Analyzing Software using Deep Learning

Reasoning about Types and Code Changes with Hierarchical Networks (Part 2)

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Summer 2020

Overview

- **Hierarchical neural networks**
- **Type prediction**

  Based on "TypeWriter: Neural Type Prediction with Search-based Validation" by Pradel et al., 2020
- **Representing code changes**

  Based on "CC2Vec: Distributed Representations of Code Changes" by Hoang et al., 2020

Types in Dynamic Progr. Langs.

- **Dynamically typed languages**:
  Extremely popular

- **Lack of type annotations**:
  - Type errors
  - Hard-to-understand APIs
  - Poor IDE support

Example

```
def find_match(color):
  candidates = get_colors()
  for candidate in candidates:
    if color == candidate:
      return color
  return None

def get_colors():
  return ["red", "blue", "green"]
```

Gradual Typing

- **Annotate some code locations with types**
  - E.g., parameter types and return types of some functions only
- **Gradual type checker**
  - Warn about inconsistencies
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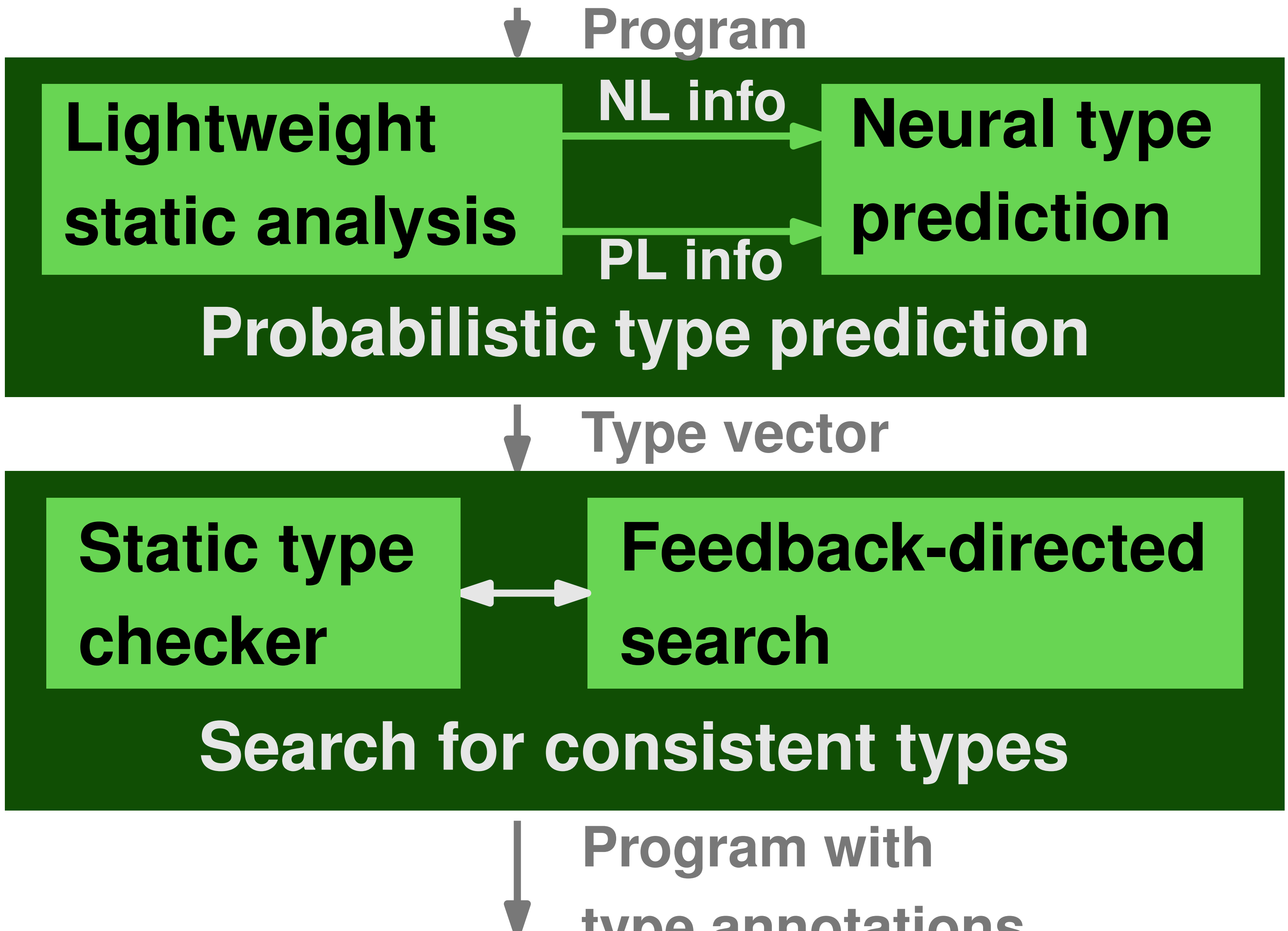
But: Annotating types is painful

How to Add Type Annotations?

