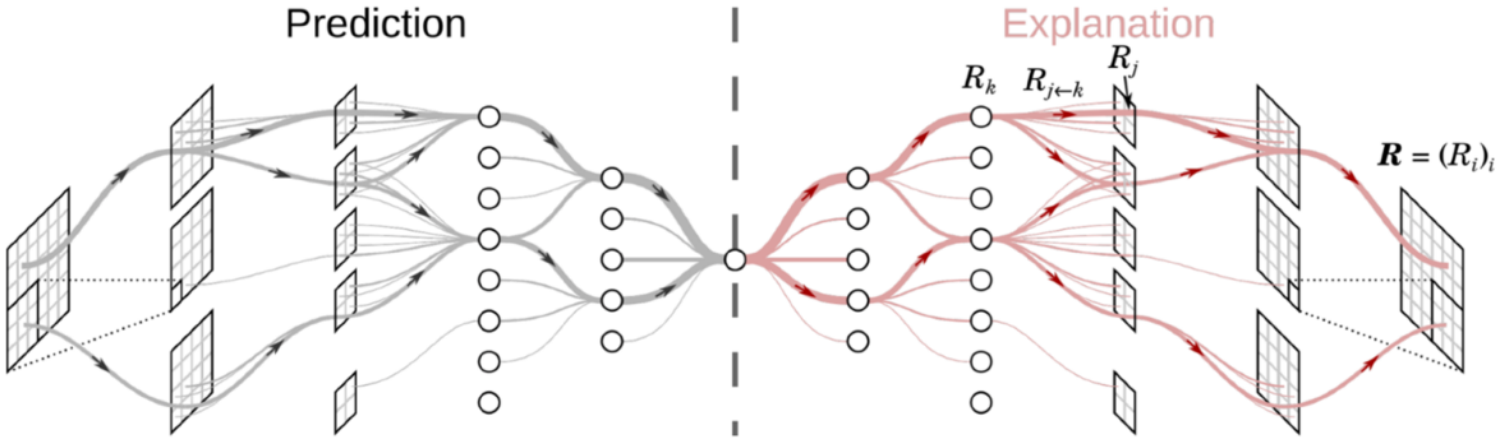
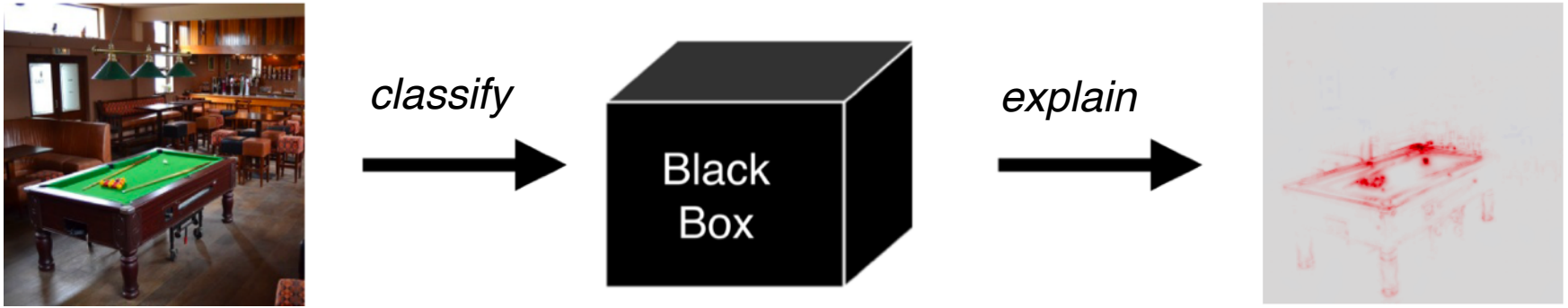
Concept-Level Explainable AI

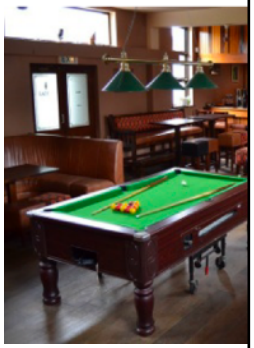
Wojciech Samek
TU Berlin & Fraunhofer HHI



Explain? Yes We Can



Explain? Yes We Can



Baehrens'10
Gradient

Sundarajan'17
Int Grad

Zintgraf'17
Pred Diff

Ribeiro'16
LIME

Haufe'15
Pattern

Zurada'94
Gradient

Symonian'13
Gradient

Zeiler'14
Occlusions

Fong'17
M Perturb

Kindermans'17
PatternNet

Lundberg'17
Shapley

Poulin'06
Additive

Bazen'13
Taylor

Montavon'17
Deep Taylor

Shrikumar'17
DeepLIFT

Landecker'13
Contrib Prop

Zeiler'14
Deconv

Bach'15
LRP

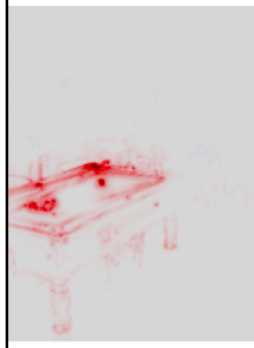
Zhang'16
Excitation BP

Springenberg'14
Guided BP

Caruana'15
Fitted Additive

Zhou'16
GAP

Selvaraju'17
Grad-CAM



XAI 1.0: Layer-wise Relevance Propagation

input x

Black Box

Rooster

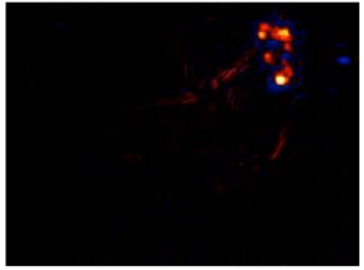
prediction $f(x)$

Idea: Decompose function

$$\sum_i R_i = f(x)$$

Explain prediction

(how much each pixel contributes to prediction)



heatmap

(Bach et al., PLOS ONE, 2015)

Layer-wise Relevance Propagation is a general approach to explain predictions of AI.

XAI 1.0: Layer-wise Relevance Propagation

Classification

cat

rooster

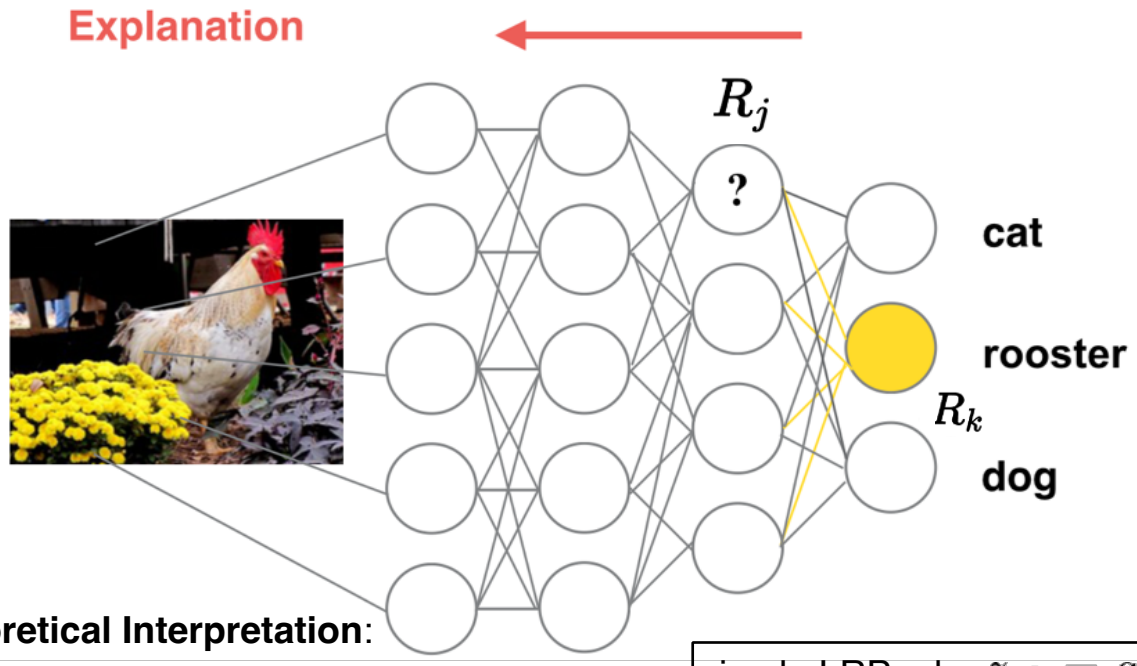
dog

Initialization

$R_k = f(x)$

Idea: Redistribute the evidence for class rooster back to image space.

XAI 1.0: Layer-wise Relevance Propagation



how much has j contributed to activation of k

LRP:

(1) decompose

$$R_{j \leftarrow k} = \frac{z_{jk}}{z_k} R_k$$

(2) aggregate

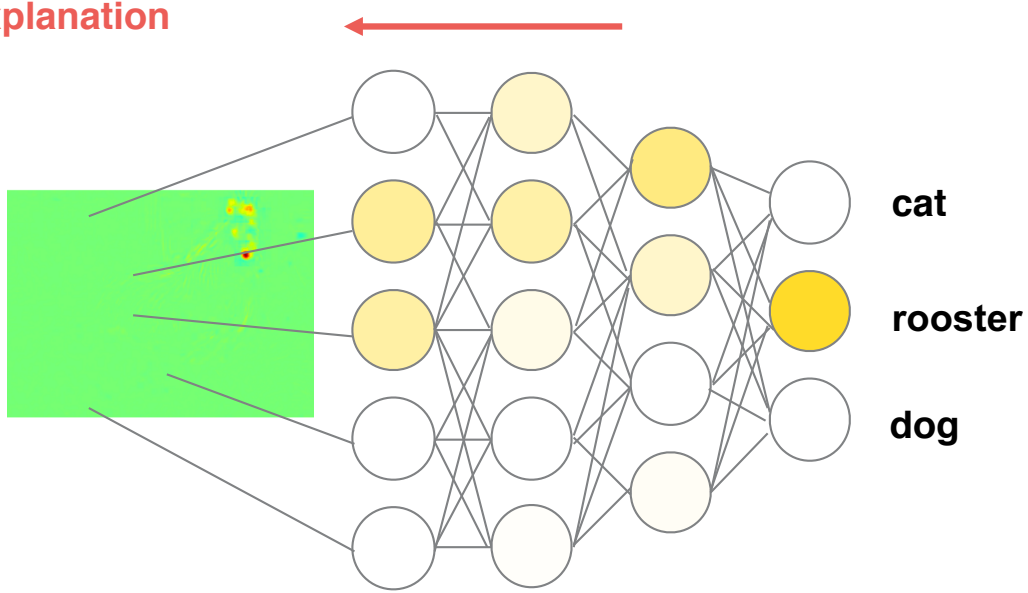
$$R_j = \sum R_{j \leftarrow k}$$

Theoretical Interpretation:
Deep Taylor Decomposition

simple LRP rule: $z_{jk} = a_j w_{jk}$

XAI 1.0: Layer-wise Relevance Propagation

Explanation

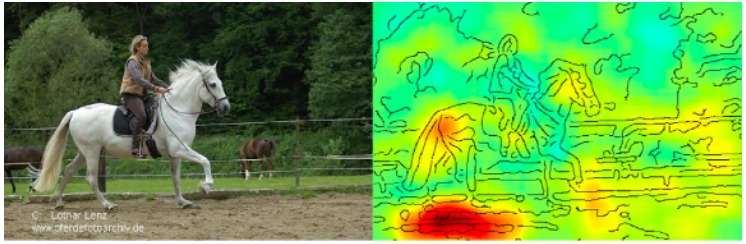


Layer-wise relevance conservation

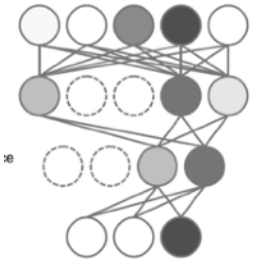
$$\sum_i R_i = \ldots = \sum_i R_i^{(l)} = \sum_j R_j^{(l+1)} = \ldots = f(x)$$

More Than Just Explaining ...

