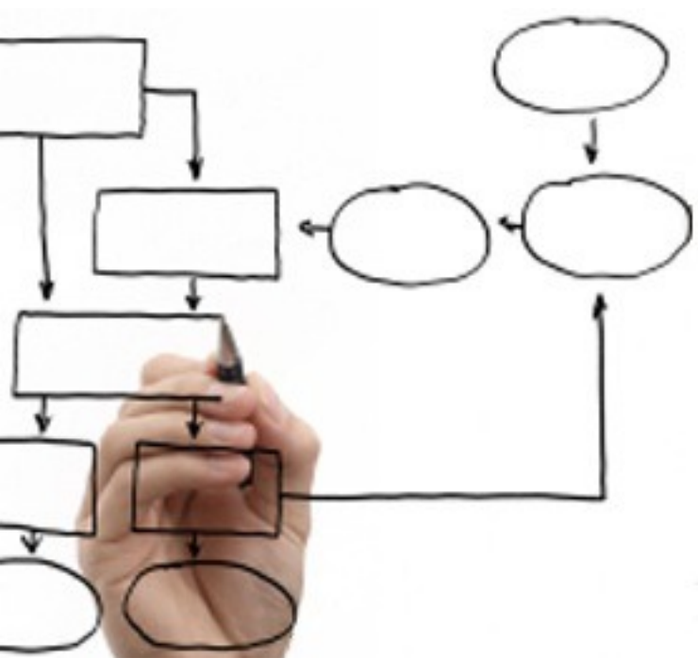
Methods for the specification and verification of business processes

MPB (6 cfu, 295AA)



Roberto Bruni

http://www.di.unipi.it/~bruni

17 - Diagnosis for WF nets

Object

We study suitable diagnosis techniques for unsoundness of Workflow nets

Some Pragmatic Considerations

We know that for a number of important classes of nets, liveness and boundedness can be decided efficiently (in polynomial time)

but we want to check soundness for a wider range of nets

Moreover, when a process is not sound, some diagnostic can be generated that indicates why it is flawed

Woflan (now inside WoPeD)

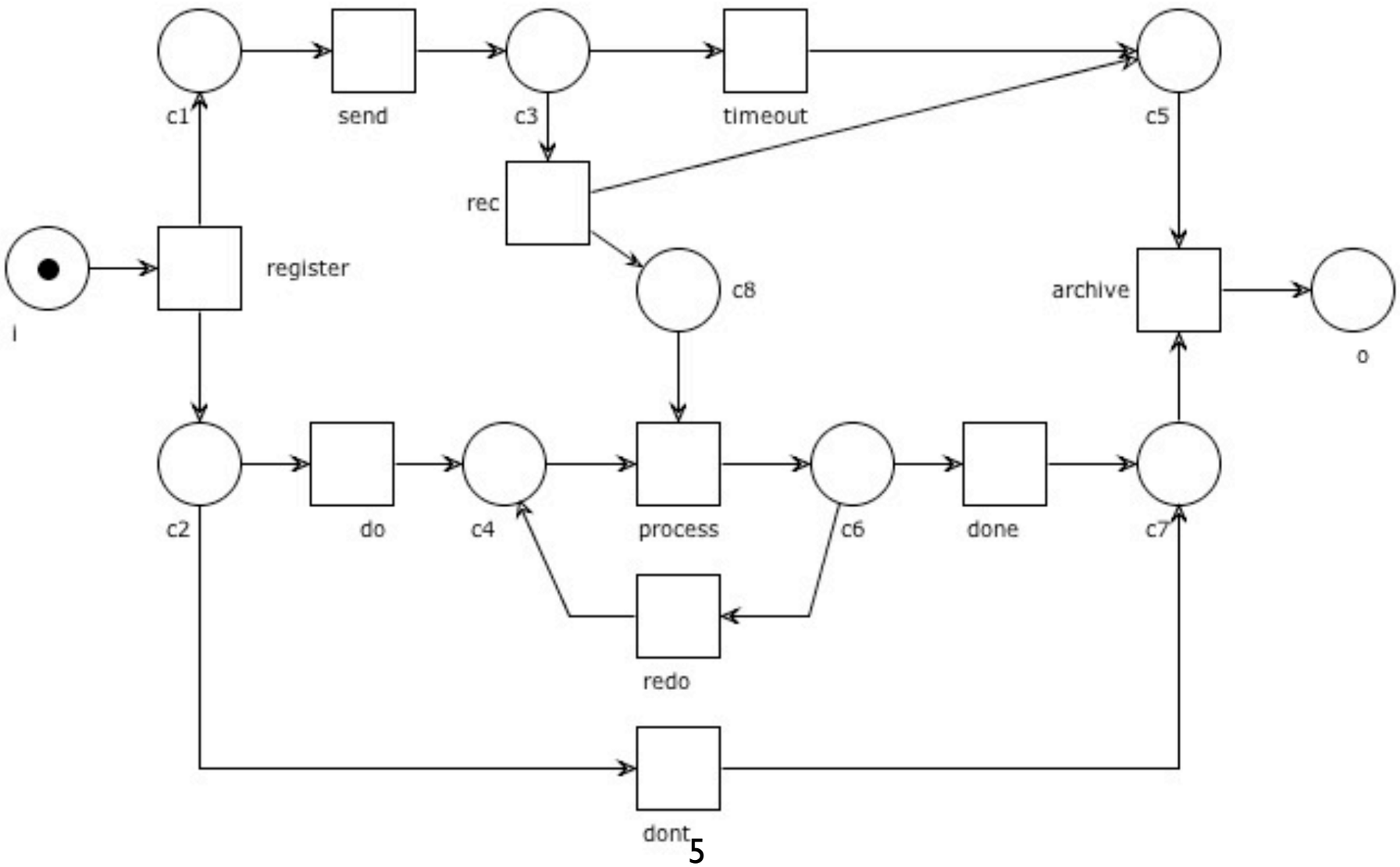
WOrkFLow ANalyzer (Windows only)
http://www.win.tue.nl/woflan/

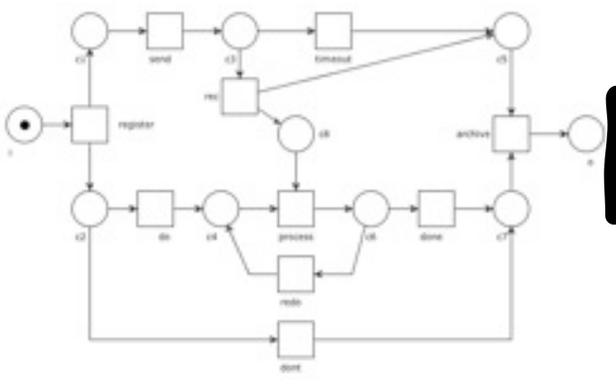
Woflan takes a workflow process definition (imported from some workflow product)

Woflan translates it to a Petri net N

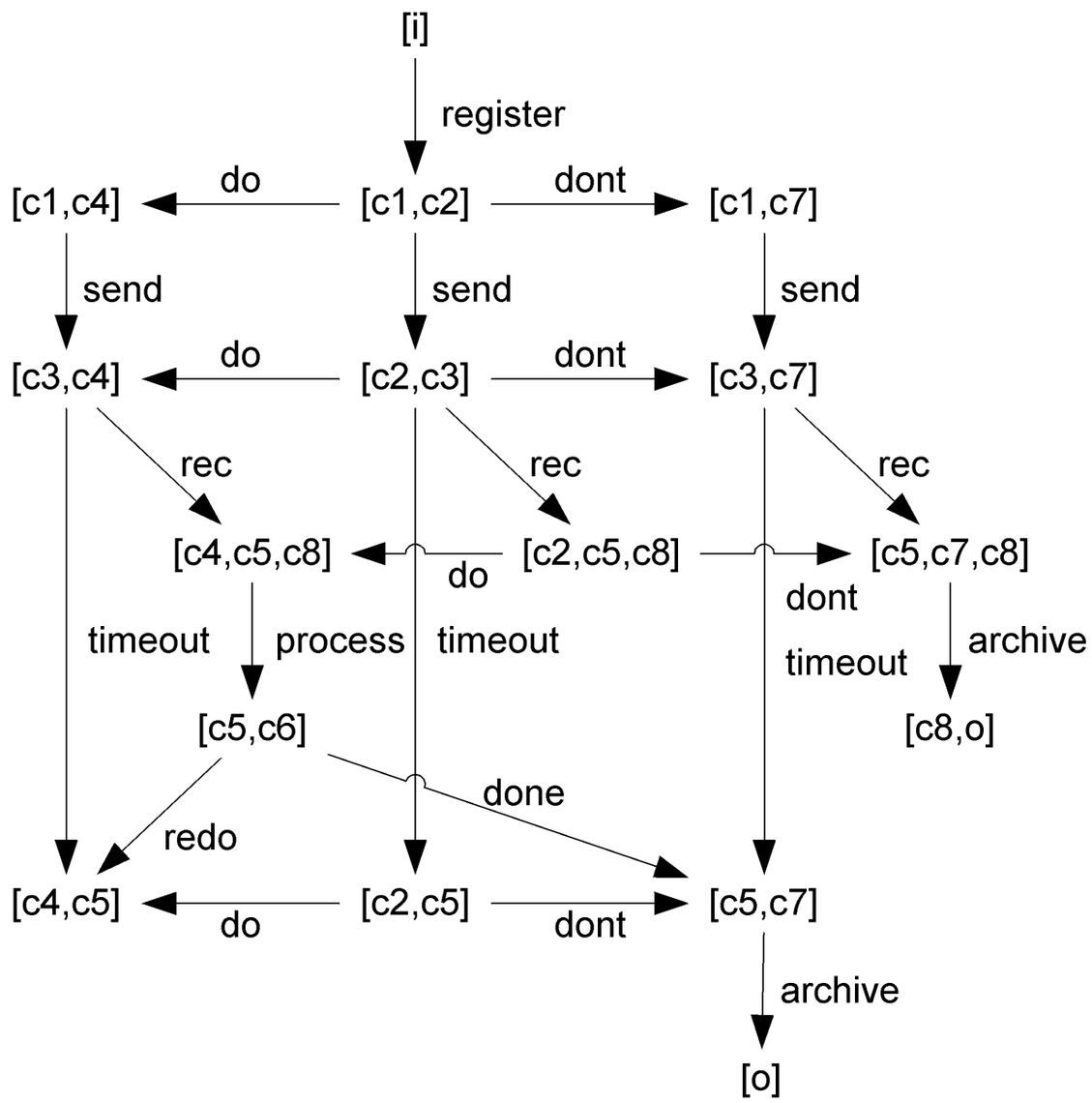
Woflan tells us if N is a sound workflow net
(Is N a workflow net? Is N* bounded? Is N* live?)
if not, provides some diagnostic information

