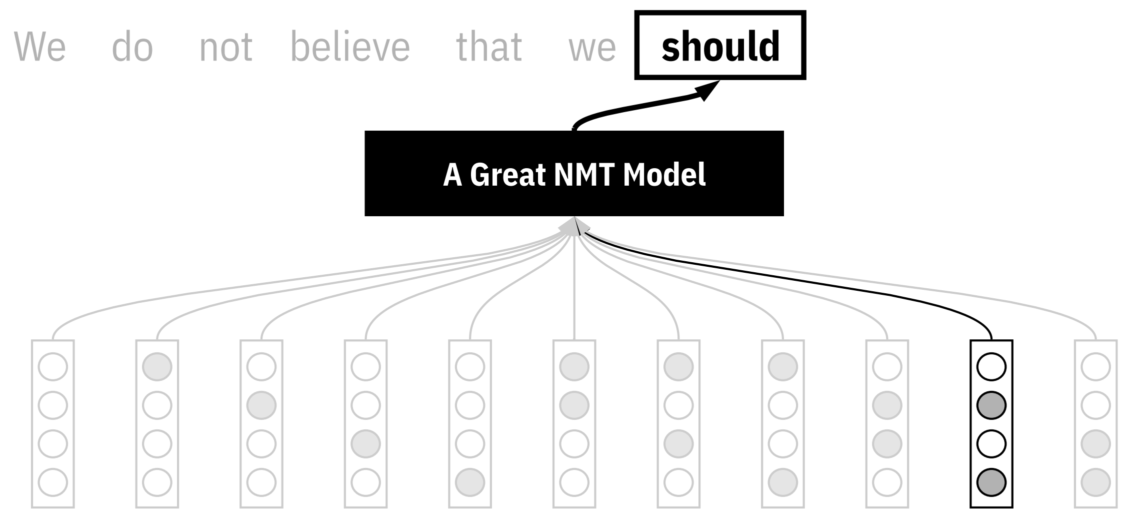
Photo Credit: Hainan Xu

“Feature” in NLP



It’s straight-forward to compute saliency for **a single dimension** of the word embedding.

“Feature” in NLP



But how to **compose** the saliency of **each dimension** into the saliency of a **word**?

