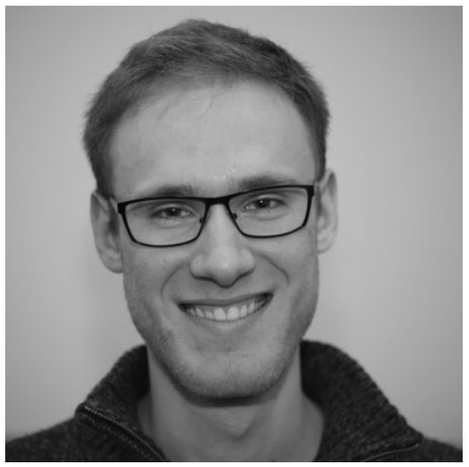
Badger: Complexity Analysis with Fuzzing and Symbolic Execution



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Complexity Analysis

discover vulnerabilities related to worst-case time/ space complexity, e.g., Denial-of-Service

```
0   public void sort (int[] a) {
1       int N = a.length;
2       for (int i = 1; i < N; i++) {
3           int j = i - 1;
4           int x = a[i];
5           while ((j >= 0) && (a[j] > x)) {
6               a[j + 1] = a[j];
7               j--;
8           }
9           a[j + 1] = x;
10      }
11  }
```

Insertion Sort

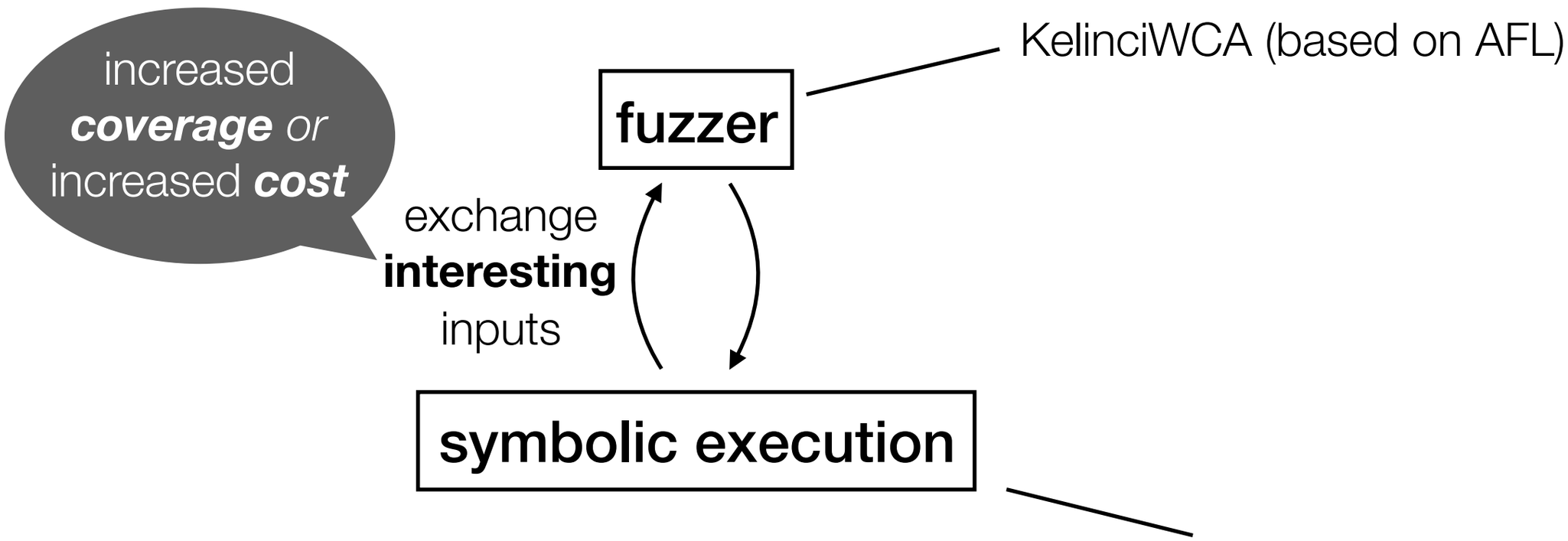
→ find worst-case input:
automated + fast + concrete