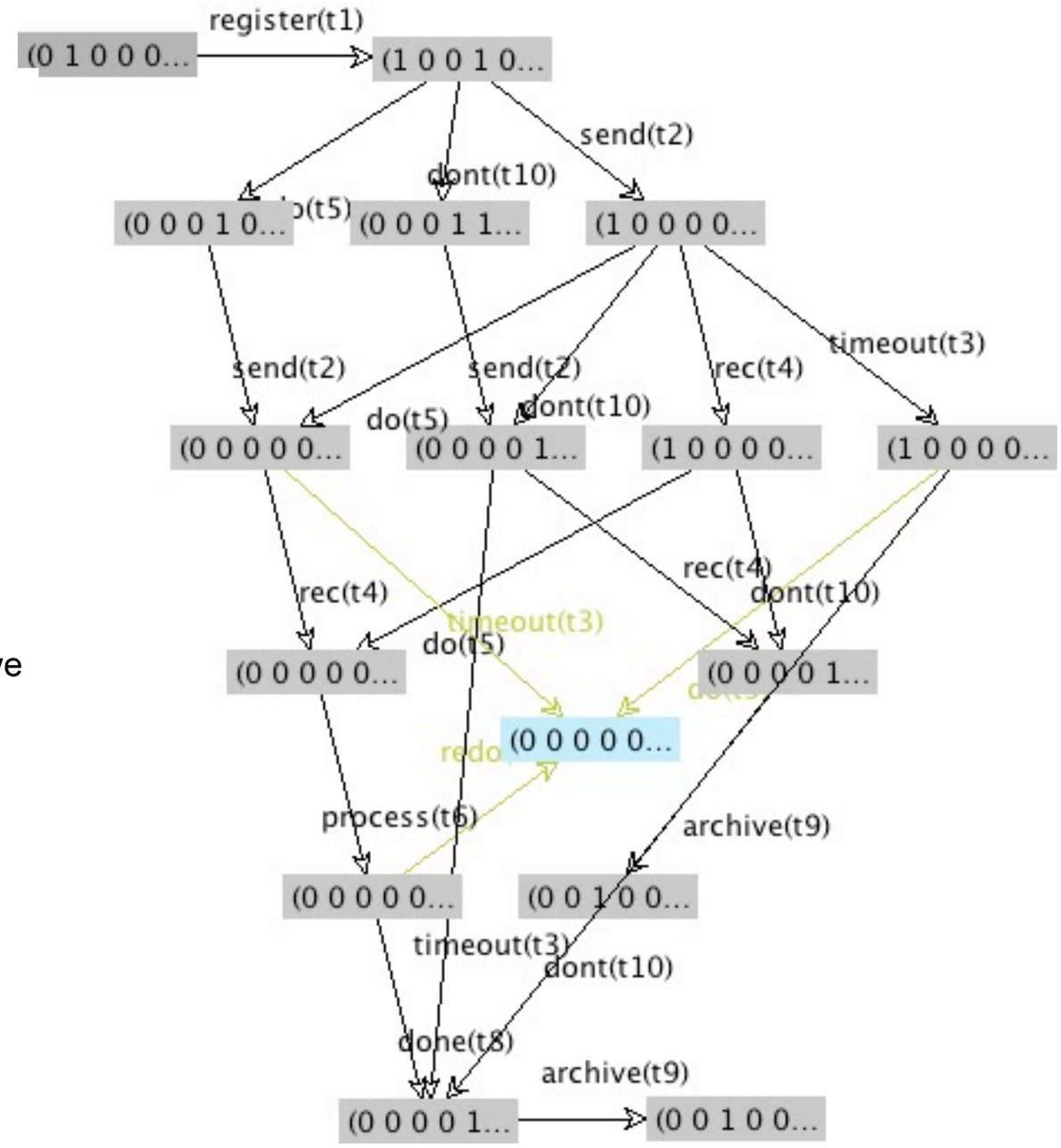
Running example



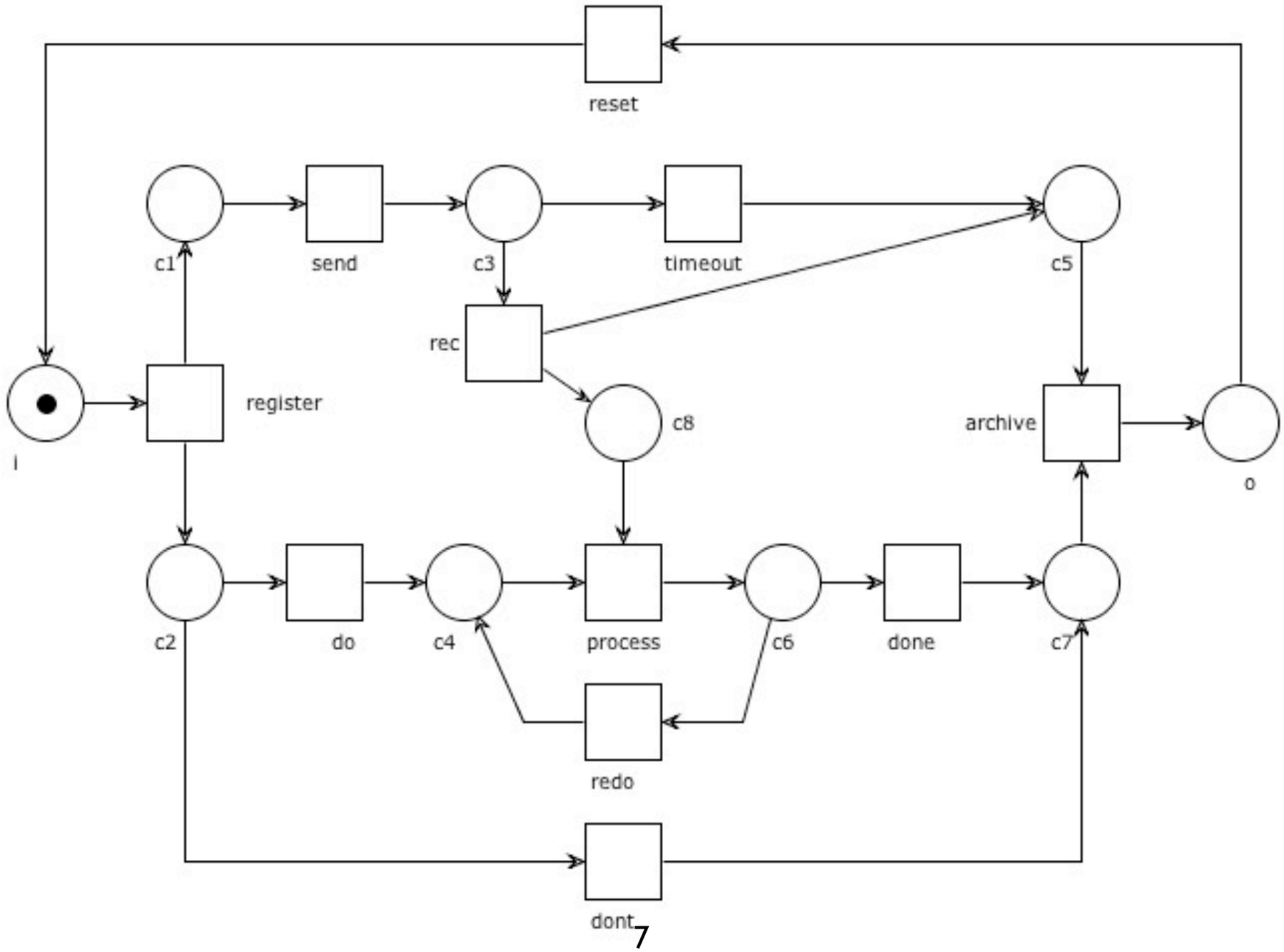


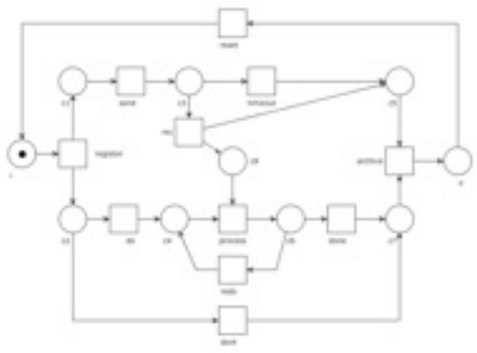
Running example



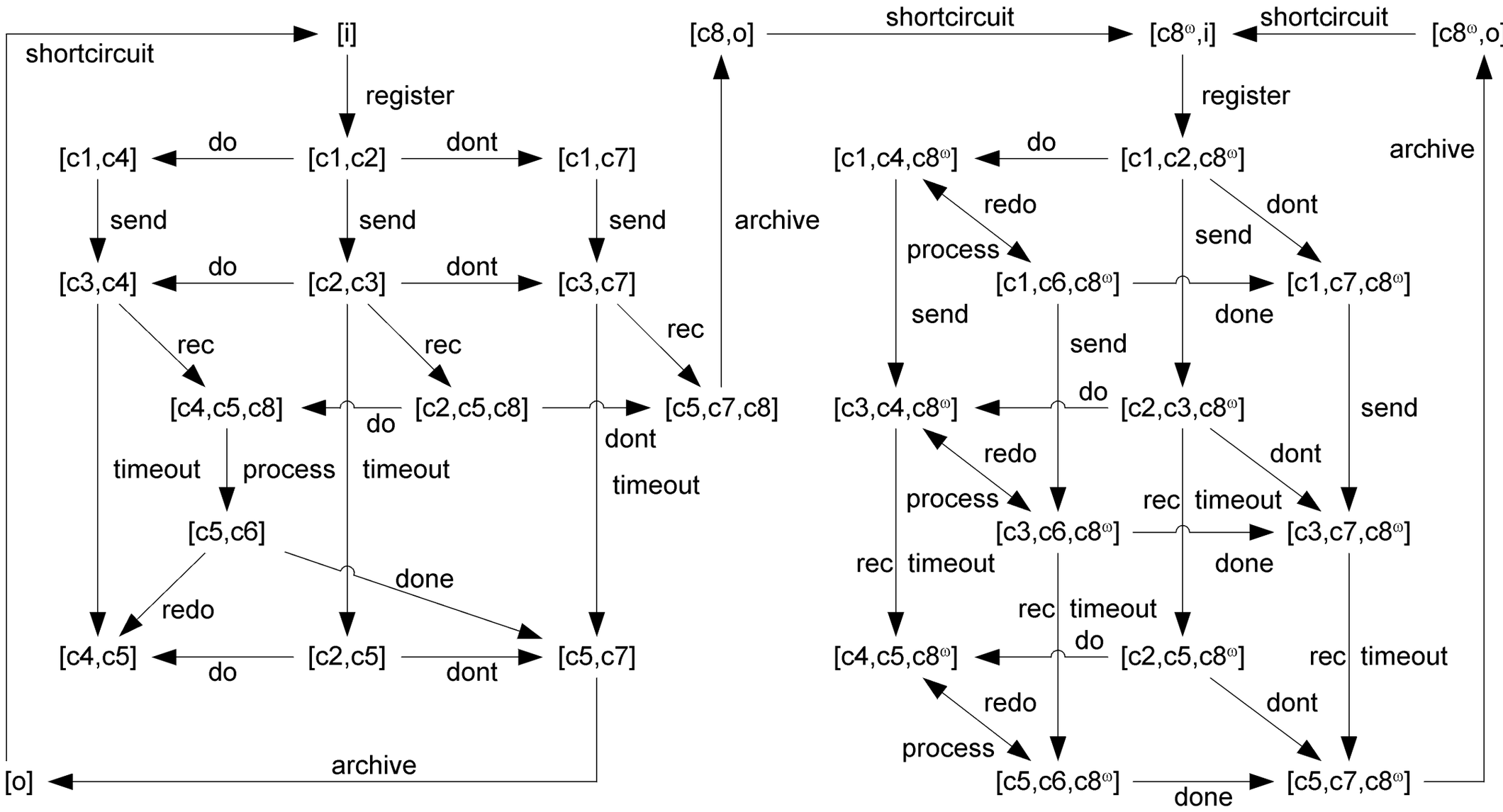


Running example: short-circuited





Running example: short-circuited



Structural analysis

S-Invariant analysis

If every place of N* is covered by a semi-positive S-invariant
then N* is bounded

Places not covered by semi-positive S-invariants are potential sources of errors

S-Coverability analysis

S-coverability is one of the basic requirements
any workflow process definition should satisfy

From a formal point of view:
there exists WF-nets which are sound but not S-coverable

Typically, these nets contain places
which do not restrict the firing of a transition,
but which are not in any S-component

S-Coverability analysis

A case is often composed by parallel threads of control (each thread imposing some order over its tasks)

The notion of S-coverability allows to reveal such threads

Quick reminder

A **subnet** $N' = (P', T', F')$ of $N = (P, T, F)$ consists of:

- a subset $P' \subseteq P$ of places
- a subset $T' \subseteq T$ of transitions
- the subset $F \cap ((P' \times T') \cup (T' \times P')) \subseteq F$ of arcs

An **S-component** is a subnet $N' = (P', T', F')$ of N that:

- is a strongly-connected S-net $(\forall t \in T'. |\bullet t| = |t \bullet| = 1)$
- for any $p \in P'$ we have $\bullet p \cup p\bullet \subseteq T'$

Quick reminder

In a S-component,
the total number of tokens in its places is constant

Any S-component
induces a uniform invariant (weights 0 and 1)

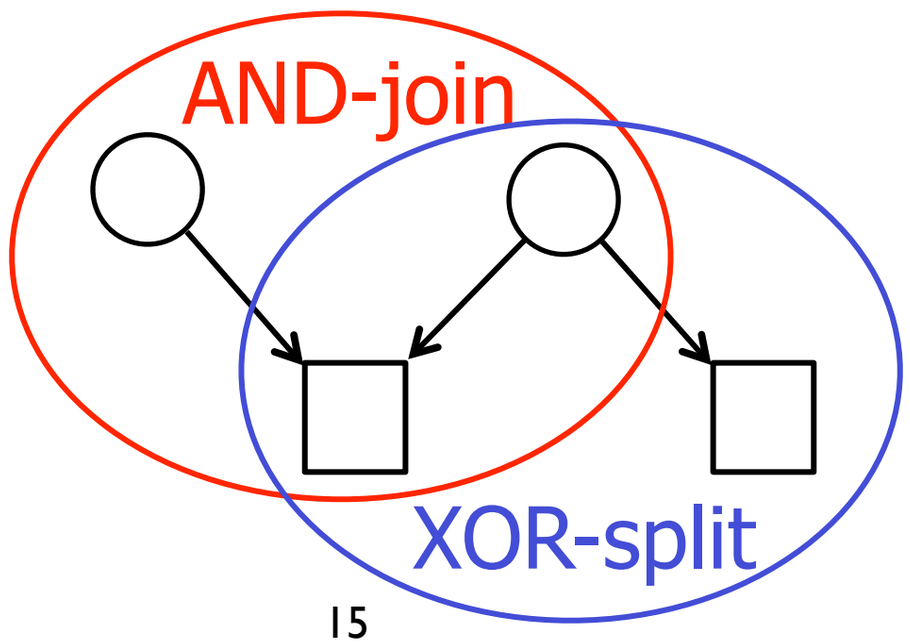
A net is **S-coverable** iff
any $p \in P$ belongs to some S-component

S-coverability implies boundedness
(because it induces a positive S-invariant)

Quick reminder

Recall that a net is **free choice** if
for any two transitions t_1 and t_2 then
either $\bullet t_1 = \bullet t_2$ or $\bullet t_1 \cap \bullet t_2 = \varnothing$

Non free-choice:
two tasks share some but not all preconditions
like a XOR-split that overlaps with an AND-join



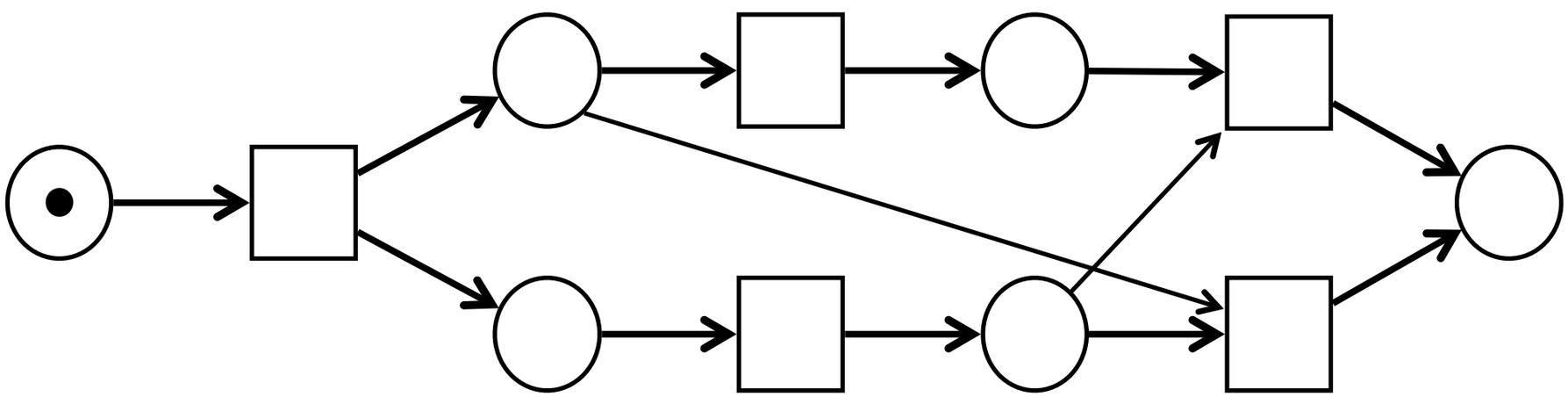
Free-Choice vs Soundness

Note that free-choice is orthogonal to soundness:

there exists WF-nets that are free-choice but not sound

there exists WF-nets that are sound but not free-choice

(below: non free-choice but sound)



