Towards Open-domain Generation of Programs from Natural Language

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@ UT Austin 10/29/2018

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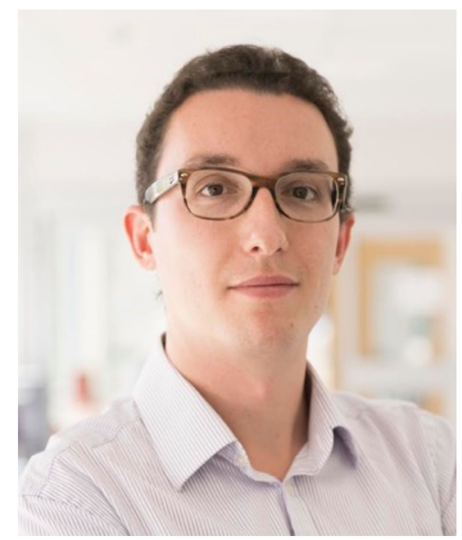
Acknowledgements

Based on work w/

Pengcheng Yin, Bogdan Vasilescu



Bowen Deng, Edgar Chen, Junxian He, Chunting Zhou, Shirley Hayati, Raphaël Olivier, Pravalika Avvaru, Anthony Tomasic

Supported by NSF

Coding =
Concept → Implementation

→ `x.sort(reverse=True)`

The (Famous) Stack Overflow Cycle

Formulate the Idea

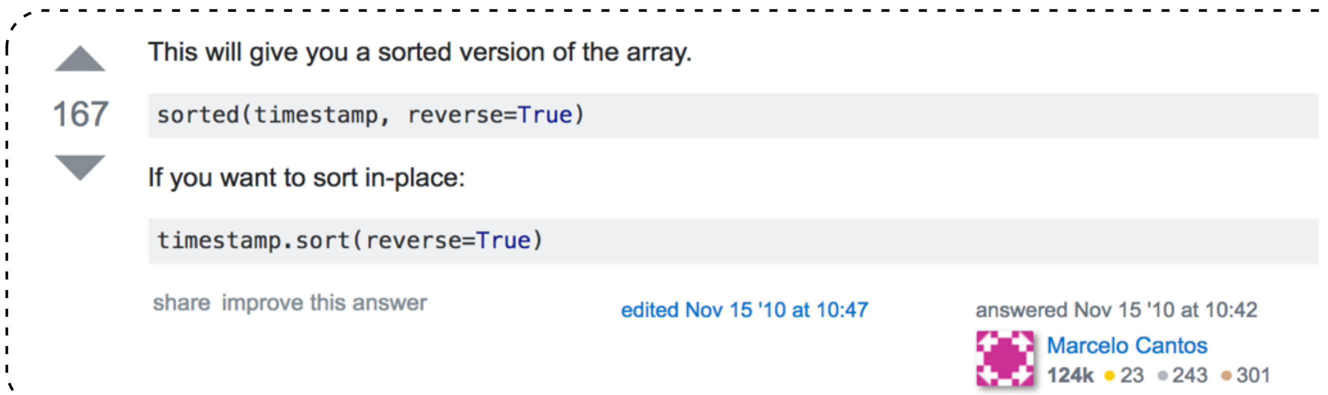
sort my_list in descending order

Search the Web

python sort list in descending order

Google stackoverflow

Browse thru. results


167

This will give you a sorted version of the array.

```
sorted(timestamp, reverse=True)
```

If you want to sort in-place:

```
timestamp.sort(reverse=True)
```

share improve this answer

edited Nov 15 '10 at 10:47

answered Nov 15 '10 at 10:42

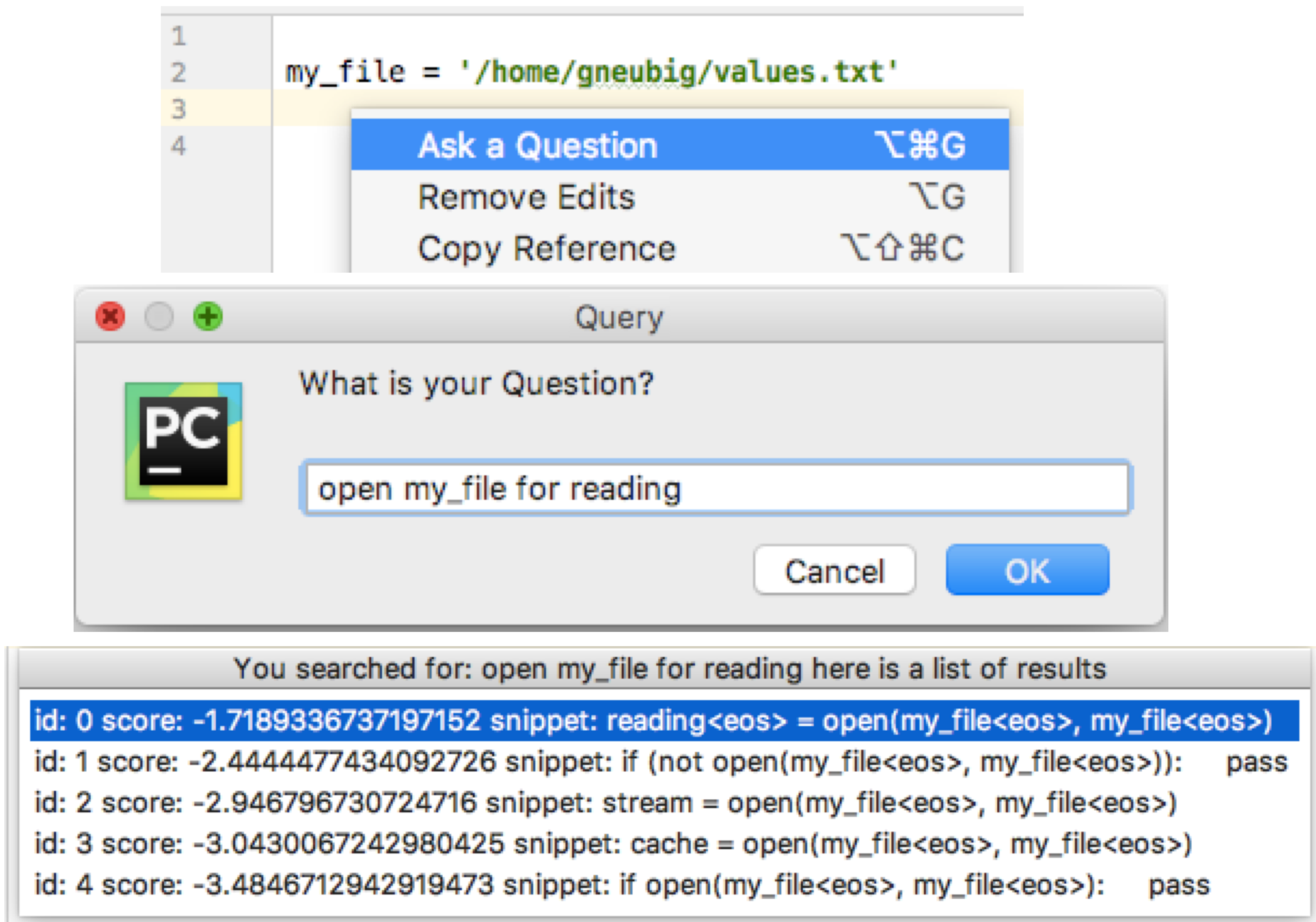
Marcelo Cantos

124k ● 23 ● 243 ● 301

Modify the result

```
sorted(my_list, reverse=True)
```

Goal: Assistive Interfaces for Programmers



Interface by William Qian

Today's Agenda: Can Natural Language Help?

- Syntactic models to create code from natural language
- Large-scale mining of open-domain datasets for code generation
- Semi-supervised learning for semantic parsing and code generation
- Retrieval-based Code Generation

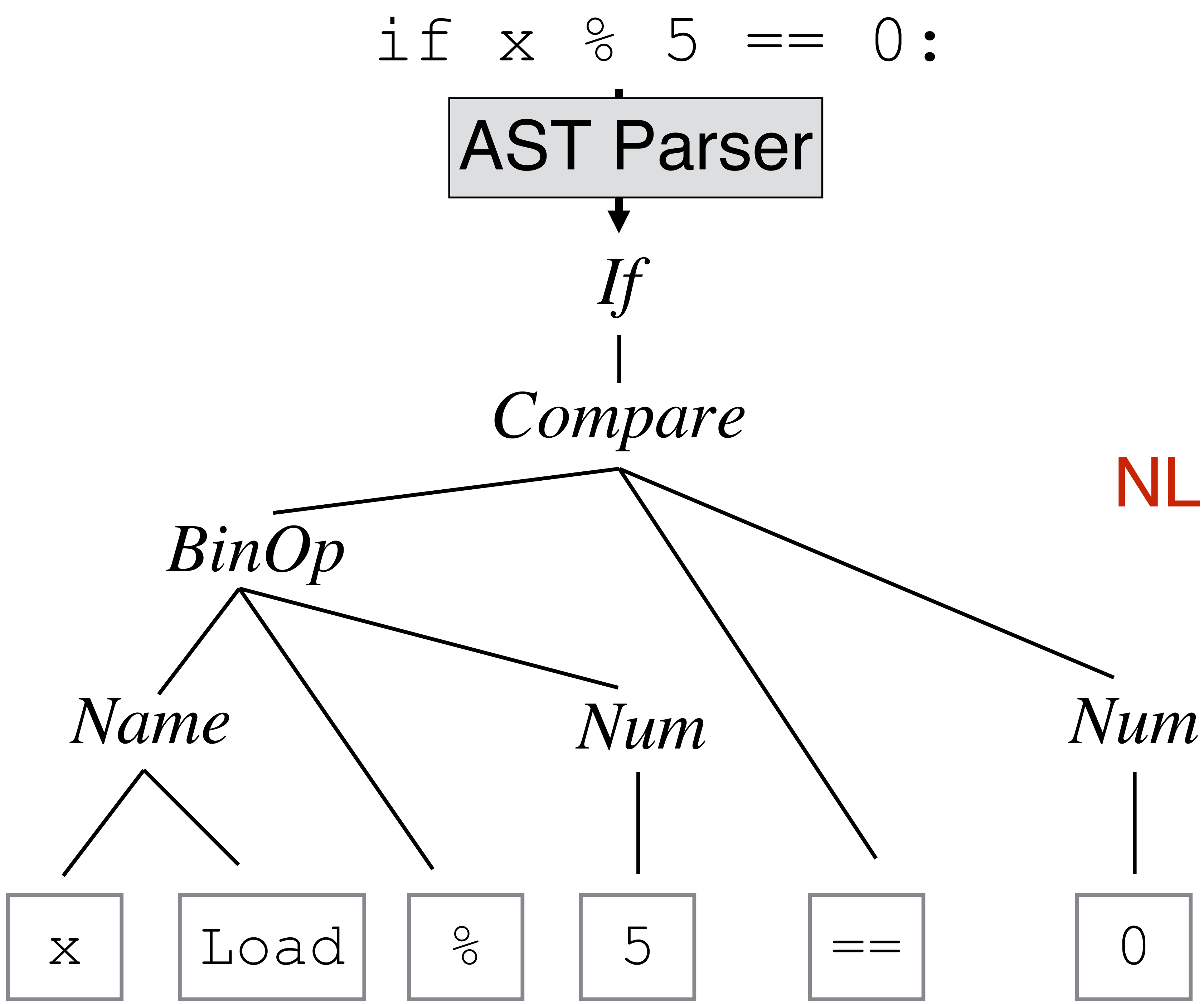
Natural Language vs. Programming Language

Natural Language vs. Code

Natural Language	**Code**
Human interpretable	Human and machine interpretable
Ambiguous	Precise in interpretation
Structured, but flexible	Structured w/o flexibility

Note: Good summary in Allamanis et al. (2017)

Structure in Code



Can we take advantage of this for better NL-code interfaces?

(used in models of Maddison & Tarlow 2014)

A Syntactic Neural Model for Code Synthesis from Natural Language

(ACL 2017)

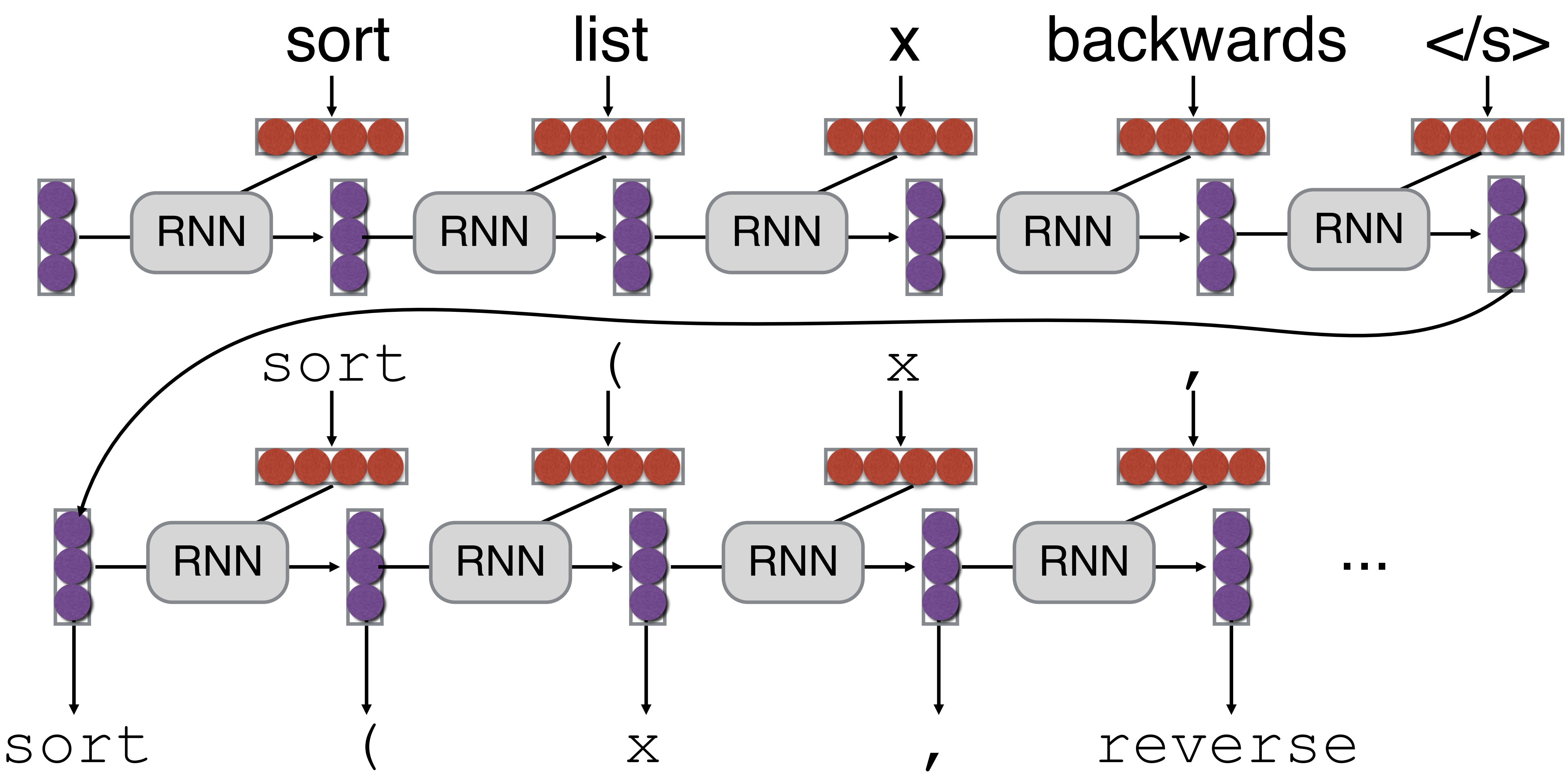
Joint Work w/ Pengcheng Yin

Previous Work

- Lots of work on rule-based methods for natural language programming (e.g. see Balzer 1985)
- Lots of work on semantic parsing w/ grammar-based statistical models (e.g. Wong & Mooney 2007)
- One work on using neural sequence-to-sequence models for code generation in Python (Ling et al. 2016)

