Predicting TypeScript Type Annotations and Definitions With Machine Learning

Ming-Ho Yee

Northeastern University

September 13, 2023

Thesis Proposal

Type migration: JavaScript to TypeScript

- Incremental migration
- Static type checking
- Better documentation
- Editor integration

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- Static type checking
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```
function f(s) {
    return s.
}
```

abc f
abc s

```
function f(s: string) {
    return s.
}
```

Symbol interface Symbolvar
charAt
charCodeAt
codePointAt
concat

Machine learning for type prediction

Predict the most likely type annotation for the given code fragment

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Classification

```
function f(x) {
    return x + 1;
}
```

Type of x	Probability
`number`	0.4221
`any`	0.2611
`string`	0.2558
other	

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Large language models for code

```
function f(x: _hole_) {
    return x + 1;
}
```

```
function f(x: number) {
    return x + 1;
}
```

Large language models (LLMs)

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The quick brown

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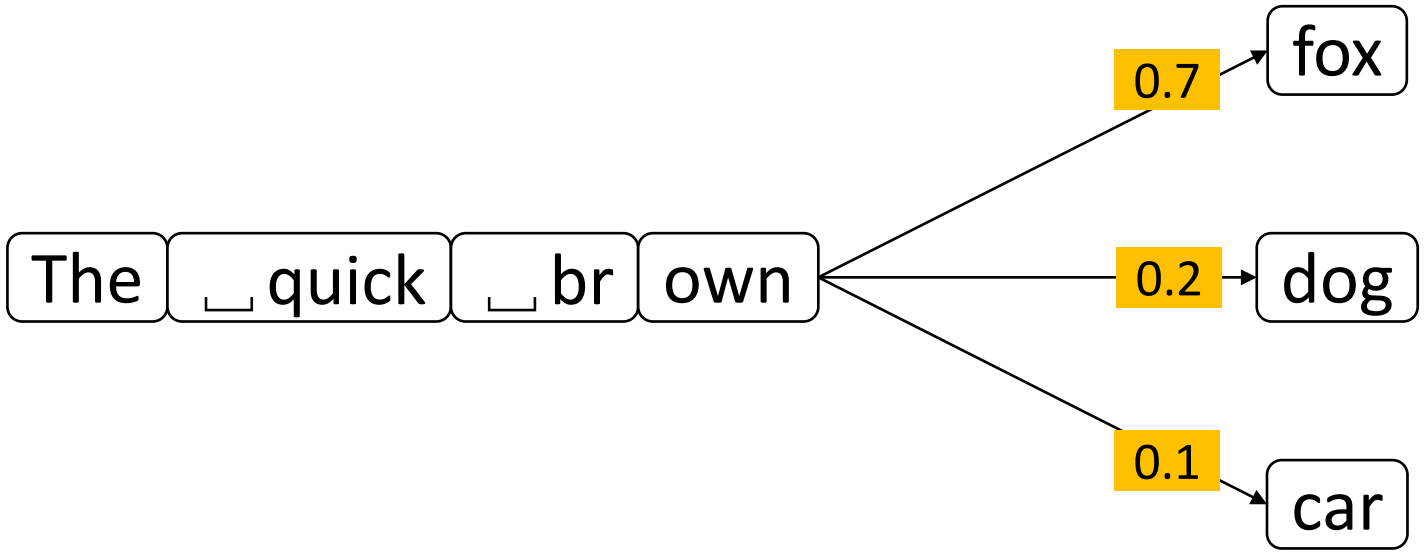

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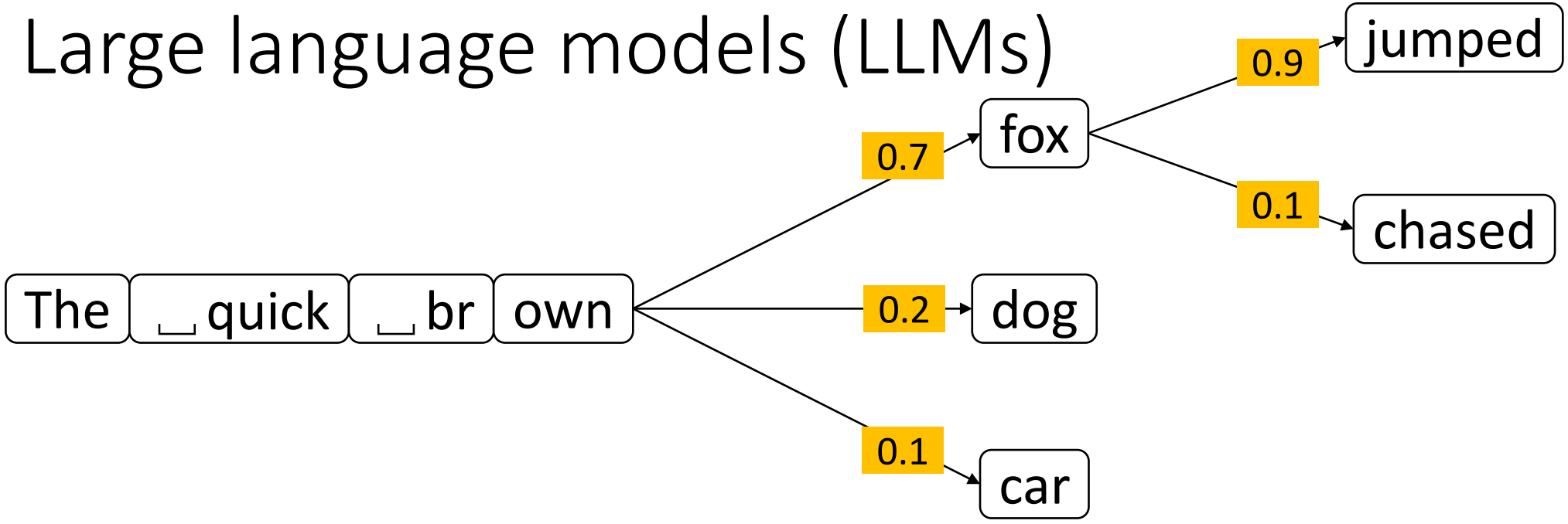

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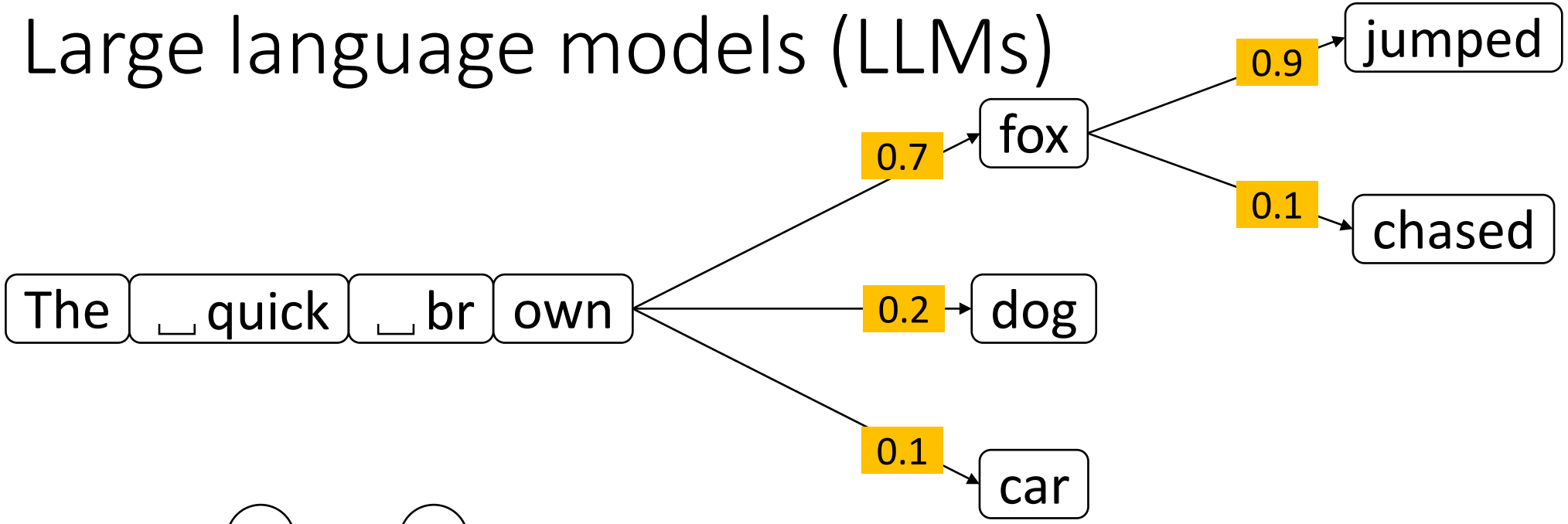

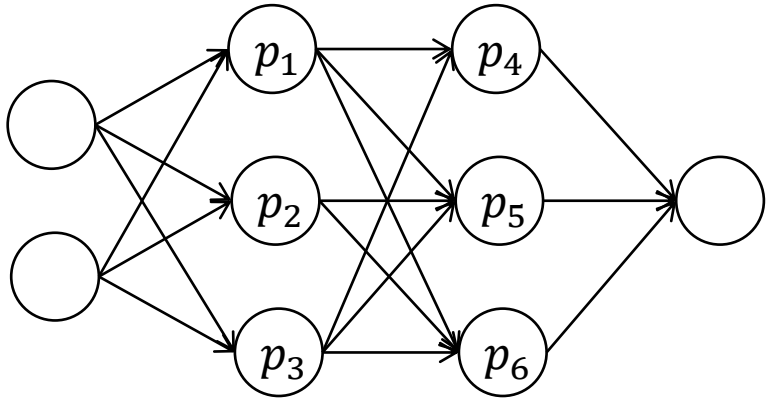

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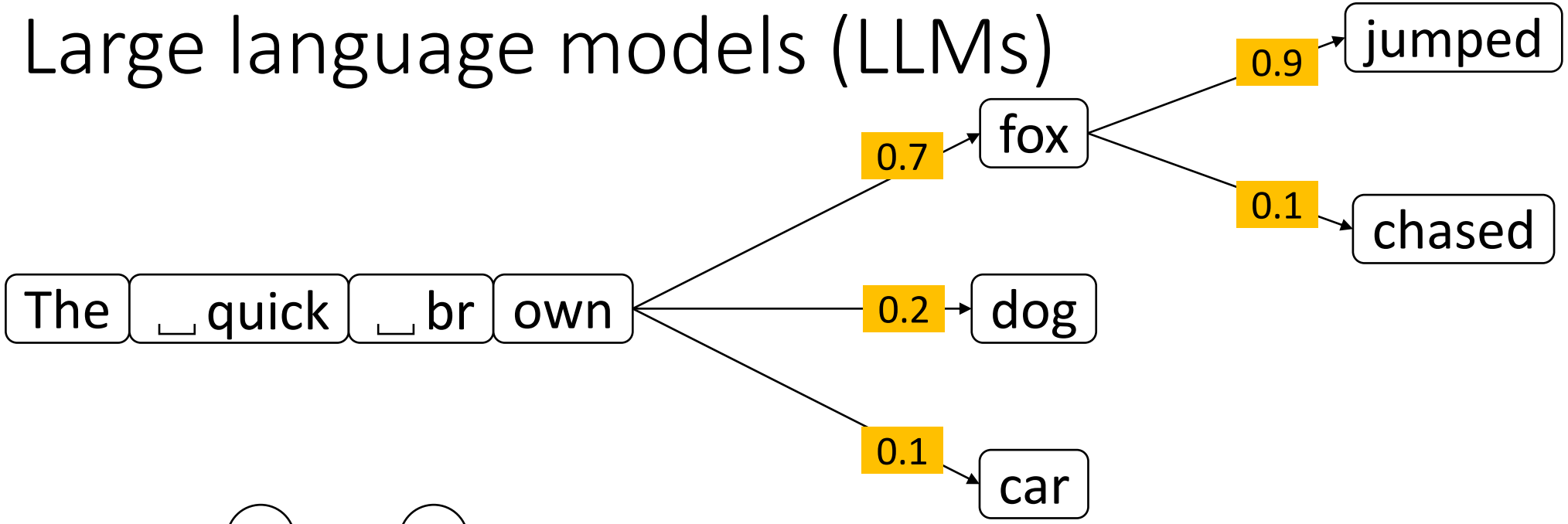
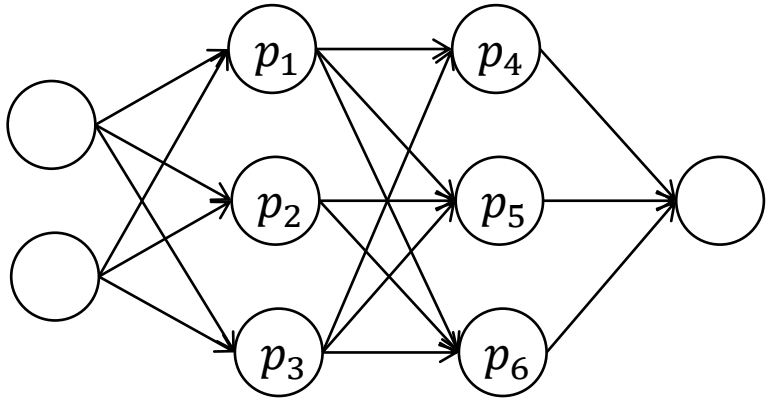
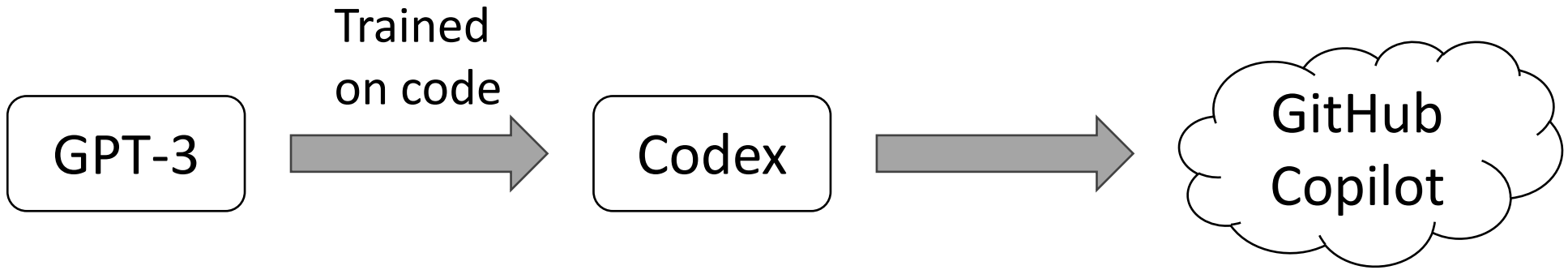




Model	Parameters	Training data
GPT-1 [2018]	117 million	4.5 GB
GPT-2 [2019]	1.5 billion	40 GB
GPT-3 [2020]	175 billion	570 GB
GPT-3.5 [2022]	175 billion	Undisclosed
GPT-4 [2023]	Undisclosed	Undisclosed

ChatGPT

Large language models for code (code LLMs)



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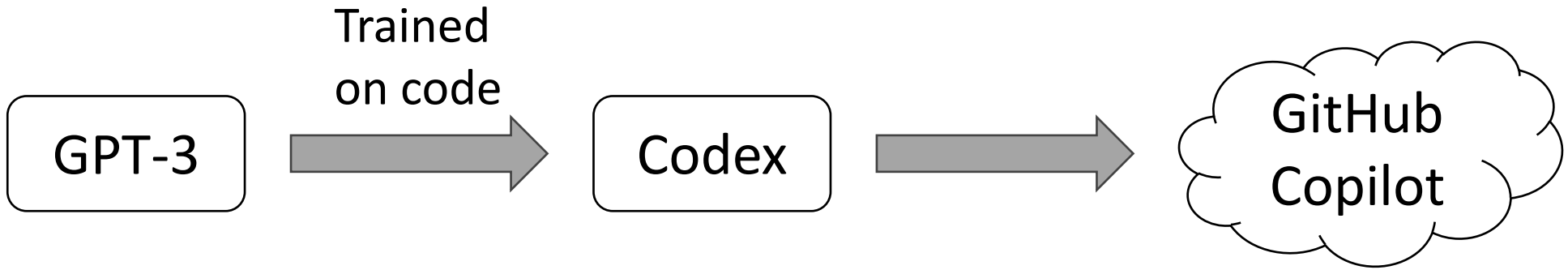

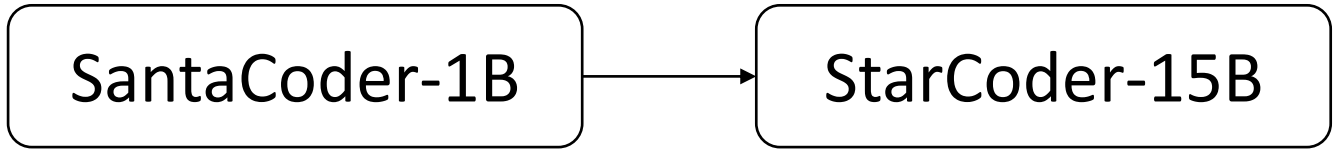

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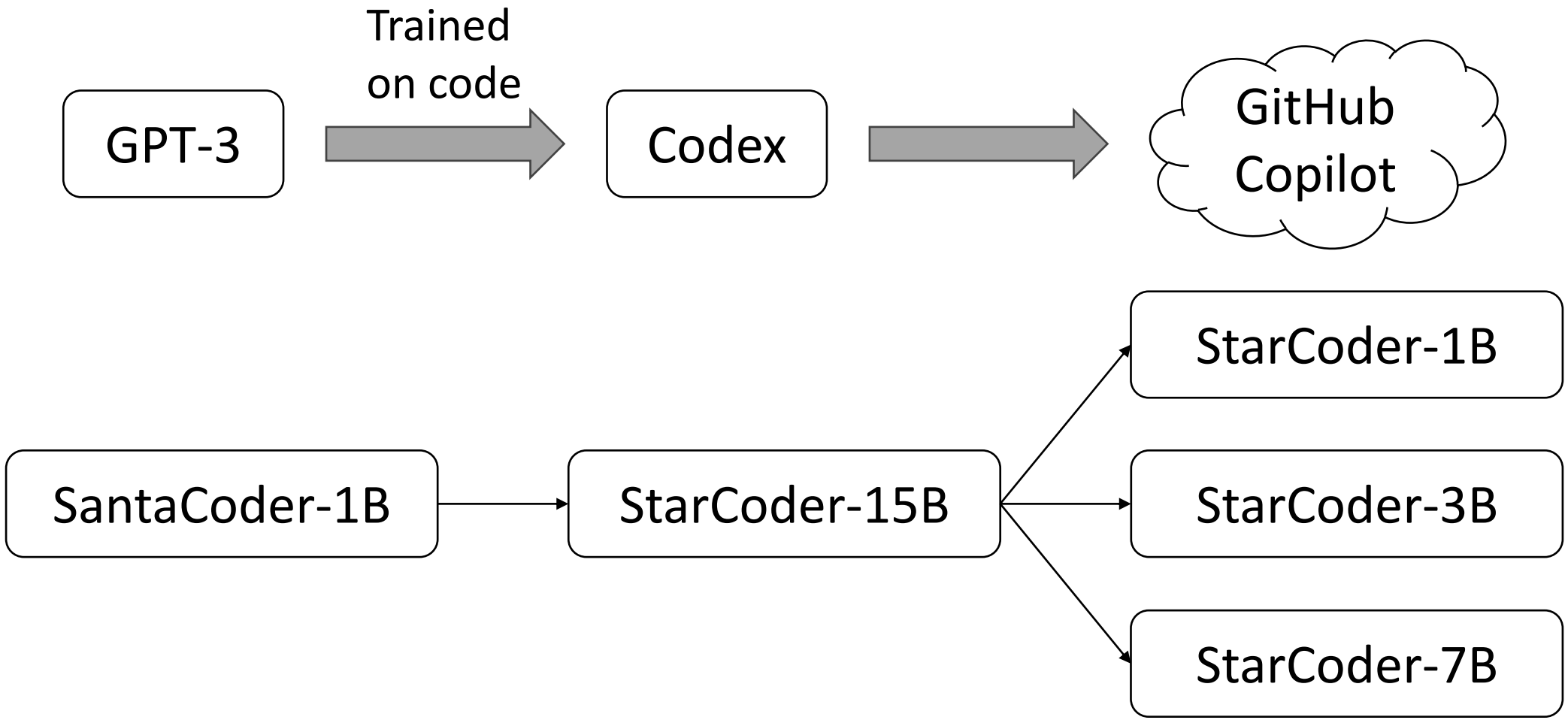

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Training

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function fact(n) {
    if (n == 0) return 1;
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Limitations of existing approaches

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Do Machine Learning Models
Produce TypeScript Types
That Type Check? [ECOOP 2023]

Yee and Guha

Limitations of existing approaches

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Do Machine Learning Models Produce TypeScript Types That Type Check? [ECOOP 2023]

Yee and Guha

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Type Prediction With Program Decomposition and Fill-in-the-Type Training

[submitted to NeurIPS 2023]

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Type Definitions

