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European Union

TOWARDS AN ENERGY EFFICIENT COMPUTATION IN ERLANG

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HUNGARIAN GOVERNMENT

European Union
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INVESTING IN YOUR FUTURE

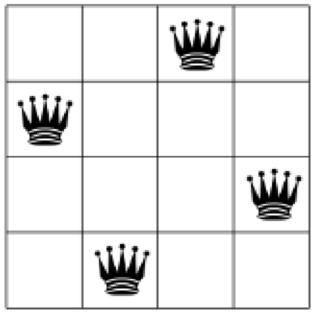
Motivation

- Environmental awareness
  - Energy conservation, minimizing energy consumption
  - Even in computers
  - Green computing

- Why Erlang?
  - Popular languages – lots of research (e.g. C++, Java, Haskell)
  - Erlang
    - Widely used in the industry
    - No such research yet

Previous work

- Tool for measuring energy consumption
- Measuring complex algorithms
  - N-queens
  - Sparse matrix multiplication
- Special attention to:
  - Lists vs arrays
  - Higher order functions
  - Parallelization (parallel map, token ring)



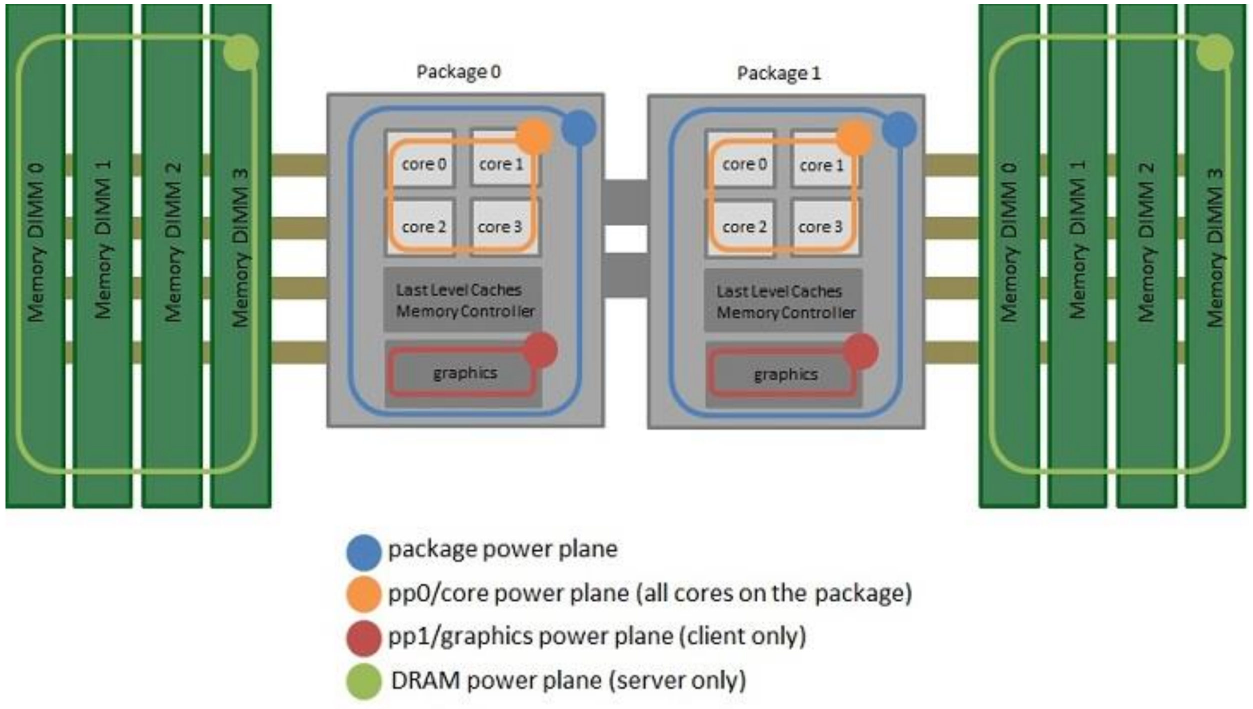
$$\begin{bmatrix} 0 & 0 & 0 & 0 \\ 5 & 8 & 0 & 0 \\ 0 & 0 & 3 & 0 \\ 0 & 6 & 0 & 0 \end{bmatrix} \times \begin{bmatrix} 3 & 0 & 0 & 0 \\ 0 & 0 & 2 & 0 \\ 5 & 3 & 0 & 7 \\ 0 & 1 & 0 & 0 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 15 & 0 & 16 & 0 \\ 15 & 9 & 0 & 21 \\ 0 & 0 & 12 & 0 \end{bmatrix}$$

New goals

- Improve methodology
- Directly measure language elements
- Measure data structures independently
- Further inspection of parallelization
  - Spawning processes
  - Sending messages
- Refactoring in order to minimize energy consumption

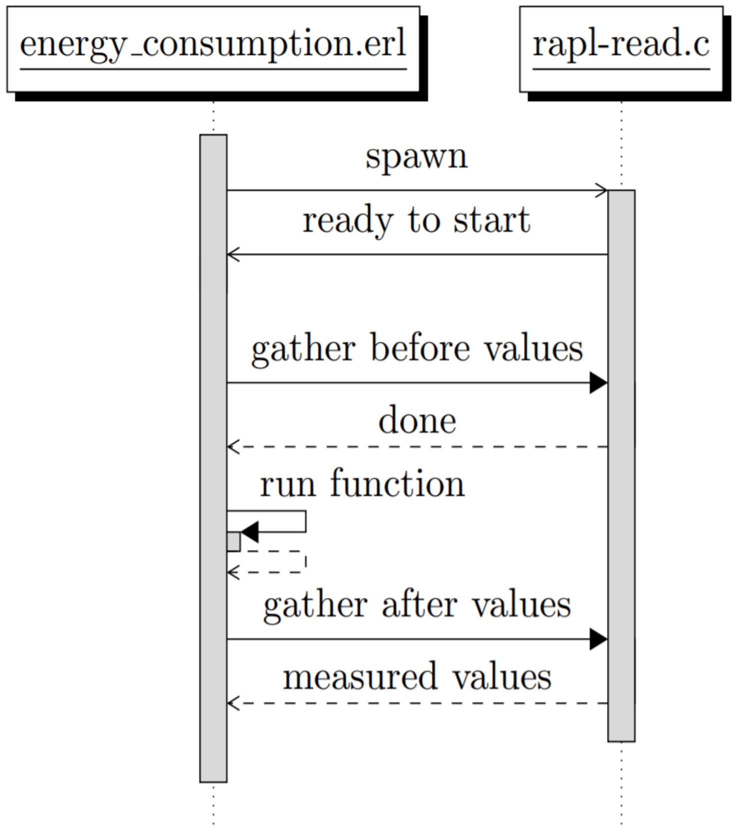
How to measure energy consumption

- Running Avarage Power Limit (RAPL)
  - Intel
  - Methods:
    - MSR
    - perf_event,
    - sysfs
  - Domains:
    - PKG – package
    - PP0 – core
    - PP1 – uncore
    - DRAM