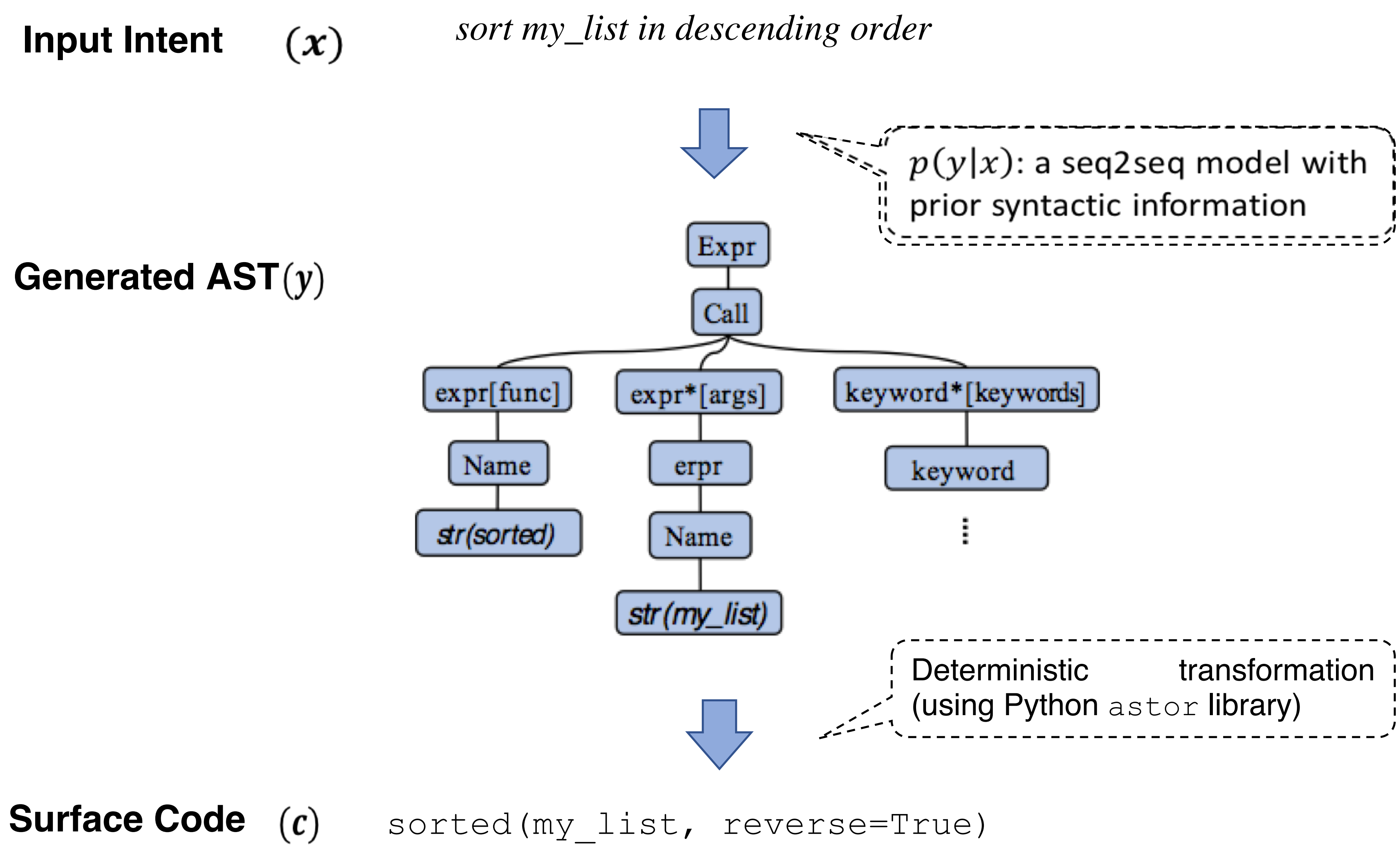
Sequence-to-sequence Models
(Sutskever et al. 2014, Bahadanau et al. 2015)

- Neural network models for transducing sequences



Proposed Method: Syntactic Neural Models for Code Synthesis

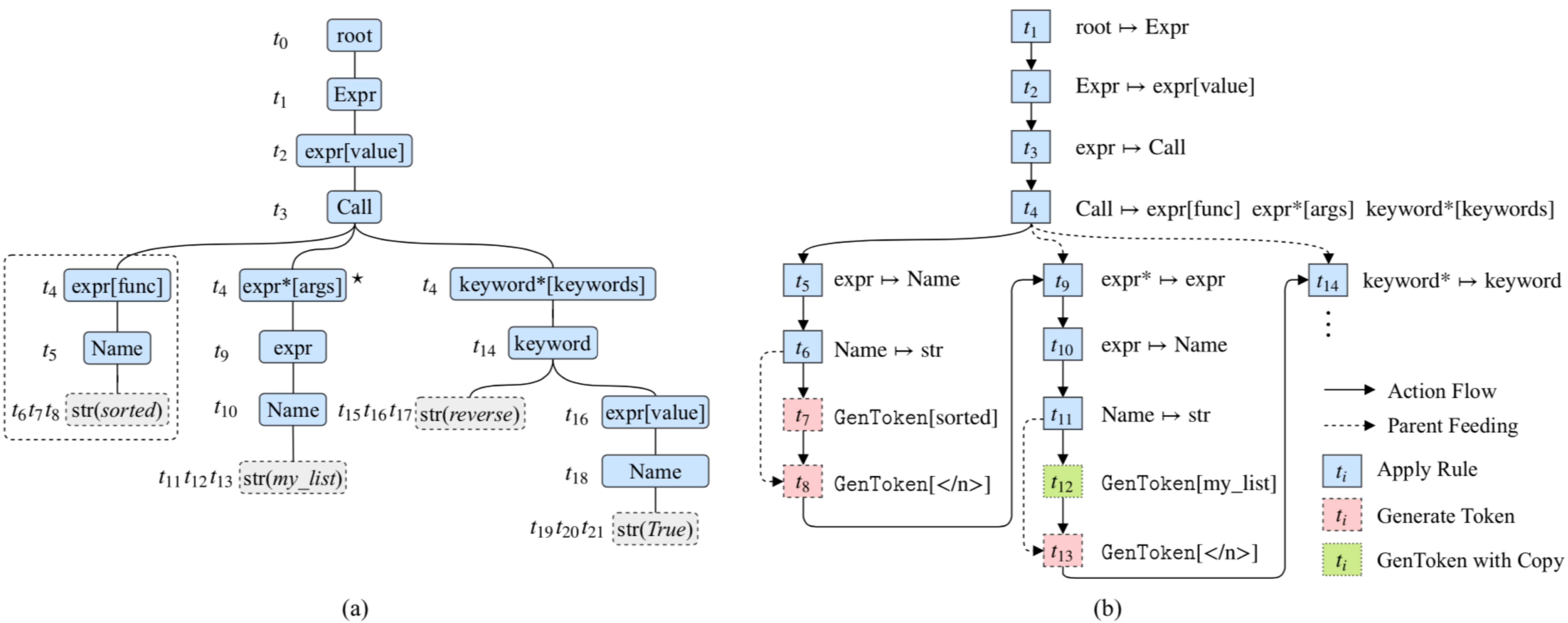
- **Key idea:** use the grammar of the programming language (Python) as prior knowledge in a neural model



NOTE: very nice contemporaneous work by Rabinovich et al. (2017)

Generation Process

- Factorize the AST into actions:
  - `ApplyRule`: generate an internal node in the AST
  - `GenToken`: generate (part of) a token

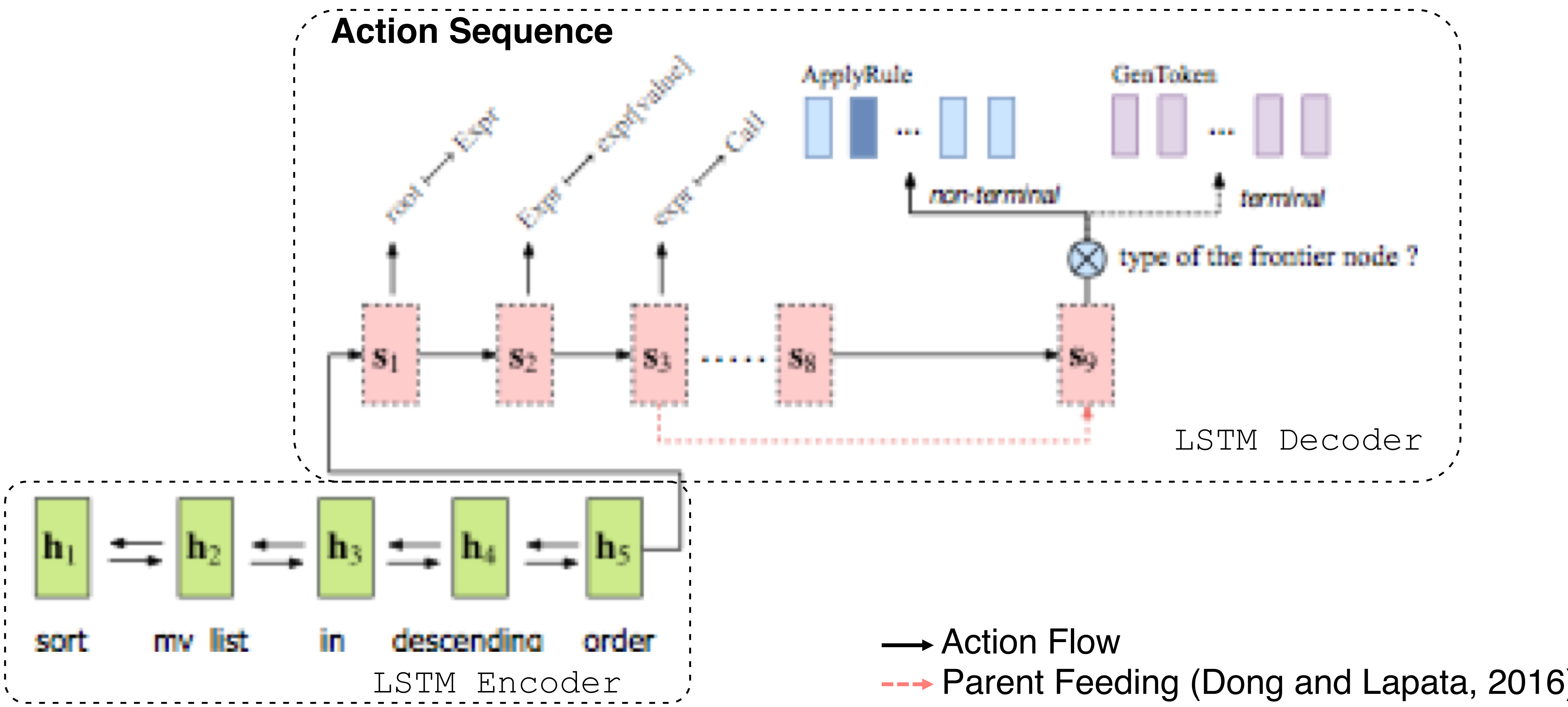


Input: `sort my_list in descending order`

Code: `sorted(my_list, reverse=True)`

Formulation as a Neural Model

- **Encoder:** summarize the semantics of the NL intent
- **Decoder:**
  - Hidden state keeps track of the generation process of the AST
  - Based on the current state, predict an action to grow the AST

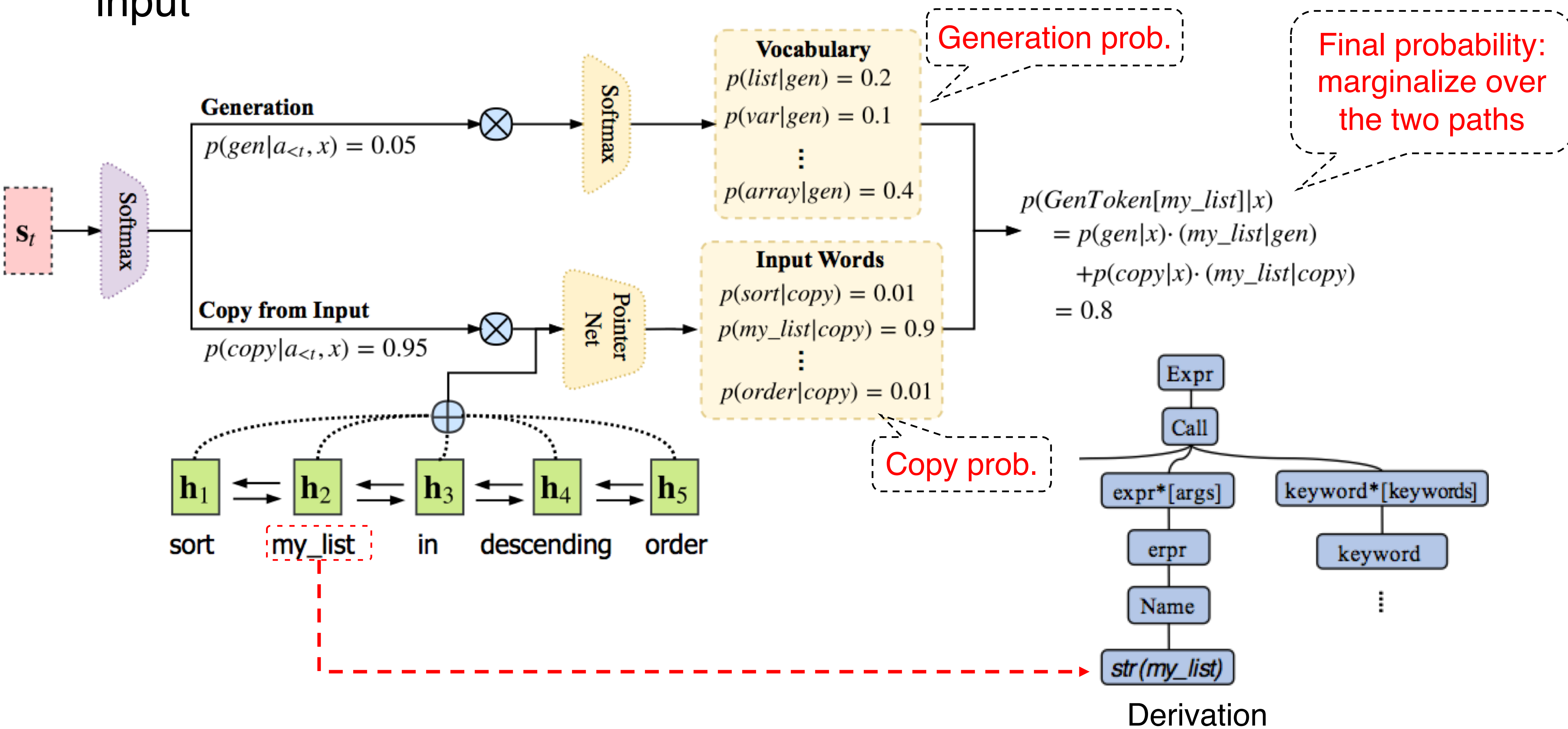


Computing Action Probabilities

- `ApplyRule[r]`: apply a production rule *r* to the current derivation

$$p(a_t = \text{APPLYRULE}[r] | x, a_{<t}) = \text{softmax}(\mathbf{W} \cdot g(\mathbf{s}_t))$$

- `GenToken[v]`: append a token *v* to the current terminal node
  - Deal with OOV: learning to generate a token or directly copy it from the input



Experiments

- **Natural Language $\longmapsto$ Python code:**
  - *HearthStone (Ling et al., 2016):* card game implementation
  - *Django (Oda et al., 2015):* web framework
- **Natural Language $\longmapsto$ Domain Specific Language (Semantic Parsing)**
  - *IFTTT (Quirk et al., 2015):* personal task automation APP

Django Dataset

- **Description:** manually annotated descriptions for 18K lines of code
- **Target code**: one liners
- Covers a wide range of real-world use cases like I/O operation, string manipulation and exception handling

Intent	*call the function _generator, join the result into a string, return the result*
Target	`return ''.join(_generator())`

