

Java-lattices 2.0.0-SNAPSHOT

Tutorial

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Introduction

Here is a short tutorial of the `java-lattices` library presenting its most important capabilities.

This is a live tutorial, which means two things :

- It evolves with the library, so the work is still in progress.
- Is is generated dynamically by the library itself, at least for some parts.

Lattice

Create your own lattice

Manually

You can define your own (small) lattice by creating its nodes and edges.

Exemple : the non-modular lattice M_5 can be defined as follow :

1. Call the empty constructor `Lattice l = new Lattice();`
2. Add nodes
3. Add edges

```
Lattice l = new Lattice();
Node a = new Node('a'); l.addNode(a);
Node b = new Node('b'); l.addNode(b);
Node c = new Node('c'); l.addNode(c);
Node d = new Node('d'); l.addNode(d);
```

```

Node e = new Node('e'); l.addNode(e);
Edge ab = new Edge(a, b); l.addEdge(ab);
Edge bc = new Edge(b, c); l.addEdge(bc);
Edge ad = new Edge(a, d); l.addEdge(ad);
Edge de = new Edge(d, e); l.addEdge(de);
Edge ec = new Edge(e, c); l.addEdge(ec);
System.out.println(l.toString());
l.save("M5.dot");

```

The two last lines help you verify your lattice with following methods :

1. A string representation on the standard output : `System.out.println(l.toString());`.
This method is inherited from `DGraph`.
2. An export in `.dot` format file with the instruction : `l.save("M5.dot");`.

Generated `M5.dot` contains :

```

digraph G {
Graph [rankdir=BT]
1 [label="a"]
2 [label="b"]
3 [label="c"]
4 [label="d"]
5 [label="e"]
1->2
1->4
2->3
4->5
5->3
}

```

With [graphviz tools](#), you can generate the following `.png` image :

From LatticeFactory

`LatticeFactory` class provides few methods to get example lattices :

1. Call `Lattice b = LatticeFactory.booleanAlgebra(13);` to get
boolean algebra with 2^{13} elements in variable `b`.
2. Call `Lattice p = LatticeFactory.permutationLattice(7);` to get
lattice of permutation of the set $1, \dots, 7$ in variable `p`.

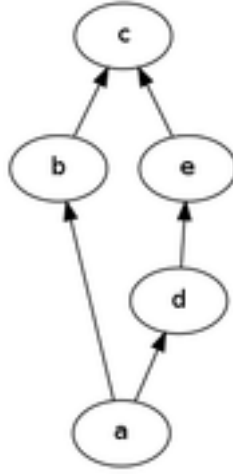


Figure 1: M_5 Lattice

3. Call `Lattice r = LatticeFactory.randomLattice(19);` to get a random lattice with 19 nodes in variable `r`.
4. Call `Lattice p = LatticeFactory.product(l, r);` to get cartesian product lattice *l**times**r* in variable `p`.
5. Call `Lattice d = LatticeFactory.doublingConvex(l, c);` to get lattice in which convex *c* of lattice *l* has been doubled in variable `d`.

From wherever you want

1. From a context, you can generate a `ConceptLattice` which is of course a lattice, by calling `context.conceptLattice(true);`. See `ConceptLattice` tutorial for more details.
2. From an implicational system, via `BijjectiveComponent`. See `BijjectiveComponent` tutorial for more details.

Basic computations

Suppose you have your own lattice in variable `l` and you want to explore its properties.

As an example, we'll use lattice M_5 previously defined.

- Top element

Let's begin with a very basic computation : the top element.

To do, use the following code : `Node top = l.top();`. Of course, you can output its content with `System.out.println(top.toString());`.

In our example, with M_5 , top element is c .

Recall that top is at the top of the representation but it is the smallest element.

- Bottom element

Continue with the dual of top element : the bottom element.

Use the following code : `Node bot = l.bottom();`.

In our example, with M_5 , bottom element is a .

- Meet of two elements

Here are main properties of lattices. A lattice is a partially ordered set (a.k.a. poset) in which least upper bound (l.u.b. or join) and greatest lower bound (g.l.b. or meet) of two elements exists.

Go on with our M_5 example, meet of nodes b and d is a . It can be computed with the following code : `Node m = l.meet(b, d);`.

- Join of two elements

Still with M_5 example, join of nodes b and d is c . It can be computed with the following code : `Node j = l.join(b, d);`.

Irreducibles computations

- Irreducible elements

Irreducible elements are of great importance in lattices.