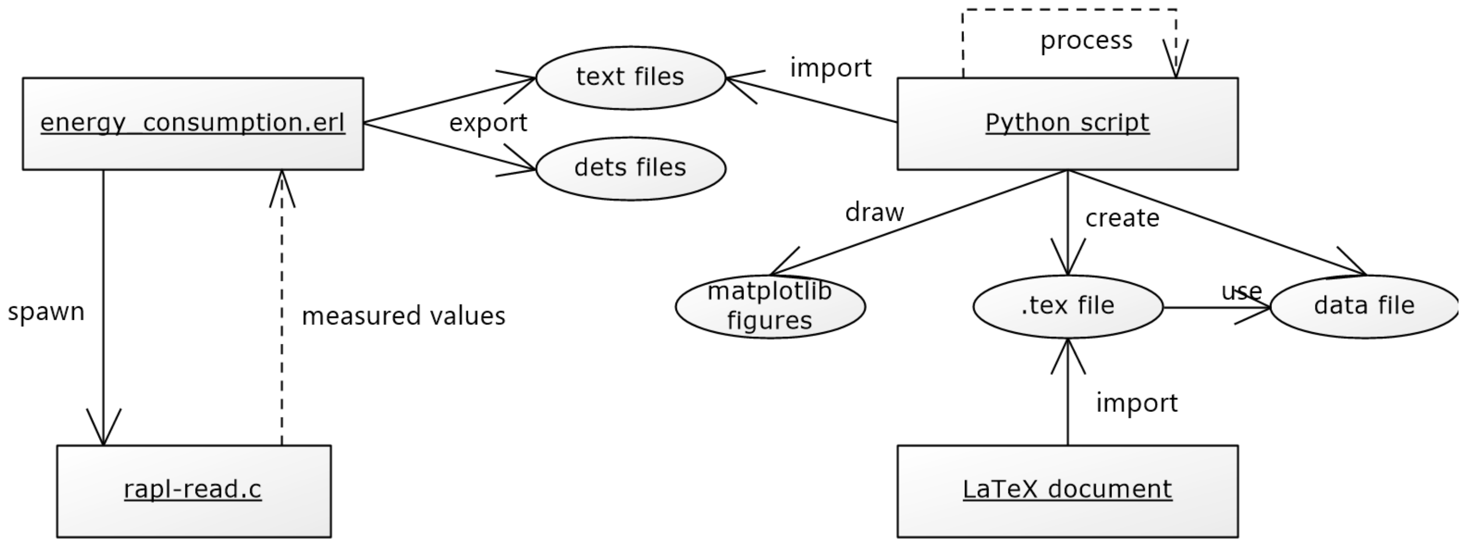
Framework for Erlang

- C program to read RAPL values
- Erlang module to run measured functions
  - Communication via ports
  - Runs the functions
  - Tells the C program when to measure
- Python GUI
  - Using TkInter
  - Setup measurement
  - Helps with organizing the measurements
  - Visualizing results



Methodology

- Methodology
  - Everything is measured 10 times
  - Discarding minimal and maximal values
  - Calculate average energy consumed
  - Also measuring runtime



Measurements

- Higher order functions
  - Important part of functional languages
  - We wanted to find the cost of passing functions as parameters
- Data structures
  - List, map, dictionary
  - What is the cost of creating these data structures?
  - What is the cost of operations?

Higher order functions

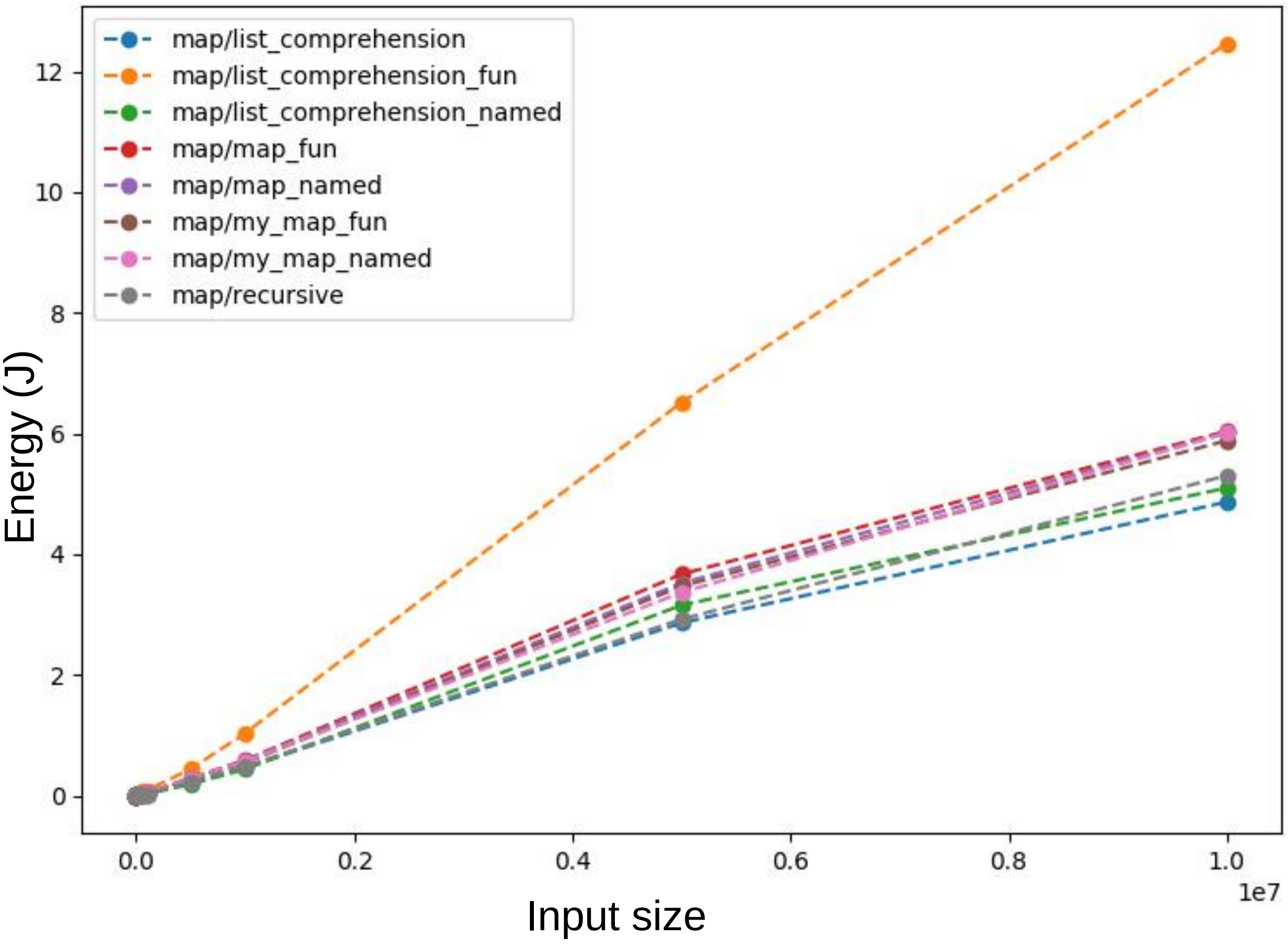
- Passing named or unnamed functions
- Using HOF, list comprehension or recursion
- Implementing our own higher order functions
- Measured:
  - map
  - filter
  - map ∘ filter

```
lists:map(fun increase/1, L).
```

```
lists:filter(fun even/1, L).
```