S-Coverability diagnosis

A net which is free-choice, live, and bounded must be S-coverable

If N* is free-choice, live and bounded must be S-coverable

Theorem: If N is sound and free-choice, then N* must be S-coverable

If N is free-choice and N* is not S-coverable... then N cannot be sound

S-Coverability diagnosis

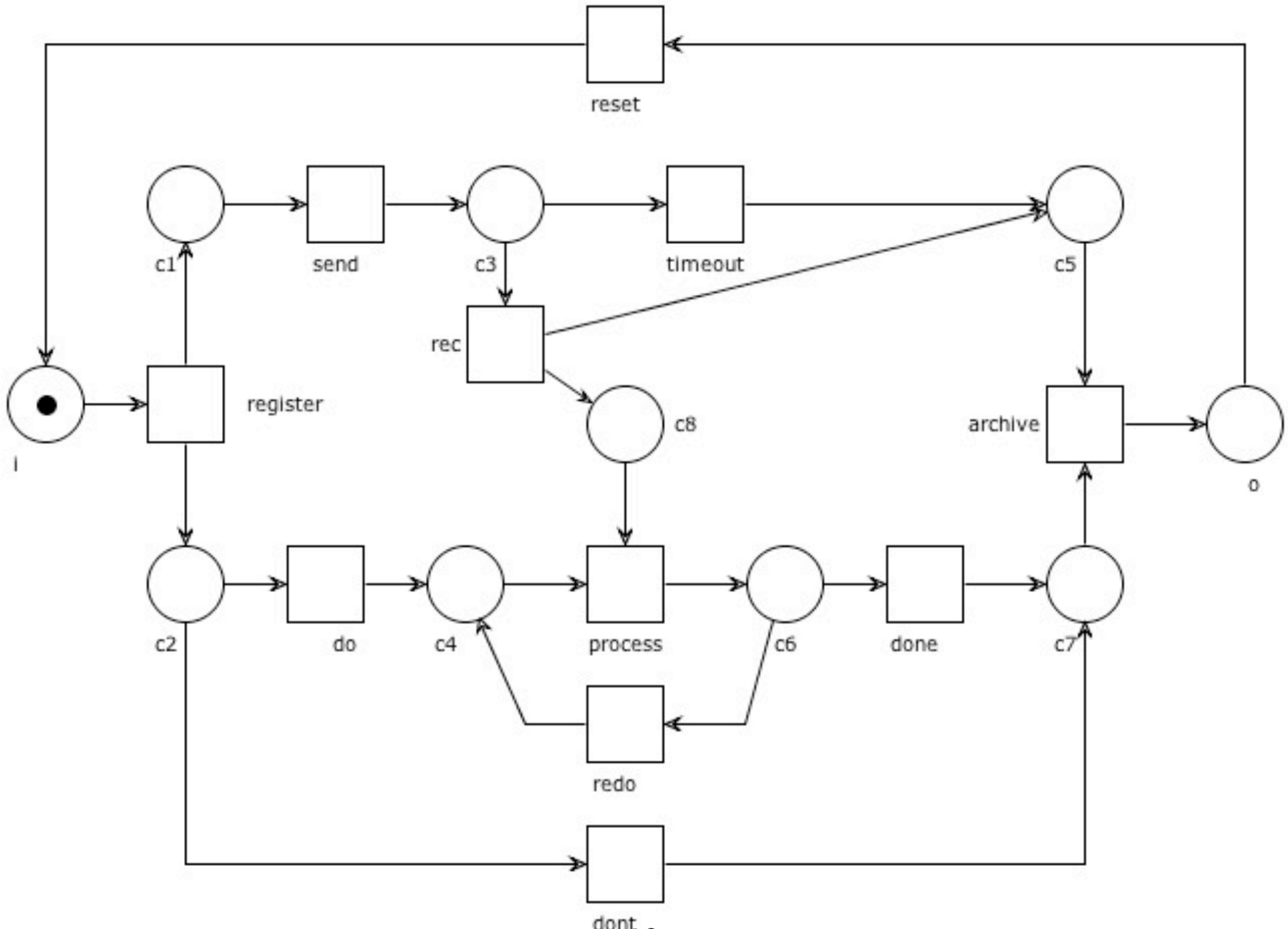
Any S-component of N* includes i, o, reset
(by strong-connectedness)

Places that are not covered by S-component are potential sources of errors

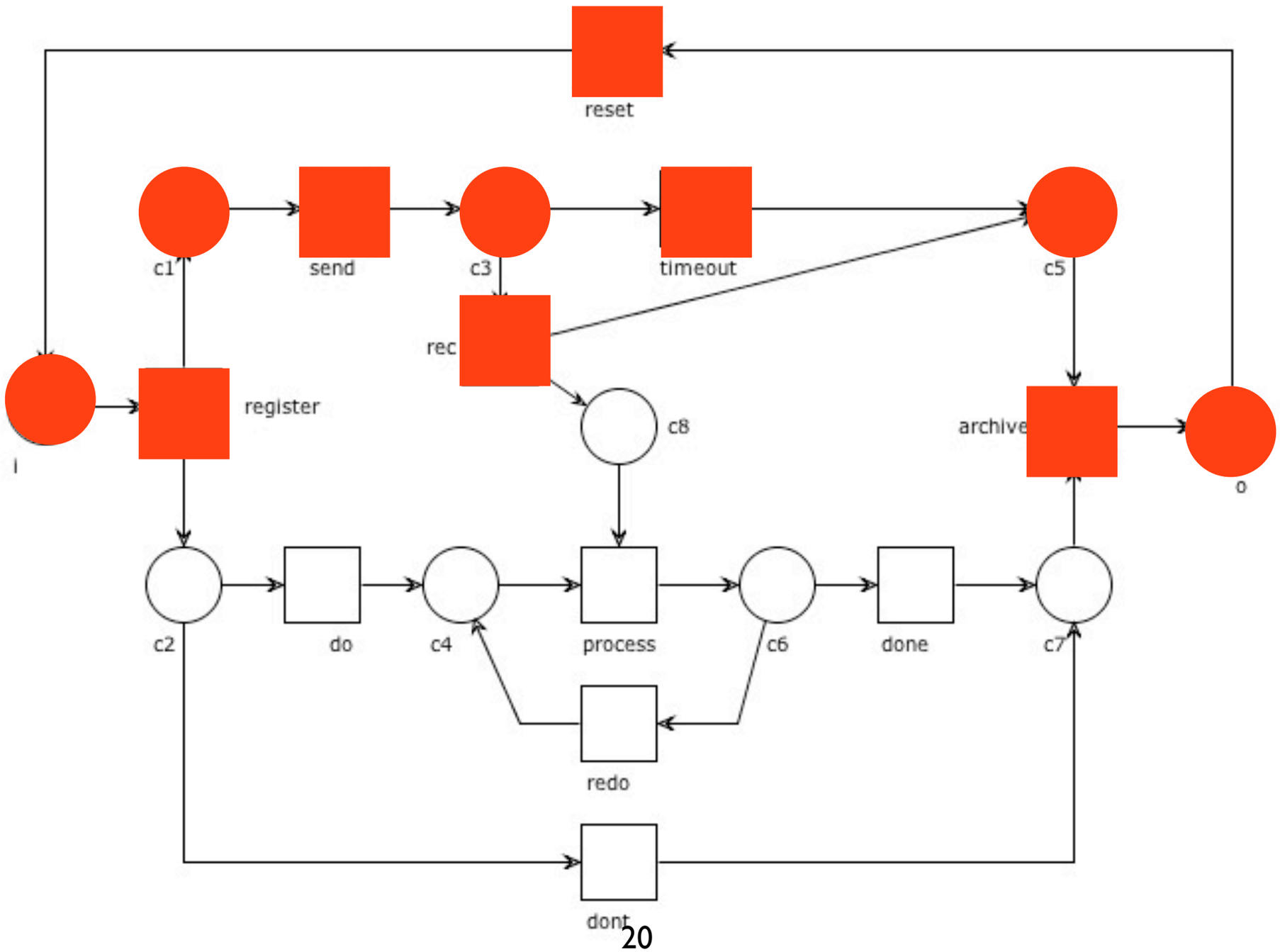
S-coverability is not a sufficient requirement for soundness

N* can be S-coverable even if N is not sound

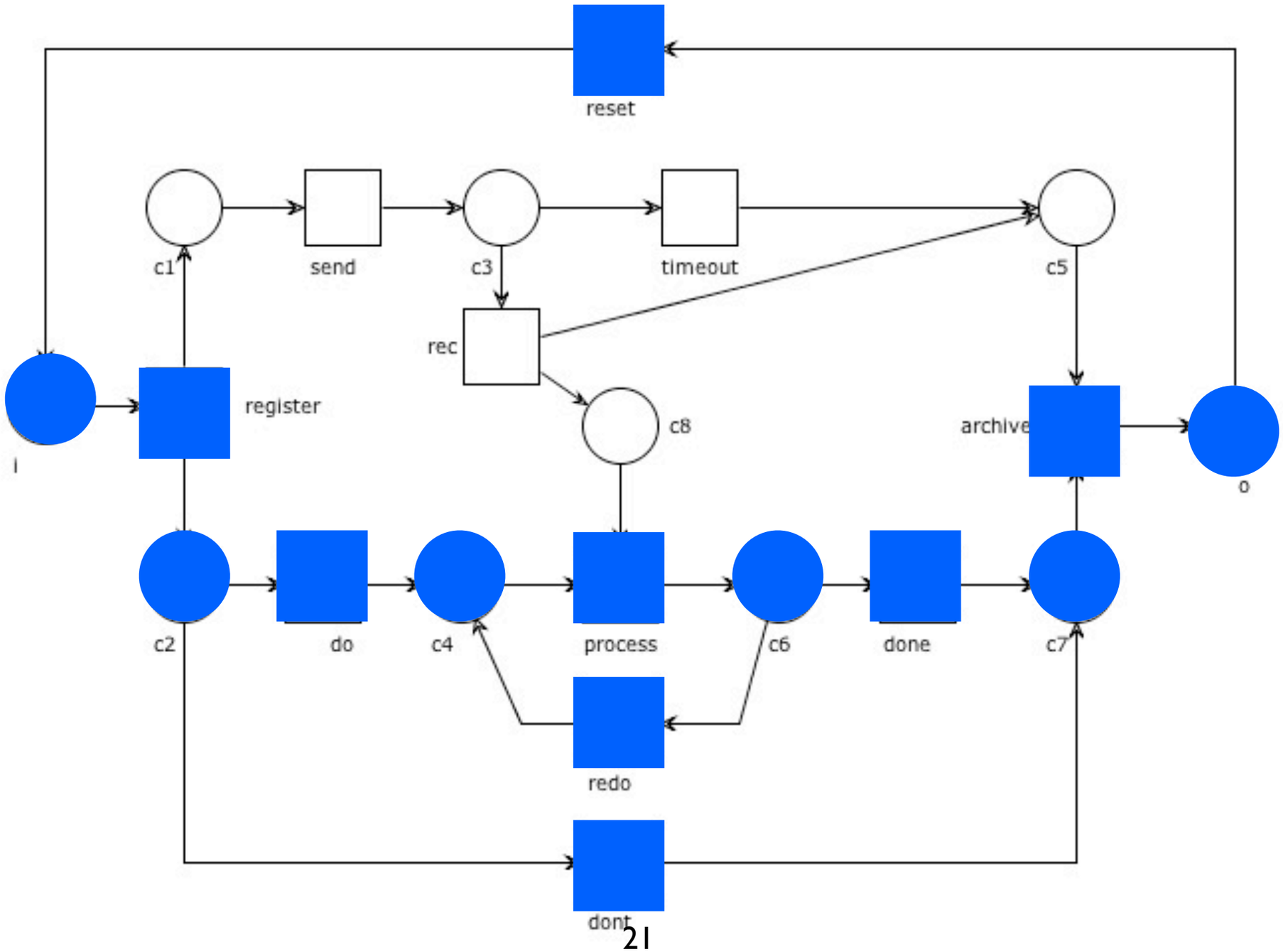
Running example: S-cover for N* ?



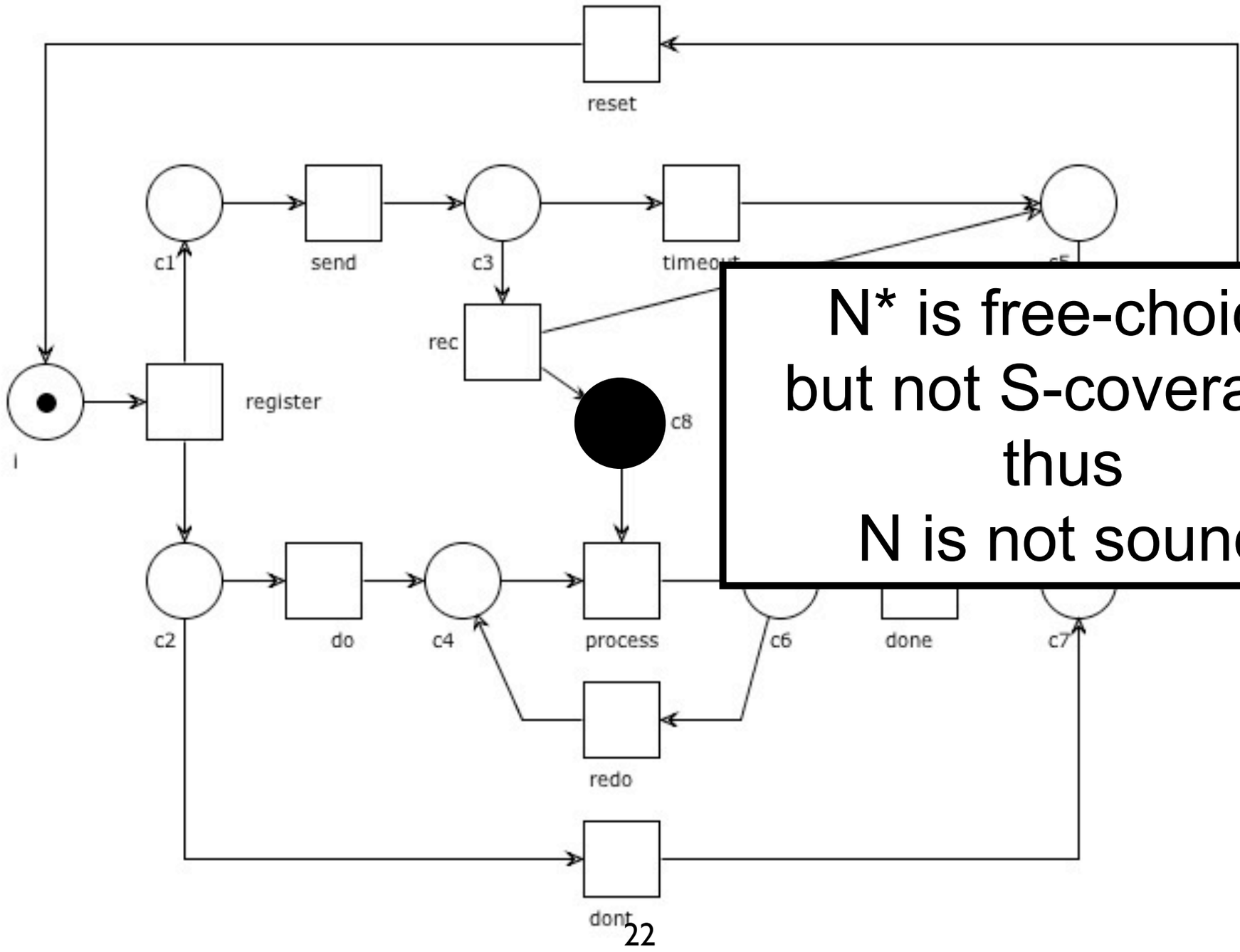
Running example: S-cover for N* ?



