Compliance Verification of Business Processes with (Constraint) Temporal Answer Set Programming

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based on

L. Giordano, A. Martelli, M. Spiotta, D. Theseider Dupré, **Business Process Verification with Constraint Temporal Answer Set Programming**, TPLP 13 (4-5), 2013. Presented at ICLP 2013.

L. Giordano, A. Martelli, M. Spiotta, D. Theseider Dupré, **Business Processes Verification with Temporal Answer Set Programming**. KiBP, 1st Int. Workshop on Knowledge-intensive Business Processes, Rome, 2012

both build on:

L. Giordano, A. Martelli, D. Theseider Dupré. **Reasoning about actions with Temporal Answer Sets**. TPLP 13 (2), 2013

Goal

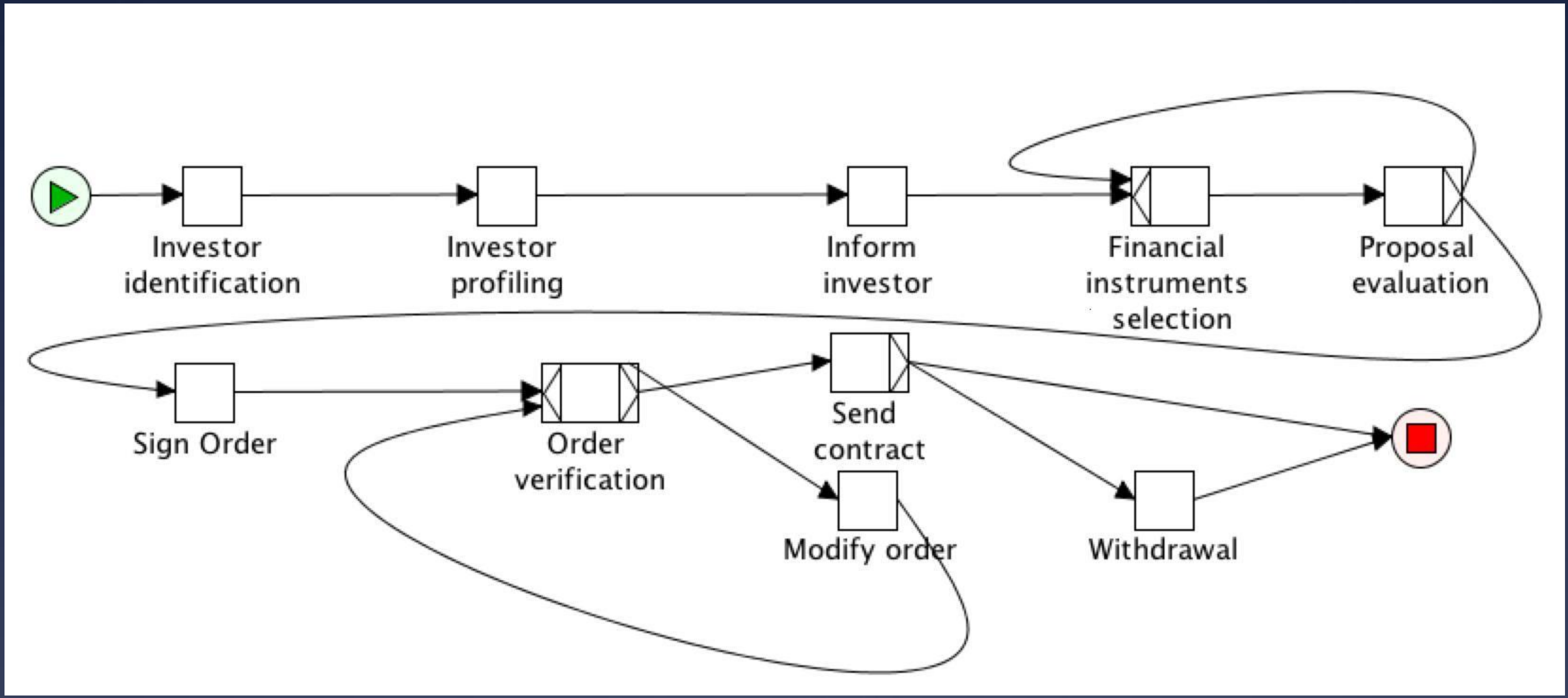
Cross-fertilize Business Process modeling with **Reasoning about actions and change in AI** and **(Constraint) Answer Set Programming**

(Constraint) Temporal Answer Set Programming combines (Constraint) ASP with Temporal Logic (DLTL)

useful for:

- Declarative or procedural process model
- Modeling background knowledge: direct effects of activities and side effects
- Constraint solving on numeric process data
- Compliance verification via Bounded Model Checking based on [Giordano, Martelli & T.D. TPLP 13]

