Program Splicing
Data-driven Program Synthesis

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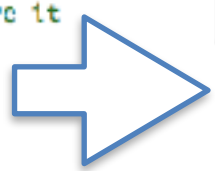
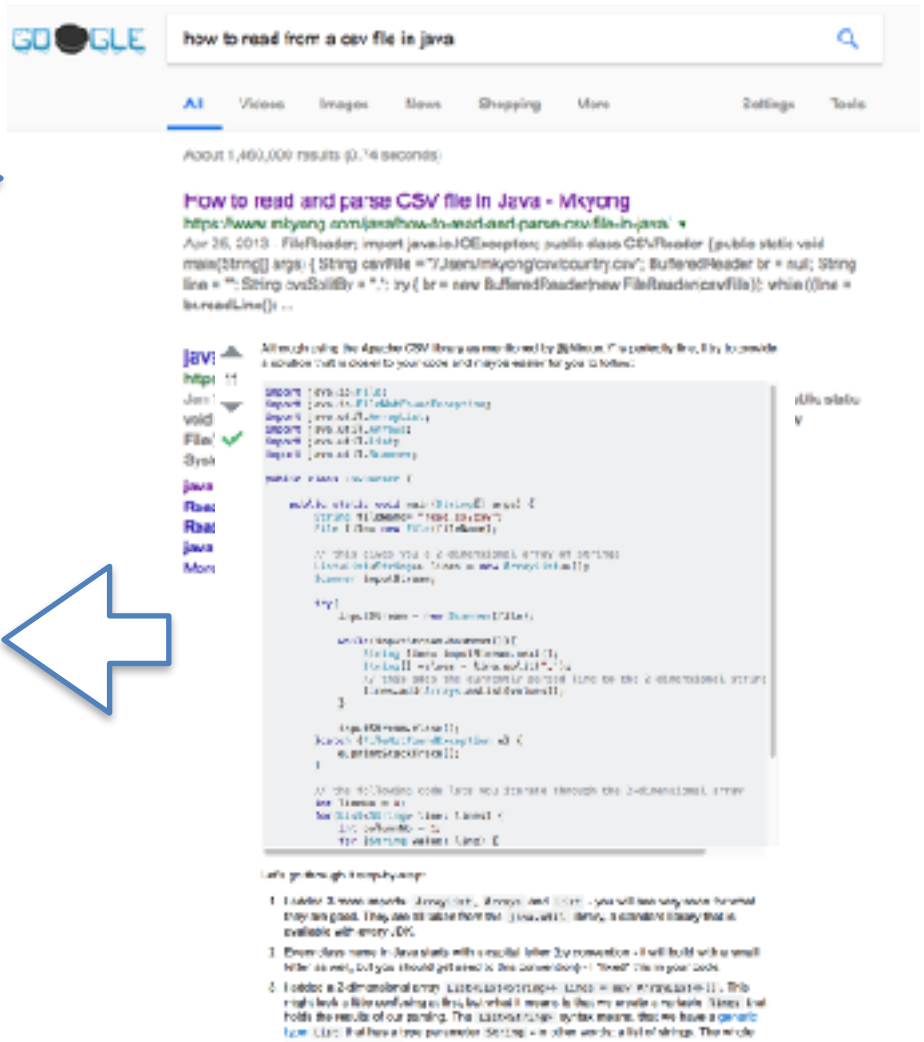
RICE

PLINY

Copying and Pasting

```
/**
 * Read a matrix from a csv file and square it
 */
int[][] csvmat(String filename) {
    int[][] mat = new int[N][N];
}
```






```
int[][] mat = new int[N][N];
String fileName= "read_ex.csv";
File file= new File(fileName);

// this gives you a 2-dimensional array of strings
List<List<String>> lines = new ArrayList<>();
Scanner inputStream;

try{
    inputStream = new Scanner(file);

    while(inputStream.hasNext()){
        String line= inputStream.next();
        String[] values = line.split( regex: ",");
        // this adds the currently parsed line to the 2-dimensional string array
        lines.add(Arrays.asList(values));
    }

    inputStream.close();
}catch (FileNotFoundException e) {
    e.printStackTrace();
}
}
```

Time consuming and bugs introduced

Program Synthesis

- Automatically generate programs
- Specification
  - Logic formula
    - index >= 0 and array[index] = x
  - Testing
    - bsearch([], 1) = -1, bsearch([1, 2], 1) = 0, ...
- Correctness

Problem

Can we use program synthesis to improve the process of copying and pasting?