- worst-case complexity: $O(n^2)$
- e.g. a=[8, 7, 6] (n=3)

Our Contributions

- combine **fuzzing** and **symbolic execution** to find algorithmic complexity vulnerabilities
- Badger, a framework for analysis of Java applications
- analysis parameterized by a cost metric
- handling of user-defined cost

Badger

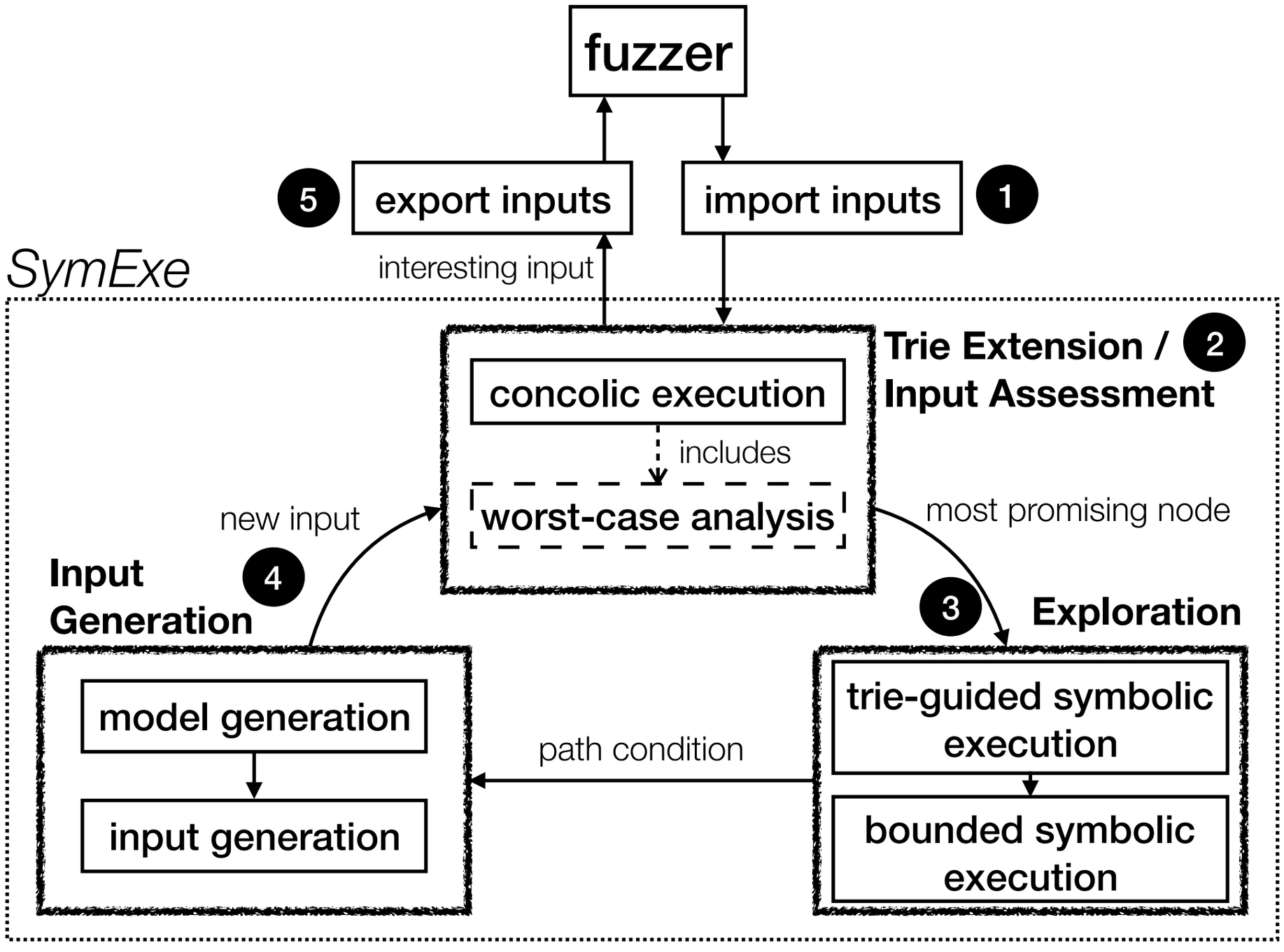


fuzzer and symbolic execution run
in **parallel**

KelinciWCA

- based on AFL, extends Kelinci [Kersten2017]
- mutation-based greybox fuzzing
- cost-guided fuzzer: coverage + cost