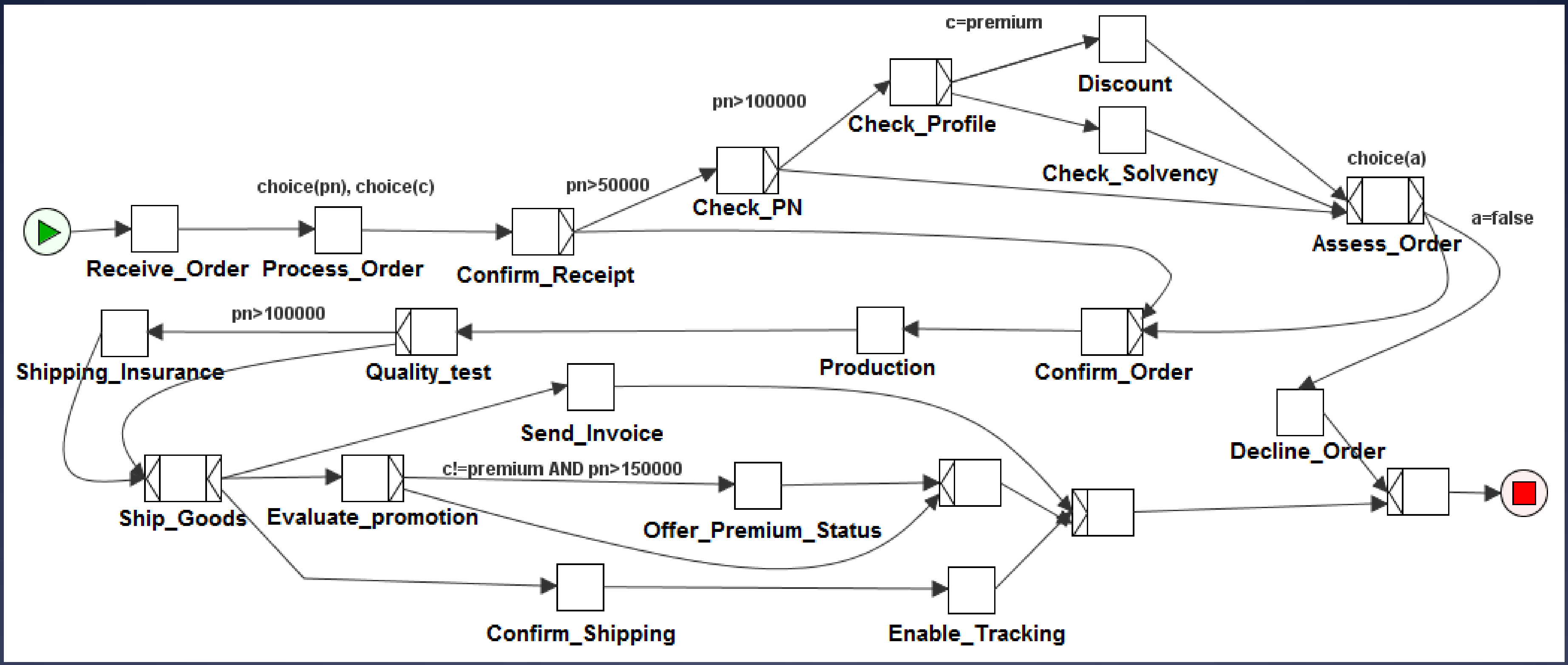
Example



Norm 1: "The firm shall provide the investor adequate information on its policies before any contract is signed"

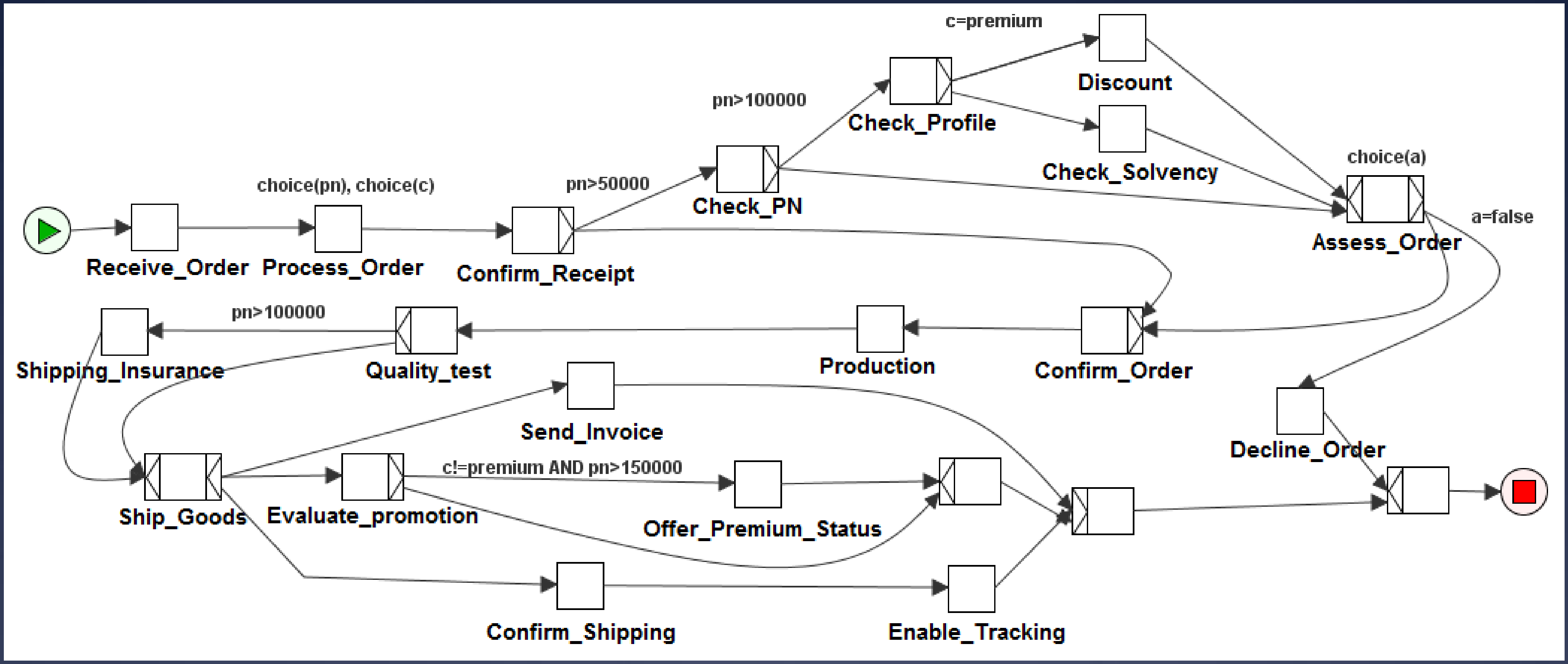
Norm 2: "If an investor signs a contract, the firm shall provide him a copy of the contract"

Example



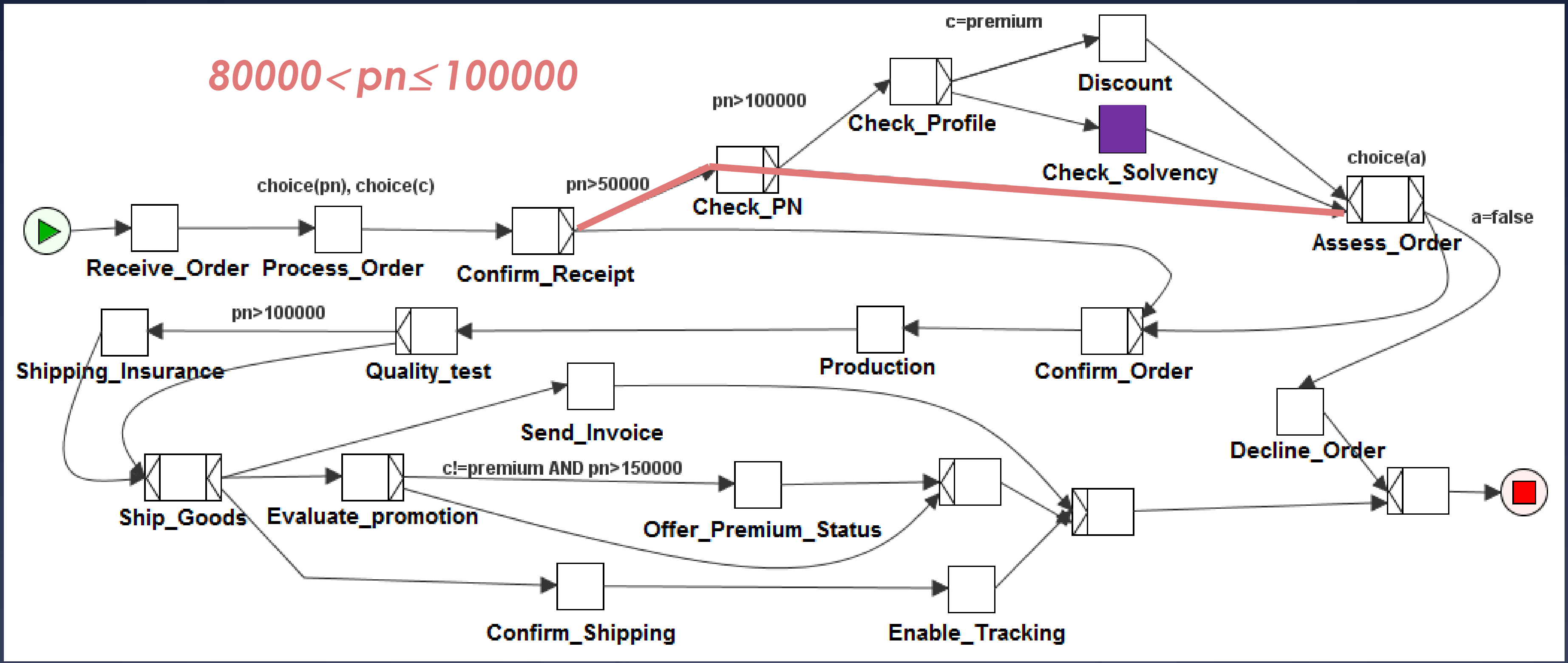
Order-delivery process adapted from [Knuplesch 2010], branching depends on variables, esp. *piece number*