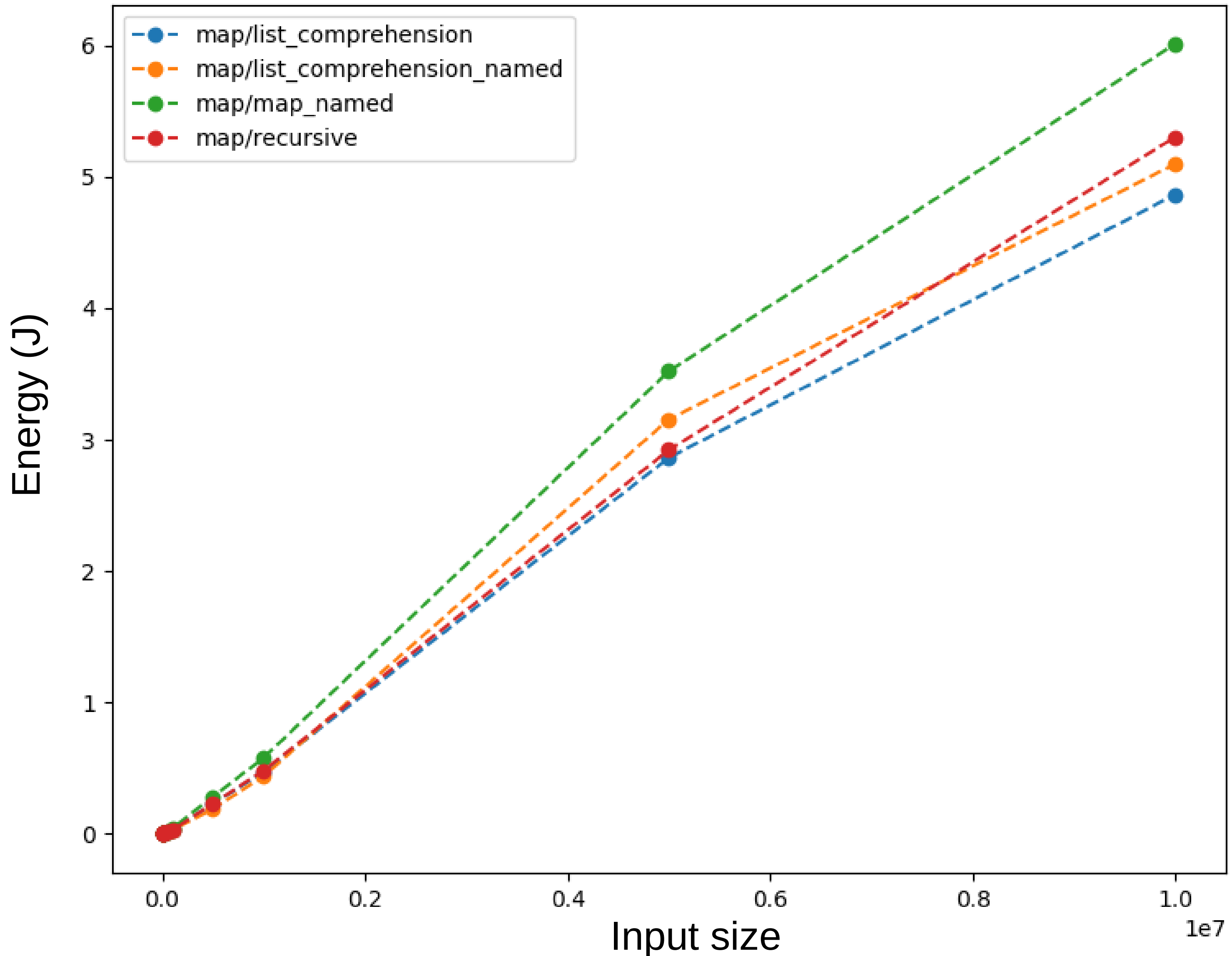
```
lists:map(fun increase/1, lists:filter(fun even/1, L)).
```

Map - results

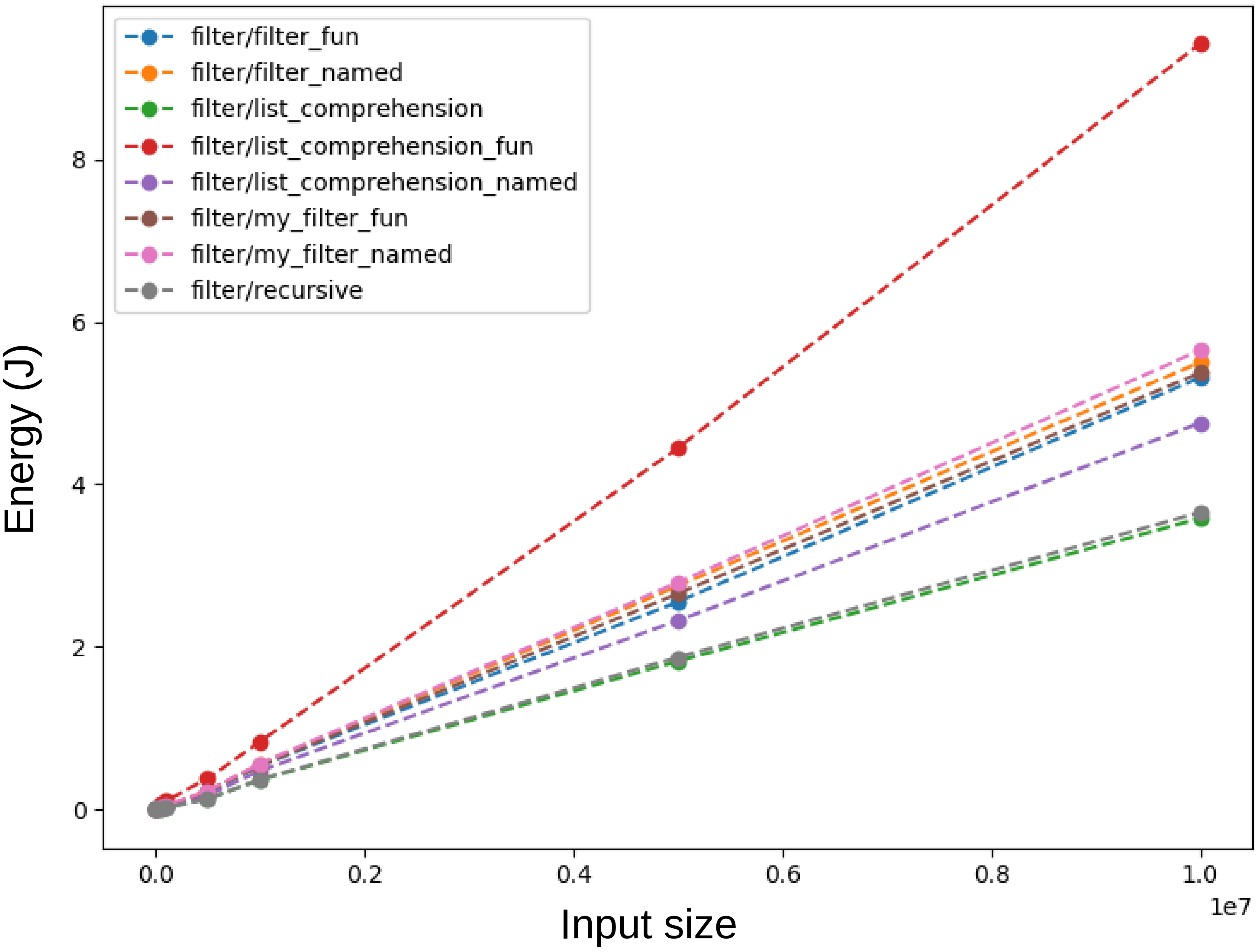


- Best
  - Recursion
  - List comp.
- Worst
  - List comp. with fun.
  - All maps
- Graph is the same based on energy and runtime

