On the role of abductive reasoning in semantic image segmentation

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Next in Line...

Introduction

- Deep Learning (DL) has shown significant advancements and usage in the last decade
- DL has reached important milestones in many fields: speech recognition, autonomous driving, computer vision, etc.

Benefits

- automatically learn pattern
- efficiently process high dimensional data
- usage of unstructured data

Limits

- data hungry
- not interpretable or explainable
- lack of flexibility

Context

- Computer Vision includes many tasks
  - object detection, scene classification, object recognition, ...
- Semantic Segmentation is a technique that enables to differentiate different objects in an image
  - it facilitates the description, categorisation, and visualisation of regions of interest in a picture
  - it can be considered an image classification task at a pixel level: associate each pixel with a specific class label

Context

- For each training image: each pixel is labeled with a semantic category
  - requirement for annotated data to succeed
    - → large number of annotations
  - precise localisation is hard to annotate
- Deeper networks work better
  - more abstract concepts
  - not sustainable structures
- Not ready for the real-world scenario
  - real world perturbations: image degradation, distortion, occlusion, etc.
  - need to continuously adapt themselves to new contexts and data

Motivation

Propose alternatives to conventional systems $\Rightarrow$ symbolic and sub-symbolic systems integration, i.e. Neuro-Symbolic architectures

1. Reduction in learning time
2. Decrease in the amount of data required to train the model
3. Greater propensity for the model to adapt to previously un-observed situations
4. Provides the system with the ability to abstract from its predictions
5. Enable the model to obtain some explainability and interpretability characteristics

Next in Line...

Abduction

- Abduction is a form of reasoning used to explain an observation by inferring causes from observed effects $\rightarrow$ *explanatory process*.

$$KB \cup H \models O.$$

Integrate abductive reasoning into the model

- use H to provide explanations for O
- use H to overcome the need of retraining the model given a new O'
- use H to reason about plausible inferences in the case of uncertainty