Rules



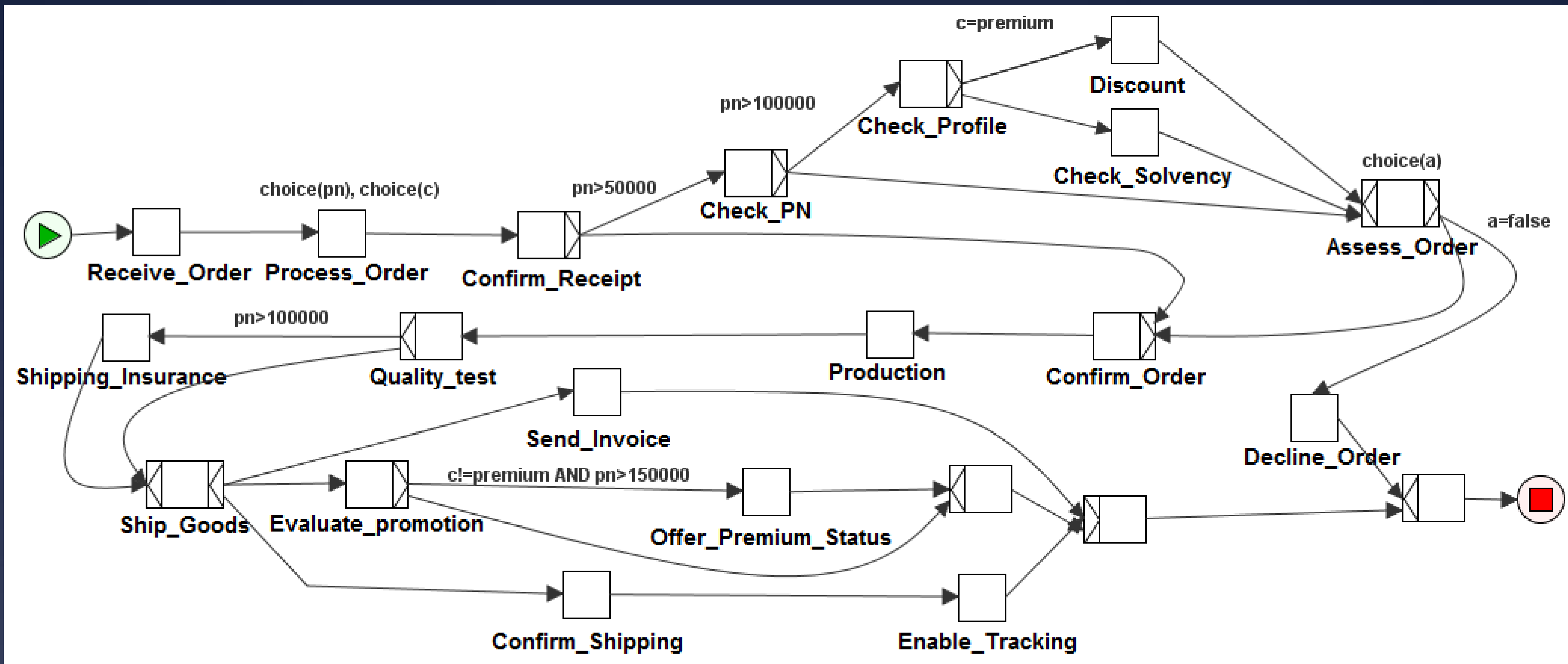
- After confirming an order, goods have to be shipped eventually
- An order shall either be confirmed or declined

Rules



- Orders with *pn>50000* shall be approved before they are confirmed
- For orders of a non-premium customer with ***pn>80000*** a solvency check is necessary before assessing the order

Rules



For orders of a non-premium customer with **pn>80000** a solvency check is necessary before assessing the order

$$\Box(pn>80000 \wedge c \neq premium \wedge \langle Assess\_Order \rangle \top \rightarrow solvency\_check\_done)$$

Representation languages

Then, we use:

- An **action language**, used to describe a domain, where effects of atomic actions and their executability conditions may involve constraints
- A **temporal logic (with constraints)**, used to express (at least) formulae to be verified

Constraints (e.g. $pn>80000$, or $x+y>k$) will be treated as atoms at the temporal logic level and the answer set level (as in [Gebser et al 09])

DLTL (with constraints)

DLTL [Henriksen & Thiagarajan 99] extends LTL: temporal operators can be indexed with regular expressions (programs) π

Temporal formulae include:

$\langle \pi \rangle\ \alpha$	there is an execution of π after which α holds
$[\pi]\ \alpha$	α holds after all possible executions of π
$[a]\ \alpha$	α holds after a

and the usual temporal logic modalities:

$\Diamond\alpha$ (eventually α), $\Box\alpha$ (always α), $\bigcirc\alpha$ (next α)

Their semantics is defined from the one of $\alpha\, \mathcal{U}^{\pi}\, \beta$ which means: there is an execution of π after which β holds, and α holds in all previous states

DLTL (with constraints)

DLTL formulae with constraints are then:

$$\bot \mid \top \mid p \mid g \mid \neg\alpha \mid \alpha \vee \beta \mid \alpha\, \mathcal{U}^{\pi}\, \beta$$

where the ps are atomic propositions and the gs are constraints in a constraint language (which we assume to have a *finite domain*)

As in [Gebser et al 09], a function γ maps constraint *atoms* (syntax) to constraints (relations on variables), then providing an interpretation for constraints (e.g. the usual interpretation for arithmetic ops and rels), $A \models_{\gamma} g$ means: $\gamma(g)$ is true for the assigment A of values to variables, e.g. $A \models_{\gamma} x+y>20$ if A(x)=15 and A(y)=10