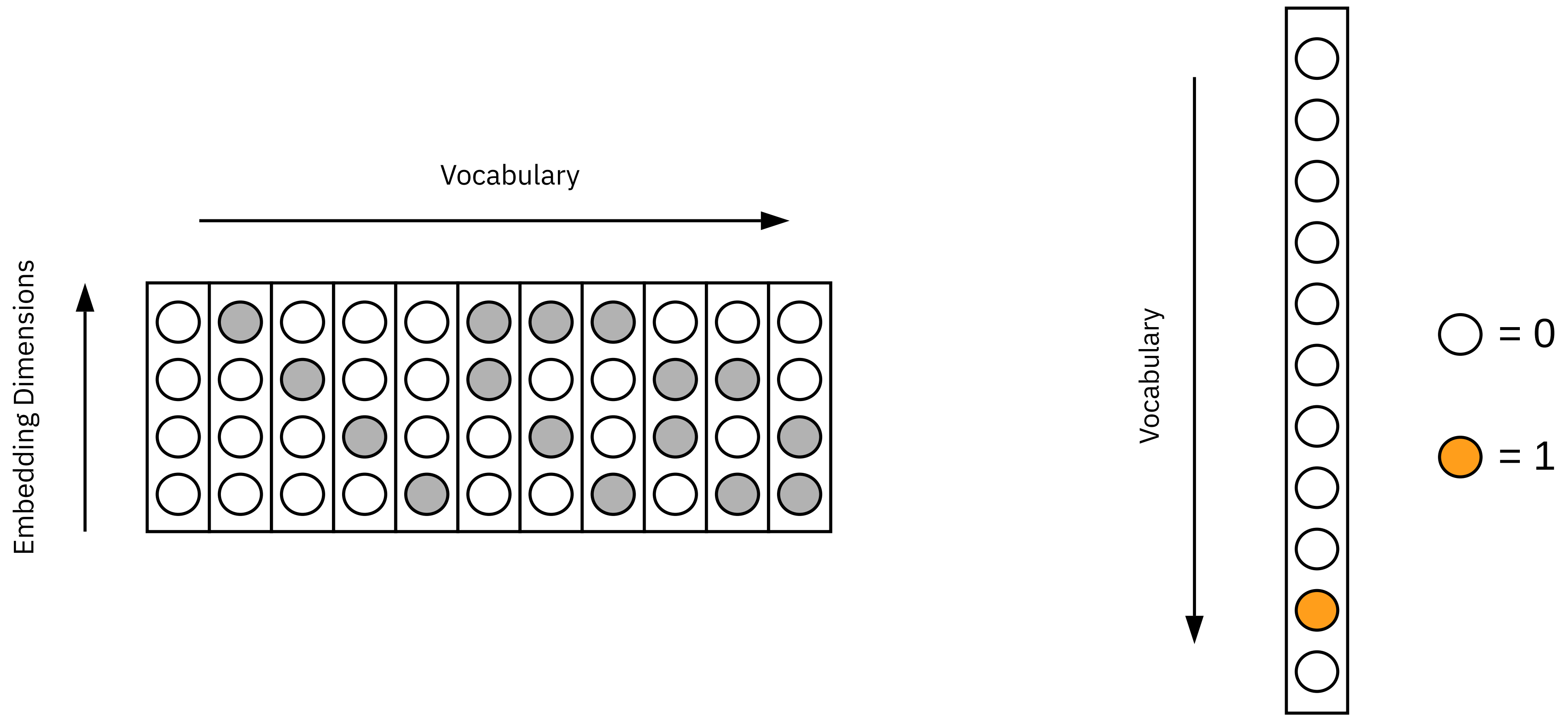
Li et al. 2016

Visualizing and Understanding Neural Models in NLP

$$\frac{1}{N}\sum_{i=1}^{N}\left|\frac{\partial y}{\partial e_i}\right|$$

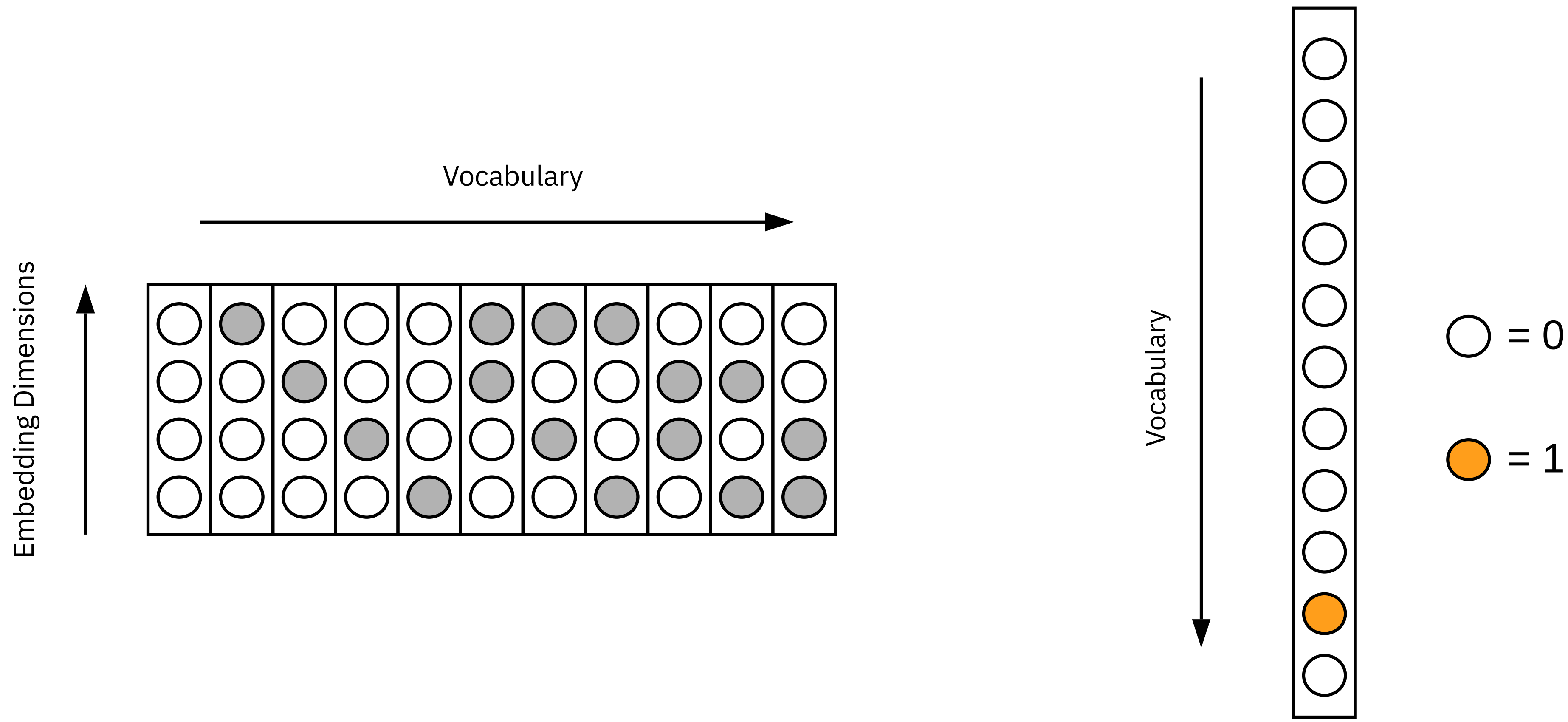
range: $(0, \infty)$

Our Proposal



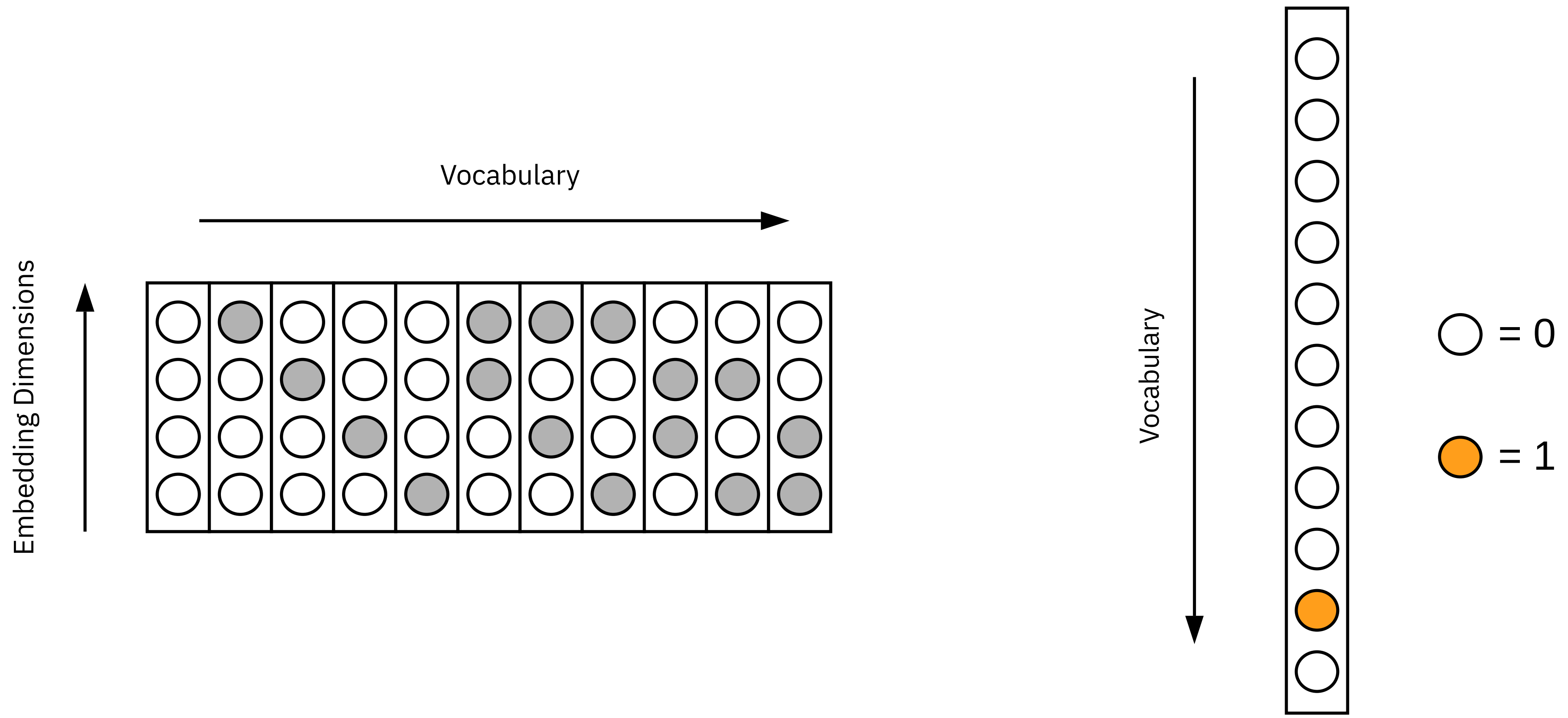
Consider word embedding look-up as a **dot product** between the **embedding matrix** and an **one-hot vector**.

Our Proposal



The **1** in the one-hot vector denotes the **identity of the input word**.

Our Proposal



Let's perturb that **1** like a **real value**!
i.e. **take gradients** with regard to the **1**.

Our Proposal

$$\sum_i e_i \cdot \frac{\partial y}{\partial e_i}$$

range: $(-\infty, \infty)$

Recall this is different from Li's proposal: $\frac{1}{N}\sum_{i=1}^{N}\left|\frac{\partial y}{\partial e_i}\right|$

Why is this proposal better?

- A input word may strongly **discourage** certain translation and **still carry a large (negative) gradient**.