```
interface Point {
    x: number,
    y: number
}
```

Generating TypeScript Type Definitions With Machine Learning [proposed work]

Thesis

Machine learning can be used to partially migrate JavaScript programs to TypeScript, by predicting type annotations and generating type definitions.

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What is the likelihood that a predicted type annotation is correct?

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```
type S = number;
function f(w, x, y, z) { ... }
```

Identifier	Ground truth	Prediction	
w	number	number	✅
x	A | B	B | A	❌
y	S	number	❌
z	number	any	❌

Accuracy: 0.25

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Accuracy: 0.25

Limitations of accuracy:

- Requires exact match
- Requires ground truth
- Predictions may not type check

TypeWeaver: type check the type annotations

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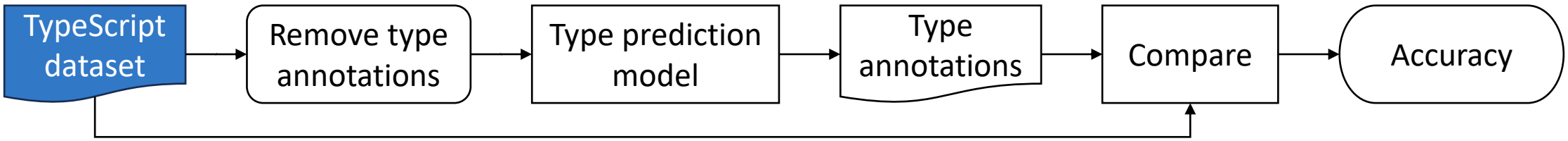
Prior work:



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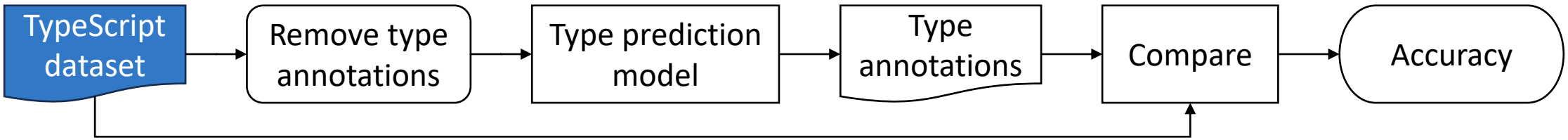

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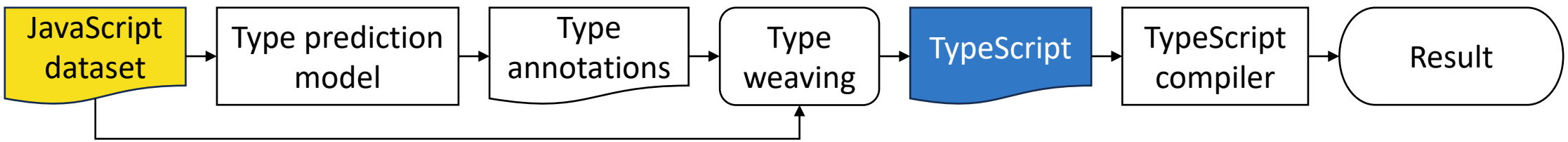

Constructing the JavaScript dataset

1. Top 1,000 most downloaded packages

2. Download source code

3. Filter and clean

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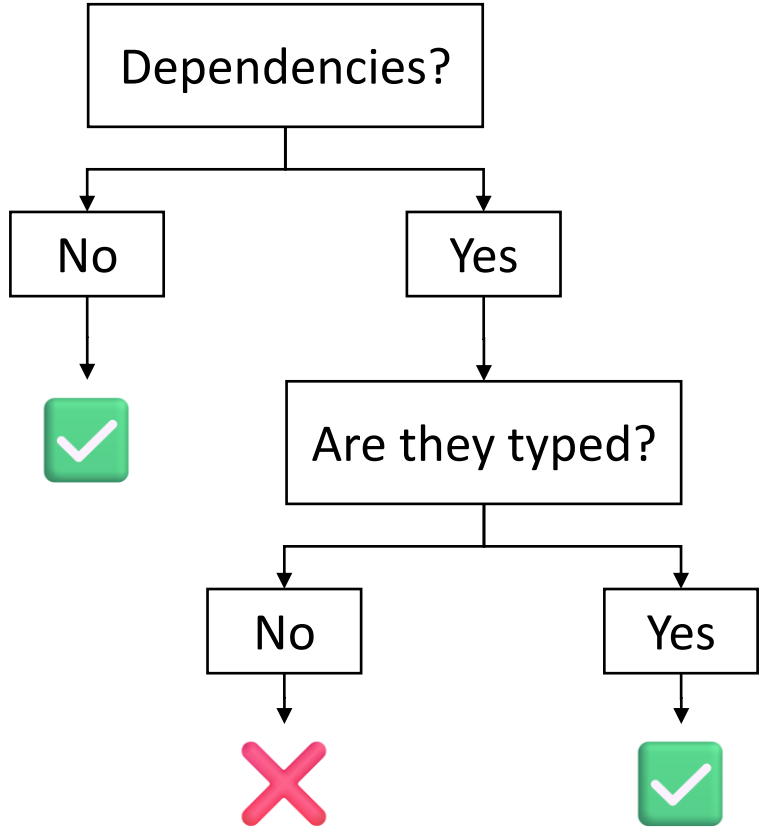