MAP - RESULTS

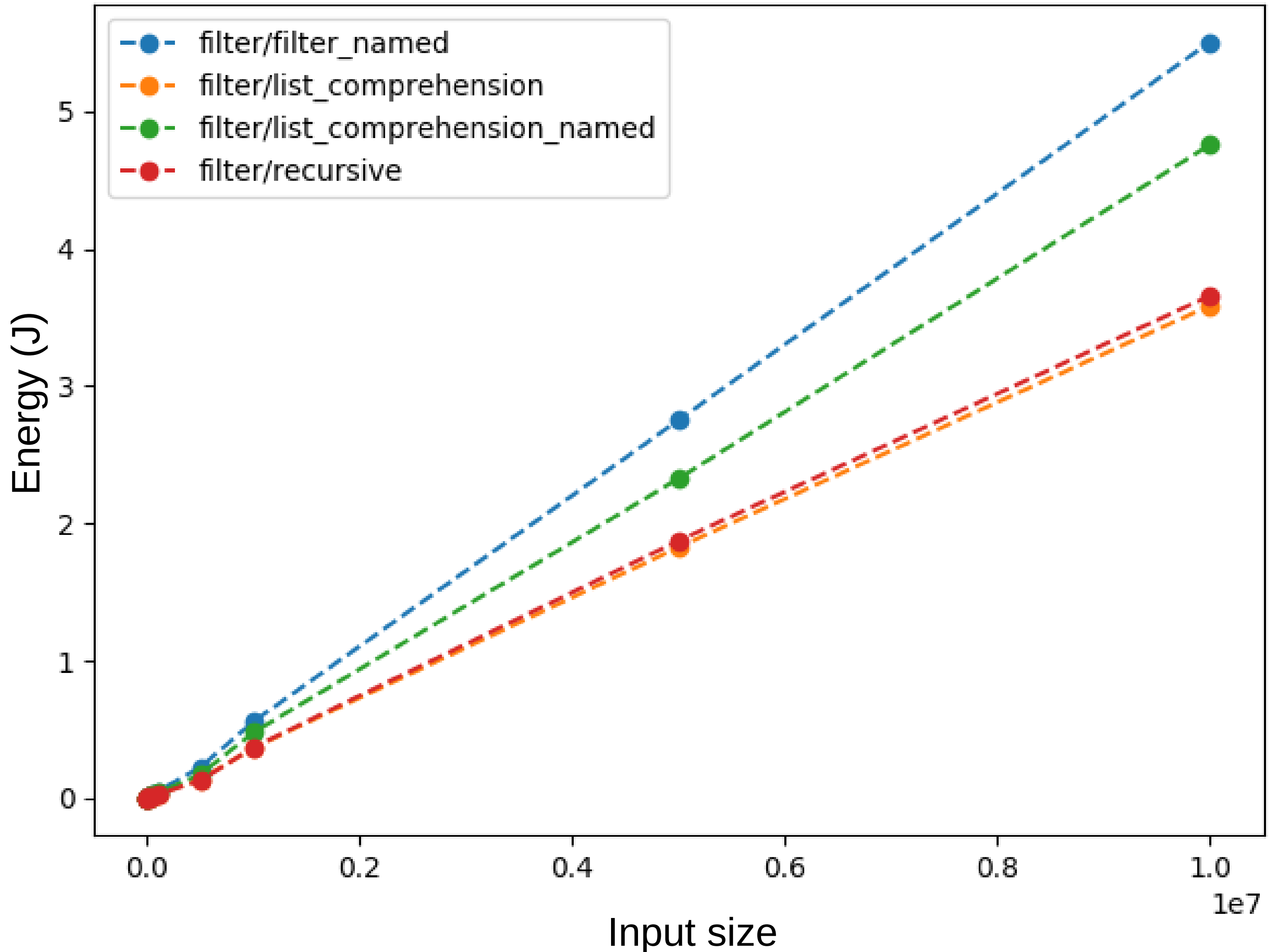

map/list_comprehension
map/list_comprehension_named
map/map_named
map/recursive
Energy (J)
Input size
1e7
0
1
2
3
4
5
6
0.0
0.2
0.4
0.6
0.8
1.0

FILTER - RESULTS

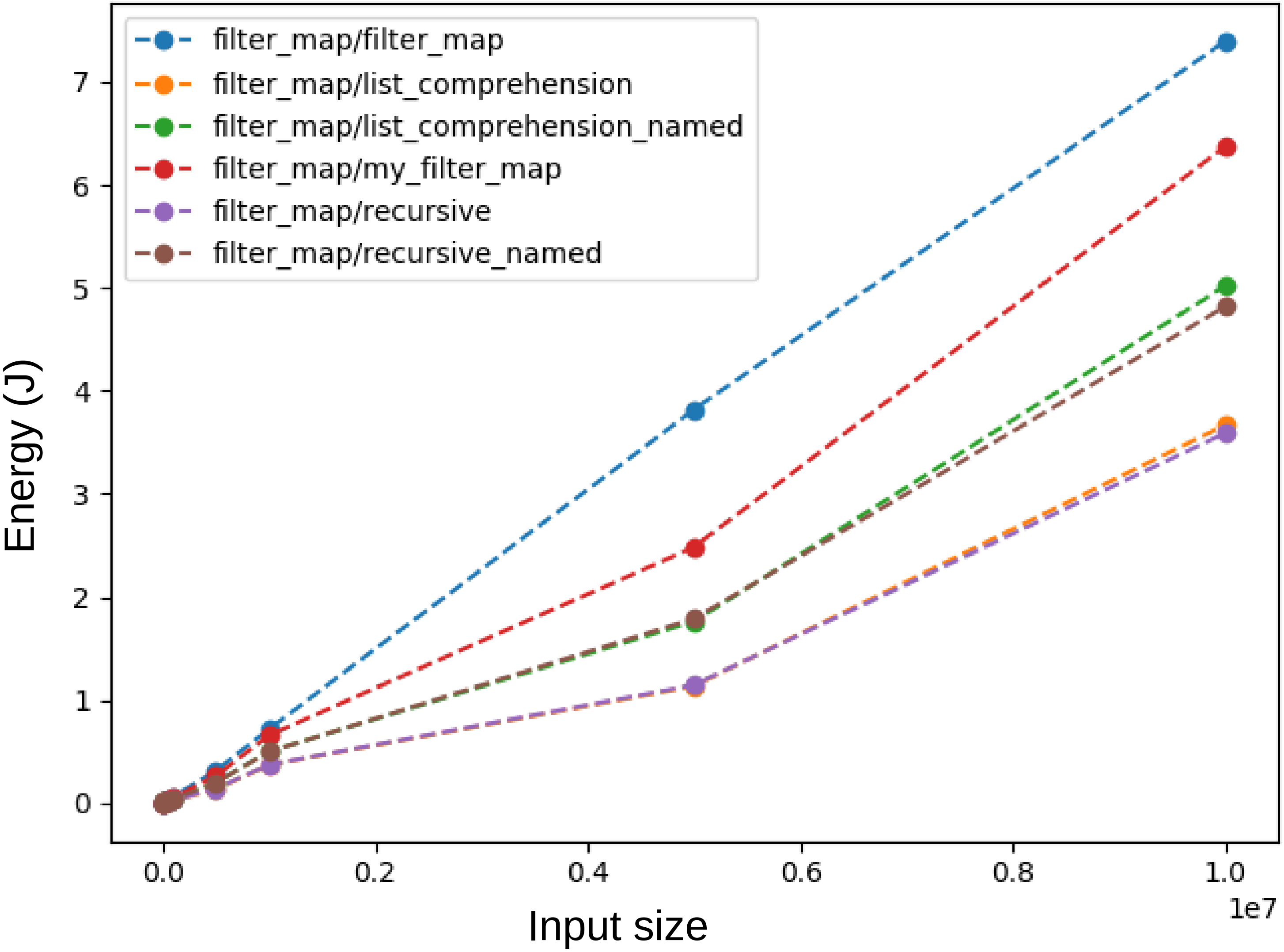


- Same results as with map

Filter - results



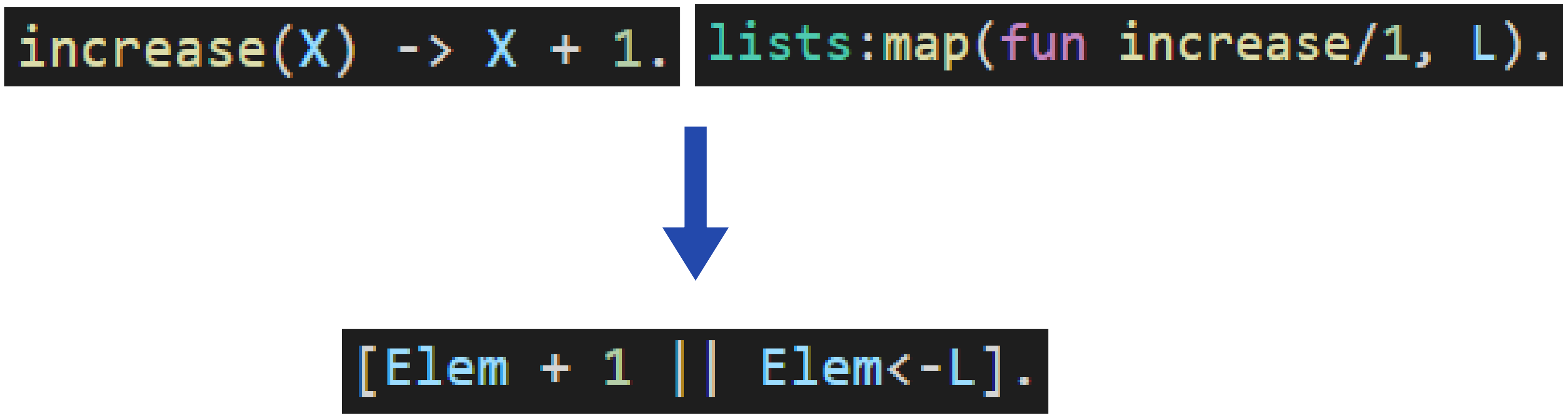
Map ∘ Filter - Results



- Larger differences
- HOF iterates over the list twice

HOFs - FINDINGS

- Refactoring higher order function calls to a simple recursive function or list comprehension reduces energy consumption and runtime
- Eliminating the HOF is not enough, we need to eliminate the called function as well to minimize energy consumption.
- This is consistent with previous findings (N-queens)



```
increase(X) -> X + 1.
```

