BUSINESS PROCESS MANAGEMENT
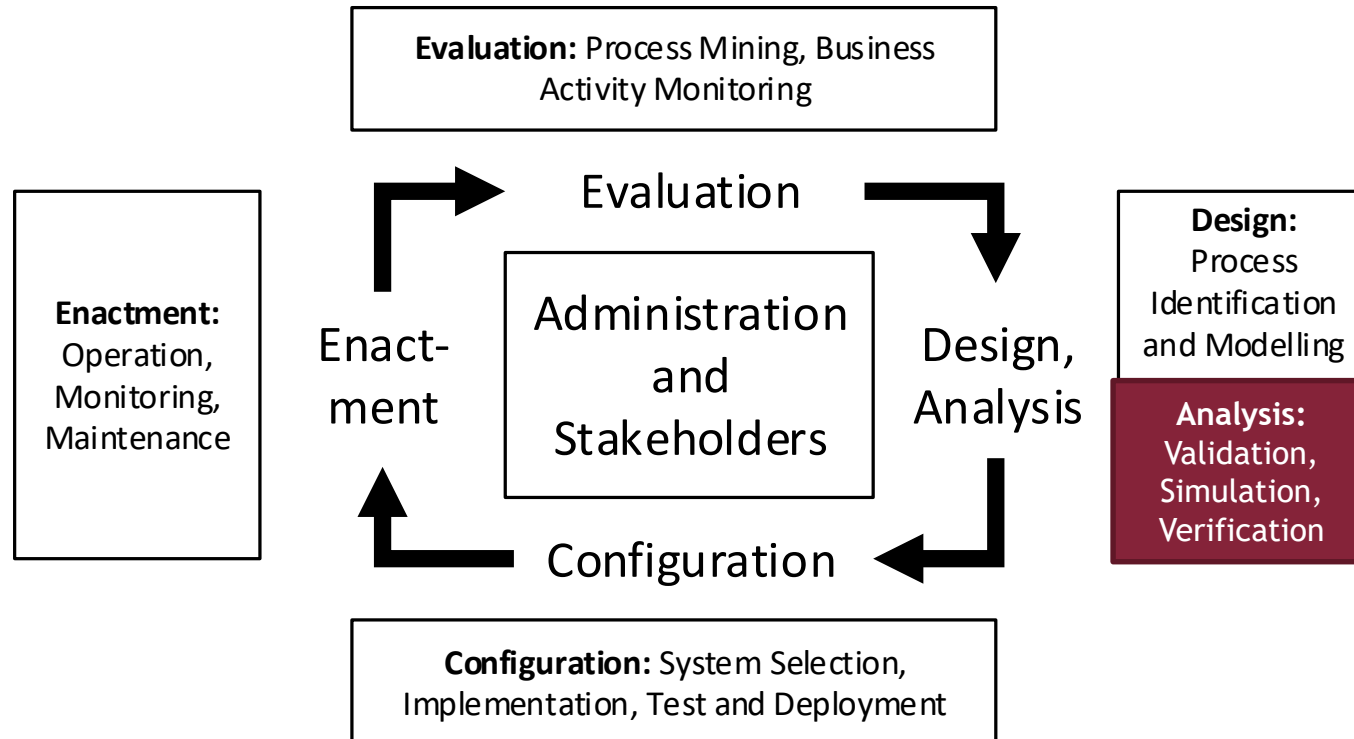
MODEL QUERY I: COMPUTATIONAL TREE LOGIC (CTL)

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AGENDA

- Why Model Query?
- Model Checking with Temporal Logic
- Computational Tree Logic (CTL)
- Application of CTL

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(PROCESS) MODELS IN THE BPM LIFECYCLE

Evaluation: Process Mining, Business Activity Monitoring

Evaluation

Enactment: Operation, Monitoring, Maintenance

Enact-ment

Administration and Stakeholders

Design, Analysis

Design: Process Identification and Modelling

Analysis: Validation, Simulation, Verification

Configuration

Configuration: System Selection, Implementation, Test and Deployment

Lecture

Model query I: CTL

- ▪ **Analyze process models** to find weaknesses and improvement potential (inefficiencies, law violations, etc.)