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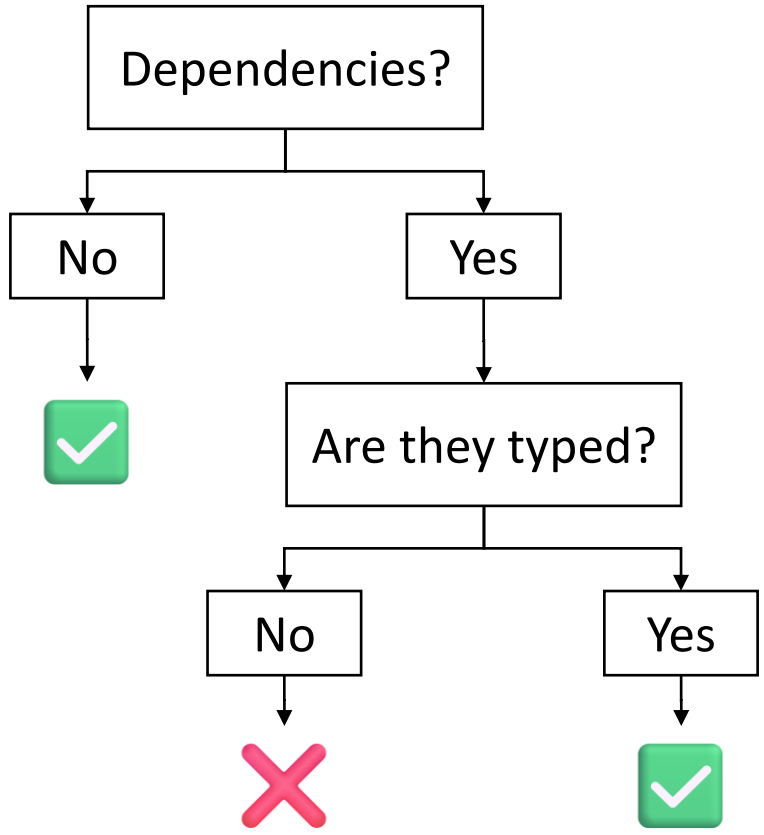

Result: 513 packages

Type weaving: JS + type annotations = TS

```
function f(x, y) {
    return x + y;
}
```

Token	Type	Probability
function		
f	string	0.6381
(		
x	string	0.4543
,		
y	number	0.4706
)		
{		
return		
x	number	0.3861
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FunctionDeclaration
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Type weaving: JS + type annotations = TS

```
function f(x, y): string {
    return x + y;
}
```

```
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```
function f(x: string, y): string {
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Type prediction front end

Original code

```
function sum_list(l) {
    let sum = 0;
    for (let i = 0; i < l.length; i++) {
        sum += l[i];
    }
    return sum;
}
```

Type prediction front end

Insert hole

```
function sum_list(l: _hole_) {
    let sum = 0;
    for (let i = 0; i < l.length; i++) {
        sum += l[i];
    }
    return sum;
}
```

Type prediction front end

Reformat input

```
<fim_prefix>function sum_list(l:
<fim_suffix>) {
    let sum = 0;
    for (let i = 0; i < l.length; i++) {
        sum += l[i];
    }
    return sum;
}<fim_middle>
```

Type prediction front end

Fill in the middle

```
<fim_prefix>function sum_list(l:
<fim_suffix>) {
    let sum = 0;
    for (let i = 0; i < l.length; i++) {
        sum += l[i];
    }
    return sum;
}<fim_middle>any[]): number {
    if (l.length === 0) {
        throw 'Empty list!';
    }
    if (l.length === 1) {
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Type prediction front end

Extract type

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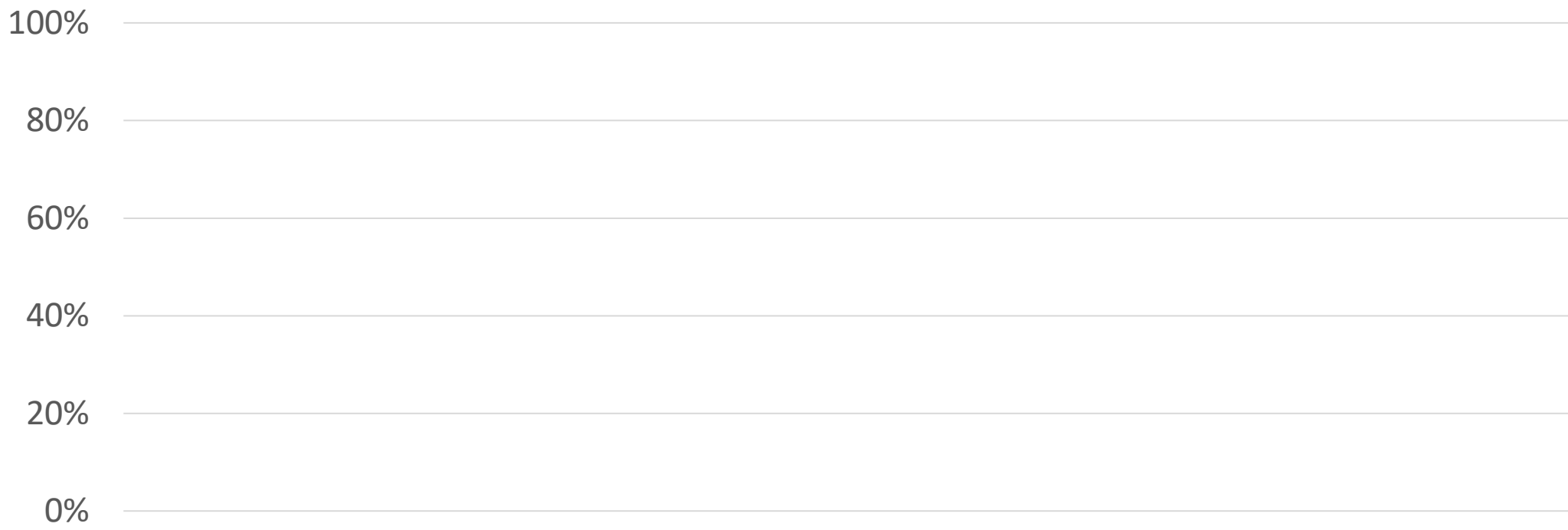
Type prediction front end

Result

```
function sum_list(l: any[]) {
    let sum = 0;
    for (let i = 0; i < l.length; i++) {
        sum += l[i];
    }
    return sum;
}
```

Percentage of packages that type check



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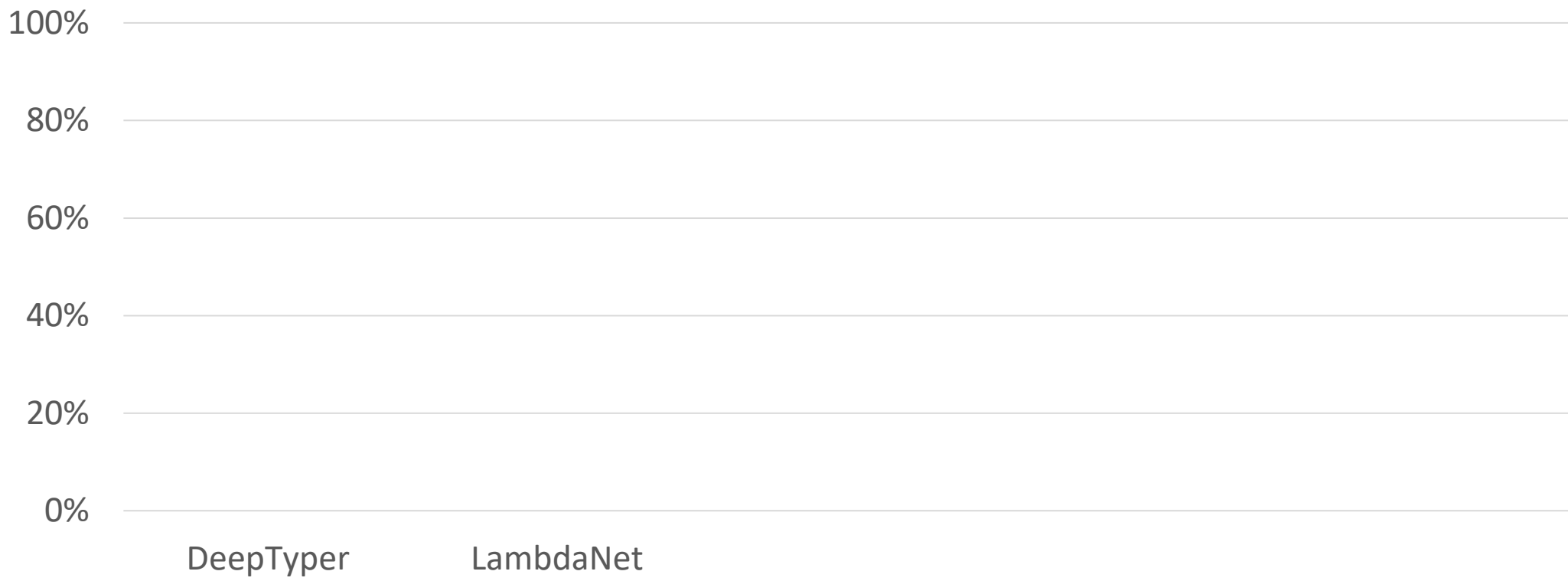

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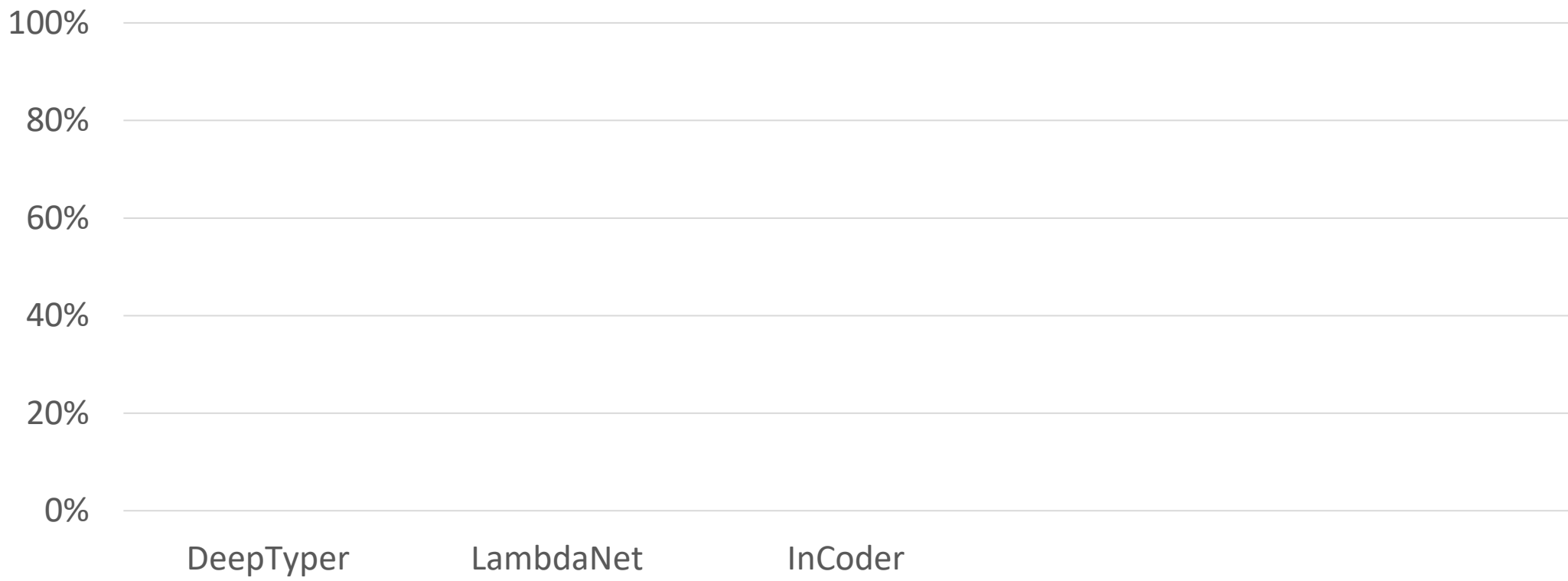