- **Option 1: Static type inference**
  - Guarantees type correctness, but very limited
- **Option 2: Dynamic type inference**
  - Depends on inputs and misses types
- **Option 3: Probabilistic type prediction**
  - Models learned from existing type annotations

Overview of TypeWriter



Extracting NL and PL Info

- **NL information**
  - Names of functions and arguments
  - Function-level comments
- **PL information**
  - Occurrences of the to-be-typed code element
  - Types made available via imports

Example

```python
def find_match(color):
  """
  Args:
    color (str): color to match on and return
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  candidates = get_colors()
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Example

Names: find_match, color

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Function-level comment

Names: get_colors

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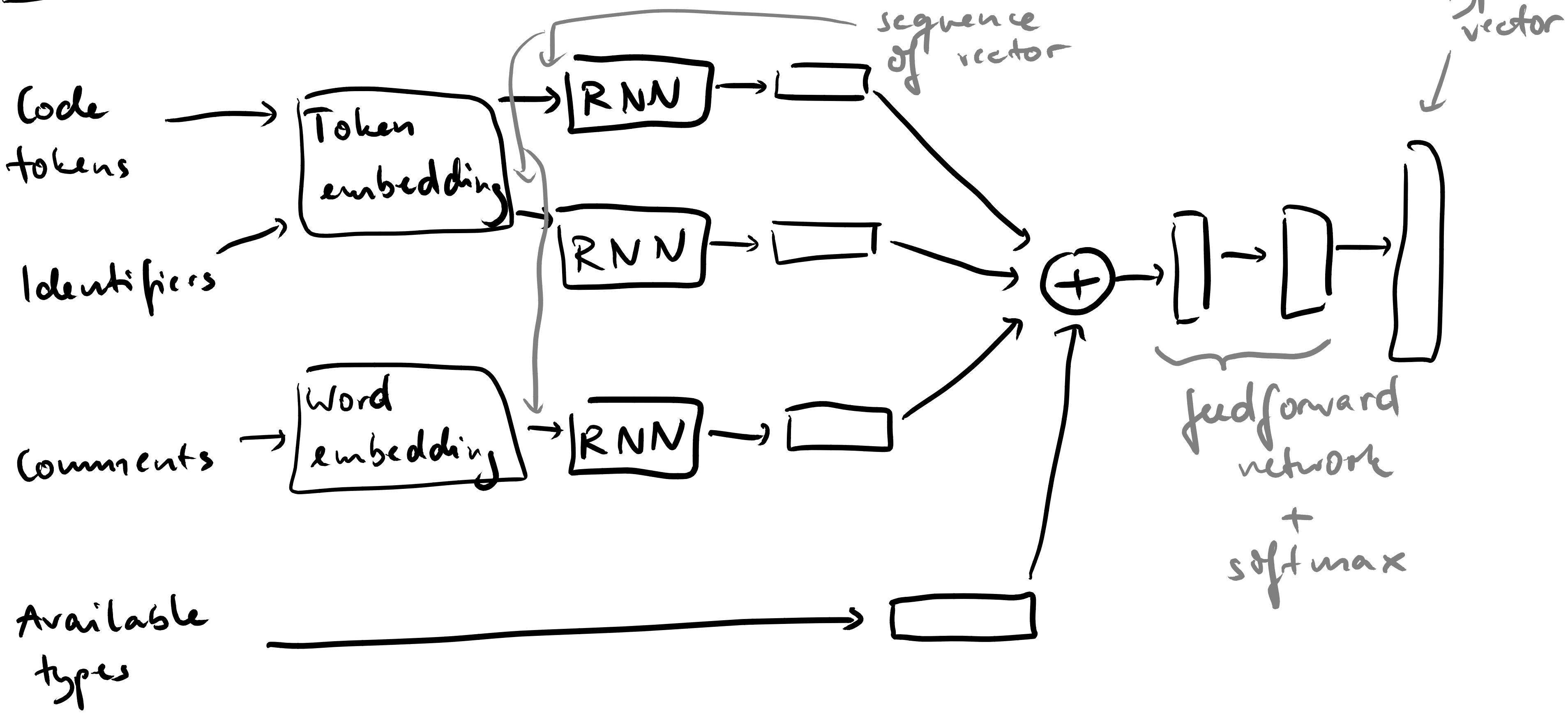
Occurrences of parameters

Return statements

Hierarchical neural network for type prediction



Output: Type Vector

- **Type prediction as a classification problem**
- **Output of the model: Type vector**
  - One element for each of top-1000 types
  - During training:

    All zero, except for the correct type
  - During prediction:

    Interpreted as probability distribution over types

Training the Model

- **Training data: Existing type annotations**
  - Multi-million line code base
  - Some types ($\approx$ 20-50%) already annotated
- **Learns to predict missing types from existing annotations**

Example of Predictions

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Predictions: int, str, bool

Predictions: str, Optional[str], None