Running example: S-cover for N*



Running example:
S-cover for N* ? No



N* is free-choice
but not S-coverable
thus
N is not sound

Split / Join Balancing

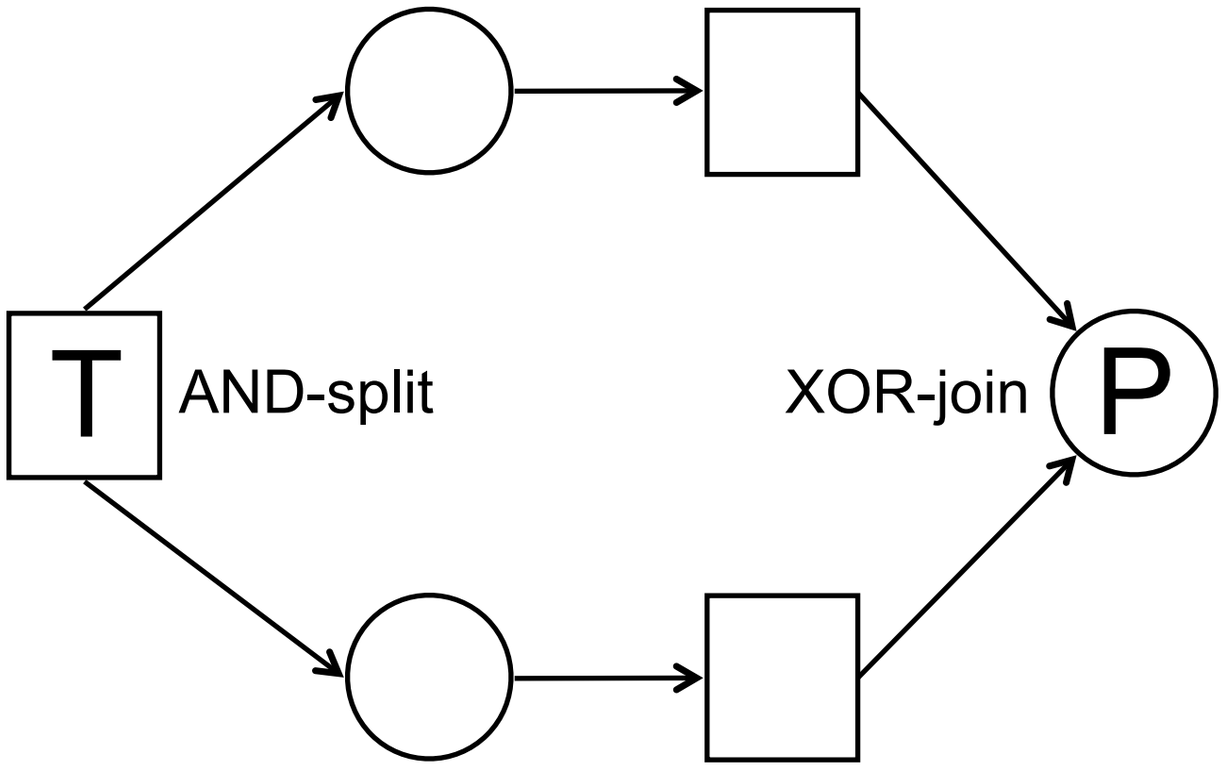
A good workflow design is characterized by a balance between AND/XOR-split and AND/XOR-joins

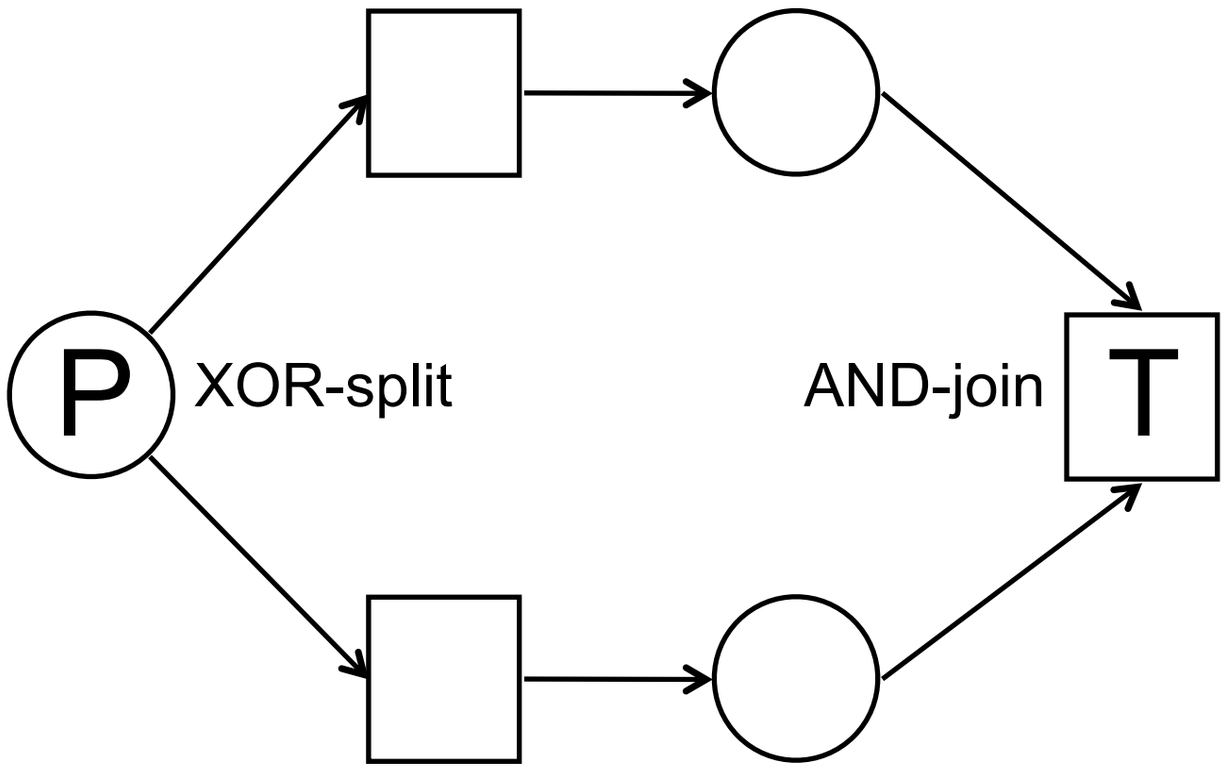
Any mismatch is a potential source of errors:

two alternative flows created via a XOR-split should not be synchronized by an AND-join **(the net could deadlock)**

two parallel flows initiated by an AND-split should not be joined by a XOR-join **(multiple tokens can be produced in the same place)**

TP-handles & PT-handles: Graphical Examples





TP- and PT-handles

Definition: A transition x and a place y form a **TP-handle** if there are two distinct elementary paths c_1 and c_2 from x to y such that the only nodes they have in common are x,y

Definition: A place x and a transition y form a **PT-handle** if there are two distinct elementary paths c_1 and c_2 from x to y such that the only nodes they have in common are x,y

Well-Structured Nets

A net is **well-handled** iff it has:
no PT-handles and no TP-handles

Definition: A net is **well-handled** iff
for any pair of nodes x and y of different kinds
(one place and one transition)
any two elementary paths c_1 and c_2 from x to y
coincide or have other nodes in common apart x,y

Definition: A workflow net N is said **well-structured**
if N* is well-handled

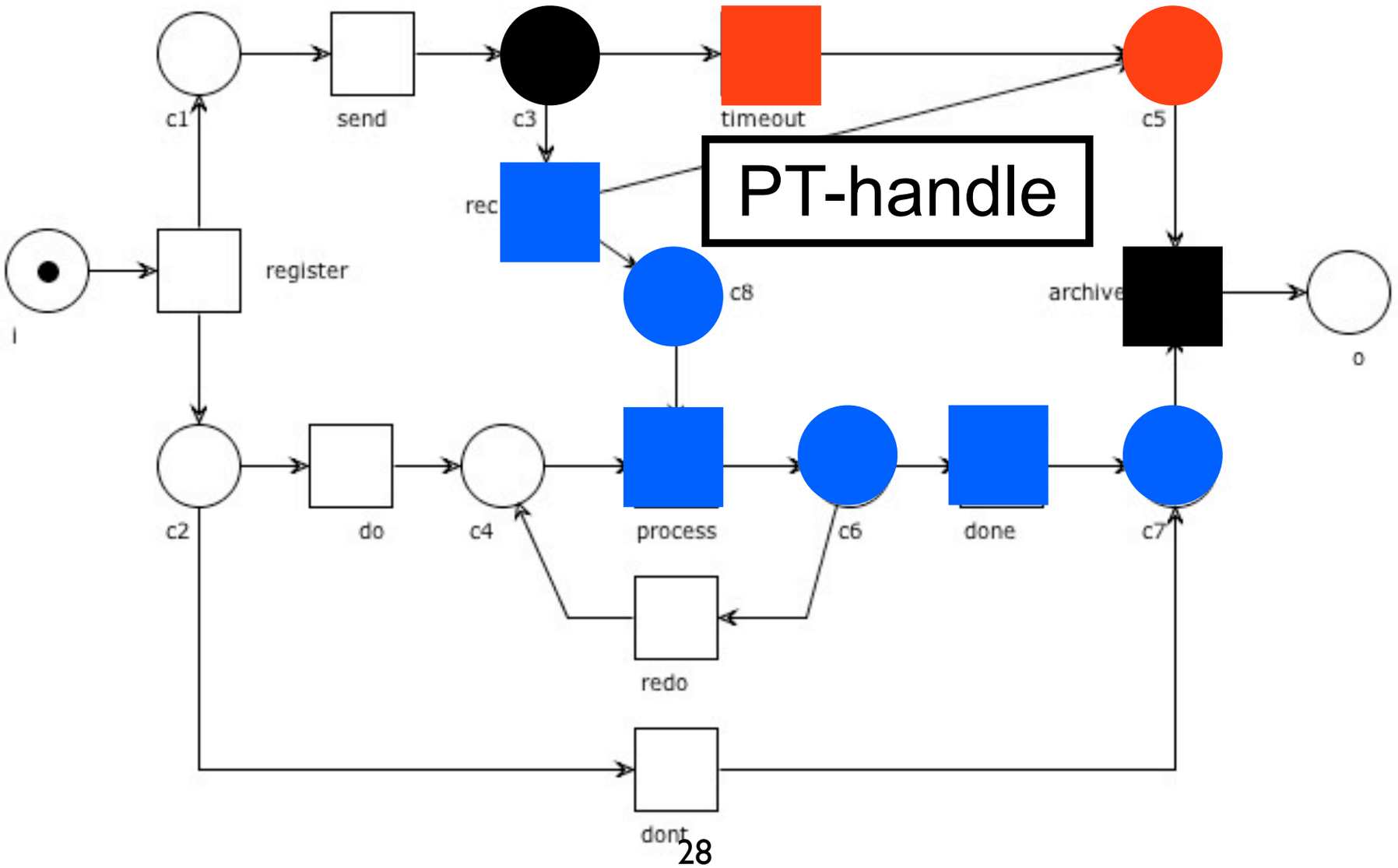
S-coverability diagnosis

Theorem:
If N is sound and well-structured, then N* is S-coverable

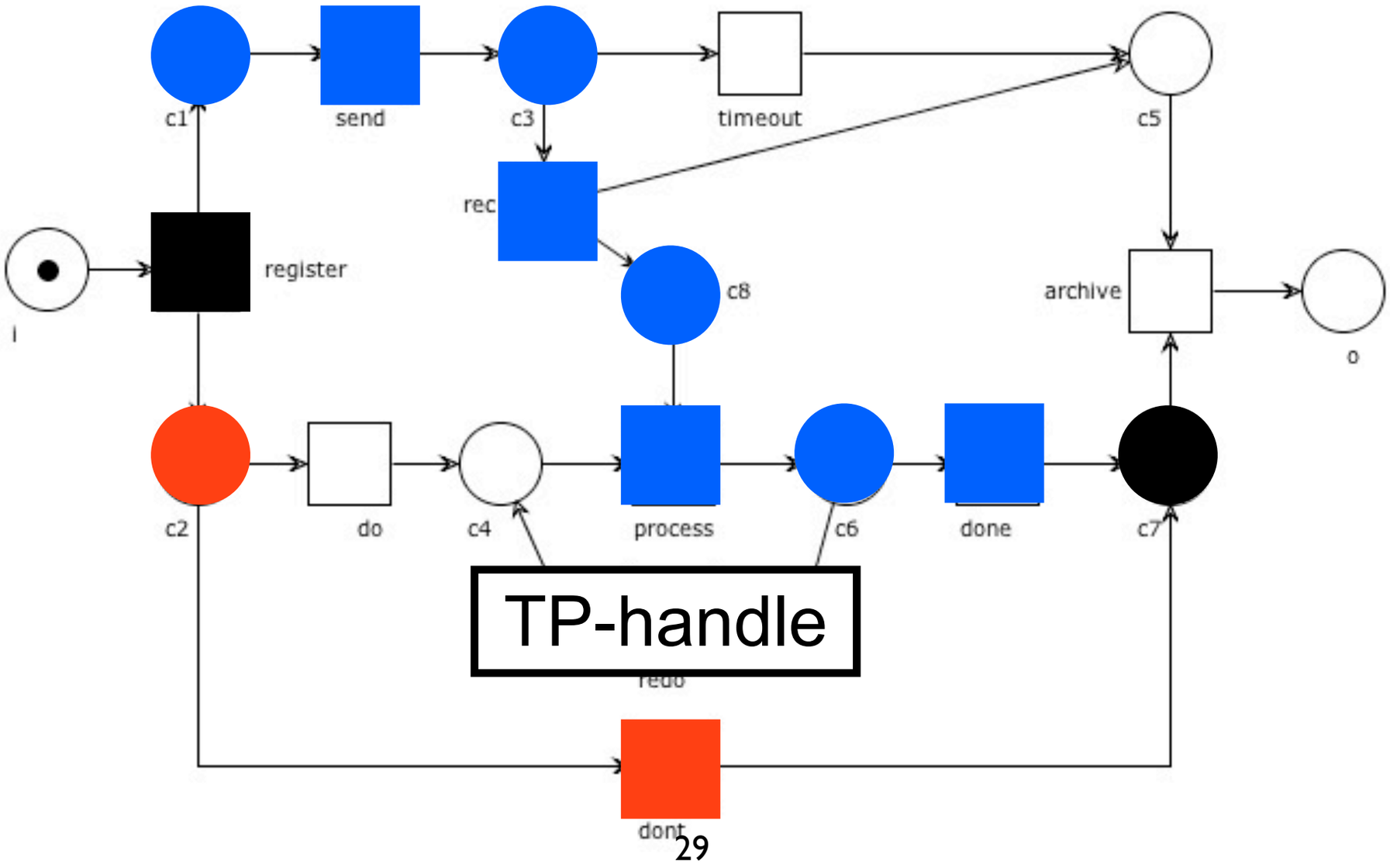
If N is well-structured and N* is not S-coverable...
then it is not sound

