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since
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*This form is a summary description of the model entitled "DiscoveryGPU" 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 the discovery protocol [1] used to dynamically detect the amount of thread workgroups that can be scheduled at the same time on a given GPU, for a given application. Each workgroup participate in a mutex-protected poll, which is closed once a workgroup is able to re-visit the poll. All workgroups that were able to participate in the poll are thus actually running in parallel on different hardware-level compute-units. As GPUs have non-preemptive scheduling, these discovered workgroups are able to safely participate in blocking synchronisation. This protocol is critical to enable safe inter-workgroup blocking synchronisation, which in turn can provide significant performance improvements in some applications.

The discovery protocol was formally specified using the LNT value-passing process calculus and analyzed using the verification tools available in the CADP toolbox. The collection of P/T nets was obtained from the LNT specifications of the protocol. Each LNT specification was translated automatically 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 of the model is parameterized by the number $N$ of threads.

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] Tyler Sorensen, Alastair F. Donaldson, Mark Batty, Ganesh Gopalakrishnan, and Zvonimir Rakamaric. Portable Inter-workgroup Barrier Synchronisation for GPUs. In Proc. of the 31st Annual ACM SIGPLAN Conference on Object-Oriented Programming, Systems, Languages, and Applications (OOPSLA'16), Amsterdam, The Netherlands, November 2016.

## Scaling parameter

| Parameter name | Parameter description | Chosen parameter values |
|---|---|---|
| $(N, V)$ | $N$ is the number of threads and $V$ is the version defined above | $\{6, ..., 15\} \times \{a, b\}$ |

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## Size of the model

| Parameter | Number of places | Number of transitions | Number of arcs | Number of units | HWB code |
|---|---|---|---|---|---|
| $N = 06, V = a$ | 63 | 85 | 273 | 9 | 2–8–27 |
| $N = 06, V = b$ | 184 | 194 | 503 | 15 | 7–8–44 |
| $N = 07, V = a$ | 73 | 99 | 318 | 10 | 2–9–31 |
| $N = 07, V = b$ | 212 | 224 | 582 | 17 | 8–9–50 |
| $N = 08, V = a$ | 83 | 113 | 363 | 11 | 2–10–35 |
| $N = 08, V = b$ | 240 | 254 | 661 | 19 | 9–10–56 |
| $N = 09, V = a$ | 93 | 127 | 408 | 12 | 2–11–39 |
| $N = 09, V = b$ | 268 | 284 | 740 | 21 | 10–11–62 |
| $N = 10, V = a$ | 103 | 141 | 453 | 13 | 2–12–43 |
| $N = 10, V = b$ | 296 | 314 | 819 | 23 | 11–12–68 |
| $N = 11, V = a$ | 113 | 155 | 498 | 14 | 2–13–47 |
| $N = 11, V = b$ | 324 | 344 | 898 | 25 | 12–13–74 |
| $N = 12, V = a$ | 123 | 169 | 543 | 15 | 2–14–51 |
| $N = 12, V = b$ | 352 | 374 | 977 | 27 | 13–14–80 |
| $N = 13, V = a$ | 133 | 183 | 588 | 16 | 2–15–55 |
| $N = 13, V = b$ | 380 | 404 | 1056 | 29 | 14–15–86 |
| $N = 14, V = a$ | 143 | 197 | 633 | 17 | 2–16–59 |
| $N = 14, V = b$ | 408 | 434 | 1135 | 31 | 15–16–92 |
| $N = 15, V = a$ | 153 | 211 | 678 | 18 | 2–17–63 |
| $N = 15, V = b$ | 436 | 464 | 1214 | 33 | 16–17–98 |