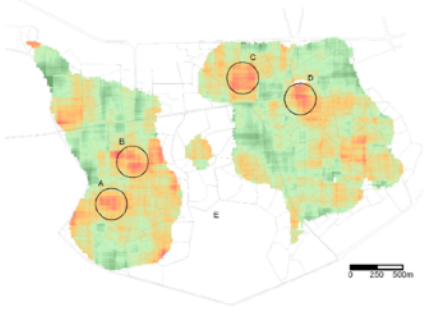
Validation & Debugging

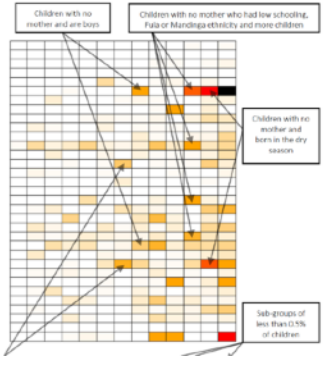


Pruning & Quantization

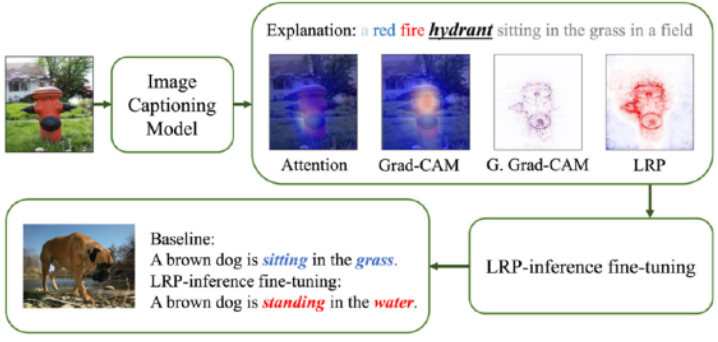


Scientific Insights



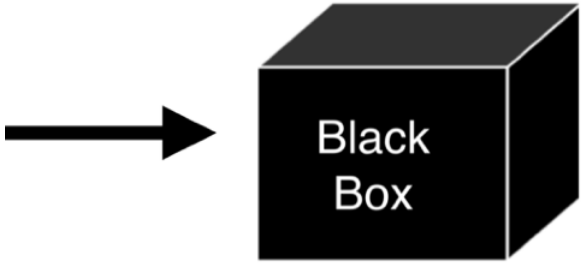


XAI-Based Model Improvement



How understandable is the explanation ?

Limitations of Attribution Maps

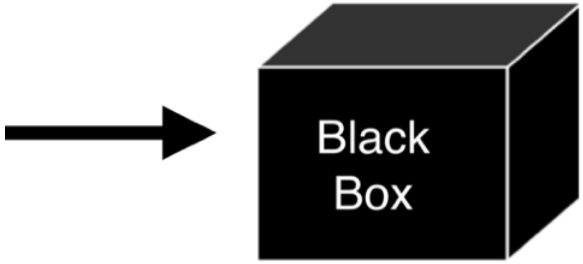


prediction:
"25-32 years old"

explain:
"compute heatmap"

interpret:
"laughing is relevant"

Limitations of Attribution Maps



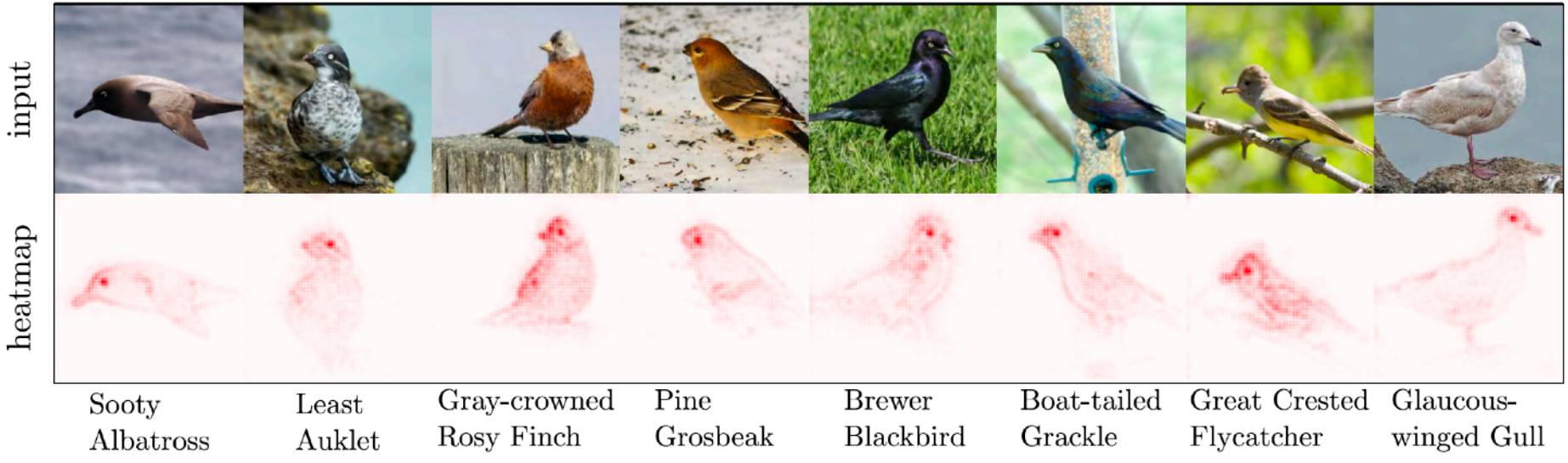
prediction:
"25-32 years old"

explain:
"compute heatmap"

interpret:
"color of teeth is relevant"

Problem: We know *where* something relevant is not *what* it is.

Limitations of Attribution Maps



Problem: Loss of explanatory value due to superposition of concepts (all relevant).

Entering XAI 2.0

From "Where" to "What": Towards Human-Understandable Explanations through Concept Relevance Propagation

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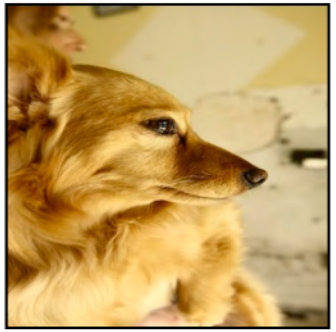
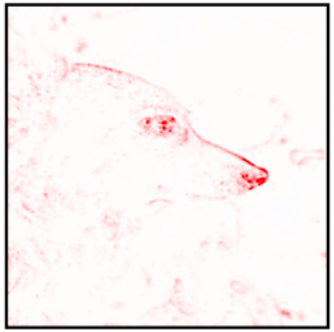
Sebastian Bosse[1] Thomas Wiegand[1,2,3] Wojciech Samek[1,2,3,†]
Sebastian Lapuschkin[1,†]

