TECHNISCHE UNIVERSITÄT DRESDEN

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

24) Event-Condition-Action Design and Conditions Analysis

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1. **Structured decisions: decision diagrams and decision tables)**
2. **Binary decision diagrams (BDD) And Ordered BDD**
   1. **Model Checking**
3. **Variability of CA**
4. **Event-Condition Action Design**
5. **Extensibility of ECA**

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?

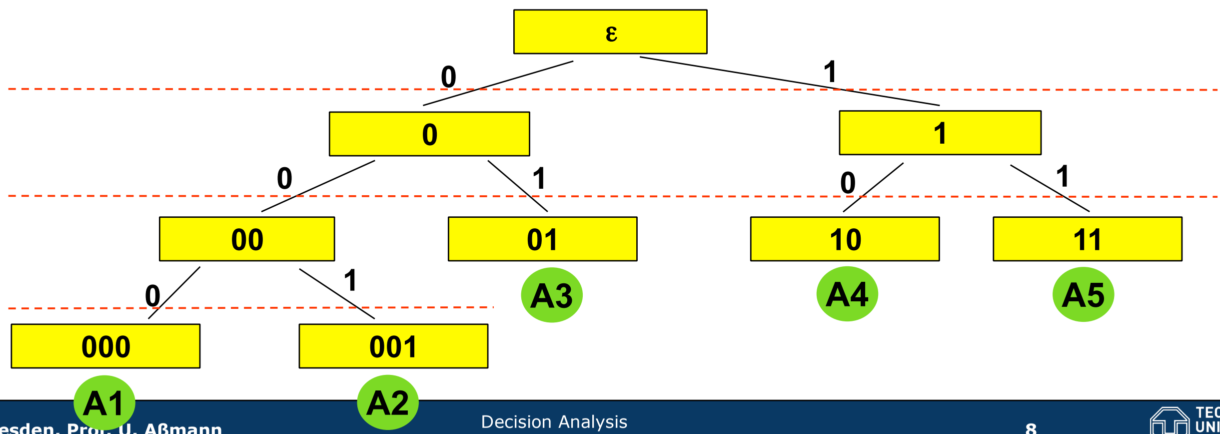
Decision Analysis (Condition-Action Analysis)