- cost metrics: timing / memory / user-defined
- maintain current highscore

SymExe with SPF



Example

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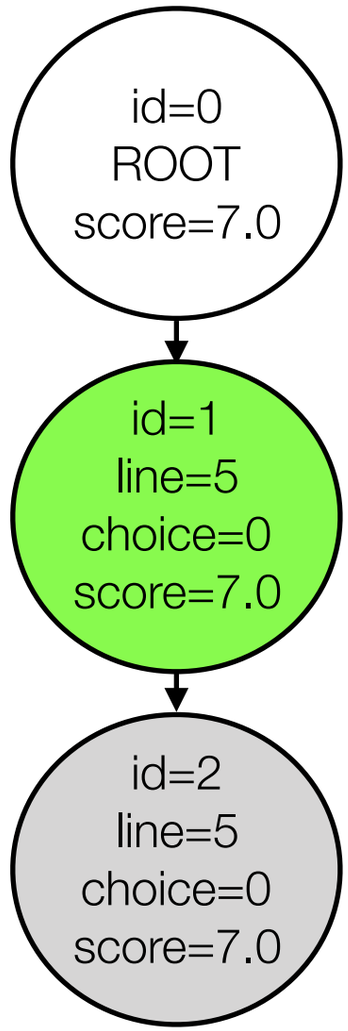
```

Insertion Sort

Trie **extension** with initial input. The **most promising** node get selected.

initial input
a=[37, 42, 48]



Example

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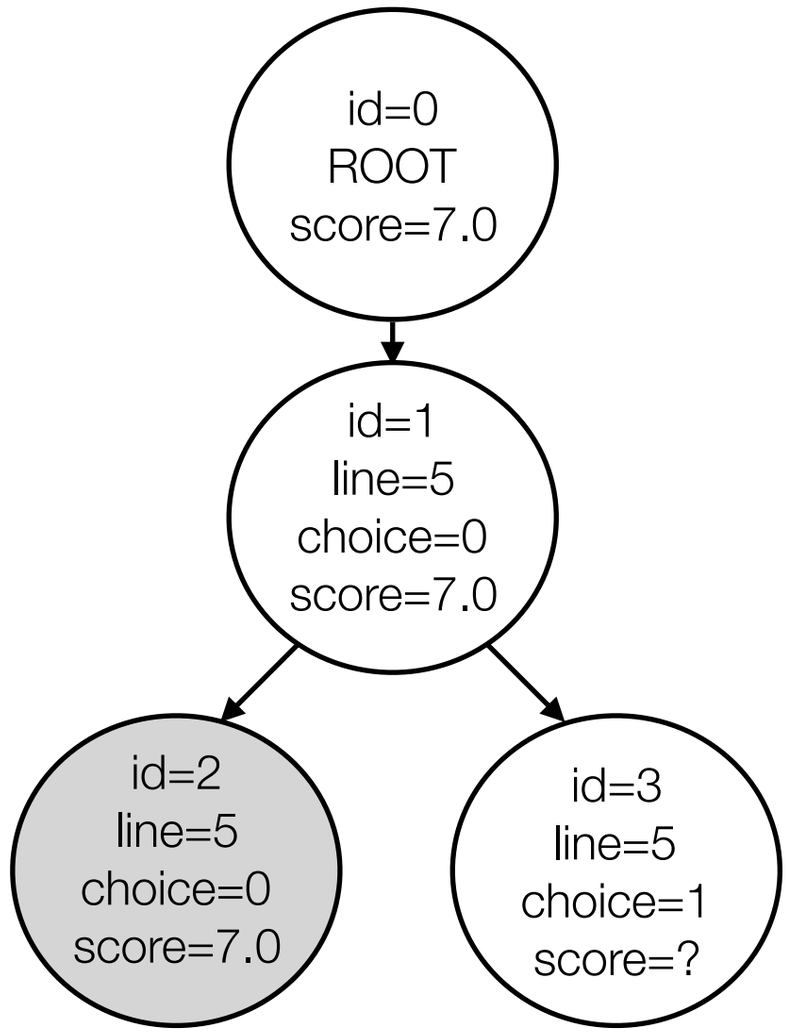
Insertion Sort

Exploration and **input generation**.



$$pc = sym\_0 \leq sym\_1 \wedge sym\_1 > sym\_2$$

new input
a=[0, 1, 0]

Example