Note that
If N* is not well-handled, N can be sound
especially if reset is involved in the handle
(it is a symptom, not a disease)

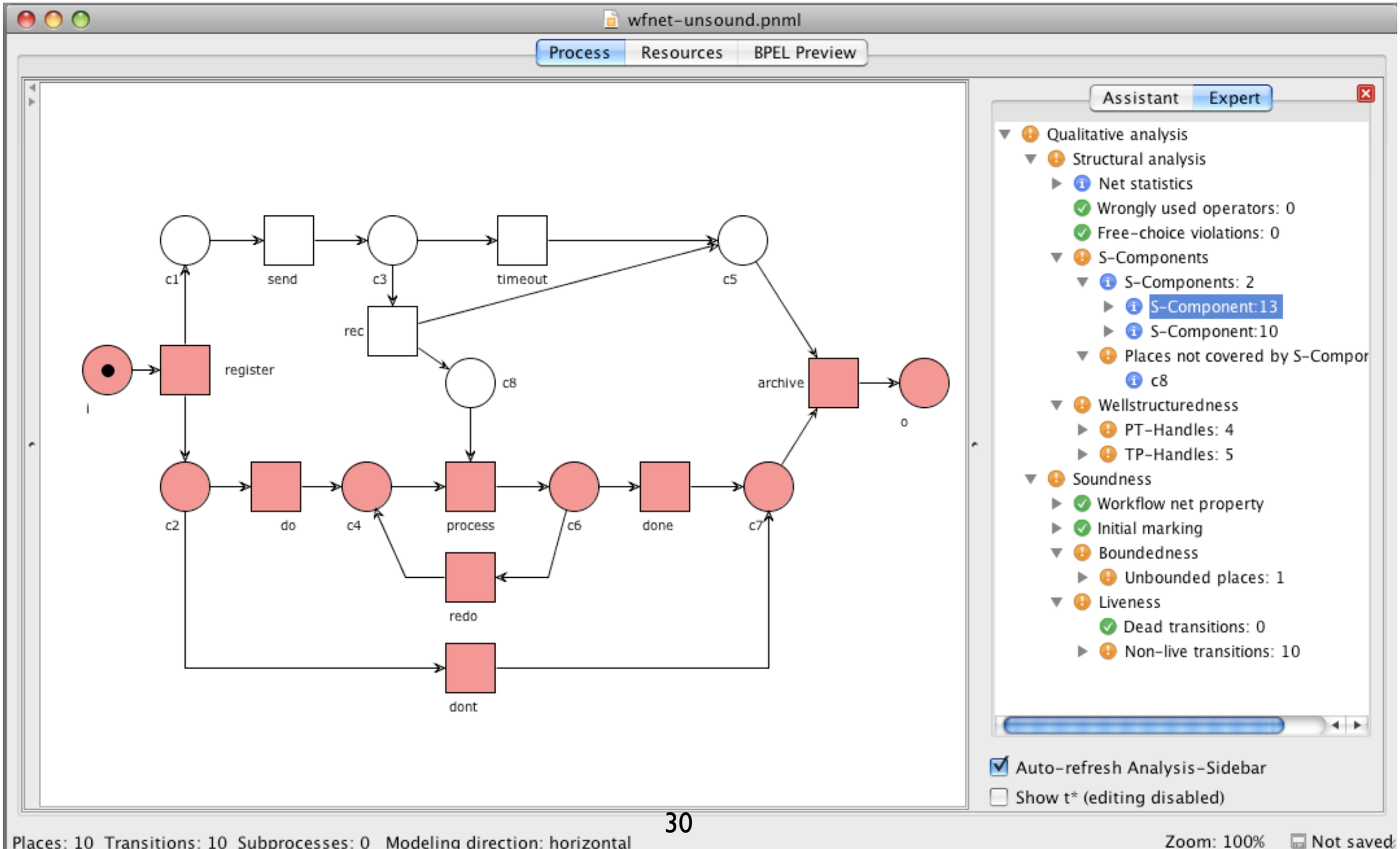
Running example: Well-structured? No



Running example: Well-structured? No



Running Example: WoPeD Diagnosis



Be careful

We are interested in well-structuring of N, not of N*

WoPeD also marks PT/TP-handles over N*

Liveness and boundedness

vs

Soundness requirements

Improper completion

Suppose N completes improperly:
from i we can reach o+M

We can do the same on N*
then we fire reset and reach i+M

we can repeat the same run and reach i+2M
and then i+3M and then i+4M and then ... i+kM

N* has some unbounded places
(all p such that M(p)>0)

Unsoundness from unboundedness

Improper completion of N implies unboundeness of N*

If N* has some unbounded places...
N could complete improperly

Unsoundness from unboundedness

If N has some unbounded places
then N* has some unbounded places...

N could complete improperly
or may violate “option to complete”

Consequences of boundedness

If N* is bounded, then:
if o+M is reachable from i in N, then M=0

If N* is bounded, then...

either N satisfies both
option to complete and proper completion
or N does not satisfy option to complete

Completion option failure

Suppose N does not satisfy the “option to complete”:
then from i we can reach M
from which we cannot mark o

We can do the same on N*
then reset is dead from M
i.e. reset is non-live in N*

N* has non-live transitions

Unsoundness from non-liveness

Option to complete fail for N implies non-liveness of N*

If reset transition is non-live in N*...
N could fail to satisfy completion option

Unsoundness from Non-Liveness

If N* **is bounded and has dead transitions**, then

if reset is dead
N and N* have the same finite reachability graph
hence N has the same dead tasks as N*
(except reset)

if reset is not dead
the reachability graphs of N and N* differ only for $o \xrightarrow{reset} i$
(because N* is bounded)
hence N has the same dead tasks as N*

Unsoundness from Non-Liveness

If **N* has non-live transitions**
then
N could have dead transitions

(but which ones?)

Error sequences

Diagnostic information

The sets of:
unbounded places of N*
dead transitions of N*
non-live transitions of N*

may provide useful information for
the diagnosis of behavioural errors
(pointing to different types of errors)

Unfortunately, this information is not always sufficient
to determine the exact cause of the error

Behavioural error sequences can overcome this problem

Error sequences

Rationale:
We want to find firing sequences such that:

every continuation of such sequences will lead to an error

they have minimal length
(none of its prefixes satisfies the above property)

Informally:
error sequences are scenarios that capture
the essence of errors made in the workflow design
(violate “option to complete” or “proper completion”)

Non-Live sequences: informally

A **non-live sequence** is a
firing sequence of minimal length
such that completion of the case is no longer possible

i.e. a witness for transition reset being non-live in N*

Non-Live sequences: fundamental property

Let N be such that:
N* is bounded
N (or equivalently N*) has no dead task

Then, N* is live
iff
N has no non-live sequences

Non-Live sequences: graphically

The analysis is possible in bounded systems only

Compute the RG of N*
Color in **red** all nodes from which there is **no path** to o

Color in **green** all nodes from which **all paths** lead to o

Color in yellow all remaining nodes
(some but not all paths lead to o)

Non-Live sequences: remarks

No **red** node implies no yellow node

No **green** node implies no yellow node

Non-Live sequences: formally

Definition:

An occurrence sequence

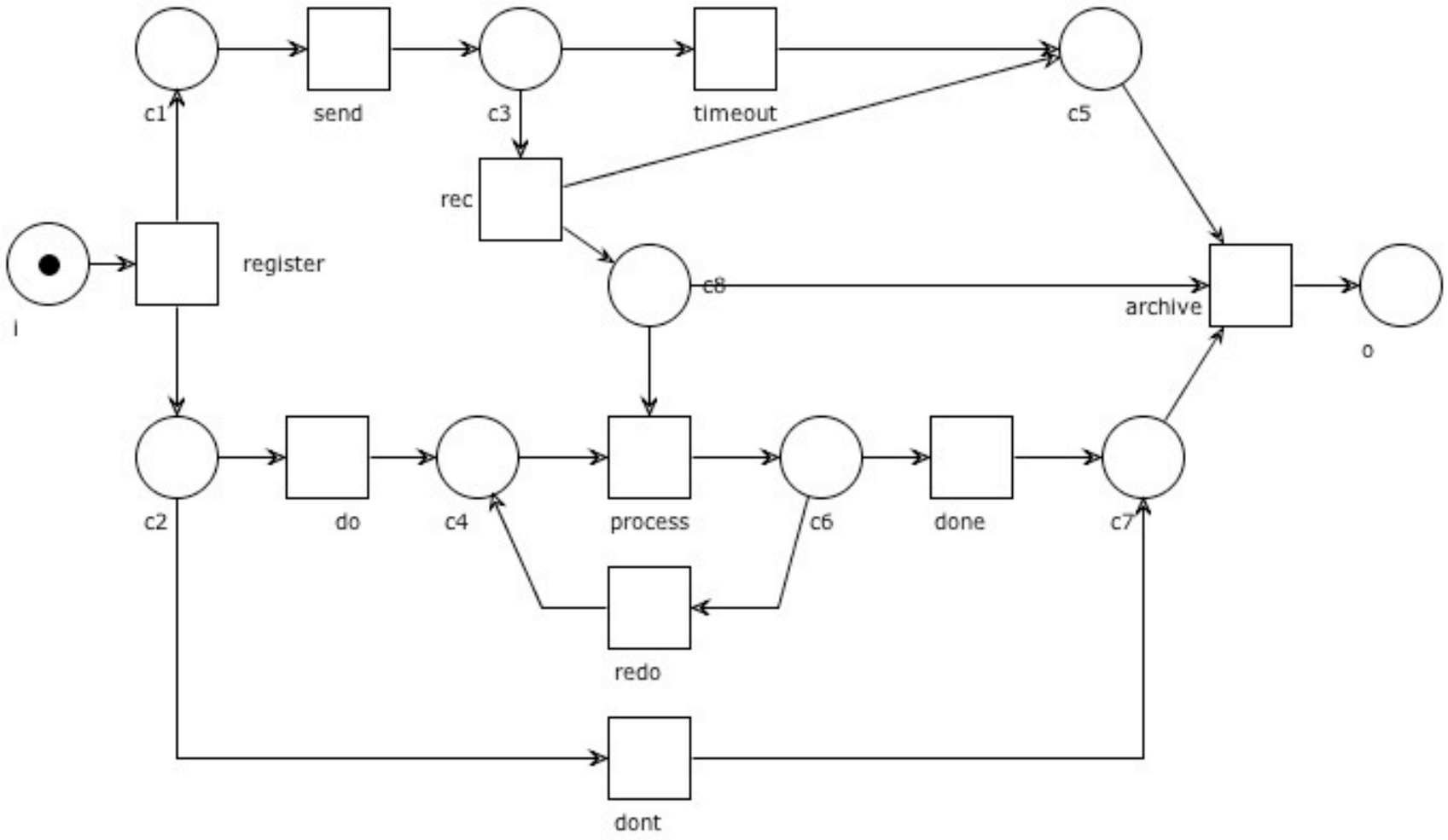
$i \xrightarrow{t_1} M_1 \ldots M_{k-1} \xrightarrow{t_k} M_k$ is **non-live** if