HearthStone Dataset

- **Description:** properties/fields of an HS card
- **Target code:** implementation as a Python class from HearthBreaker

Intent (Card Property)

<name> Divine Favor </name> <cost> 3 </cost> <desc> Draw cards until you have as many in hand as your opponent </desc>

Target (Python class, extracted from HearthBreaker)

```
class DivineFavor(SpellCard):
  def __init__(self):
    super().__init__("Divine Favor", 3, CHARACTER_CLASS.PALADIN,
                     CARD_RARITY.RARE)
  def use(self, player, game):
    super().use(player, game)
    difference = len(game.other_player.hand) - len(player.hand)
    for i in range(0, difference):
      player.draw()
```

[Ling *et al.*, 2016]

IFTTT Dataset

- Over 70K user-generated task completion snippets crawled from ifttt.com
- Wide variety of topics: home automation, productivity, *etc*.
- Domain-Specific Language (DSL): IF-THIS-THEN-THAT structure, much simpler grammar

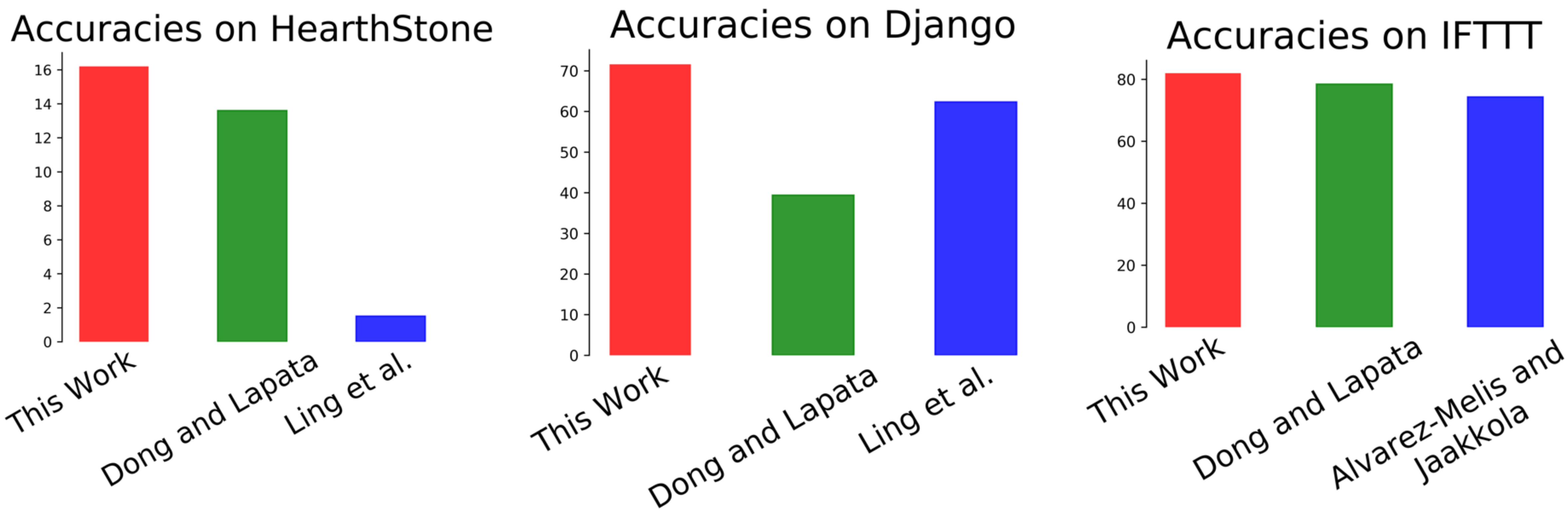
https://ifttt.com/applets/1p-autosave-your-instagram-photos-to-dropbox

Intent *Autosave your Instagram photos to Dropbox*

Target **IF** Instagram.AnyNewPhotoByYou **THEN** Dropbox.AddFileFromURL

[Quirk *et al.*, 2015]

Results



- Baseline systems (*do not model syntax a priori*):
  - –Latent Predictor Network [Ling *et al.*, 2016]
  - –Seq2Tree [Dong and Lapata., 2016]
  - –Doubly recurrent RNN [Alvarez-Melis and Jaakkola., 2017]
- **Take Home Msg:**
  - –Modeling syntax helps for code generation and semantic parsing

Examples

Intent *join app_config.path and string 'locale' into a file path, substitute it for localedir.*

Pred.

```
localedir = os.path.join(app_config.path, 'locale') ✓
```

Intent *self.plural is an lambda function with an argument n, which returns result of boolean expression n not equal to integer 1*

Pred.

```
self.plural = lambda n: len(n) ✗
```

Ref.

```
self.plural = lambda n: int(n!=1)
```

Intent *<name> Burly Rockjaw Trogg </name> <cost> 5 </cost> <attack> 3 </attack> <defense> 5 </defense> <desc> Whenever your opponent casts a spell, gain 2 Attack. </desc> <rarity> Common </rarity> ...*

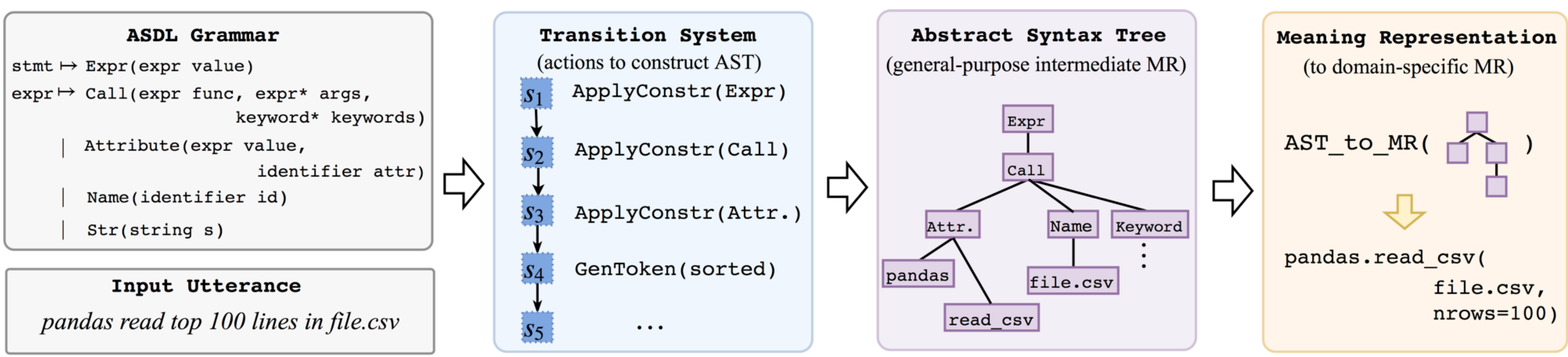
Ref.

```
class BurlyRockjawTrogg(MinionCard):
    def __init__(self):
        super().__init__('Burly Rockjaw Trogg', 4, CHARACTER_CLASS.ALL, CARD_RARITY.COMMON)
    def create_minion(self, player):
        return Minion(3, 5, effects=[Effect(SpellCast(player=EnemyPlayer()),
            ActionTag(Give(ChangeAttack(2)), SelfSelector()))]) ✓
```

tokens copied from input

TranX Parser [Yin+18]

- Transition-based AST parser based on "abstract syntax description language"
- Can define language flexibly for various types of semantic parsing
- Good results out-of-the-box!



https://github.com/pcyin/tranX

Learning to Mine NL/Code Pairs from Stack Overflow

(MSR 2018)

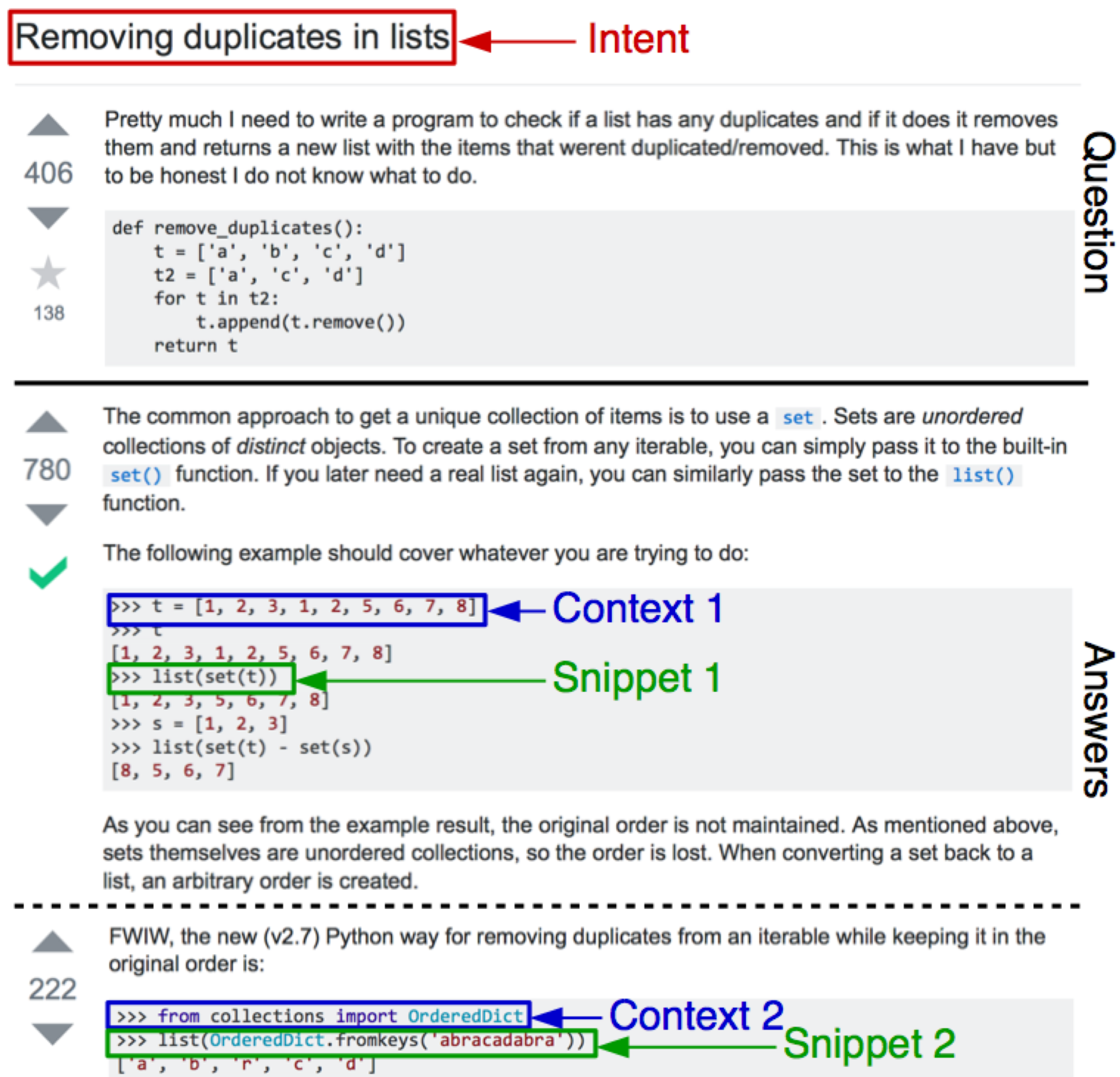
Joint Work w/
Pengcheng Yin, Bowen Deng, Edgar Chen, Bogdan Vasilescu

Datasets are Important!

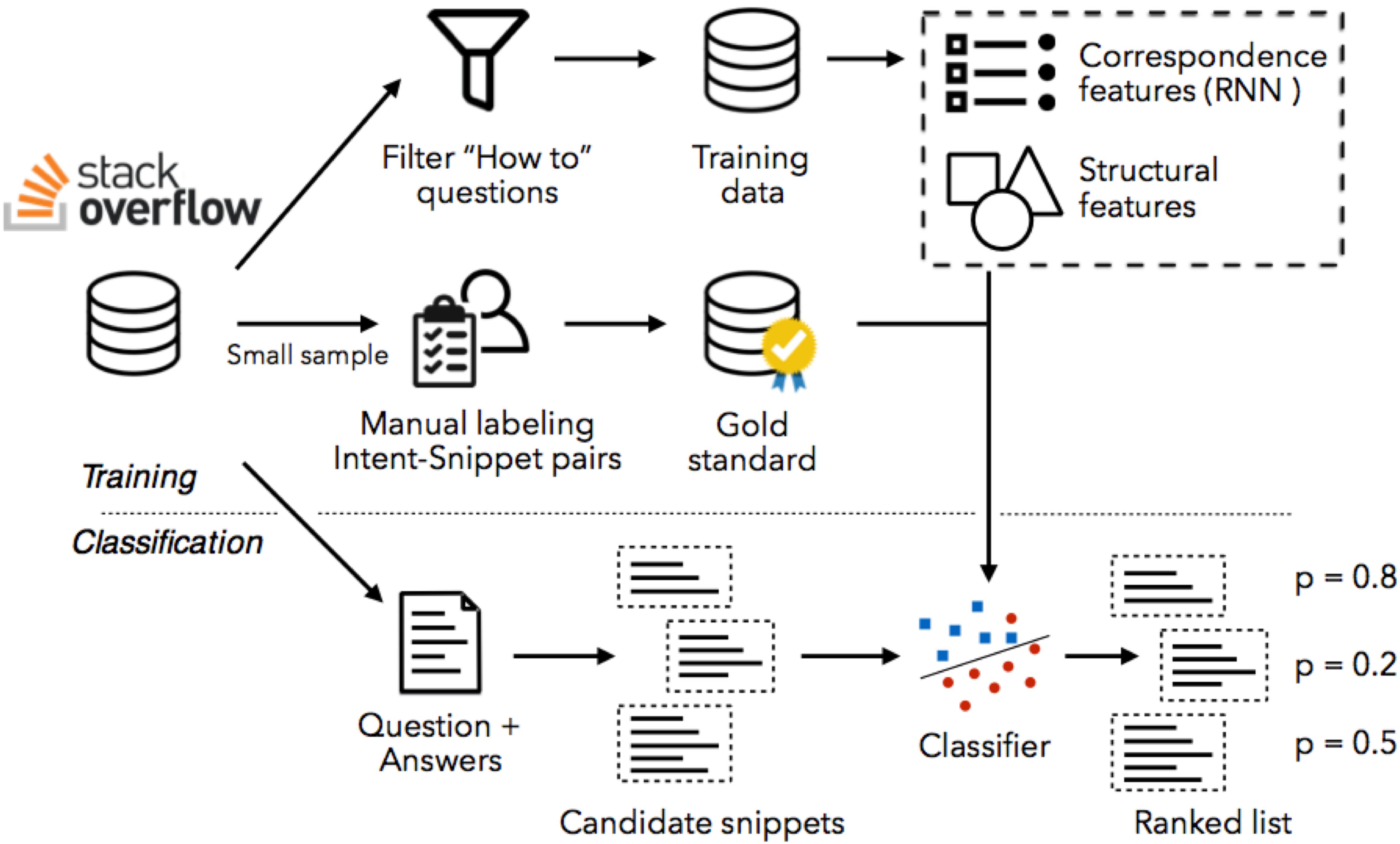
- Our previous work used Django, HearthStone, IFTTT, manually curated datasets
- It couldn't have been done without these
- But these are **extremely specific, and small**

StackOverflow is Promising!