- Those are **salient** words, but shouldn't be **aligned**.
- **Absolute value/L2-norm** falls into this pit.

Evaluation

- Evaluation of interpretations is **tricky**!
- Fortunately, there's **human judgments** to rely on.
- Need to do **force decoding** with NMT model.

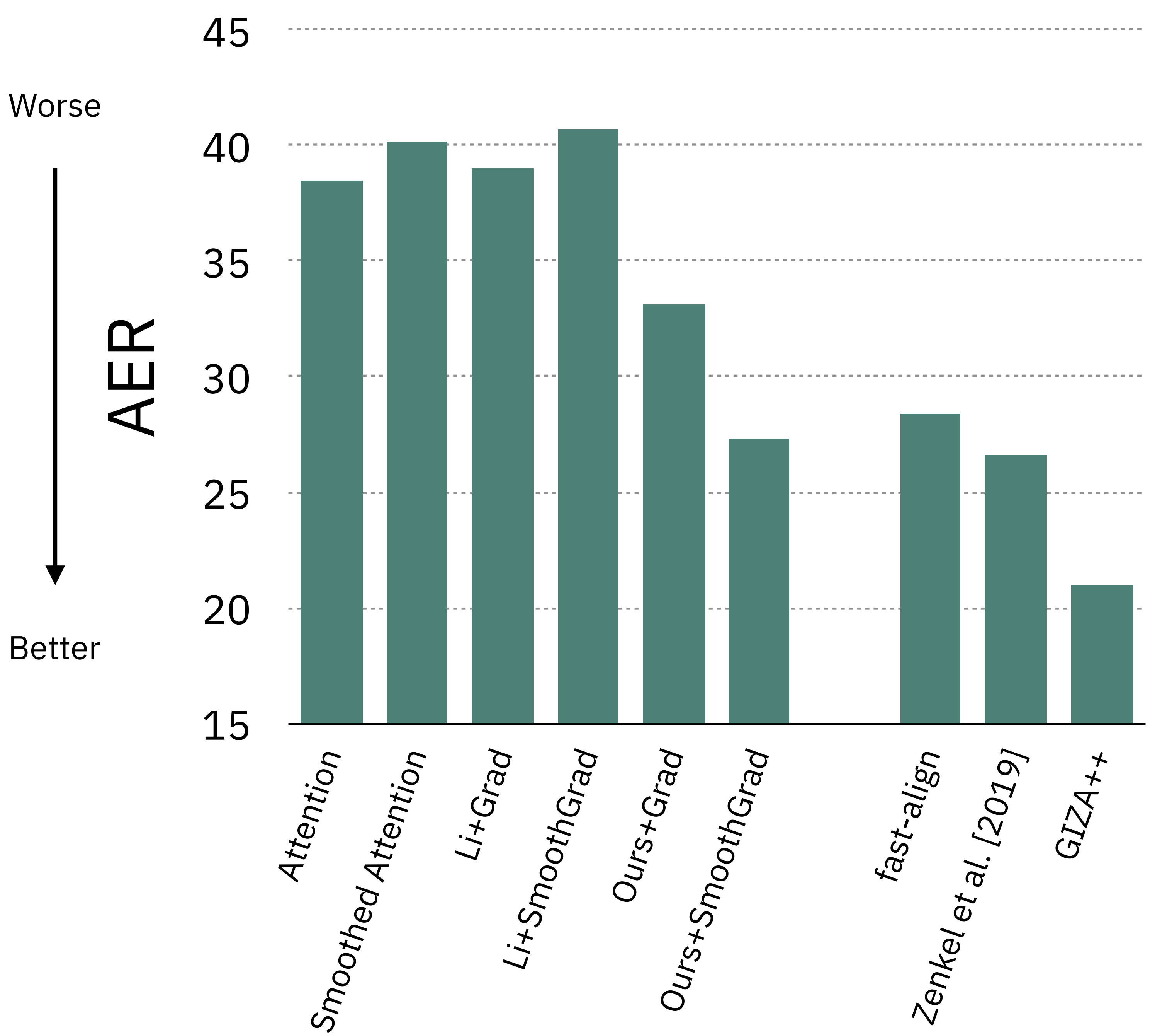
Setup

- Architecture: **Convolutional S2S, LSTM, Transformer** (with fairseq default hyper-parameters)
- Dataset: Following Zenkel et al. [2019], which covers **de-en**, **fr-en** and **ro-en**.
- SmoothGrad hyper-parameters: ***N=30*** and ***σ=0.15***

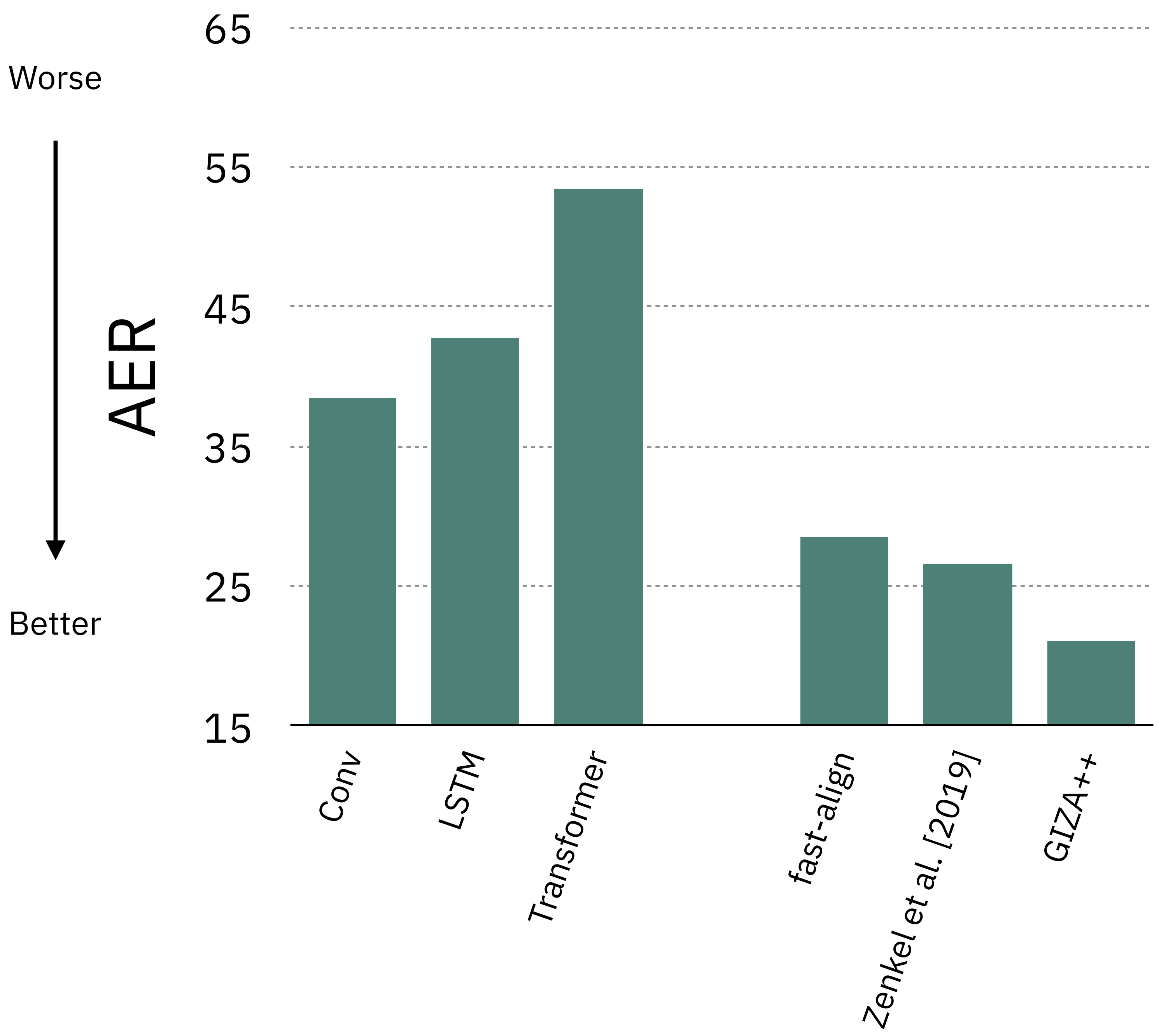
Baselines

- **Attention weights**
- **Smoothed Attention**: forward pass on multiple corrupted input samples, then average the attention weights over samples
- **[Li et al. 2016]**: compute element-wise absolute value of embedding gradients, then average over embedding dimensions
- **[Li et al. 2016] + SmoothGrad**