Related work

- Sketching (PLDI 2005)
  - Holes in a program
  - Does not use external code
- Code Transplantation (ISSTA 2015)
  - Not efficient
  - Does not search for relevant code snippets

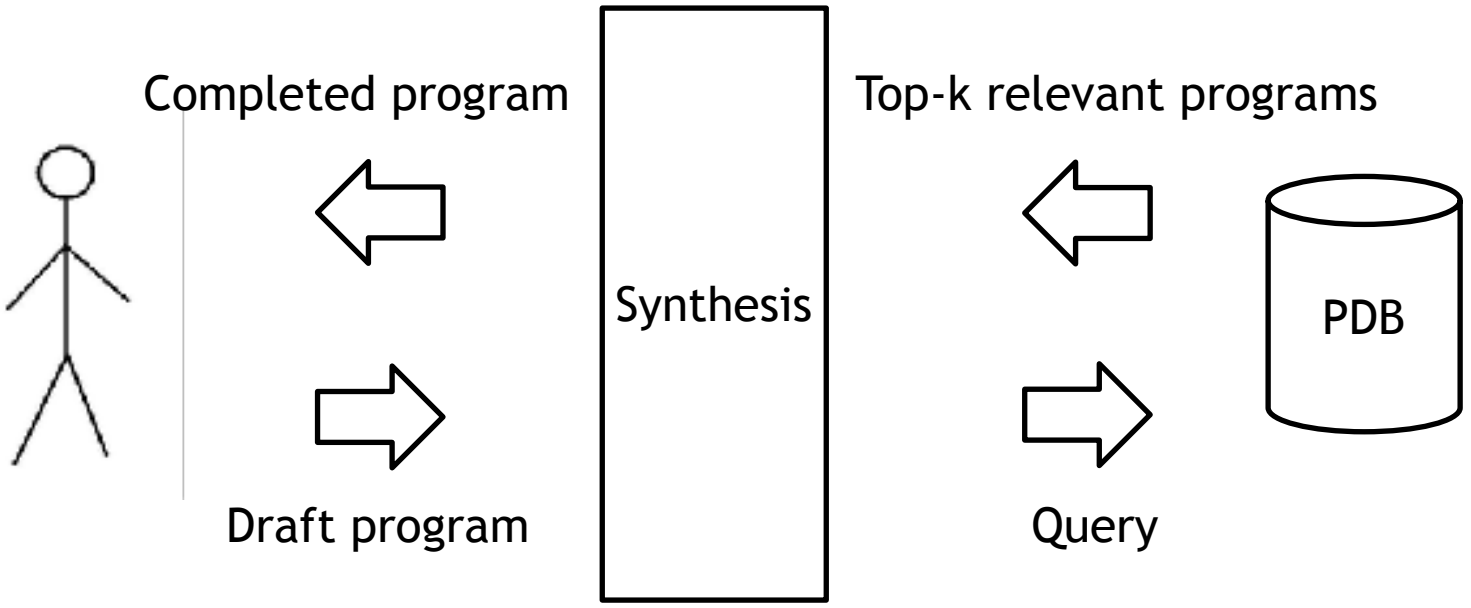
Program Splicing

- Automate process of copying and pasting
- Use large corpus of over 3.5 million programs
- Ensure correctness

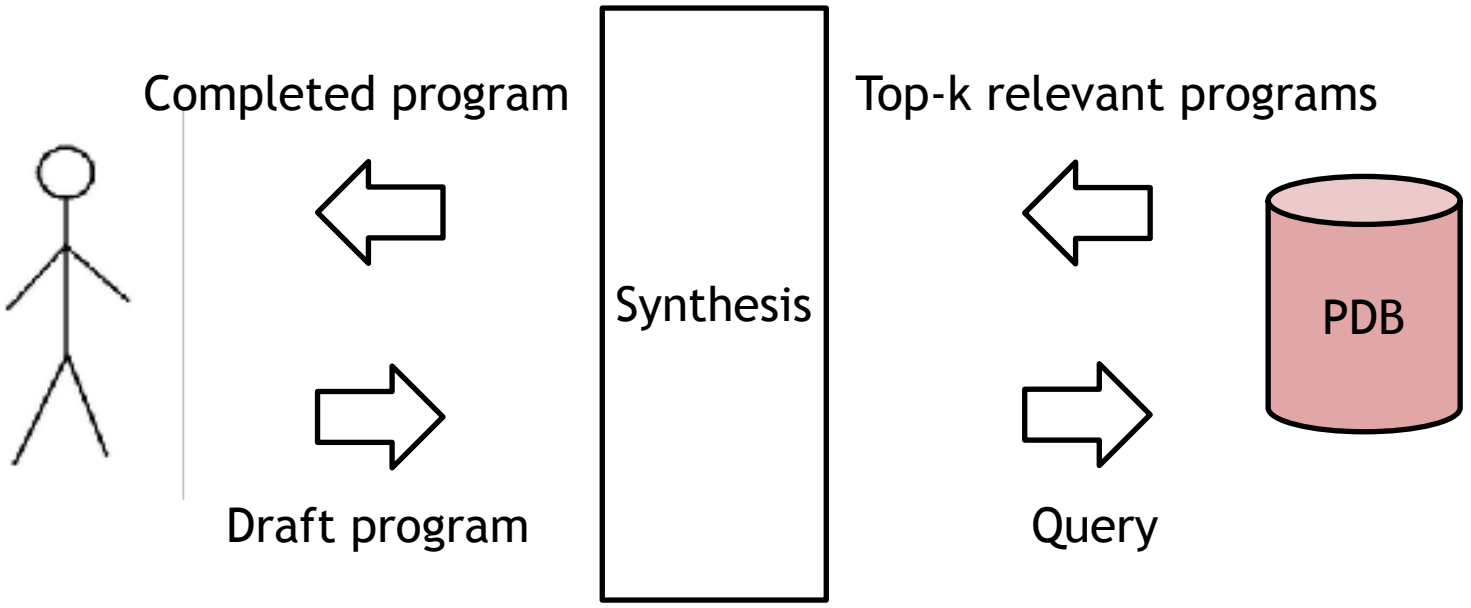
Demo

- How does a programmer use program splicing?