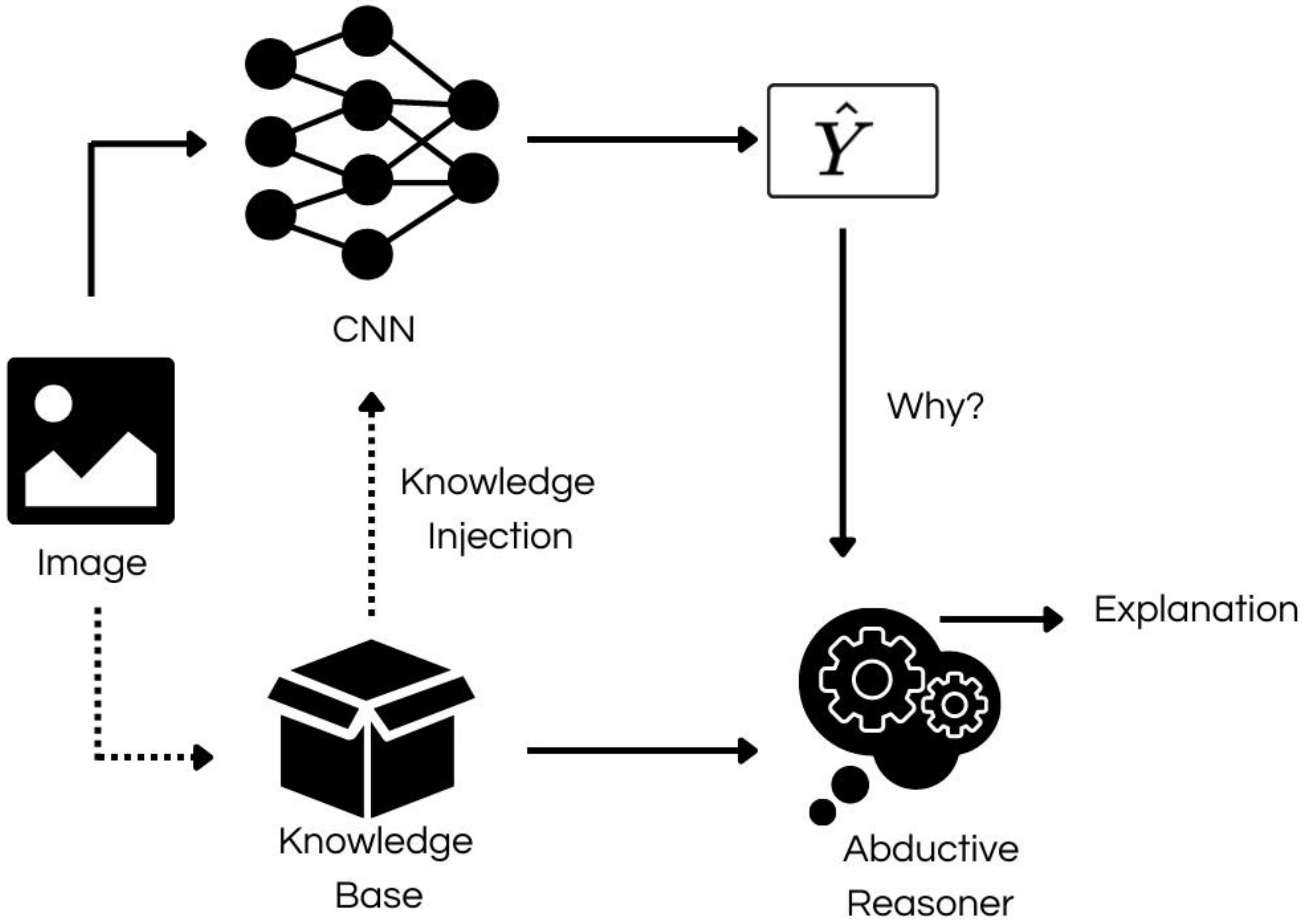
Challenges

1. Data scarcity
   - creation of fresh hypotheses as new potential examples: knowledge creation
2. Robustness
   - empower models with reasoning to shield against noise
   - new hypotheses enhance the model's ability to reason and make judgments in previously untested and undiscovered circumstances
3. Explainability
   - explain specific observations based on general knowledge
   - fortifying and enhancing the explainability of a model: generation of plausible explanations

Next in Line...

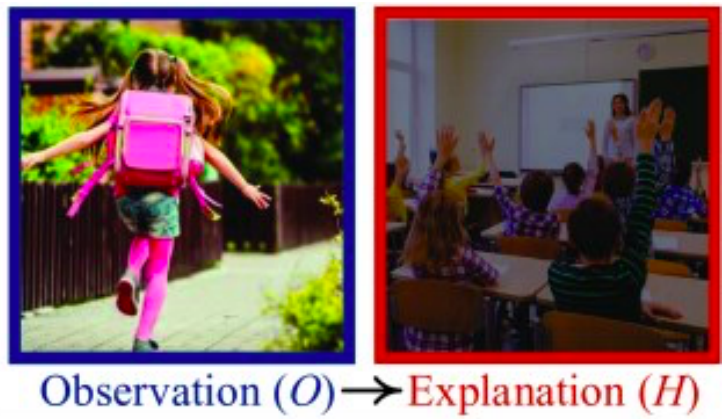
Framework I

Inject rules and provide post-hoc explanation via abductive reasoning.
Challenge (1), *Challenge (3)*