DLTL with constraints

A model is $M = (\sigma, V, v)$ where σ is an infinite sequence of actions, V and v provide, for each prefix τ of σ (the state reached after τ) an interpretation of atomic propositions, and an assignment for constraint variables. Then:

M, $\tau \vDash p$ iff $p \in V(\tau)$

M, $\tau \vDash g$ iff $v(\tau) \vDash_\gamma g$

M, $\tau \vDash \alpha\, \mathcal{U}^\pi \beta$ iff in σ, after τ, there is an execution τ' of π such that M, $\tau\tau' \vDash \beta$ and for all intermediate states $\tau\tau''$, M, $\tau\tau'' \vDash \alpha$

Temporal action language

implicit

$$\Box\,(\, l_0 \leftarrow l_1 , \ldots , l_m , \mathit{not}\, l_{m+1} , \ldots, \mathit{not}\, l_n \,)$$

l_0 is a fluent literal or temporal fluent literal ($[a]l$ or $\circ l$)

The l_i can be:

fluent literals,
constraint literals,
temporal (constraint or fluent) literals,
dynamic constraint literals, i.e. constraint literals also involving variables x° , i.e. ‘x in the next state’

with some restriction ensuring that successor states only depend on current state

Action laws, causal laws, persistence can be expressed

Action laws, causal laws

Example of **action law**:

$$\Box\ ([inform]informed)$$

Persistence:

$$\Box\ ([a]\ l \leftarrow l\ ,\ not\ [a]\ \neg l\ )$$

Static causal laws model dependencies within the same state and then also side effects, e.g.:

$$\Box\ (\neg\, confirmed \leftarrow deleted)$$

where "deleted " = "order deleted by customer" and " confirmed" = "order confirmed for the seller"

Causal laws

Dynamic causal laws:

$$\Box\ (\bigcirc\, l \leftarrow t_1, \ldots, t_m, \text{not } t_{m+1}, \ldots, \text{not } t_n)$$

The t_i's can be of the forms l_i or $\bigcirc\, l_i$

Then we can represent side effects of *changes* of fluents, e.g.:

$$\neg f, \bigcirc f$$

i.e. f becomes true

Ramifications & BPs

[Weber et al. 2010] use clauses (in classical logic) to model dependencies, and the Possible Models Approach [Winslett 1988] to deal with ramifications

the intended states after an action are those:

- where direct effects hold
- where the background axioms are satisfied
- that differ minimally from the state before the action

But one of their examples is:

insurance claim accepted when accepted by reviewer A and by reviewer B

Ramifications & BPs

If this is modeled as the material implication:

$$claimAccRevA \wedge claimAccRevB \supset claimAccepted$$

and the PMA is used, if A already accepted and B accepts, this either makes *claimAccepted* true or *claimAccRevA* false

The static causal rule

$$claimAccepted \leftarrow claimAccRevA\ ,\ claimAccRevB$$

can be used to have only *claimAccepted* change as a side effect, while still intending that the implication holds

Ramifications & BPs

The implication may be false if e.g. we allow the acceptance to be overridden later by a supervisor

In this case dynamic laws are appropriate:

$$
\begin{aligned}
O\ \mathit{claimAccepted} \leftarrow\ & O\ \mathit{claimAccRevA}\ ,\\
& \neg\ \mathit{claimAccRevB},\ O\ \mathit{claimAccRevB}
\end{aligned}
$$

i.e., if the conjunction of acceptances *becomes* true, we have the side effect, which:

- remains true by default persistence
- may be made false while its original cause remains true

Constraint Temporal Answer Sets

Given a set P of rules, we define a **Constraint Temporal Answer Set** combining Temporal AS in [Giordano, Martelli & T.D.13] and Constraint AS in [Gebser et al 09]

It is a partial temporal interpretation (σ,S) where S is a set of temporal literals of the form $[a_1;\ldots;a_k]l$ where $a_1;\ldots;a_k$ is a prefix of σ

It is defined relative to an assignment v to constraint variables at each prefix of a σ

Then, we define for the various types of literals their being satisfied by (σ,S) at the prefix $a_1;\ldots;a_k$ given v

Constraint Temporal Answer Sets

Given an interpretation (σ,S), for each prefix $a_1;\ldots;a_k$ we compute a different constraint reduct, a set of rules

$$[a_1;\ldots;a_k]\ H \leftarrow\ \text{Body}$$

obtained from rules in P:

- eliminating constraint literals true at $a_1;\ldots;a_k$ given v (if all true)
- and extended literals $\mathbf{not}\ l$ true at $a_1;\ldots;a_k$ (if all true)

reduct = union of reducts for all prefixes

(σ,S) is a constraint temporal answer set wrt v if S is minimal among the R such that (σ,R) satisfies the rules in the reduct

Extensions

Given a domain description (P,Q) where P is a set of rules, and Q is a set of (constraint) DLTL formulas, its **extensions** (i.e. models) are constraint temporal answer sets of P whose corresponding temporal model satisfies formulae in Q

Validity of a formula α for a d.d. (P,Q) corresponds to verifying that there is no extension of $(P, \{Q \wedge \neg \alpha\})$

Modeling Business Processes

The control flow of a business process can be modeled in several ways

- a **program** (regular expression) in a DLTL constraint: $\langle\pi\rangle\, \top$ (only structured, sequential programs) [Giordano et al. CLIMA 10]
- **declarative** temporal constraints (e.g. ConDec/Declare from van der Aalst et al)
- «classical» graphical **workflow notation** (BPMN, YAWL)

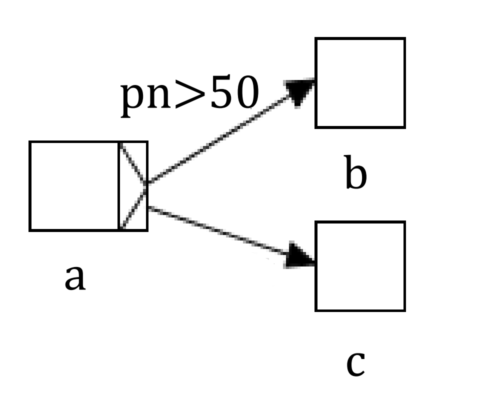
Modeling Business Processes

We used a **translation from basic workflow constructs** of YAWL to the temporal action language, based on the *enabling* of actions and arcs

An action precondition is its being enabled

Causal laws define enabling of action based on enabling of incoming arcs (one/all for XOR/AND)

Actions enable and disable arcs



$[a]\ en\_arc\_a\_b \leftarrow\ pn > 50$
$[a]\ en\_arc\_a\_c \leftarrow\ not\ pn > 50$

Modeling Business Processes

The model provides information on which **actions** have a **variable as output**:

$[a]\ x \in [0..1000000]$

Across other actions, the value of x **persists**, we model this via a fluent $change\_x$ which is non persistent and false by default:

$x^{\circ} = x \leftarrow \circ \neg change\_x$
$[a]\ change\_x$
$\neg change\_x \leftarrow \text{not } change\_x$

