TECHNISCHE UNIVERSITÄT DRESDEN

Fakultät Informatik, Institut für Software- und Multimediatechnik, Lehrstuhl für Softwaretechnologie

24) Decision Analysis (Condition-Action and Event-Condition-Action Analysis)

Prof. Dr. U. Aßmann
Technische Universität Dresden
Institut für Software- und Multimediatechnik
Gruppe Softwaretechnologie
http://st.inf.tu-dresden.de

Version 11-1.1, 04.01.12

1. Structured decisions: decision diagrams and decision tables)
2. Binary decision diagrams (BDD) And Ordered BDD
3. Model Checking
4. Event-Condition Action Design

Obligatory Reading

- Balzert, Kapitel über Entscheidungstabellen
- Ghezzi 6.3 Decision-table based testing
- Pfleeger 4.4, 5.6
- Randal E. Bryant. Graph-based algorithms for Boolean function manipulation. IEEE Transactions on Computers, C-35:677-691, 1986.
- Red Hat. JBoss Enterprise BRMS Platform 5: JBoss Rules 5 Reference Guide. (lots of examples for ECA Drools)
  - http://docs.redhat.com/docs/en-US/JBoss_Enterprise_BRMS_Platform/5/pdf/JBoss_Rules_5_Reference_Guide/JBoss_Enterprise_BRMS_Platform-5-JBoss_Rules_5_Reference_Guide-en-US.pdf

References

- Decision algebra:
  - Danylenko, Antonina, Lundberg, Jonas, Löwe, Welf. Decisions: Algebra and Implementation. In Machine Learning and Data Mining in Pattern Recognition. Perner, Petra(ed.) Lecture Notes in Computer Science, 6871, Springer 2011. http://dx.doi.org/10.1007/978-3-642-23199-5_3
- ECA state of the art
  - REWERSE-DEL-2004-I5-D1
    José Júlio Alferes, James Bailey, Mikael Berndtsson, François Bry, Jens Dietrich, Alex Kozlenkov, Wolfgang May, Paula-Lavinia Pătrânjan, Alexandre Miguel Pinto, Michael Schroeder, and Gerd Wagner:
    Wolfgang May (editor): *State-of-the-art on evolution and reactivity.*
    http://rewerse.net/publications/rewerse-publications.html#REWERSE-DEL-2004-I5-D1
  - http://en.wikipedia.org/wiki/Complex_event_processing
- ECA Engines
  - Websphere Jrules engine
    http://www-01.ibm.com/software/integration/business-rule-management/decision-server/
  - JBOSS Rules http://www.jboss.org/drools
  - http://docs.redhat.com/docs/de-DE/JBoss_Enterprise_BRMS_Platform/index.html

Goal

- **Decision analysis** (Condition analysis) is a very important method to analyze complex decisions
  - Understand that several views on a decision tree exist (tables, BDD, OBDD)
- **Condition-action analysis** can also be employed for requirements analysis
  - Understand how to describe the control-flow of methods and procedures and their actions on the state of a program
- **Event-condition-action-based design (ECA-based design)** relies on condition-action analysis
- Understand that model checking is a technology with future

24.1 DECISION ANALYSIS WITH DECISION TREES AND TABLES (CONDITION-ACTION ANALYSIS)

A House-Selling Expert System

- *Ok, I do not like bungalows, but my wife does not like that the car stands in free space in winter. Hmm... I rather would like to have the half double house... But we need anyway 2 floors, because I need this space for my hobbies. My wife also would like a garden....*
- How does the system analyze the customers requirements and derive appropriate proposals?

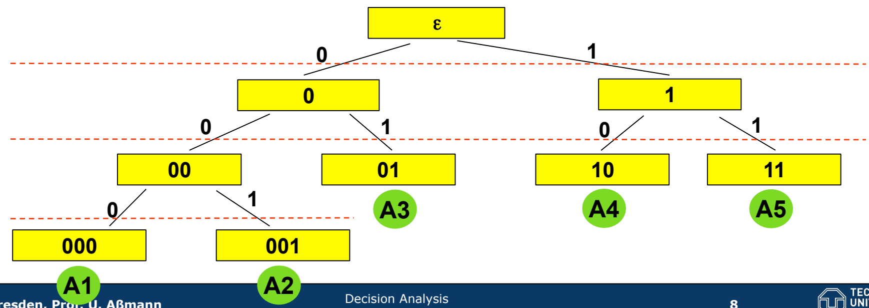
Decision Analysis (Condition-Action Analysis)

