
TÁMOP-4.2.2.C-11/1/KONV-2012-0004

National Research Center for Development and Market Introduction of Advanced Information and Communication Technologies

# SYNCHRONOUS PRODUCT GENERATION FOR CONTROLLER OPTIMIZATION

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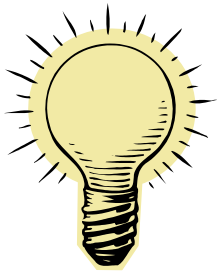
# SCOPE

- **Authors come from *model checking***
  - Qualitative verification of large models
  - Special techniques to handle complex systems
- **Similar problems in controller optimization**
  - Similarities between controlled systems and LTL model checking
  - Quantitative aspects appear



**Can our techniques be used here?**

# OUTLINE

- **Motivation**
- **Symbolic techniques**
  - Decision diagrams
  - Saturation
- **Synchronous product generation**
  - Symbolic encoding
  - Using saturation

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- **Possible applications**
  - Reachability
  - Cheapest path
- **Other useful model checking techniques**
  - Temporal logics
  - Cheapest (counter)example

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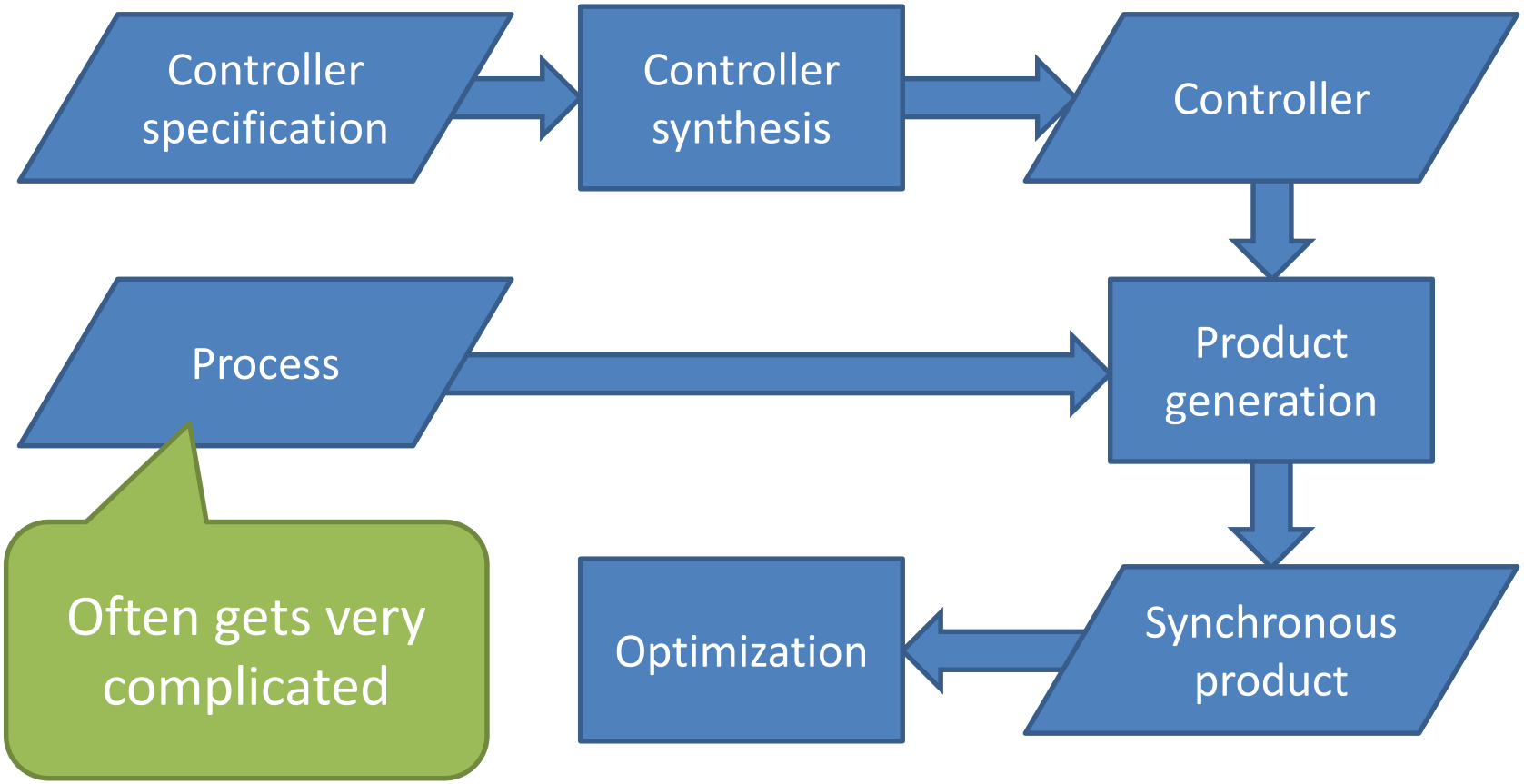
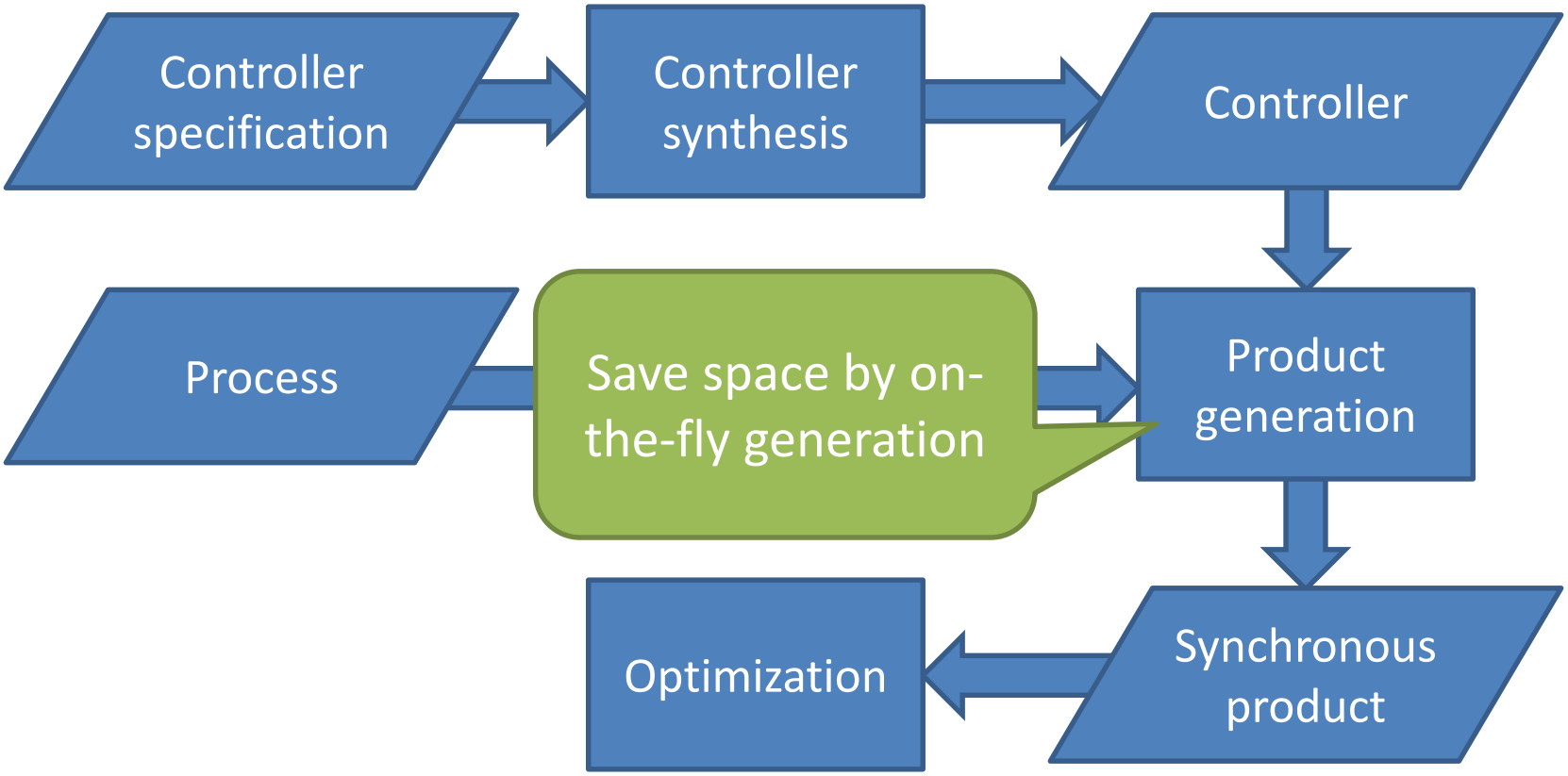
# MOTIVATION