Other **fluents persist**:

$[a]\ f \leftarrow f, \text{not } [a] \neg f$

Verification

In [Giordano, Martelli & T.D. TPLP13] we defined a **translation** of domain descriptions **to ASP** and an **encoding** in ASP of **Bounded Model Checking** (following [Heljanko & Niemelä 03])

- BMC, given a system and a formula, searches for a model
- Infinite paths are represented as finite paths of length k with a loop back from state k to a previous state
- The search proceeds iteratively, increasing k until a model is found (if one exists)

Translation

Our translation is defined so that **extensions** of domain descriptions correspond to (constraint) **answer sets** of the translation

- occurs(Action,State) (State is a number)
- holds(Literal,State)

e.g. for [a]f1 ← f2 :

holds(f1,S') ← state(S), next(S,S'),occurs(a,S),holds(f2,S)

- sat(Formula,State)

defined inductively on the structure of the DLTL Formula

Translation

Constraint literals are represented using CSP variables value(x,s) for the value of process variable x at state s

[a] en_arc_a_b $\leftarrow$ pn > 50

becomes

holds(en_arc_a_b,S') $\leftarrow$
state(S),next(S,S'),occurs(a,S),value(pn,S) $> 50

$x^{\circ} = x \leftarrow \circ \neg change\_x$

becomes

value(x,S') $= value(x,S) $\leftarrow$
state(S),next(S,S'),not holds(change_x,S')

BP Verification

The approach in [Giordano, Martelli & T.D. TPLP 13] is suitable for verifing system with infinite computations (and finite state space)

In BPs only executions that reach the end are considered *sound*

Finite executions can be represented as infinite ones with a final dummy action

In practice, we restrict to finite traces

Completeness of BMC

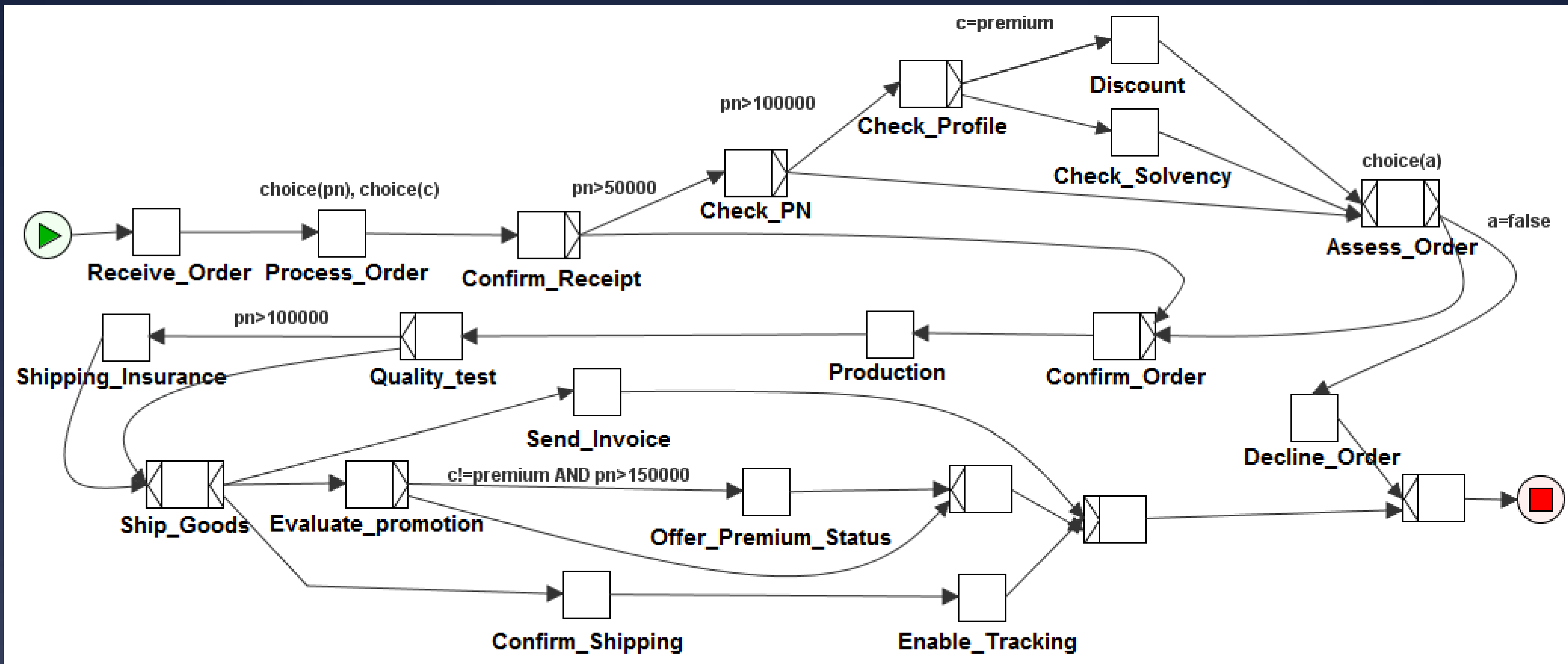
BMC is in general a partial decision procedure

Completeness can be obtained for special classes of formulae, or for general formulae, computing a **completeness threshold** *t* (using bounds up to *t* is enough to find a model if one exists) [Biere et al. 03,06, Clarke et al. 04, Giordano et al. KR12]