Architecture



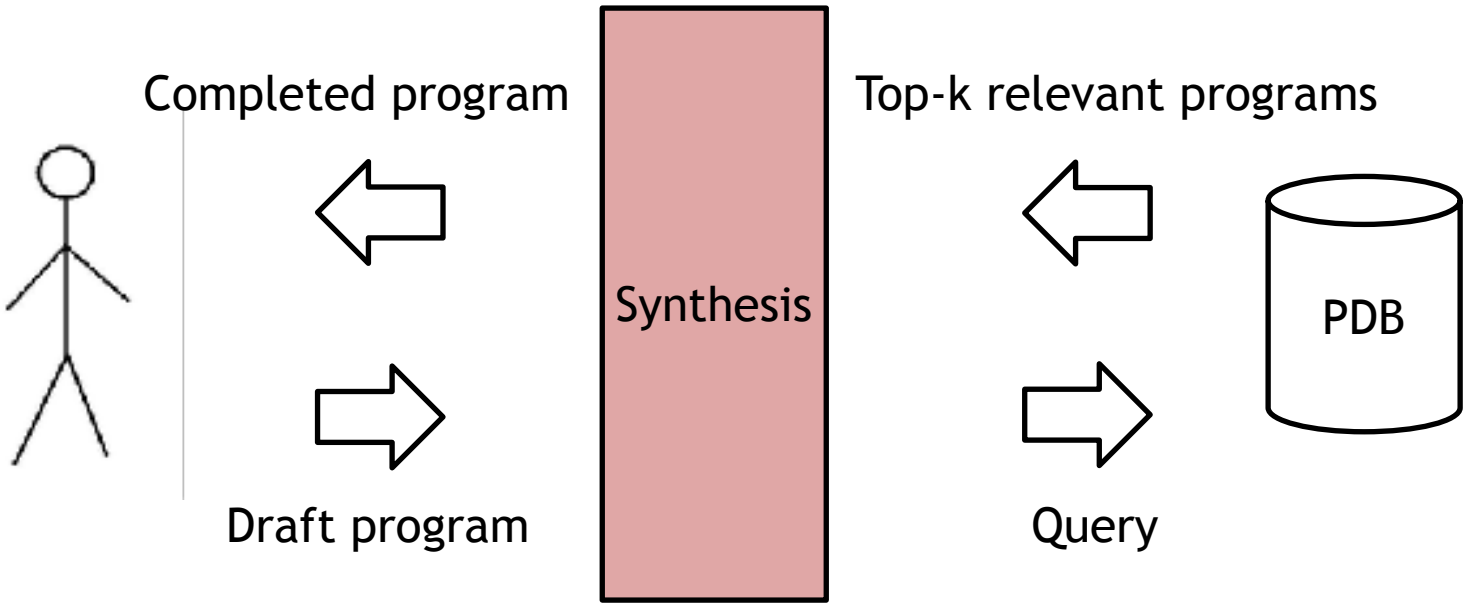
Architecture



PDB

- Efficient relevant code retrieval
- 3.5 million Java programs with features
  - Github, SourceForge
  - Natural language terms
    - "read": 0.10976, "matrix": 0.65858, ...
- Similarity metrics and KNN search
- Fast top-k query
  - 1-2 orders of magnitude faster than no-SQL database systems

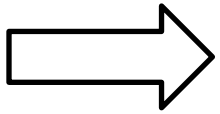
Architecture

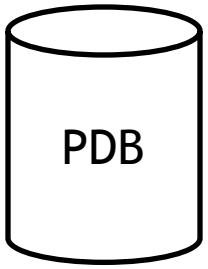


Relevant programs

```
int [][] csvmat(String filename) {
    int[][] mat = new int[N][N];

    /* COMMENT:
     * Read a matrix from a csv file
     *
     * REQ:
     * String filename = "matrix.csv";
     * int[][] m = new int[N][N];
     * __solution__
     * return test_matrix(m);
     */
     ??
}
```






```
List<String[]> read_csv(String inFile) {
    List<String[]> rowList = new ArrayList<String[]>();
    try (BufferedReader br = new BufferedReader(new FileReader(inFile))
        String line;
        while ((line = br.readLine()) != null) {
            String[] lineItems = line.split(",");
            rowList.add(lineItems);
        }
        br.close();
    }
    return rowList;
}
```

```
int[][] read_csv(int[][] m,int r,int c, String filename) {
    File f = new File(filename);
    Scanner scanner = new Scanner(f);
    for(int i=0; i<r; ++i){
        String line = scanner.nextLine();
        String[] fields = line.split(",");
        for(int j = 0; j < c; ++j) {
            m[i][j] = parseInt(fields[j]);
        }
    }
    return m;
}
```

```
public void main(String arg[]) {
    String file = arg[0];
    int row = Integer.parseInt(arg[1]);
    int col = Integer.parseInt(arg[2]);
    int[][] test = new int[row][col];
    String delimiter = ",";
    Scanner sc = new Scanner(file);
    for(int i = 0; i < row; ++i) {
        String line = sc.nextLine();
        String[] testStr = line.split(delimiter);
        for(int j = 0; j < col; ++j) {
            test[i][j] = Integer.parseInt(testStr[j]);
        }
    }

    return test;
}
```