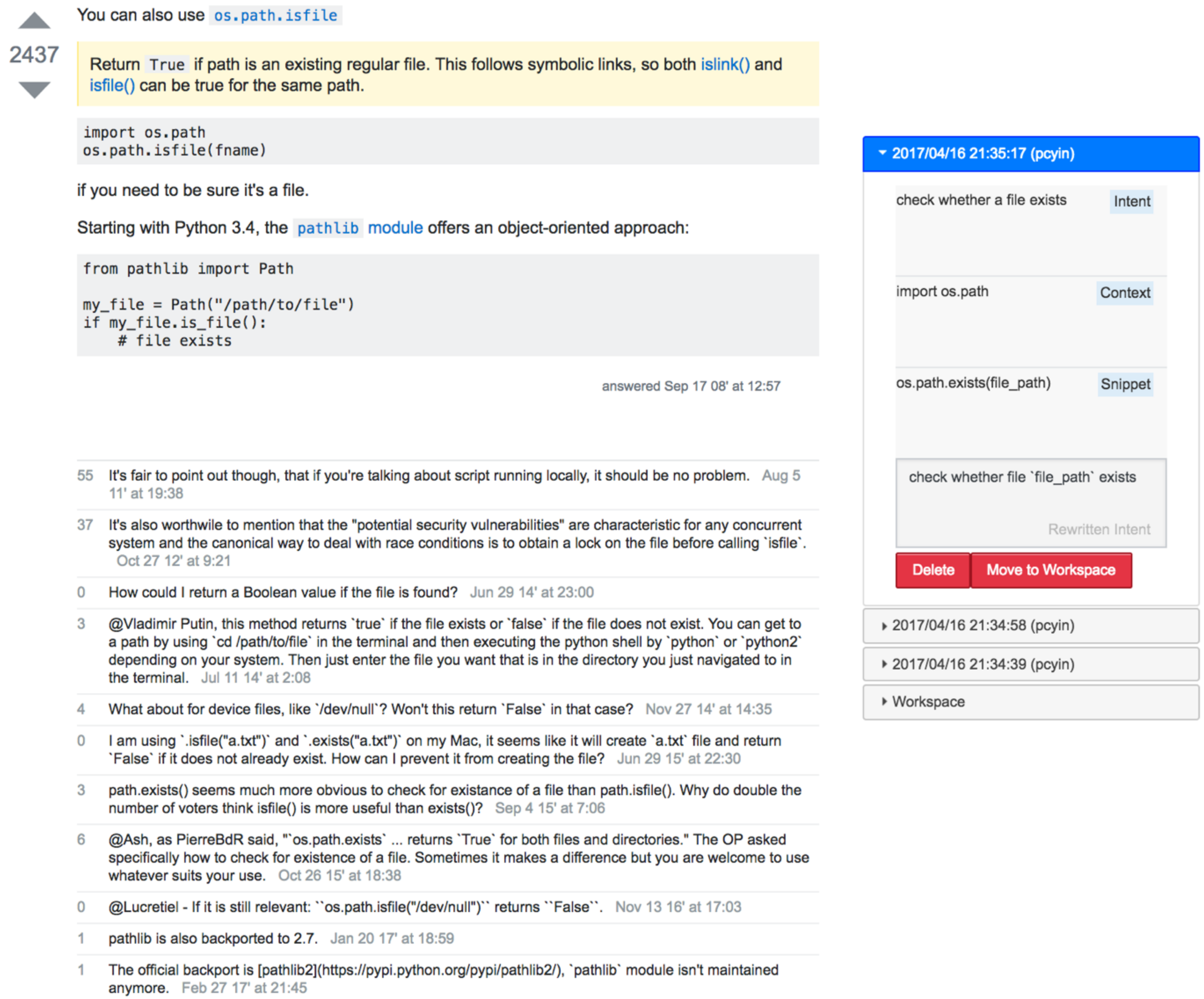
- StackOverflow promises a large data source for code synthesis
- But code snippets don't necessarily reflect the answer to the original question



Mining Method



Annotation



- ~100 posts for Python/Java

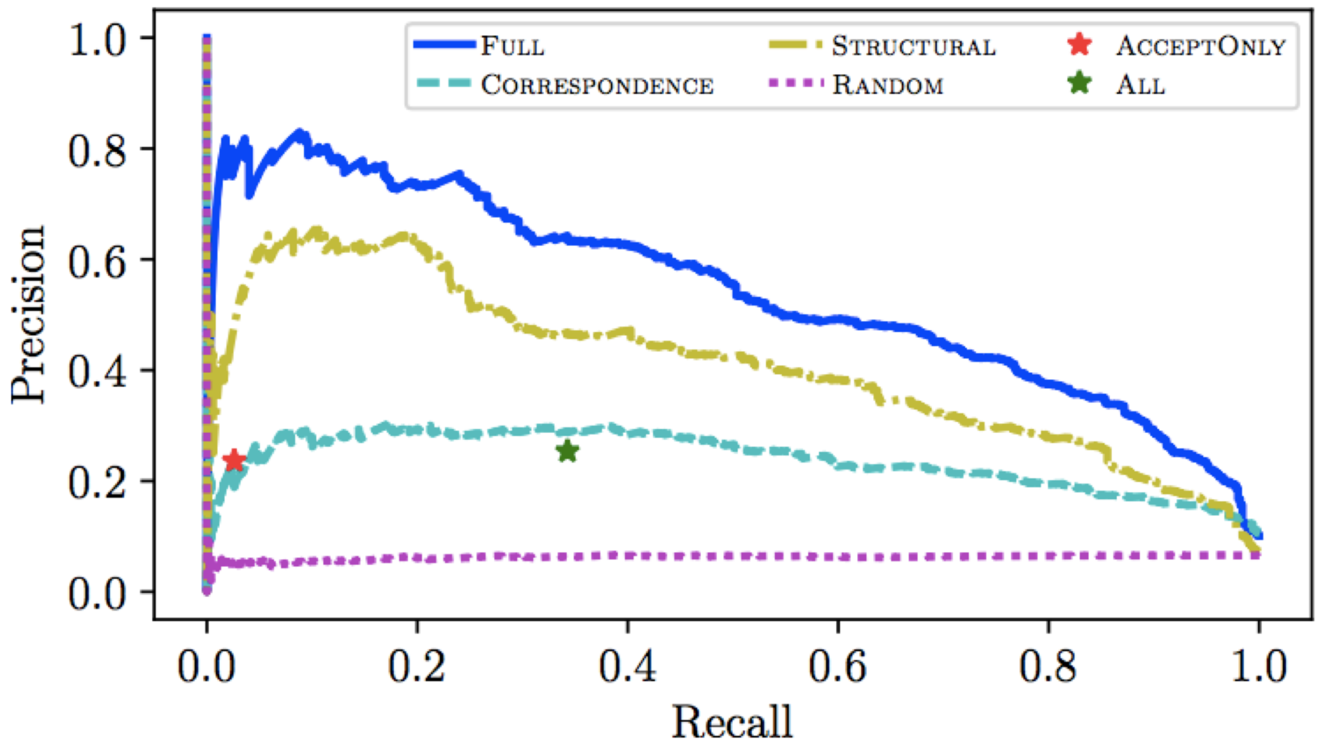
Features (1): Structural Features

- "does this look like a valid snippet?"
  - **Position:** Is the snippet a full block? The start/end of a block? The only block in an answer?
  - **Code Features:** Contains import? Starts w/ assignment? Is value?
  - **Answer Quality:** Answer is accepted? Answer is rank 1, 2, 3?
  - **Length:** What is the number of lines?

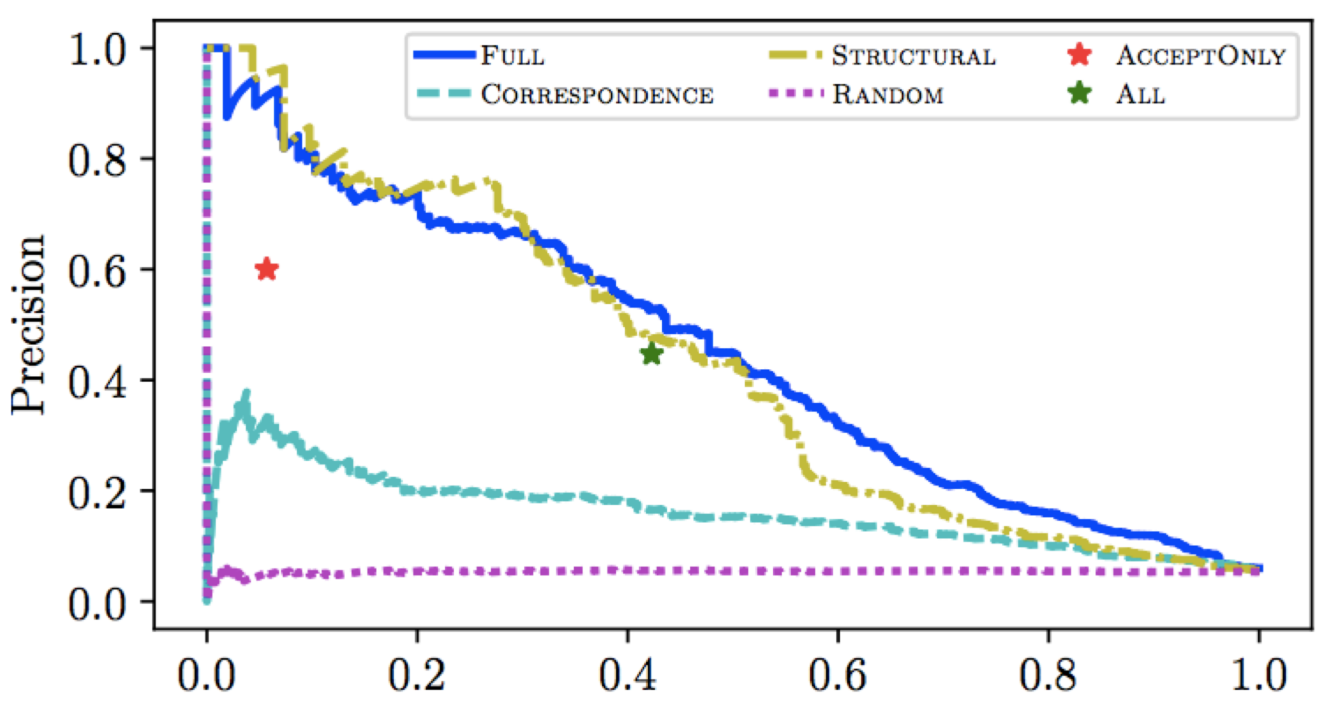
Features (2): Correspondence Features

- "do the intent and snippet look like they match?"
  - Train an RNN to predict P(intent | snippet) and P(snippet | intent) given heuristically extracted noisy data
  - Use log probabilities and normalized by z score over post, etc.

Main Results



(b) Precision-Recall Curve on Python

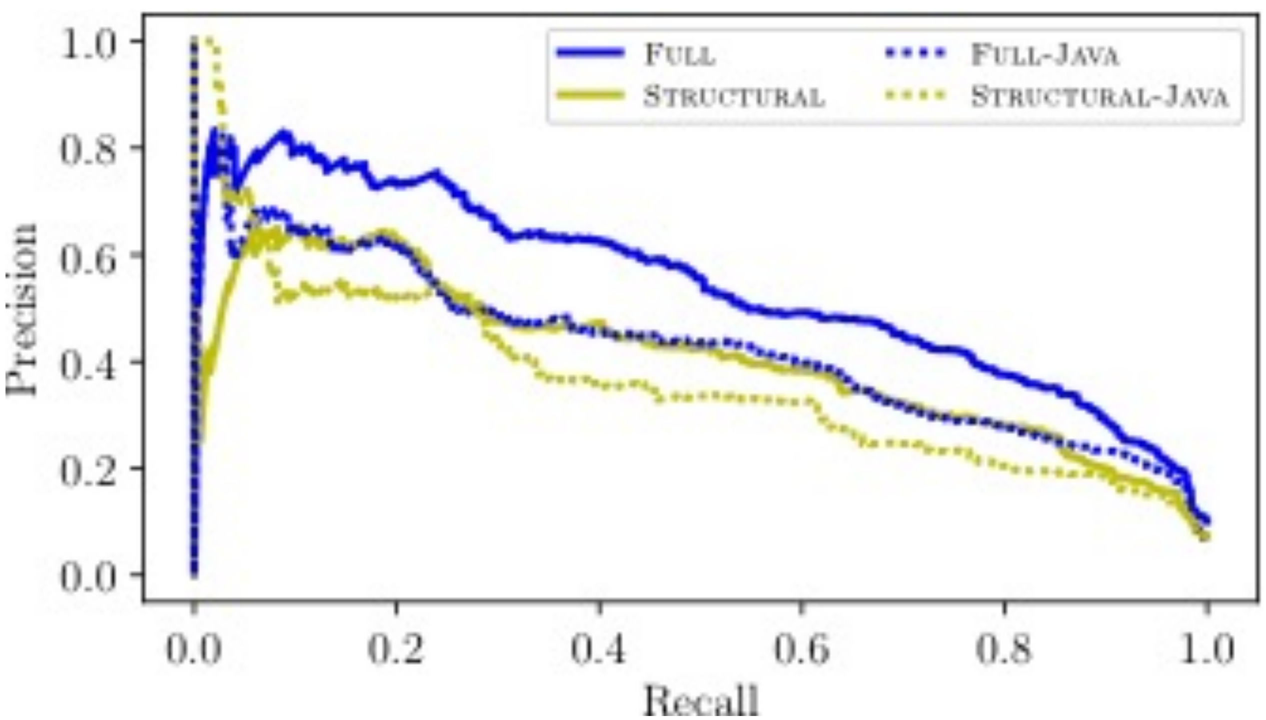


- On both Python and Java, better results than heuristic strategies
- Both structural and correspondence features were necessary

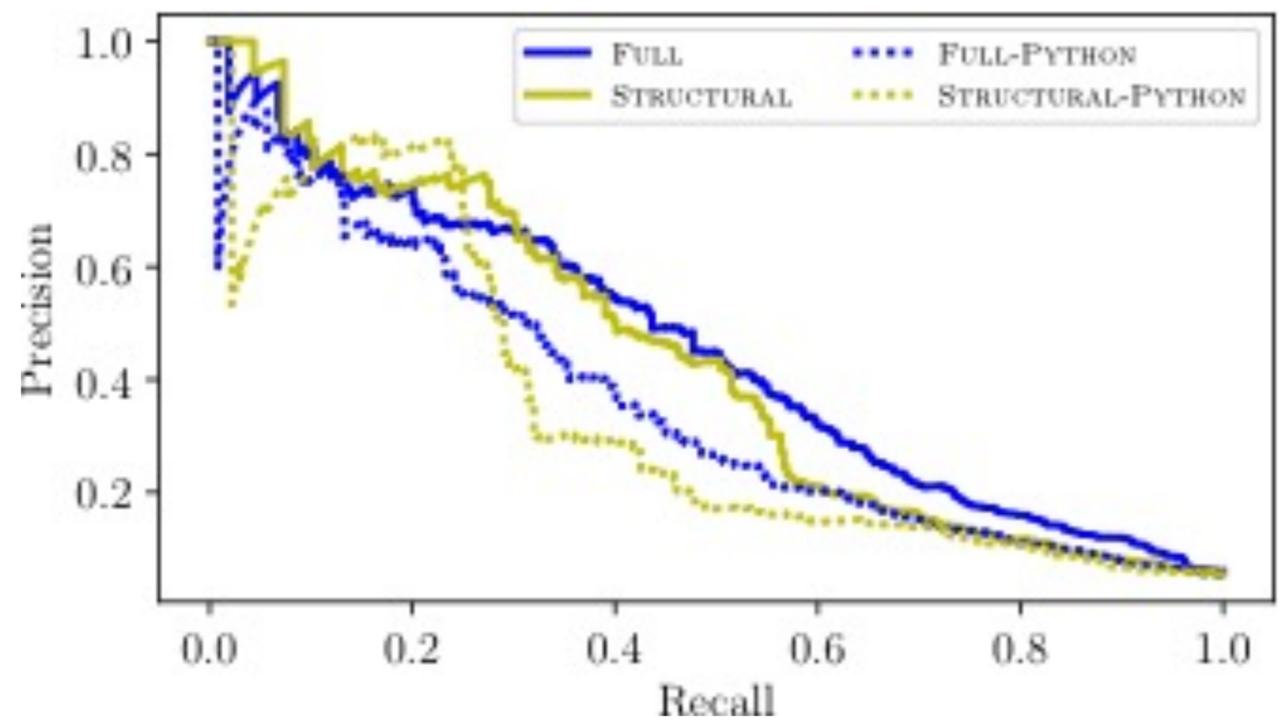
Transfer Learning

- Can we perform classification w/ no labeled data for that language?