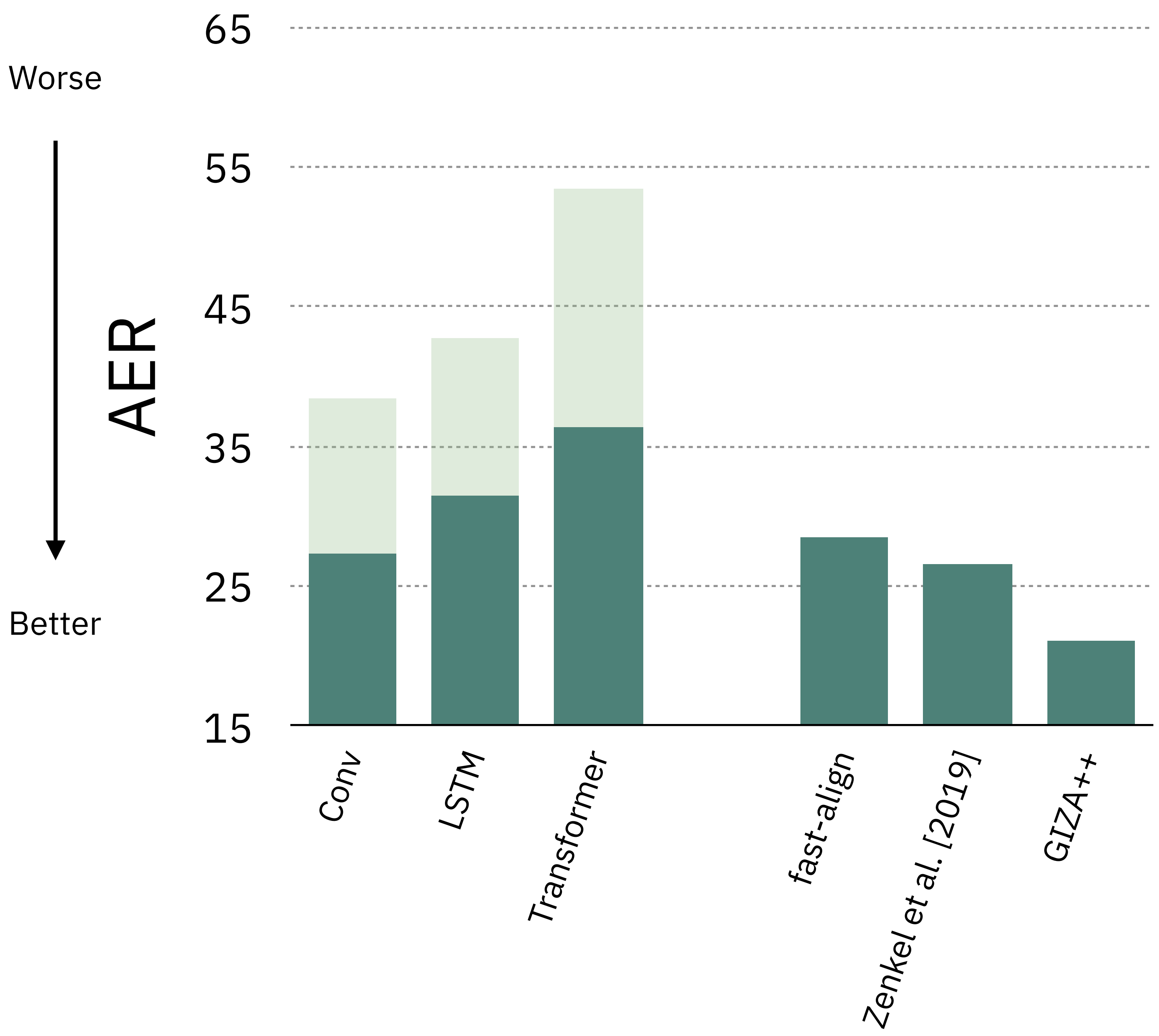
Convolutional S2S on de-en



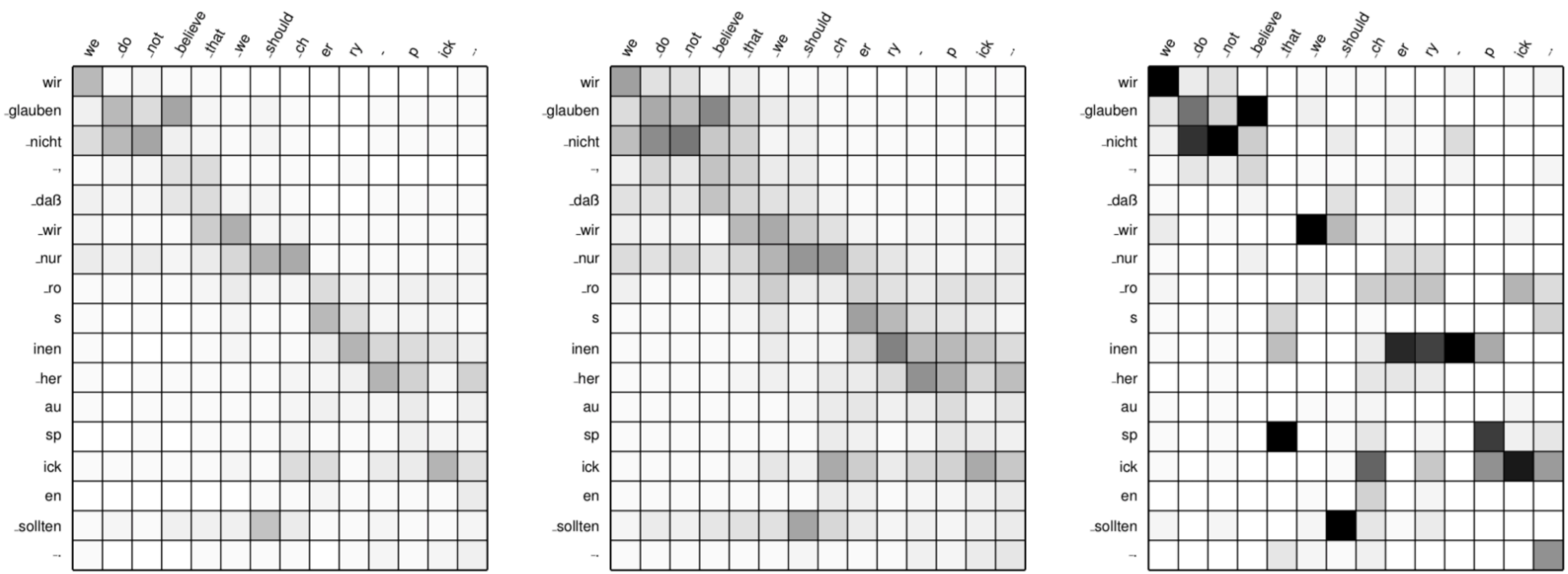
Attention on de-en



Ours+SmoothGrad on de-en



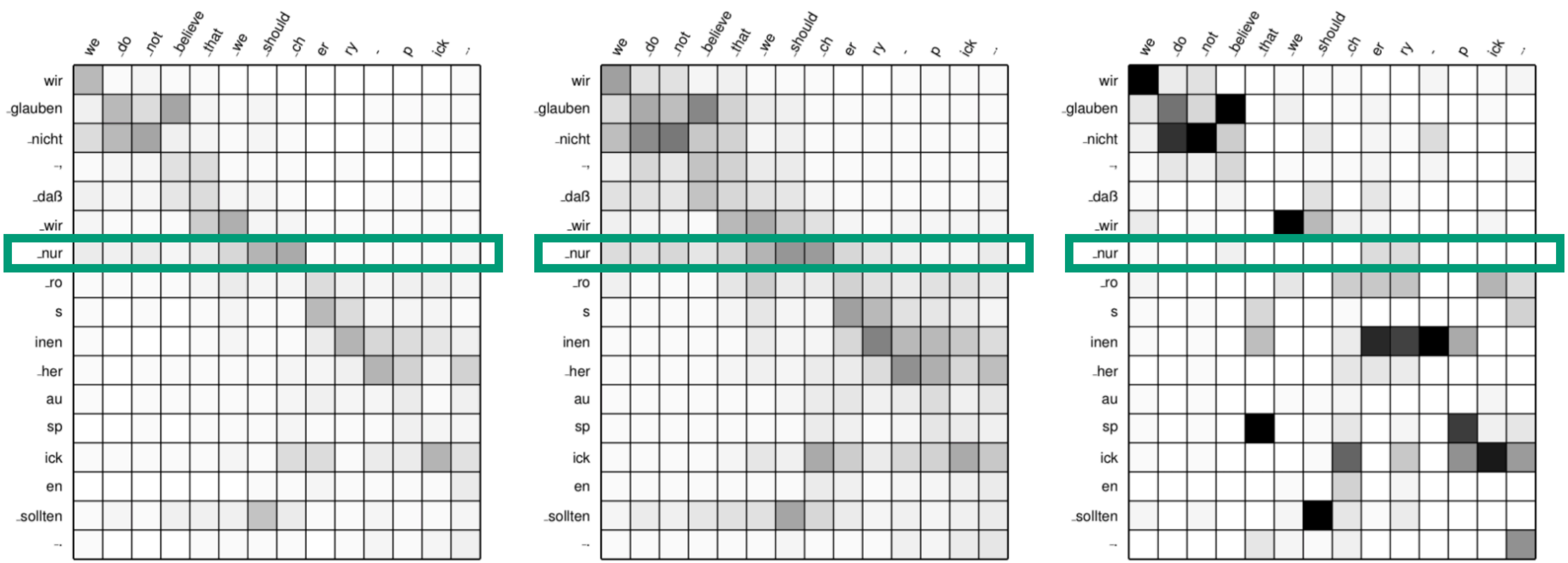
Li vs. Ours



(a) Attention (b) Li (c) Ours

Li vs. Ours

(English: We do not believe that we should cherry-pick .)