Controller specification
Controller synthesis
Controller
Process
Product generation
Often gets very complicated
Optimization
Synchronous product

# MOTIVATION


Controller specification
Controller synthesis
Controller
Process
Save space by on-the-fly generation
Product generation
Optimization
Synchronous product

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# MULTI-VALUED DECISION DIAGRAM

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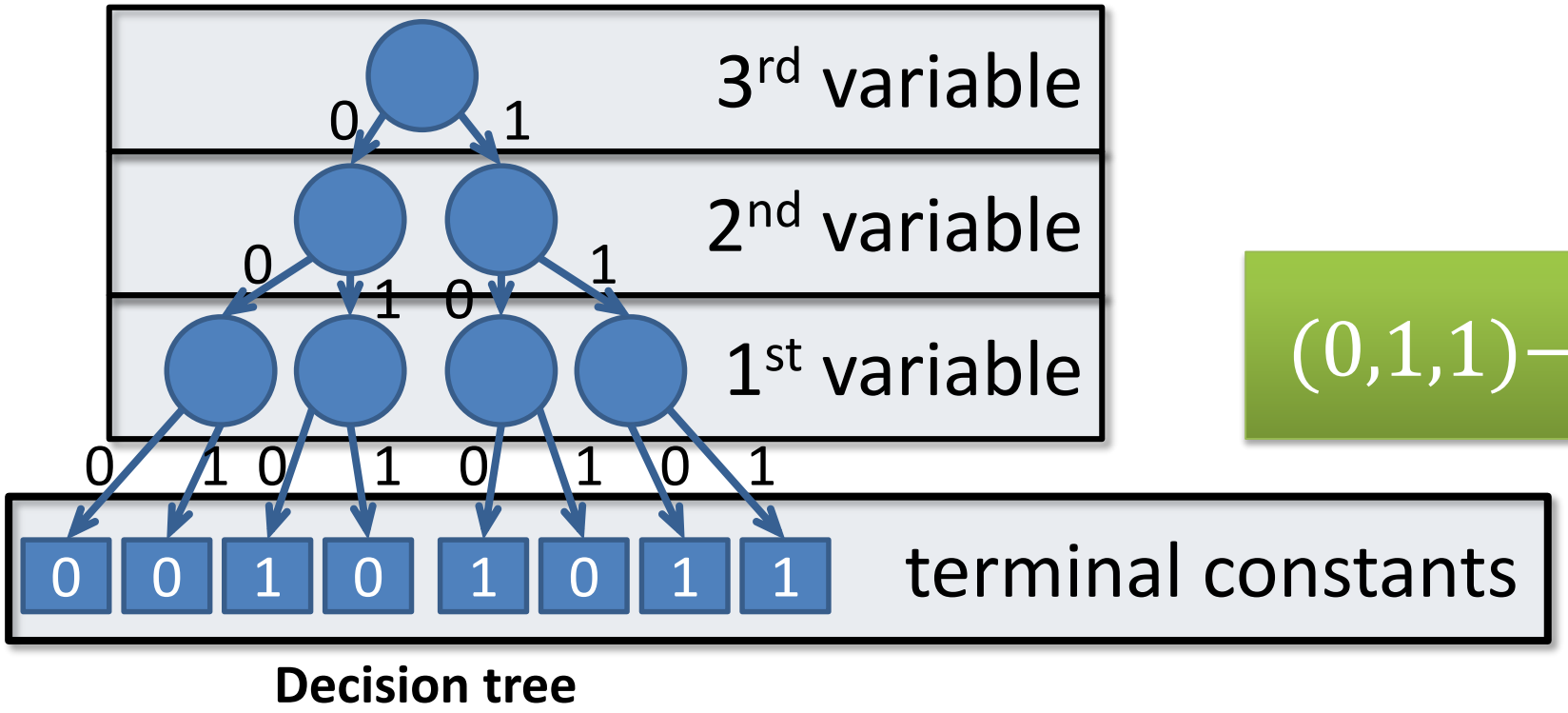
- **Derived from decision trees**
  - variables are ordered into levels