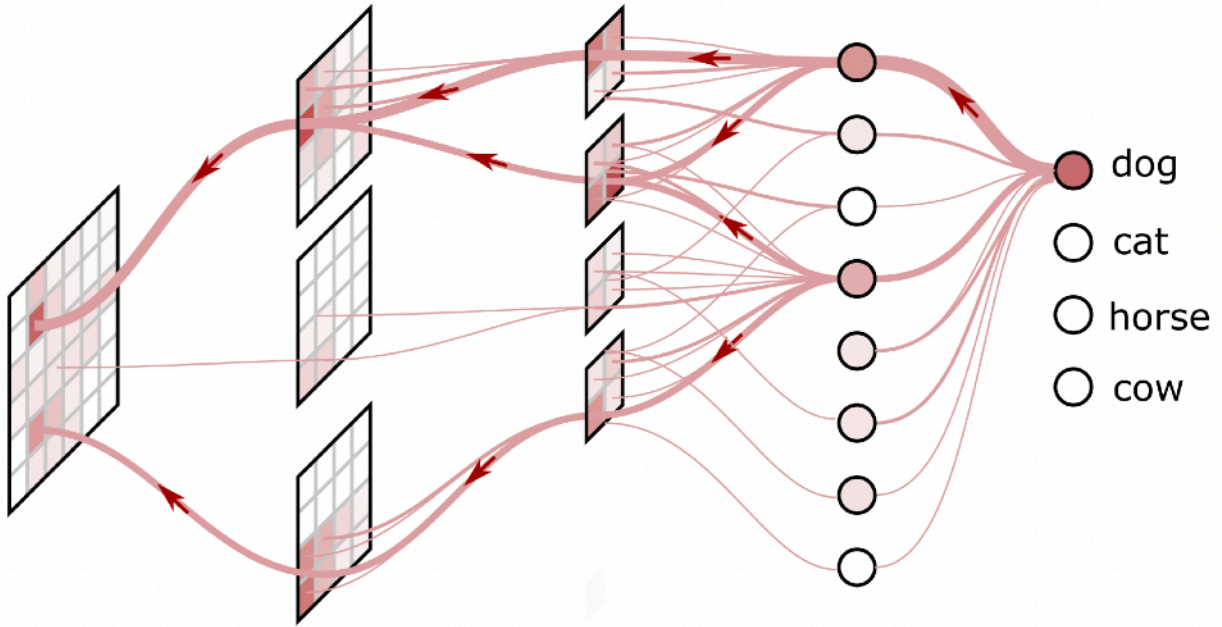
https://arxiv.org/abs/2206.03208

Concept Relevance Propagation

(i) Conditional Explanations

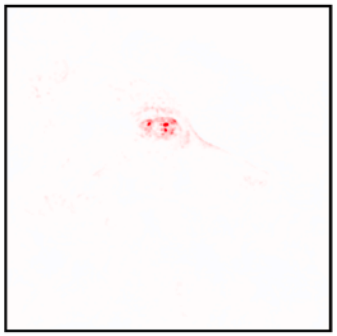


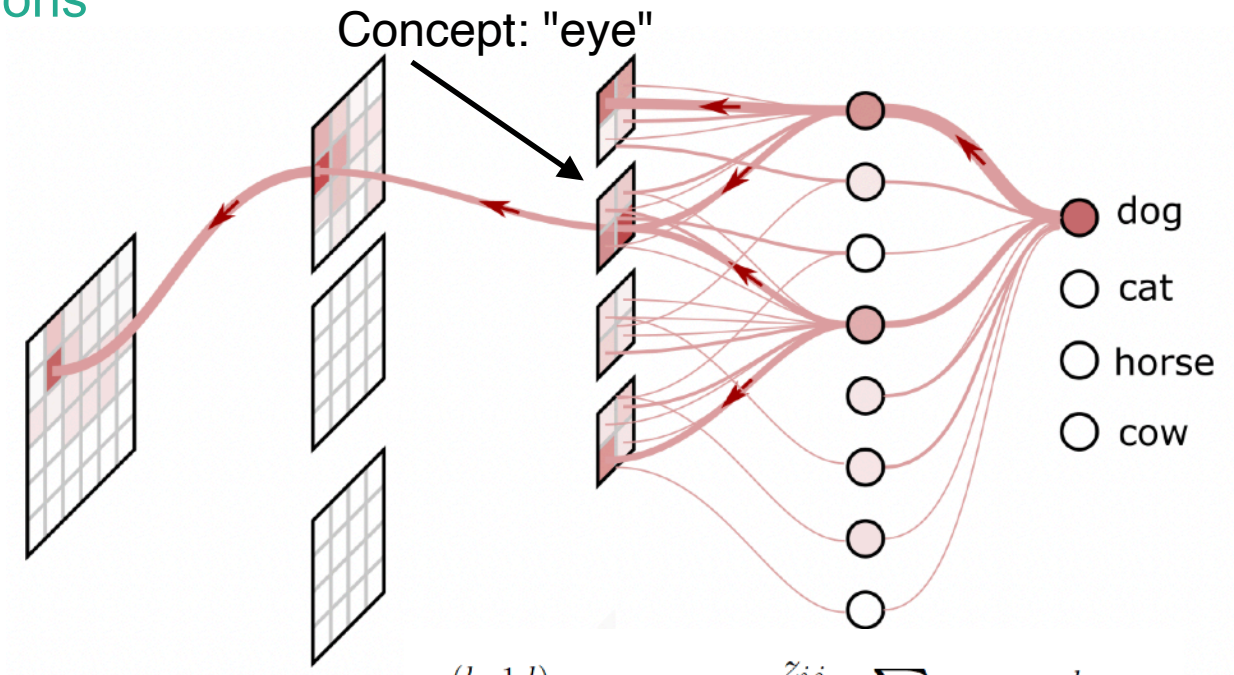




Concept Relevance Propagation

(i) Conditional Explanations

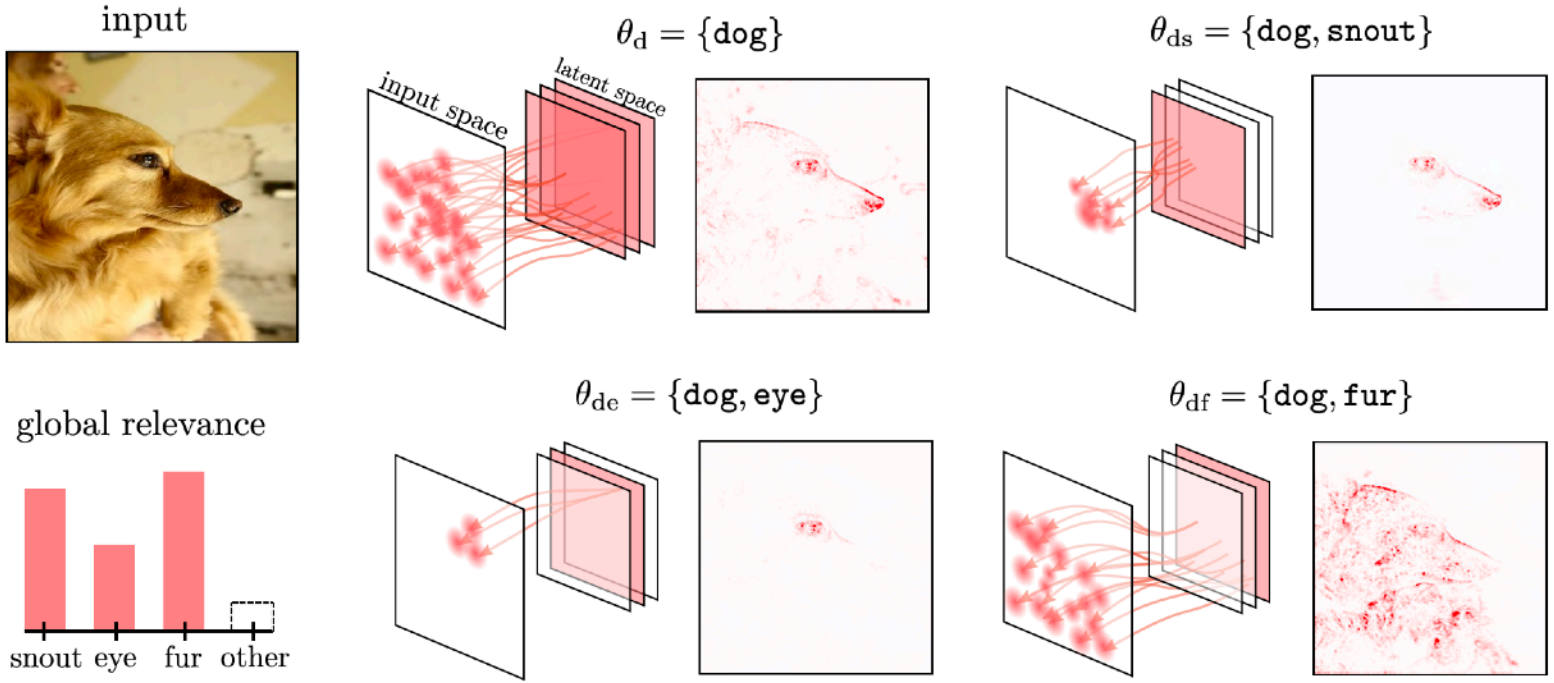




$$R_{i\leftarrow j}^{(l-1,l)}(\mathbf{x}|\theta\cup\theta_l) = \frac{z_{ij}}{z_j}\cdot\sum_{c_l\in\theta_l}\delta_{jc_l}\cdot R_j^l(\mathbf{x}|\theta)$$

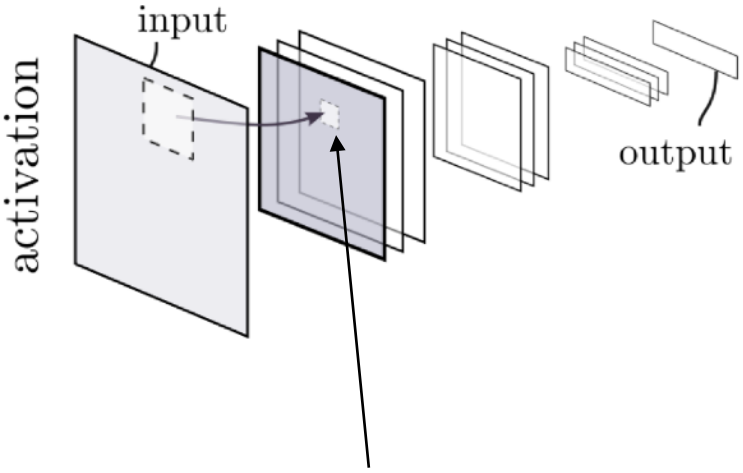
Concept Relevance Propagation

(i) Conditional Explanations



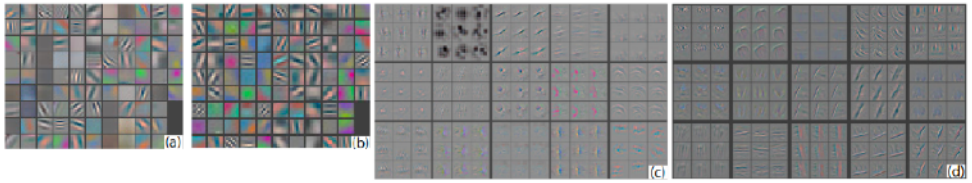
But usually we do not know what concept the channel is encoding?

Addressing the "What"-Question



What does this channel encode?

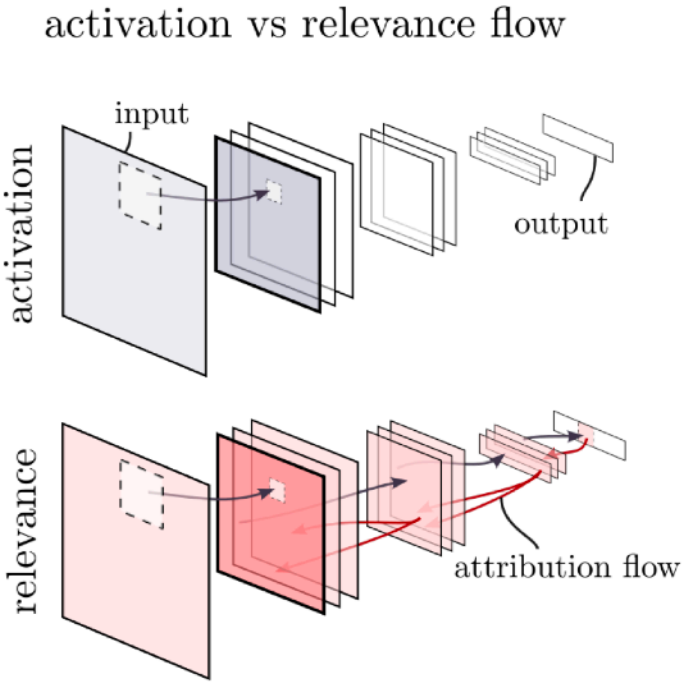
(Zeiler et al., 2014) feature visualization