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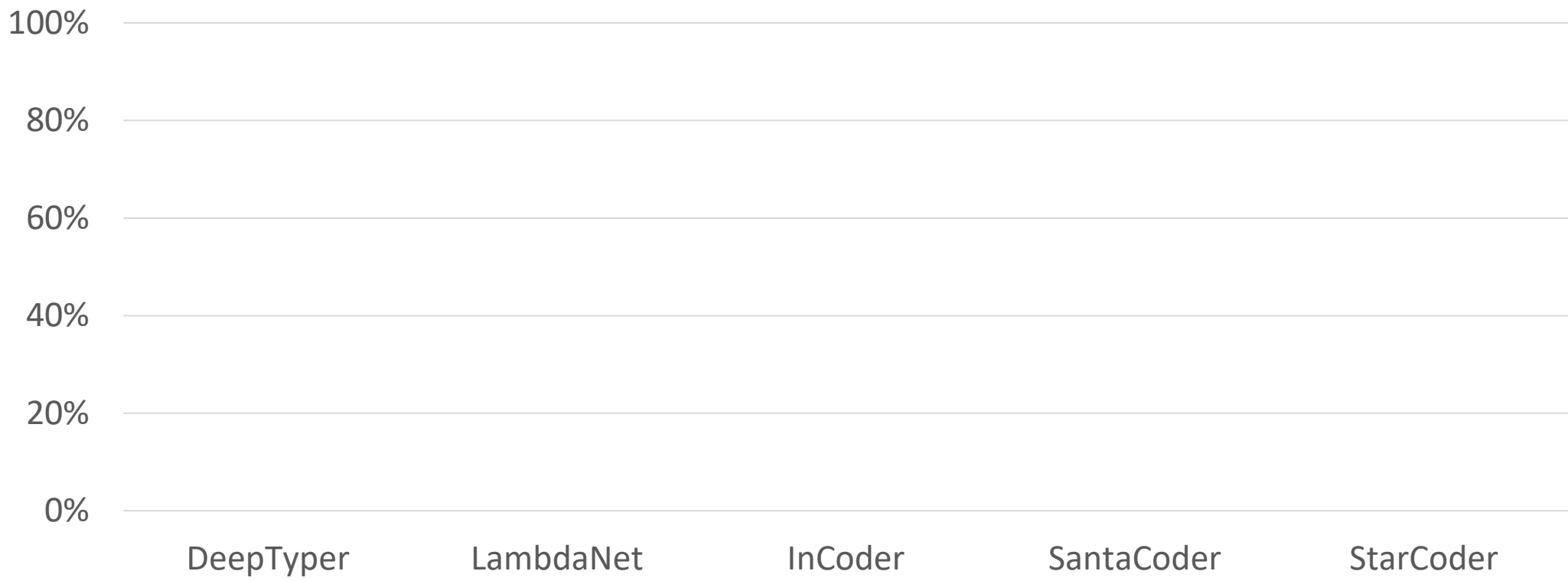

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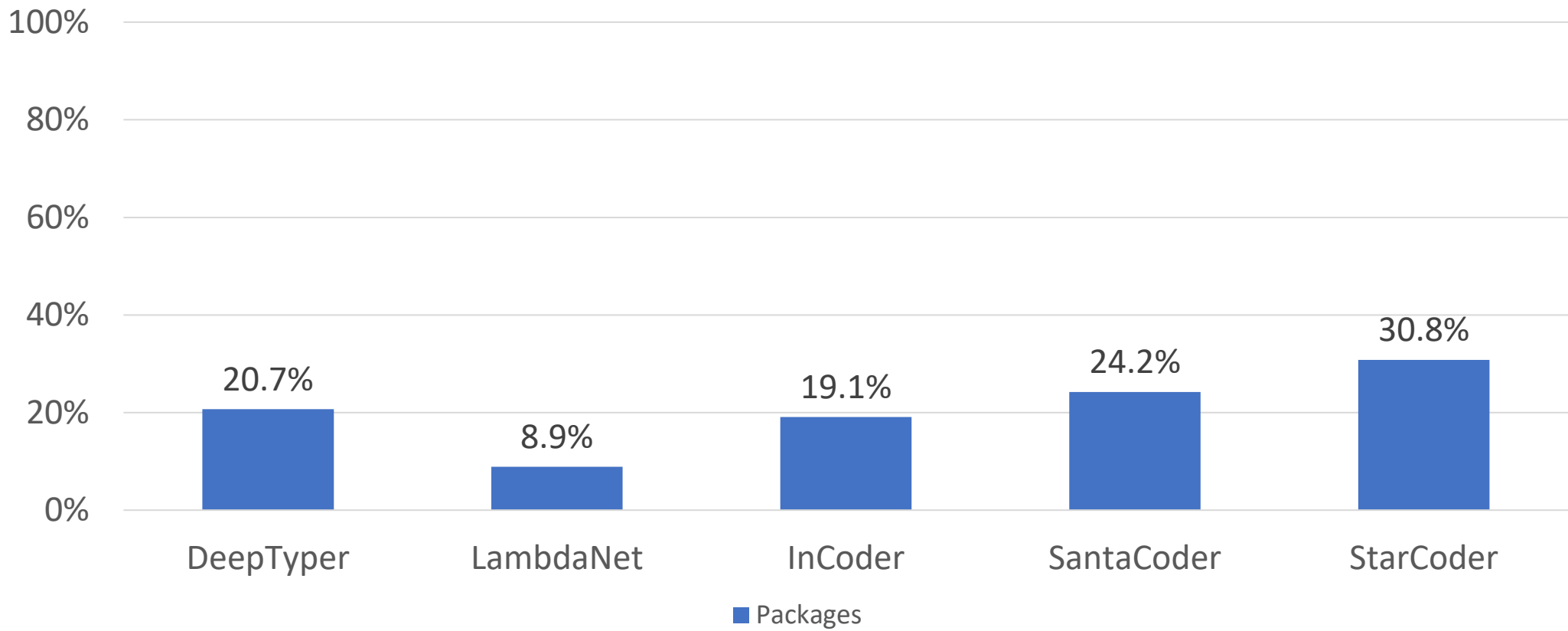
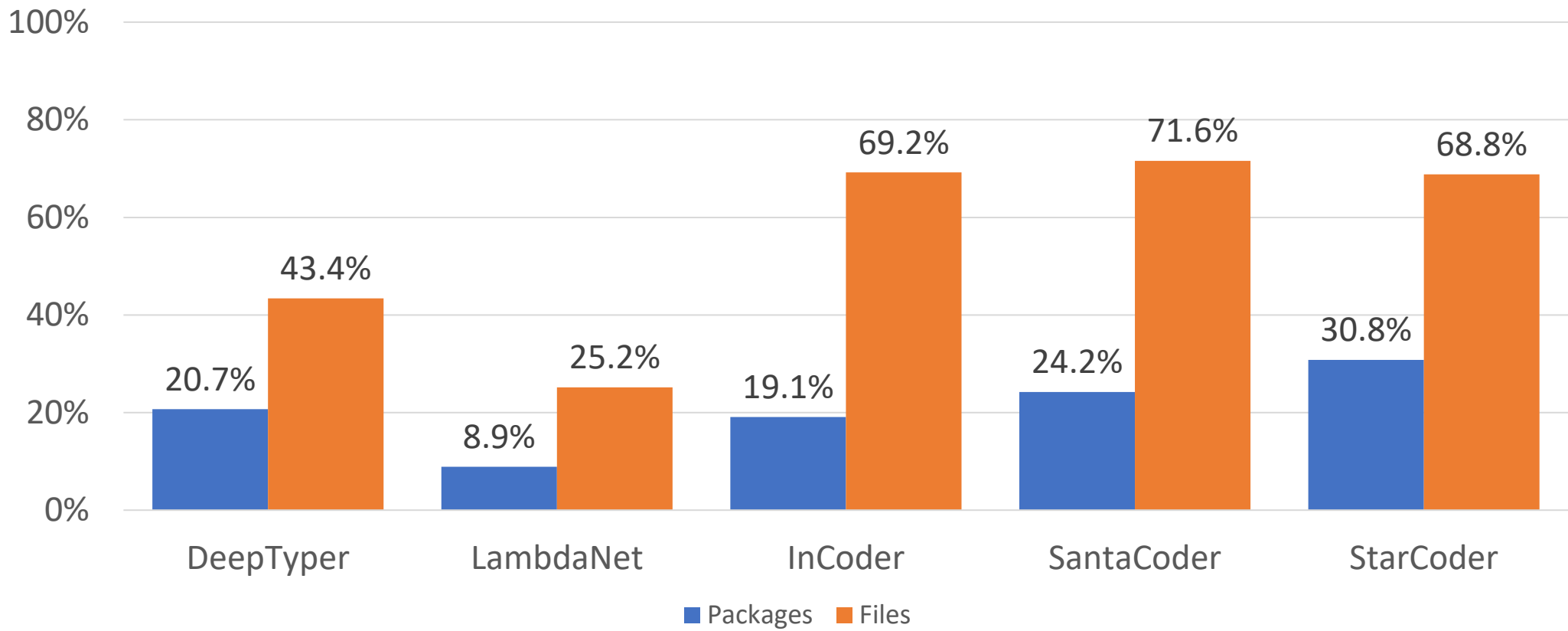


Percentage of packages/files that type check



Percentage of trivial annotations
(in files that type check)

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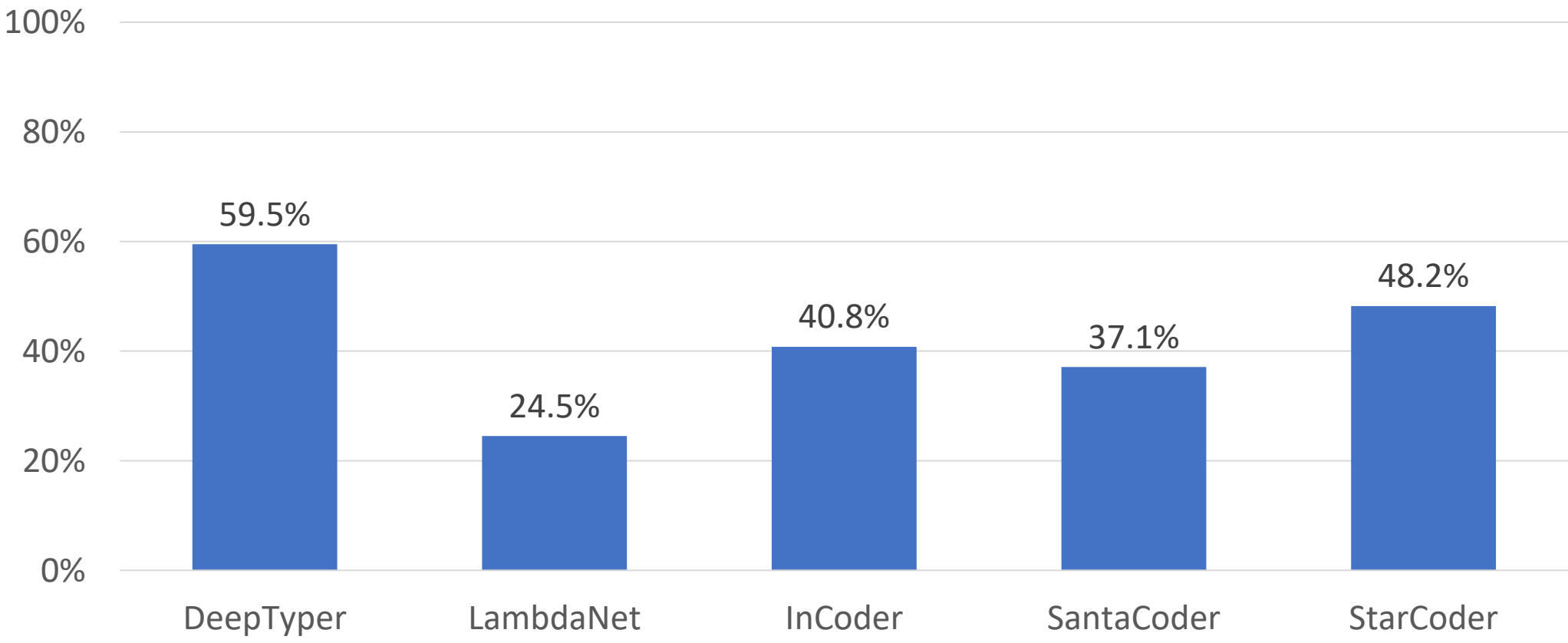

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Improving type prediction

Improving type prediction

Dataset quality

TypeScript dataset

Improving type prediction

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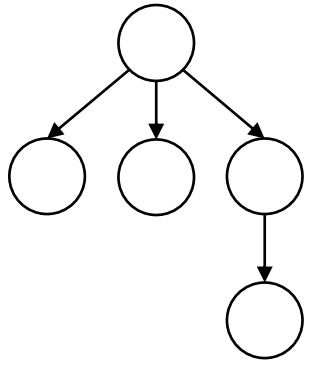
TypeScript dataset

Program decomposition

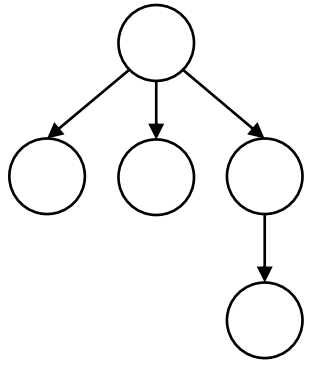


Improving type prediction

Dataset quality

TypeScript dataset

Program decomposition



Fill-in-the-type training

```
function f(x: _hole_) {
    return x + 1;
}
```

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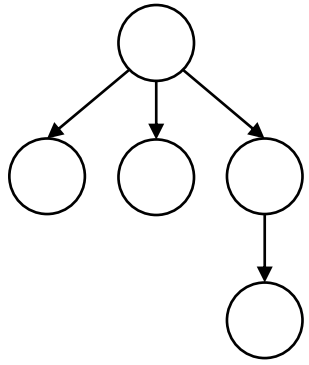