(a) Attention (b) Li (c) Ours

Summary

- For each of these interpretation methods:
  - Attention: maximum transparency on **how the model works**, but is hard to **interpret**
  - Stand-alone Alignment Models: gives **best word alignments**, but has nothing to do with the **translation model**
  - Saliency: **a good combination of both worlds!**

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How about other NLP tasks?

- **Text Classification**:
  [Aubakirova and Bansal 2016][Arras et al. 2016]
- **Sentiment Analysis**:
  [Li et al. 2016][Arras et al. 2017]
- **Question Answering**:
  [Mudrakarta et al. 2018]

Assumption

Post-hoc Interpretation

=

How did the model make decision

Assumption

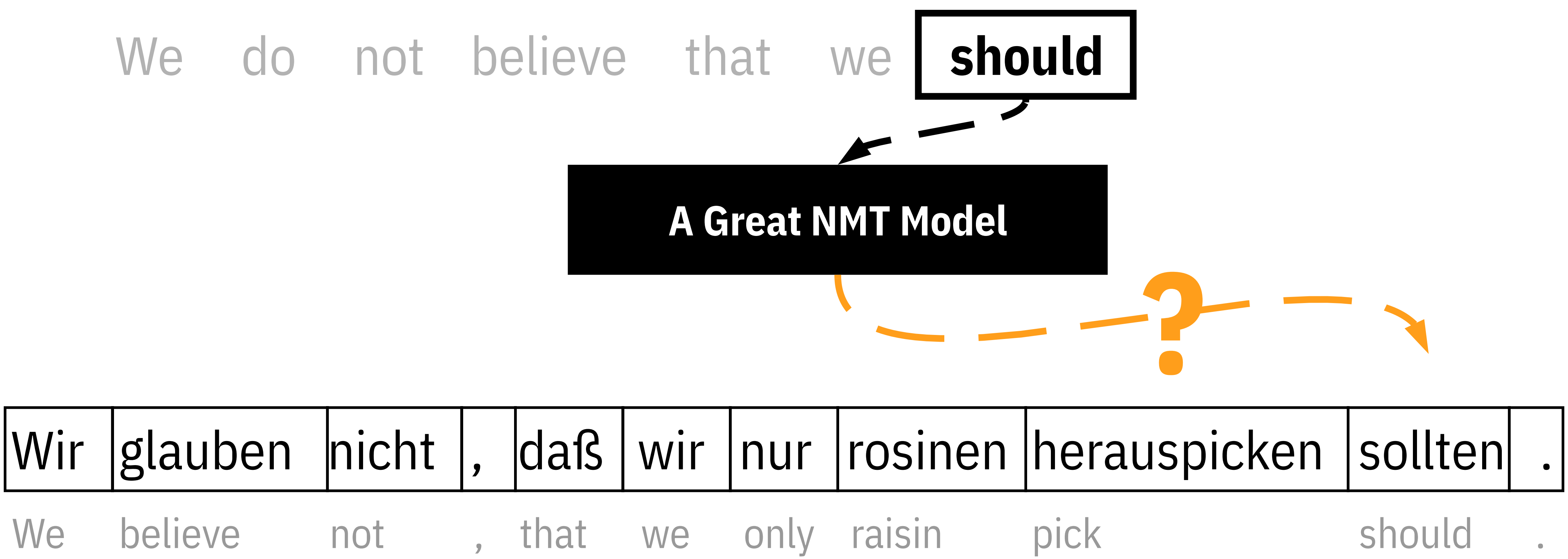
Post-hoc Interpretation

=

How did the model make decision

?

Quick Flashback



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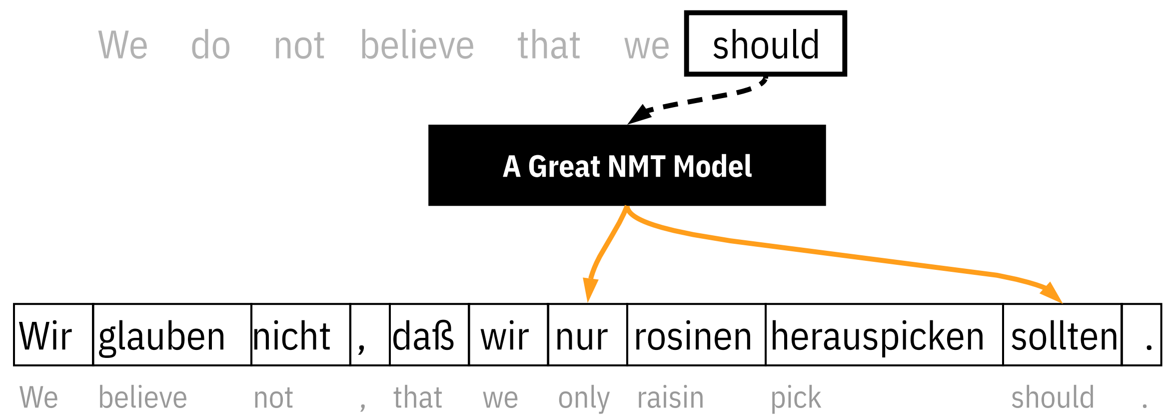
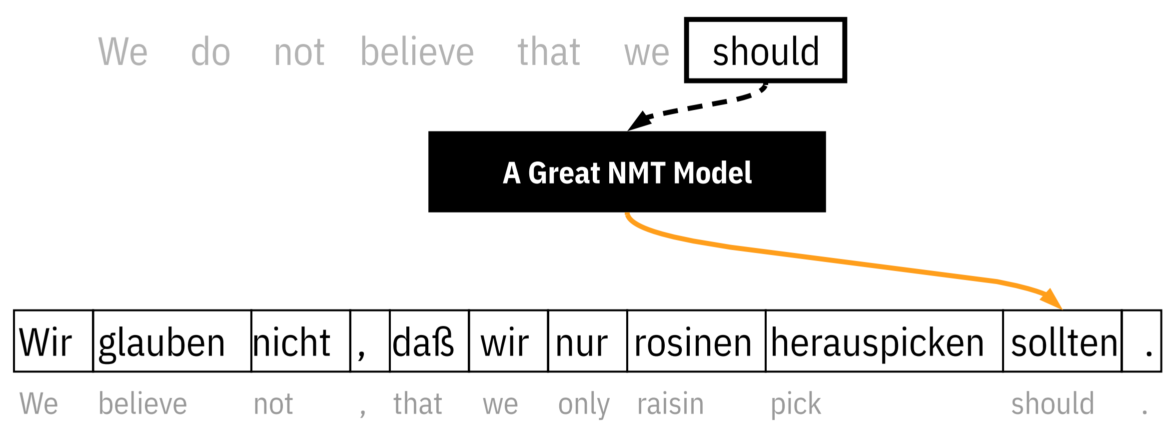


Li et al. 2016

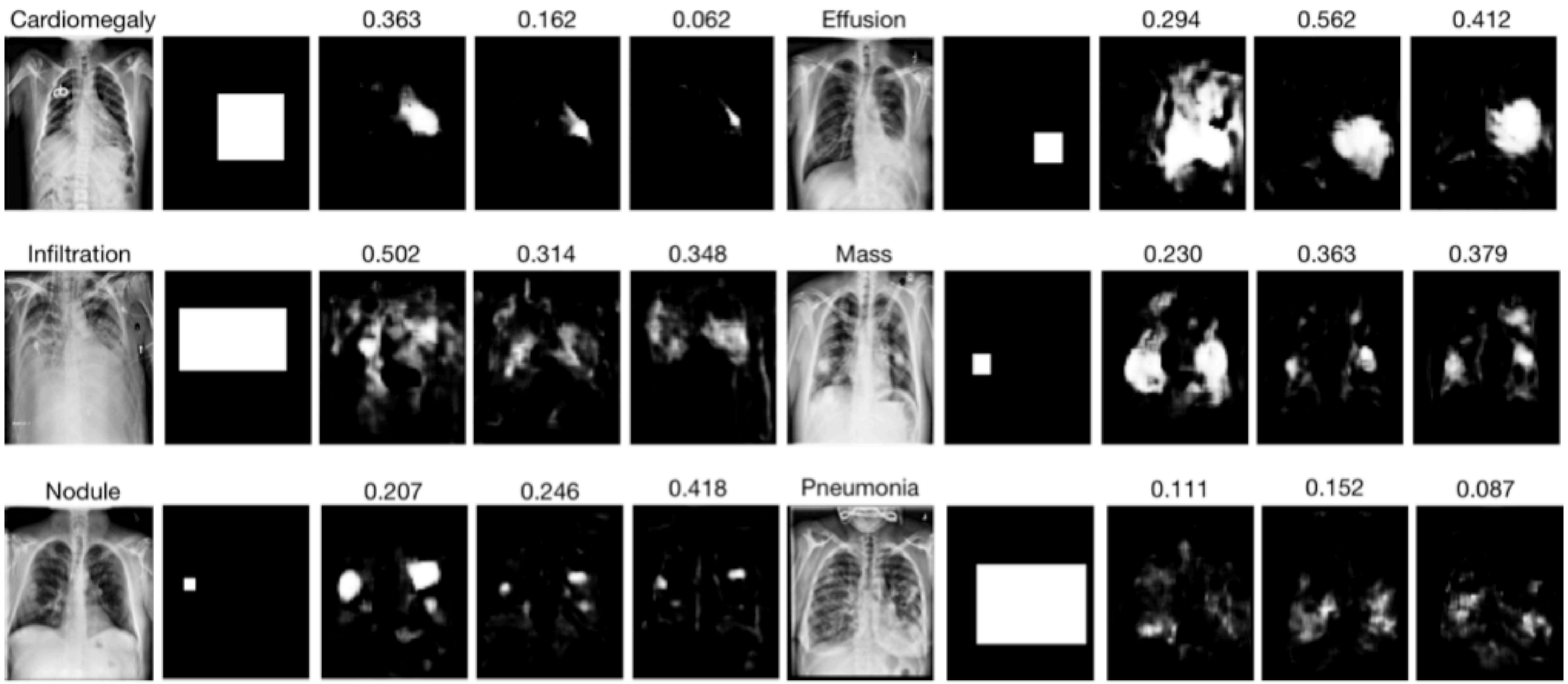


Ours+SmoothGrad

Research Question

- How can we **quantitatively test** the effectiveness of model interpretation methods in the context of NLP?
- What are the said “effectiveness” **correlated** with? model size? architecture? task performance?