Recall a join irreducible j in a lattice l is a special element that can NOT be obtained as a join of others. Of course, meet irreducibility is the dual notion.

A nice characterization of join irreducible is the following : j is a join irreducible if and only if it has only one predecessor, usually noted j^- .

Dually, m is a meet irreducible if and only if it has only one successor, usually noted m^+ .

You can compute the set of join irreducibles of a lattice l with `TreeSet<Node> joinIrr = l.joinIrreducibles();`.

Dually, you can compute the set of meet irreducibles of a lattice l with `TreeSet<Node> meetIrr = l.meetIrreducibles();`.

In the previous example M_5 , nodes b, d, e are join and meet irreducibles.

- New example

Consider the all new lattice :

```
Lattice l = new Lattice();
Node b = new Node('b'); l.addNode(b);
Node c = new Node('c'); l.addNode(c);
Node d = new Node('d'); l.addNode(d);
Node e = new Node('e'); l.addNode(e);
Node f = new Node('f'); l.addNode(f);
Node g = new Node('g'); l.addNode(g);
Node t = new Node('t'); l.addNode(t);
Edge bc = new Edge(b, c); l.addEdge(bc);
Edge bd = new Edge(b, d); l.addEdge(bd);
Edge be = new Edge(b, e); l.addEdge(be);
Edge cf = new Edge(c, f); l.addEdge(cf);
Edge df = new Edge(d, f); l.addEdge(df);
Edge dg = new Edge(d, g); l.addEdge(dg);
Edge eg = new Edge(e, g); l.addEdge(eg);
Edge ft = new Edge(f, t); l.addEdge(ft);
Edge gt = new Edge(g, t); l.addEdge(gt);
l.save("Example.dot");
```

Such lattice is better understood with a nice picture :

Here, join irreducibles are c, d and e whereas meet irreducibles are c, d, f and g

- Irreducible generators

Given a node n which is NOT a join irreducible, you can compute join irreducibles such that n is join of these elements.

For example, with our new example, node f is generated with two join irreducibles c and d , computed with `TreeSet<Comparable> joingen = l.joinIrreducibles(f);`.

Dually, `TreeSet<Comparable> meetgen = l.meetIrreducibles(d);` show that node d is obtained as meet of f and g that are meet irreducibles.

To conclude on these irreducibles, you can compute the subgraph of all irreducibles with `DAGraph dag = l.irreduciblesSubgraph();`, and get following result :

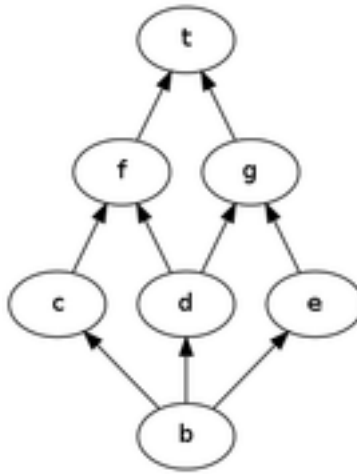


Figure 2: Example Lattice

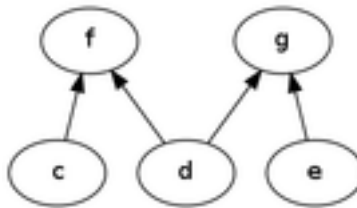


Figure 3: Irreducible Graph

And, last but not least, you can compute the context :

```
Observations: c e f g
Attributes: c d e
c: c
e: e
f: c d
g: d e
```

in which observations are meet irreducibles, attributes are join irreducibles, and an attribute is extent of an observation when its join irreducible node is greater than the meet irreducible node in the lattice.

That computation is done by `Context ctx = l.getTable();`.

The whole source code to get these results is the following :

```
Lattice l = new Lattice();
Node b = new Node('b'); l.addNode(b);
Node c = new Node('c'); l.addNode(c);
Node d = new Node('d'); l.addNode(d);
Node e = new Node('e'); l.addNode(e);
Node f = new Node('f'); l.addNode(f);
Node g = new Node('g'); l.addNode(g);
Node t = new Node('t'); l.addNode(t);
Edge bc = new Edge(b, c); l.addEdge(bc);
Edge bd = new Edge(b, d); l.addEdge(bd);
Edge be = new Edge(b, e); l.addEdge(be);
Edge cf = new Edge(c, f); l.addEdge(cf);
Edge df = new Edge(d, f); l.addEdge(df);
Edge dg = new Edge(d, g); l.addEdge(dg);
Edge eg = new Edge(e, g); l.addEdge(eg);
Edge ft = new Edge(f, t); l.addEdge(ft);
Edge gt = new Edge(g, t); l.addEdge(gt);
DAGraph dag = l.irreduciblesSubgraph();
dag.save("IrreducibleGraph.dot");
Context ctx = l.getTable();
ctx.save("IrreducibleGraph.txt");
```

Closure computations

- `joinClosure` method

First recall that any lattice L is isomorphic to the lattice obtained by replacing each node n of L by the node containing all join irreducible predecessors of n .