Fill-in-the-type training

```
function f(x: _hole_) {
    return x + 1;
}
```

Program typedness

```
function f(x: any) {
    return x + 1;
}
```

Dataset quality

Dataset quality

```
function f(x) {
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```

Dataset quality

```
function f(x) {
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~~~


export default {
    group: "typography",
    currentPage: 2
}
```

Dataset quality

```
function f(x) {
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export default {
    group: "typography",
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}


export const TabIcons = [
    'tab', 'code-braces', 'tags', 'target'
]
export function getTabIcon(tabType: number) {
    return TabIcons[tabType];
}
```

Dataset quality

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    return x + 1;
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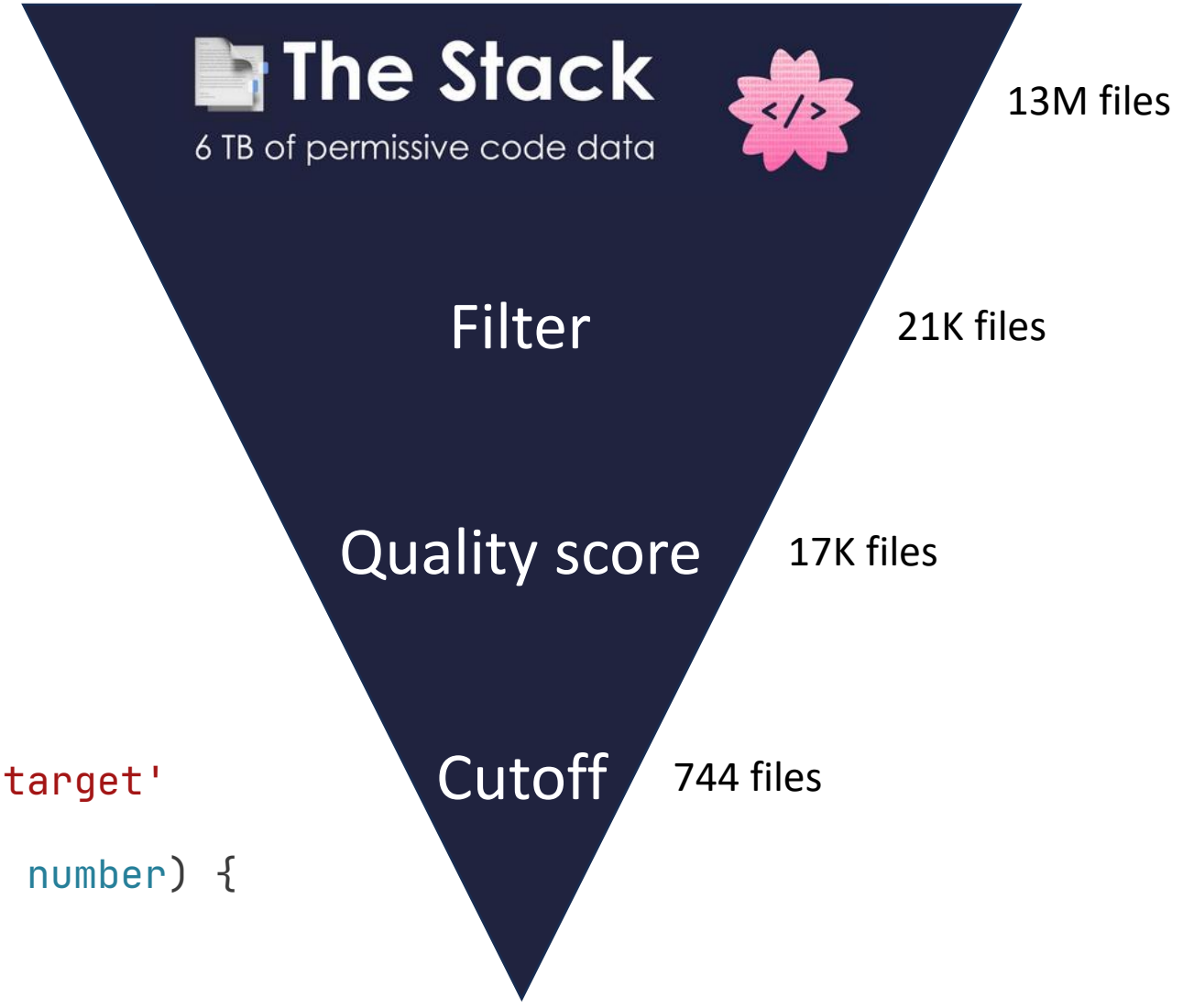

Program decomposition

```
let greeting = "Hello";
let suffix = "!";

// Produces a greeting for the given name
const hello = (name) => {
    return greeting + " " + name;
};

function helloGen(name) {
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    };
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}
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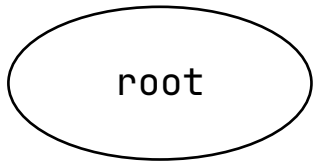

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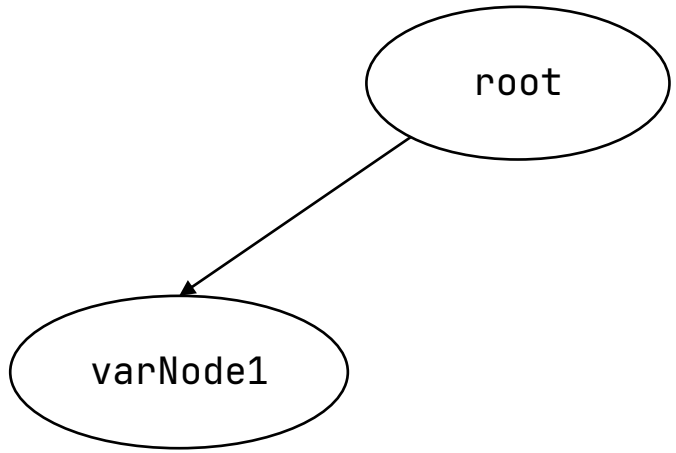

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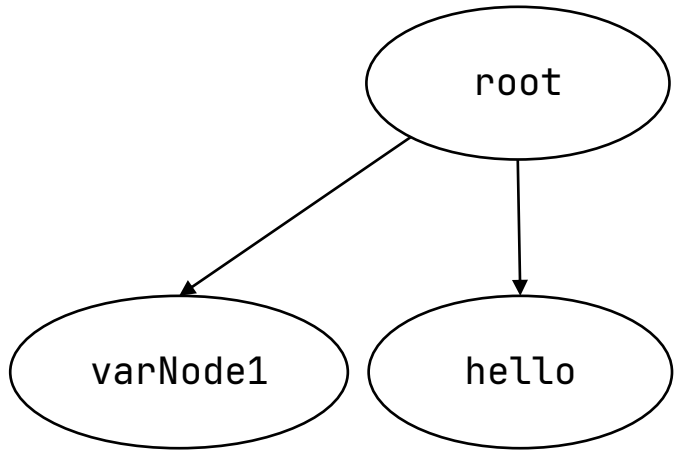

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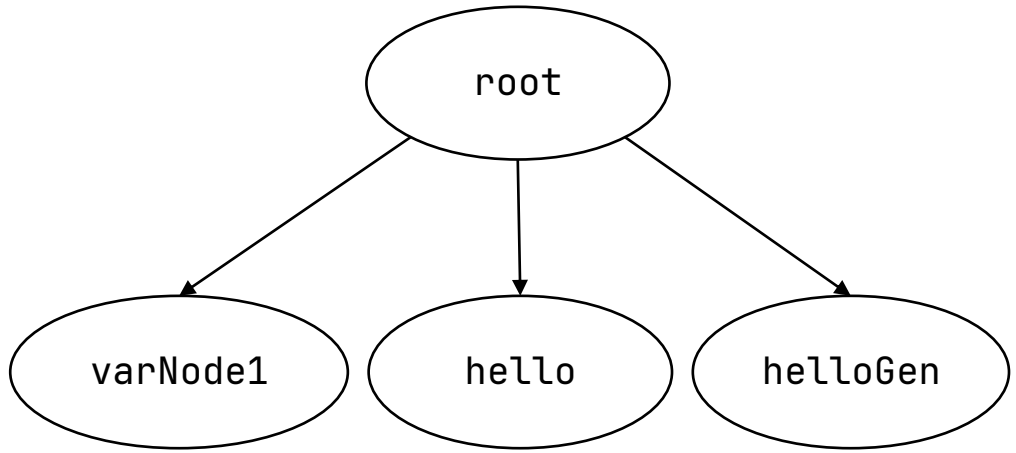

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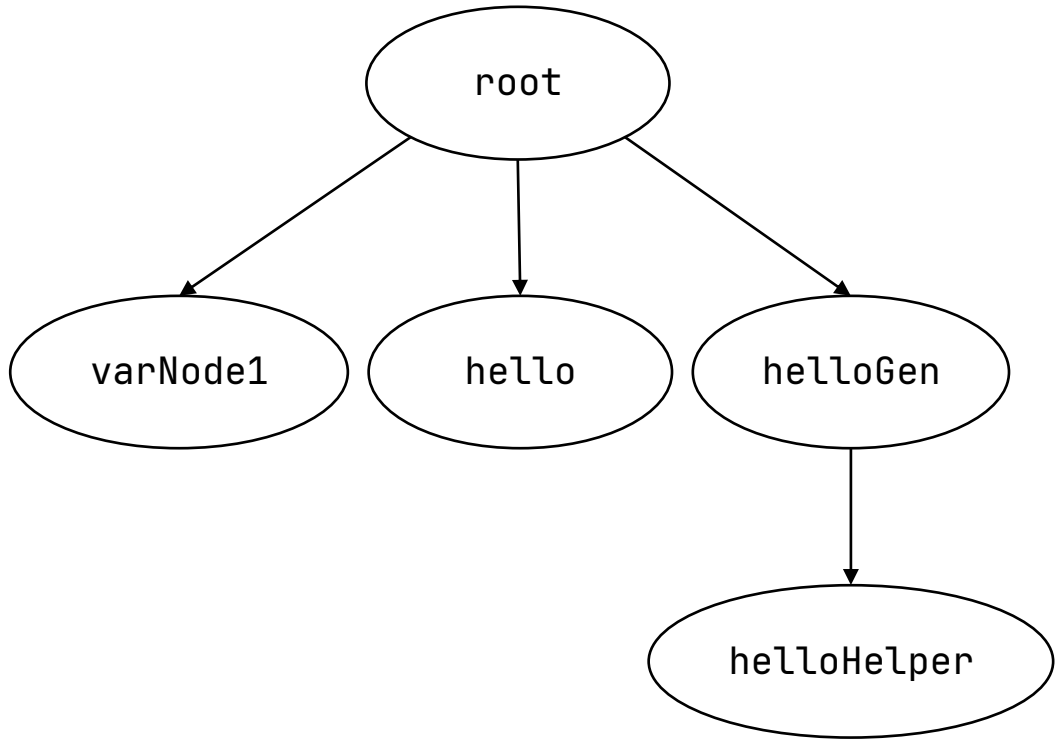

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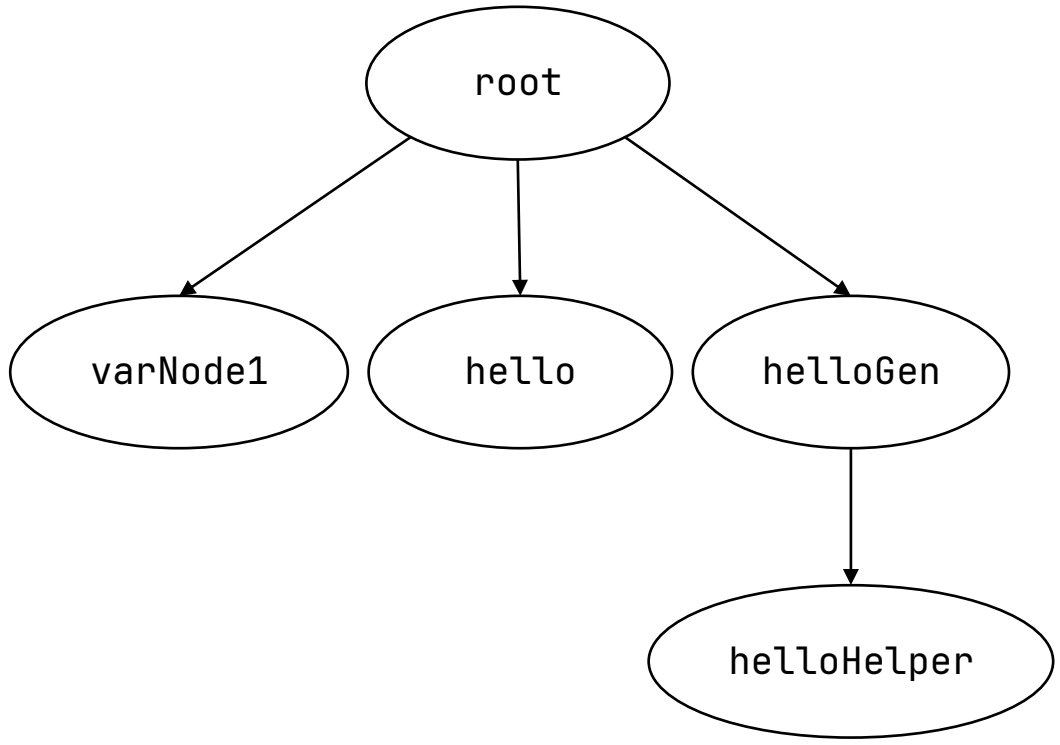