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THE NEED FOR AUTOMATIC MODEL QUERY

7000 models

600 models

100 models

700 models

2200 models

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[Mendling 2007]
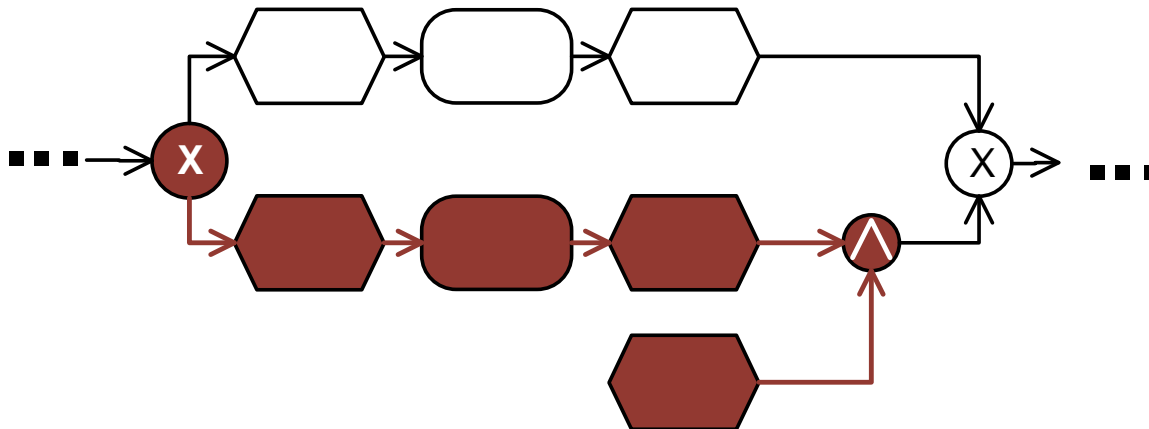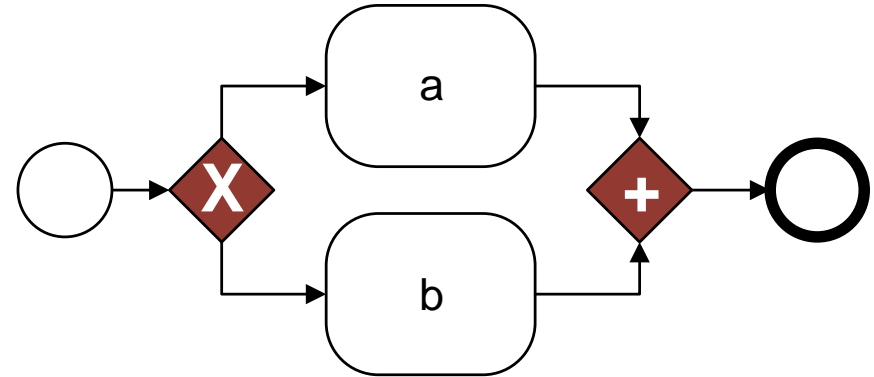
EXEMPLARY PATTERNS FOR MODEL QUERY