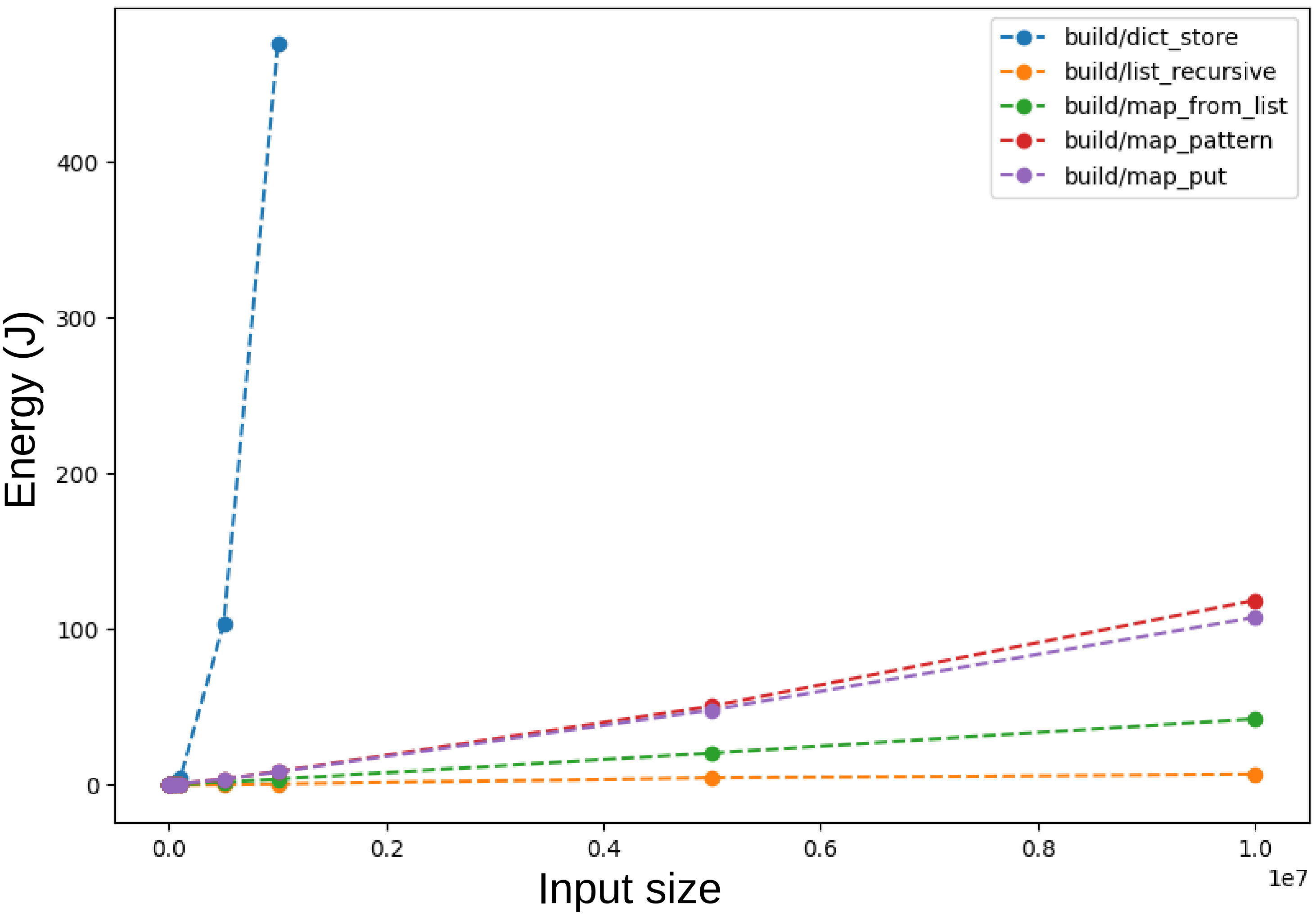
```
lists:map(fun increase/1, L).
```

```
[Elem + 1 || Elem<-L].
```

Data structures

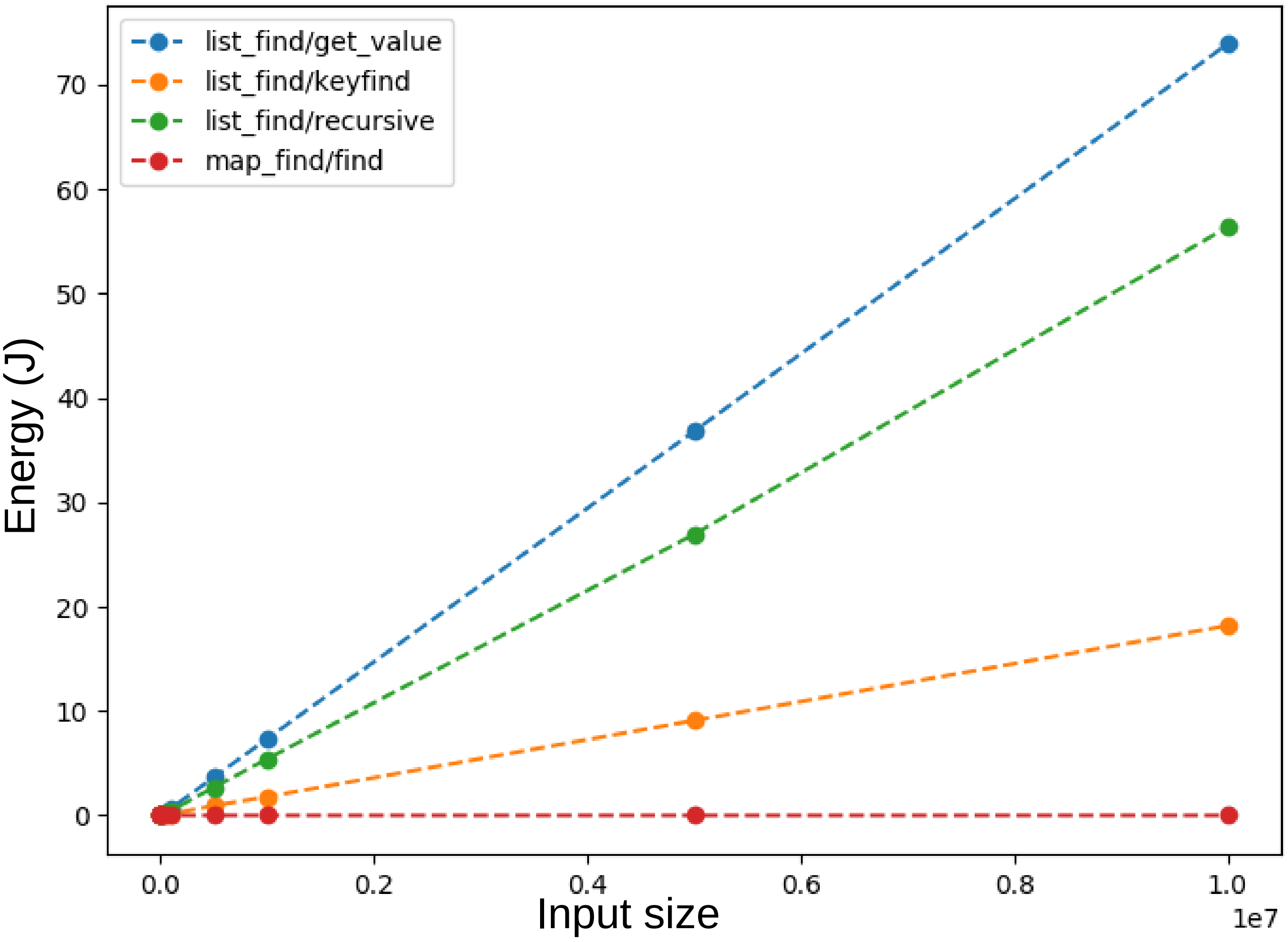
- Investigating different ways to store key-value pairs
  - list of tuples
  - map
  - dict
- Measuring different operations on those data structures
  - find
  - delete
  - update
  - building the data structure