```
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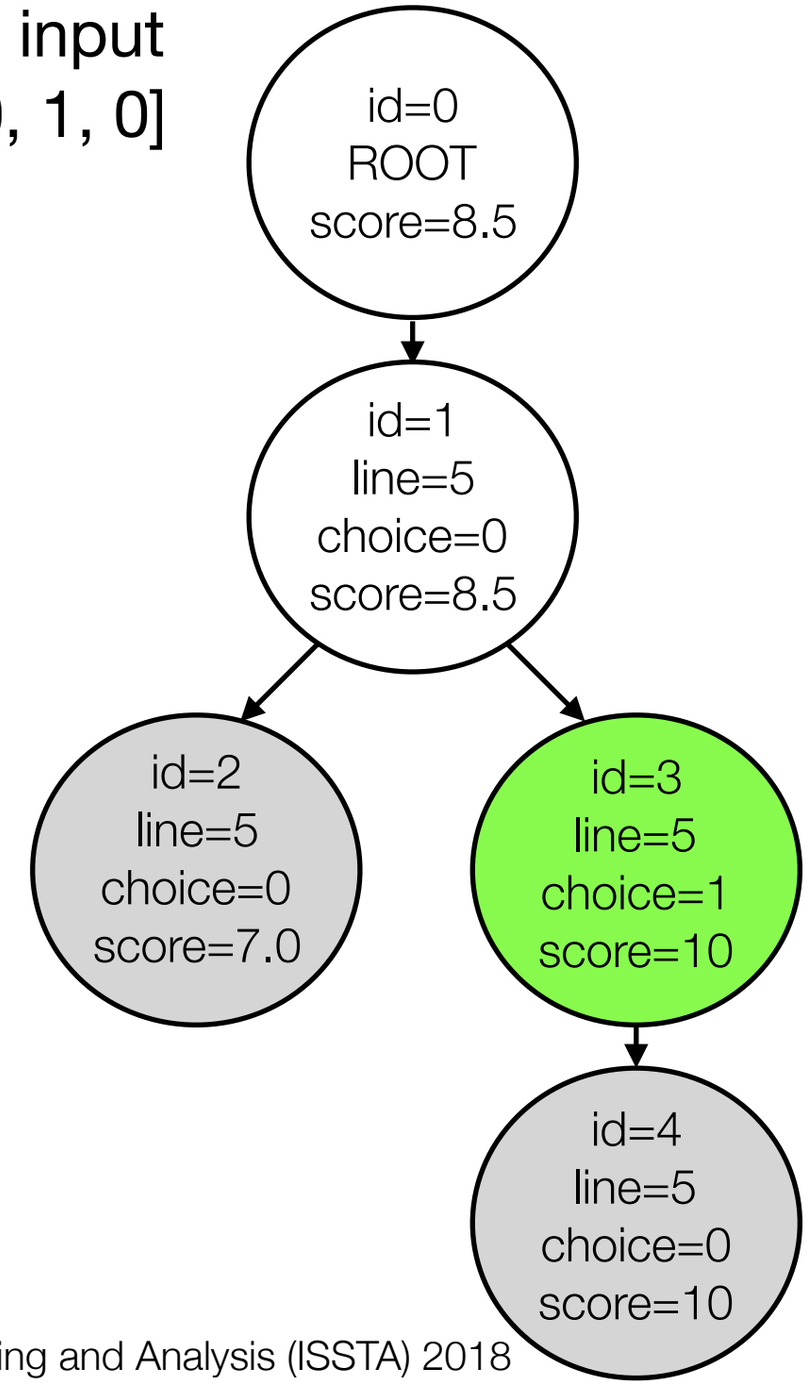
Insertion Sort