(Chen et al., 2020) data-based activation maximization

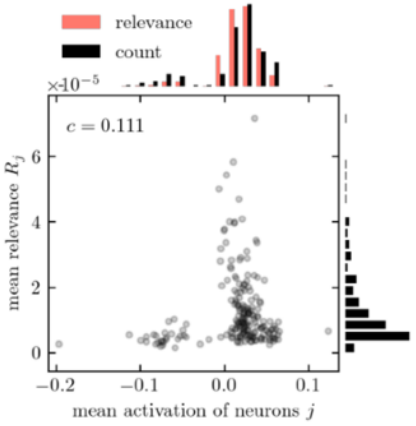
Relevance Maximization

or why Activation Maximization is not the Answer



activation = stimulation
without task-context

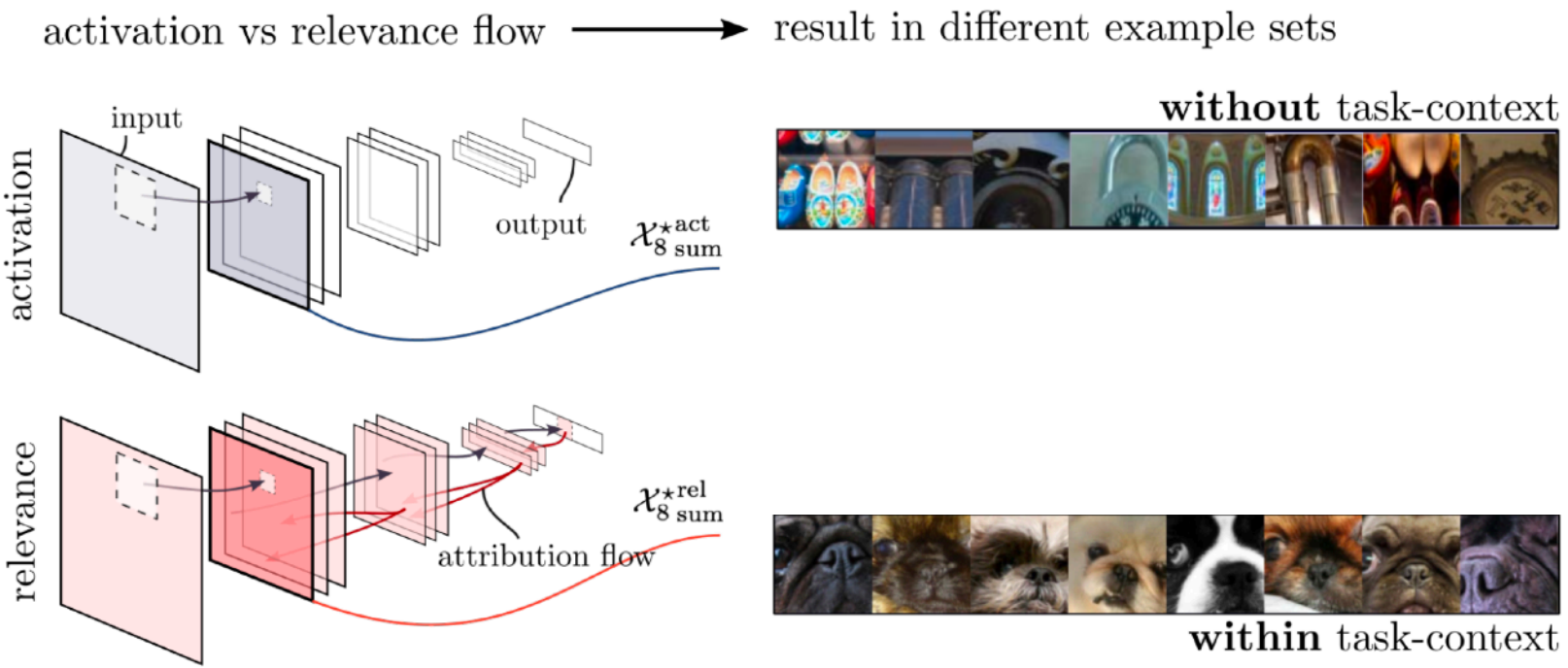
relevance = usufulness
within a task-context



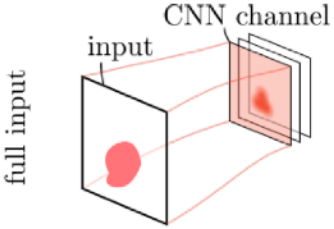
practically no correlation between activation and relevance

Concept Relevance Propagation

(ii) Understand the "What"-Question through RelMax



More Insights Into Reference Samples



typical scenario in literature:

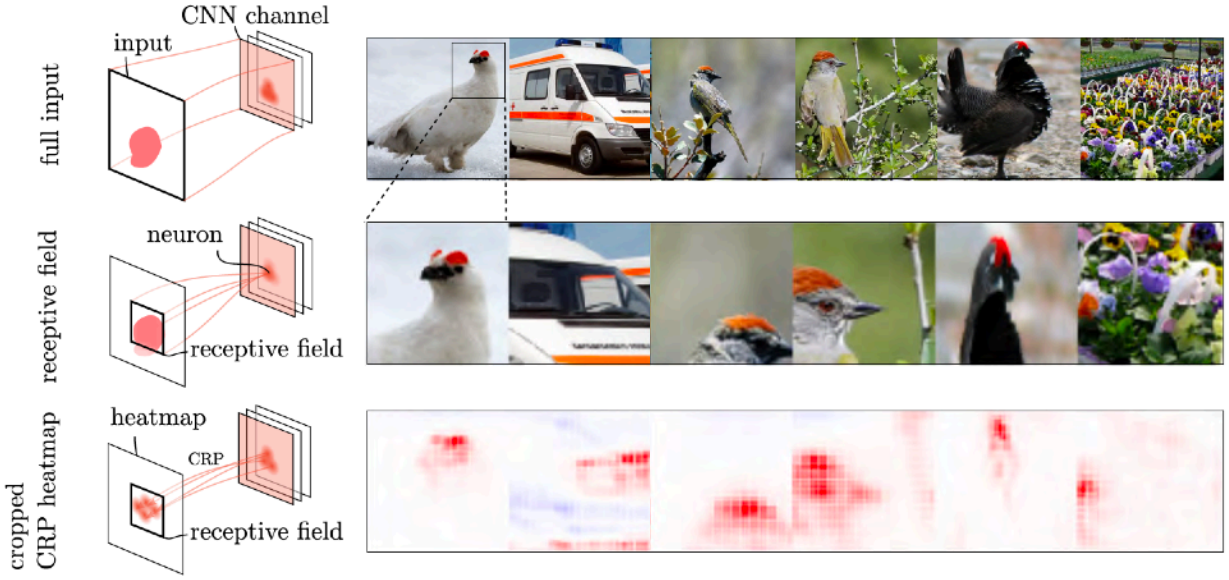
provide **full input-sized** explanatory examples.

?

which one is / are the relevant feature(s) ?