BUILDING - RESULTS



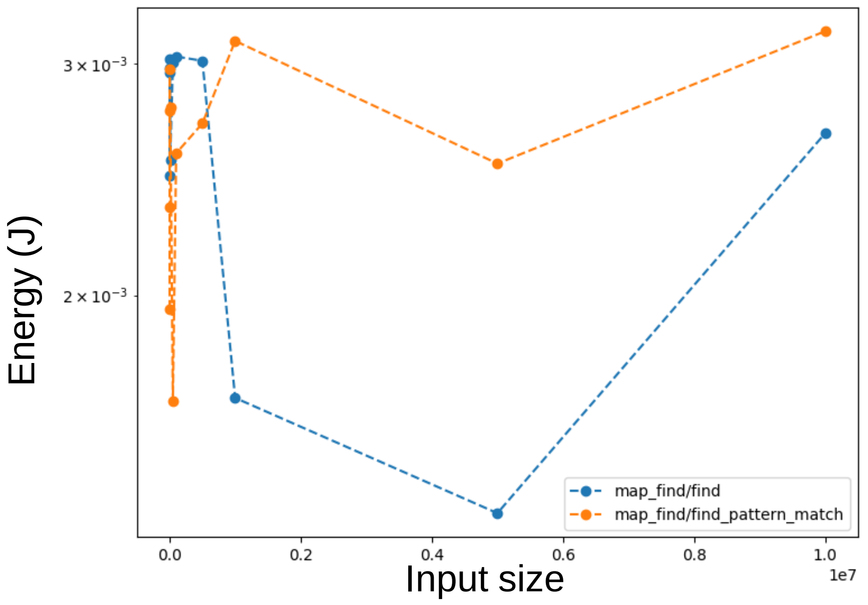
- Dicts are expensive
- Lists are cheap
- Building a list then map is cheaper than building map directly

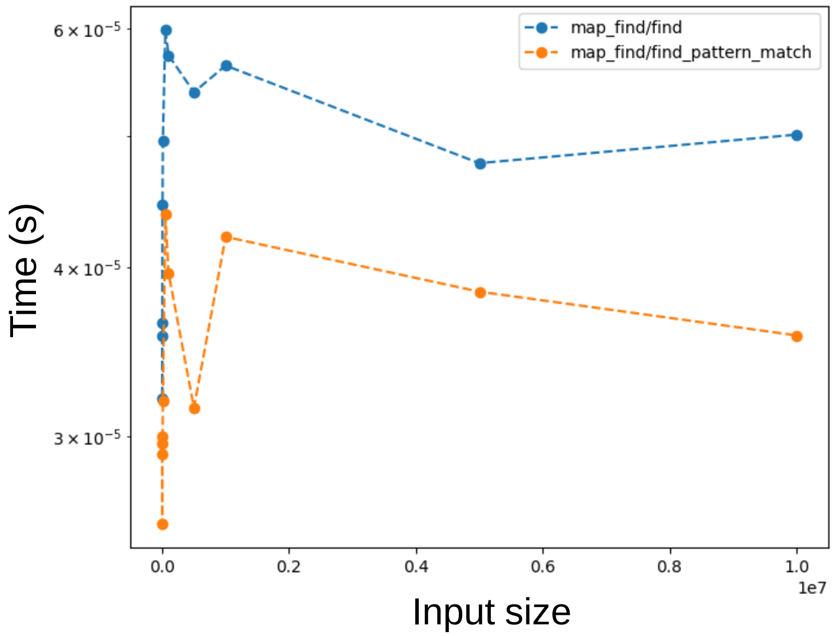
FIND - RESULTS



- proplists:get_value vs lists:keyfind

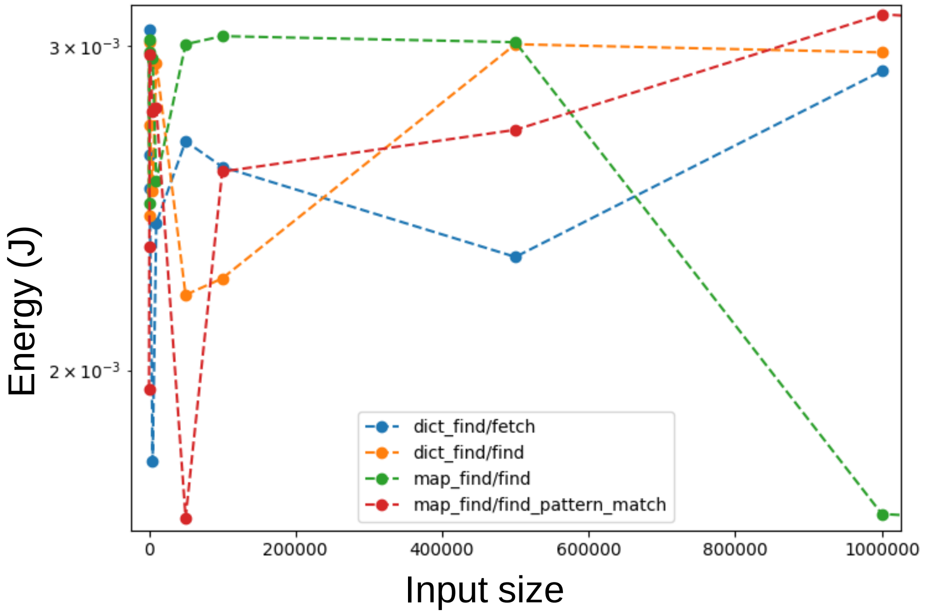
Find - results

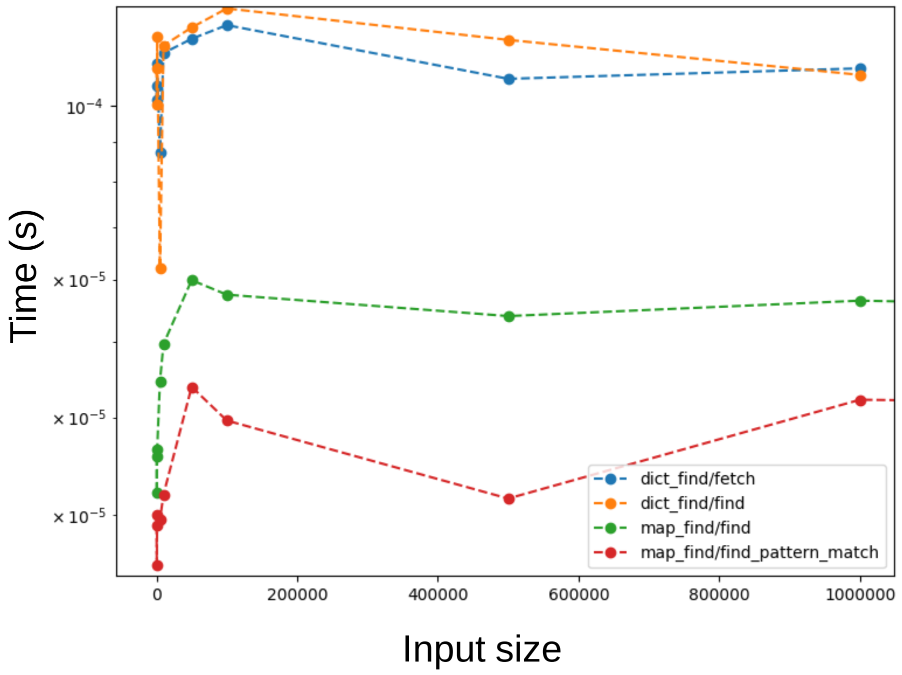




- Finding with pattern matching is faster, but consumes more energy
- Using the find function consumes the least energy but is slower
- Needs more testing