- **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

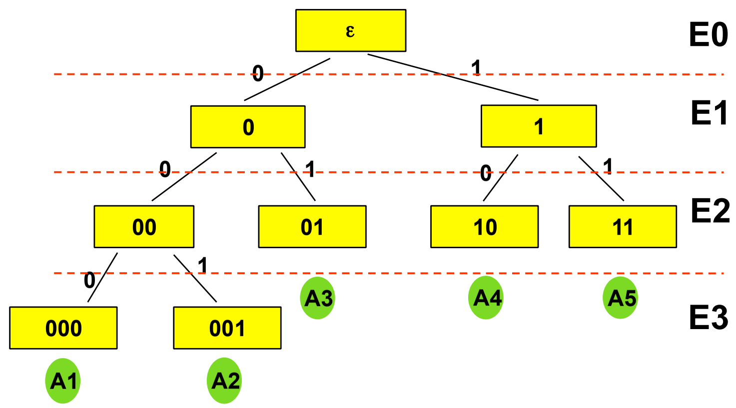
- Decisions can be analyzed with a ***decision tree***, a simple form of a decision algebra
- A trie (Präfixbaum) is a tree which has an edge marking
  - Every path in the trie assembles a word from a language of the marking
- A trie on IB = {0,1} is called ***decision tree***
  - Paths denote sequences 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
```



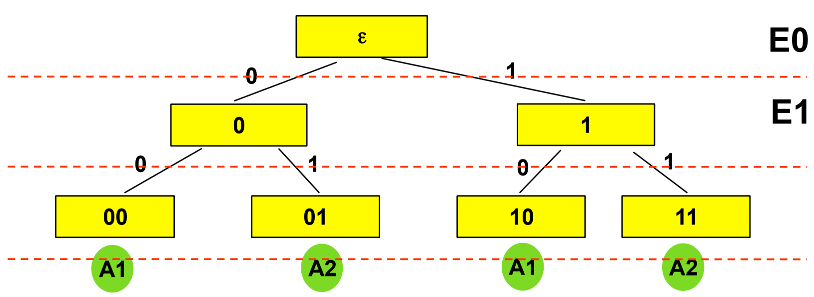
Decision Tables

- 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

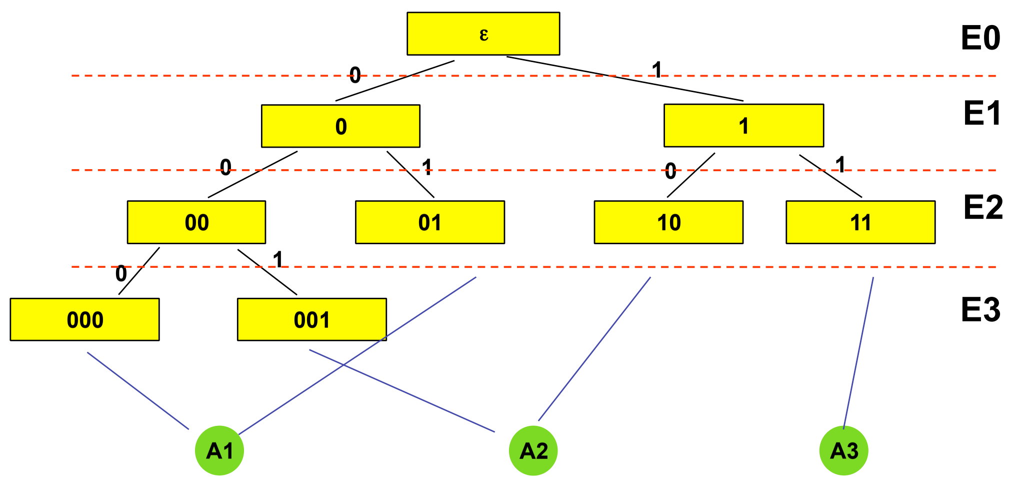
- With action = {true, false}, boolean decision tables are truth tables

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