- **Decision analysis** is necessary when complex, intertwined decisions should be made
  - In requirements analysis and elicitation
  - In complex business cases, described with business rules
  - In testing, for specification of complex test cases
- Decision analysis can be made in a **decision algebra**
  - Boolean functions and their representations:
    - Truth tables, decision trees, BDD, OBDD
    - Decision tables
  - Static single assigment form (SSA) (not treated here)
  - Lattice theory, such as formal concept analysis (FCA) (not treated here)
- Decision trees and tables collect actions based on conditions
- Condition action analysis is a decision analysis that results in actions
  - A simple form of event-condition-action (ECA) rules
  - However, without events, only conditions

Which conditions provoke which actions?

Decision Trees

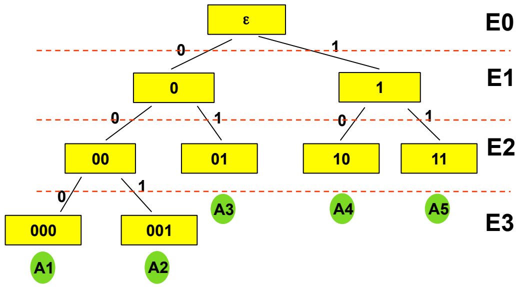
- Decisions can be analyzed with a *decision tree*, a simple form of a decision algebra
- A trie (Präfixbaum) is a tree which has an edge marking
  - Every path in the trie assembles a word from a language of the marking
- A trie on IB = {0,1} is called ***decision tree***
  - Paths denote sequences of decisions (a set of vectors over IB). A path corresponds to a vector over IB
  - A set of actions, each for one sequence of decisions
  - Sequences of decisions can be represented in a path in the decision tree



Decision Trees with Code Actions

- The action may be code
- The inner nodes of same tree layer correspond to a condition E[i]
- Then, a Trie is isomorphic to an If-then-else cascade

```
if (E0) then // case E0 === true
if (E1) then
if(E2) then        A5
else                     A4
else // case E0 === false
if (E1) then
if(E2) then        A3
else
if (E3) then       A2
else               A1
```



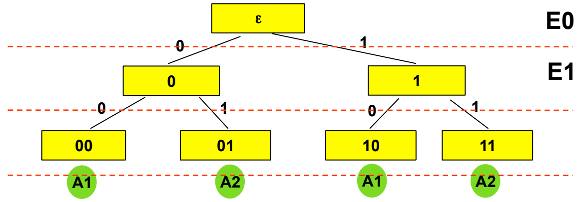
Decision Tables

- An alternative representation of decision trees are **decision tables**
- Conditions and actions can be entered in a table

Condition E0	yes	yes	no	no
Condition E1	yes	no	yes	no
Action A1		X		X
Action A2	X		X	

Boolean cross product

Multiple choice quadrant



How to Construct A Decision Table

1) Elaborate decisions
2) Elaborate actions
3) Enter into table
4) Construct a cross boolean product as upper right quadrant (set of boolean vectors)
5) Construct a multiple choice quadrant (lower right) by associating actions to boolean vectors
6) Consolidate
   - Coalesce yes/no to "doesn't matter"
   - Introduce Else rule

What Students Should Do to Professors After Exams

Points <= 30	yes	yes	yes	yes	No	No	No	no
50 < Points	yes	yes	no	no	yes	yes	no	no
St. Francophil?	yes	no	yes	no	yes	no	yes	No
Student pays a Bordeaux			X				X	
Professor pays a Bordeaux					X			
Professor pays a beer						X		
Student pays a beer				X				
Professor drinks a beer	X	X						X

Common Columns Can Be Folded

Points <= 30	yes	-	yes	no	no	no
50 < Points	yes	no	no	yes	yes	no
St. Francophil?	-	yes	no	yes	no	no
Student pays a Bordeaux		X				
Professor pays a Bordeaux				X		
Professor pays a beer					X	
Student pays a beer			X			
Professor drinks a beer	X					X

Or Abbreviated to Else Action (Consolidated Decision Table)

Points <= 30	-	yes	No	No	Else
50 < Points	no	no	yes	yes	
Francophil?	yes	no	yes	no	
Student pays a Bordeaux	X				
Professor pays a Bordeaux			X		
Professor pays a beer				X	
Student pays a beer		X			
Professor drinks a beer					X