WEAKNESS DETECTION

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[Becker et al. 2010; 2012]
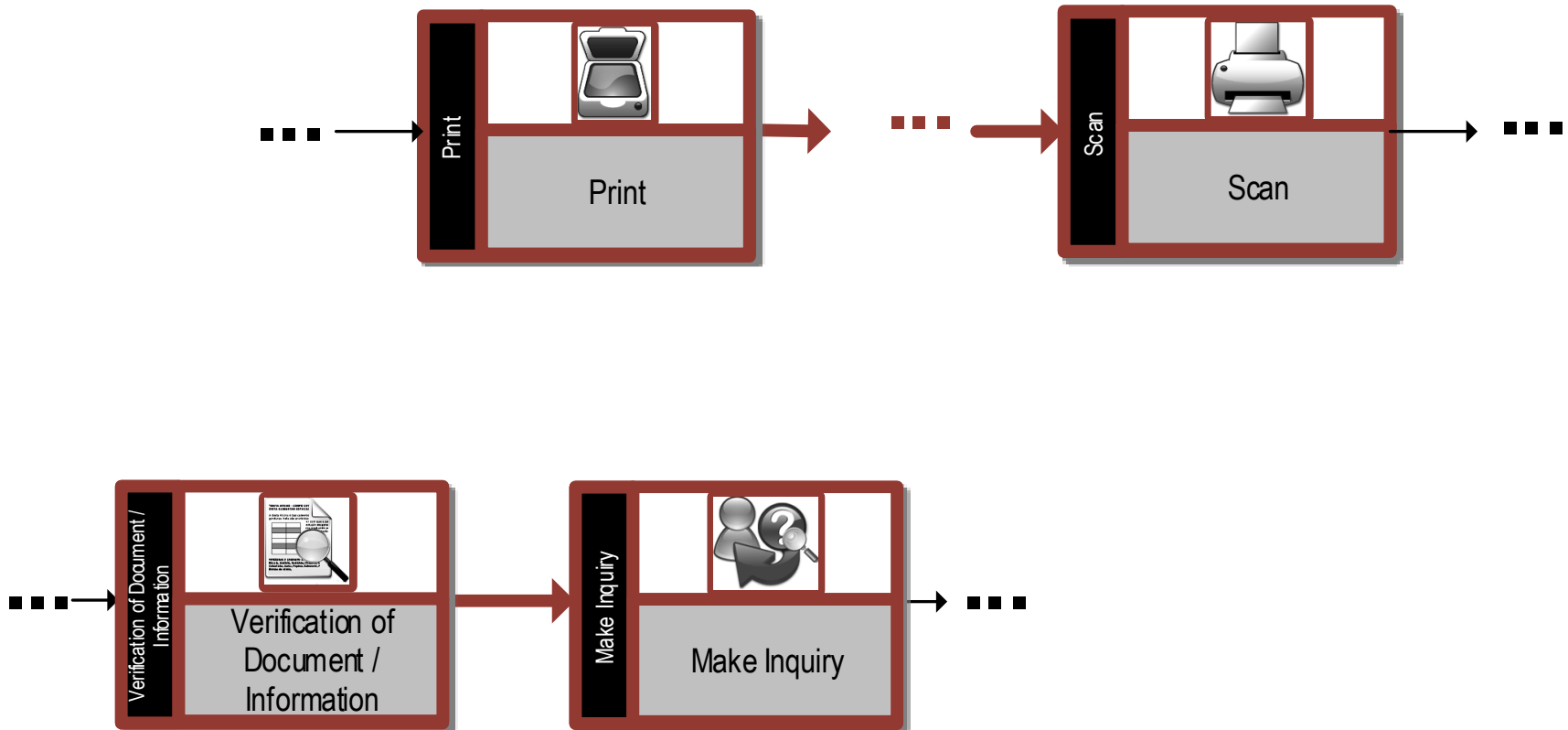
EXEMPLARY PATTERNS FOR MODEL QUERY

COMPLIANCE CHECKING
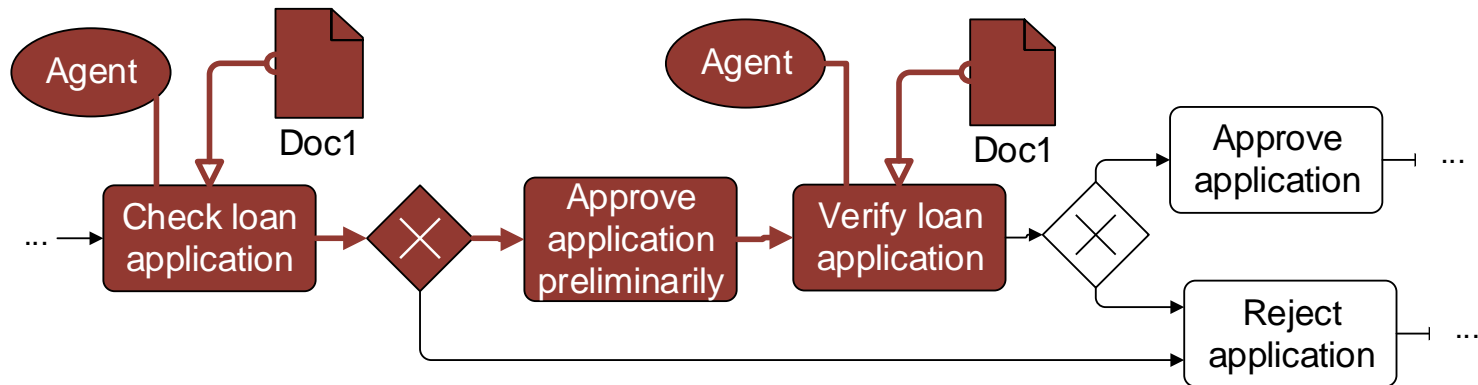
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[Knorr and Stormer 2001; Awad et al. 2008]