$(0,1,1) \rightarrow 1$

# MULTI-VALUED DECISION DIAGRAM

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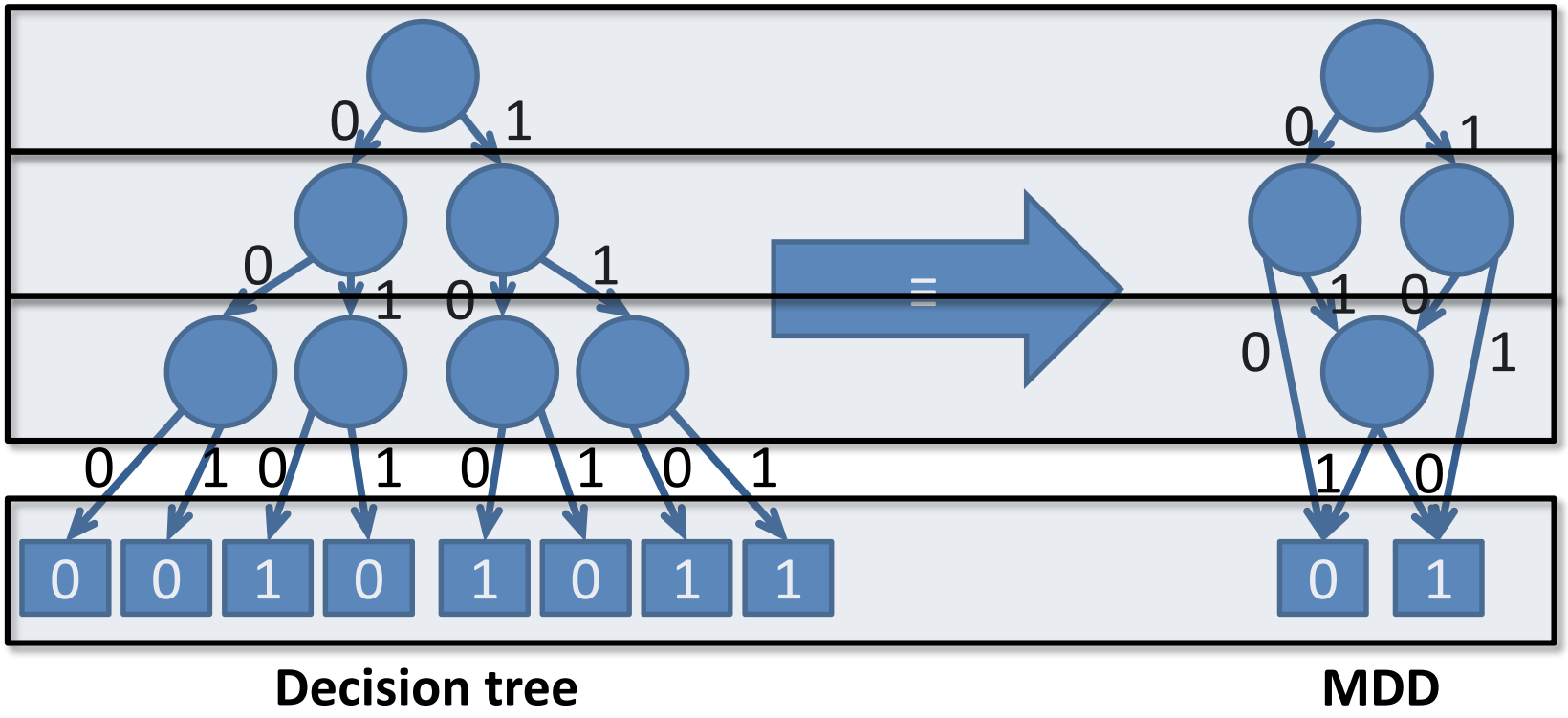
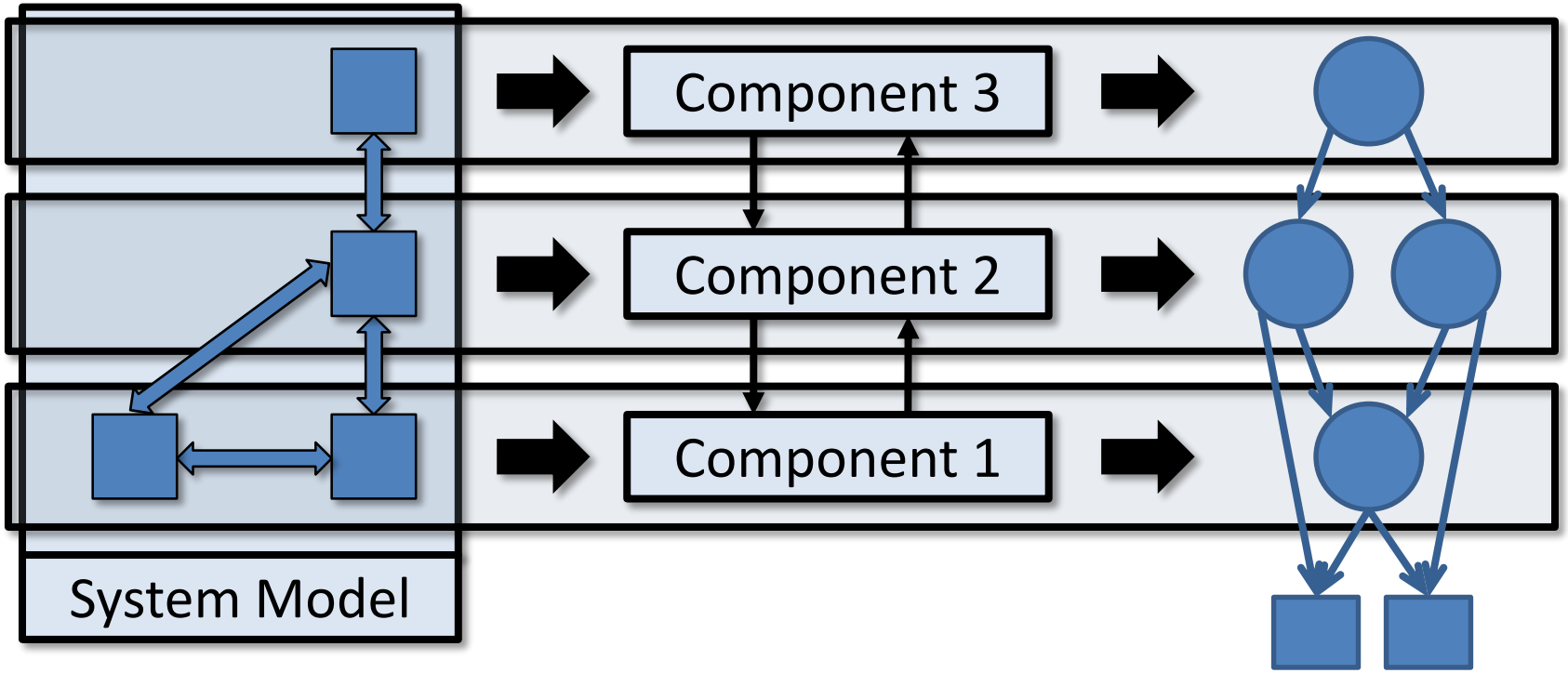
- **Derived from decision trees**
  - variables are ordered into levels
- **Special reduction rules**
  - in a bottom-up fashion, applying reduction from level-to-levels
- **Compact representation of multi valued functions**