Filling in the holes

- Enumerative search

```
int [][] csvmat(String filename) {
    int[][] mat = new int[N][N];

    /* COMMENT:
     * Read a matrix from a csv file
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     * return test_matrix(m);
     */
    ??
}
```

```
public void main(String arg[]) {
    String file = arg[0];
    int row = Integer.parseInt(arg[1]);
    int col = Integer.parseInt(arg[2]);
    int[][] test = new int[row][col];
    String delimiter = ",";
    Scanner sc = new Scanner(file);
    for(int i = 0; i < row; ++i) {
        String line = sc.nextLine();
        String[] testStr = line.split(delimiter);
        for(int j = 0; j < col; ++j) {
            test[i][j] = Integer.parseInt(testStr[j]);
        }
    }

    return test;
}
```

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    String delimiter = ",";
    Scanner sc = new Scanner(file);
    for(int i = 0; i < row; ++i) {
        String line = sc.nextLine();
        String[] testStr = line.split(delimiter);
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        }
    }

    return test;
}
```

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    int[][] mat = new int[N][N];

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```
public void main(String arg[]) {
    String file = arg[0];
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    int[][] test = new int[row][col];
    String delimiter = ",";
    Scanner sc = new Scanner(file);
    for(int i = 0; i < row; ++i) {
        String line = sc.nextLine();
        String[] testStr = line.split(delimiter);
        for(int j = 0; j < col; ++j) {
            test[i][j] = Integer.parseInt(testStr[j]);
        }
    }

    return test;
}
```

Variable Renaming

- Undefined variables

```
int [][] csvmat(String filename) {
    int[][] mat = new int[N][N];

    /*
     * ...
     */
    String delimiter = ",";
    Scanner sc = new Scanner(file);
    for(int i = 0; i < row; ++i) {
        String line = sc.nextLine();
        String[] testStr = line.split(delimiter);
        for(int j = 0; j < col; ++j) {
            test[i][j] = Integer.parseInt(testStr[j]);
        }
    }
}
```

```
int [][] csvmat(String filename) {
    int[][] mat = new int[N][N];

    /*
     * ...
     */
    String delimiter = ",";
    Scanner sc = new Scanner(file);
    for(int i = 0; i < row; ++i) {
        String line = sc.nextLine();
        String[] testStr = line.split(delimiter);
        for(int j = 0; j < col; ++j) {
            test[i][j] = Integer.parseInt(testStr[j]);
        }
    }
}
```

Testing

- Filtering out incorrect programs

```
/* COMMENT:
 * Read a matrix from a csv file
 *
 * REQ:
 * String filename = "matrix.csv";
 * int[][] mat = new int[N][N];
 * __solution__
 * return test_matrix(mat);
 */
String file = arg[0];
int row = Integer.parseInt(arg[1]);
int col = Integer.parseInt(arg[2]);
int[][] test = new int[row][col];
String delimiter = ",";
Scanner sc = new Scanner(file);
for(int i = 0; i < row; ++i) {
    String line = sc.nextLine();
    String[] testStr = line.split(delimiter);
    for(int j = 0; j < col; ++j) {
        test[i][j] = Integer.parseInt(testStr[j]);
    }
}
```

```
/* COMMENT:
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```

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 * return test_matrix(mat);
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String delimiter = ",";
Scanner sc = new Scanner(filename);
for(int i = 0; i < N; ++i) {
    String line = sc.nextLine();
    String[] testStr = line.split(delimiter);
    for(int j = 0; j < N; ++j) {
        mat[i][j] = Integer.parseInt(testStr[j]);
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}
```

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 * return test_matrix(mat);
 */
for(int i = 0; i < row; ++i) {
    String line = sc.nextLine();
    String[] testStr = line.split(delimiter);
    for(int j = 0; j < col; ++j) {
        mat[i][j] = Integer.parseInt(testStr[j]);
    }
}
```

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     * __solution__
     * return test_matrix(mat);
     */
    String delimiter = ",";
    Scanner sc = new Scanner(filename);
    for(int i = 0; i < N; ++i) {
        String line = sc.nextLine();
        String[] testStr = line.split(delimiter);
        for(int j = 0; j < N; ++j) {
            mat[i][j] = Integer.parseInt(testStr[j]);
        }
    }
}
```