But computing the threshold may be unfeasible

For loop-free workflows the length of the longest run can be used as threshold

BP Verification



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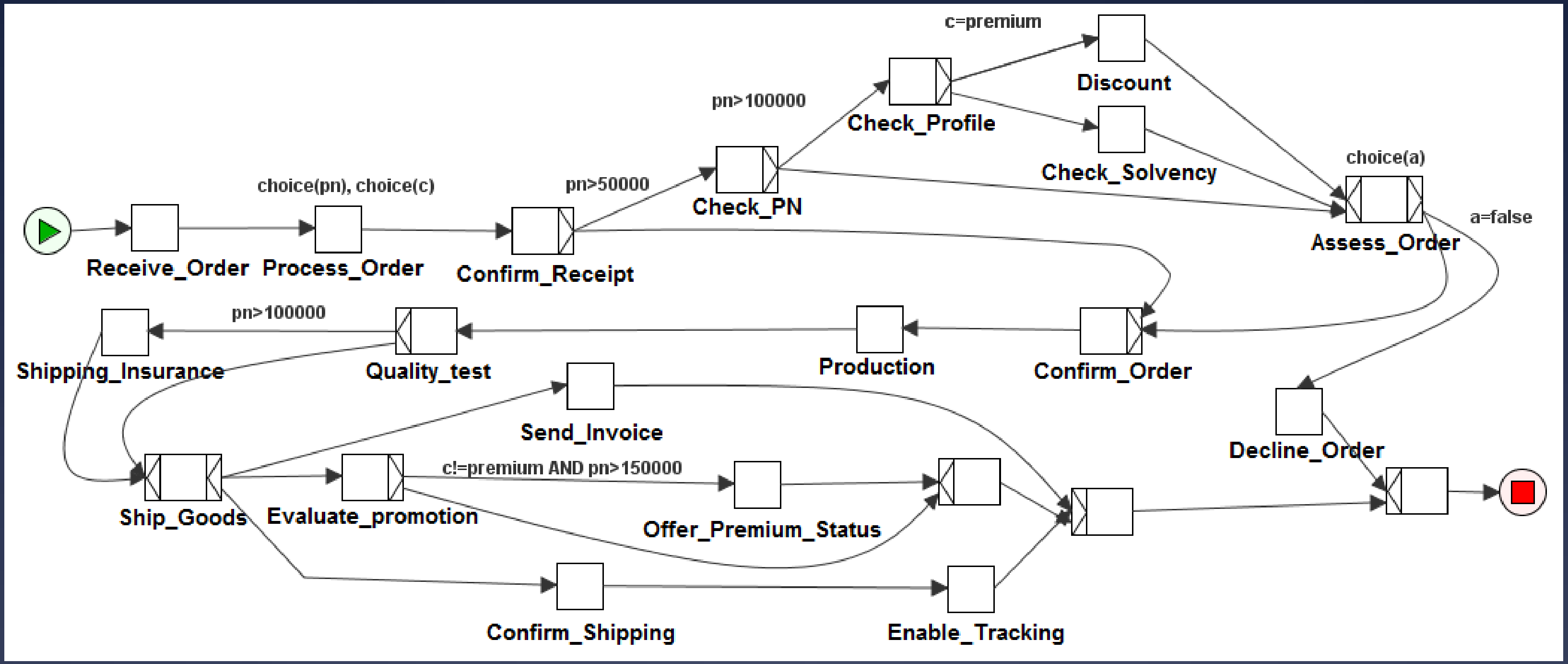
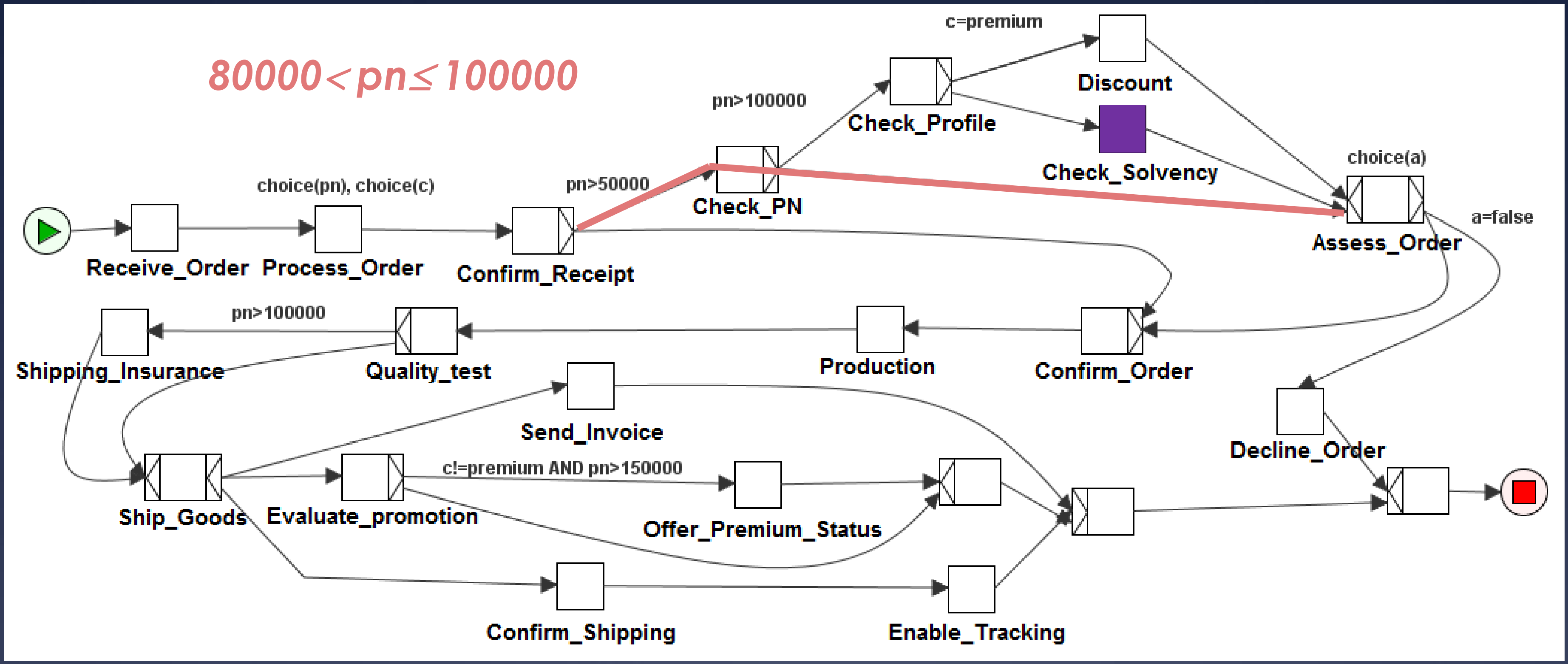
BP Verification



Running the translation in ***clingcon*** we get (in ≅ 0.1s)