Assessment of new input and **extension** of the trie. New **most promising** node gets selected.

new input
a=[0, 1, 0]



Research Questions

RQ1: Since Badger combines fuzzing and symbolic execution, is it better than each part on their own in terms of:

(a) Quality of worst-case, and

(b) Speed?

RQ2: Is KelinciWCA better than Kelinci in terms of:

(a) Quality of worst-case, and

(b) Speed?

RQ3: Can Badger reveal worst-case vulnerabilities?

Experiments

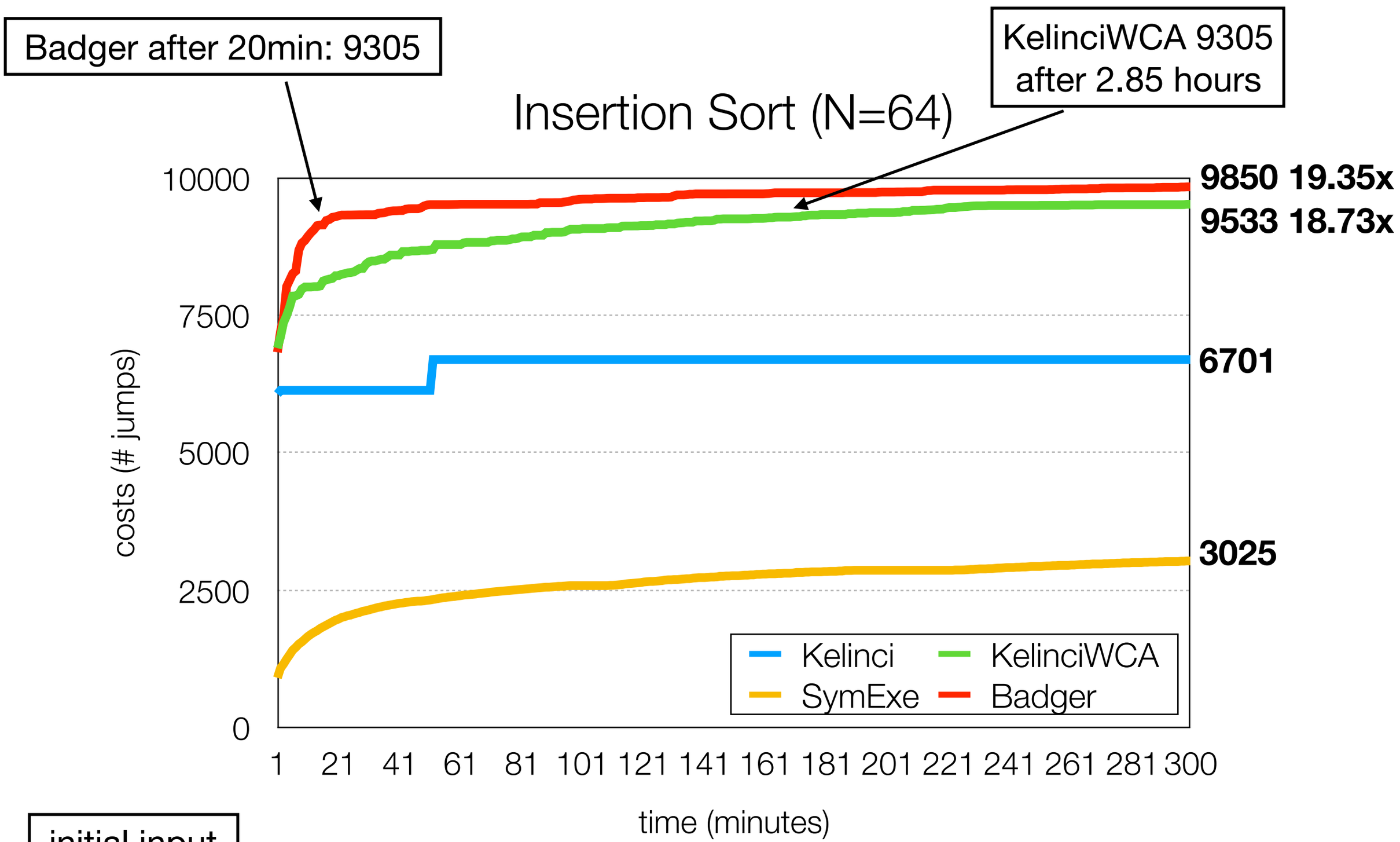
ID	Subject
1	Insertion Sort
2	Quicksort
3a	Regular Expression (fixed input)
3b	Regular Expression (fixed regex)
4	Hash Table
5	Compression
6	Image Processor
7	Smart Contract