Benchmark

Benchmarks	Synthesis Time (s)	LOC	Var	Holes (expr-stmt)	Test	μScalpel
Sieve Prime	4.6	12-17	2	2-1	3	162.1
Collision Detection	4.2	10-15	2	2-1	4	N/A
Collecting Files	3.0	13-25	2	1-1	2	timeout
Binary Search	15.4	12-20	5	1-1	3	timeout
HTTP Server	41.1	24-45	6	1-2	2	N/A
Prim's Distance Update	61.1	53-58	11	1-1	4	timeout
Quick Sort	77.2	11-18	6	1-1	1	timeout
CSV	88.4	13-23	4	1-2	2	timeout
Matrix Multiplication	108.9	13-15	8	1-1	1	timeout
Floyd Warshall	110.4	9-12	7	1-1	7	timeout
HTML Parsing	140.4	20-34	5	1-2	2	N/A
LCS	161.5	29-36	10	0-1	1	timeout

Efficient synthesis algorithm

Benchmarks	Synthesis Time (s)	LOC	Var	Holes (expr-stmt)	Test	μScalpel
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No need to write many tests

Benchmarks	Synthesis Time (s)	LOC	Var	Holes (expr-stmt)	Test	μScalpel
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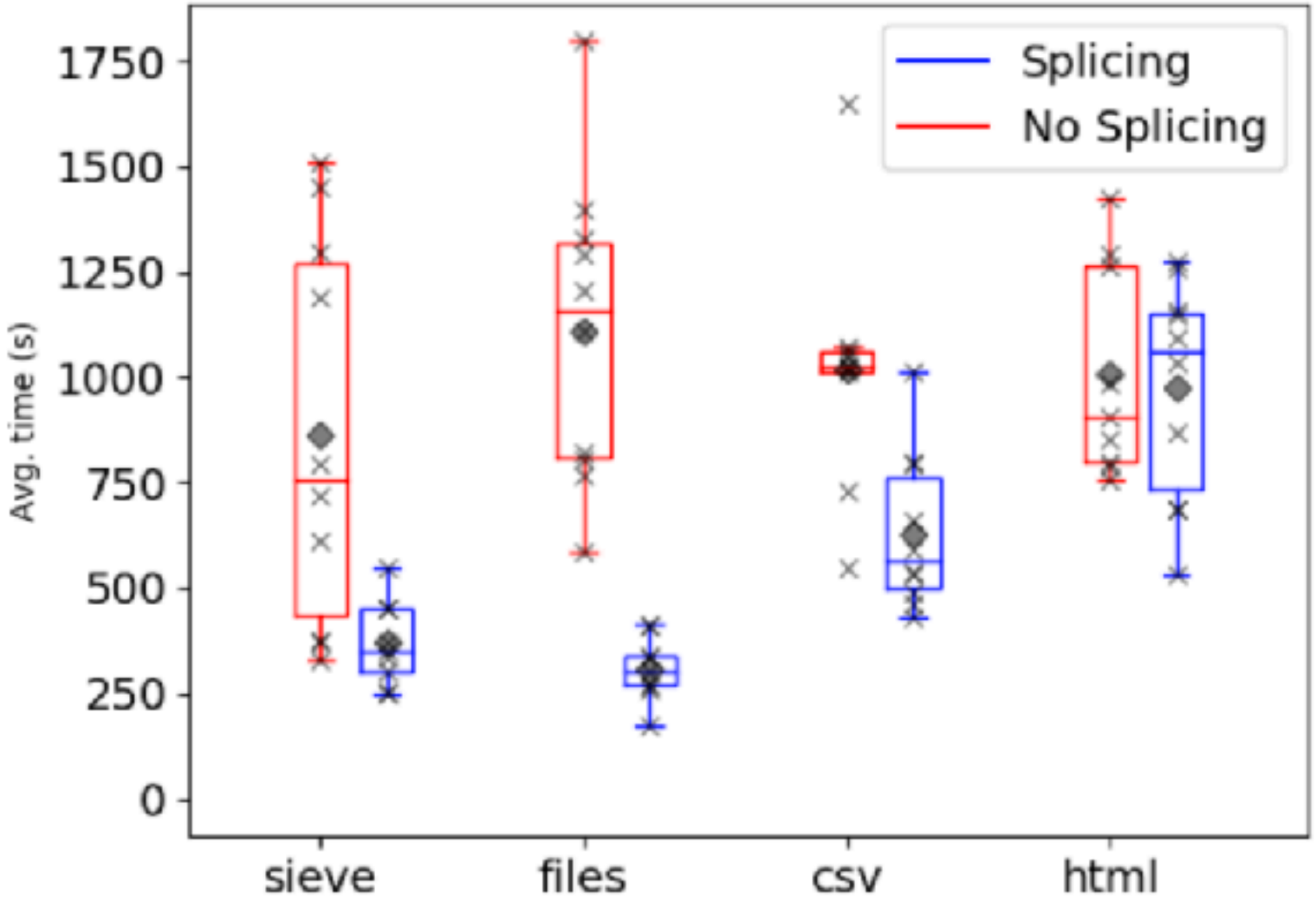
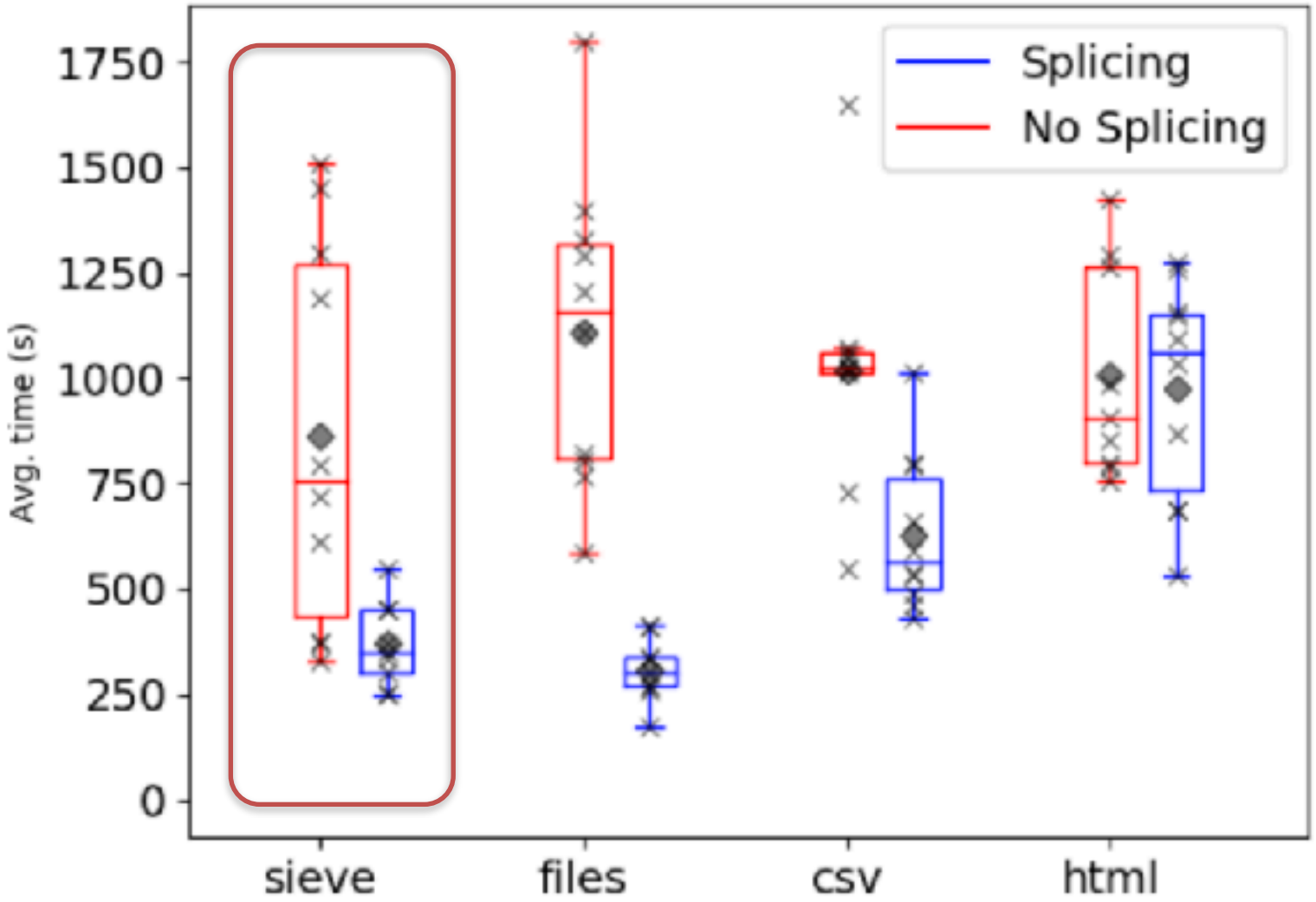
User study