## 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 2.7 on all 20 instances (10 values of $N$ × 2 values of $V$).
[b] stated by CÆSAR.BDD version 2.7 on all 20 instances (10 values of $N$ × 2 values of $V$).
[c] stated by CÆSAR.BDD version 2.7 on all 20 instances (10 values of $N$ × 2 values of $V$).
[d] stated by CÆSAR.BDD version 2.7 on all 20 instances (10 values of $N$ × 2 values of $V$).
[e] stated by CÆSAR.BDD version 2.7 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 2.7 to be true on 10 instance(s) out of 20, and false on the remaining 10 instance(s).
[i] stated by CÆSAR.BDD version 2.7 on all 20 instances (10 values of $N$ × 2 values of $V$).
[j] stated by CÆSAR.BDD version 2.7 to be true on 10 instance(s) out of 20, and false on the remaining 10 instance(s).
[k] stated by CÆSAR.BDD version 2.7 to be true on 10 instance(s) out of 20, and false on the remaining 10 instance(s).
[l] stated by CÆSAR.BDD version 2.7 on all 20 instances (10 values of $N$ × 2 values of $V$).
[m] stated by CÆSAR.BDD version 2.7 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 |
|---|---|---|---|---|
| $N = 06, V = a$ | 1.77156e+06 [u] | ? | 1 | 8 |
| $N = 06, V = b$ | 6.13871e+09 [v] | ? | 1 | 8 |
| $N = 07, V = a$ | 1.94872e+07 [w] | ? | 1 | 9 |
| $N = 07, V = b$ | $\geq$ 1.59038e+11 [x] | ? | 1 [y] | 9 |
| $N = 08, V = a$ | 2.14359e+08 [z] | ? | 1 | 10 |
| $N = 08, V = b$ | $\geq$ 4.16622e+11 [aa] | ? | 1 [ab] | 10 |
| $N = 09, V = a$ | 2.35795e+09 [ac] | ? | 1 | 11 |
| $N = 09, V = b$ | $\geq$ 1.44163e+12 [ad] | ? | 1 | 11 |
| $N = 10, V = a$ | 2.59374e+10 [ae] | ? | 1 | 12 |
| $N = 10, V = b$ | $\geq$ 5.47101e+12 [af] | ? | 1 [ag] | 12 |
| $N = 11, V = a$ | 2.85312e+11 [ah] | ? | 1 | 13 |
| $N = 11, V = b$ | $\geq$ 1.61943e+13 [ai] | ? | 1 [aj] | 13 |
| $N = 12, V = a$ | 3.13843e+12 [ak] | ? | 1 | 14 |
| $N = 12, V = b$ | $\geq$ 3.85496e+13 [al] | ? | 1 [am] | 14 |
| $N = 13, V = a$ | 3.45227e+13 [an] | ? | 1 | 15 |
| $N = 13, V = b$ | $\geq$ 7.55166e+13 [ao] | ? | 1 [ap] | 15 |
| $N = 14, V = a$ | 3.7975e+14 [aq] | ? | 1 | 16 |
| $N = 14, V = b$ | $\geq$ 1.23851e+14 [ar] | ? | 1 [as] | 16 |
| $N = 15, V = a$ | 4.17725e+15 [at] | ? | 1 | 17 |
| $N = 15, V = b$ | $\geq$ 4.73641e+14 [au] | ? | 1 [av] | 17 |

[o] safe by construction – stated by the CÆSAR compiler.
[p] stated by CÆSAR.BDD version 3.3 on all 20 instances (10 values of $N$ × 2 values of $V$).
[q] stated by CÆSAR.BDD version 2.7 on all 20 instances (10 values of $N$ × 2 values of $V$).
[r] stated by CÆSAR.BDD version 2.7 to be true on 11 instance(s) out of 20, and unknown on the remaining 9 instance(s).
[s] stated by CÆSAR.BDD version 2.7 to be false on 11 instance(s) out of 20, and unknown on the remaining 9 instance(s).
[t] stated by CÆSAR.BDD version 2.7 to be false on 11 instance(s) out of 20, and unknown on the remaining 9 instance(s).
[u] stated by CÆSAR.BDD version 2.7.
[v] stated by CÆSAR.BDD version 2.7.
[w] stated by CÆSAR.BDD version 2.7.
[x] stated by CÆSAR.BDD version 2.7.
[y] stated by the CÆSAR compiler.
[z] stated by CÆSAR.BDD version 2.7.
[aa] stated by CÆSAR.BDD version 2.7.
[ab] stated by the CÆSAR compiler.
[ac] stated by CÆSAR.BDD version 2.7.
[ad] stated by CÆSAR.BDD version 2.7.
[ae] stated by CÆSAR.BDD version 2.7.
[af] stated by CÆSAR.BDD version 2.7.
[ag] stated by the CÆSAR compiler.
[ah] stated by CÆSAR.BDD version 2.7.
[ai] stated by CÆSAR.BDD version 2.7.
[aj] stated by the CÆSAR compiler.
[ak] stated by CÆSAR.BDD version 2.7.
[al] stated by CÆSAR.BDD version 2.7.
[am] stated by the CÆSAR compiler.

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[an] stated by CÆSAR.BDD version 2.7.
[ao] stated by CÆSAR.BDD version 2.7.
[ap] stated by the CÆSAR compiler.
[aq] stated by CÆSAR.BDD version 2.7.
[ar] stated by CÆSAR.BDD version 2.7.
[as] stated by the CÆSAR compiler.
[at] stated by CÆSAR.BDD version 2.7.
[au] stated by CÆSAR.BDD version 2.7.
[av] stated by the CÆSAR compiler.