Python



Java



Examples

I_1: *Remove specific characters from a string in python*
URL: https://stackoverflow.com/questions/3939361/

Top Predictions:

S_1 `string.replace('1', '')` ✓

S_2 `line = line.translate(None, '!@#$')` ✓

S_3 `line = re.sub('[!@#$]', '', line)` ✓

I_2: *Get Last Day of the Month in Python*
URL: https://stackoverflow.com/questions/42950/

Top Predictions:

S_1 `calendar.monthrange(year, month)[1]` ✓

S_2 `calendar.monthrange(2100, 2)` ✓

S_3 `(datetime.date(2000, 2, 1) - datetime.timedelta(days=1))` ✓

I_3: *Delete a dictionary item if the key exists*
URL: https://stackoverflow.com/questions/15411107/

Top Predictions:

S_1 `mydict.pop('key', None)` ✓

S_2 `del mydict[key]` ✓

S_3 `new_dict = {k: mydict[k] for k in keys_to_keep}` ✗

I_4: *Python:take the content of a list and append it to another list*
URL: https://stackoverflow.com/questions/8177079/

Top Predictions:

S_1 `list2.append(list1)` ✗

S_2 `list2.extend(list1)` ✓

S_3 `list1.extend(mylog)` ✓

CoNaLa: Code Natural-language Challenge

- ~2500 mined and manually verified examples
- ~600k automatically mined examples


```
{
 "question_id": 36875258,
 "intent": "copying one file's contents to another in python",
 "rewritten_intent": "copy the content of file 'file.txt' to file 'file2.txt’”,
 "snippet": "shutil.copy('file.txt', 'file2.txt’)”
}
{
  "question_id": 22240602,
  "intent": "How do I check if all elements in a list are the same?",
  "rewritten_intent": "check if all elements in list `mylist` are the same",
  "snippet": "len(set(mylist)) == 1"
}
```


http://conala-corpus.github.io

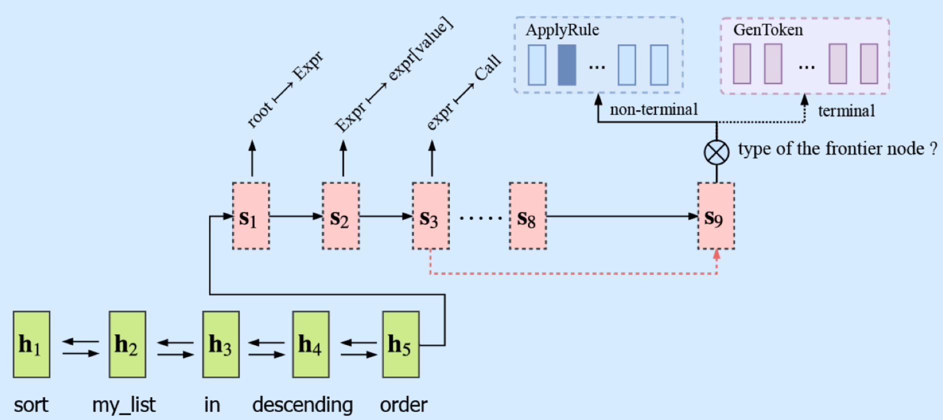
StructVAE: Semi-supervised Learning for Semantic Parsing

(ACL 2018)

Joint Work w/
Pengcheng Yin, Junxian He, Chunting Zhou

Motivation

Neural Models are Data Hungry



Purely supervised neural semantic parsing models require large amounts of training data

Data Collection is Costly

Copy the content of file 'file.txt' to file 'file2.txt'

```
shutil.copy('file.txt','file2.txt')
```

Get a list of words `words` of a file 'myfile'

```
words = open('myfile').read().split()
```

Check if all elements in list `mylist` are the same

```
len(set(mylist)) == 1
```

Collecting parallel training data costs  and 

[Yin et al., 2018] 1700 USD for 3K Python code generation examples

[Berant et al., 2013] 3000 USD for 5.7K question-to-logical form examples

Existing Solutions

Weakly supervised Learning

Q: Which college did Obama go to?

(and (Type University)
(Education BarackObama))

A: Occidental College, Columbia Univ.

Clarke et al. (2010)

Liang et al. (2011)

Berant et al. (2013)

Berant and Liang (2014)

Yih et al. (2015)

Data Augmentation

*What states border **texas**?*

```
is_state(x) and
        border(x, texas)
```

*What states border **ohio**?*

```
is_state(x) and
        border(x, ohio)
```

Jia and Liang, (2016)

Wang et al. (2015)

Zero-Shot Learning and Domain Adaptation

Fan et al. (2017)

Su and Yan, (2017)

Herzig and Berant, (2018)

Semi-supervised Semantic Parsing

Limited Amount of Labeled Data

Sort my_list in descending order

```
sorted(my_list, reverse=True)
```

Copy the content of file 'file.txt' to file 'file2.txt'

```
shutil.copy('file.txt',
            'file2.txt')
```

Check if all elements in list `mylist` are the same

```
len(set(mylist)) == 1
```

+

Extra Unlabeled Utterances

Get a list of words `words` of a file 'myfile'

Convert a list of integers into a single integer

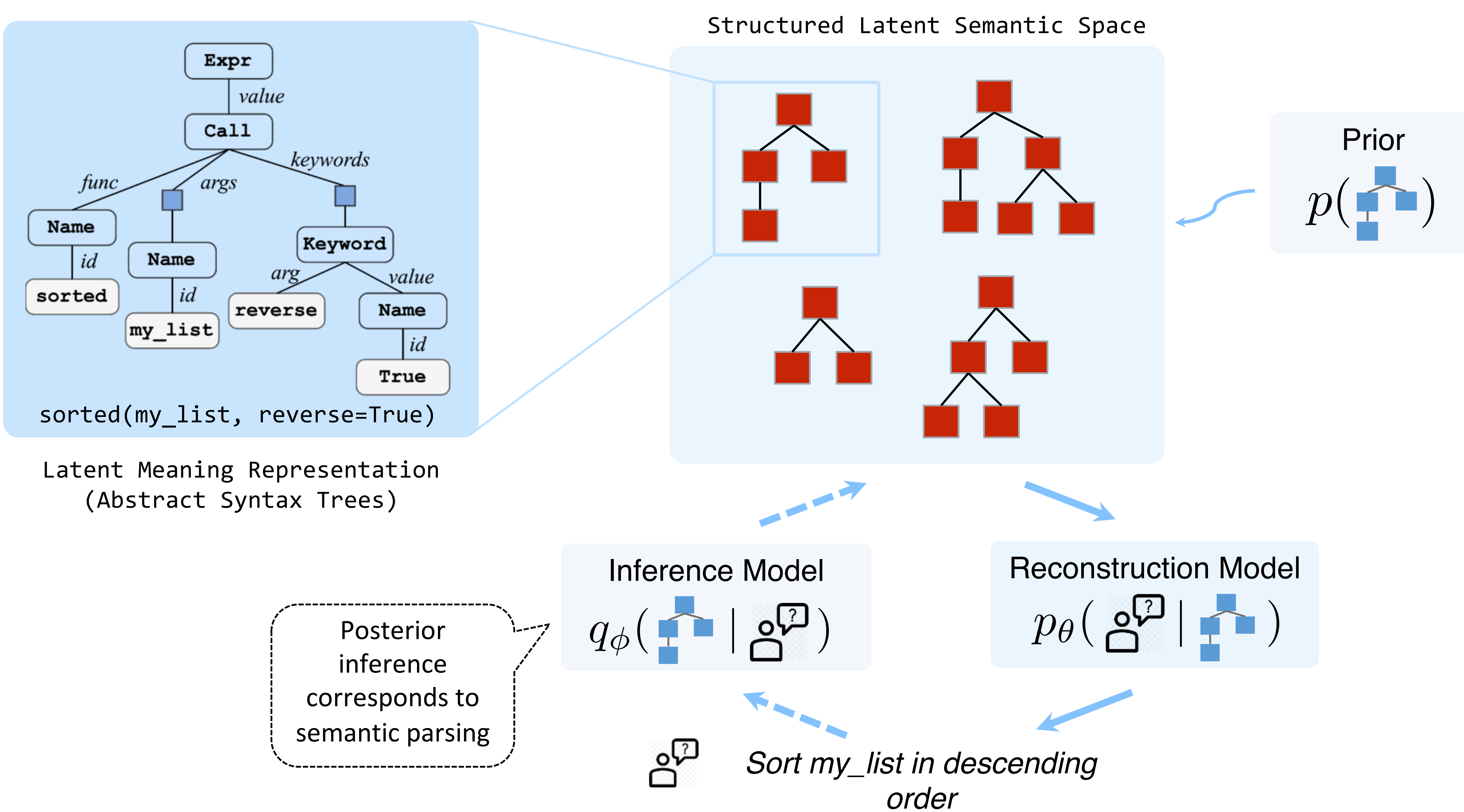
Format a datetime object `when` to extract date only

Swap values in a tuple/list in list `mylist`

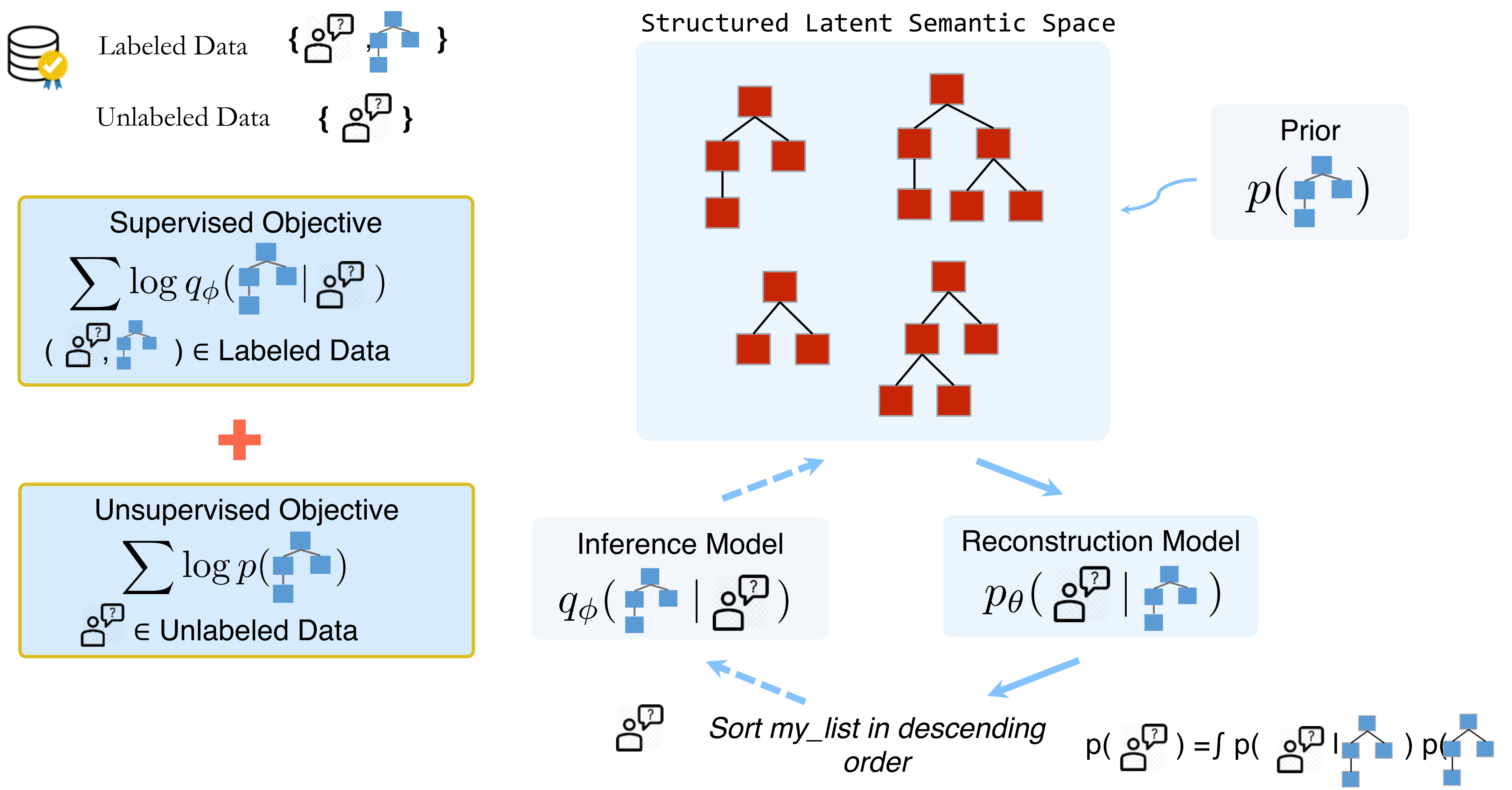
BeautifulSoup search string 'Elsie' inside tag 'a'

Convert string to lowercase

Tree-structured Latent Variables

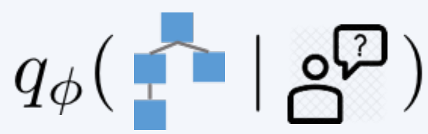


Semi-supervised Learning w/ StructVAE



StructVAE: VAEs with Structured Latent Variables

Inference Model

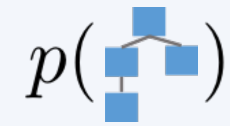


Neural semantic parser

Reconstruction Model

Neural sequence-to-sequence model

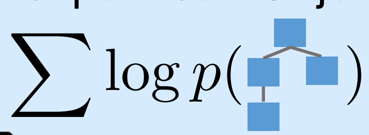
Prior

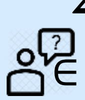


Neural Language Model

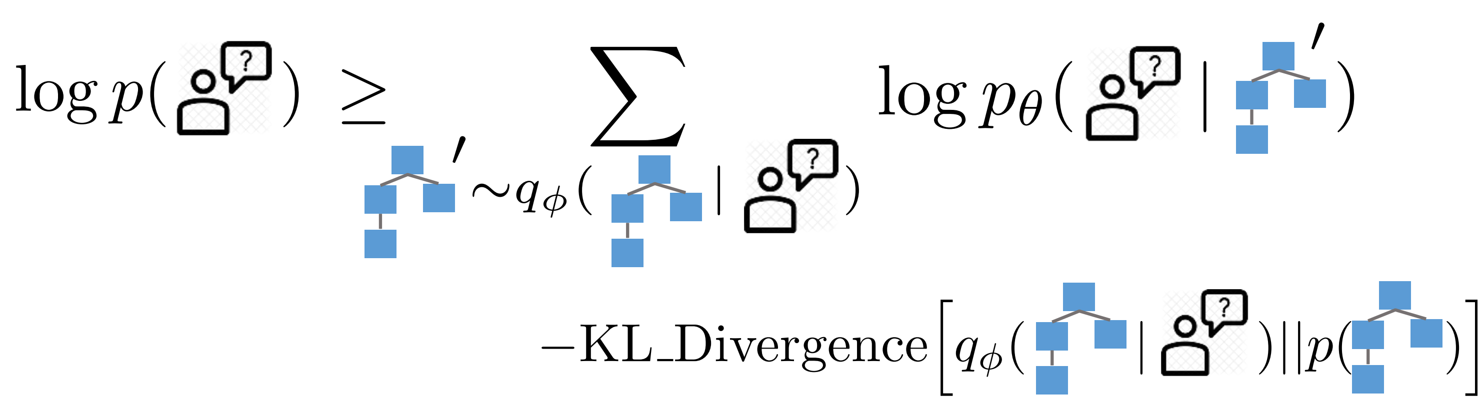
(use linearized trees as inputs)

Unsupervised Objective



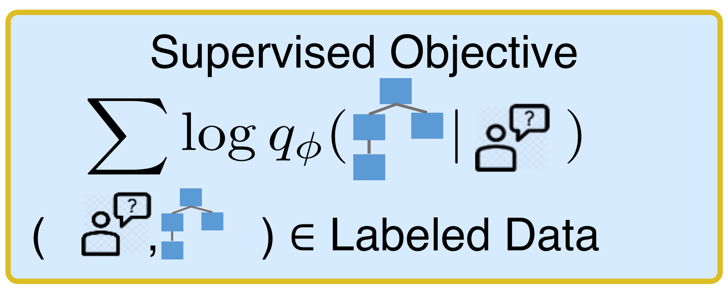
 Unlabeled Data

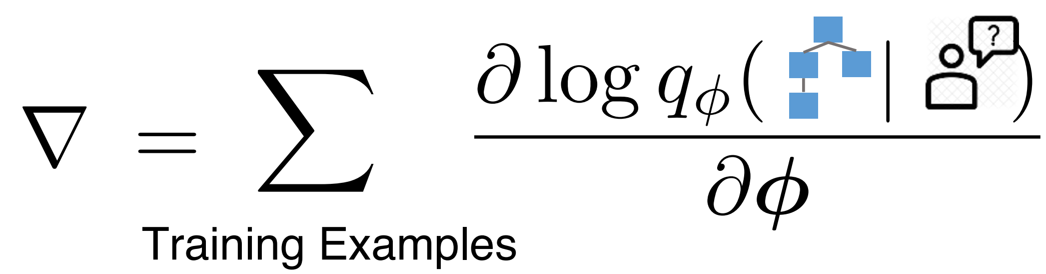
Variational approximation of the marginal likelihood



[Miao and Blunsom, 2016]

How Does Unsupervised Data Help?