- all markings are distinct
- M_{k-1} is yellow
- M_k is red

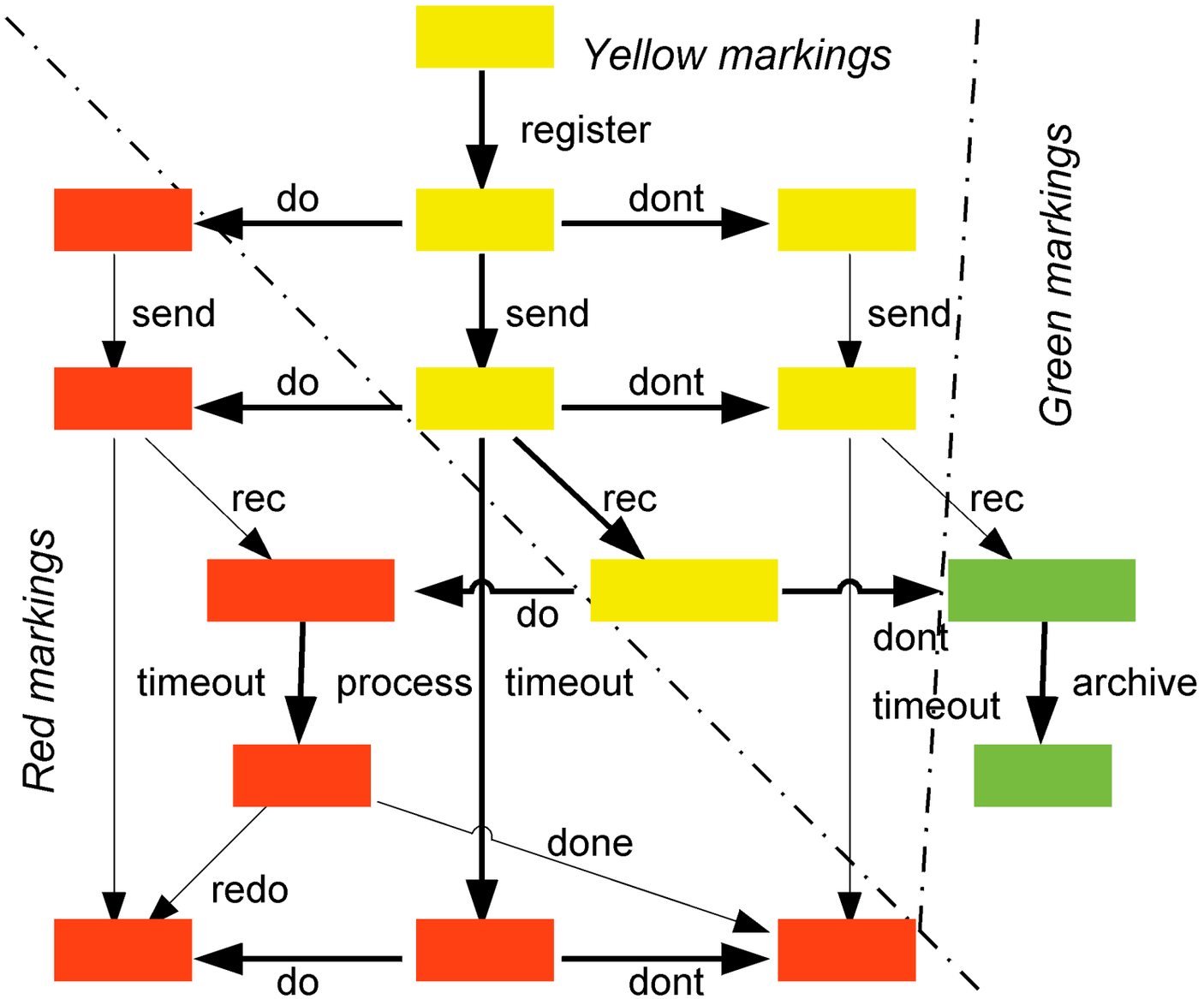
Firing t_k removes the option to complete!

Then, the firing sequence $t_1 \ldots t_k$ is also called **non-live**

Running example: slight variant



Running example variant: colored RG



register, do

register, send, do

register, send, timeout

register, send, rec, do

register, send, dont, timeout

and also?

Unbounded sequences: informally

An **unbounded sequence** is a
firing sequence of minimal length such that
every continuation implies a violation of proper completion

i.e. a witness for unboundedness

Unbounded sequences: fundamental property

N* is bounded
iff
N has no unbounded sequences

Undesired markings:
infinite-weighted markings or markings greater than o

Unbounded sequences: graphically

Compute the CG of N*

Color in **green** all nodes from which
undesired markings are not reachable

Color in **red** all nodes from which
no green marking is reachable
(undesired markings are unavoidable)

Color in yellow all remaining nodes
(undesired markings are reachable but avoidable)

Unbounded sequences: remarks

No **red** node implies no yellow node

No **green** node implies no yellow node

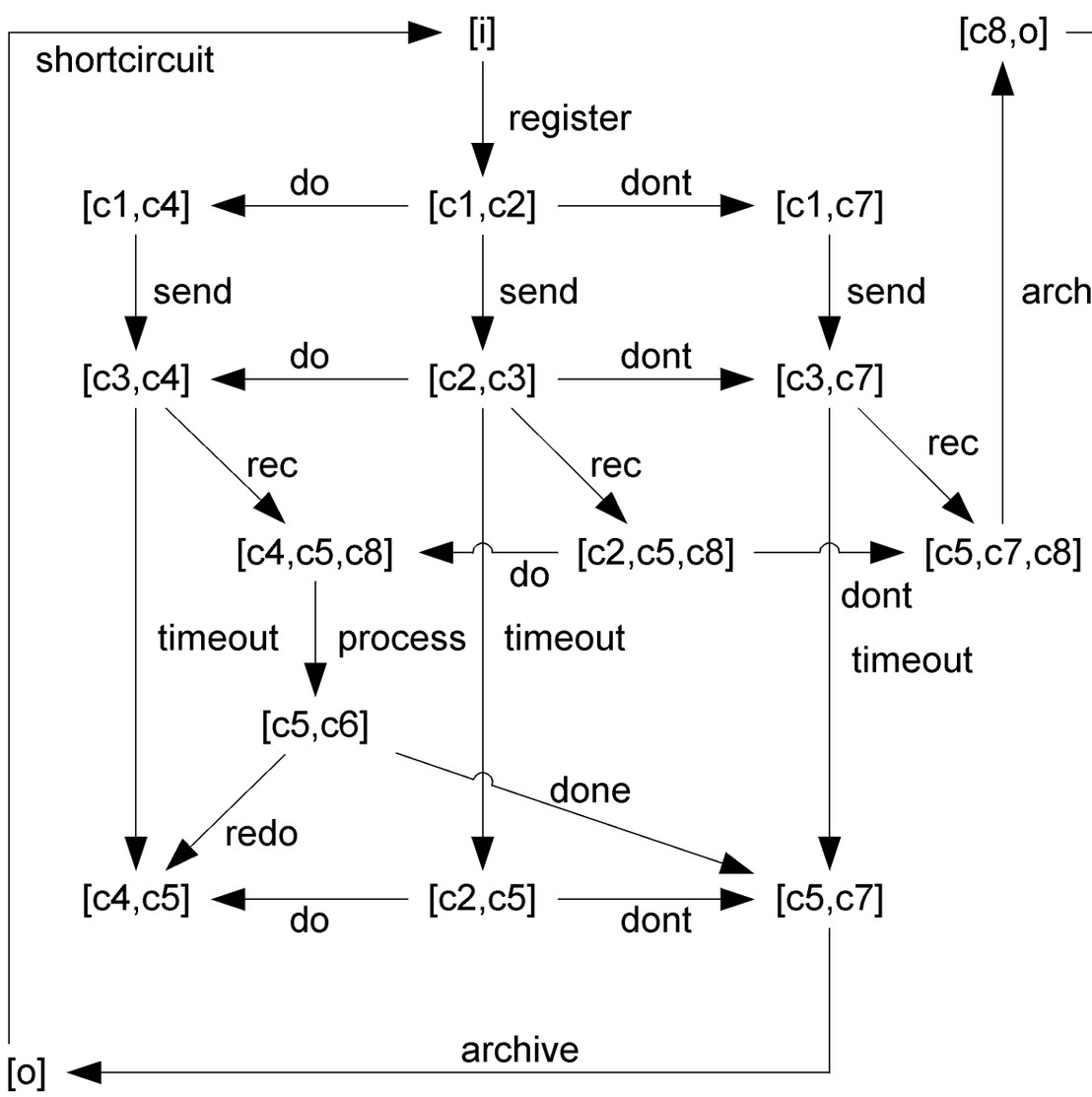
Restricted coverability graph (RCG)

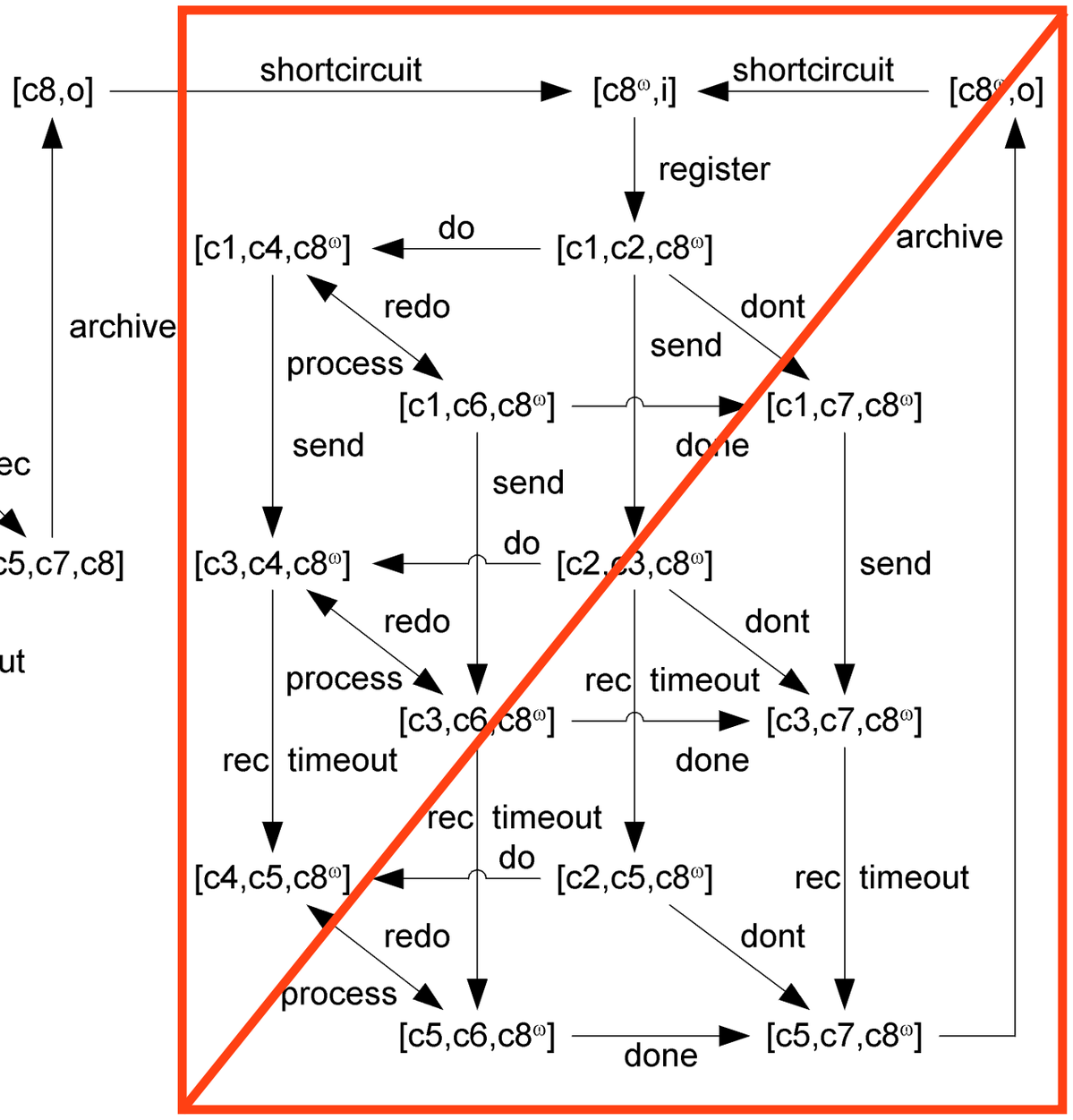
CG can become very large (intractable!)

Basic observation:
infinite-weighted markings leads to infinite-weighted markings
and they will be all red

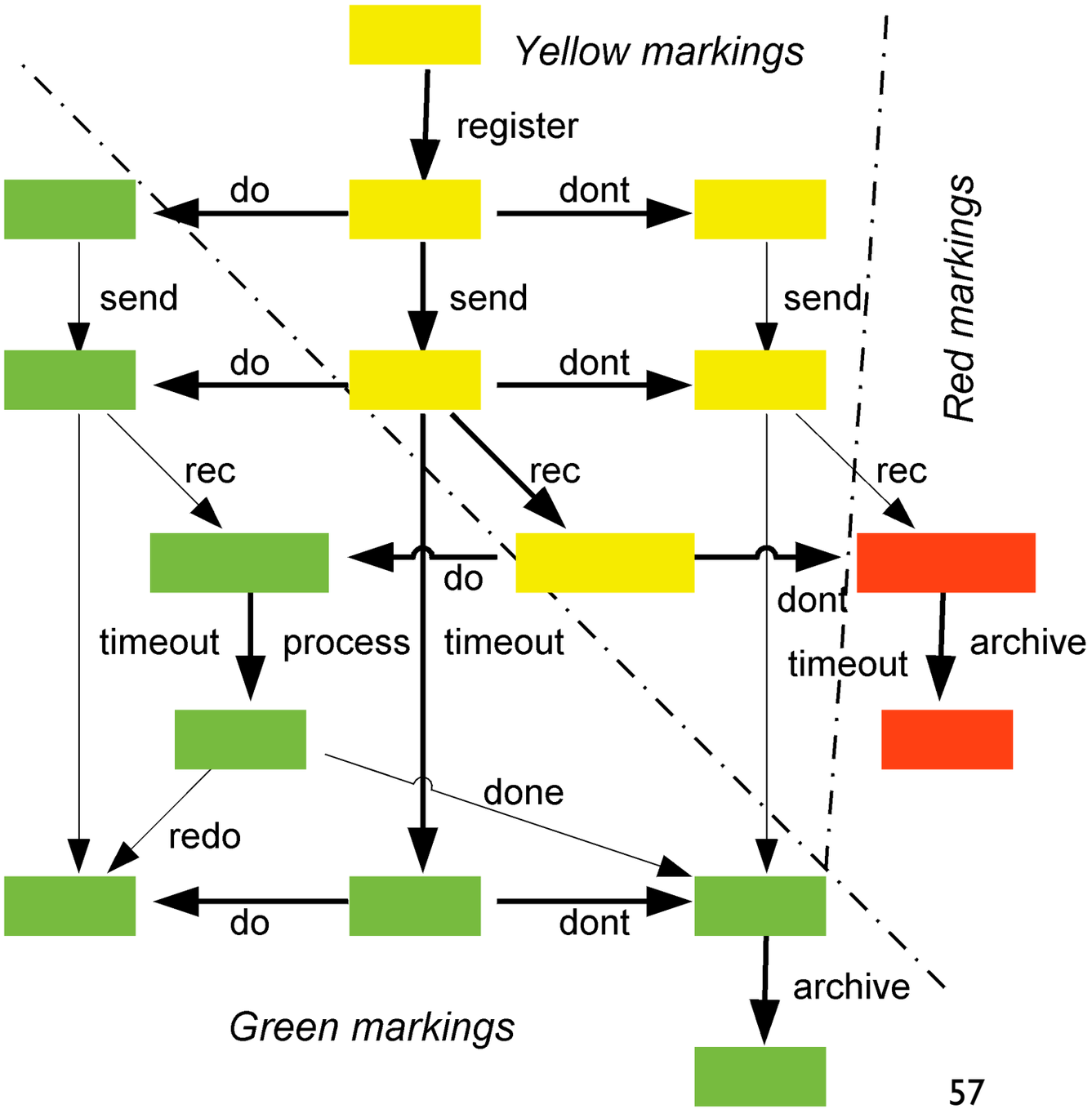
We can just avoid computing them!