Predictions: List[str], List[Any], str

Challenges

- **Imprecision**
  - Some predictions are wrong
  - Developers must decide which suggestions to follow
- **Combinatorial explosion**
  - For each missing type: One or more suggestions
  - Exploring all combinations: Practically impossible

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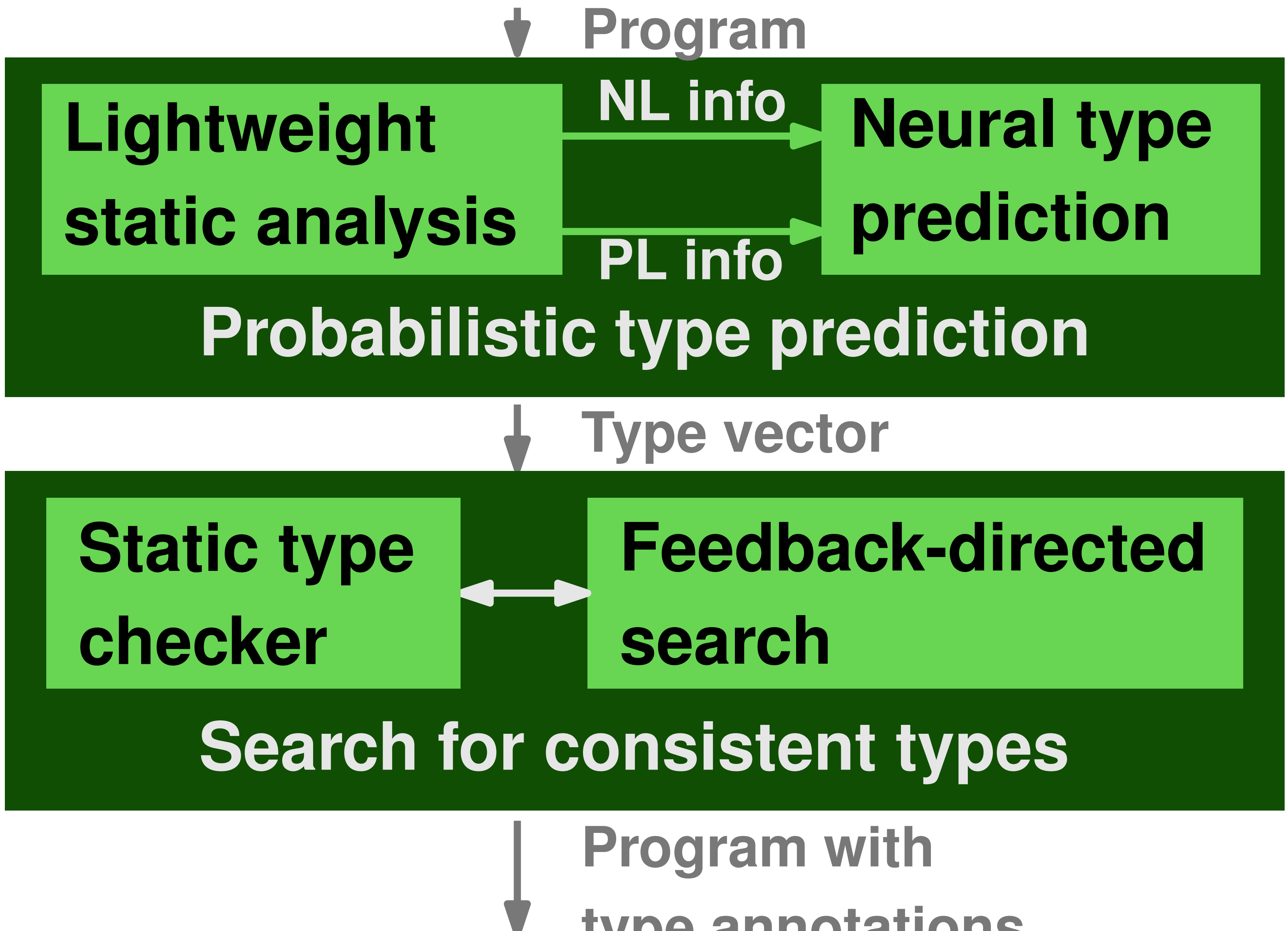

Searching for Consistent Types

- **Top-k predictions for each missing type**
  - Filter predictions using gradual type checker
  - E.g., pyre and mypy for Python, flow for JavaScript
- **Combinatorial search problem**
  - For type slots S and k predictions per slot: $(k+1)^{|S|}$ possible type assignments

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Too large to explore exhaustively!

Feedback Function

- **Goal: Minimize missing types without introducing type errors**

- **Feedback score (lower is better):**

$$v \cdot n_{missing} + w \cdot n_{errors}$$

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Default: $v = 1$, $w = 2$,
i.e., higher weight for errors

Search Strategies

- **Optimistic vs. pessimistic**

  Optimistic: Add top-most predicted type everywhere and then remove types

  Pessimistic: Add one type at a time

- **Greedy vs. non-greedy**

  Greedy: If score decreases, keep the type

  Non-greedy: Backtrack to avoid local minima

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Results

- **Neural model**
  - Precision: 58-73% in top-1, 50-92% in top-5
  - Recall: 50-58% in top-1, 69-72% in top-5
- **Model and search together**
  - Best strategy adds 72% of type-correct types and completely annotates 44% of files
- **In use at Facebook**
  - Thousands of suggested types accepted by developers with minimal changes