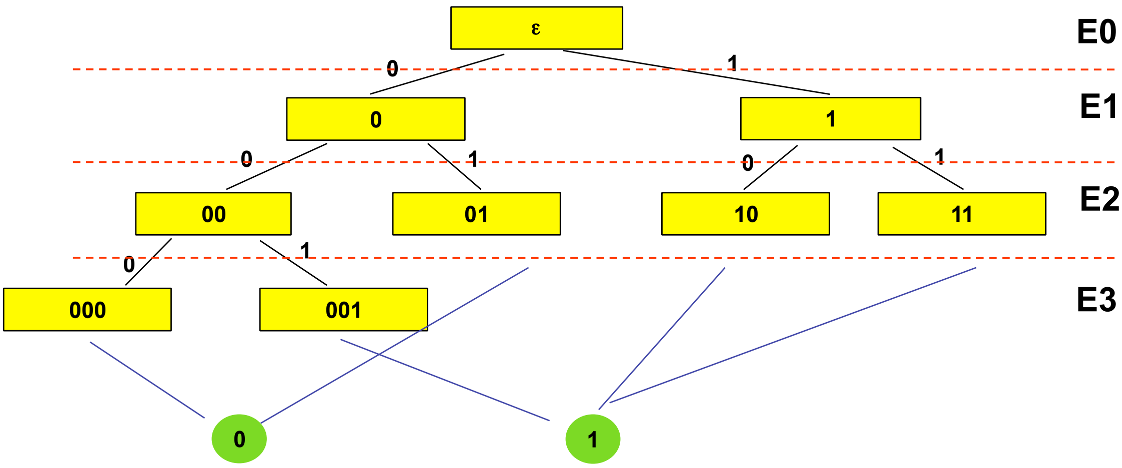
BDDs (Binary Decision Diagrams)

- 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

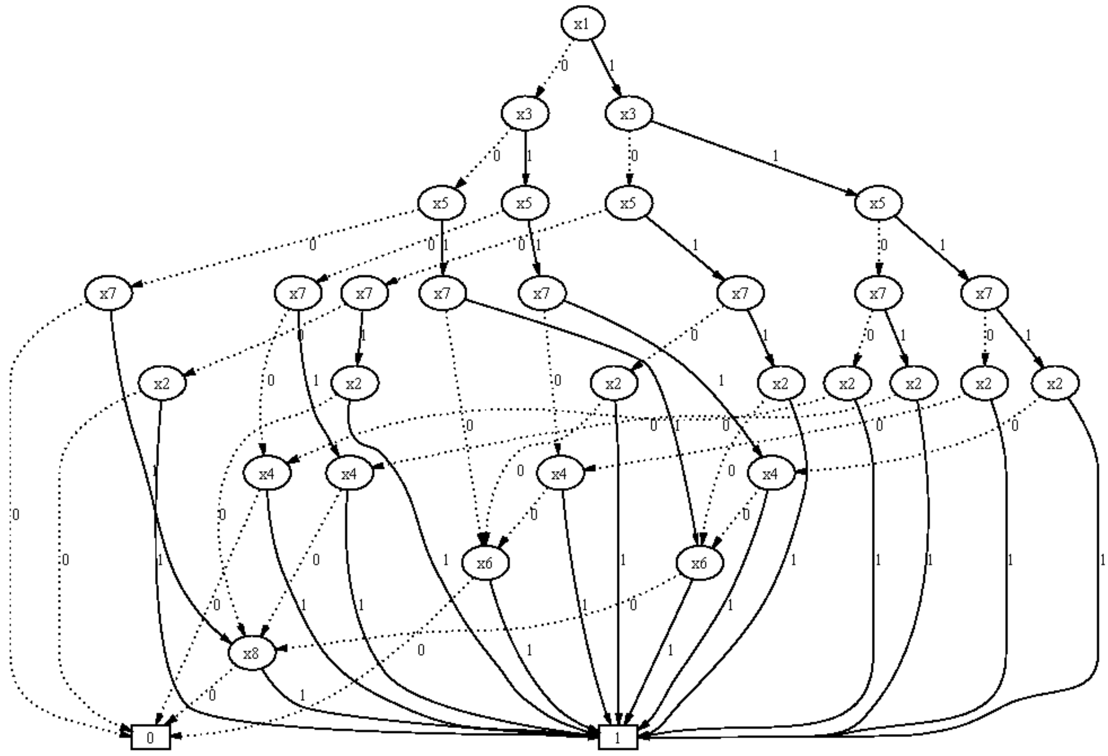


OBDDs (Ordered Binary Decision Diagrams)

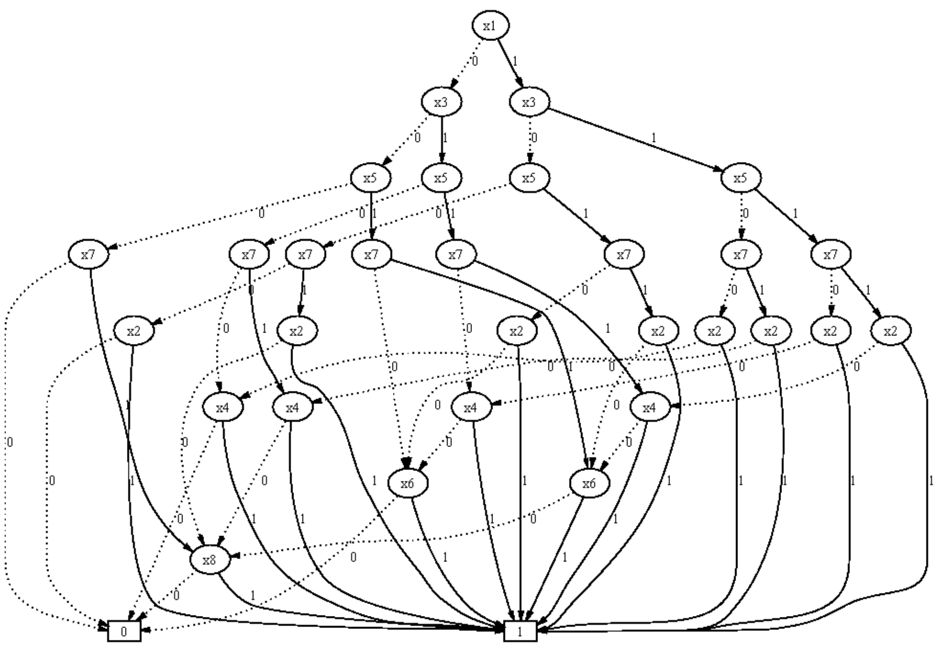
- Problem: for one boolean function there are many BDD
  - Idea: introduce a standardized order for the variables
  - Result: orderd binary decision diagrams
- In all OBDD holds
  - for all children u of parents v ord(u) > ord(v).
- For one order of variables there is one normal form OBDD (canonical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

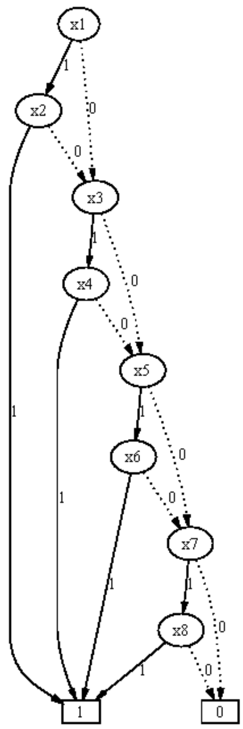
```
compareBooleanFunction() = {
   Fix variable order for two BDD
   Transform both BDD into OBDD
   Compare both OBDD syntactically