Given a lattice l , calling `l.joinClosure()`; returns this isomorphic lattice. Be careful of the fact that `joinClosure()` actually returns a `ConceptLattice`.

Using the previous example, you get :

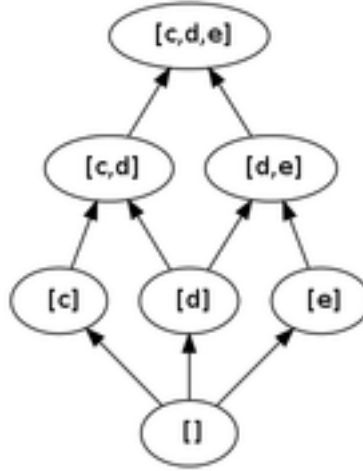


Figure 4: Join Closure

- `meetClosure` method

This is the dual of the previous method which is used in the same way.

From our example, `l.meetClosure()`; gives :

- `irreducibleClosure` method

This time, we get the two previous results in one `ConceptLattice`.

From our example, `l.irreducibleClosure()`; gives :

The full source code to get these computations is :

```
Lattice l = new Lattice();
Node b = new Node('b'); l.addNode(b);
Node c = new Node('c'); l.addNode(c);
Node d = new Node('d'); l.addNode(d);
Node e = new Node('e'); l.addNode(e);
Node f = new Node('f'); l.addNode(f);
Node g = new Node('g'); l.addNode(g);
Node t = new Node('t'); l.addNode(t);
Edge bc = new Edge(b, c); l.addEdge(bc);
```

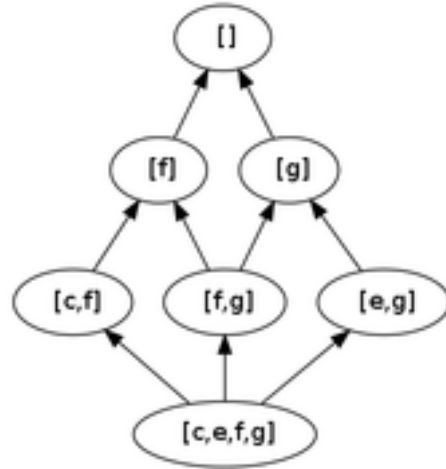



Figure 5: Meet Closure

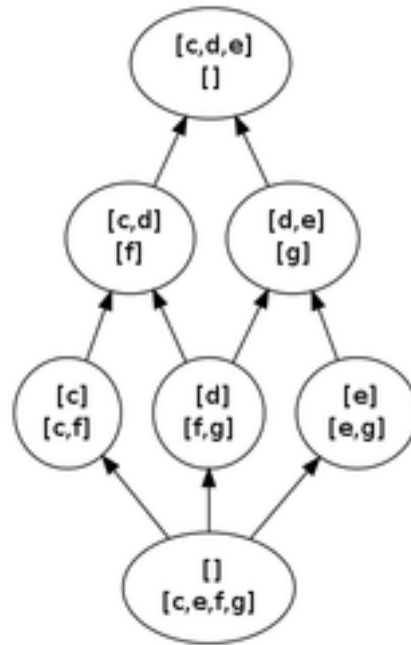


Figure 6: Irreducible Closure

```

Edge bd = new Edge(b, d); l.addEdge(bd);
Edge be = new Edge(b, e); l.addEdge(be);
Edge cf = new Edge(c, f); l.addEdge(cf);
Edge df = new Edge(d, f); l.addEdge(df);
Edge dg = new Edge(d, g); l.addEdge(dg);
Edge eg = new Edge(e, g); l.addEdge(eg);
Edge ft = new Edge(f, t); l.addEdge(ft);
Edge gt = new Edge(g, t); l.addEdge(gt);
ConceptLattice jc = l.joinClosure();
jc.save("JoinClosure.dot");
ConceptLattice mc = l.meetClosure();
mc.save("MeetClosure.dot");
ConceptLattice ic = l.irreducibleClosure();
ic.save("IrreducibleClosure.dot");

```

Implicational System computations

- getImplicationalSystem method

An implicational system of a lattice corresponds to the set of functional dependencies, a database notion, on join irreducibles of the lattice.