Computer Vision



Yao et al. 2018

Weakly Supervised Medical Diagnosis and Localization from Multiple Resolutions

Main Challenge

No ground-truth interpretation

Lexical Agreements

- Frequently studied for interpretability [Linzen et al. 2016][Marvin and Linzen 2018][Gulordava et al . 2018][Giulianelli et al. 2018]
- They concentrate on evaluating **probing task performance**, i.e. whether the model can **predict** the lexical agreements properly

E.g. Subject-Verb Agreements

However , most people , having been subjected to news footage of the devastated South Bronx , ...

A. look B. looks

E.g. Subject-Verb Agreements

*However , most **people** , having been subjected to news **footage** of the devastated South **Bronx** , ...*

A. look B. looks

E.g. Subject-Verb Agreements

*However , most **people** , having been subjected to news **footage** of the devastated South **Bronx** , ...*

A. look

E.g. Subject-Verb Agreements

*However , most **people** , having been subjected to **news footage** of the devastated **South Bronx** , ...*

A. look **B. looks**

"Probing Task"

The Test

*However , most **people** , having been subjected to news **footage** of the devastated South **Bronx** , **look***

The Test

*However , most **people** , having been subjected to news **footage** of the devastated South **Bronx** , **looks***

The Test

*However , most **people** , having been subjected to news **footage** of the devastated South **Bronx** , **look***

The interpretation passes the test, if $\forall$ w $\in$ {*footage, Bronx*}, s.t.

$$\psi(\textit{people}) > \psi(\mathrm{w})$$

ψ: feature importance/saliency

The Test

*However , most **people** , having been subjected to news **footage** of the devastated South **Bronx** , **looks***

The interpretation passes the test, if ∃ w ∈ {*footage, Bronx*}, s.t.

$$\psi(\textit{people}) < \psi(w)$$

ψ: feature importance/saliency

The Test

- We constructed test set based on two existing human-annotated corpus
  - **Penn Treebank**: new, multiple attractors
  - **syneval**: Marvin and Linzen [2018], single attractor
- We plan to construct another one with **CoNLL-2012 coreference resolution dataset** -- stay tuned!

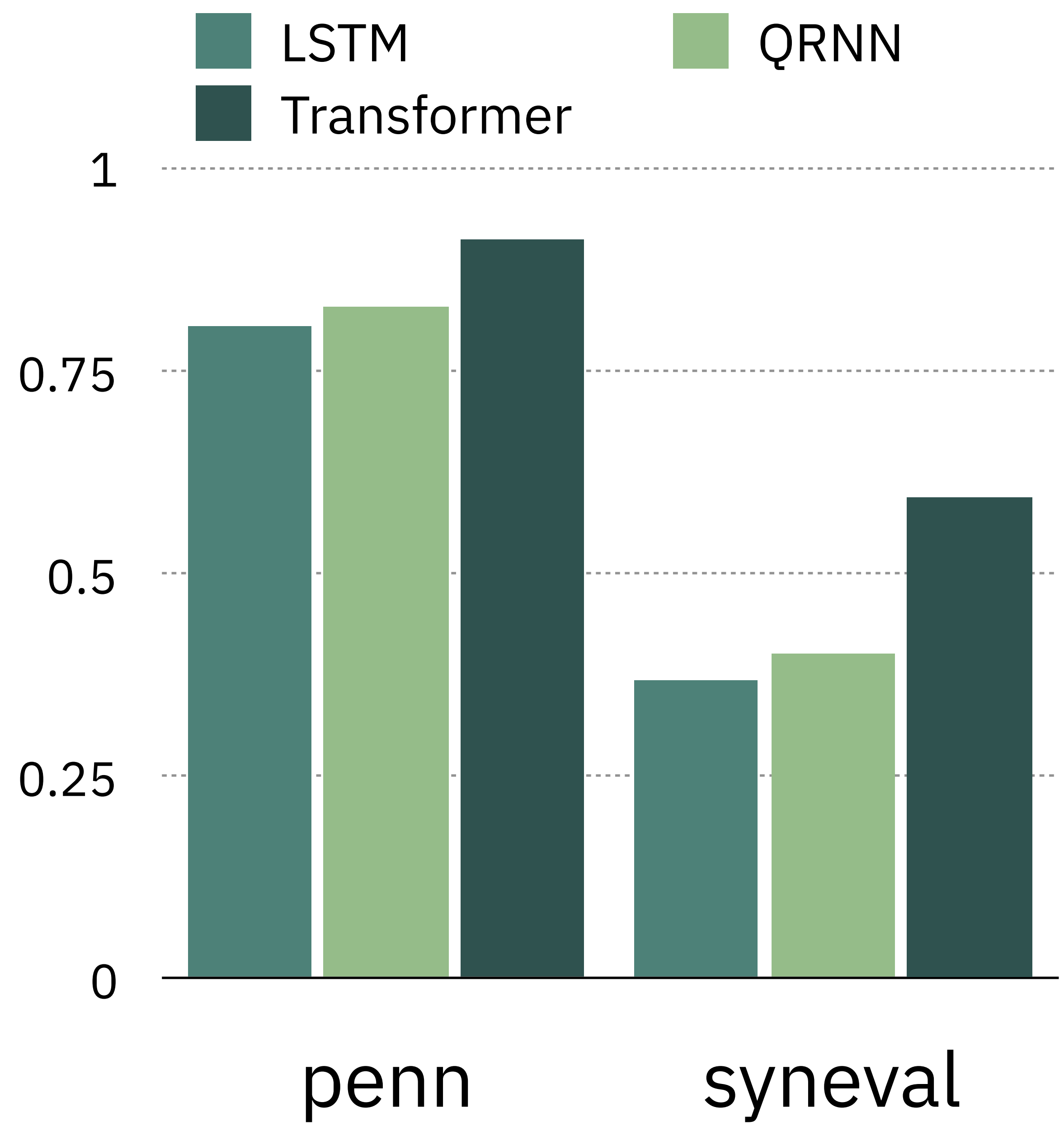
Interpreted Model

- **Language Model!**
- With final linear layer replaced with one that is **fine-tuned** for predicting specific agreement of interest
  - Word prediction may introduce **out-of-scope agreements** and interfere with evaluation

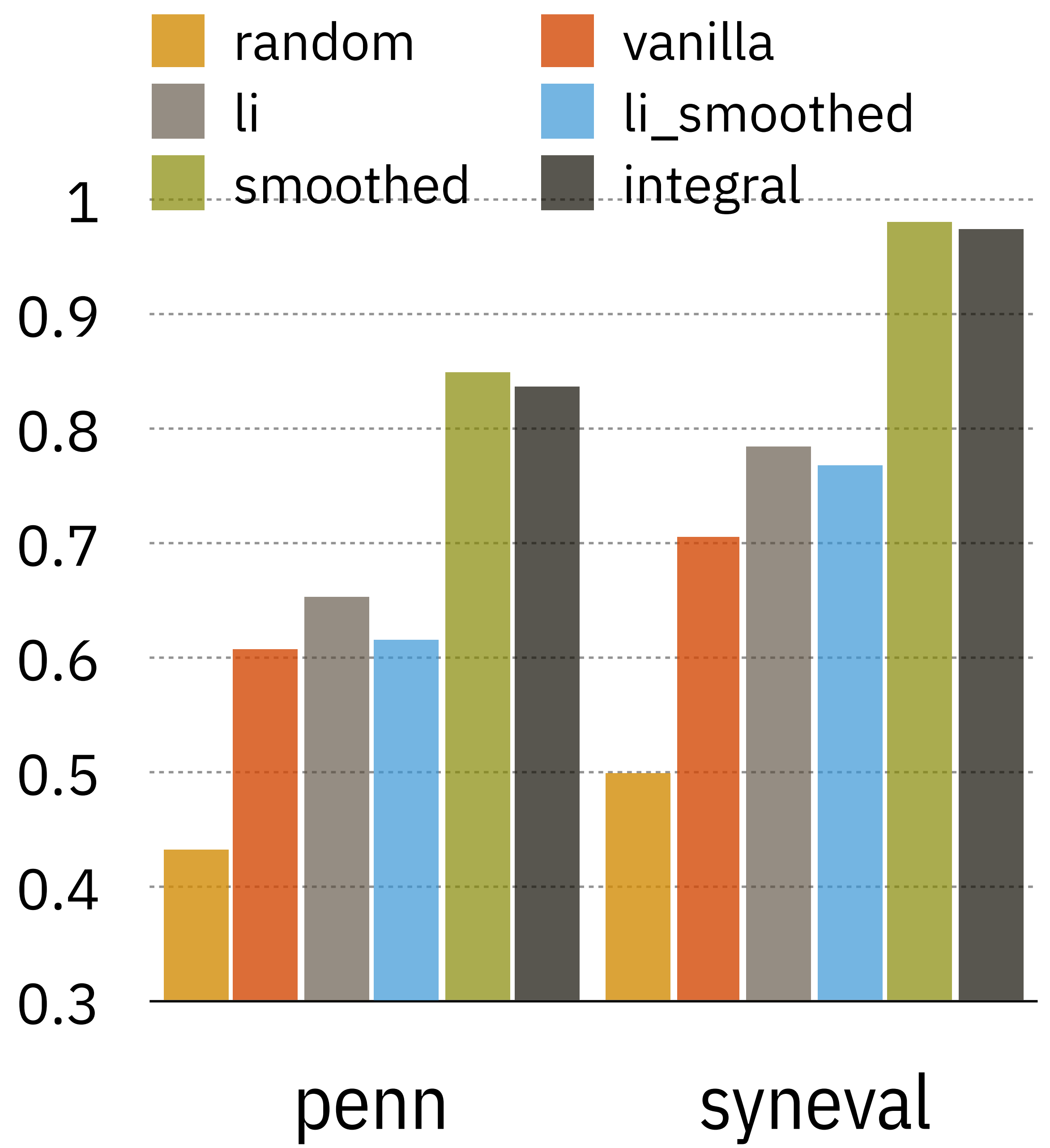
Experiment

- Architectures:
  - **LSTM model**, trained on WikiText-2
  - **QRNN model** [Bradbury et al. 2017], trained on WikiText-2
  - **Transformer model w/ adaptive input** [Baevski and Auli, 2018], trained on WikiText-103
- All the fine-tuning was done on WikiText-2
  - For subject-verb agreement, the verb tagging is done with Stanford POS-tagger