- Evaluate whether program splicing can help human developers
  - 12 graduate students and six professionals
  - Web-based programming environment
  - Four programming problems
    - Two were done using our system
    - Two were done without using our system
  - Internet search encouraged
  - Programming time

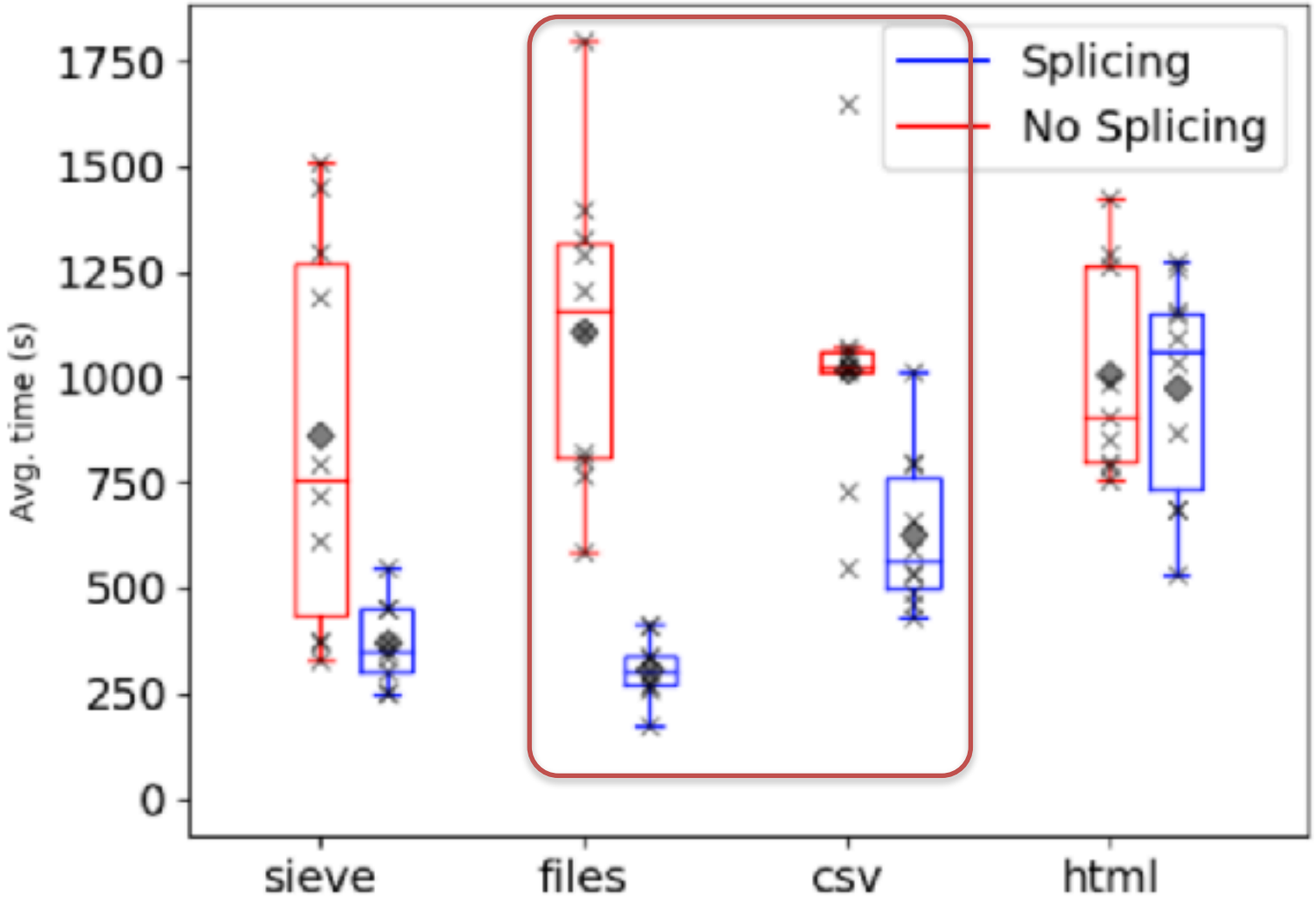
User study


Splicing
No Splicing
Avg. time (s)
1750
1500
1250
1000
750
500
250
0
sieve
files
csv
html