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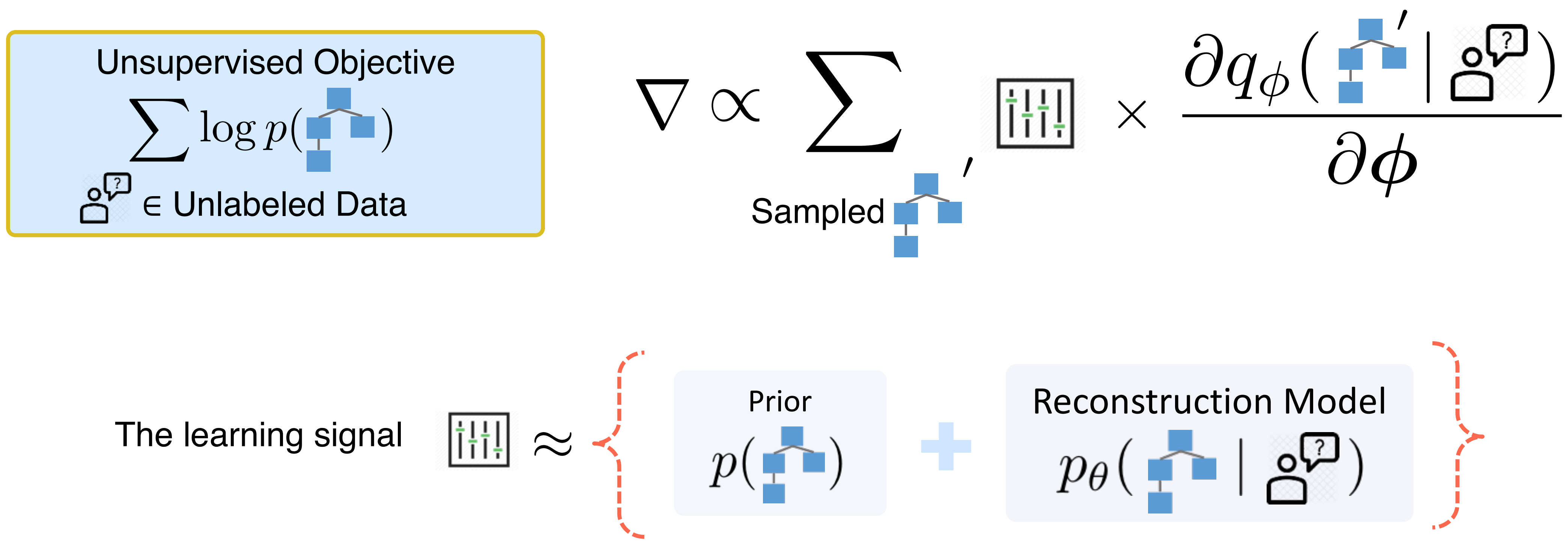
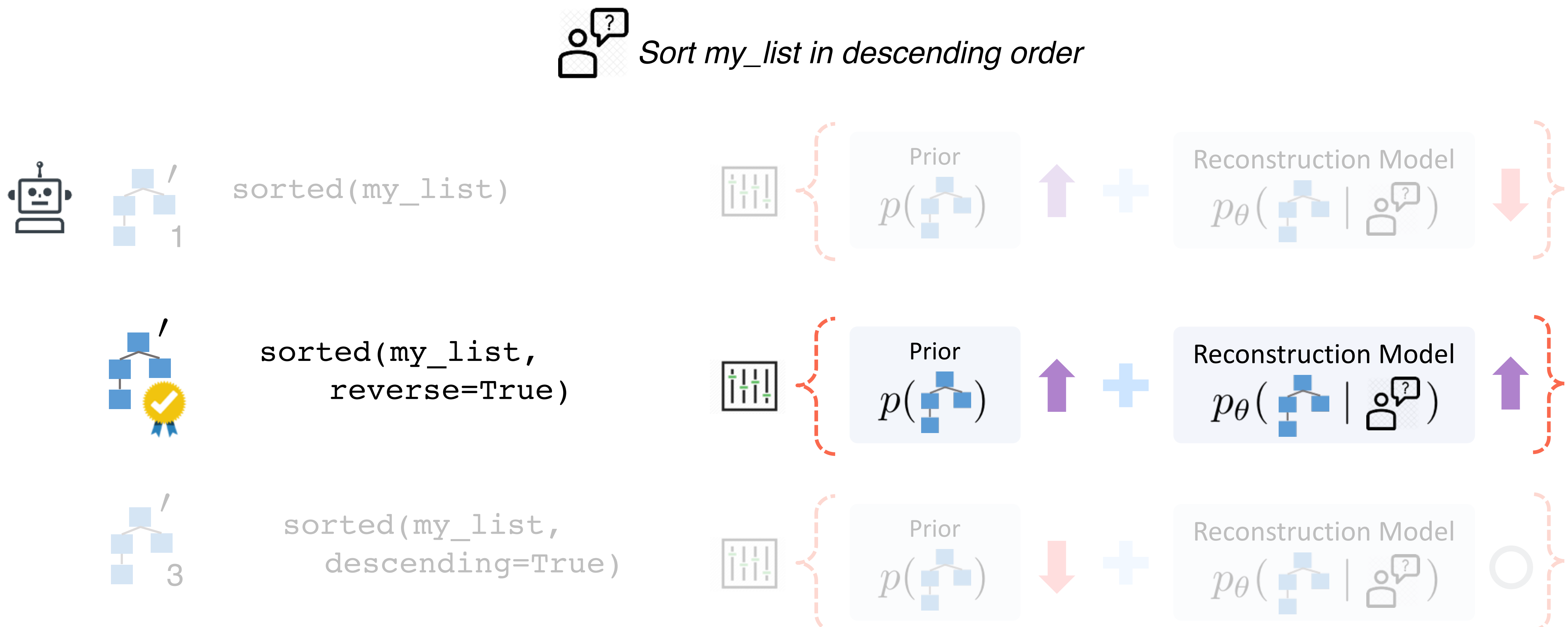


Learning signal acts as the tuning weights of gradients received by different sampled latent meaning representations from the inference model

How Does Unsupervised Data Help?

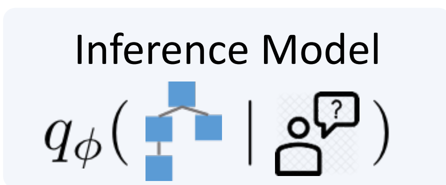


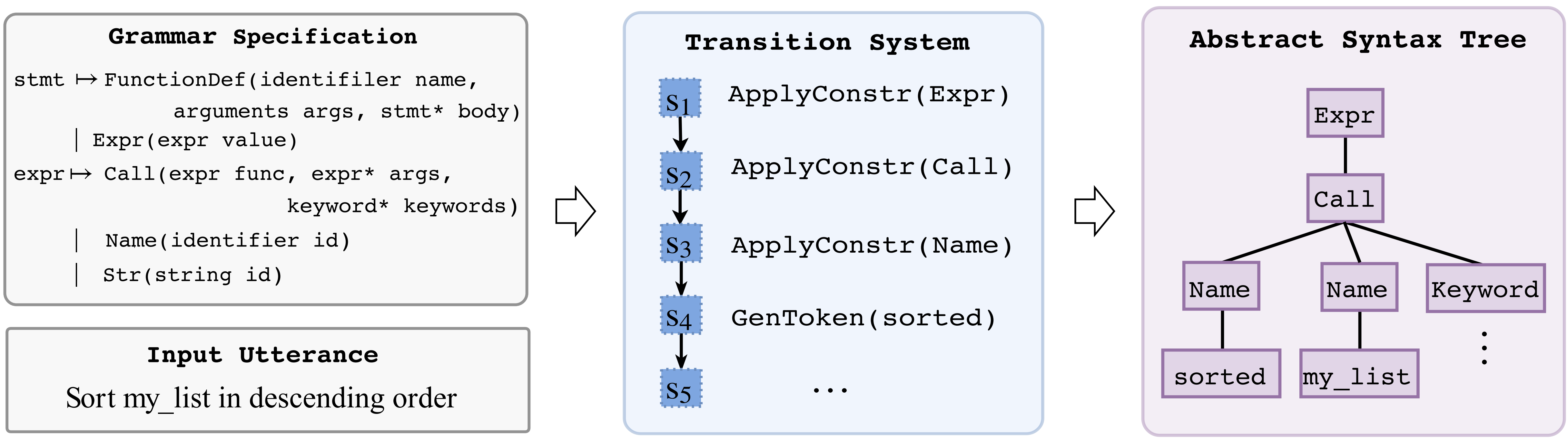
Learning fevers sampled latent meaning representations that are both:

- Faithfully encode the semantics of the utterance -> high reconstruction score
- Succinct and natural -> high prior probability

The Inference Model: AST-based Parser

A transition-based parser that transduces natural language utterances into Abstract Syntax Trees



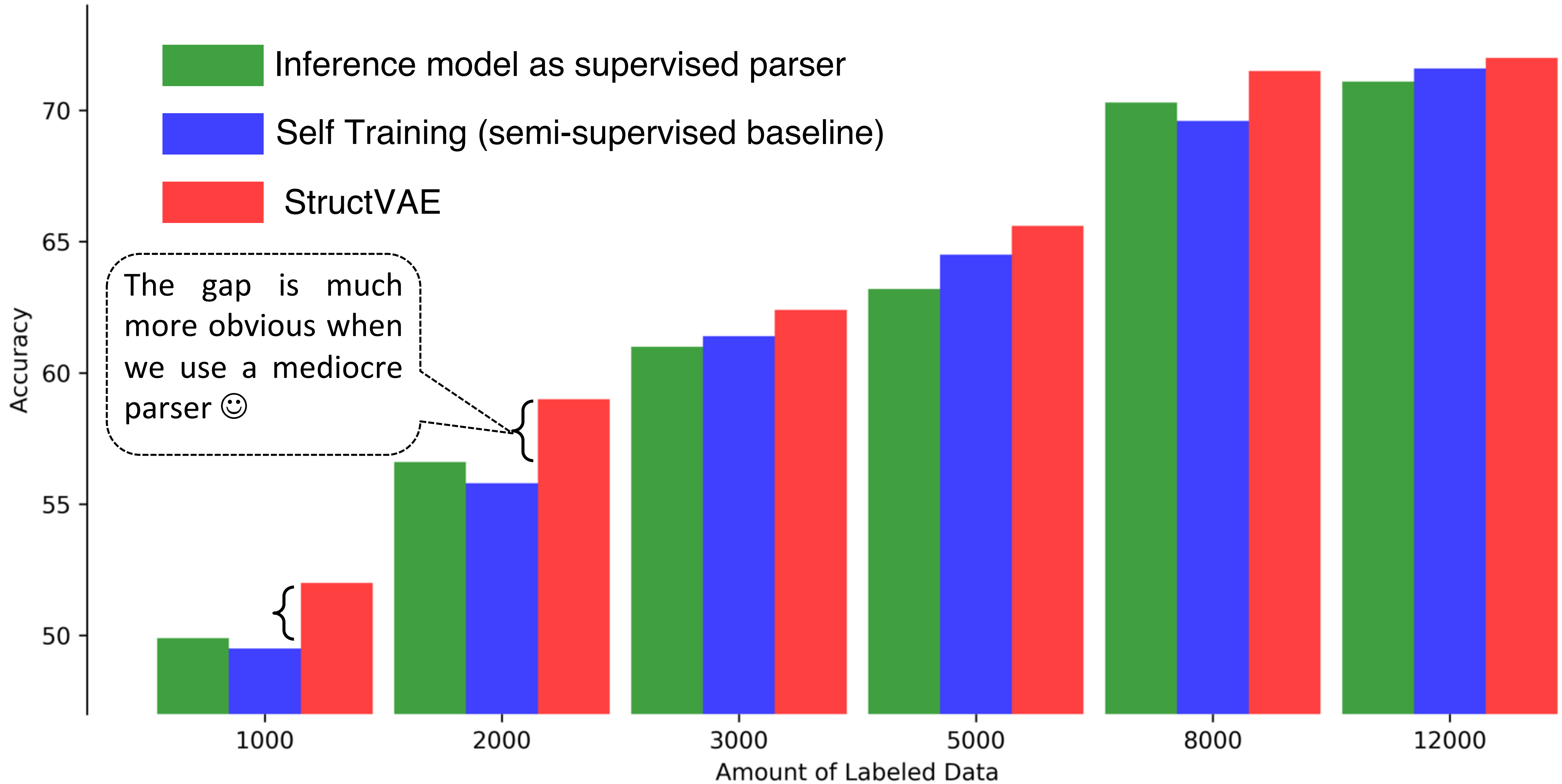


[Yin and Neubig, 2017; Rabinovich et al. 2017]

Research Questions

- **RQ1** Does StructVAE outperforms purely supervised semantic parsers with extra unlabeled data?
- **RQ2** Can we get some empirical evidence about why StructVAE works?

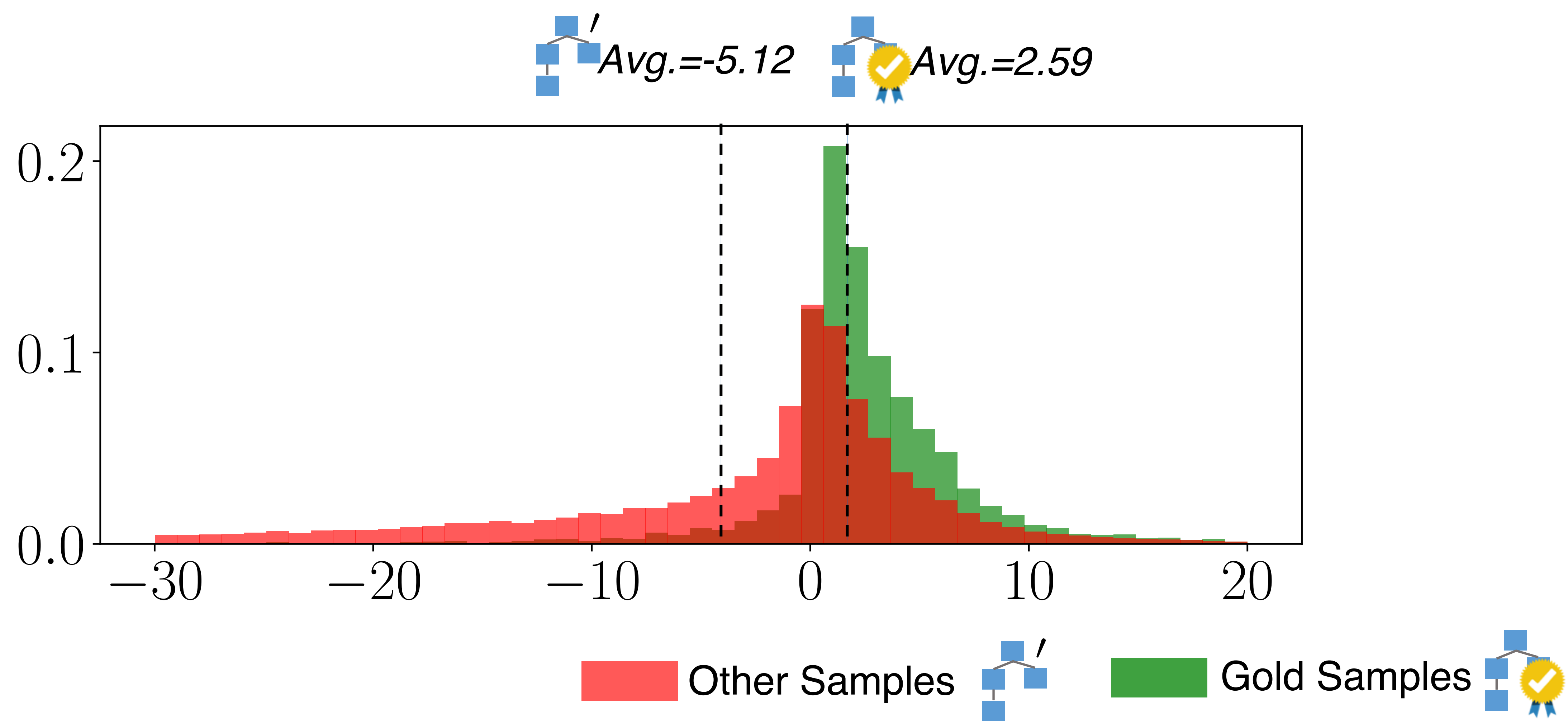
StructVAE vs. Baselines



all available training utterances as unlabeled data

Why does StructVAE Work?