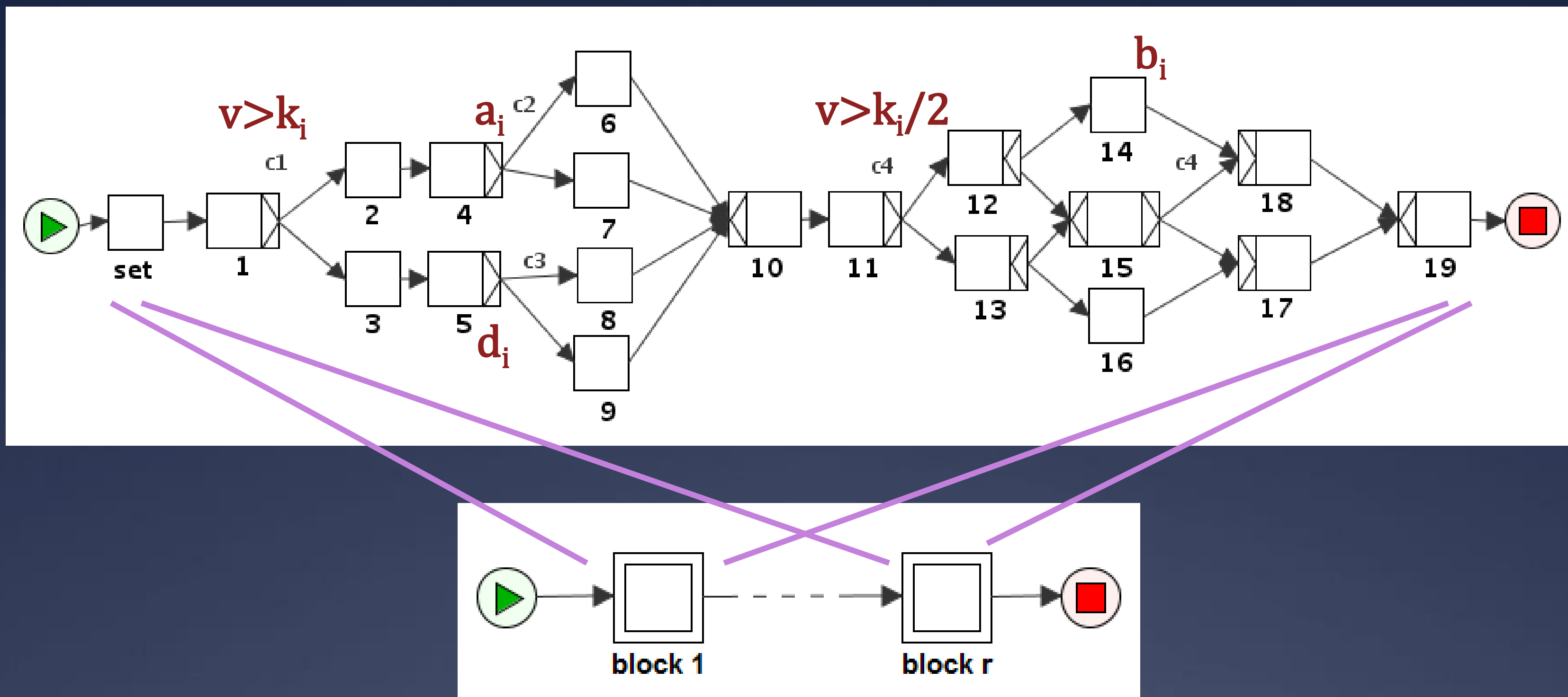
- $\square(pn>50000 \wedge \langle Confirm\_Order \rangle \top \rightarrow a=true)$ **valid**
- $\square(pn>80000 \wedge c \neq premium \wedge \langle Assess\_Order \rangle \top \rightarrow solvency\_check\_done)$ **non valid**

BP Verification



if *clingcon* is asked to provide *weak answer sets*,
for the s after pn is assigned,
value(pn,s) is given the domain *[80001..100000]*

Scalability



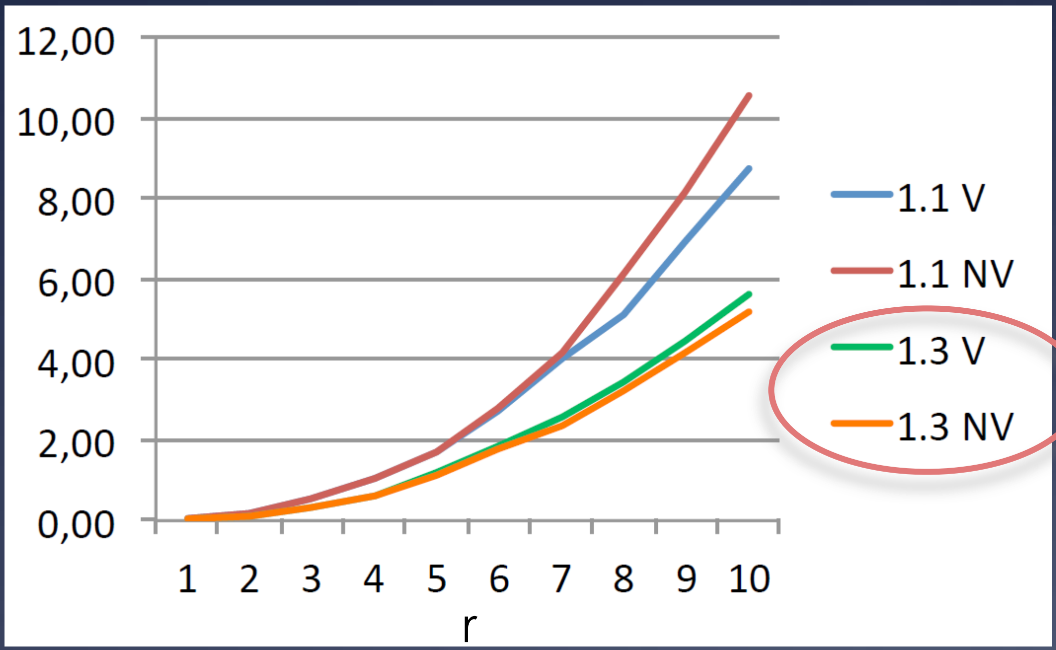
$c1_i$ implies $c4_i$ and c_{i+1} $(k_i > k_{i+1})$, then

$\square(a_1 \rightarrow \lozenge\, b_r)$ **valid**

while

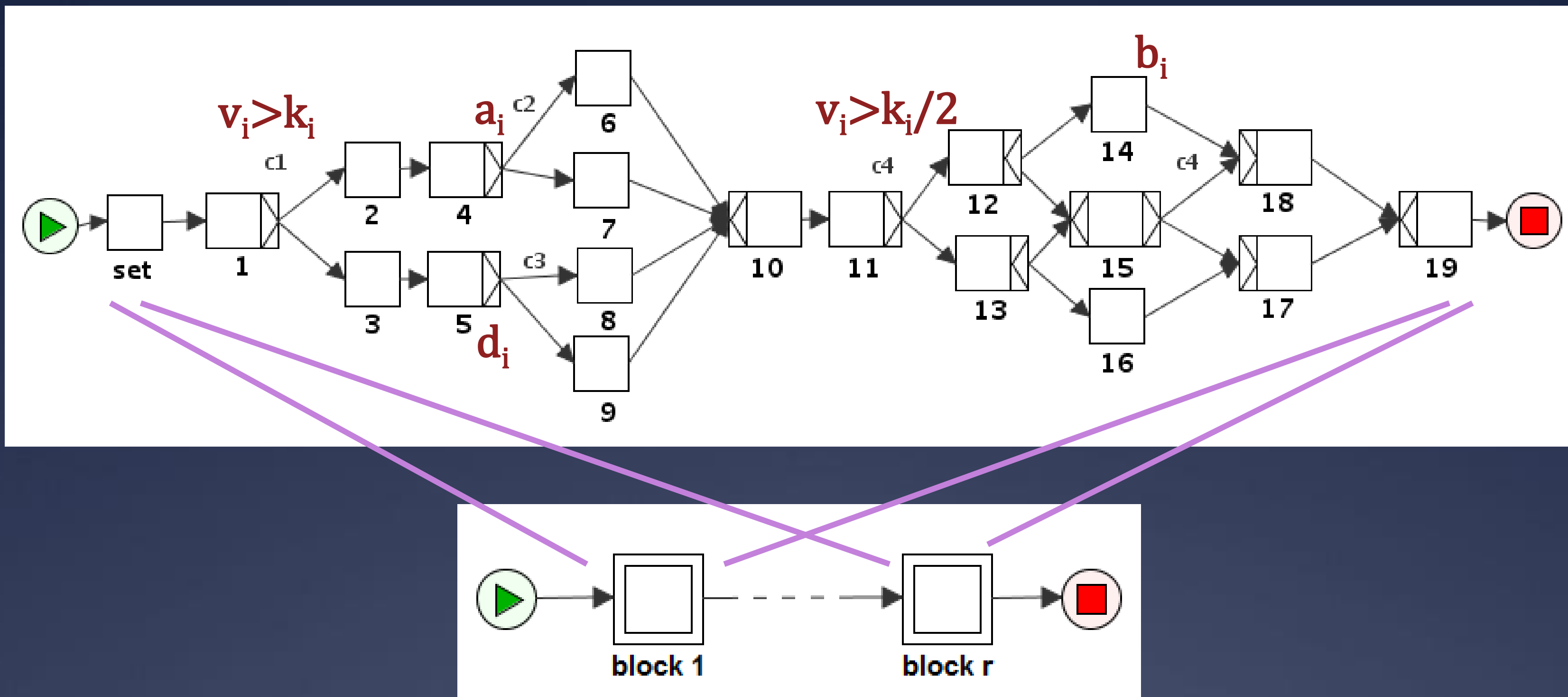
$\square(d_1 \rightarrow \lozenge\, b_r)$ **non valid**