Applications of Decision Tables and Trees

- Requirements analysis
  - Deciding (decision analysis, case analysis)
  - Complex case distinctions (more than 2 decisions)
- Design:
  - Describing the behavior of methods
  - Describing business rules
    - Before programming if-cascades, better make first a nice decision tree or table
  - Formal design methods
  - CASE tools can generate code automatically
- Configuration management of product families
  - Decisions correspond here to configuration variants
  - Processor=i486?
  - System=linux?
  - Same application as #ifdefs in C preprocessor

24.2 NORMALIZING CONTROL FLOW WITH NORMALIZED BDD

Truth Tables

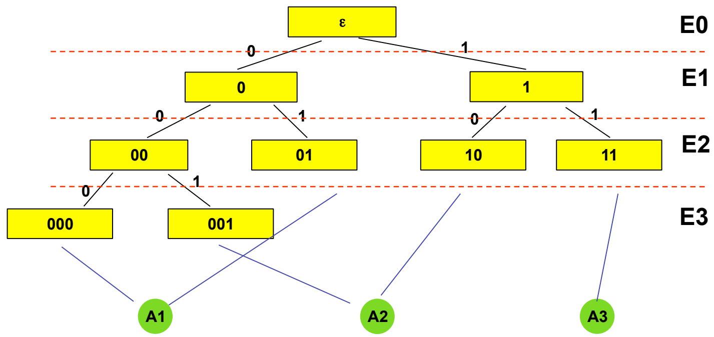
- With action = {true, false}, boolean decision tables are truth tables

Condition E0	Yes	Yes	No	No
Condition E1	Yes	No	Yes	No
Value of F = 0	X		X	
Value of F = 1		X		X

E0	E1	F
Yes	Yes	0
Yes	No	1
No	Yes	0
No	No	1

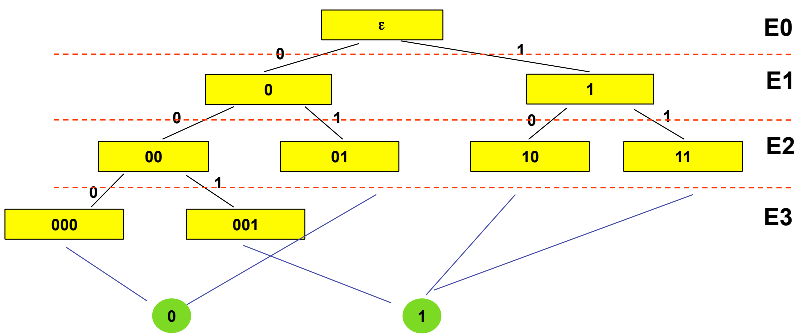
BDDs (Binary Decision Diagrams)

- BDD are dags that result by merging the same subtrees of a decision tree into one (common subtree elimination)



BDDs (Binary Decision Diagrams)

- If the action is just a boolean value boolean functions f: IB^n --> IB can be represented
- The decisions E[i] are regarded as boolean variables

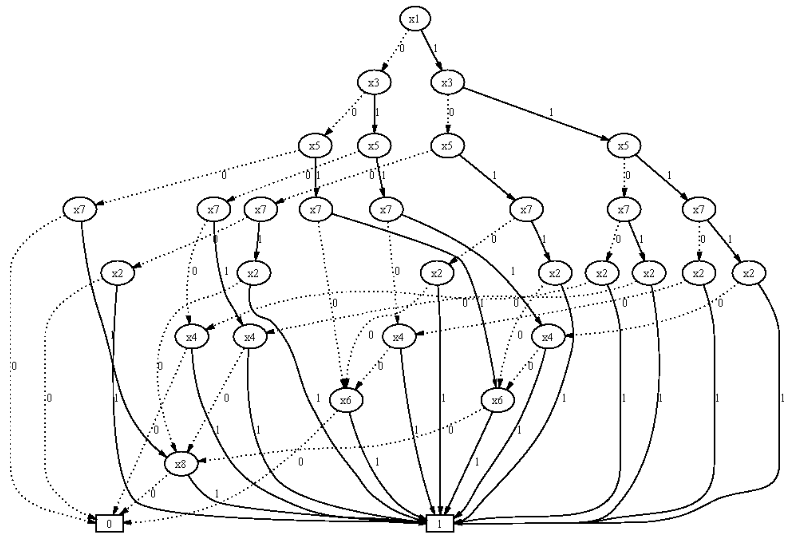


OBDDs (Ordered Binary Decision Diagrams)