Framework I

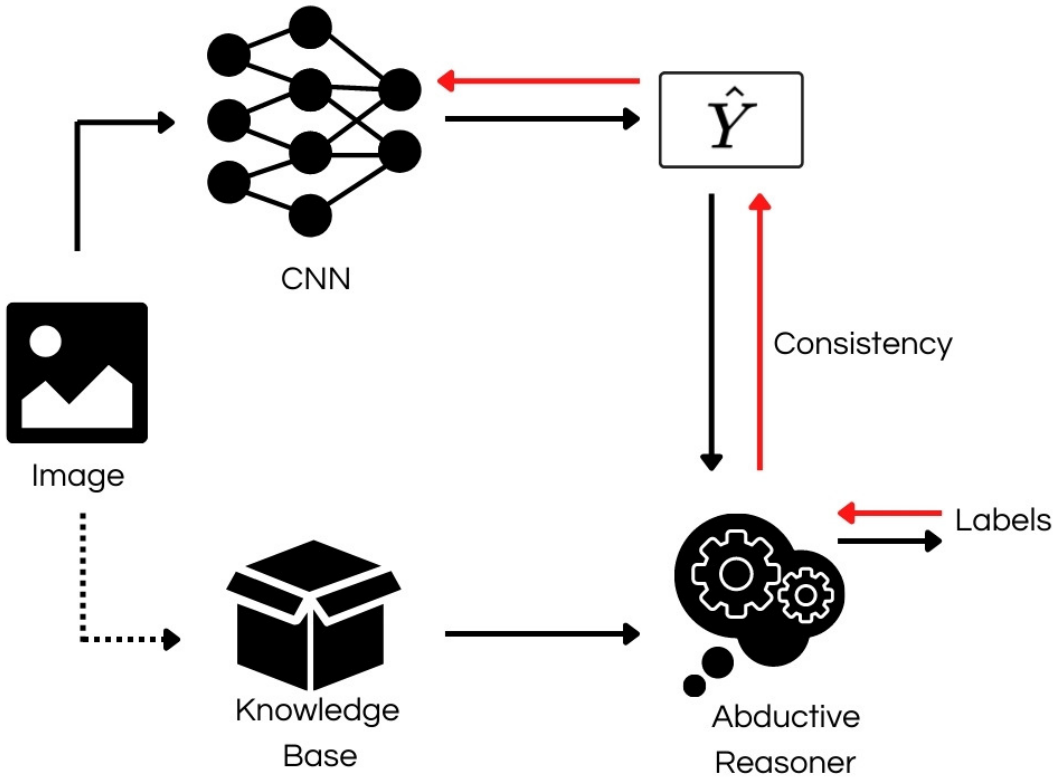
- Knowledge injection
  - Guided learning
    - i.e., altering the learning process
  - Predictor structuring
    - i.e., altering the structure
- Post-hoc explanation



[Liang et al., 2022]

Framework II

Revising model's output with abducibles.
Challenge (1), *Challenge (2)*



Framework II

- Bridging Machine Learning and Logical Reasoning by Abductive Learning[Dai et al., 2019]
  - Input: $D = \{(x_1, y_1), (x_2, y_2), ..., (x_n, y_n)\}$
  - Primitive symbols: $\mathcal{P} = (p_1, p_2, ..., p_r)$

$$KB \cup f(x_i) \models y_i.$$

1. Perception model f mapping raw data $\rightarrow$ primitive logic facts: $f : \mathcal{X} \rightarrow \mathcal{P}$
2. Abduce pseudo label (primitive logic facts) and find consistency btw perceived symbols and abducibles.
3. Correct and re-train f in case of inconsistency.

Next in Line...

Conclusions

Summing up

- Use of *abducibles* to enable model training and adaption without the need for a large number of samples
- Construction of an *explainable framework*: incorporation of knowledge representation and abductive reasoning into black-box technologies
- Connection between high-level *reasoning* and low-level *perception*
- ? How to combine well symbolic and sub-symbolic AI more efficiently is still an *open question*

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References

[Dai et al., 2019] Dai, W.-Z., Xu, Q., Yu, Y., and Zhou, Z.-H. (2019).

Bridging machine learning and logical reasoning by abductive learning.

In Wallach, H., Larochelle, H., Beygelzimer, A., d'Alché Buc, F., Fox, E., and Garnett, R., editors, *Advances in Neural Information Processing Systems*, volume 32. Curran Associates, Inc.

https://proceedings.neurips.cc/paper/2019/hash/9c19a2aa1d84e04b0bd4bc888792bd1e-Abstract.html.

[Liang et al., 2022] Liang, C., Wang, W., Zhou, T., and Yang, Y. (2022).

Visual abductive reasoning.

In *2022 IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR 2022)*. IEEE Press

DOI:10.1109/CVPR52688.2022.01512.