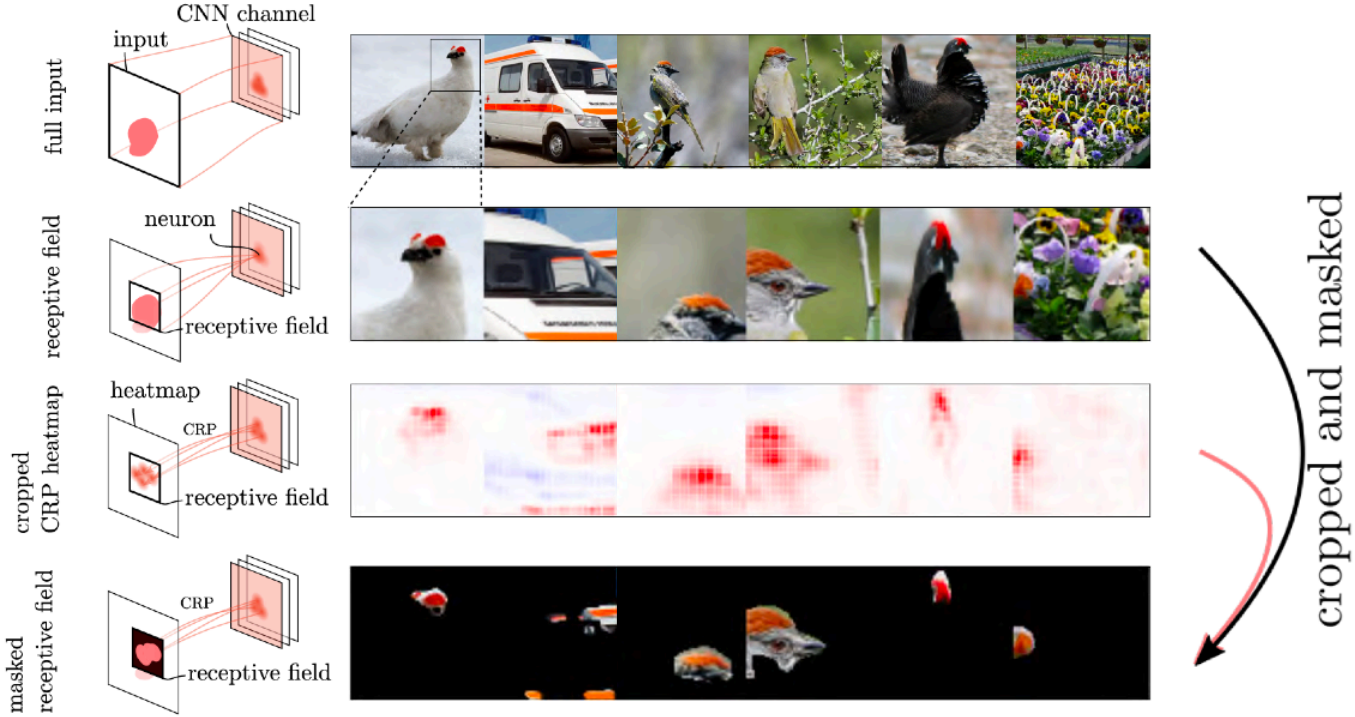
More Insights Into Reference Samples

More Insights Into Reference Samples

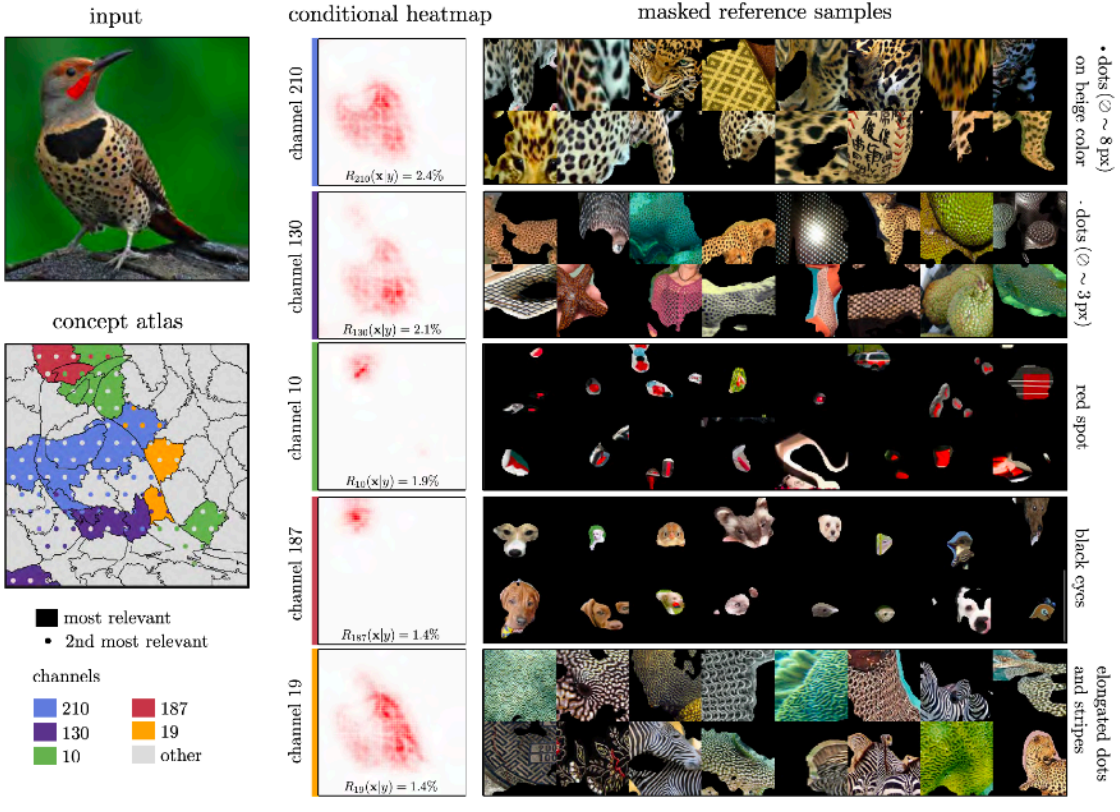


Concept Relevance Propagation

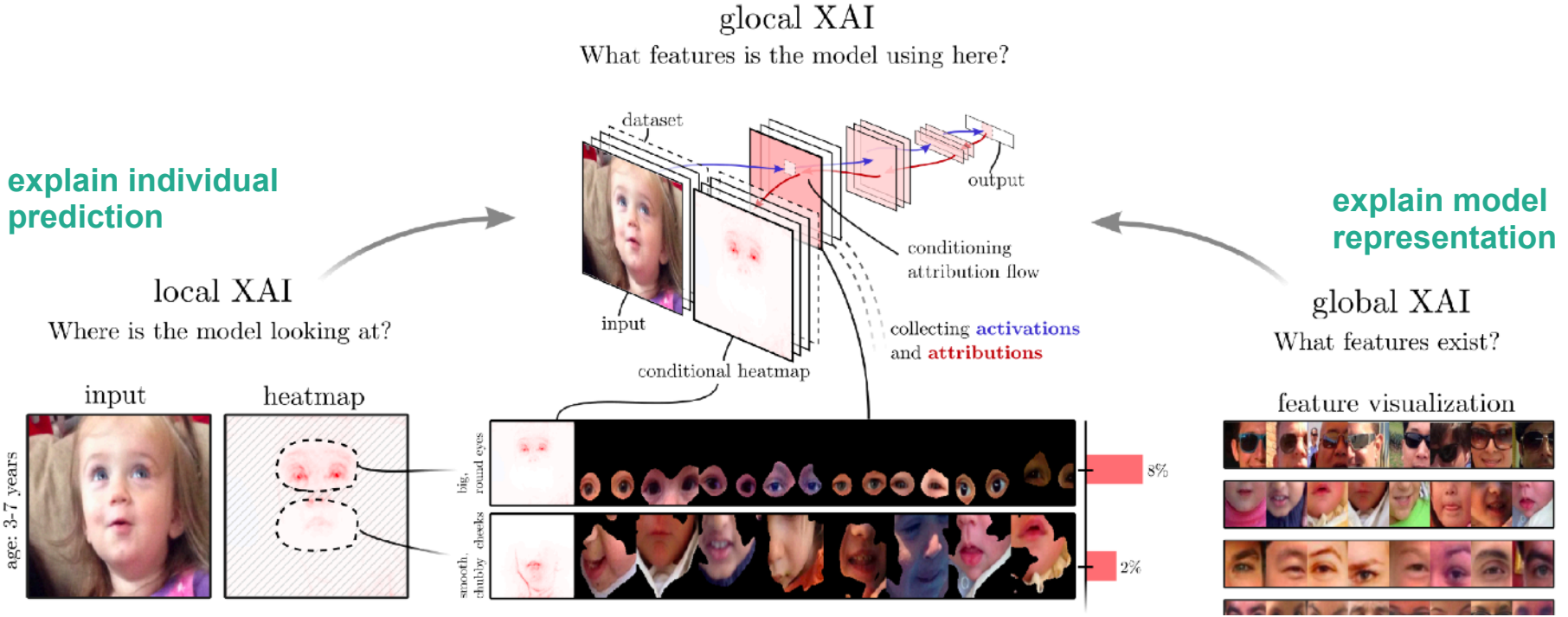
(iii) Highlight the Key Feature of a Concept