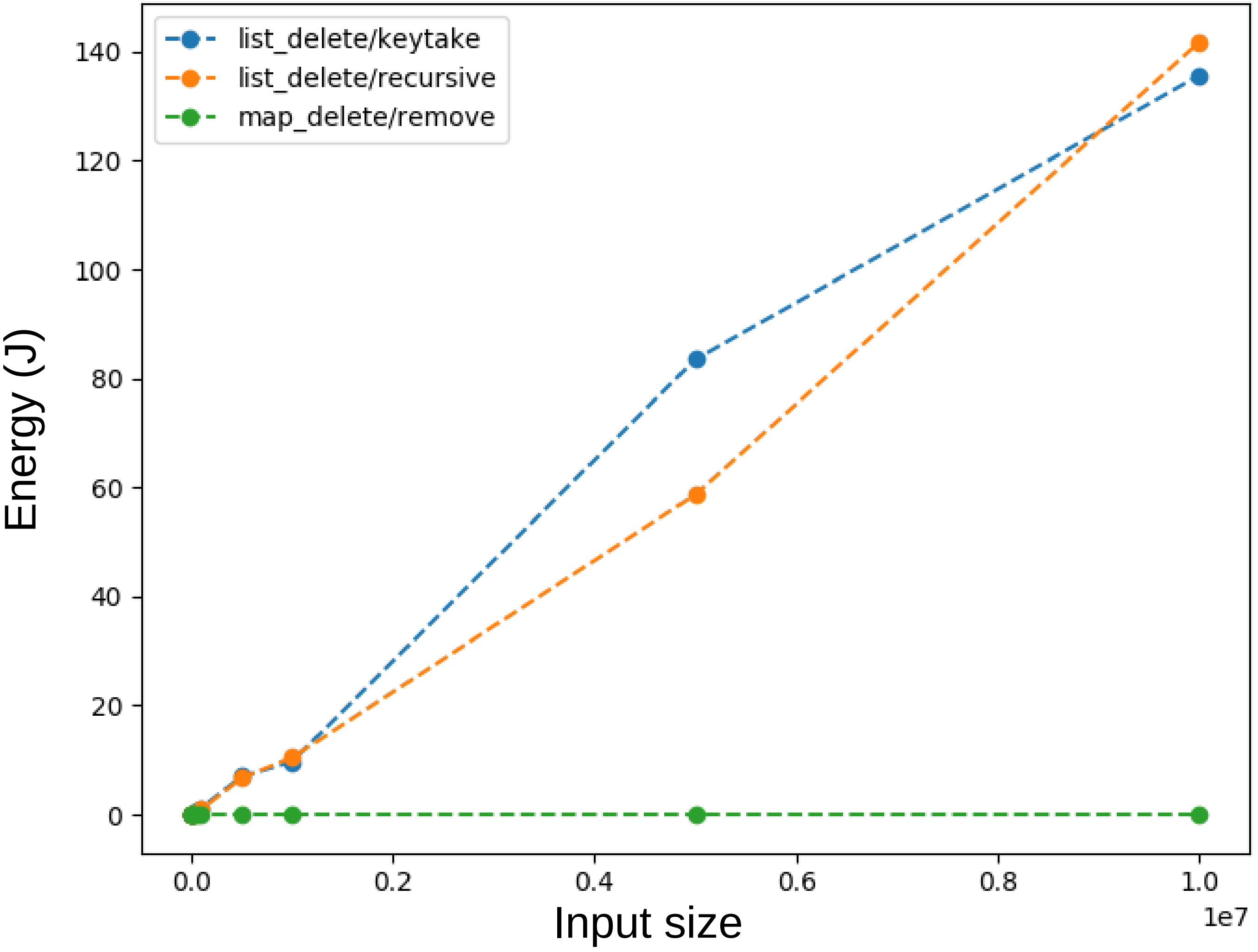
Find - results





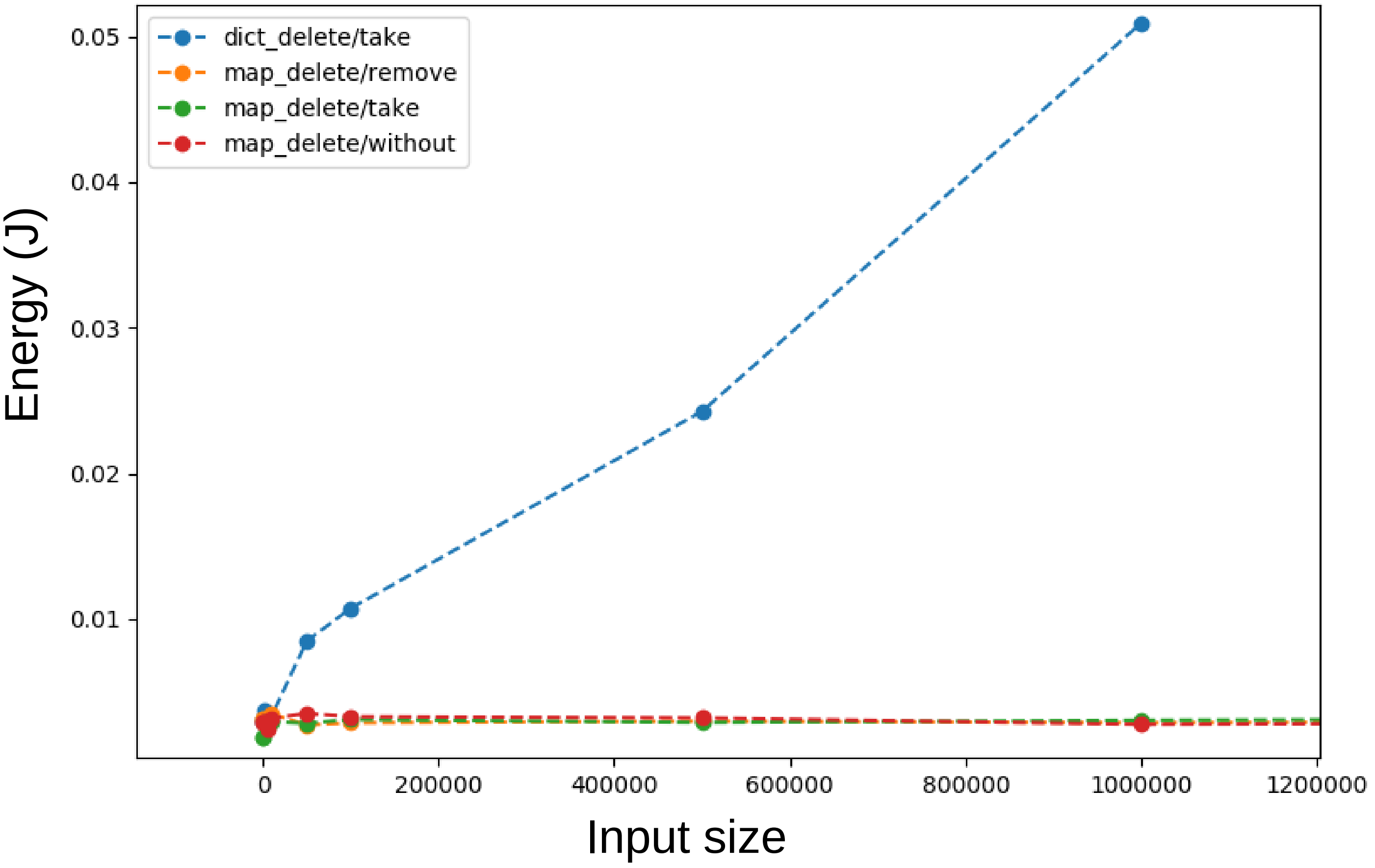
- Finding in a dict is similar to finding in a map,
- Maps are quicker
- Energy consumption may be better for maps (cannot construct large enough dicts)