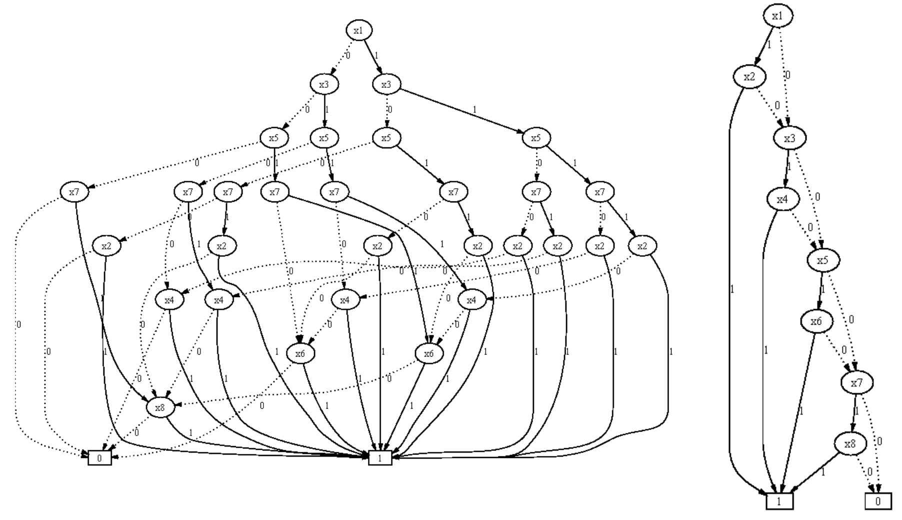
- Problem: for one boolean function there are many BDD
  - Idea: introduce a standardized order for the variables
  - Result: orderd binary decision diagrams
- In all OBDD holds
  - for all children u of parents v ord(u) > ord(v).
- For one order of variables there is one normal form OBDD (canonical OBDD)
- Leads to an efficient **BDD-based comparison algorithm of boolean functions**:

```
compareBooleanFunction() = {
   Fix variable order for two BDD
   Transform both BDD into OBDD
   Compare both OBDD syntactically
}
```

Complex BDD

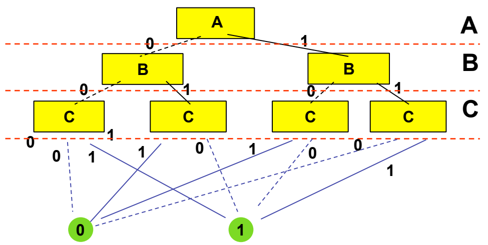


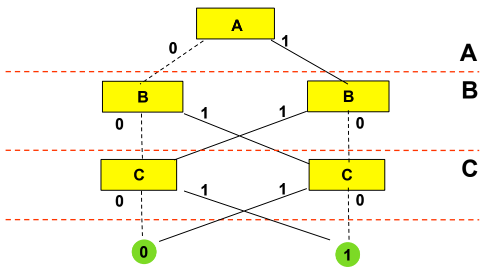
The Influence of Variable Ordering



If-cascades, BDD and OBDD

if A then
  if B then
    if C then true else false
  else
    if C then false else true
else
  if B then
    if C then false else true
  else
    if C then true else false





Variable order is [A,B,C]

Normalizing Wild Procedures: Normalized If-Structures with OBDD

- There is only one canonical OBDD for one order
- Develop *normalized and factorized* if-structures with it:
  1. Elaborate arbitrary decision tree
  2. Choose a variable order
  3. Transform to OBDD
  4. Transform to If structure
  5. Factor out common subtrees by subprograms

Acyclic control flow can be represented canonically by an OBDD

- Reengineering
  - Structuring of legacy procedures: read in control-flow; construct control-flow graph
  - Produce a canonical OBDD for all acyclic parts of control-flow graph
  - Pretty-print again
  - Or: produce a statechart
- Configuration management
  - Development of canonical versions of C preprocessor nestings
- Help to master large systems

24.3 MODEL CHECKING LARGE STATE SPACES

Many mathematical data types can be represented with decision algebras (most efficiently with BDD/OBDD):