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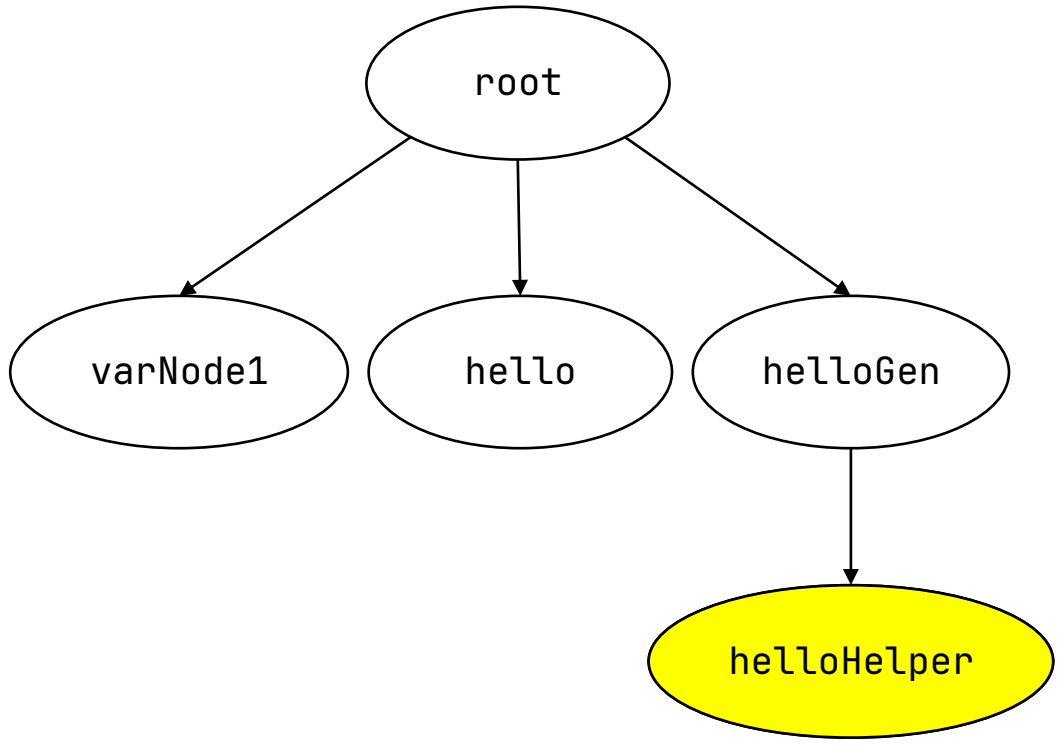

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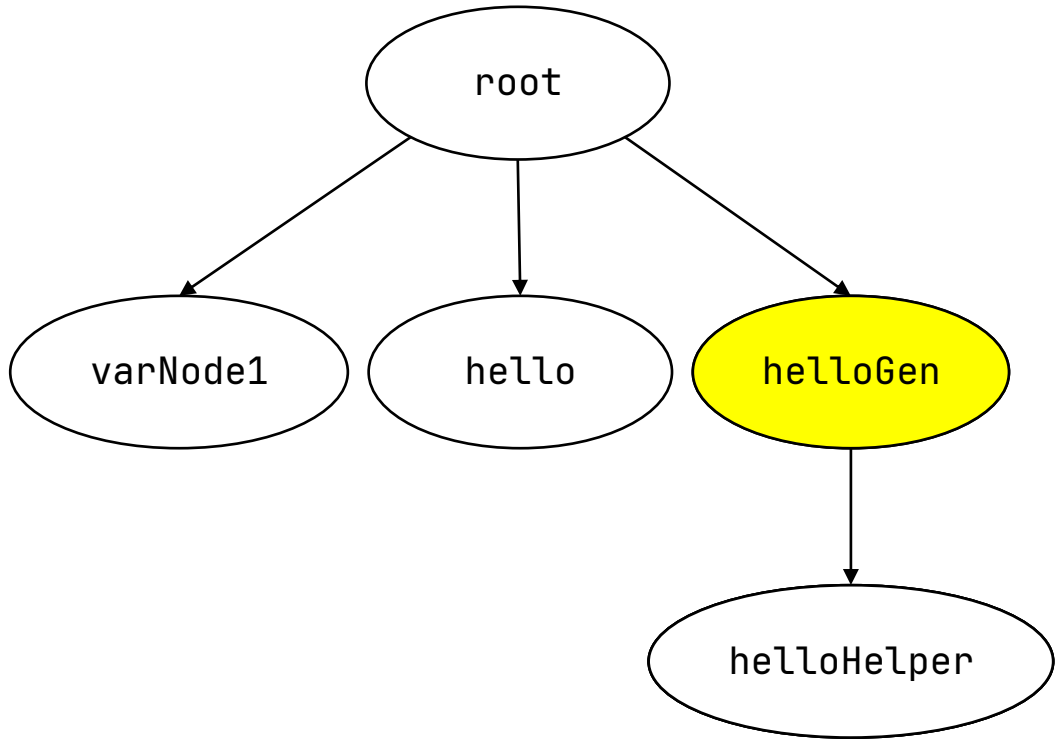

Fill-in-the-type training

```
function sum_list(l: _hole_) {
    let sum = 0;
    for (let i = 0; i < l.length; i++) {
        sum += l[i];
    }
    return sum;
}
```

Fill-in-the-type training

```
function sum_list(l: any[]): number {
    if (l.length === 0) {
        throw 'Empty list!';
    }
    if (l.length === 1) {
        return l[0];
    }
    return sum) {
    let sum = 0;
    for (let i = 0; i < l.length; i++) {
        sum += l[i];
    }
    return sum;
}
```

Fill-in-the-type training

Fill in the middle

```
function sumThree(a: number, b: number, c: number): number {
    return a + b + c;
}
```

Fill-in-the-type training

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```
function sumThree(a: number, b: number, c: number): number {
    return a + b + c;
}
```

Fill-in-the-type training

Fill in the middle

```
<fim_prefix>function sumThree(a: number, b:
<fim_suffix>}
<fim_middle>number, c: number): number {
    return a + b + c;
```

Fill-in-the-type training

Fill in the middle

```
<fim_prefix>function sumThree(a: number, b:
<fim_suffix>}
<fim_middle>number, c: number): number {
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<fim_prefix>function sumThree(a: number, b:
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Fill in the middle

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<fim_prefix>function sumThree(a: number, b:
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Fill in the type

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function sumThree(a: number, b: number, c) {
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Fill-in-the-type training

Fill in the middle

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<fim_prefix>function sumThree(a: number, b:
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```

Fill in the type

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<fim_prefix>function sumThree(a: number, b:
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    return a + b + c;
}<fim_middle>number
```

Program typedness

Both programs type check

```
function f(x: any) {
    return x + 1;
}
```

```
function f(x: number) {
    return x + 1;
}
```

Program typedness

Both programs type check

```
function f(x: any) {
    return x + 1;
}
```

```
function f(x: number) {
    return x + 1;
}
```

Type annotation	Score
unknown	1.0
any	0.5
Function	0.5
undefined	0.2
null	0.2

Program typedness

Both programs type check

```
function f(x: any) {
    return x + 1;
}
```

Score: 500

```
function f(x: number) {
    return x + 1;
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```

Score: 0

Type annotation	Score
unknown	1.0
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Score: 0

Type annotation	Score
unknown	1.0
any	0.5
Function	0.5
undefined	0.2
null	0.2

We also use this metric during type prediction

Percentage of files that type check

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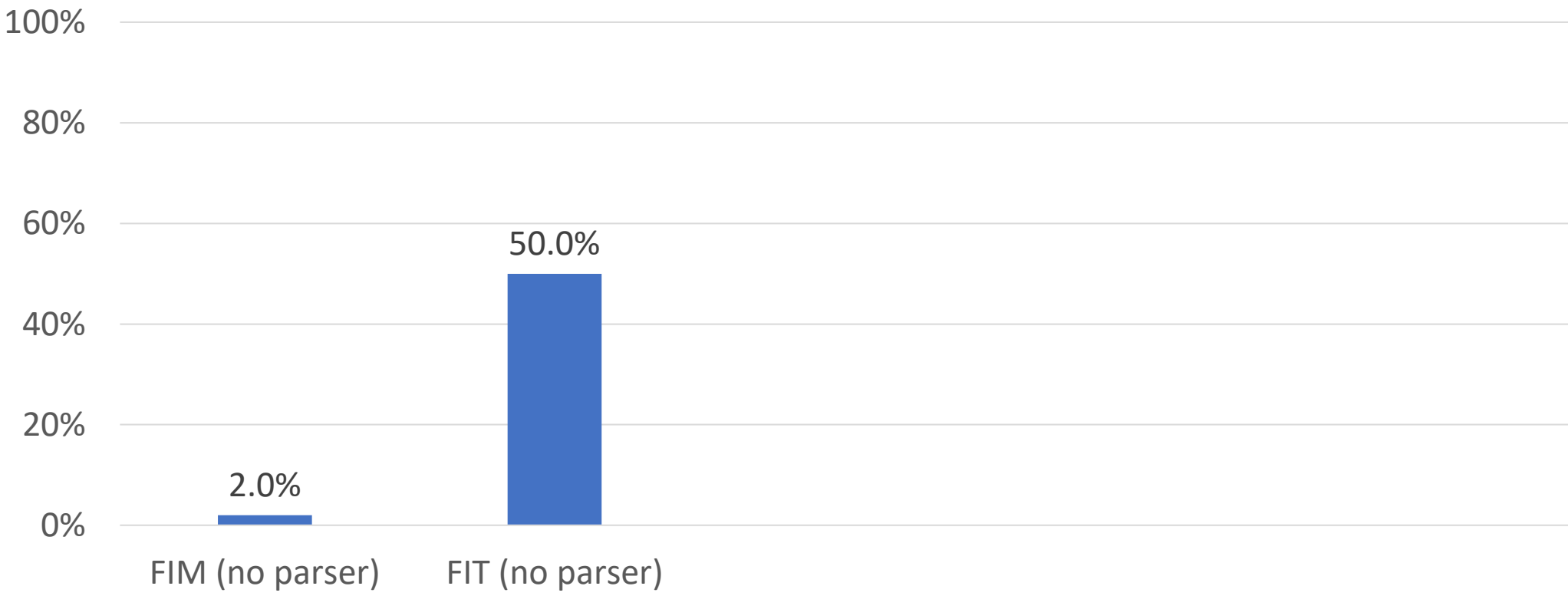
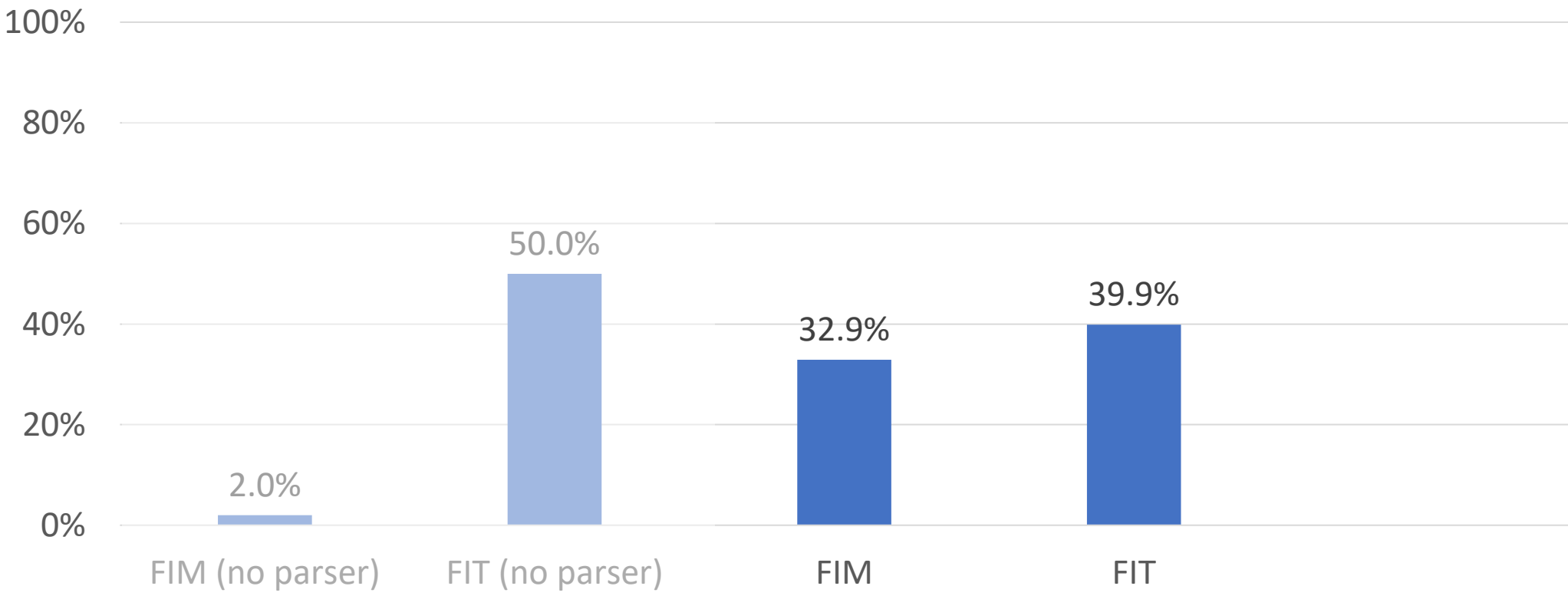