each experiment for 5 hours and 5 times

we report the average values (our full data set is available online)

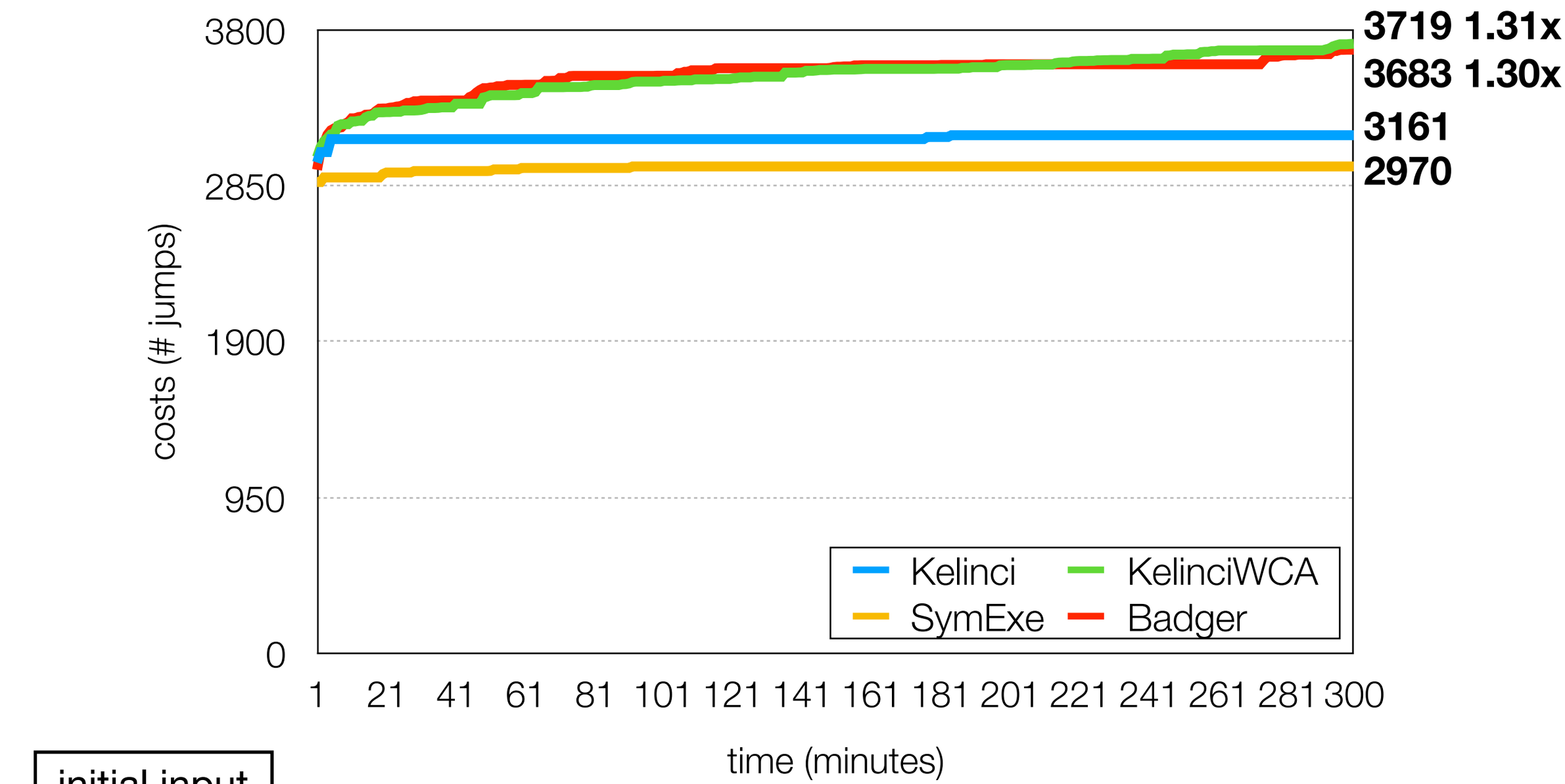
Badger after 20min: 9305

KelinciWCA 9305 after 2.85 hours

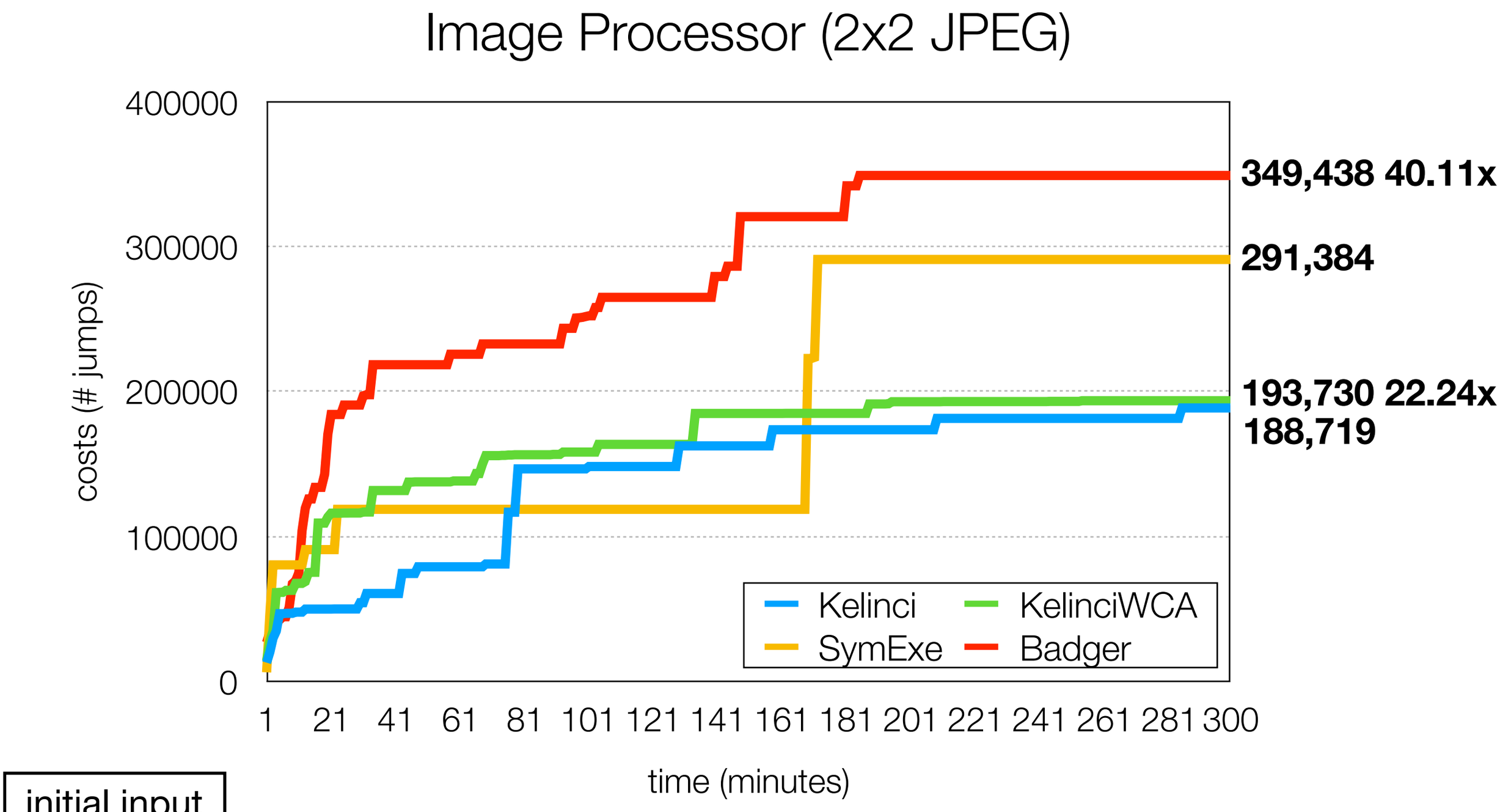


initial input score: 509