- Functions over finite domains of size n [Bryant86]
  - Associate to every element a vector from IB^k, where k = ld n
  - Code sets with sets of such vectors
  - Map again to boolean algebra
- Sets, partial orders and lattices (e.g., in Z, VDM, SETL)
  - Represent subsets of a set in the powerset lattice of the set
  - Map the powerset lattice to a boolean algebra (theorem of Stone)
  - Use a BDD to encode the sets
  - Uniform efficient representation in space and time
- Relations and graphs
  - Interprete the elements of the relation (the edges) as sets of ordered k-tuples
  - Represent as in the case of sets
- State machines
  - Data-flow graphs
- Propositional logic formulas

- BDD and OBDD are very compact representation for state machines, boolean functions, predicate logic, and modal logic
- Build a basis for checking state transition systems with modal logic (model checking)
  - System is modeled as a state transition system and encoded as OBDD
  - Features of the system (predicates, logic formulas) are encoded as OBDD, too
  - Important: System **and** predicates to be checked are both encoded as OBDD
- Model checking:
  - Then, a model checker compares the OBDDs and checks whether a feature holds in a state
  - Effectively, the model checker only compares normalized representations of boolean functions, the OBDD

The Use of Model Checking

- State spaces up to 2**120 can be handled
- Model checking checks whether features hold in states of large state spaces
  - Used in hardware verification
    - Proving circuits correct
  - Software verification
    - Safety-critical systems
    - Minimization of boolean circuits
- Very important technique for verification of safety-critical hard- and software

24.4 EVENT-CONDITION-ACTION BASED DESIGN (ECA)

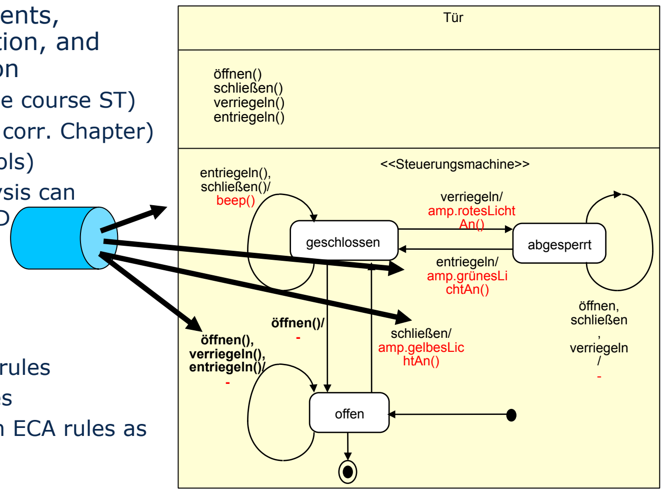
Event-Condition-Action Design

- Decision analysis is invoked when events occur
- Event-condition-action (ECA) based design uses
  - ECA rules with condition-action analysis
  - Complex event processing (CEP) for recognition of complex events

Given some (complex) events, which conditions provoke which actions?

ECA with State-Based Specifications

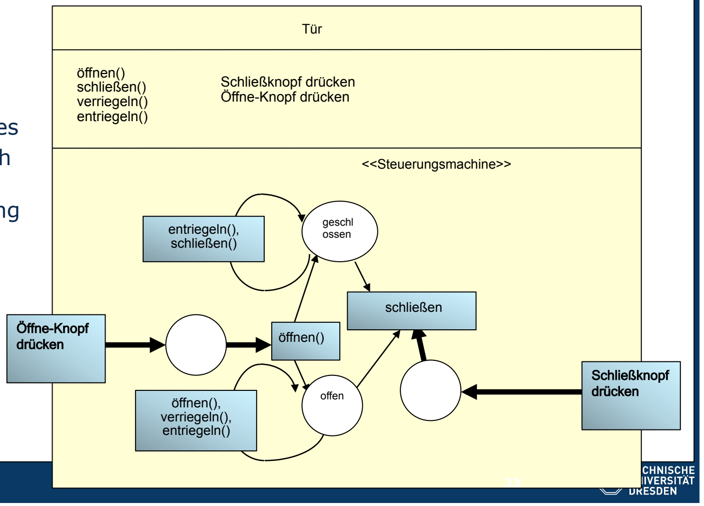
- An event-condition-action (ECA) system listens on channel(s) for events, analyses a condition, and executes an action
  - Statecharts (see course ST)
  - Petri Nets (see corr. Chapter)
  - ECA rules (Drools)
  - Condition analysis can be done by BDD
  - Verification by model checking
- Process:
  - Collect all ECA rules
  - Collect all states
  - Link states with ECA rules as transitions