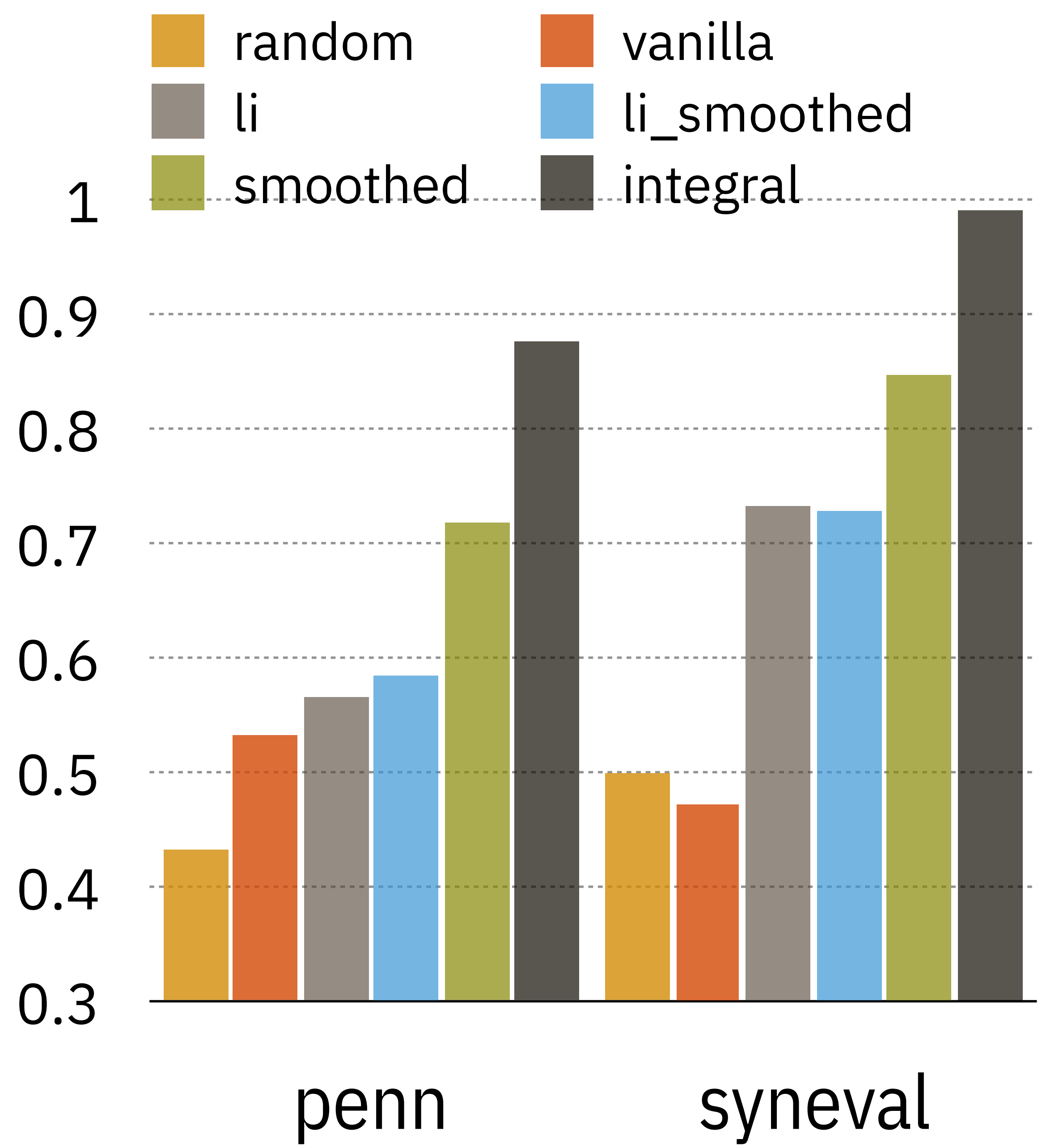
Probing Task Performance



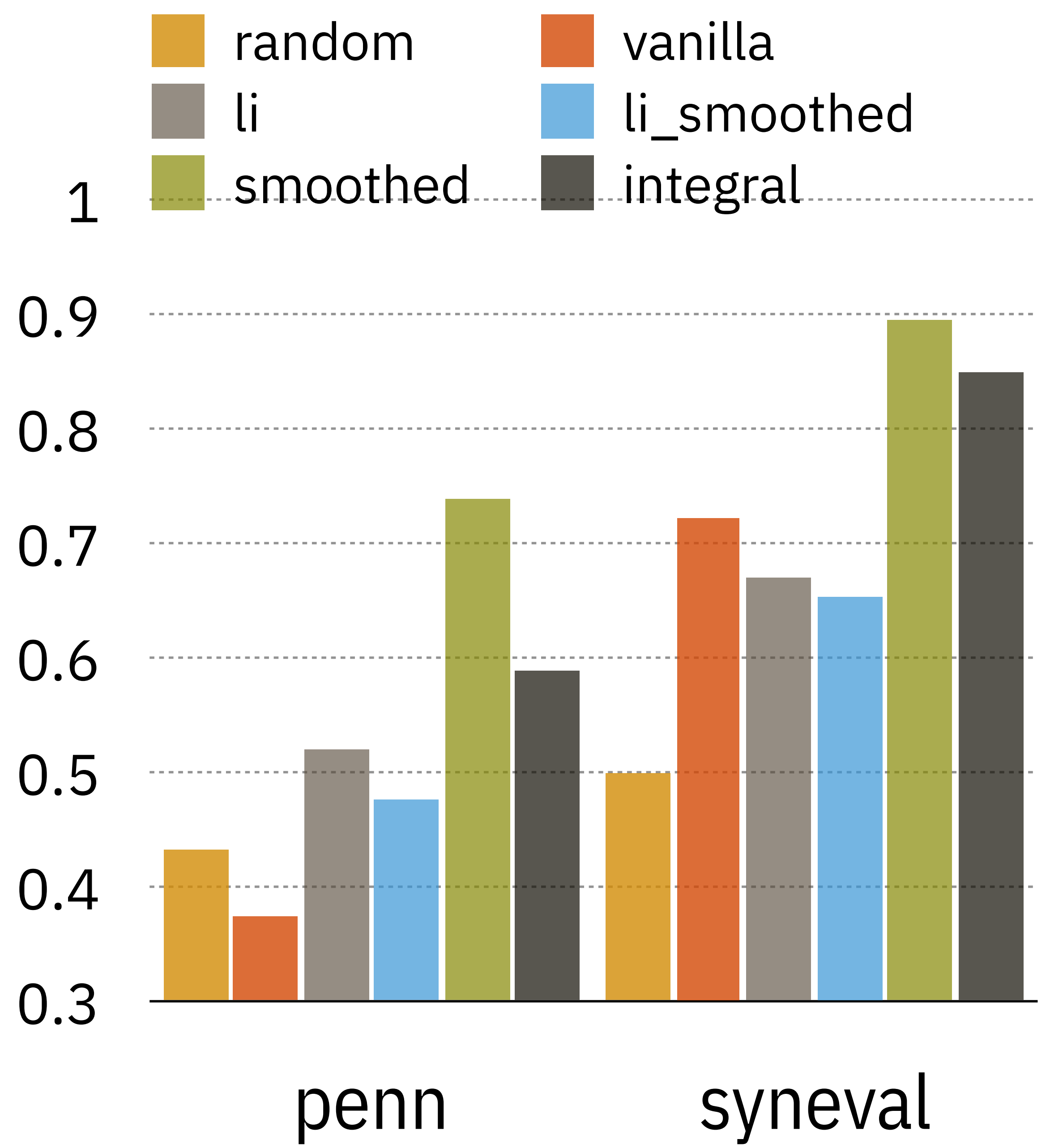
Interpretation of LSTM



Interpretation of QRNN



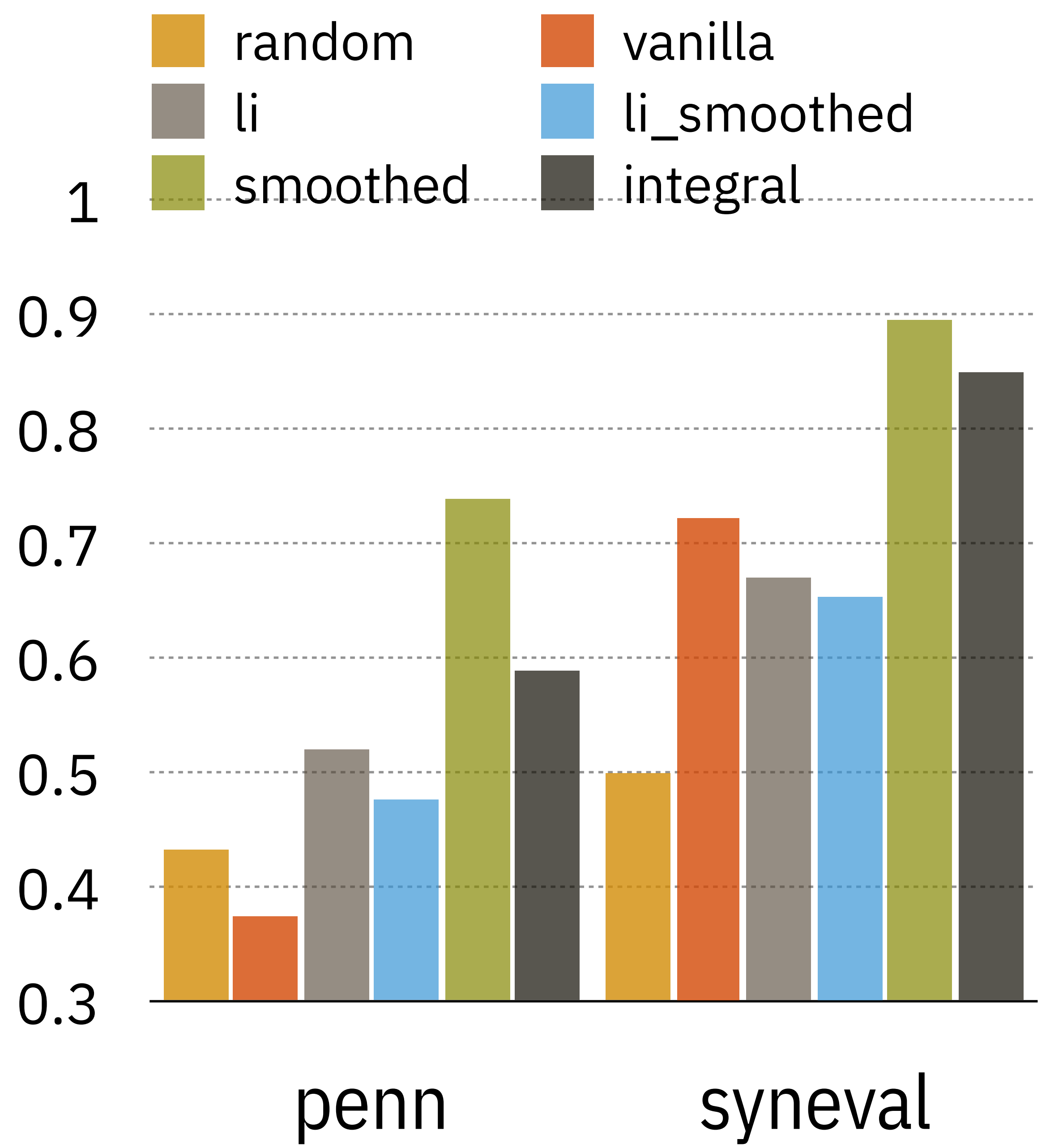
Interpretation of Transformer



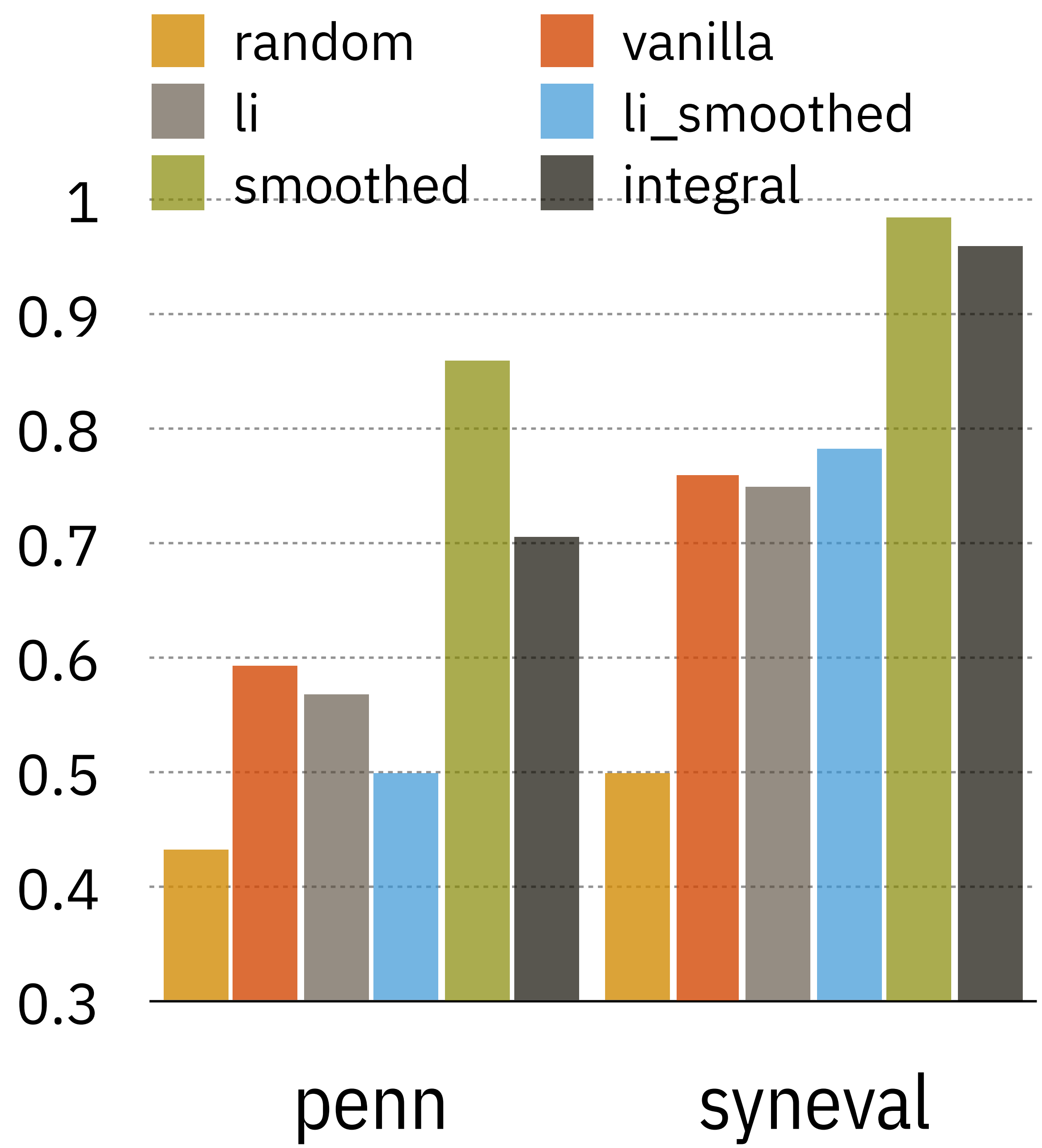
What's up with Transformer?

- Two hypothesis:
  - **Deep model** hurts interpretability
  - **Too many heads** hurts interpretability
- SOTA model: 16 layers, 8 heads
- Diagnostic model:
  - 4 layers, 8 heads
  - 4 layers, 1 head