Concept Atlas

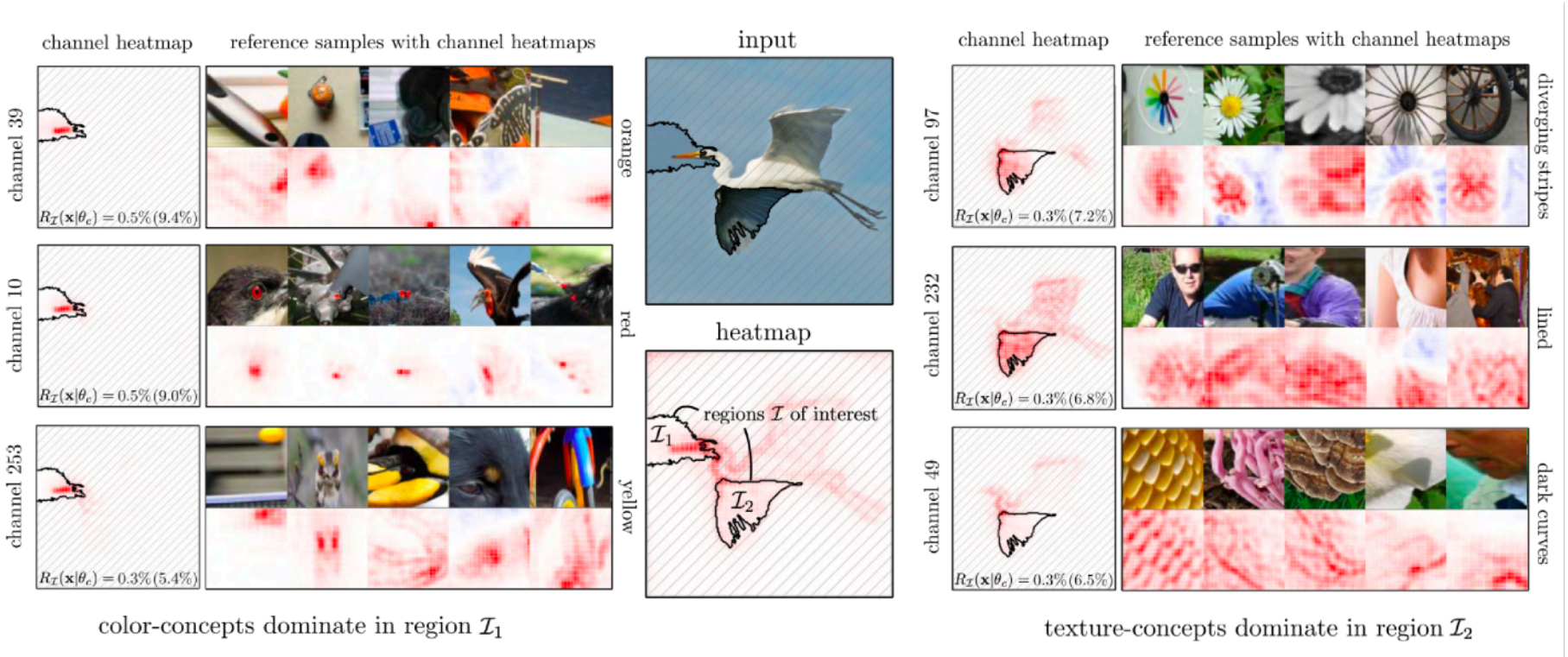


Concept Relevance Propagation

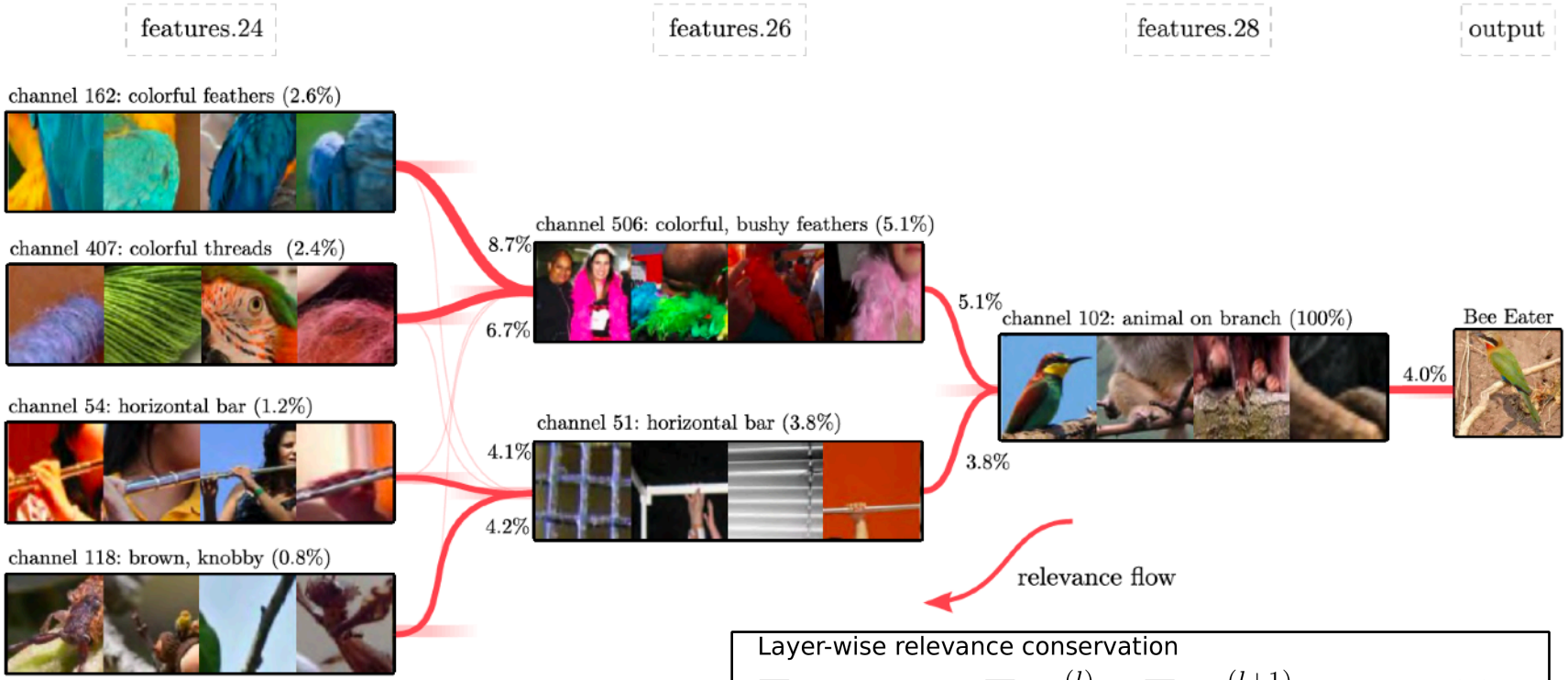


(Achtibat et al. 2022)

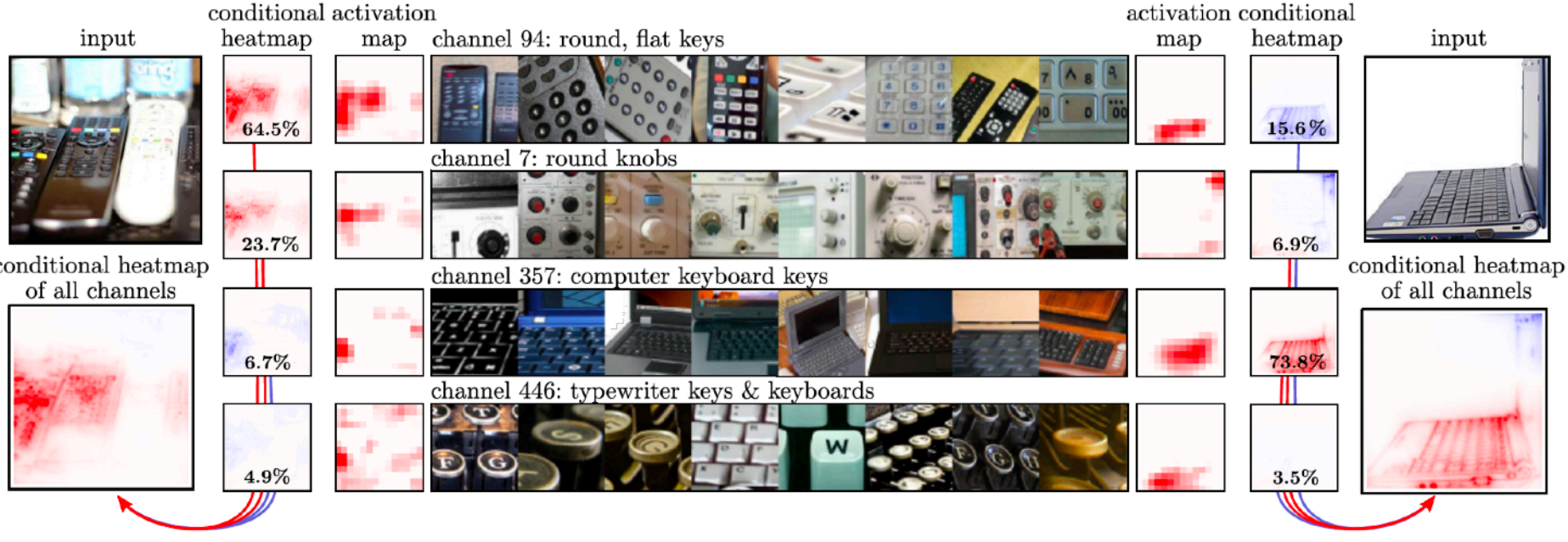
Local Analyses as a Bottom-Up Complement