Percentage of files that type check



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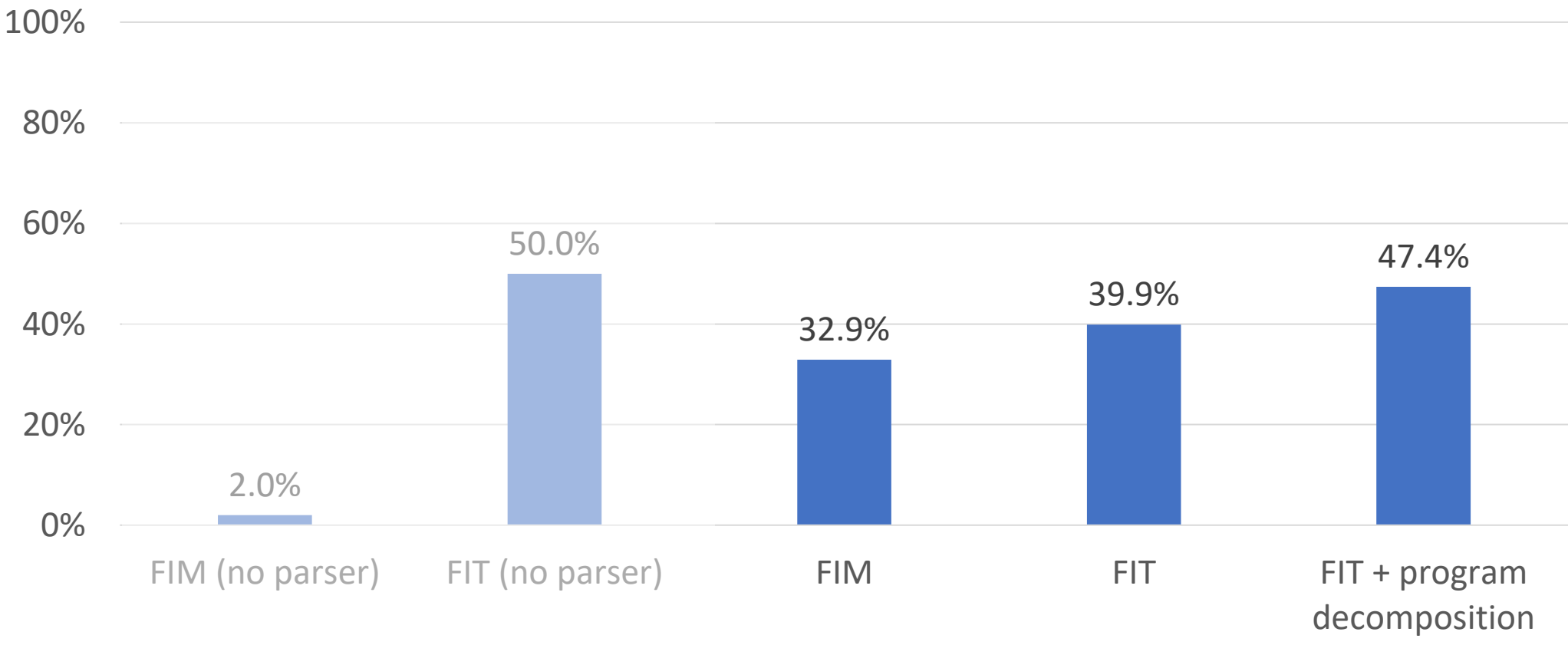
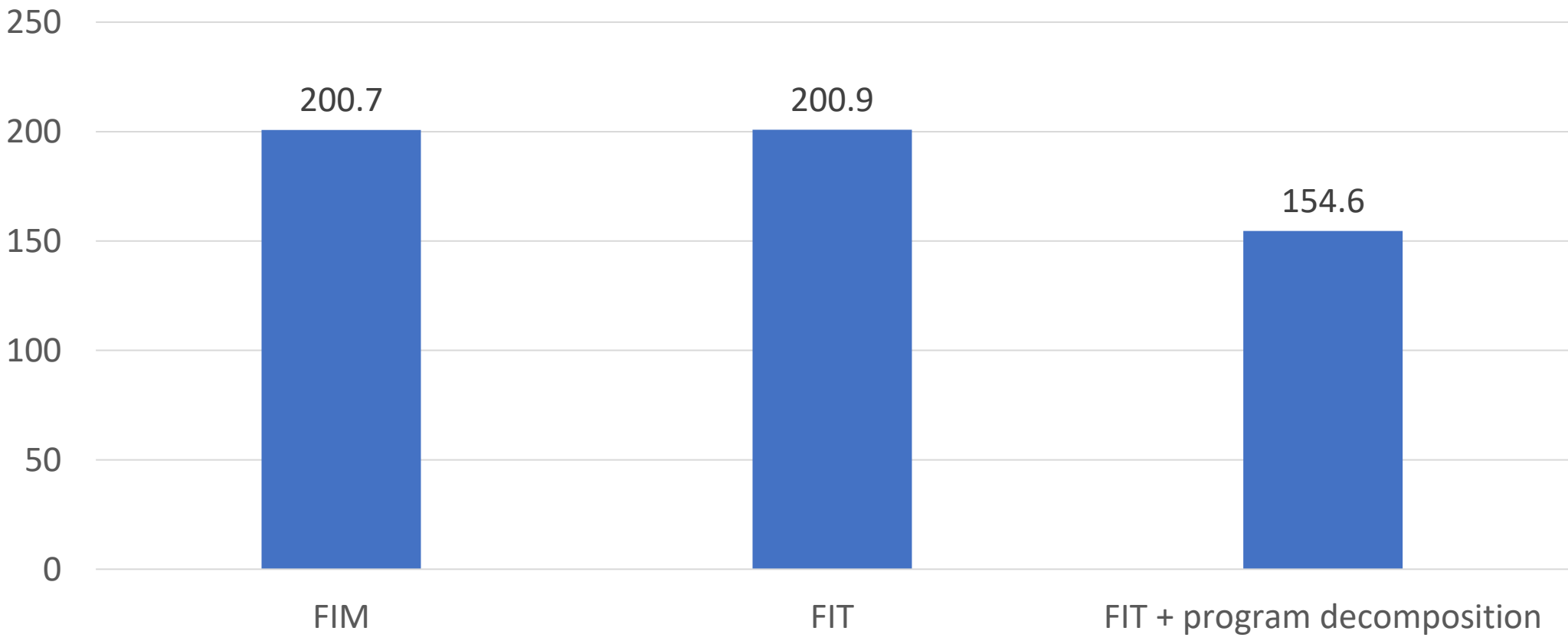


Typedness scores



Thesis

Machine learning can be used to partially migrate JavaScript programs to TypeScript, by predicting type annotations and **generating type definitions**.

Do Machine Learning Models Produce TypeScript Types That Type Check? [ECOOP 2023]
Yee and Guha

Type Prediction With Program Decomposition and Fill-in-the-Type Training
[submitted to NeurIPS 2023]
Cassano, Yee, Shinn, Guha, and Holtzen

Generating TypeScript Type Definitions With Machine Learning [proposed work]

Problem definition

```
function dist(p1, p2) {
    const dx = p2.x - p1.x;
    const dy = p2.y - p1.y;
    return Math.sqrt(dx*dx + dy*dy);
}
```

Problem definition

```
function dist(p1: Point, p2: Point) {
    const dx = p2.x - p1.x;
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    return Math.sqrt(dx*dx + dy*dy);
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Problem definition

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function dist(p1: Point, p2: Point) {
    const dx = p2.x - p1.x;
    const dy = p2.y - p1.y;
    return Math.sqrt(dx*dx + dy*dy);
}

interface Point {
    x: number,
    y: number
}
```

Approach

Approach

```
<commit_before>...
<commit_msg>...
<commit_after>...
```

Approach

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Approach

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    const dx = p2.x - p1.x;
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    return Math.sqrt(dx*dx + dy*dy);
}
<commit_msg>Add type annotations and interfaces
<commit_after>interface Point {
    x: number,
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}

function dist(p1: Point, p2: Point) {
    const dx = p2.x - p1.x;
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    return Math.sqrt(dx*dx + dy*dy);
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<commit_msg>Migrate to TypeScript
<commit_after>interface Point {
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    y: number
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Approach

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<commit_before>function dist(p1: Point, p2) {
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}
<commit_msg>Add more types
<commit_after>interface Point {
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    y: number
}

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    const dy = p2.y - p1.y;
    return Math.sqrt(dx*dx + dy*dy);
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Approach

```
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<commit_msg>Add the type definition for Point
<commit_after>interface Point {
    x: number,
    y: number
}

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    const dx = p2.x - p1.x;
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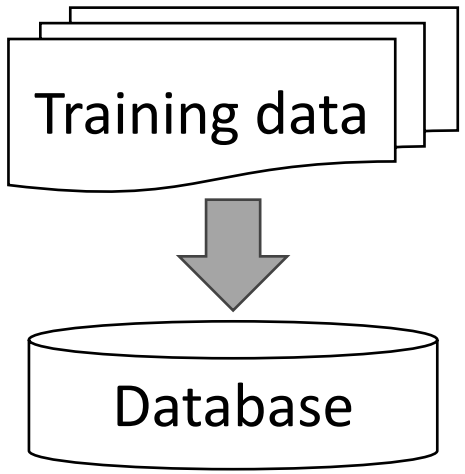
```

Alternative approaches

Alternative approaches

Database of types



Alternative approaches

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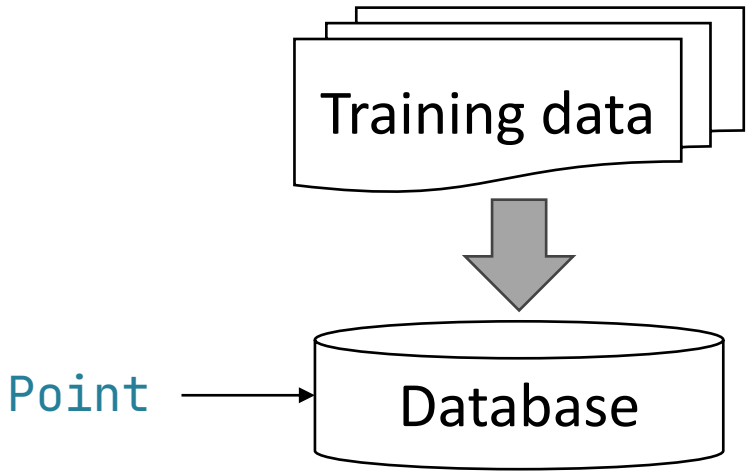

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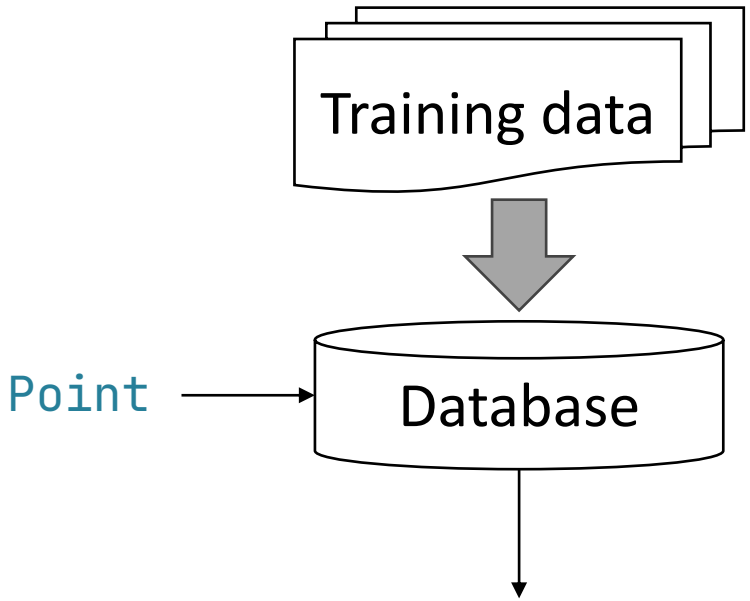