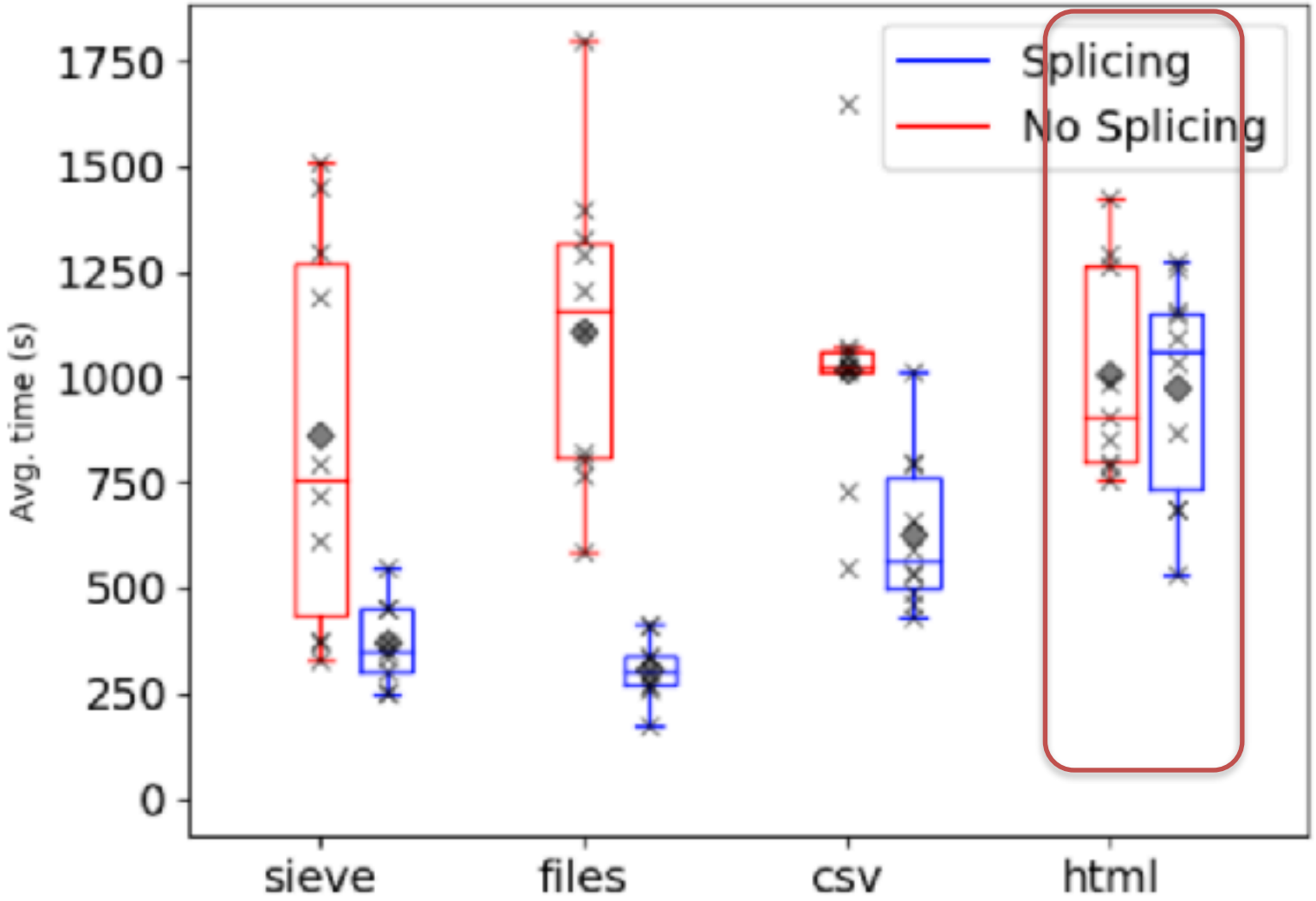
Deceptively simple



No standard solutions



Good documentations and tests were hard to write



Conclusion

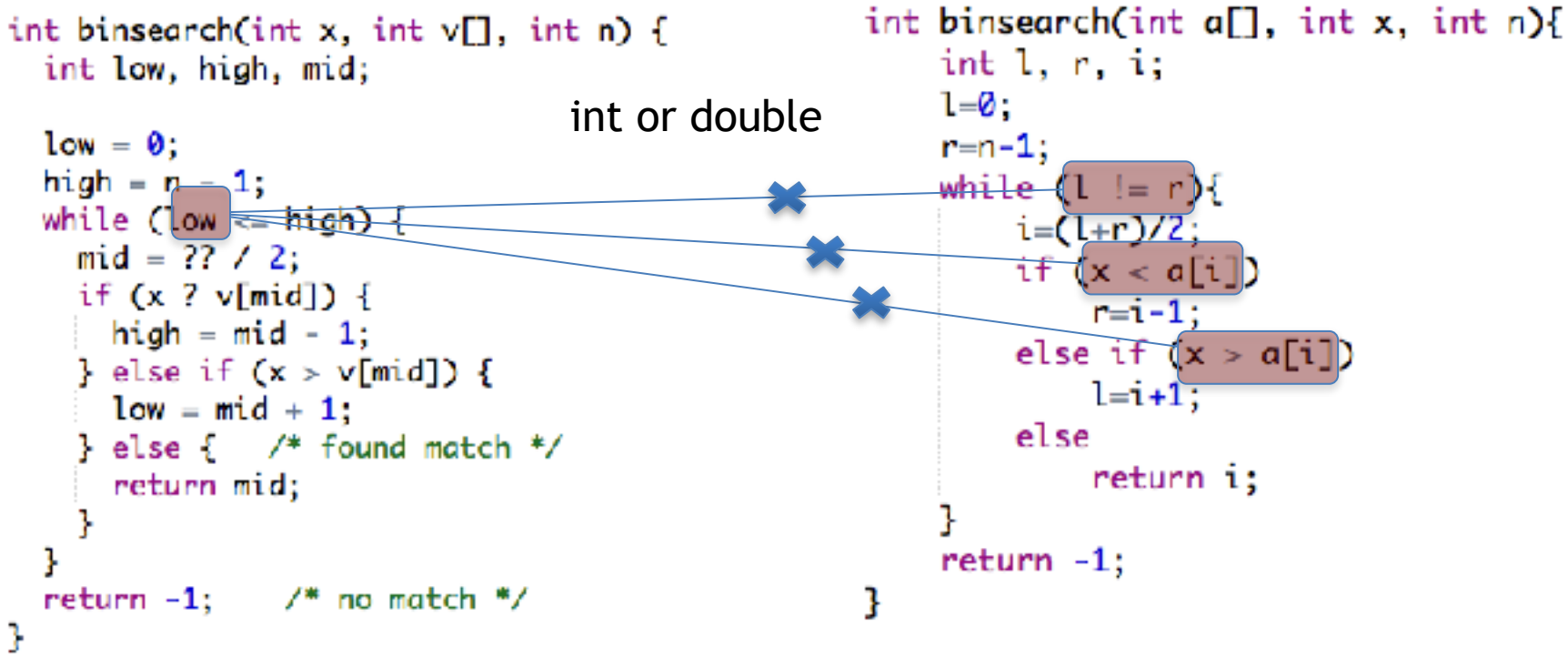
- Program Splicing
  - Large code corpus
  - Enumerative search
  - Efficient algorithm
- Fast code reuse
  - No standard solutions
  - Easy to test
- Future work
  - Synthesis algorithm improvement

Heuristics

- A set of heuristics
  - Types
  - Context
- Huge search space reduction

Heuristics - types

- Ignore expressions with incompatible types



Heuristics - context

- Ignore expressions with no common parents