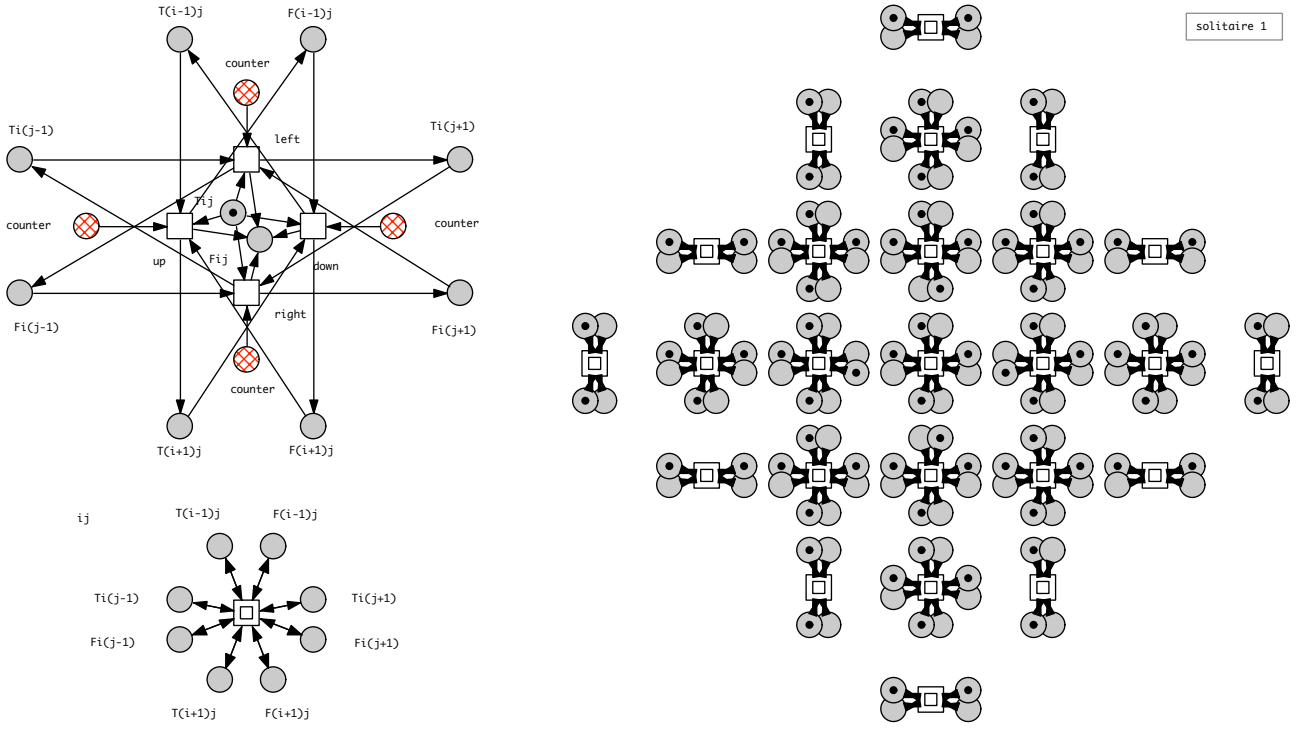
Monika Heiner
monika.heiner@b-tu.d

This form is a summary description of the model entitled "Solitaire" proposed for the Model Checking Contest @ Petri Nets. Models can be given in several instances parameterized by scaling parameters. Colored nets can be accompanied by one or many equivalent, unfolded P/T nets. Models are given together with property files (possibly, one per model instance) giving a set of properties to be checked on the model.

Description

Solitaire is a popular board game requiring non-obvious solution strategies; see [wiki] for the rules of the game. The objective of the Petri nets is to generate one/some/all strategies (paths) to reach a solution, i.e., a state where just one stone is left. The auxiliary place *counter* gives the current number of stones on the board; added to simplify the specification of the target state (any state with *counter* = 1). Solitaire is played on different boards; we give Petri nets for the most popular ones: square board (0), English board (1), French board (2), each in two versions: with/out counter [H05]. The existence of a solution may depend on the initially empty field; all initial markings have been chosen to enable a solution. Encoding this game as coloured Petri net would permit the generation of arbitrary boards of scalable size.



General solitaire pattern for one field (left), and its composition to the 7×7 *English board (right).*

References

H05 M Heiner: About some Applications of Petri Net Theory - My Petri Net Picture Book; Talk, Adventmatik 2003, Paderborn, December 2003, http://www-dssz.informatik.tu-cottbus.de/publications/slides/2003_paderborn_pn_applications.sld.pdf.

Wiki Wikipedia: Peg solitaire; http://en.wikipedia.org/wiki/Peg_solitaire, last access 12/2013.