Running example: RCG vs CG





Running example: colored RCG



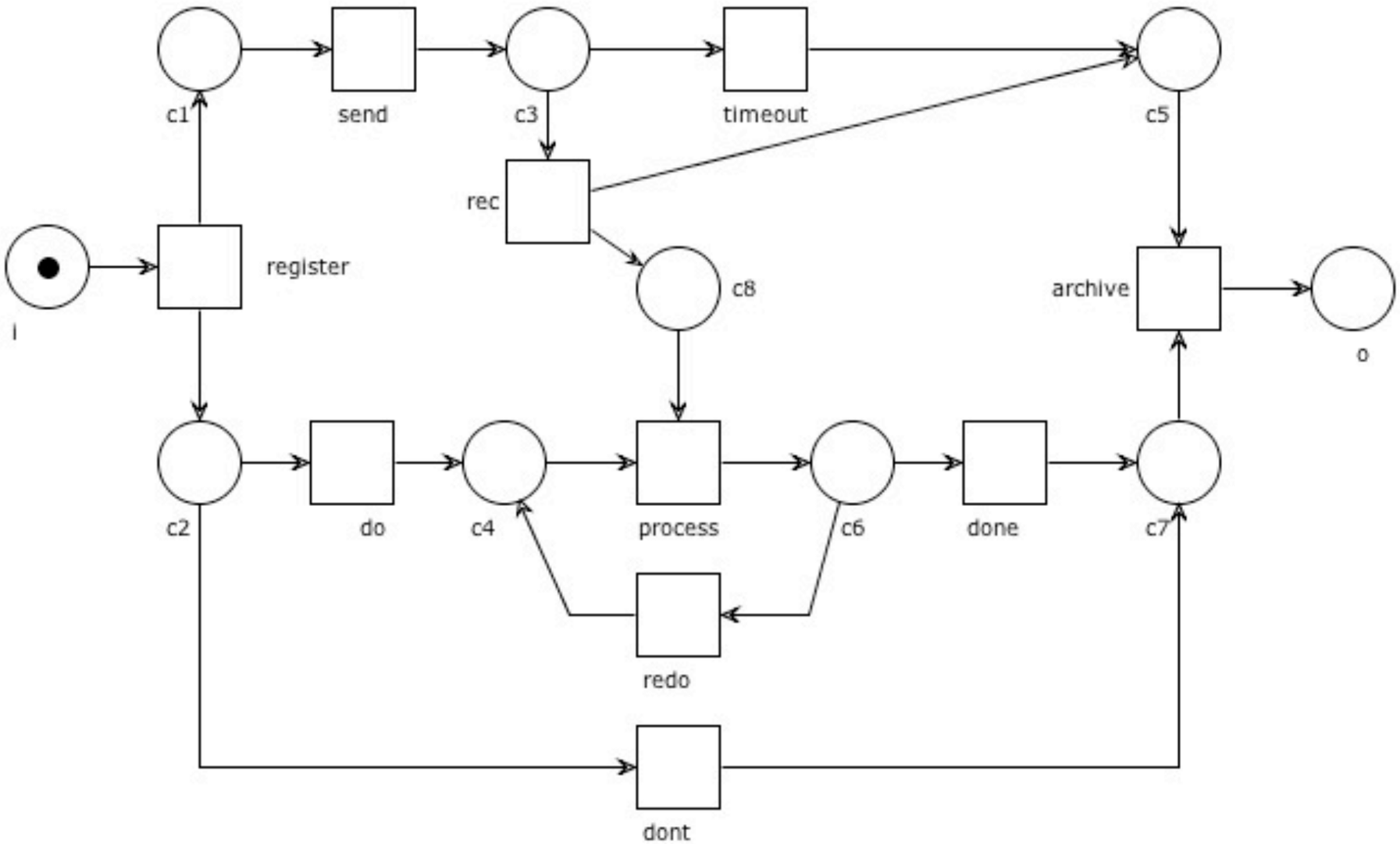
register, dont, send, rec

register, send, dont, rec

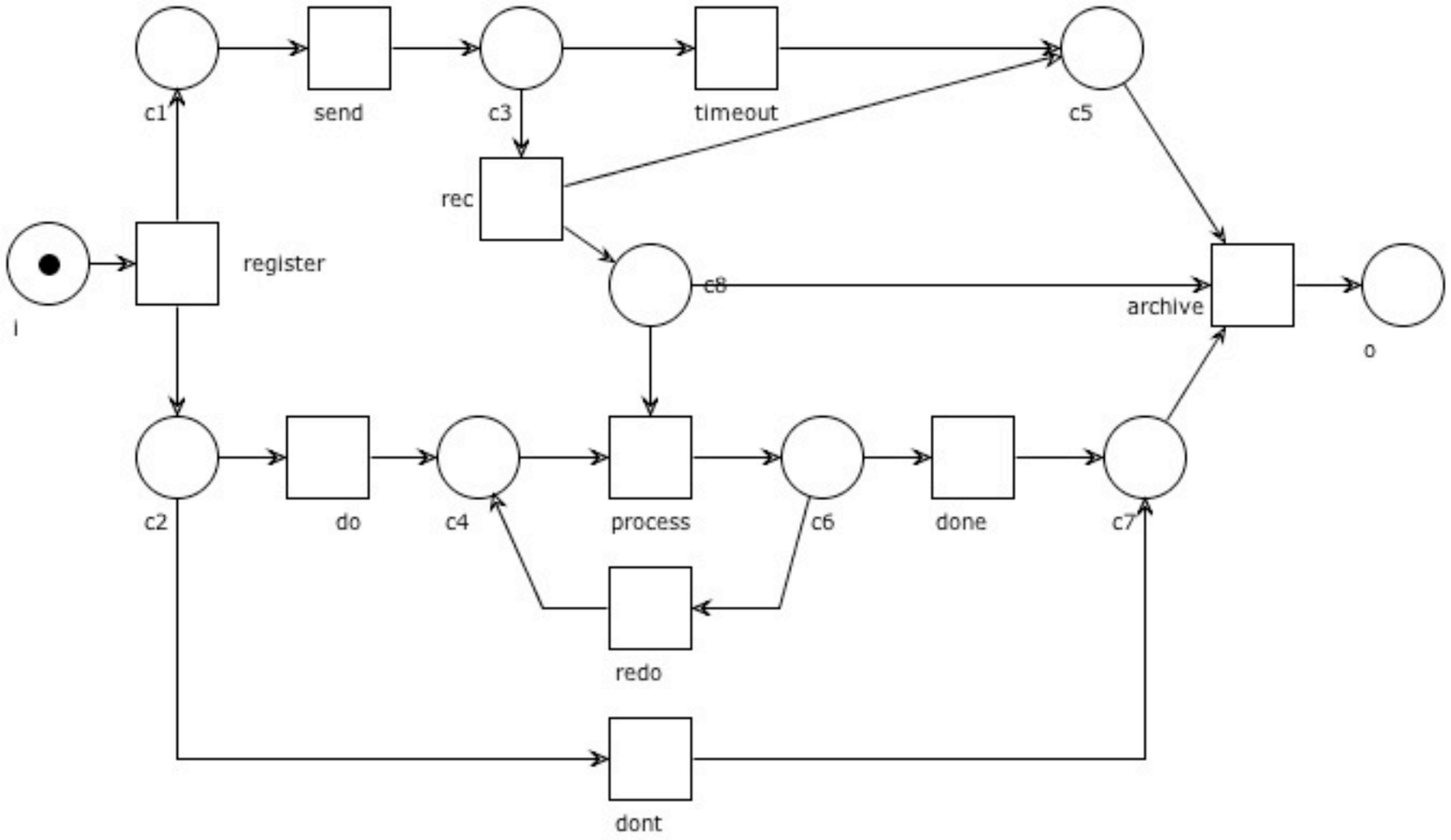
and also?

Practice with WoPeD (and Woflan)

