Harnessing the power of GPUs for model checking

Anton Wijs
Eindhoven University of Technology

On-The-Fly State Space Exploration

Construct a state space, given a model of a concurrent system [3]
Model = set of interacting finite-state Labelled Transition Systems

New hash-table design for GPUs, with fine-grained parallelism
Elements are placed in buckets using warp-the-line technique

Threads work in groups to generate state successors
Parallelism at state-level

Block-local shared memory used for state caches
Local duplicate detection reduces global hash table access

Work forwarding per block from one search iteration to the next
Speeds up fetching new work for the next iteration

State Space Decomposition

Decompose explicit graph into Strongly Connected Components
Decompose graph of Markov Decision Process into Maximal End Components [2]

Decomposition based on Forward/Backward Breadth-First Search
Uses trimming to remove trivial components in each iteration

In each iteration, many BFSs can be performed in the search regions in parallel
Achieves massive parallelism

Novel combined forward/backward thread kernel
Combines both procedures in one state scan

New simplified pivot selection for each search region at the start of an iteration
Reuses input transition array as hash table for enforced data races to select pivots

Probability Computations

Perform numerical computations for probabilistic model checking [1, 4]
Needed to check if a probabilistic property holds in a discrete or continuous time Markov Chain

Solving systems of linear equations and performing matrix-vector multiplication
Parallel matrix-vector multiplication used in Jacobi method for solving equation systems

Parallel termination checking achieves significant speedup
Fast checking if next iteration is needed

Novel restructuring of input ensures coalesced memory access by threads
Faster reading of input reduces multiplication run time up to four times

States / transitions are grouped in segments of 15 and 32 states
Coincides with a half and a full warp of threads

10-100x speedup

15-79x speedup

20-35x speedup

References

[1] Parallel Probabilistic Model Checking on General Purpose Graphics Processors
D. Bošiščki, S. Edelkamp, D. Sulewski, and A.J. Wijs

[2] GPU-Based Graph Decomposition into Strongly Connected and Maximal End Components
D. Bošiščki, J.-P. Katoen, and A.J. Wijs

[3] GPUexplore: Many-Core On-The-Fly State Space Exploration Using GPUs
A.J. Wijs and D. Bošiščki

[4] Improving GPU Sparse Matrix-Vector Multiplication for Probabilistic Model Checking
A.J. Wijs and D. Bošiščki

Tools available at http://www.win.tue.nl/~awijs