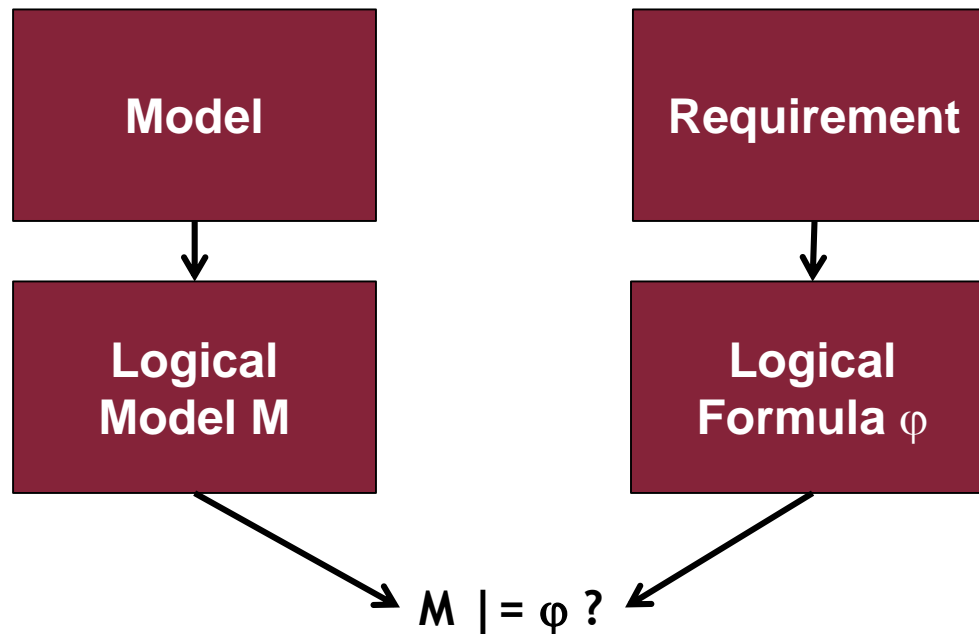# AGENDA

- Why Model Query?
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MODEL CHECKING

- Given a (process) model M and a formula φ, model checking is the problem of verifying whether or not φ is true in M (written M |= φ)

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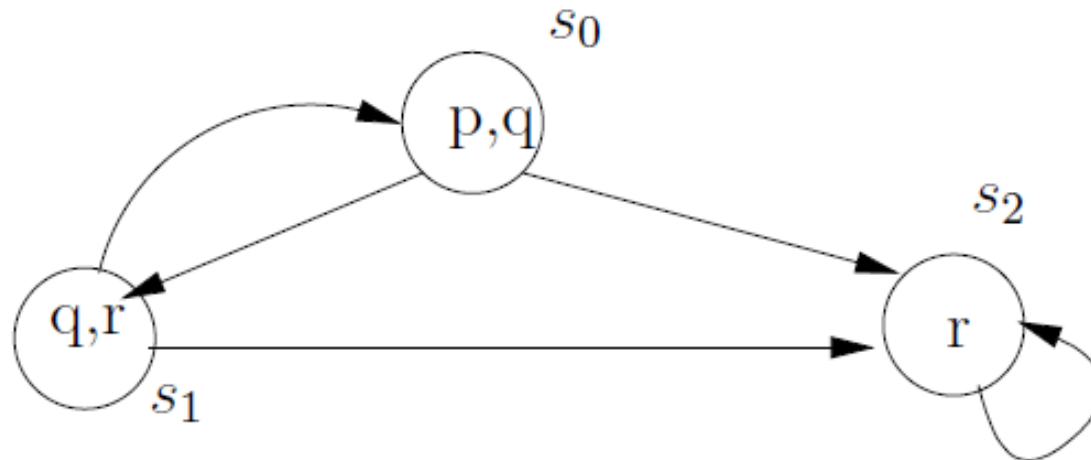[http://www.cs.ucl.ac.uk/staff/f.raimondi/]

TRANSITION SYSTEMS

- A transition system represents a system (e.g., a process model) by means of states and transitions between states

- Transition system: $M=(S,R_t,L)$

- Set of states S

- Binary relation $R_t \subseteq S \times S$

- Labelling function $L: S \rightarrow 2^{AP}$

- AP is a set of atomic propositions (see above).

