Integration of antichain algorithms in automata library

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Motivations

Scenario

- A developer wants to implement automata antichain algorithms
- How to implement antichains ?
- Which tools to use for the automata representation ?

Motivations

- There exists libraries to use antichains, but not easy to integrate when using automata
- Having antichains in automata library *seems* to be needed

Ease the implementation of antichain-based algorithms for developers

My contributions

Objectives

- The goal of the thesis was to define a use case algorithm using antichains:
  Language universality check $L(A) \stackrel{?}{=} \Sigma^*$ **using antichains**
- Then implement it in an automata library:
  Owl: ω**-automata library**

At the end we should have something like:

```
owl -I myautomaton.hoa \
hoa --- complete --- universality-check --- string
```

My contributions

Content

- `poset` library, a `Java` library that provides interfaces to interact with antichains [Bou]
- Use case implementation: algorithm for checking universality of NFA using antichains [DWDHR06]
- a *User Guide* (this work) on how to integrate an algorithm in `Owl` [KMS18]

The main goal is to provide a framework to implement antichain algorithms in automata libraries

Main references I

[Boh14] Aaron Bohy.
Antichain based algorithms for the synthesis of reactive systems.
PhD thesis, Université de Mons, 2014.

[Bou] Hakim Boulahya.
hqwisen / poset ů GitLab.
https://gitlab.com/hqwisen/poset.

[DWDHR06] M. De Wulf, L. Doyen, T. A. Henzinger, and J. F. Raskin.
Antichains: A New Algorithm for Checking Universality of Finite Automata.
In *Computer Aided Verification*, volume 4144, pages 17–30. Springer Berlin Heidelberg, Berlin, Heidelberg, 2006.

Main references II

[KMS18] Jan Kretínský, Tobias Meggendorfer, and Salomon Sickert.
Owl: A library for \omega -words, automata, and LTL.
In *Automated Technology for Verification and Analysis - 16th International Symposium, ATVA 2018, Los Angeles, CA, USA, October 7-10, 2018, Proceedings*, pages 543–550, 2018.

`poset` library

`poset` is a `Java` library providing interfaces for:
orders, bounds and antichains

- All functions are implemented using the `FunctionalInterface`: single method class using lambda expressions syntax
- Antichains (and closed sets) are implemented using `Set` interfaces
- Interfaces use generic types, and default implementations make use of builtin interfaces: `Set` for set of elements and `List` for vectors representation

`poset` functions

Orders

```
interface Order<T> extends BiPredicate<T, T>
```

- With implementations for: $\subseteq$, $\sqsubseteq$ and $\preceq$

Bounds

```
public interface Bound<T>{
  T compute(T a, T b, Order<T> order)
}
```

- With an implementation for the greatest lower bound $a \sqcap b$

Antichains

```java
interface Antichain<E> extends Set<E>
```

- With one default implementation using a `LinkedList`[1] to store the incomparable elements
- Available methods are the usual for the `Set` interface (add, remove, contains, etc.) and the union ($\cup$) and intersection ($\cap$) operations

Closed sets

- Mainly antichains where the containment $\in$ is tested against the lower closure $\downarrow\lceil L \rceil$

[1] preferred because it is more needed to add/remove elements than accessing them

`poset` examples

How it works

- Import the functions

```
import poset.orders.LEQ
import poset.bounds.GreatestLowerBound
import poset.AntichainList
```

- Create them

```
var leq = new LEQ() // The partial order
var glb = new GreatestLowerBound() // required to
    compute the intersection
var a1 = new AntichainList<>(leq, glb)
var a2 = new AntichainList<>(leq, glb)
```

How it works

- Use it

```
a1.add(List.of(3, 1))
//  a1 ==> [[3, 1]]
a1.add(List.of(2, 2))
// a1 ==> [[3, 1], [2,
    2]]
a2.add(List.of(0, 2))
// a2 ==> [[0, 2]]
```

```
a1.union(a2)
// $ ==> [[3, 1], [2, 2]]
a2.add(List.of(2, 3))
// a2 ==> [[2, 3]]
a1.union(a2)
// $ ==> [[3, 1], [2, 3]]
a1.intersection(a2)
// $  ==> [[2, 2]]
```

`Owl` introduction

`Owl` description

`Owl` is a *"Java tool collection library for ω-words, ω-automata and linear temporal logic"*

- It can be used either as a command line interface or a library (`Java` and `C++` API)
- Its a library used mainly for ω-automata and LTL translations

How we use it

- We use `Owl` as a library to use the automata structures
- And we also use `Owl` as a CLI to run the algorithms

Integration in `Owl`

How to integrate ?

`Owl` uses a pipelines logic to execute the different modules

```
owl -I myautomaton.hoa \
hoa --- complete --- universality-check --- string
```

- The goal is to integrate the antichain-based language universality check of an automaton in `Owl`
- It provides a nice interface to integrate any kind of modules that can be chained together to produce a result

Integration in `Owl`


```
owl -I myautomaton.hoa \
hoa --- complete --- universality-check --- string
```

Decomposition of the modules

- `hoa`: Module reading the input automaton in Hanoi Omega Automata format[2]
- `complete`: built-in module to complete the input automaton
- `universality-check`: The integrated antichain algorithm
- `string`: the output module, writing `true` or `false` in this case

[2] ω-automata have the same structure as NFA so the HOA format can still be used to represent NFAs

Implementation of $L(A) \stackrel{?}{=} \Sigma^*$

- The `univerality-check` module is the implementation of the backward antichain algorithm for universality check of an automaton [DWDHR06]
- It uses `Owl` library to interact with automata structures
- It uses `poset` library to build the symbolic representation using antichains