Concept Composition

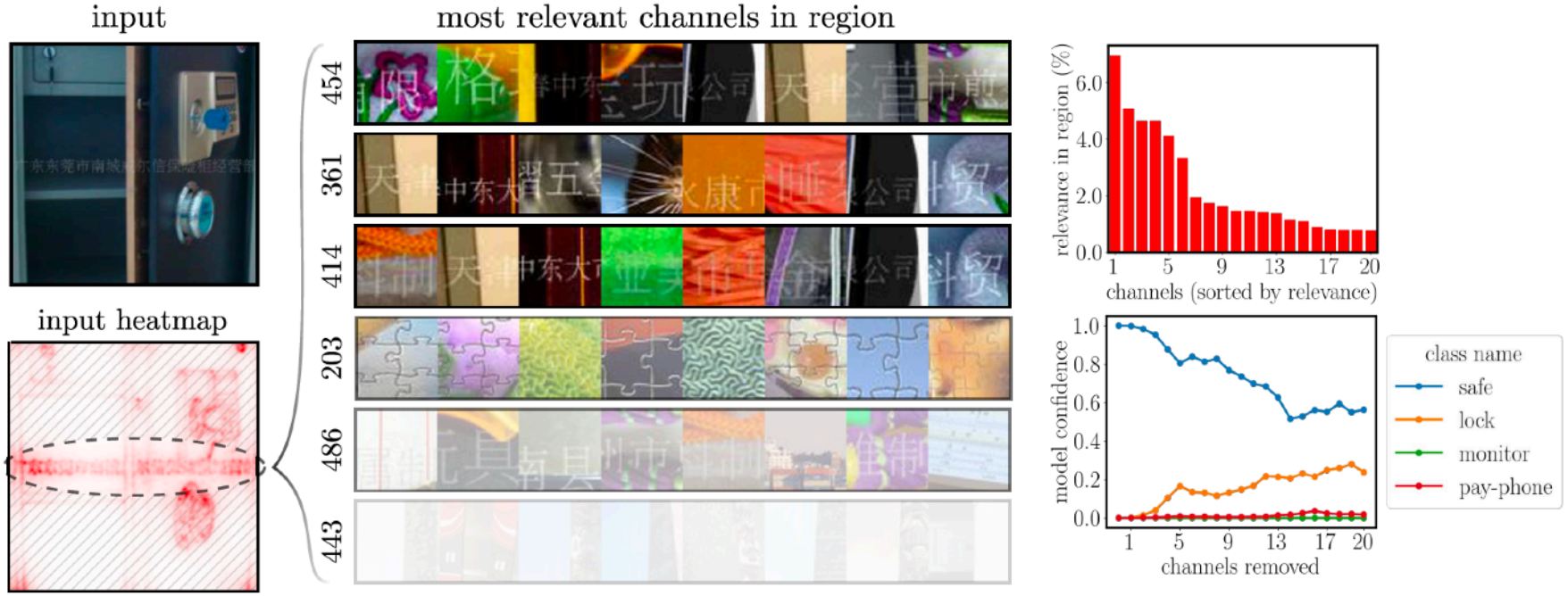


Understanding Concept Spaces



Identifying Clever Hans

Concept-based Reverse Search



Identifying Clever Hans

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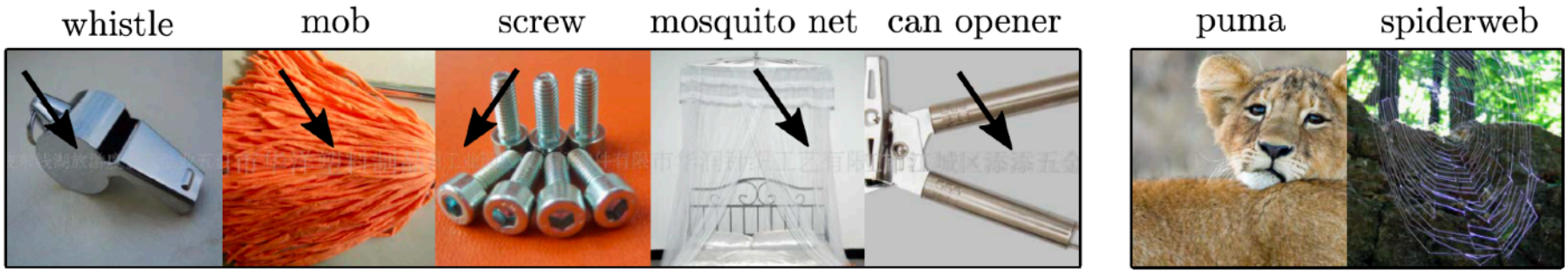
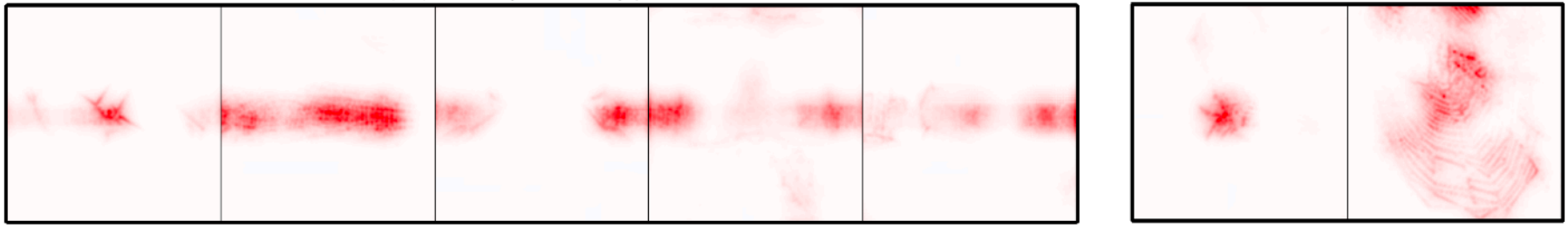
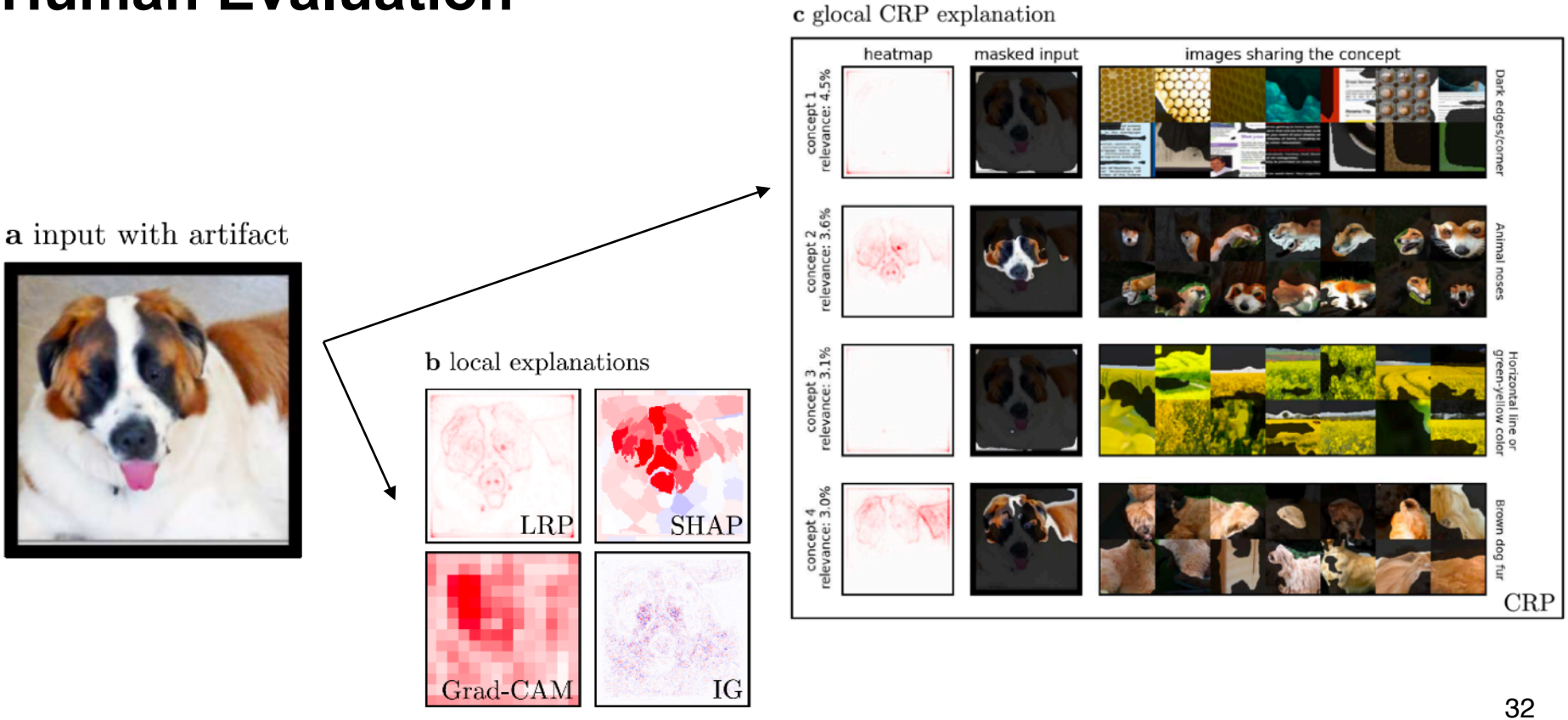


conditional heatmap $R(\mathbf{x}|\theta = \{c_{361}, y\})$

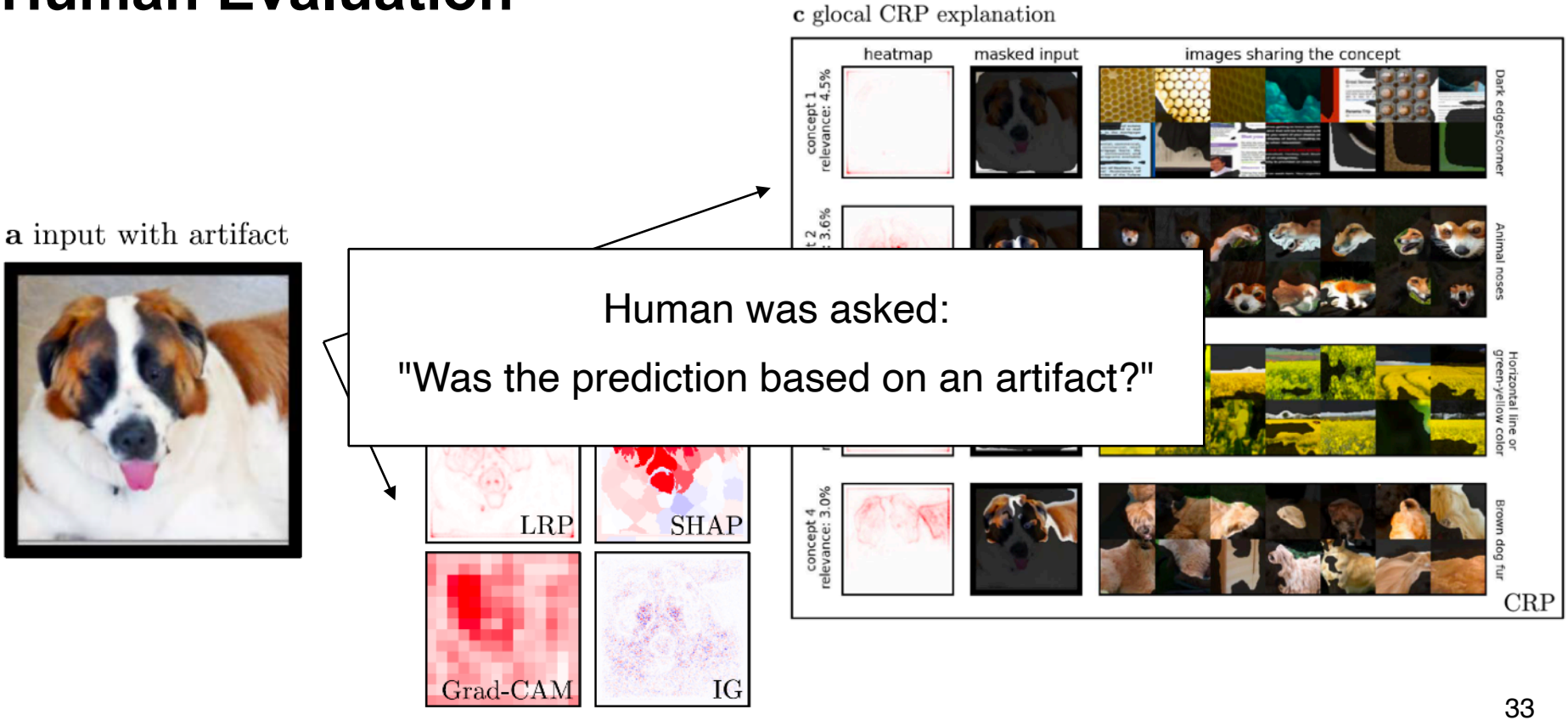


Fixing the Model: Adapt encoding space globally [Anders, Weber, et al. 2022] or rather outcome-dependently?