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Alternative approaches

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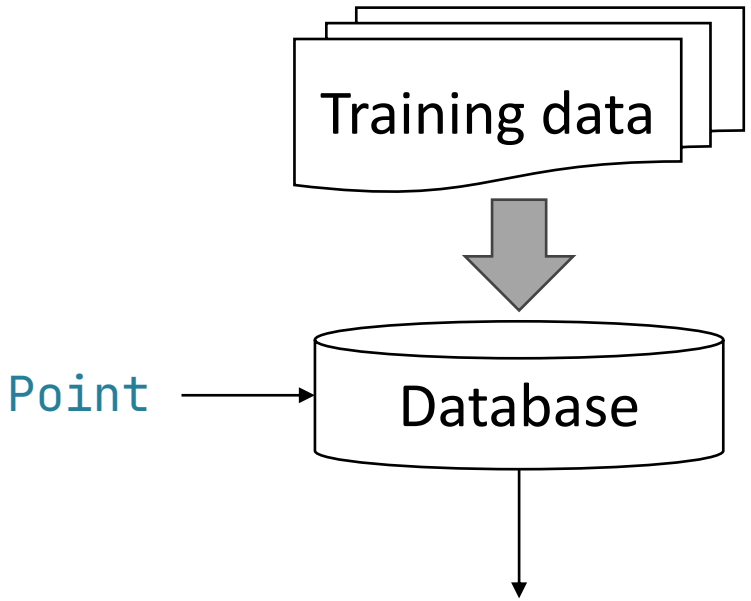


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```

Type definitions first

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Alternative approaches

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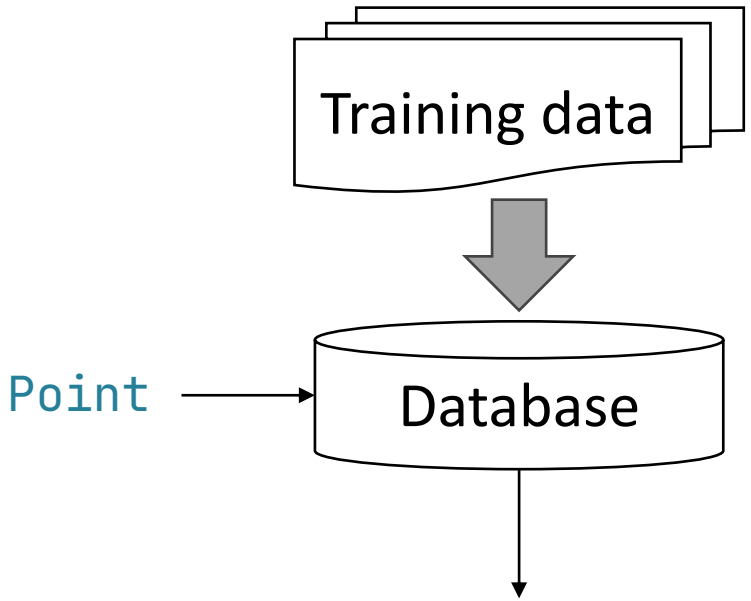


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```
interface _hole_ {
    x: number,
    y: number
}
```

Status report

Completed

- Test harness
- Baseline experiments
- Initial fine-tuning
- Initial evaluation

Status report

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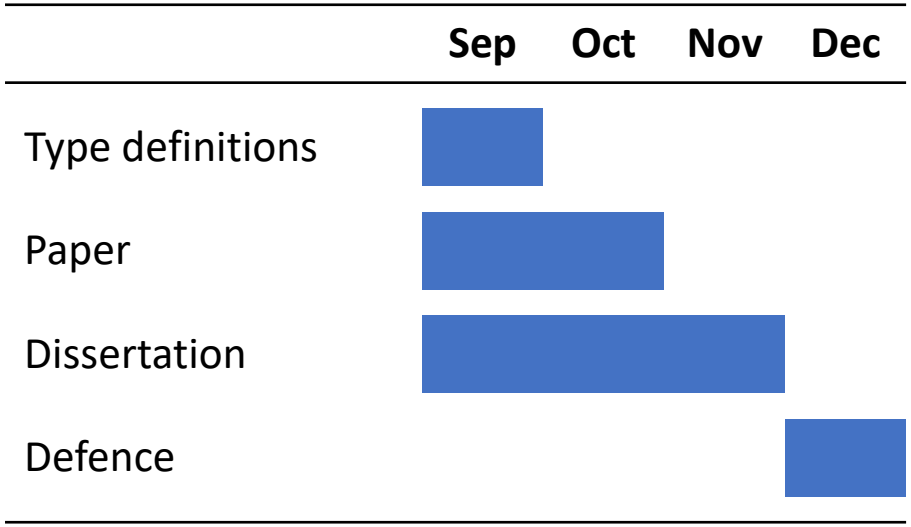
Next steps

- Analyze results
- Different training formats
- More rigorous evaluation
- Ablation studies

Schedule


Sep
Oct
Nov
Dec
Type definitions
Paper
Dissertation
Defence

Conclusion

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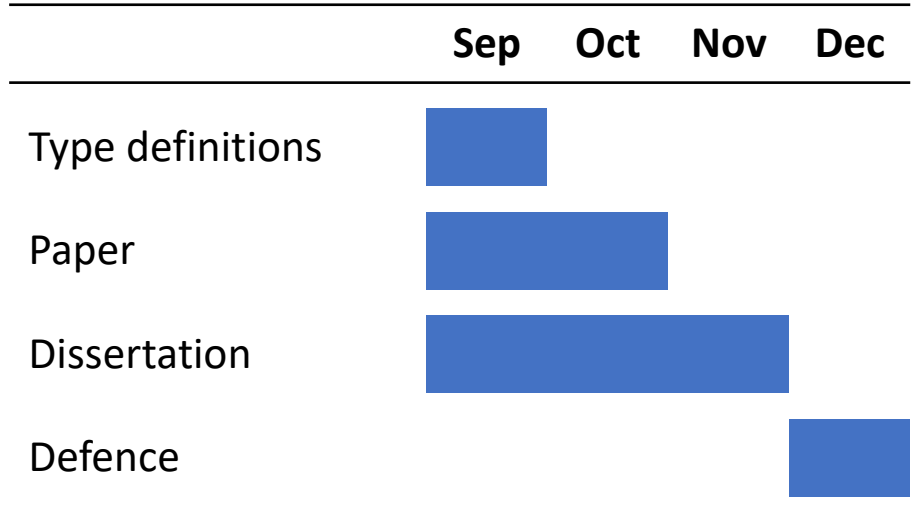

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Thank you!

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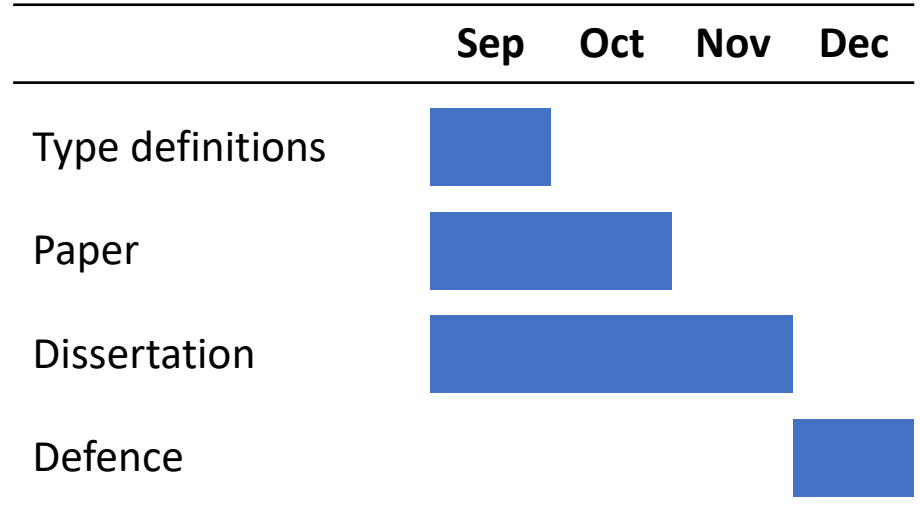
    x: number,
    y: number
}
```

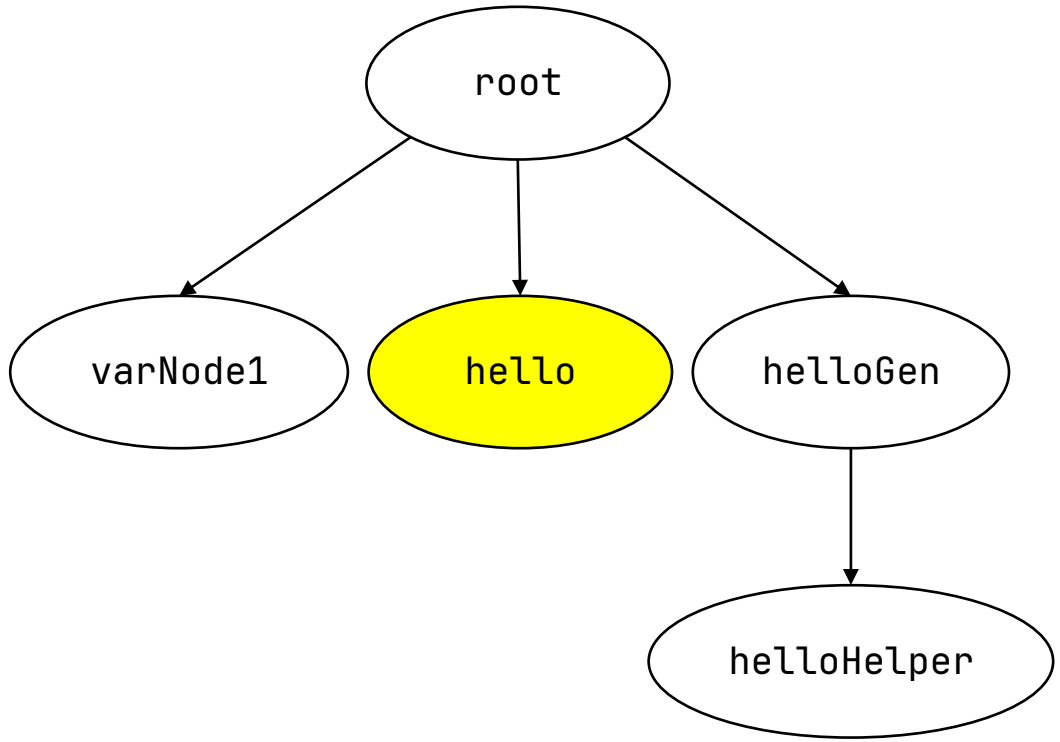


Program decomposition – with usages

```
let greeting = "Hello";
let suffix = "!";

// Produces a greeting for the given name
const hello = (name) => {
    return greeting + " " + name;
};

function helloGen(name) {
    const helloHelper = () => {
        return hello(name) + suffix;
    };
    return helloHelper;
}
```



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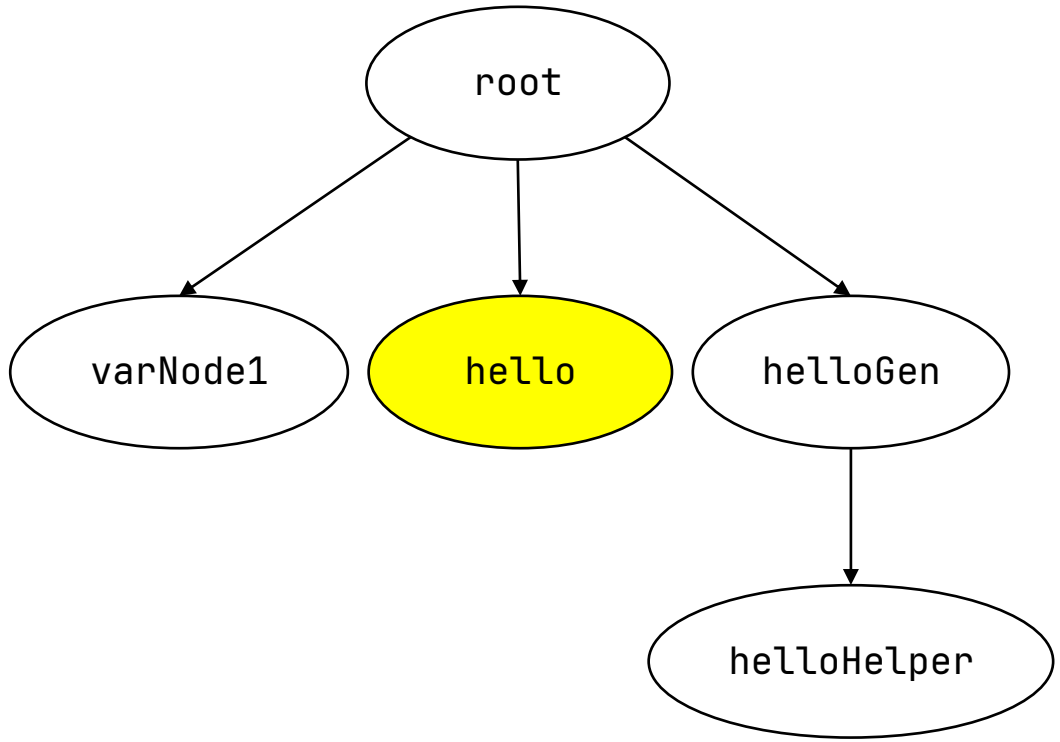

Program decomposition – with usages

```
let greeting = "Hello";
let suffix = "!";

/* Example usages of 'hello' are shown below:
    hello(name) + suffix */
// Produces a greeting for the given name
const hello = (name) => {
    return greeting + " " + name;
};

function helloGen(name) {
    const helloHelper = () => {
        return hello(name) + suffix;
    };
    return helloHelper;
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```