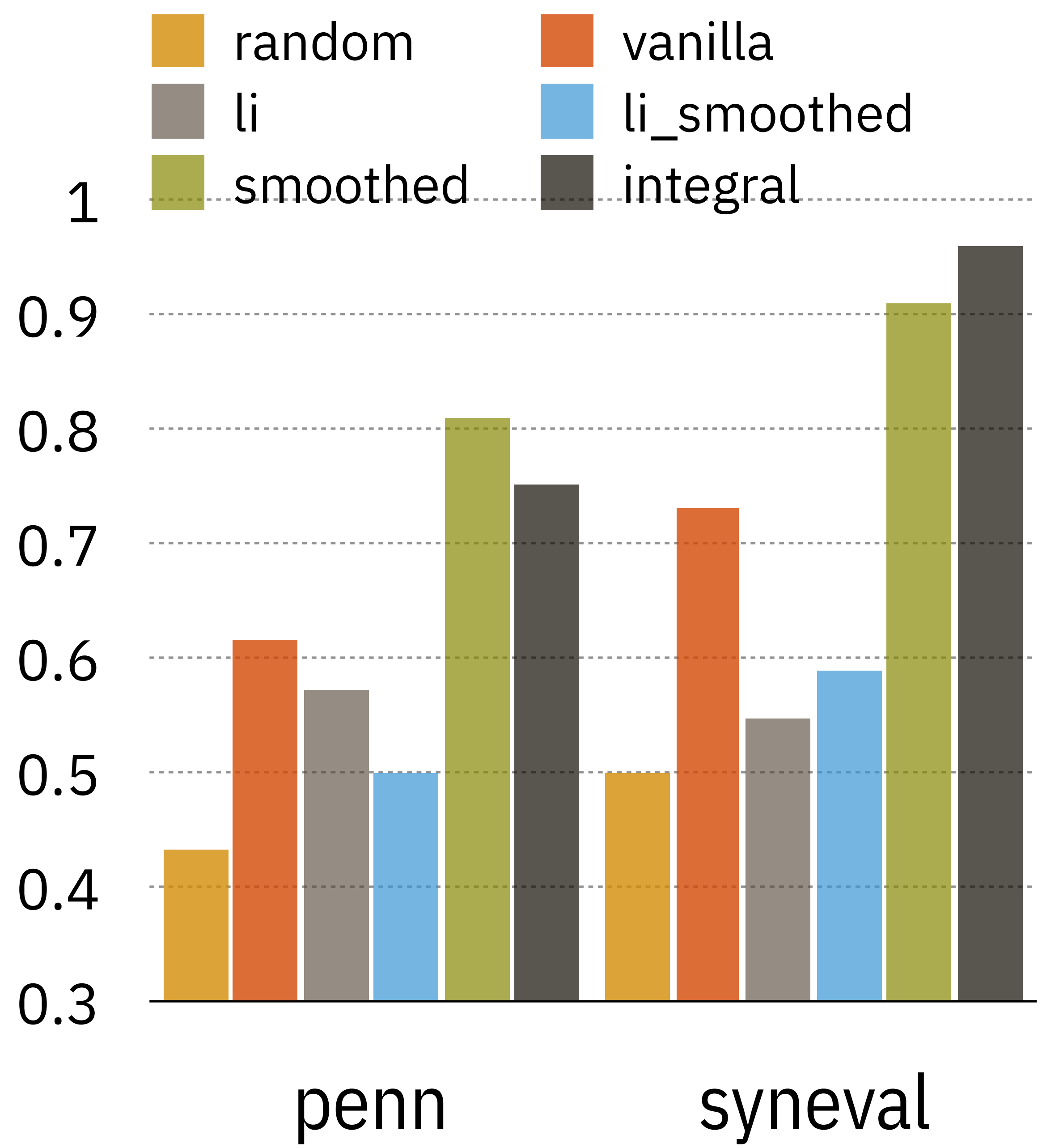
16 layers, 8 heads



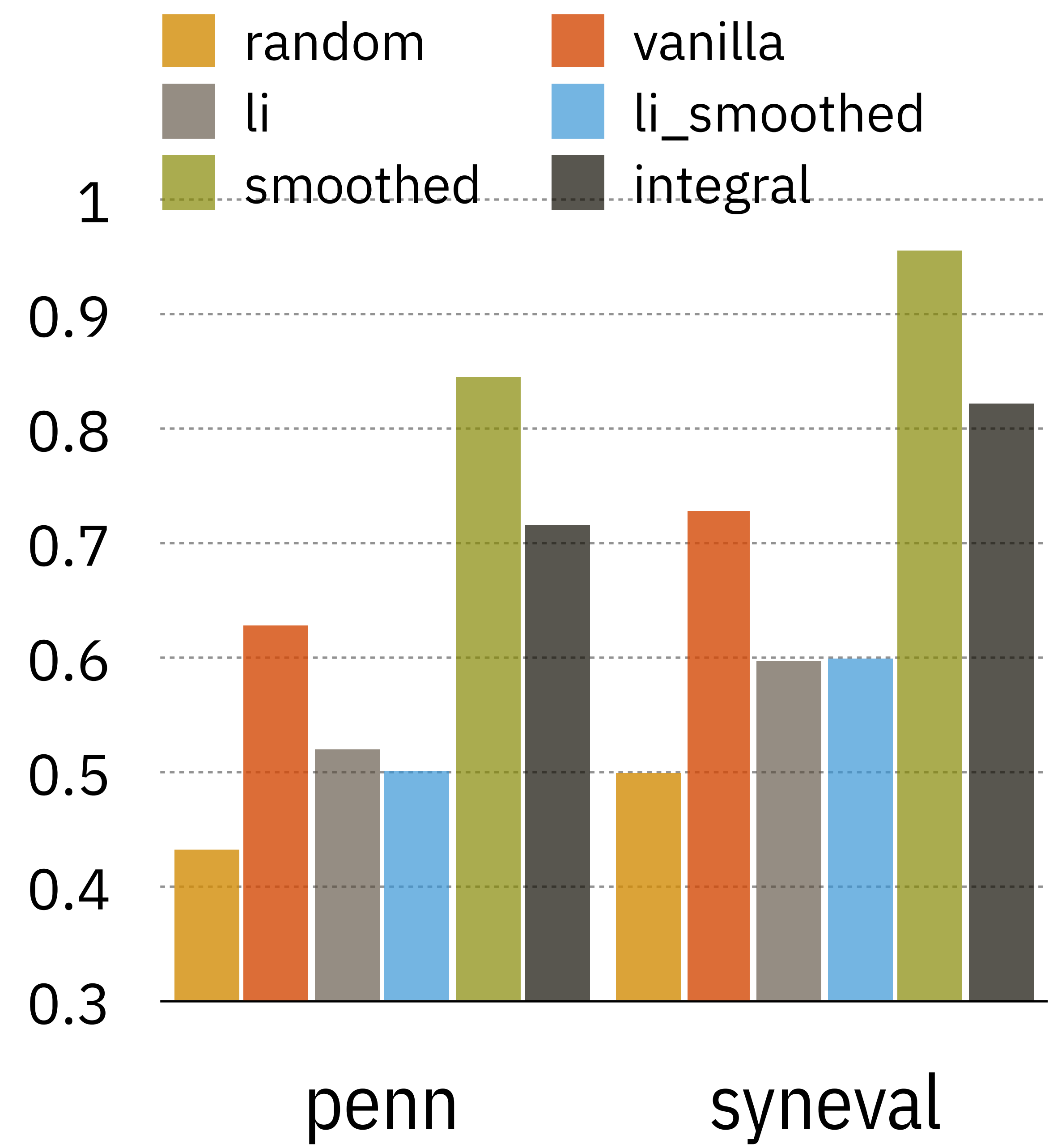
4 layers, 8 heads



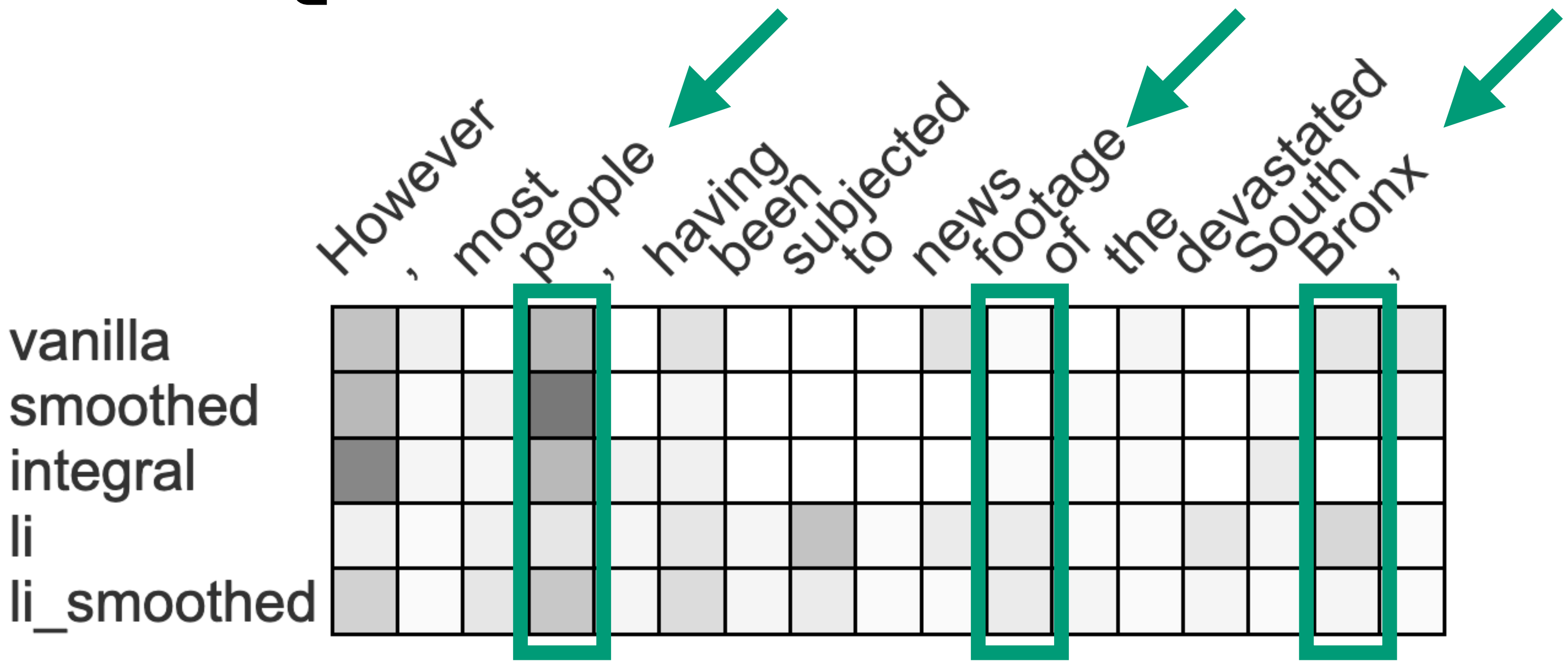
4 layers, 4 heads



4 layers, 2 heads



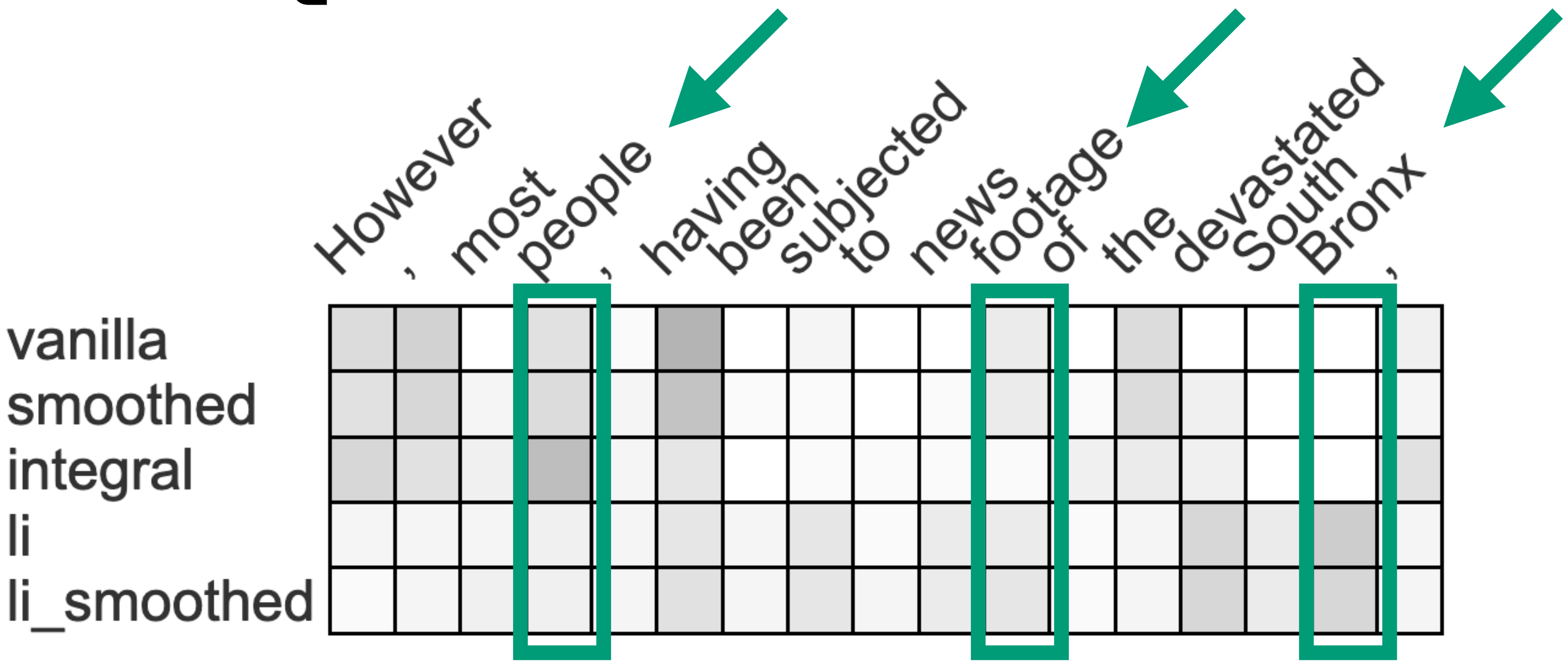
Some Qualitative Checks



- Are those interpretations just looking at the immediate previous word?

  - No. They seems to get a lot of things right!

Some Qualitative Checks



- Are they the same with different architectures?
  - No. Different architectures work differently.

Summary

- Lexical agreements open up possibilities to do **rigorous quantitative checks** for post-hoc interpretation methods in the context of NLP
- Our proposed method **works the best** consistently
- **Deep NLP models** can be **out-of-reach** for existing interpretation methods.

Outline

- A Quick Tour of Interpretability
  - Model Transparency
  - Post-hoc Interpretations
- Moving Visual Interpretability to Language:
  - Word Alignment for NMT Via Model Interpretation
  - Benchmarking Interpretations Via Lexical Agreement
- Future Work

Future Work

- **Better interpretation method** that works for the deep architectures in NLP.
- How can we use interpretability in **real-world applications (QE?)**, or **improve our models**?
- How can we use interpretability to validate whether the model learned certain **linguistic properties**?

Thanks!

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