- For each unlabeled utterance, compute the learning signal for gold samples and other (imperfect) samples



Learning Signal

Join p and cmd into a file path, substitute it for f

	Parser Score $q_{\phi}(\;\mid\;)$	Prior $p(\;)$	Reconstruction Score $p_{\theta}(\;\mid\;)$	Learning Signal
✔ `f = os.path.join(p, cmd)`	-1.00	-24.33	**-2.00**	**9.14**
✘ `p = path.join(p, cmd)`	-8.12	-27.89	**-20.96**	**-9.47**

Split string pks by ‘,’ , substitute the result for primary_keys

	Parser Score $q_{\phi}(\;\mid\;)$	Prior $p(\;)$	Reconstruction Score $p_{\theta}(\;\mid\;)$	Learning Signal
✔ `primary_keys = pks.split(’,’)`	**-2.38**	**-10.24**	-11.39	**2.05**
✘ `primary_keys = pks.split + ’,’`	**-1.83**	**-20.41**	-14.87	**-2.60**

Retrieval-based Neural Code Generation

(EMNLP 2018)

Joint Work w/
Shirley Hayati, Raphaël Olivier, Pravalika Avvaru,
Pengcheng Yin, Anthony Tomasic

The Stack Overflow Cycle

Formulate the Idea

sort my_list in descending order

Search the Web

python sort list in descending order

Google stackoverflow

Browse thru. results

167

This will give you a sorted version of the array.

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sorted(timestamp, reverse=True)
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If you want to sort in-place:

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edited Nov 15 '10 at 10:47

answered Nov 15 '10 at 10:42

Marcelo Cantos

124k ● 23 ● 243 ● 301

Modify the result

```
sorted(my_list, reverse=True)
```

Can we do the same thing in code generation models?!

Reminder: Syntax-based Generation

Input: `params is an empty list`

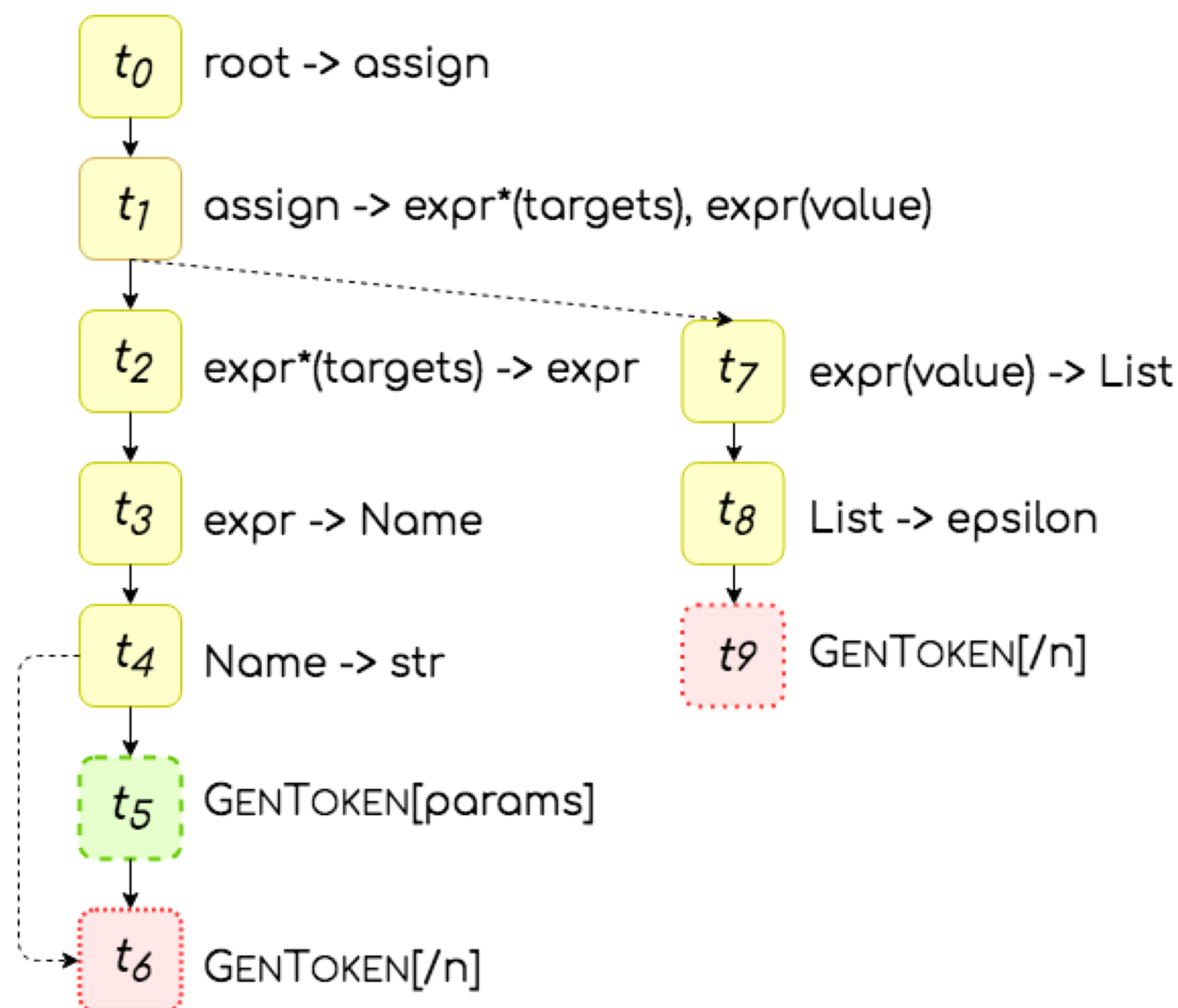
Output: `params = [ ]`

Neural Model: bidirectional Encoder-Decoder with Action Embedding, Context Vector, Parent Feeding, Copying Mechanism

Actions:

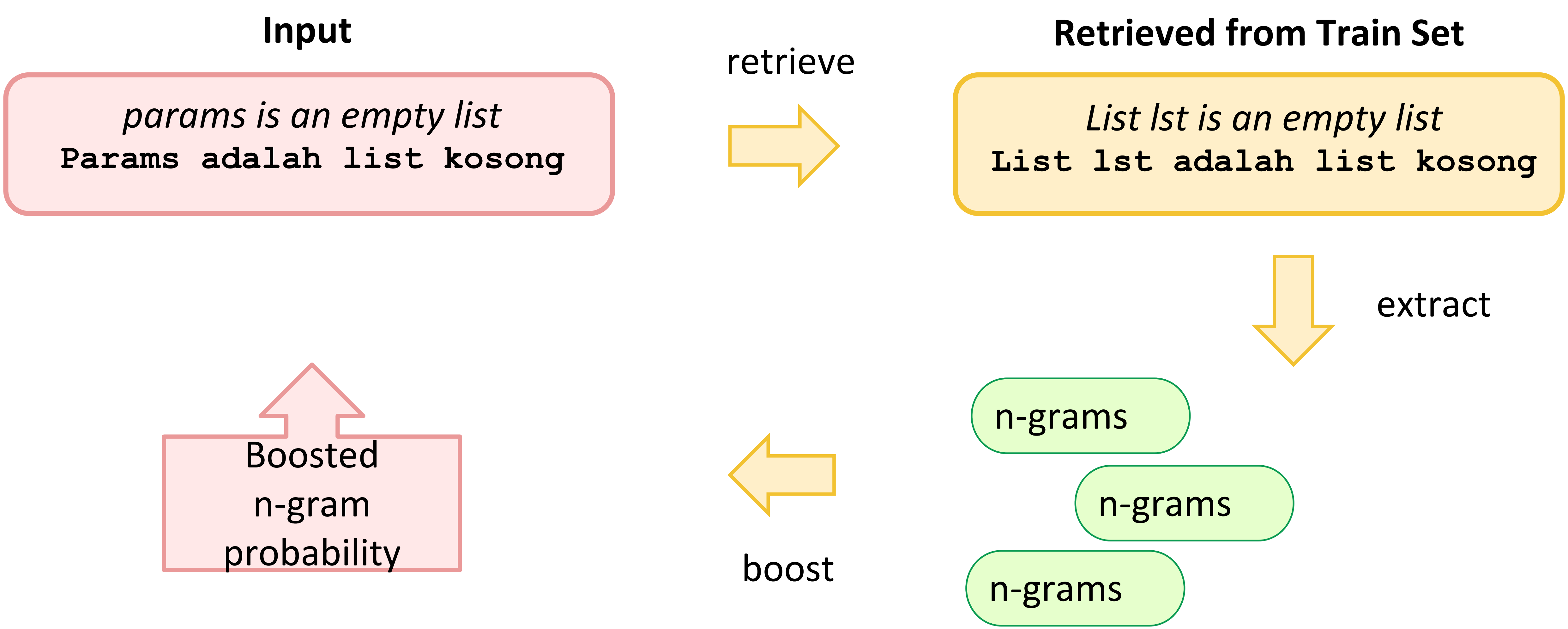
Apply Rule
Generate Token
Generate Token with Copy

Action Tree:

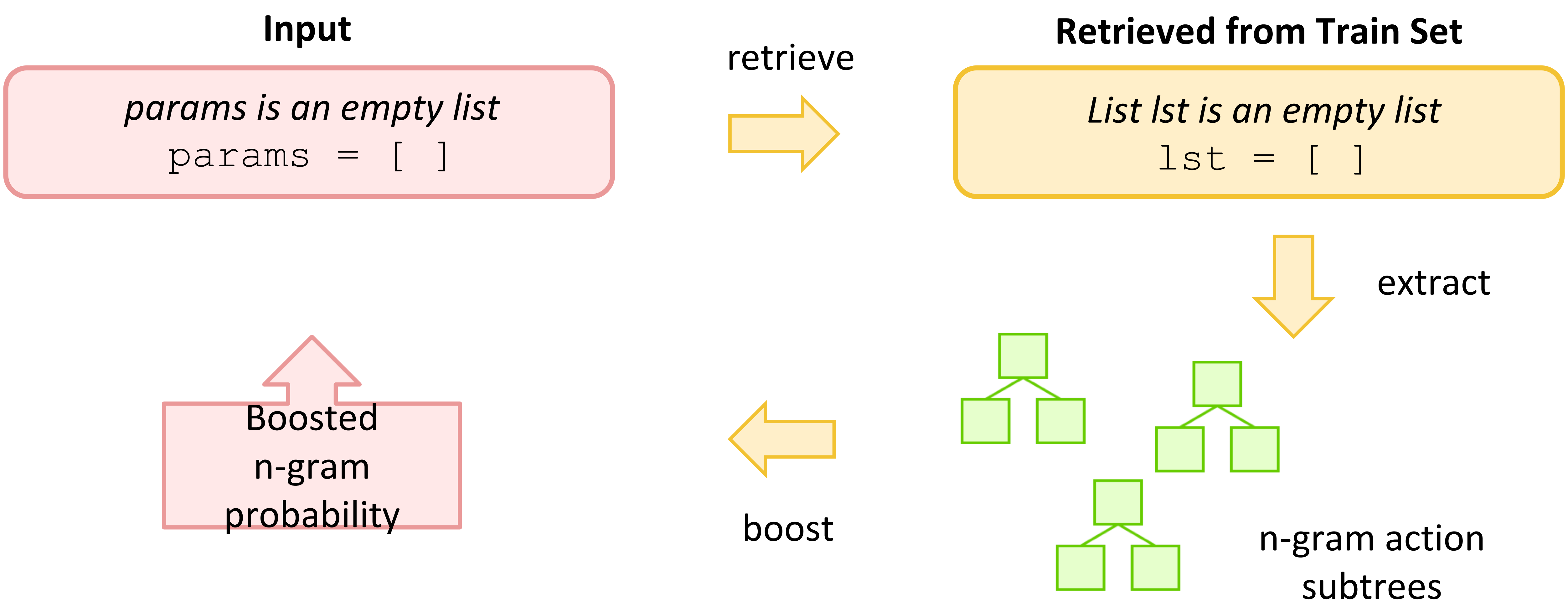


Neural Machine Translation + Retrieval

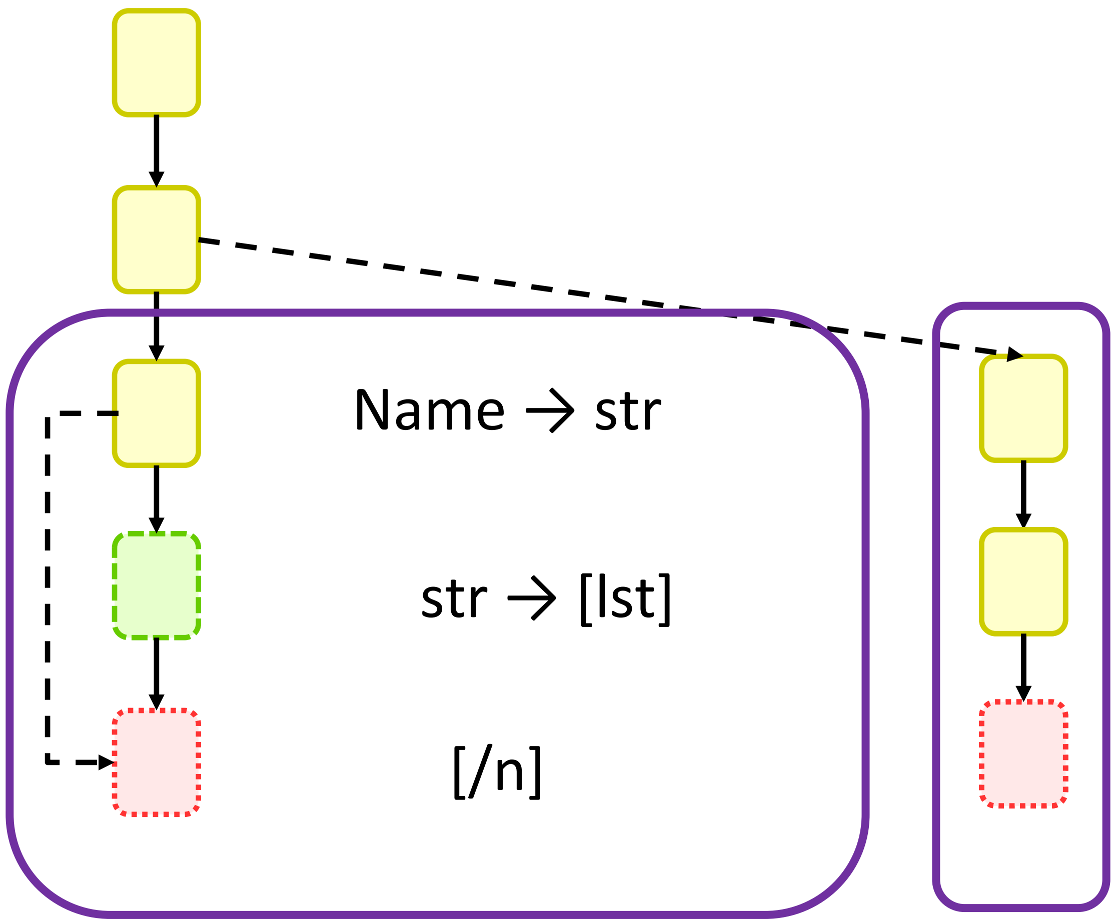
[Gu+2018, Zhang+2018]



