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This form is a summary description of the model entitled "StigmergyElection" 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

This model describes a system of N agents performing a variation of a bully election. In the following, we assume that each agent has a unique ID from a totally ordered set (for simplicity, here we assume that those IDs range from 0 to $N-1$). In a typical bully election, each agent initially considers itself to be the leader; advertises the ID of its current leader to other agents; and, upon receiving a message with a lower ID, it selects that as its new leader.

In this variation, no explicit messaging takes place. Rather, we exploit an indirect communication mechanism based on stigmergy variables [1]. When an agent assigns a value to such a variable, the value receives a timestamp marking the time of assignment. Agents asynchronously broadcast values after performing an assignment, and receivers will replace their own value with the received one if the latter is newer (i.e., it has a higher timestamp). In this example, each agent stores the ID of its current leader in a stigmergy variable ℓ, initially set to N for every agent. As the system evolves, each agent repeatedly assigns its own ID to ℓ, but only as long as $\ell > \text{ID}$.

This collection of P/T nets was derived from an initial specification of the system (parameterized by the number N of agents), which was described in LAbS [1], a language that natively supports stigmergy variables. Each instance of this specification, for a given value of N, was then automatically translated into an LNT model by means of the SLiVER tool [2] [3].

Each LNT model was then translated to LOTOS, and then to an interpreted Petri net using the CADP toolbox. Finally, a P/T net was obtained by stripping out all data-related information (variables, types, assignments, guards, etc.) from the interpreted Petri net, leading to a NUPN (Nested-Unit Petri Net) model translated to PNML using the CÆSAR.BDD tool.

Each instance is also parameterized by its version V, which specifies how the NUPN has been produced from the LOTOS specification. V is either equal to "*a*" if the NUPN has been generated *after* applying all the structural and data-flow optimizations of the CÆSAR compiler for LOTOS, or to "*b*" if the NUPN has been generated *before* these optimizations.

References

[1] R. De Nicola, L. Di Stefano, and O. Inverso, "Multi-agent systems with virtual stigmergy," Sci. Comput. Program., vol. 187, p. 102345, 2020, doi: 10.1016/j.scico.2019.102345.

[2] L. Di Stefano, F. Lang, and W. Serwe, "Combining SLiVER with CADP to Analyze Multi-agent Systems," in 22nd International Conference on Coordination Models and Languages (COORDINATION), Valletta, Malta, Jun. 2020, vol. 12134, pp. 370–385. doi: 10.1007/978-3-030-50029-0_23.

[3] SLiVER tool: `https://github.com/labs-lang/sliver`

Scaling parameter

Parameter name	Parameter description	Chosen parameter values
(N, V)	N is the number of agents and V is the version defined above	$\{2...11\} \times \{a, b\}$

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Size of the model

Parameter	Number of places	Number of transitions	Number of arcs	Number of units	HWB code
$N = 2, V = a$	30	66	196	4	2–3–10
$N = 2, V = b$	291	332	734	5	3–3–23
$N = 3, V = a$	44	118	467	5	2–4–14
$N = 3, V = b$	427	518	1323	7	4–4–32
$N = 4, V = a$	58	218	1238	6	2–5–18
$N = 4, V = b$	563	780	2680	9	5–5–41
$N = 5, V = a$	72	450	3637	7	2–6–22
$N = 5, V = b$	699	1266	6741	11	6–6–50
$N = 6, V = a$	86	1042	11192	8	2–7–26
$N = 6, V = b$	835	2416	20130	13	7–7–59
$N = 7, V = a$	100	2618	34799	9	2–8–30
$N = 7, V = b$	971	5542	65199	15	8–8–68
$N = 8, V = a$	114	6882	107626	10	2–9–34
$N = 8, V = b$	1107	14564	216524	17	9–9–77
$N = 9, V = a$	128	18490	329609	11	2–10–38
$N = 9, V = b$	1243	41210	720585	19	10–10–86
$N = 10, V = a$	142	50162	999212	12	2–11–42
$N = 10, V = b$	1379	120600	2385526	21	11–11–95
$N = 11, V = a$	156	136650	3001363	13	2–12–46
$N = 11, V = b$	1515	357966	7842915	23	12–12–104