First recall our example :

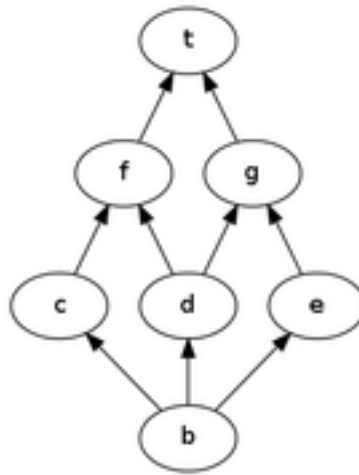


Figure 7: Example Lattice

Then take its join closure :

Thus, the only functional dependency you can get is :

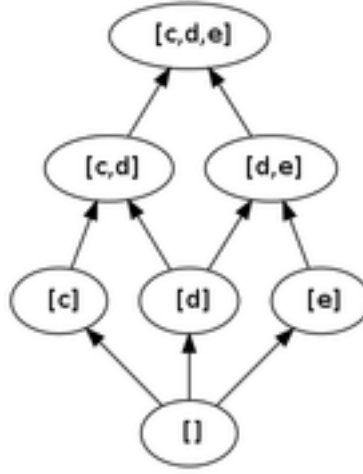


Figure 8: Join Closure

`c e -> d`

However, the `getImplicationalSystem` method returns a right maximal system. Then, the instruction `l.getImplicationalSystem()` returns :

`c d e`
`c e -> c d e`

- `getDependencyGraph` method

The dependency graph is a condensed representation of a lattice that encodes its minimal generators, and its canonical direct basis. In the dependency graph, nodes are join irreducibles, edges correspond to the dependency relation between join-irreducibles :

$j \rightarrowtail j'$ if and only if there exists a node x in the lattice such that x is not greater than j and j' , and $x \vee j' > j$

Edges are labeled with the smallest subsets X of join-irreducibles such that the join of elements of X corresponds to the node x of the lattice.

The dependency graph is generated in $\mathcal{O}(nj^3)$ where n is the number of nodes of the lattice, and j is the number of join-irreducibles of the lattice.

Going on with the same lattice, we get its dependency graph with `l.getDependencyGraph()` ;

- `getCanonicalDirectBasis` method

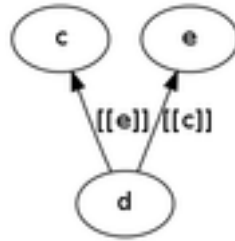


Figure 9: Dependency Graph

The canonical direct basis is a condensed representation of a lattice encoding by the dependency graph.

This canonical direct basis is deduced from the dependency graph of the lattice : for each edge *brightarrow* a valued by a subset X , the rule $a + X \rightarrow b$ is a rule of the canonical direct basis.

With our example, `l.getCanonicalDirectBasis()` gives :

```

c d e
c e -> d

```

;

- `getMinimalGenerators()` method

Minimal generators a condensed representation of a lattice encoding by the dependency graph.

Minimal generators are premises of the canonical direct basis that is deduced from the dependency graph of the lattice.

With our example, `l.getMinimalGenerators()` gives :

```
[[c,e]]
```

To conclude this section about implicationnal systems, here is the full source code to get these computations :

```

Lattice l = new Lattice();
Node b = new Node('b'); l.addNode(b);
Node c = new Node('c'); l.addNode(c);
Node d = new Node('d'); l.addNode(d);
Node e = new Node('e'); l.addNode(e);

```

```

Node f = new Node('f'); l.addNode(f);
Node g = new Node('g'); l.addNode(g);
Node t = new Node('t'); l.addNode(t);
Edge bc = new Edge(b, c); l.addEdge(bc);
Edge bd = new Edge(b, d); l.addEdge(bd);
Edge be = new Edge(b, e); l.addEdge(be);
Edge cf = new Edge(c, f); l.addEdge(cf);
Edge df = new Edge(d, f); l.addEdge(df);
Edge dg = new Edge(d, g); l.addEdge(dg);
Edge eg = new Edge(e, g); l.addEdge(eg);
Edge ft = new Edge(f, t); l.addEdge(ft);
Edge gt = new Edge(g, t); l.addEdge(gt);
ImplicationalSystem is = l.getImplicationalSystem();
is.save("ImplicationalSystem.txt");
DGraph dGraph = l.getDependencyGraph();
dGraph.save("DependencyGraph.dot");
ImplicationalSystem cdb = l.getCanonicalDirectBasis();
cdb.save("CanonicalDirectBasis.txt");