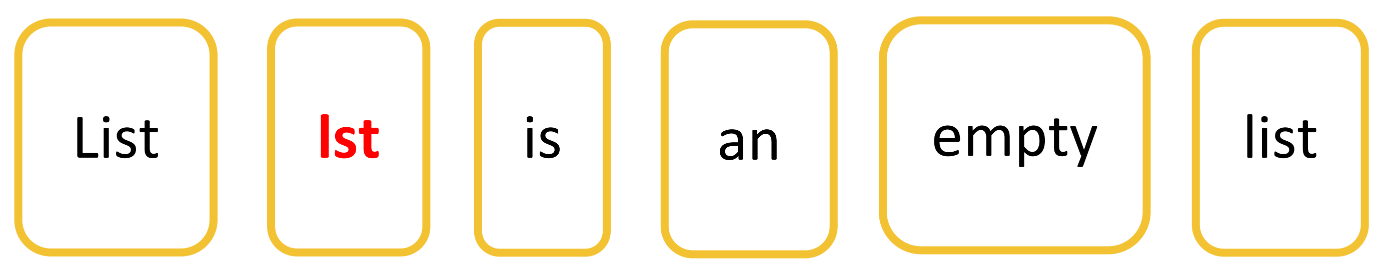
ReCode: Neural Code Retrieval + Generation



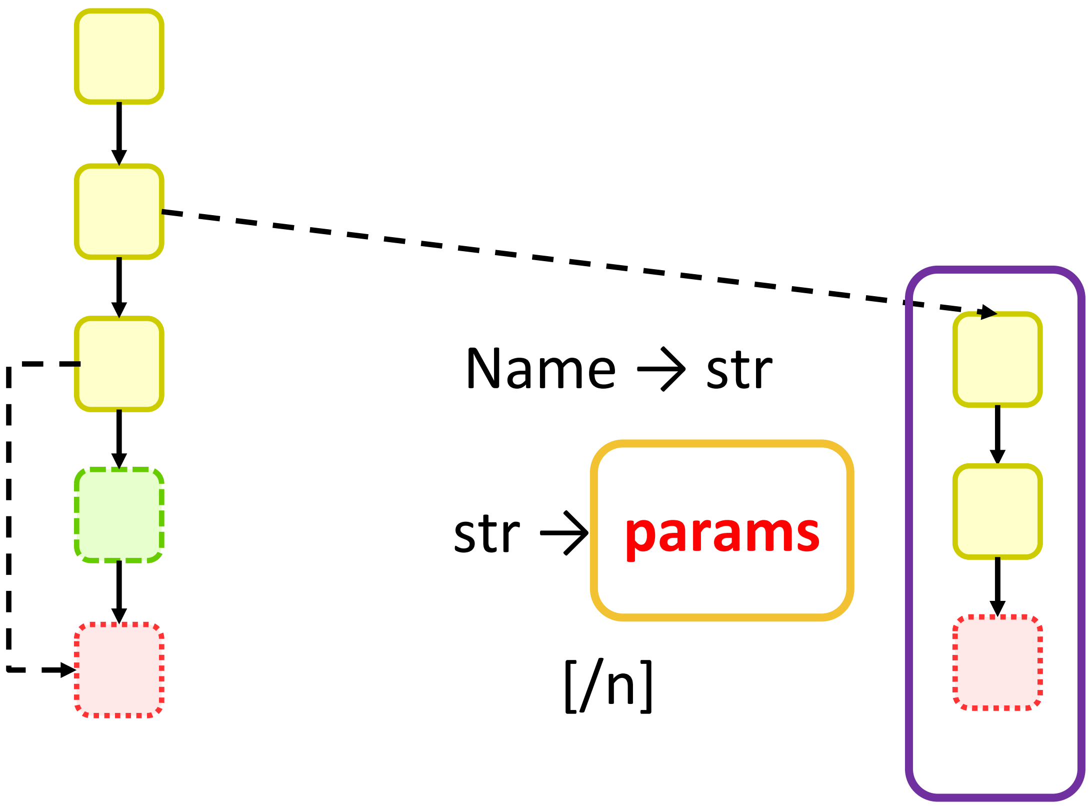
N-gram Action Subtrees



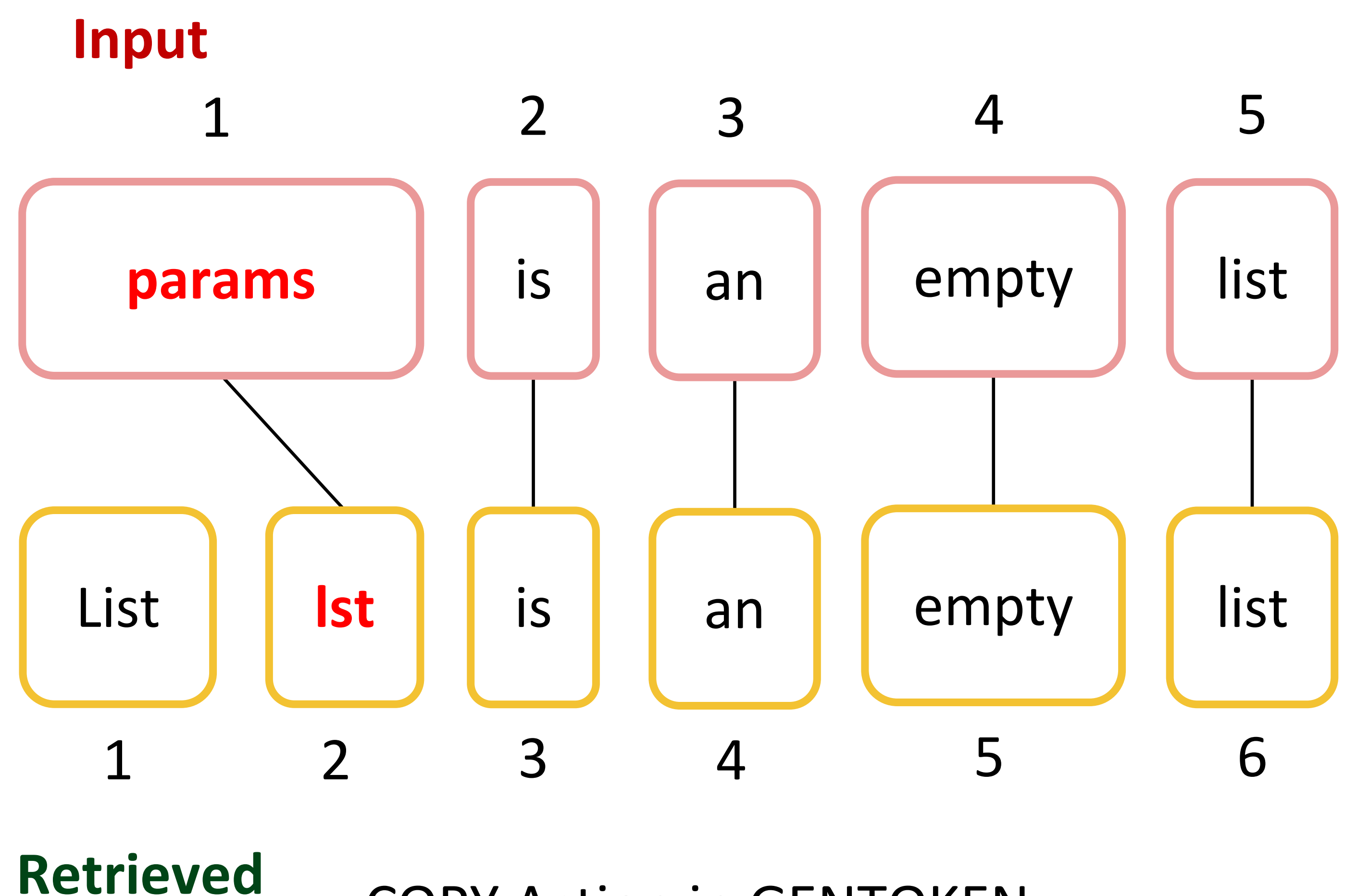
3-Gram Action Subtree



N-gram Action Subtrees w/ Copying

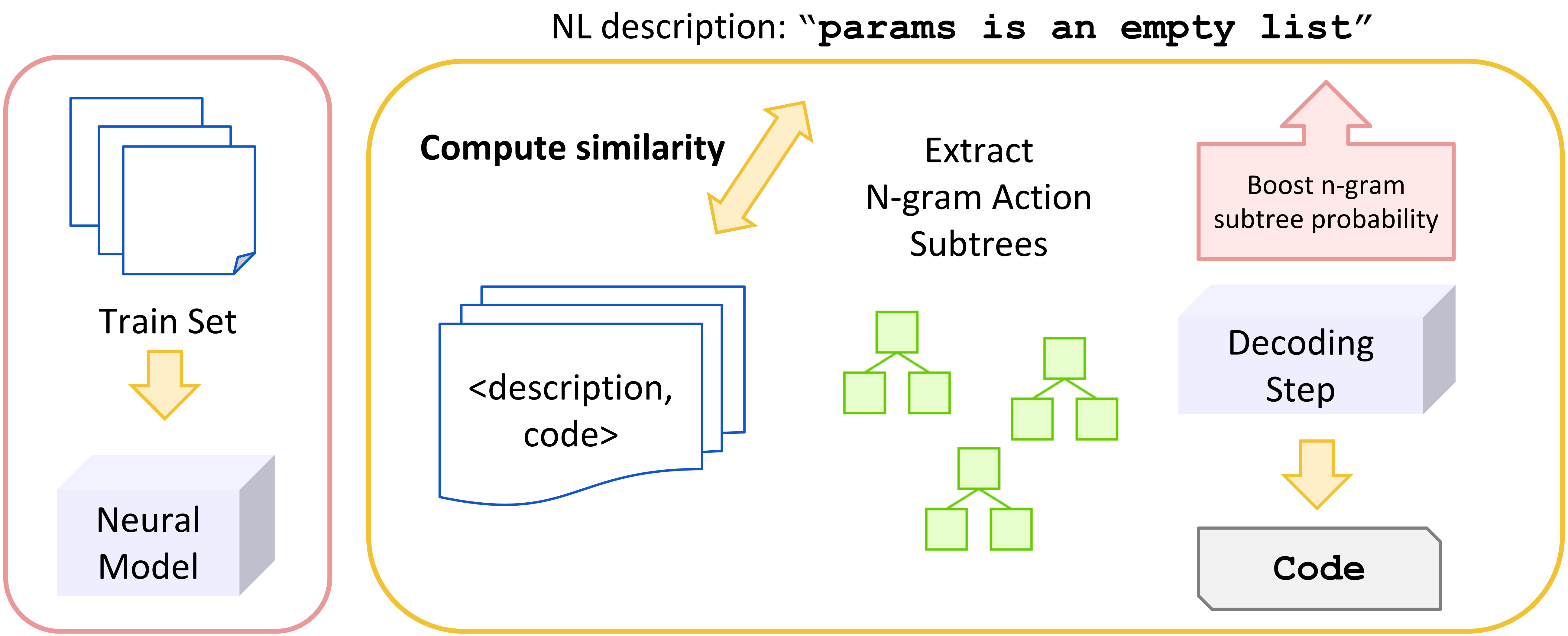


3-Gram Action Subtree



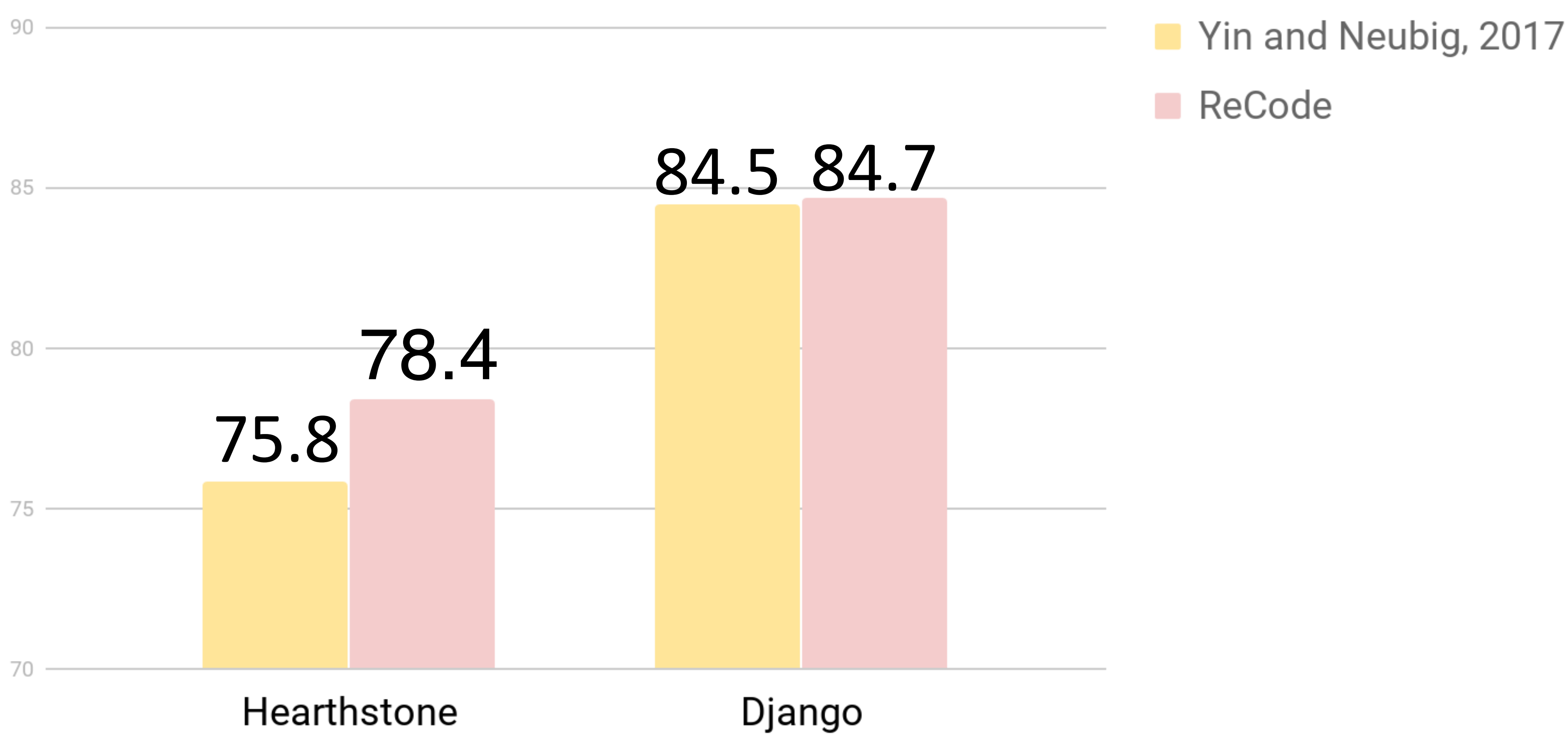
COPY Action in GENTOKEN

ReCode Pipeline



Results

All improvements are statistically significant with $p < 0.001$



Conclusion

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- Data-driven language → code within reach!
- Modeling structure of the PL is important and helpful
- Data is difficult, but we're making progress through mining
- Semi-supervised learning and retrieval to take advantage of large datasets

Questions?