no significant difference between Badger and KelinciWCA



initial input score: 2829



initial input
score: 8712

Existing Solutions

- **Fuzzing**
  e.g. SlowFuzz [Petsios2017]
- **Symbolic Execution**
  e.g. WISE [Burnim2009] , SPF-WCA [Luckow2017]
- **Fuzzing + Symbolic Execution**
  e.g. Driller [Stephens2016]

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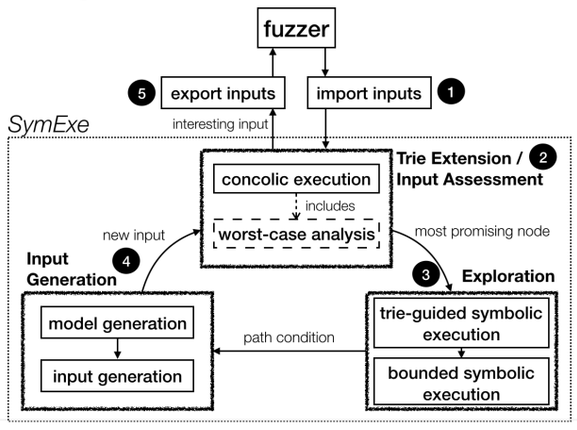

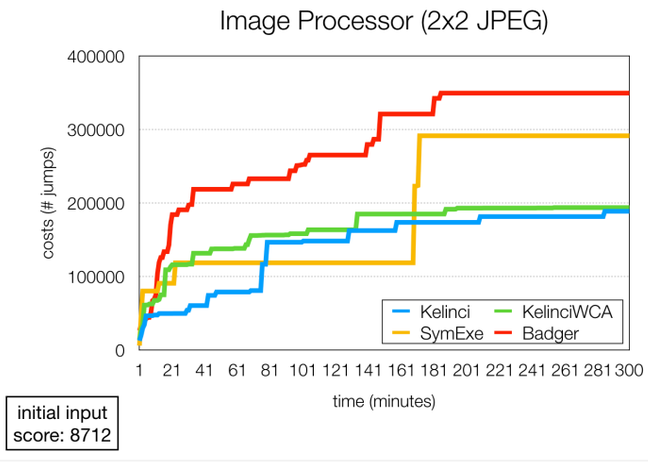

`git clone https://github.com/isstac/badger.git`

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