Comparison

- The main goal of implementating antichain algorithms is because they perform better than the usual state-of-the-art solutions for the problem
- Main comparison for $L(A) \stackrel{?}{=} \Sigma^*$: *antichain-based* vs *subset construction*

What to compare

1. `Owl` (antichain) vs `VCSN` (subset)
   - `VCSN` is an automata library in `C++` with `Python` bindings
   - It has been chosen for the comparison because it is easy to use and provide lots of functions:

     ```
     a.determinize().complete().complement().is_useless()
     ```

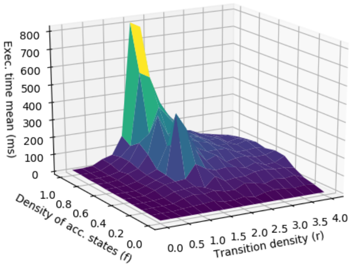
2. `Owl` (antichain) vs `NuSMV` and `CUDD` (antichain)
   - `NuSMV` and `CUDD` are the tools used in the paper [DWDHR06] that introduced the antichain based algorithm for our use case

- We want to check that the `Owl` implementation is better that the subset construction
- and is at least as efficient as the one introduced in the original paper

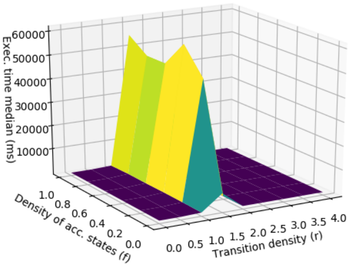
Random automata generation

- $\Sigma = \{0, 1\}$
- $r = \frac{k_\sigma}{|Q|}$, the transition density where k_σ is a number of state pairs, chosen uniformly at random
- $f = \frac{m}{|Q|}$, the density of accepting states where m is the number of accepting states

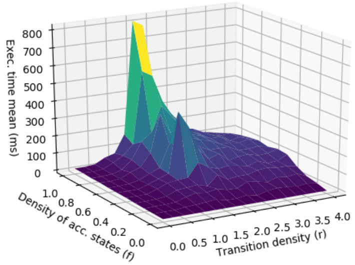
Owl


Exec. time mean (ms)
800
700
600
500
400
300
200
100
0
Density of acc. states (f)
1.0
0.8
0.6
0.4
0.2
0.0
Transition density (r)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0

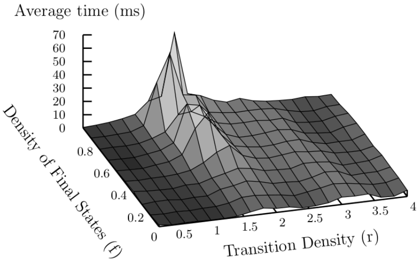
VCSN


Exec. time median (ms)
60000
50000
40000
30000
20000
10000
Density of acc. states (f)
1.0
0.8
0.6
0.4
0.2
0.0
Transition density (r)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0

Owl



NuSMV*

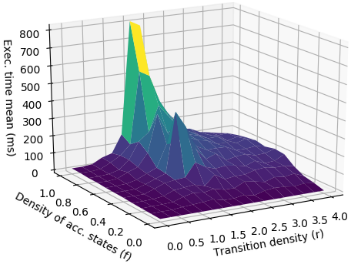


First results[3]: 10x slower... Why ?

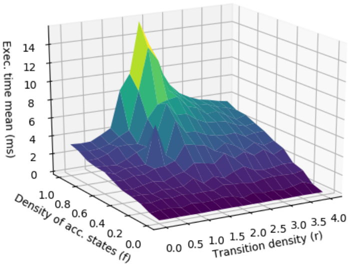
***Those results are taken from [DWDHR06] and were not rerun**

[3] Those are the results given in the thesis paper

Owl

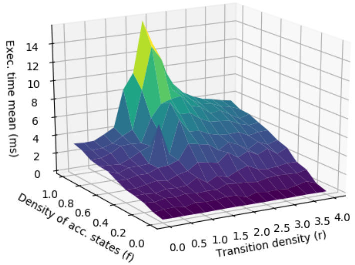


Owl with transitions stored in `HasMap`

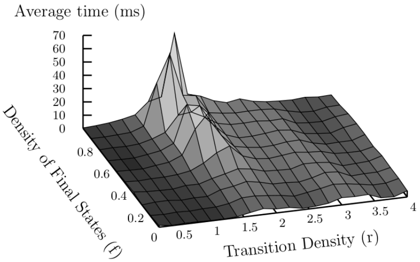


Successors and predecessors were computed on the fly

Owl


Exec. time mean (ms)
0
2
4
6
8
10
12
14
Density of acc. states (f)
1.0 0.8 0.6 0.4 0.2 0.0
Transition density (r)
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0

NuSMV*


Average time (ms)
70
60
50
40
30
20
10
0
Density of Final States (f)
0.8
0.6
0.4
0.2
0
Transition Density (r)
0.5 1 1.5 2 2.5 3 3.5 4

Conclusion

Last year objectives

- Provide an API and implement it against `Owl` ✓
- Provide some implementation for antichains depending on the universe of the sets ✓
- Define the algorithms to test our antichains implementation against ✓
- Study the performance of those implementations ✓

Future work

`poset` library

- Improving the default implementation of `poset` library
- Add support for closure operations

Integration

- A better support of NFA in `Owl`
- `Owl` can be more user-friendly
- Integrate antichains in `VCSN` since it is more user-friendly
- `Owl` has LTL support, so there are other possibilities of implementation and integration such as *antichain based algorithms for the synthesis of reactive systems* [Boh14]

Thanks for listening