}
```

Complex BDD



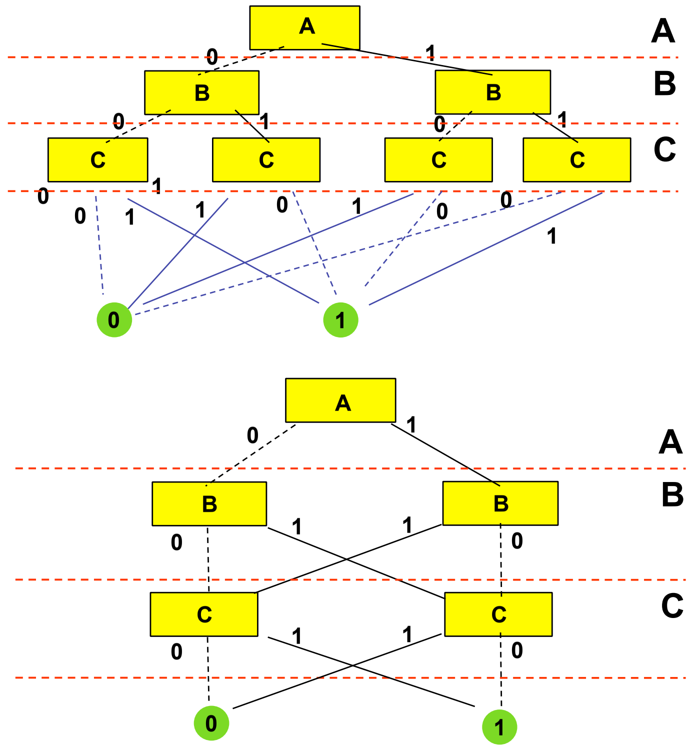
The Influence of Variable Ordering





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

Applications

- 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

24.2.2 MODEL CHECKING LARGE STATE SPACES

Representation of Mathematical Structures in Decision Algebras (BDD and OBDD)

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

Model Checking on BDD

- 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

24.3 VARIABILITY OF CA RULES

Variability

- Variability means that actions are exchanged for boolean combinations

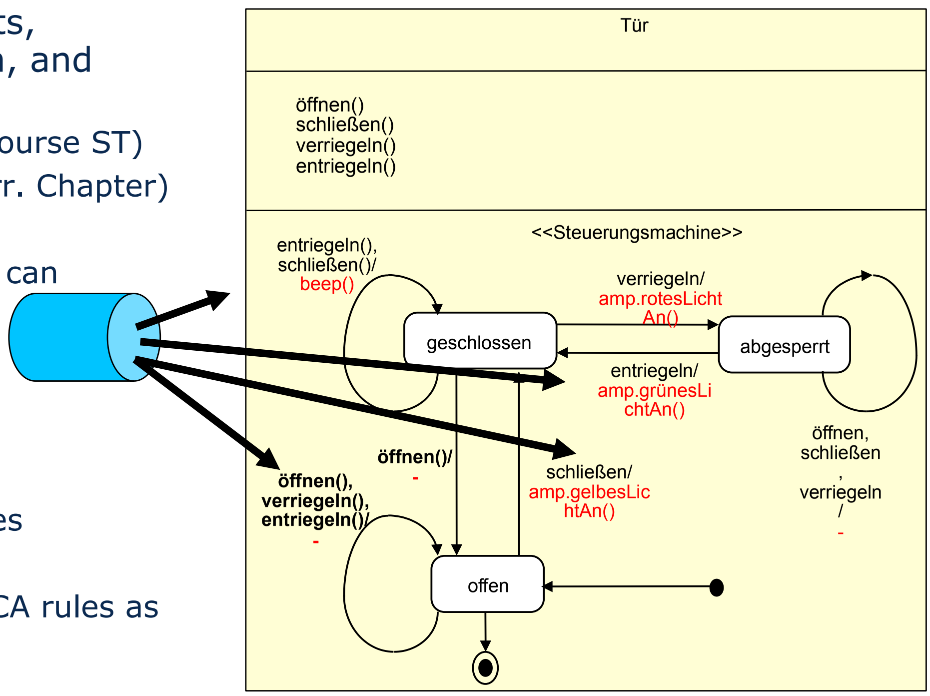
Variability is simple in CA-Systems

24.4 EVENT-CONDITION-ACTION BASED DESIGN (ECA)

- 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