Scalability



Variant with (pure) ASP conditions (run in *clingo*)

Scalability



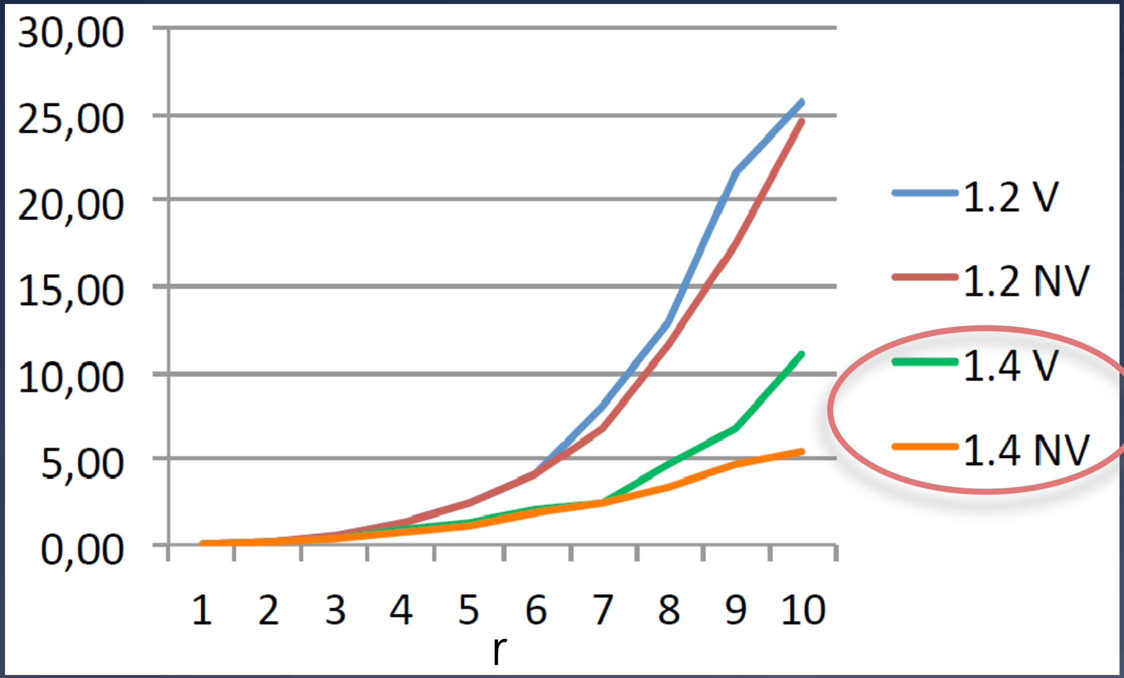
but $c4_r$ is $\bigwedge(v_i > k_i'/2)$, with $k_i' < k_i$, then, O(12^r) runs and

$\Box(\bigwedge a_i \rightarrow \Diamond b_r)$ **valid**

while

$\Box(\bigwedge d_i \rightarrow \Diamond b_r)$ **non valid**

Scalability



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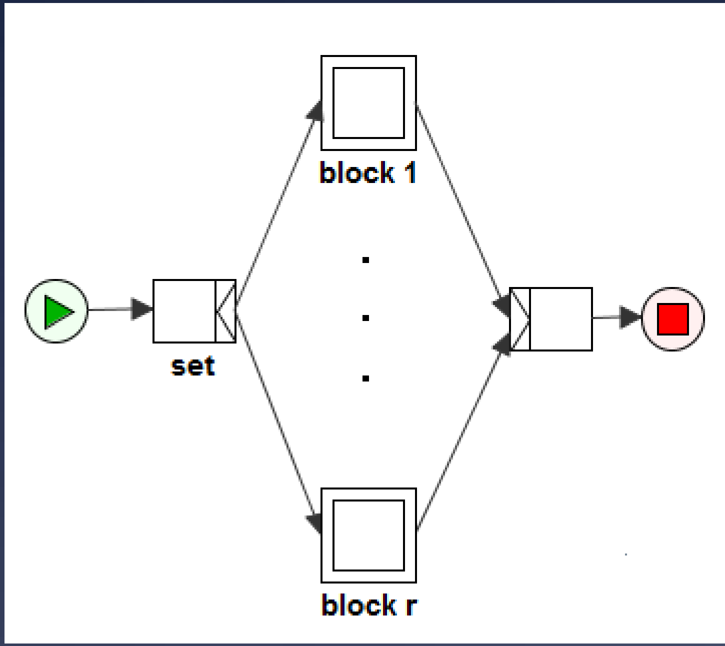

$c1_i$ is $v>k_i$ ($v_i>k_i$)

$c4_i$ is $v>k_i/2$ ($v_i>k_i/2$)

$\square \wedge (a_i \rightarrow \Diamond\, b_i)$ **valid**

$\square\ \wedge (d_i \rightarrow \Diamond\, b_i)$ **non valid**

r=4 $10^{25} \div 10^{28}$ different runs, $10 \div 100$ s verification time

r=5 $10^{36} \div 10^{40}$ different runs, $100 \div 10000$ s verif. time

Conclusions

Constraint Temporal Answer Set Programming combines temporal logic with:

- Nonmonotonic knowledge representation of actions and change [Giordano, Martelli & T.D. TPLP 13], also suitable for flexible modeling of obligations [Giordano et al ICAIL 13]
- Constraint reasoning

We have shown that current (C)ASP technology already makes the framework useful for **verifying compliance of business processes** (also) **involving conditions on numerical data**