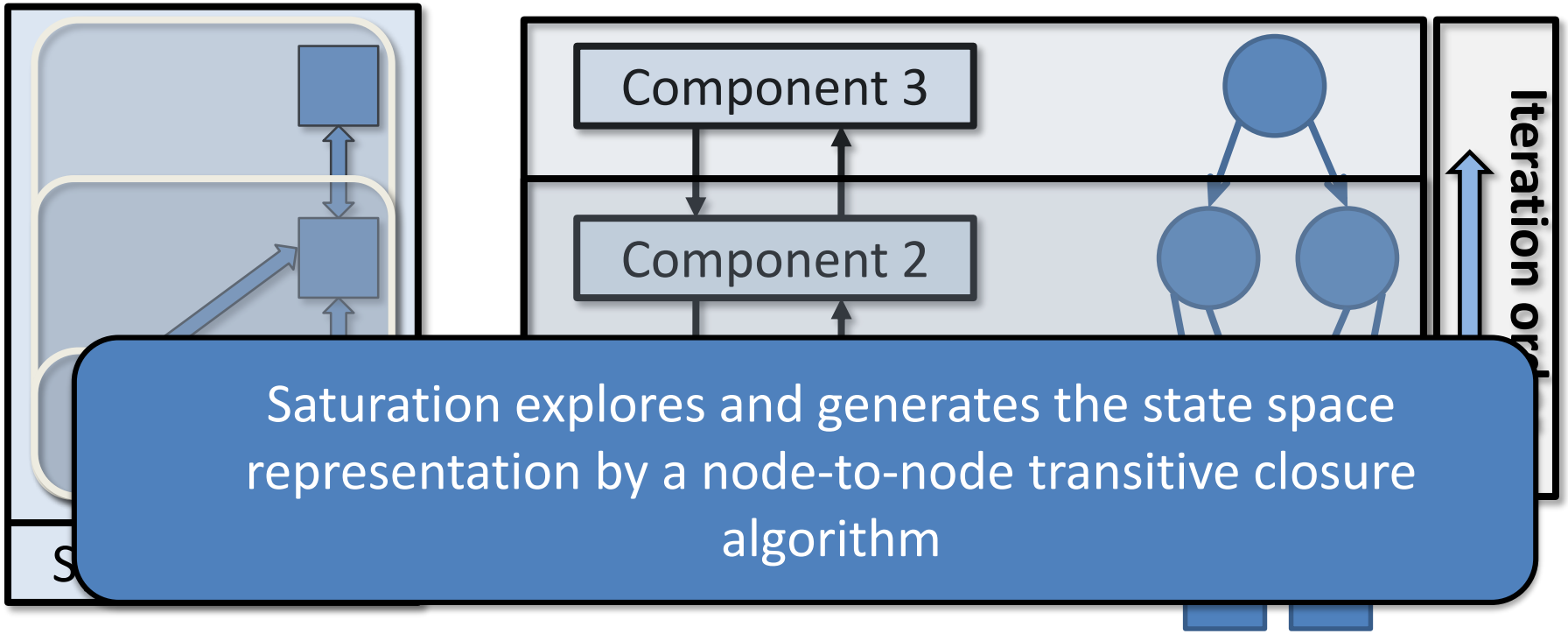
# SYMBOLIC ALGORITHM

- **Symbolic encoding instead of explicit state representation**
  - Decomposition is needed
- **Saturation uses componentwise encoding**



# SPECIAL ITERATION

- **Uses the primarily defined order of the decision diagram variable encoding**
- **Local exploration in a greedy manner**
  - Efficiently exploits **locality** of systems
- **Exploring global synchronization events if needed**