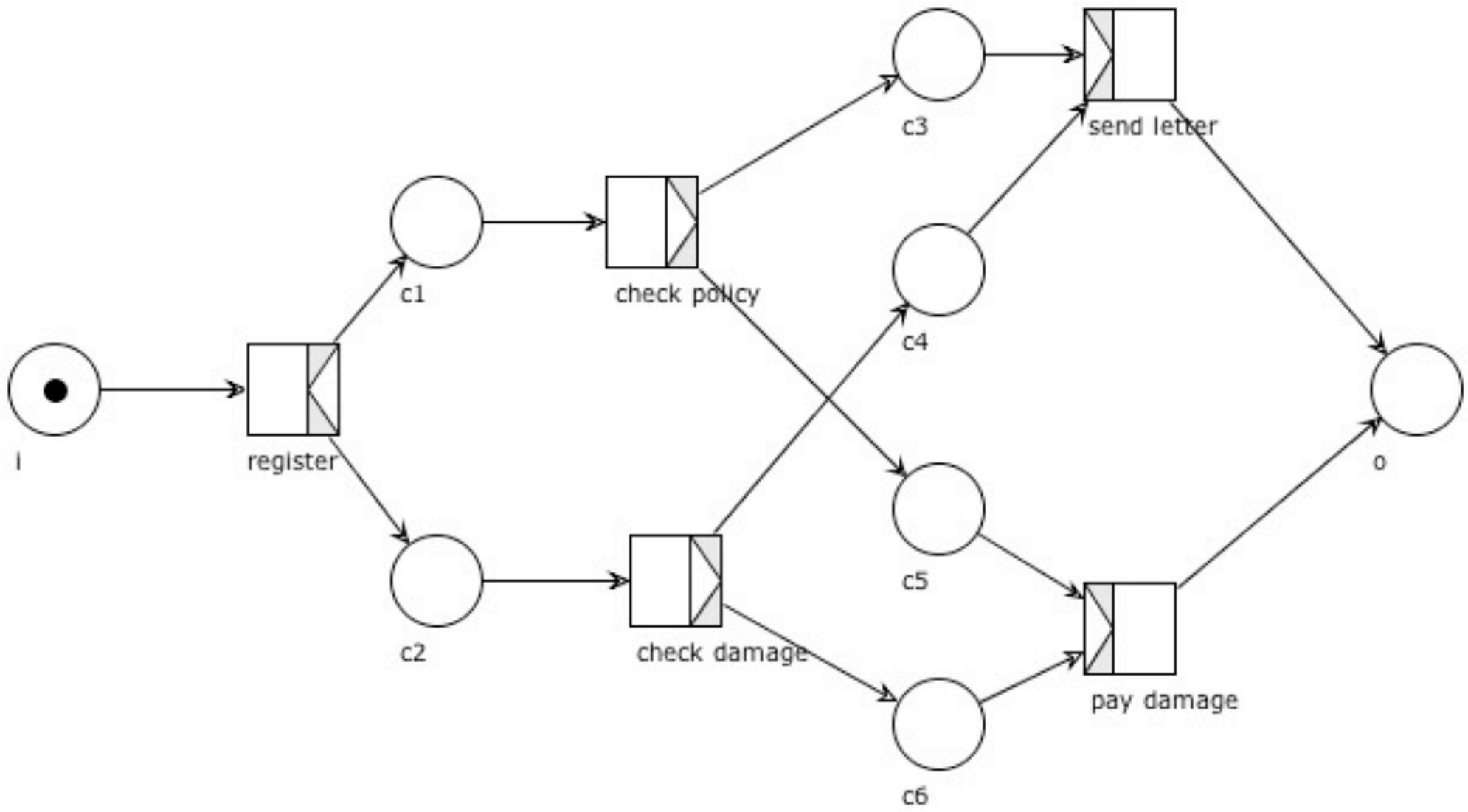
Analyse the running example



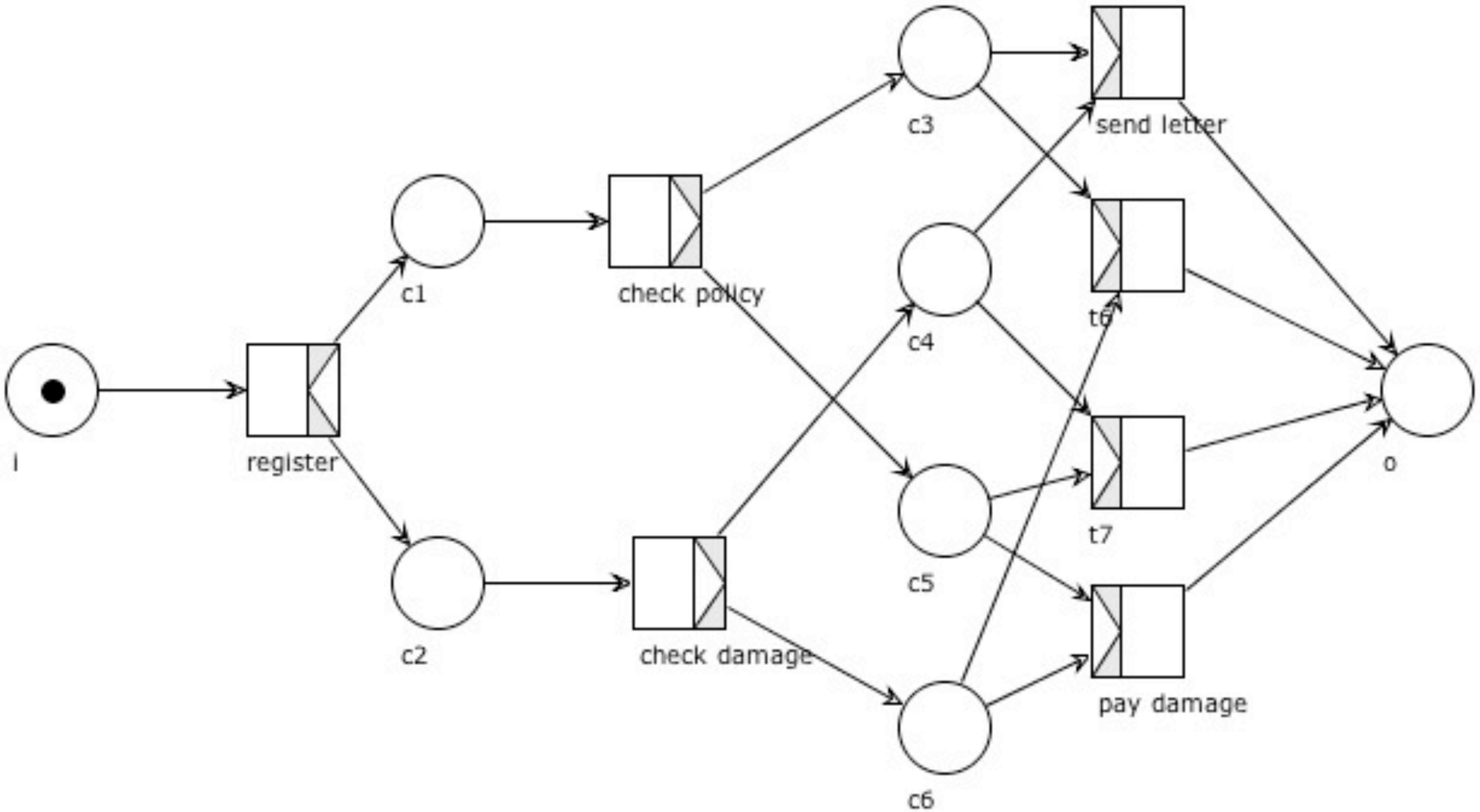
Analyse the running example variant



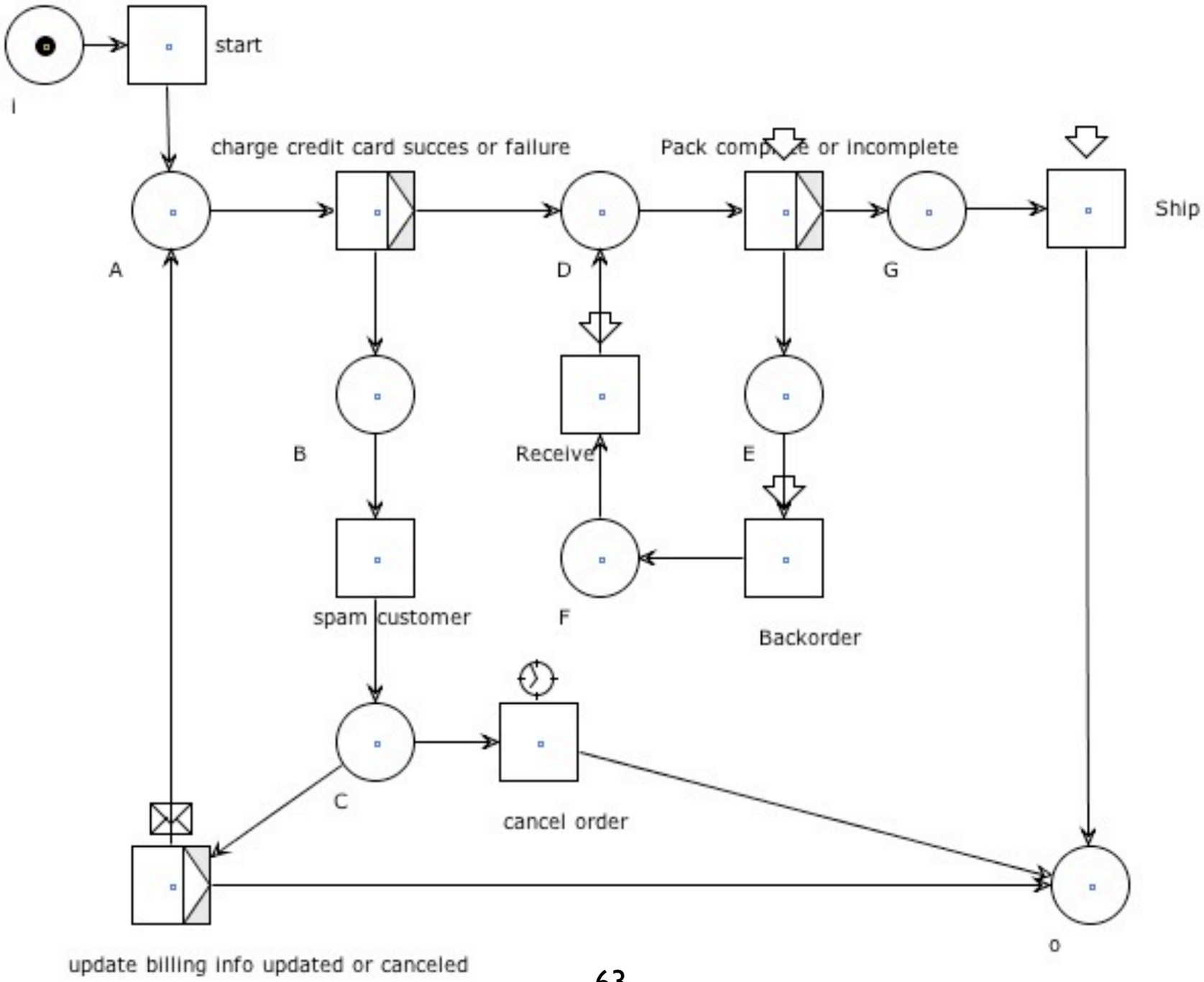
Analyse this net



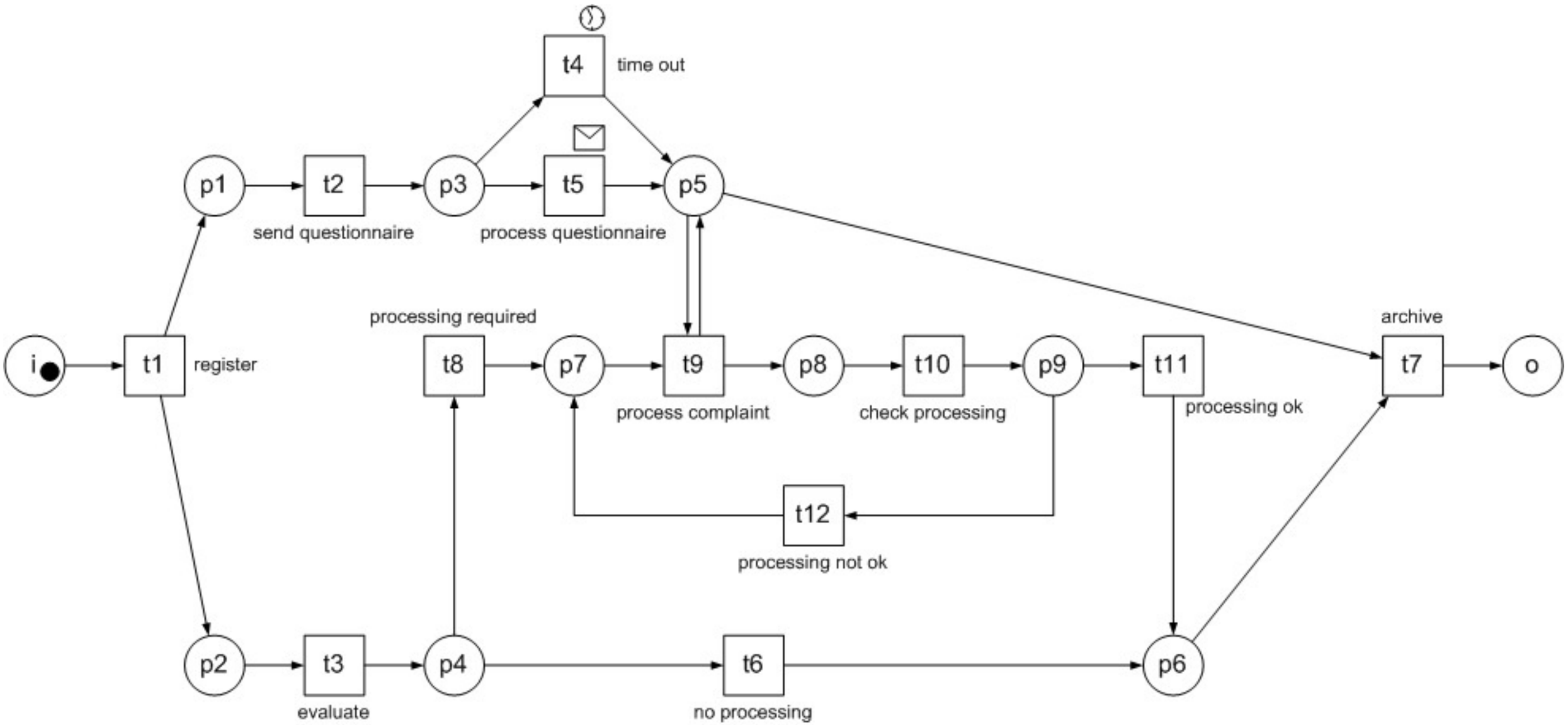
Analyse this net



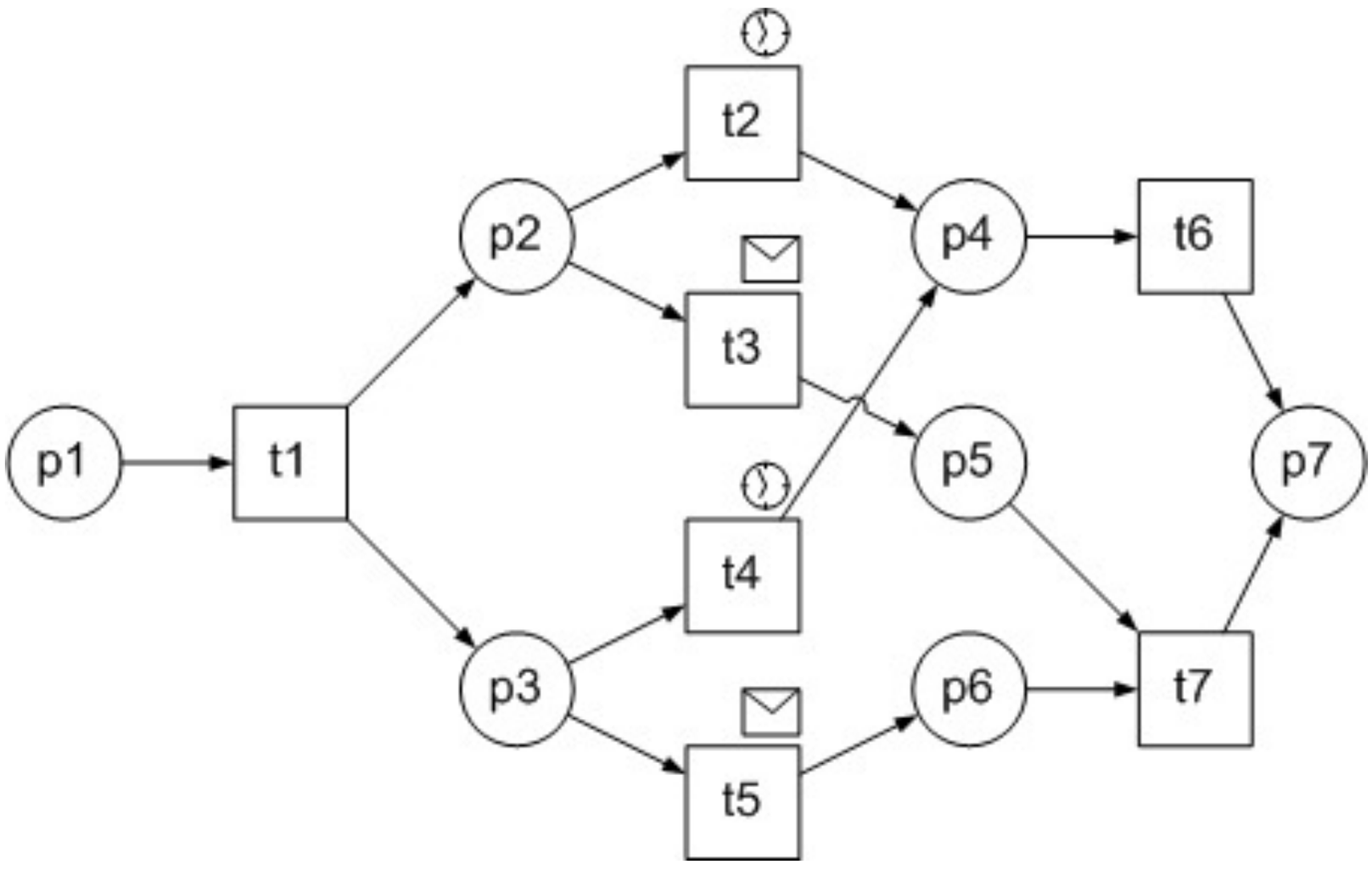
Analyse this net



Analyse this net



Analyse this net



Design and analysis of WF-net

The workflow of a computer repair service (CRS) can be described as follows.
A customer brings in a defective computer and the CRS checks the defect and hands out a repair cost calculation back. If the customer decides that the costs are acceptable, the process continues, otherwise she takes her computer home unrepaired. The ongoing repair consists of two activities, which are executed, in an arbitrary order. The first activity is to check and repair the hardware, whereas the second activity checks and configures the software. After each of these activities, the proper system functionality is tested. If an error is detected another arbitrary repair activity is executed, otherwise the repair is finished.

Model the described workflow as a sound workflow net.

Design and analysis of WF-net

A hospital wants to establish a rating workflow for their doctors. To make the workflow reliable two different roles are assigned. The first one is a referee from the newly created quality assurance department while the second one represents the managing director of the hospital. Both roles execute all of their tasks independently from each other.

The referee starts a new case regarding a certain doctor by interviewing patients. Since a patient interview workflow is already established, it is simply integrated in the new workflow. Meanwhile, the director asks an external expert to review the work of the doctor under rating. Unfortunately, since the expert only gets a low expenses fee, it can happen that the expert is not responding in time. If that happens, another expert has to be asked (who could also not respond in time, i.e. the procedure repeats). If an expert finally sends an expertise, it is received by the director and forwarded to the referee. The referee files the results containing the patient interviews as well as the expertise and afterward creates a report. While the referee is doing this, the manager fills a cheque to pay the expenses of the expert.

Model the described workflow as a sound workflow net.