Delete - results



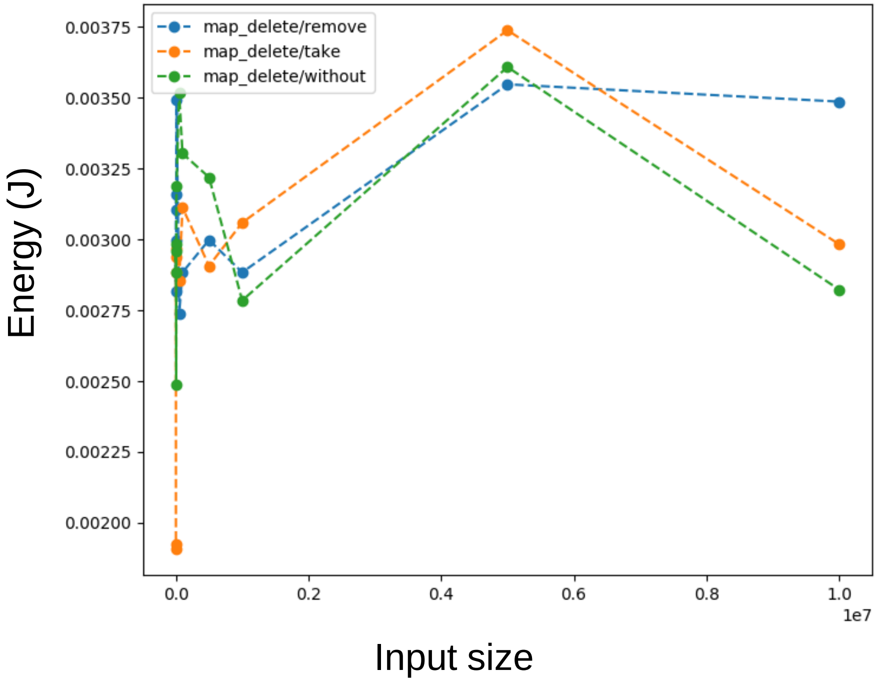
- No conclusive difference between the two ways to delete
- Much worse than deleting from a map (as expected)

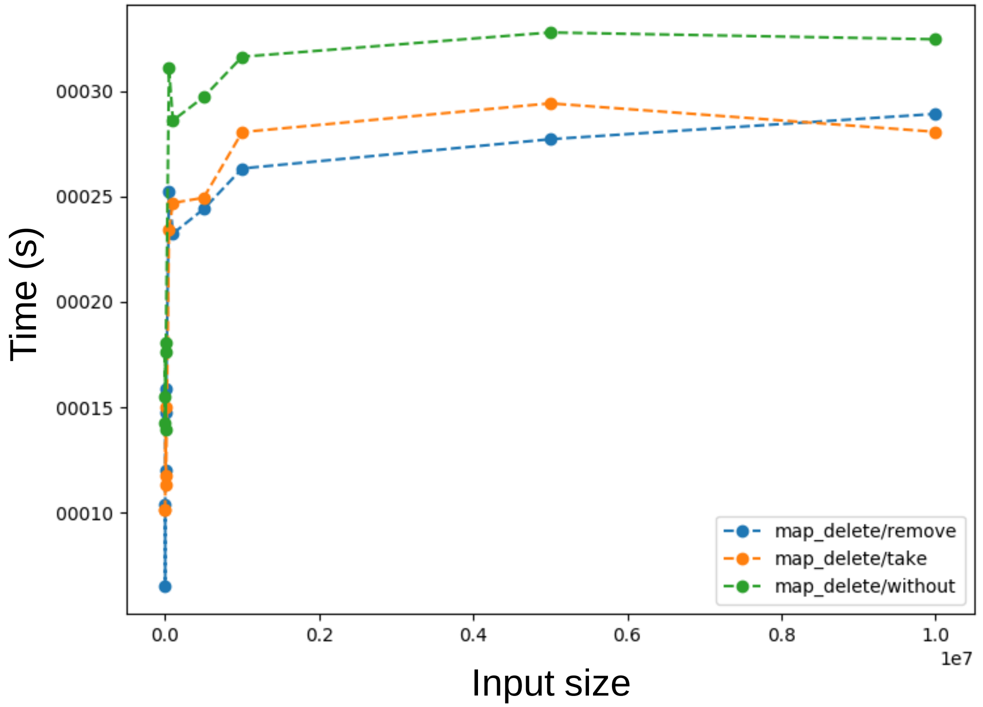
DELETE - RESULTS



- Deleting from a dict is worse than deleting from a map

DELETE - RESULTS





- Deleting with maps:without is the slowest, but consumes the least energy
- Needs more testing

Update - Results

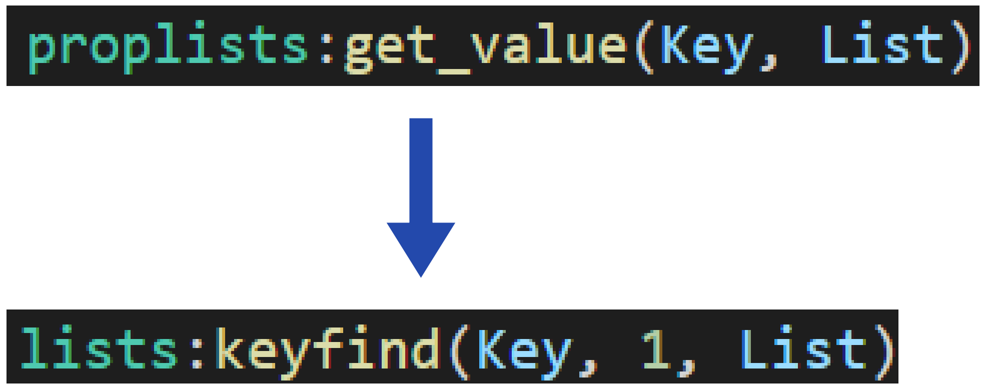
- Results for updating an element in out dictionaries show the same patterns as deleting an element.
- Maps are the most efficient
- Dicts are in the middle
- Lists perform the worst

DATA STRUCTURES - FINDINGS

- Most of the differences between the data structures can be attributed to different representations
- Interesting findings are:
    - We should use lists:keyfind instead of proplists:get_value
    - With maps the quickest solution is not always the more efficient
        - More investigation is needed, because measured values are so small

DATA STRUCTURES - FINDINGS

- Refactoring may be possible between different implementations of functions on the same data structure
- Based on the cost to build every data structure we may be able to decide how many of each operation is needed until it is worth building a different data structure



```
proplists:get_value(Key, List)
```

```
lists:keyfind(Key, 1, List)
```

Conclusions

- Tool for measuring energy consumption
- Higher order functions have an overhead
  - It may be eliminated by rewriting the calls to higher order functions with recursion or list comprehensions
  - Function calls should also be eliminated
- Erlang built-in functions on the same data structures can have significant differences in performance

Future work

- Investigating the cost of spawning processes and sending messages
- Measuring different algorithmic skeletons for parallelization
- Creating refactorings based on our findings using RefactorErl

THANK YOU FOR YOUR ATTENTION!

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