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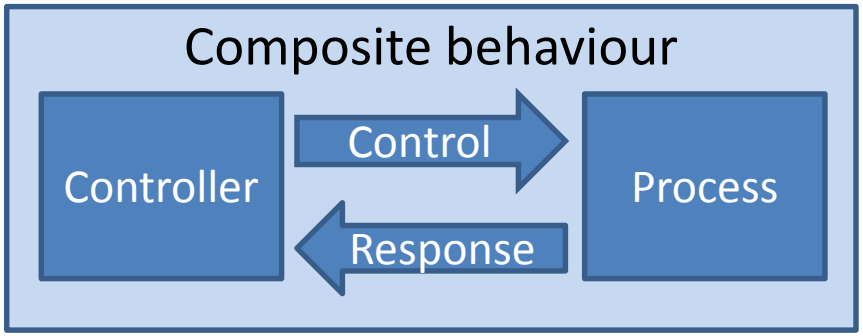
# COMPOSITE BEHAVIOUR

- **Controlled system is given as high-level model**
  - Components, events
  - Labeled states
- **Controller can be specified as:**
  - Temporal logic formula
  - Büchi automaton
    - Reading labels of states



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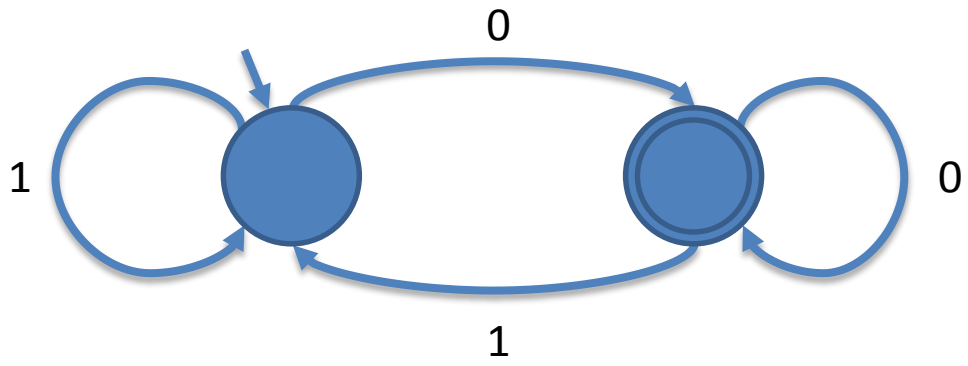



**Accepted language:**
Any word with infinitely many 0's

# SYMBOLIC ENCODING

**How to map components to decision diagram variables?**

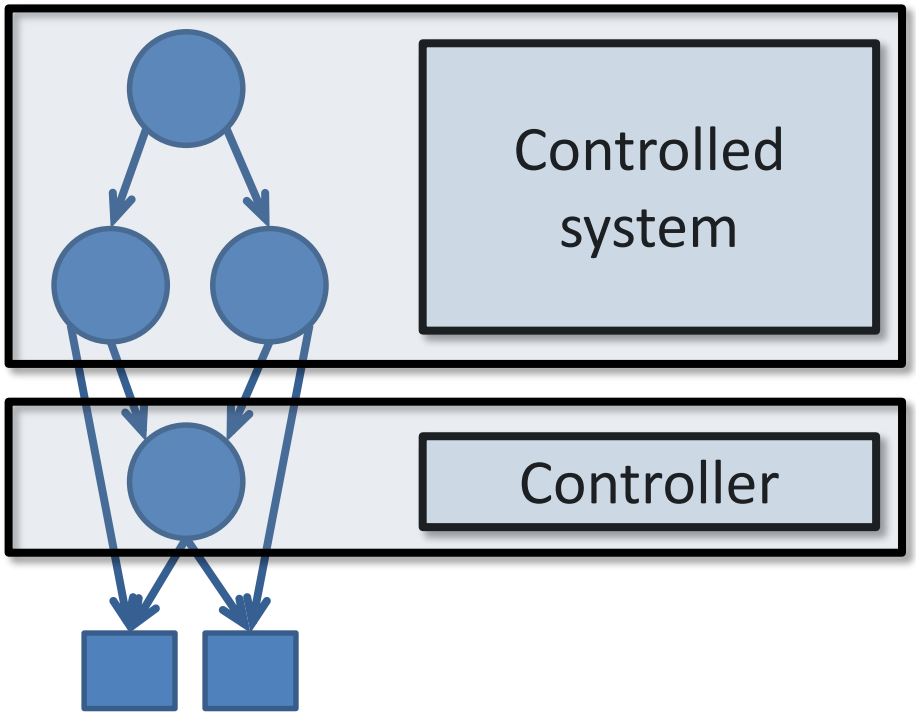
**How to encode transitions?**

**How to do these efficiently?**

# SYMBOLIC ENCODING

## How to map components to decision diagram variables?

- **Each component gets its own variable**
- **The controller automaton gets an additional one**
- **Variable ordering?**
  - Controller goes to the bottom level
  - Locality can be preserved