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)] ✔

(a) stated by CÆSAR.BDD version 3.7 on all 20 instances (10 values of N × 2 values of V).
(b) stated by CÆSAR.BDD version 3.7 on all 20 instances (10 values of N × 2 values of V).
(c) stated by CÆSAR.BDD version 3.7 on all 20 instances (10 values of N × 2 values of V).
(d) stated by CÆSAR.BDD version 3.7 on all 20 instances (10 values of N × 2 values of V).
(e) stated by CÆSAR.BDD version 3.7 on all 20 instances (10 values of N × 2 values of V).
(f) from place 1 one cannot reach place 0.
(g) place 0 is a source place.
(h) stated by CÆSAR.BDD version 3.7 on all 20 instances (10 values of N × 2 values of V).
(i) stated by CÆSAR.BDD version 3.7 on all 20 instances (10 values of N × 2 values of V).
(j) stated by CÆSAR.BDD version 3.7 on all 20 instances (10 values of N × 2 values of V).
(k) stated by CÆSAR.BDD version 3.7 to be true on 10 instance(s) out of 20, and false on the remaining 10 instance(s).
(l) stated by CÆSAR.BDD version 3.7 on all 20 instances (10 values of N × 2 values of V).
(m) stated by CÆSAR.BDD version 3.7 on all 20 instances (10 values of N × 2 values of V).
(n) the definition of Nested-Unit Petri Nets (NUPN) is available from `http://mcc.lip6.fr/nupn.php`

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Behavioural properties

safe — *in every reachable marking, there is no more than one token on a place* .... ✔[o]
dead place(s) — *one or more places have no token in any reachable marking* .... ?[p]
dead transition(s) — *one or more transitions cannot fire from any reachable marking* .... ?[q]
deadlock — *there exists a reachable marking from which no transition can be fired* .... ?[r]
reversible — *from every reachable marking, there is a transition path going back to the initial marking* .... ?[s]
live — *for every transition t, from every reachable marking, one can reach a marking in which t can fire* .... ?[t]

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
$N = 2, V = a$	57 [u]	?	1	3
$N = 2, V = b$	216668 [v]	?	1	3
$N = 3, V = a$	227 [w]	?	1	4
$N = 3, V = b$	1.82823e+07 [x]	?	1	4
$N = 4, V = a$	977 [y]	?	1	5
$N = 4, V = b$	1.46067e+09 [z]	?	1	5
$N = 5, V = a$	4411 [aa]	?	1	6
$N = 5, V = b$	1.13198e+11 [ab]	?	1	6
$N = 6, V = a$	20473 [ac]	?	1	7
$N = 6, V = b$	8.61448e+12 [ad]	?	1	7
$N = 7, V = a$	96723 [ae]	?	1	8
$N = 7, V = b$	6.4834e+14 [af]	?	1	8
$N = 8, V = a$	462753 [ag]	?	1	9
$N = 8, V = b$	4.8468e+16 [ah]	?	1	9
$N = 9, V = a$	2.23499e+06 [ai]	?	1	10
$N = 9, V = b$	$\geq$ 3.54165e+18 [aj]	?	1 [ak]	10
$N = 10, V = a$	1.08733e+07 [al]	?	1	11
$N = 10, V = b$	$\geq$ 1.14103e+20 [am]	?	1 [an]	11
$N = 11, V = a$	5.31996e+07 [ao]	?	1	12
$N = 11, V = b$	$\geq$ 3.35249e+20 [ap]	?	1 [aq]	12

[o] safe by construction – stated by the CÆSAR compiler.
[p] stated by CÆSAR.BDD version 3.7 to be false on 17 instance(s) out of 20, and unknown on the remaining 3 instance(s).
[q] stated by CÆSAR.BDD version 3.7 to be false on 17 instance(s) out of 20, and unknown on the remaining 3 instance(s).
[r] stated by CÆSAR.BDD version 3.7 to be true on 7 instance(s) out of 20, false on the remaining 10 instance(s), and unknown on the remaining 3 instance(s).
[s] stated by CÆSAR.BDD version 3.7 to be false on 7 instance(s) out of 20, and unknown on the remaining 13 instance(s).
[t] stated by CÆSAR.BDD version 3.7 to be false on 7 instance(s) out of 20, and unknown on the remaining 13 instance(s).
[u] stated by CÆSAR.BDD version 3.7.
[v] stated by CÆSAR.BDD version 3.7.
[w] stated by CÆSAR.BDD version 3.7.
[x] stated by CÆSAR.BDD version 3.7.
[y] stated by CÆSAR.BDD version 3.7.
[z] stated by CÆSAR.BDD version 3.7.
[aa] stated by CÆSAR.BDD version 3.7.
[ab] stated by CÆSAR.BDD version 3.7.
[ac] stated by CÆSAR.BDD version 3.7.
[ad] stated by CÆSAR.BDD version 3.7.
[ae] stated by CÆSAR.BDD version 3.7.
[af] stated by CÆSAR.BDD version 3.7.
[ag] stated by CÆSAR.BDD version 3.7.
[ah] stated by CÆSAR.BDD version 3.7.
[ai] stated by CÆSAR.BDD version 3.7.
[aj] stated by CÆSAR.BDD version 3.7.
[ak] stated by the CÆSAR compiler.
[al] stated by CÆSAR.BDD version 3.7.

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(am) stated by CÆSAR.BDD version 3.7.
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