Human Evaluation

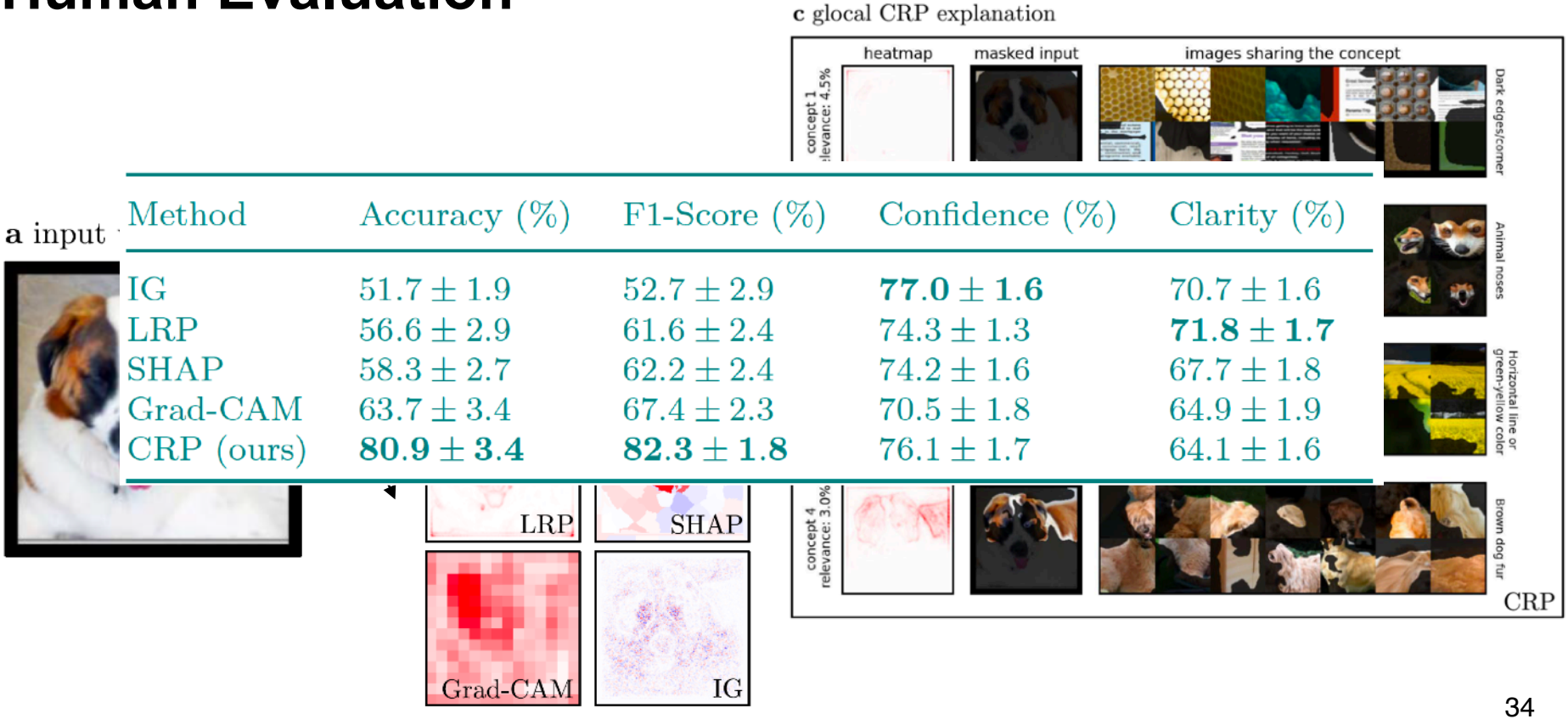


Human Evaluation

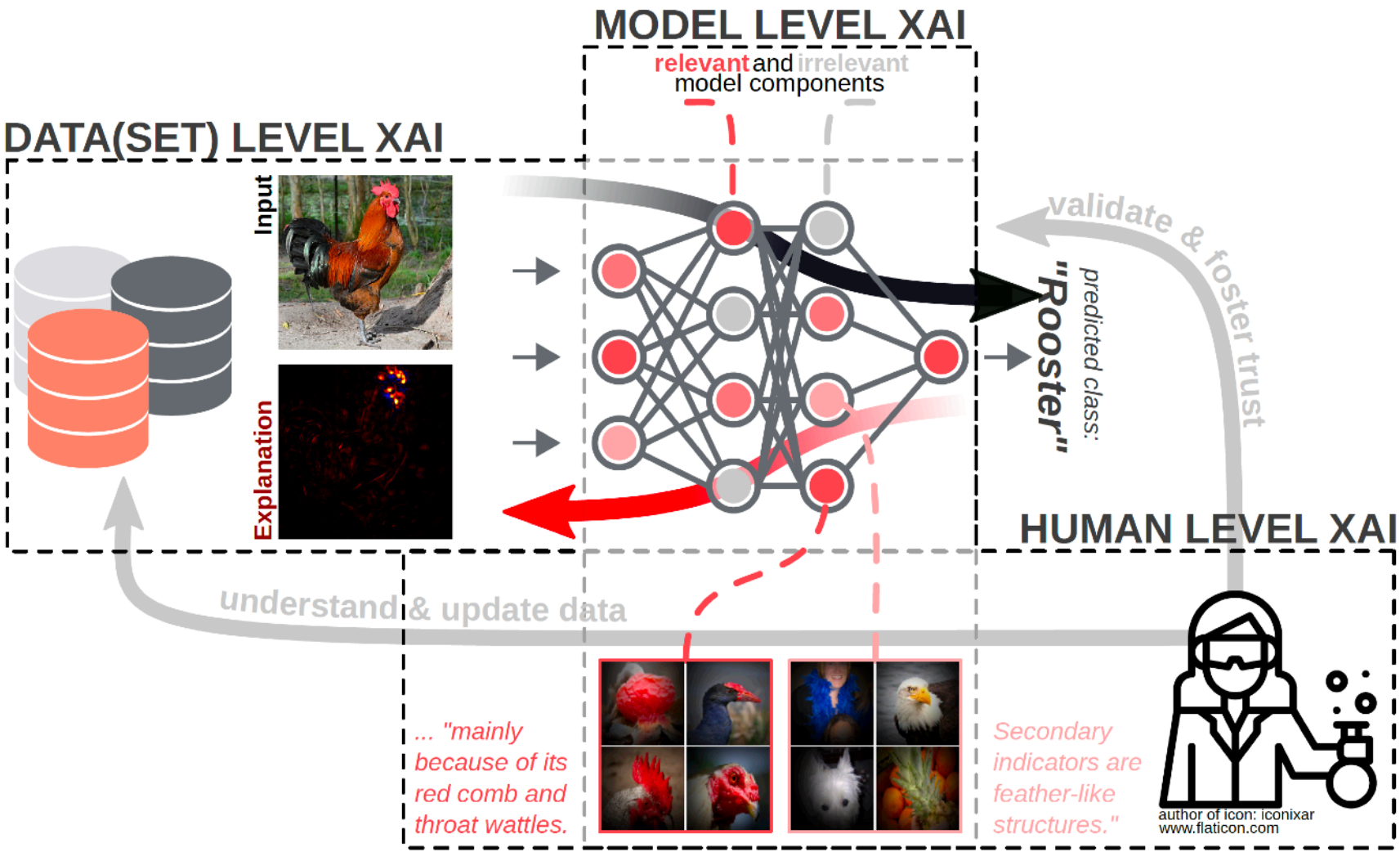


Human Evaluation

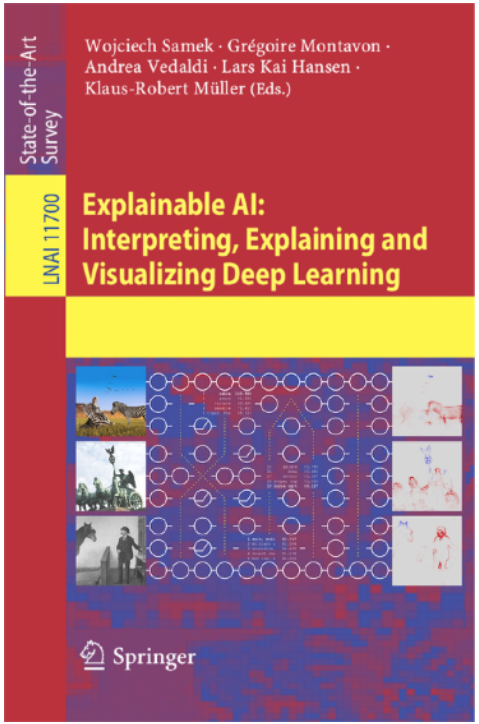
Method	Accuracy (%)	F1-Score (%)	Confidence (%)	Clarity (%)
IG	51.7 ± 1.9	52.7 ± 2.9	$\mathbf{77.0 \pm 1.6}$	70.7 ± 1.6
LRP	56.6 ± 2.9	61.6 ± 2.4	74.3 ± 1.3	$\mathbf{71.8 \pm 1.7}$
SHAP	58.3 ± 2.7	62.2 ± 2.4	74.2 ± 1.6	67.7 ± 1.8
Grad-CAM	63.7 ± 3.4	67.4 ± 2.3	70.5 ± 1.8	64.9 ± 1.9
CRP (ours)	$\mathbf{80.9 \pm 3.4}$	$\mathbf{82.3 \pm 1.8}$	76.1 ± 1.7	64.1 ± 1.6



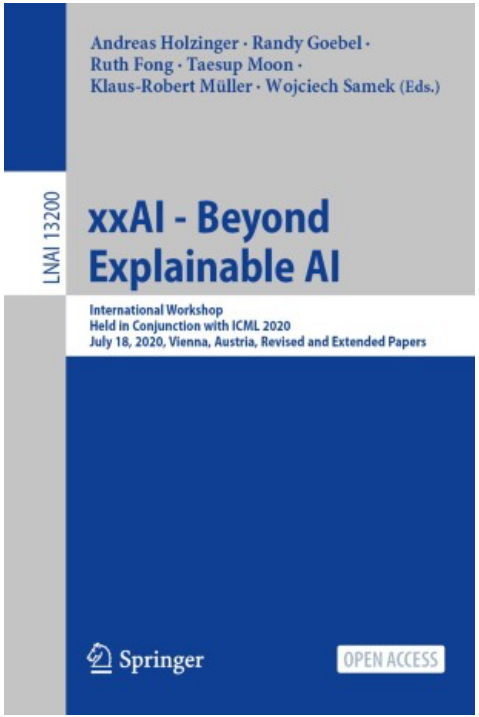
Conclusion


MODEL LEVEL XAI
relevant and irrelevant model components
DATA(SET) LEVEL XAI
Input
Explanation
validate & foster trust
predicted class:
"Rooster"
HUMAN LEVEL XAI
understand & update data
... "mainly because of its red comb and throat wattles.
Secondary indicators are feather-like structures."
author of icon: iconixar
www.flaticon.com

From XAI to XXAI



(2019)



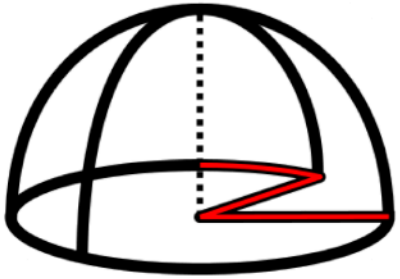
(2022)

New directions in XAI:

- Explain & Improve
- Concept-Level XAI
- Regression, RL, Unsup. L.
- Non-interpretable domains
- Beyond Explaining

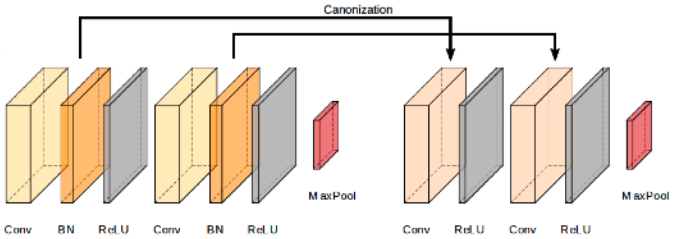
...

Toolboxes



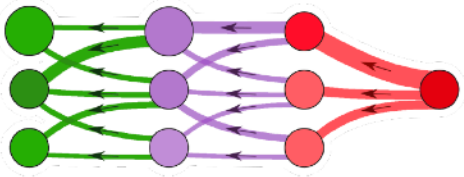
zennit

Canonization



QUANTUS

iNNvestigate



ExplainableAI.jl

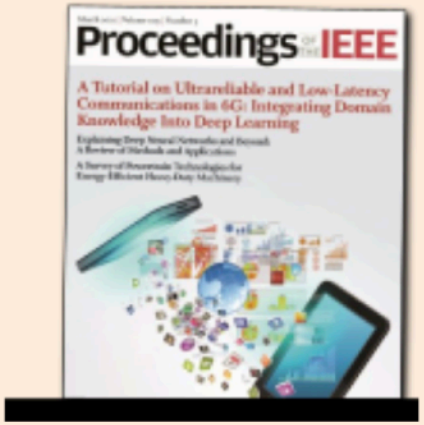
Refs: [Alber *et al.* 2019; Anders, Neumann, *et al.* 2021; Motzkus *et al.* 2022; Hedström *et al.* 2022; Hill 2022]

References

W Samek, G Montavon, S Lapuschkin, C Anders, KR Müller

Explaining Deep Neural Networks and Beyond: A Review of Methods and Applications

Proceedings of the IEEE, 109(3):247-278, 2021



With the broader and highly successful usage of machine learning (ML) in industry and the sciences, there has been a growing demand for explainable artificial intelligence (XAI). Interpretability and explanation methods for gaining a better understanding of the problem-solving abilities and strategies of nonlinear ML, in particular, deep neural networks, are, therefore, receiving increased attention. In this work, we aim to: 1) provide a timely overview of this active emerging field, with a focus on “ post hoc ” explanations, and explain its theoretical foundations; 2) put interpretability algorithms to a test both from a theory and comparative evaluation perspective using extensive simulations; 3) outline best practice aspects, i.e., how to best include interpretation methods into the standard usage of ML; and 4) demonstrate successful usage of XAI in a representative selection of application scenarios. Finally, we discuss challenges and possible future directions of this exciting foundational field of ML.

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