# SYMBOLIC ENCODING

## How to encode transitions?

- **Synchronization is required:**
  - Controller must act based on step of controlled system
  - Locality cannot be preserved
    - Labels of every local state necessary
    - Local transitions does not know unaffected states
    - Local → global
    - Saturation is degraded
- **Solution using *constrained saturation***
  - Omit synchronization by system state
    - Transitions can be freely combined
  - *Constrain* target states
    - To legal states

# SYMBOLIC ENCODING

## How to do these efficiently?

- **Constraint for target states**
  - Prevent transitions that lead to illegal states
- **Legal states?**

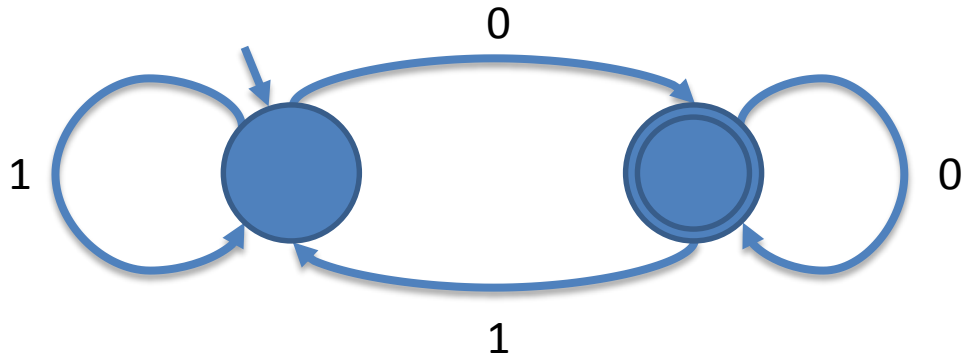



Tableau automaton

# USING SATURATION

## How to do these efficiently?

- **Constraint for target states**
  - Prevent transitions that lead to illegal states
- **Legal states:**
  - Input condition of automaton state is satisfied by system state
  - Can be precomputed based on the automaton
  - Does not affect locality

- **Constrained saturation:**
  - Explores the state space of the product directly
  - Constrains explored states to legal states
  - Legal states can be characterized without enumerating them
    - By evaluating them on the fly

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# POSSIBLE APPLICATIONS

- **Reachability**
  - Does the controller allow the system to **reach a desired** state?
  - Does it force the system to **avoid bad states**?
- **Shortest path**
  - What is the cheapest way to reach a state?
  - What is the cheapest way to fire an event in the high-level model?
  - Cheap in terms of:
    - Number of used transitions
    - Controller states passed
    - Controller transitions
- **Feasability of controller sequences**
  - Can the controller perform a sequence of actions in the system?
  - What is the cheapest way to do this?

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# MODEL CHECKING TECHNIQUES

- **Temporal properties**
  - Describe temporal behavior with logic
  - E.g.: Signal alarm whenever a fault is detected
- **Model checking**
  - Exhaustive analysis of possible behaviors regarding the temporal property
  - **Counterexample** if property does not hold, or **example** where property holds
    - Shortest
    - Cheapest

- **Possible applications:**
  - Does the controller let the system perform a desired behavior?
  - Does the controller force the system to avoid a bad behavior?
  - What is the cheapest way to perform a certain behavior?

# SUMMARY

- **Complex systems can have very large state spaces**
  - Symbolic techniques can efficiently handle this
- **On-the-fly generation of synchronous product**
  - Controller and controlled system together
- **Efficient algorithm using saturation**
  - Constrained saturation allows legal states only
- **Possible applications in optimization**
  - Qualitative and quantitative analysis

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