- The relation R_t is serial, i.e., for every state $s \in S$, there exists a state s' such that sR_ts'
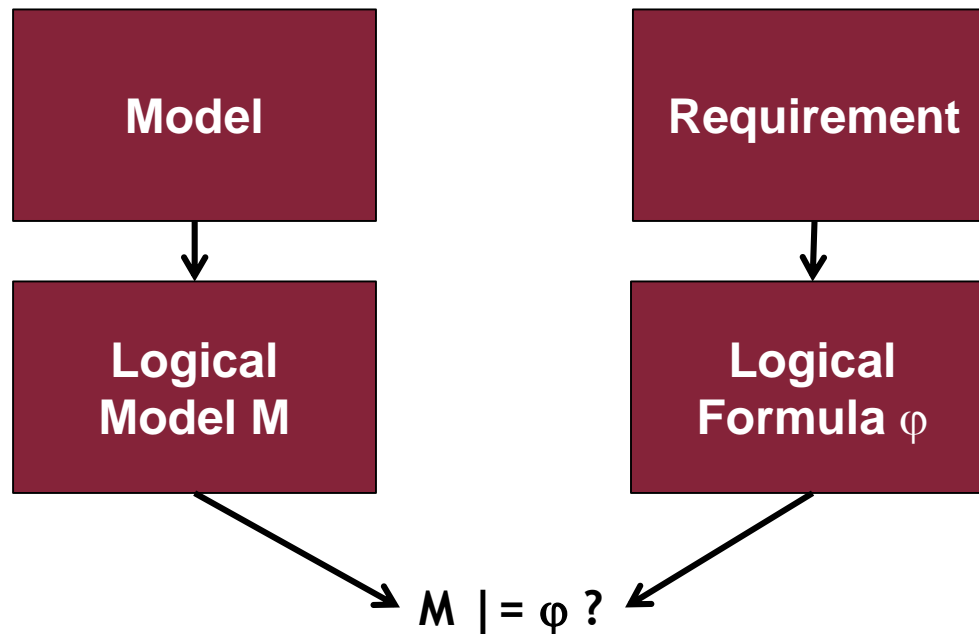
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EXAMPLE

- $M=(S,R_t,L)$

- $S=\{s_0,s_1,s_2\}$
- $R_t=\{(s_0,s_1), (s_0,s_2), (s_1,s_0), (s_1,s_2), (s_2,s_2)\}$,
- $L(s_0)=\{p,q\}$, $L(s_1)=\{q,r\}$, $L(s_2)=\{r\}$

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MODEL CHECKING

- Given a (process) model M and a formula φ, model checking is the problem of verifying whether or not φ is true in M (written M |= φ)

Model	Requirement
Logical Model M	Logical Formula φ

M |= φ ?

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TEMPORAL LOGIC

- Many model checking approaches are based mainly on temporal logic

- Various kinds of temporal logic:
  - Linear Temporal Logic (LTL),
  - Computational Tree Logic (CTL)
  - CTL*, …

- Here: CTL

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- Why Model Query?
- Model Checking with Temporal Logic
- **Computational Tree Logic (CTL)**
- Application of CTL

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CTL SYNTAX

- Set of atomic propositions P={p_1, p_2, . . .}
- Atomic propositions stand for atomic facts which may hold in a model, e.g.
  - "check invoice"
  - "grant credit"
  - "employee"

- CTL Syntax:

$$\varphi ::= p_i \mid \neg\varphi \mid \varphi \wedge \varphi \mid \varphi \vee \varphi \mid \varphi \rightarrow \varphi \mid AX\varphi \mid EX\varphi \mid AF\varphi \mid EF\varphi \mid AG\varphi \mid EG\varphi \mid A[\varphi U\varphi] \mid E[\varphi U\varphi]$$