```

Arrow computations

First recall basic definitions about arrows in a lattice :

Let m and j be respectively meet and join irreducibles of a lattice l . Recall that m has a unique successor say m^+ and j has a unique predecessor say j^- , then :

- j “Up Arrow” m (stored has “Up”) iff j is not less or equal than m and j is less than m^+ .
- j “Down Arrow” m (stored has “Down”) iff j is not less or equal than m and j^- is less than m .
- j “Up Down Arrow” m (stored has “UpDown”) iff j “Up” m and j “Down” m .
- j “Cross” m (stored has “Cross”) iff j is less or equal than m .
- j “Circ” m (stored has “Circ”) iff neither j “Up” m nor j “Down” m nor j “Cross” m .

Given a lattice l , the instruction `l.getArrowRelation()`; returns a `DGraph` in which :

- Nodes are join or meet irreducibles of the lattice.

- Edges content encodes arrows as String “Up”, “Down”, “UpDown”, “Cross”, “Circ”.

Still using the same example, we get :

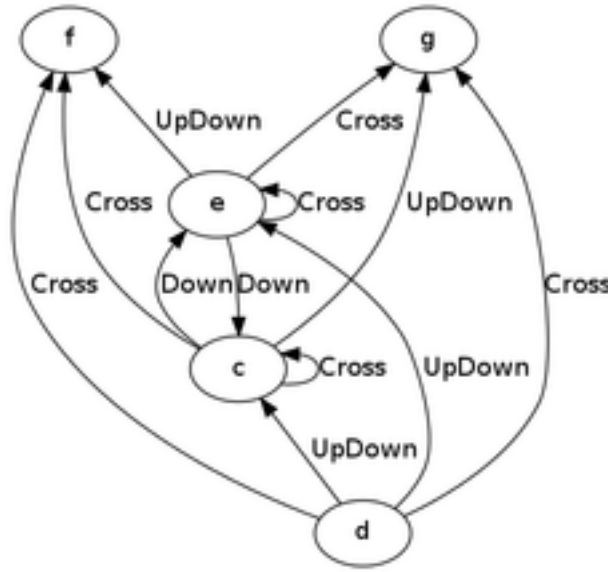


Figure 10: Arrow Relation

You can use the following source code to get these results :

```

Lattice l = new Lattice();
Node b = new Node('b'); l.addNode(b);
Node c = new Node('c'); l.addNode(c);
Node d = new Node('d'); l.addNode(d);
Node e = new Node('e'); l.addNode(e);
Node f = new Node('f'); l.addNode(f);
Node g = new Node('g'); l.addNode(g);
Node t = new Node('t'); l.addNode(t);
Edge bc = new Edge(b, c); l.addEdge(bc);
Edge bd = new Edge(b, d); l.addEdge(bd);
Edge be = new Edge(b, e); l.addEdge(be);
Edge cf = new Edge(c, f); l.addEdge(cf);
Edge df = new Edge(d, f); l.addEdge(df);
Edge dg = new Edge(d, g); l.addEdge(dg);
Edge eg = new Edge(e, g); l.addEdge(eg);
Edge ft = new Edge(f, t); l.addEdge(ft);
Edge gt = new Edge(g, t); l.addEdge(gt);

```

```
ArrowRelation ar = l.getArrowRelation();
DGraph dar = new DGraph((DGraph) ar);
dar.save("TutoArrowRelation.dot");
```

ConceptLattice

Creating a concept lattice

Using the `ConceptLattice` class, it is easy to create a concept lattice from any closure system, e.g. an implicationnal system or a context.

From a context

For instance, it is possible to use one of the `cxt` file from examples, in the following manner :

```
Context ctx = new Context("tealady.cxt");
ConceptLattice cl = ConceptLattice.completeLattice(ctx);
```

From an implicationnal system

For instance, it is possible to use the `random` method, in the following manner :

```
ImplicationalSystem is = ImplicationalSystem.random(5, 10);
ConceptLattice cl = ConceptLattice.completeLattice(is);
```

Computations from Lattice class

The `ConceptLattice` is inherited from the `Lattice` class, thus it is possible to use the following methods with a concept lattice.

BijectiveComponent