Scaling parameter

Parameter name	Parameter description	Chosen parameter values
B	shape and size of the board	5×5 square board (0), 7×7 English board (1), 7×7 French board (3)

Monika Heiner
monika.heiner@b-tu.d

Size of the model

Parameter	Number of places	Number of transitions	Number of arcs
$B = 0$	50	84	456
$B = 0$, with counter	51	84	540
$B = 1$	66	76	456
$B = 1$, with counter	67	76	532
$B = 2$	74	92	552
$B = 2$, with counter	75	92	644

Structural properties

ordinary — *all arcs have multiplicity one* ..... ✔
simple free choice — *all transitions sharing a common input place have no other input place* ..... ✘ [a]
extended free choice — *all transitions sharing a common input place have the same input places* ..... ✘ [b]
state machine — *every transition has exactly one input place and exactly one output place* ..... ✘ [c]
marked graph — *every place has exactly one input transition and exactly one output transition* ..... ✘ [d]
connected — *there is an undirected path between every two nodes (places or transitions)* ..... ✔ [e]
strongly connected — *there is a directed path between every two nodes (places or transitions)* ..... ? [f]
source place(s) — *one or more places have no input transitions* ..... ? [g]
sink place(s) — *one or more places have no output transitions* ..... ✘ [h]
source transition(s) — *one or more transitions have no input places* ..... ✘ [i]
sink transitions(s) — *one or more transitions have no output places* ..... ✘ [j]
loop-free — *no transition has an input place that is also an output place* ..... ✔ [k]
conservative — *for each transition, the number of input arcs equals the number of output arcs* ..... ? [l]
subconservative — *for each transition, the number of input arcs equals or exceeds the number of output arcs* ..... ✔ [m]
nested units — *places are structured into hierarchically nested sequential units* [n] ..... ✘

Behavioural properties

safe — *in every reachable marking, there is no more than one token on a place* ..... ? [o]
deadlock — *there exists a reachable marking from which no transition can be fired* ..... ✔ [p]
reversible — *from every reachable marking, there is a transition path going back to the initial marking* ..... ✘
quasi-live — *for every transition t, there exists a reachable marking in which t can fire* ..... ✔
live — *for every transition t, from every reachable marking, one can reach a marking in which t can fire* ..... ✘

[a] stated by CÆSAR.BDD version 2.0 on all 6 instances ($B \in \{0,1,2\}$, with and without counter).
[b] stated by CÆSAR.BDD version 2.6 on all 6 instances ($B \in \{0,1,2\}$, with and without counter).
[c] stated by CÆSAR.BDD version 2.0 on all 6 instances ($B \in \{0,1,2\}$, with and without counter).
[d] stated by CÆSAR.BDD version 2.0 on all 6 instances ($B \in \{0,1,2\}$, with and without counter).
[e] stated by CÆSAR.BDD version 2.0 on all 6 instances ($B \in \{0,1,2\}$, with and without counter).
[f] stated by CÆSAR.BDD version 2.0 to be false on all 3 instances with counters, and true on all 3 instances without counters.
[g] stated by CÆSAR.BDD version 2.0 to be true on all 3 instances with counters, and false on all 3 instances without counters.
[h] stated by CÆSAR.BDD version 2.0 on all 6 instances ($B \in \{0,1,2\}$, with and without counter).
[i] stated by CÆSAR.BDD version 2.0 on all 6 instances ($B \in \{0,1,2\}$, with and without counter).
[j] stated by CÆSAR.BDD version 2.0 on all 6 instances ($B \in \{0,1,2\}$, with and without counter).
[k] stated by CÆSAR.BDD version 2.0 on all 6 instances ($B \in \{0,1,2\}$, with and without counter).
[l] stated by CÆSAR.BDD version 2.0 to be false on all 3 instances with counters, and true on all 3 instances without counters.
[m] stated by CÆSAR.BDD version 2.0 on all 6 instances ($B \in \{0,1,2\}$, with and without counter).
[n] the definition of Nested-Unit Petri Nets (NUPN) is available from http://mcc.lip6.fr/nupn.php
[o] the nets corresponding to instances without counters are safe because they are covered with P-invariants having a single token in the initial place – found by CÆSAR.BDD version 2.0 to be false on all 3 instances with counters, and unknown on the remaining 3 instance(s).
[p] special deadlocks (dead states) correspond to the solutions we are looking for; confirmed at MCC'2014 by Lola and Tapaal on all 6 instances.

Monika Heiner
monika.heiner@b-tu.d

Size of the marking graphs

Parameter	Number of reachable markings	Number of transition firings	Max. number of tokens per place	Max. number of tokens per marking
$B = 0$	1.6098×10^7 [q]	2.1396×10^8 [r]	1 [s]	25 [t]
$B = 0$, with counter	?	?	24	49 [u]
$B = 1$	?	?	1	33 [v]
$B = 1$, with counter	?	?	32	65 [w]
$B = 2$	?	?	1	37 [x]
$B = 2$, with counter	?	?	36	73 [y]

Other properties

Deadlocks (dead states) which correspond to a solution can be identified by: sum over all places $T_{i,j} = 1$, or counter=0. All places are covered by 1-P-invariants, except the counter place. All nets enjoy some symmetries.

[q] computed at MCC'2014 by Marcie, PNMC, and PNXDD; exact value: 16,098,428.
[r] computed at MCC'2014 by Marcie; exact value: 213,958,152.
[s] computed at MCC'2014 by Marcie and PNMC.
[t] number of initial tokens, because the net is sub-conservative.
[u] number of initial tokens, because the net is sub-conservative.
[v] number of initial tokens, because the net is sub-conservative.
[w] number of initial tokens, because the net is sub-conservative.
[x] number of initial tokens, because the net is sub-conservative.
[y] number of initial tokens, because the net is sub-conservative.