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CTL SEMANTICS

- Unary Operators
    - A: for All paths
    - E: there Exists a path
    - X: neXt state
    - F: in a Future state
    - G: Globally in the future
- Binary Operator
    - U: Until
- Example
    - AG(p→(EFq)): "It is globally the case that, if p is true, then there exists a path such that at some point in the future q is true"

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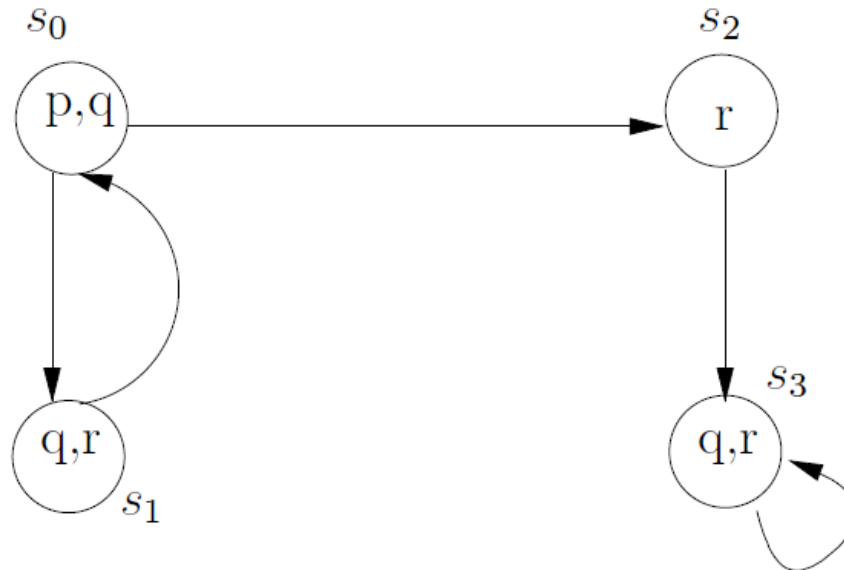Prof. Dr. Patrick Delfmann, Dr. Carl Corea

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CTL SEMANTICS

- Let $M=(S,R_t,L)$ be a transition system.
- Let φ be a CTL formula and $s \in S$
- $M, s \models \varphi$ is defined inductively on the structure of φ:

- $M, s \models p$ iff $p \in L(s)$
- $M, s \models \neg\varphi$ iff $M, s \not\models \varphi$
- $M, s \models \varphi \wedge \psi$ iff $M, s \models \varphi$ and $M, s \models \psi$
- $M, s \models \varphi \vee \psi$ iff $M, s \models \varphi$ or $M, s \models \psi$
- $M, s \models AX\varphi$ iff $\forall s'$ such that sR_ts', $M, s' \models \varphi$
- $M, s \models EX\varphi$ iff $\exists s'$ such that sR_ts' and $M, s' \models \varphi$

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- $M, s_1 \models AG\varphi$ iff   for all paths $(s_1, s_2, s_3, s_4, \ldots)$ such that $s_i R_t s_{i+1}$ and for all i, it is the case that $M, s_i \models \varphi$

- $M, s_1 \models EG\varphi$ iff   there is a path $(s_1, s_2, s_3, s_4, \ldots)$ such that $s_i R_t s_{i+1}$ and for all i it is the case that $M, s_i \models \varphi$

- $M, s_1 \models AF\varphi$ iff   for all paths $(s_1, s_2, s_3, s_4, \ldots)$ such that $s_i R_t s_{i+1}$, there is a state s_i such that $M, s_i \models \varphi$

- $M, s_1 \models EF\varphi$ iff   there is a path $(s_1, s_2, s_3, s_4, \ldots)$ such that $s_i R_t s_{i+1}$, and there is a state s_i such that $M, s_i \models \varphi$

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CTL SEMANTICS

- $M, s_1 \models A[\varphi U \psi]$ iff   for all paths $(s_1, s_2, s_3, s_4, ...)$
  such that $s_i R_t s_{i+1}$ and there is
  a state s_j such that $M, s_j \models \psi$
  and $M, s_i \models \varphi$ for all $i < j$.