ECA with Petri Nets

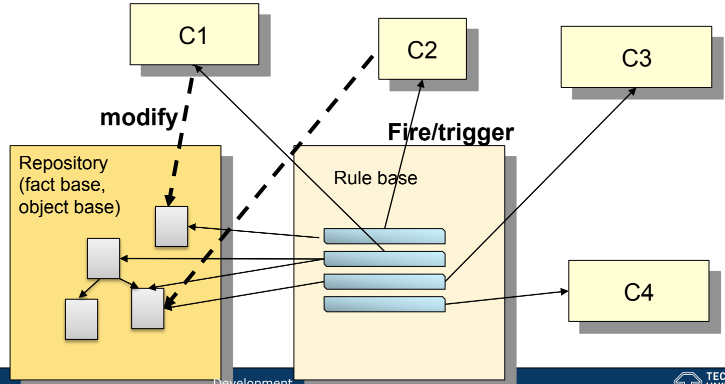
- In a Petri Net, an **event-generating channel** is a transition with fan-in=0
- Listening to the events, the Petri Net can do condition-action analysis

- Process:
  - Collect all ECA rules
  - Collect all states
  - Link states with ECA rules as subnets reacting on event-generating channels



ECA-based Blackboard Style

- The ECA-blackboard has two repositories: a fact/object base and a rule base
- The **rule base** is an active repository (i.e., an active component) that coordinates all other components
  - It investigates the state of the repository. If an event has occured by entering something in the repository (modify), components are fired/ triggered to work on or modify the repository



JBOSS ECA Rule Engine

- Drools (.drl-files) is an active repository with ECA rule processing
- Ex. Fire Alarm Rules [JRules]:

```
rule "Status output when things are ok"
when
  not Alarm()
  not Sprinkler( on == true )
then
  System.out.println( "Everything is ok" );
end

rule "Raise the alarm when we have one or more fires"
when
  exists Fire() // tests whether a Fire object exists
then
  insert( new Alarm() );
  System.out.println( "Raise the alarm" );
end
```


Ex. Fire Alarm

- Create a blackboard and fill the object base

```
// make a new blackboard
KnowledgeBuilder kbuilder = KnowledgeBuilderFactory.newKnowledgeBuilder();
// add a .drl-file to the rule base
kbuilder.add( ResourceFactory.newClassPathResource( "fireAlarm.drl",
     getClass() ), ResourceType.DRL );
if ( kbuilder.hasErrors() )
  System.err.println( kbuilder.getErrors().toString() );
// open a session with the blackboard
StatefulKnowledgeSession ksession = kbase.newStatefulKnowledgeSession();

// allocate objects in the object/fact base
String[] names = new String[]{"kitchen","bedroom","office","livingroom"};
Map<String,Room> name2room = new HashMap<String,Room>();
for( String name: names ) {
  Room room = new Room( name ); name2room.put( name, room );
  ksession.insert( room );
  Sprinkler sprinkler = new Sprinkler( room ); ksession.insert( sprinkler );
}
ksession.fireAllRules();
```

```
// output>> "Everything is ok"
```

- Raise fire by inserting a Fire object into the object base

```
Fire kitchenFire = new Fire( name2room.get( "kitchen" ) );
Fire officeFire = new Fire( name2room.get( "office" ) );

// insert into the session
FactHandle kitchenFireHandle = ksession.insert( kitchenFire );
FactHandle officeFireHandle = ksession.insert( officeFire );

// investigate:
ksession.fireAllRules();
```

```
// output>> "Raise the alarm"
```


The End: What Have We Learned

- Decision analysis (Condition-Action analysis) is an important analysis
  - to describe requirements,
  - to describe complex behavior of a procedure
- Decision analysis must be encoded in a decision algebra
  - Boolean functions, decision trees, relations, graphs, automata can be encoded in OBDD
  - The control-flow of a procedure can be normalized with a BDD and OBDD
  - Conditions in large state spaces can be encoded in OBDD and efficiently checked
- ECA-based design reacts on events and conditions with actions