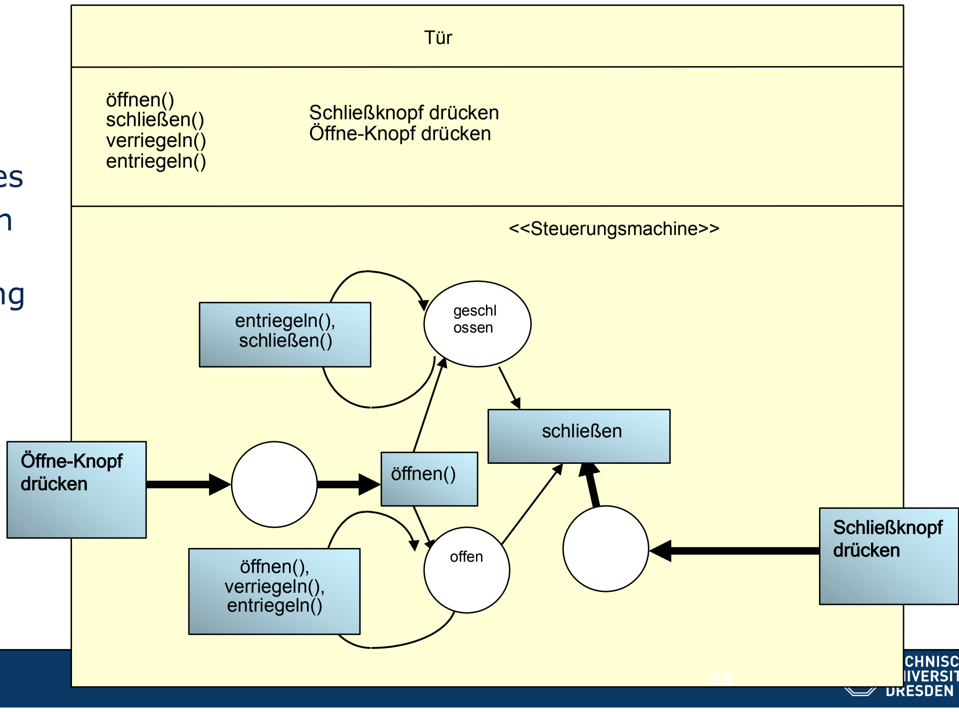
Given some (complex) events, which conditions provoke which actions?

- 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



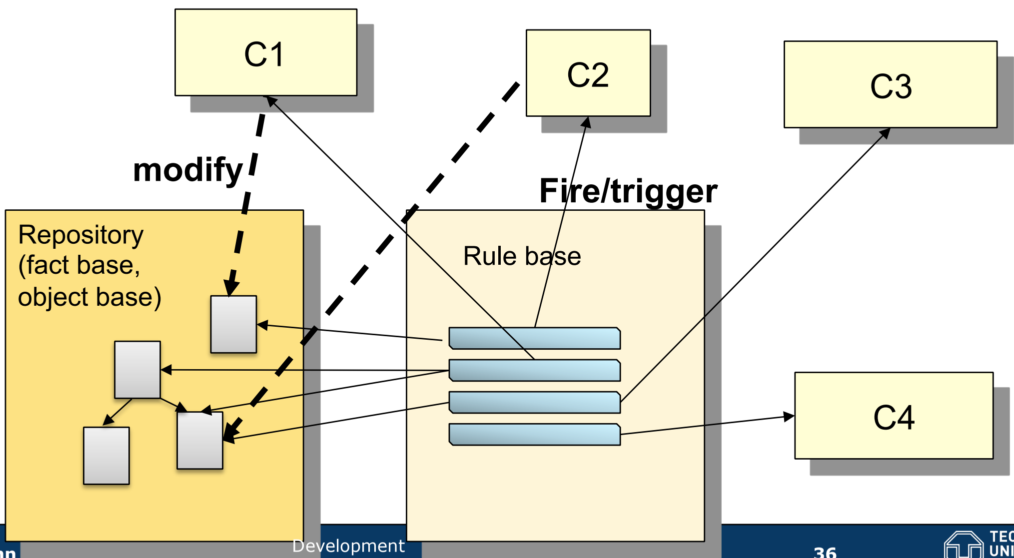
ECA with Petri Nets

- 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"
```


24.5 EXTENSIBILITY OF ECA RULES

Extensibility of ECA Rule Systems

- Extensibility means to add more ECA rules
- Rules are open constructs
- Problem: new rules should be conflict-free with the old rules
- Harmless extension is usually not provable
- In general, contracts of the old system cannot be retained

ECA-Systems are extensible, but harmlessness of extensions are hard to prove

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