- $M, s_1 \models E[\varphi U \psi]$ iff   there exists a path $(s_1, s_2, s_3, s_4, \ldots)$
  such that $s_i R_t s_{i+1}$ and there is
  a state s_j such that $M, s_j \models \psi$
  and $M, s_i \models \varphi$ for all $i < j$.

- We write $M \models \varphi$ if a formula is true in all states of a model.

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- M, s_0 |= EX($\neg$p)
- M, s_0 |= EX(r)
- M, s_1 |= AG(q $\lor$ r)
- M, s_2 |= A[rUq]

- M, s_0 |= A[pUq]
- M, s_1 |= E[qUEG(r)]
- M, s_0 |= $\neg$AG(q) ←
- M, s_1 |= EF(AG(q))

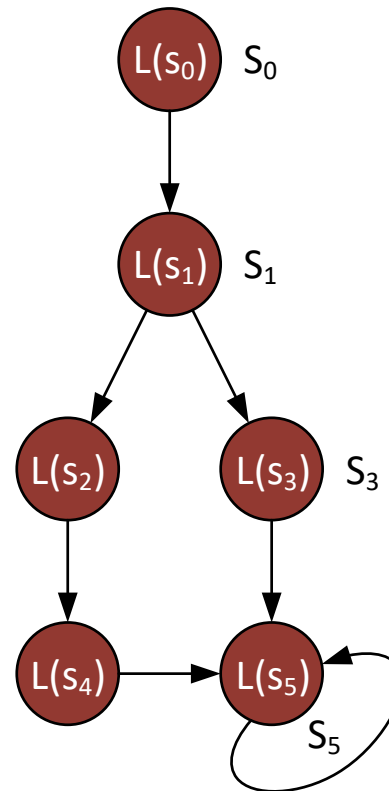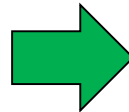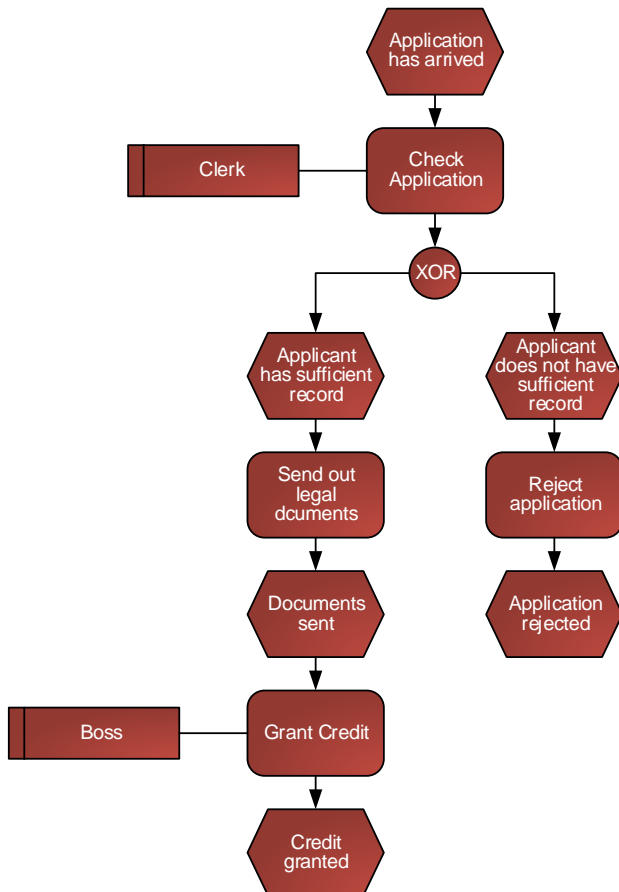**This is true, because it is not the case, that on all paths there is globally q (cf. $s_0 \rightarrow s_2$)**

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AGENDA

- Why Model Query?
- Model Checking with Temporal Logic
- Computational Tree Logic (CTL)
- **Application of CTL for BPM**

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CONCEPTUAL PROCESS MODELS AND CTL

- How can we use CTL to analyze (process) models?

- **Step 1:** transform a model into a transition system
  - activities → states
  - labels → atomic propositions
  - annotated objects → atomic propositions

- **Step 2:** create CTL formulas representing, e.g., compliance rules or weakness patterns

- **Step 3:** check the transition system with a CTL model checker

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COMPLIANCE EXAMPLE

- L(s0)={start}
- L(s1)={n_check_application, o_clerk}
- L(s2)={n_send_out_legal_documents}
- L(s3)={n_reject_application}
- L(s4)={n_grant_credit, o_boss}
- L(s5)={end}

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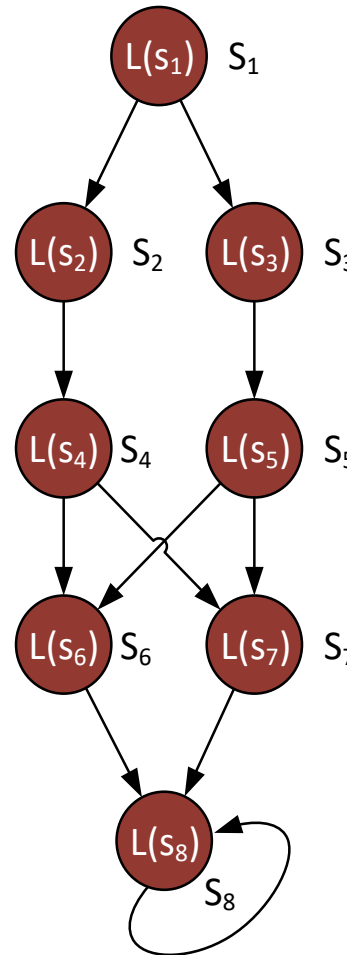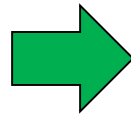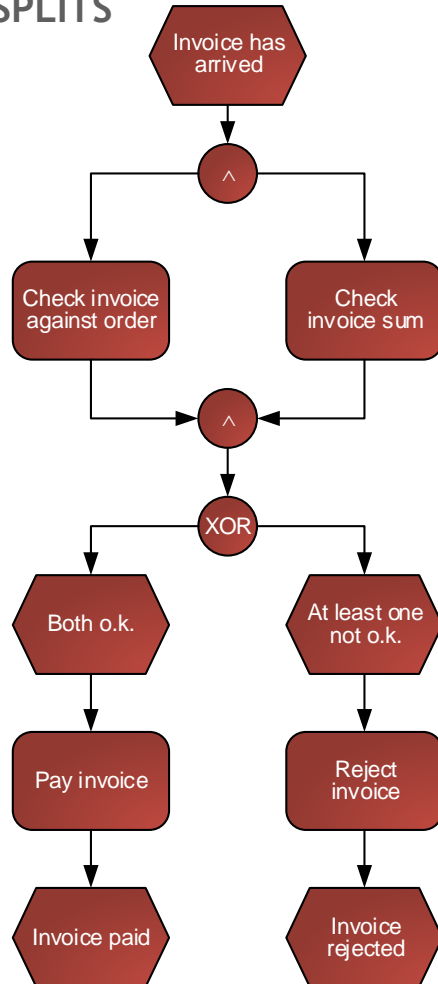Prof. Dr. Patrick Delfmann, Dr. Carl Corea

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COMPLIANCE EXAMPLE

- Rule 1: Legal Documents have to be sent to the customer, before a credit can be granted

- $M, s_0 \models A[(\neg n\_grant\_credit) U n\_send\_out\_legal\_documents]$

- Rule 2: Credits can only be granted by the boss

- $M, s_0 \models \neg EF(n\_grant\_credit \wedge \neg o\_boss)$

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CAUTION!

AND SPLITS

- L(s1)={start}
- L(s2)={Check_invoice _against_order}
- L(s3)={Check_invoice _sum}
- L(s4)={Check_invoice _sum}
- L(s5)={Check_invoice _against_order}
- L(s6)={Pay_invoice}
- L(s7)={Reject _invoice}
- L(s8)={end}

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KEY LEARNINGS

- BPMN models can be transformed into a transition system (M)
- (Legal) regulations can be transformed into formulas
- For compliance checking, queries are ALWAYS formulated starting in s_0

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BUSINESS PROCESS MANAGEMENT

MODEL QUERY 1: COMPUTATIONAL TREE LOGIC (CTL)