A. Artifact description

This artifact supports the PPoPP'16 paper: Multi-Core On-The-Fly SCC Decomposition.

A.1   Abstract

The artifact described here consists of experiments that evaluate our novel multi-core on-the-fly strongly connected component (SCC) algorithm, called UFSCC. With these experiments we demonstrate scalability and show that our algorithm outperforms existing work on a 64-core machine on various types of graphs. This artifact paper describes how to compile and run the necessary tools, and provides a description on how to reproduce all experiments that described in the paper.

A.2   Description

The artifact implements the UFSCC algorithm in existing tool sets. The main point of interest is the performance gain by increasing the number of processors. The artifact consists of two parts:

- experiments for an *on-the-fly* environment, in which an input graph is provided implicitly and computed on-the-fly. The model checker LTSMIN [3] is used for these experiments. Here, UFSCC is compared with Tarjan's sequential SCC algorithm [9] and Renault's parallel SCC algorithm [7].

- experiments for an *offline* environment, in which an input graph is provided explicitly, i.e. with all vertices and edges of the graph are known beforehand. The tool provided by Hong et. al [2], which we refer to as HONG-UFSCC, is used for these experiments. Here, UFSCC is compared with Tarjan's sequential SCC algorithm [9] and Hong's parallel SCC algorithm [2].

Regarding the structure of this paper, we first provide a check list (App. A.2.1) describing specific properties of the artifact. We then show where all necessary files can be found in App. A.2.2. This is followed by specifics on hardware and software dependencies (App. A.2.3, App. A.2.4). App. A.3 describes the installation procedure. Finally, App. A.4 and App. A.5 explain how to perform and analyze experiments.

A.2.1   Check-list (artifact meta information)

- **Algorithm:** graph, on-the-fly, strongly connected components, multi-core, scalability
- **Program:** LTSMIN model checker, HONG-UFSCC
- **Data set:** included data sets for:
  - LTSMIN: BEEM (BEnchmarks for Explicit Model checkers [6]) + synthetic graphs
  - HONG-UFSCC: real-world + synthetic + selected BEEM graphs
- **Run-time environment:** POSIX / Linux
- **Hardware:** 64bit x86 multi-core machine with 64 cores
- **Output:** CSV with performance info, option to compile PDF table/graph from CSV
- **Experiment workflow:** bash script executes experiments
- **Publicly available?:** open source via Github

A.2.2   How delivered

The source code for the used tools (in which our algorithm is implemented) is available at Github:

https://github.com/utwente-fmt/ppopp16

This project contains guidelines on how to install the required tools and (most of) the experiments combined with scripts to perform the tests and analyze the results. Structurally, the project contains the following:

- A bash script `install.sh`, this script provides commands to compile and install LTSMIN and HONG-UFSCC (we provide detailed installation instructions in App. A.3).

- A directory `experiments` that contains:
  - A bash script `benchmark.sh`, this script is used to run all experiments.
  - A Python script `parse-output.py`, this script is used to analyze the program output and store the results in a CSV file (or in case of a failure, copy the program output to a failure folder).
  - A Python script `csv2graph.py`, this script generates either a time or speedup graph for a specific graph.
  - A Python script `csv2table.py`, this script generates a table containing info regarding times and speedups for multiple graphs.
  - A Python script `csv2scatter.py`, this script generates a scatterplot containing info regarding times and speedups for multiple graphs.
  - A bash script `parse-csv.sh`, this script is intended as an example on how to extract graphs/tables from the generated CSV data (using the `csv2..` scripts).
  - A directory `results-paper` that contains the CSV outputs for our experiments that we present in the PPoPP paper.
  - A directory `graphs`, that contains:
    - A directory `beem`, this contains a set of input graphs obtained from the BEEM database.
    - A directory `beem-selected`, this contains the input graphs for six 'selected' input graphs from the beem directory.
    - A directory `synthetic`, this contains several synthetically generated input graphs.

Due to size restrictions, the input graphs for the 'offline' experiments are provided in a separate zip file, provided at:

http://mab.to/MHjH2OC90

This zip file contains two non-empty directories: `real-offline` and `constructed-offline`. In order to perform the offline experiments, please copy these directories to the `graphs` directory.

The `real-offline` directory contains various real-world graphs. The `livej` [1], `patent` [10] and `pokec` [8] graphs were obtained from the SNAP [4] database. The graph `wiki-links`[1] represents Wikipedias page-to-page links. The `random`, `rmat` and `ssca2` graphs represent random graphs with real-world characteristics and were generated from the GTGraph [5] suite using default parameters. Using the Green-Marl tool [11], the graphs were transformed to a binary format (to be used in the HONG-UFSCC tool).

A.2.3   Hardware dependencies

To replicate our experiments, a 64-core x86 machine with 64 bit addressing is required. We performed all our experiments on a machine with 4 AMD Opteron[TM] 6376 processors, each with 16 cores, forming a total of 64 cores and 128GB of main memory.

The experiments are specifically (hardcoded) set up to be tested with 64 cores. However, it is still possible to obtain meaningful results with fewer cores by using slightly altered scripts (which can be provided on request). Testing with more than 64 cores is not possible with the used tools.

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[1] Obtained from http://haselgrove.id.au/wikipedia.htm

A.2.4 Software dependencies

We recommend evaluating the artifact on POSIX / Linux. We performed our experiments on Ubuntu 14.04. To install LTSMIN and HONG-UFSCC and run the experiments, the following dependencies are required:

- `g++` (with builtin atomic functions and OpenMP support)
- `popt` (version $\geq$ 1.7, package `libpopt-dev`)
- `zlib` (package `zlibc zlib1g zlib1g-dev`)
- `Flex` (package `flex`)
- `Apache Ant` (package `ant`)
- `make`
- `automake`
- `autoconf`
- `libtool`
- `DiVinE` (patched, see App. A.3.1 for installation)
- `Python` 2.7.X with the modules `numpy` and `scipy` (packages `python-numpy` and `python-scipy`)
- A `Latex` installation with the `pgfplots` package installed (package `texlive-latex-extra`)

A.3 Installation

We show how to install the LTSMIN tool in App. A.3.1 and how to install the HONG-UFSCC tool in App. A.3.2.

A.3.1 Installing LTSmin

Before installing LTSMIN, a patched version of DiVinE 2.4 is required. The source code for DiVinE is available at:

`https://github.com/utwente-fmt/divine2.git`

In the `divine2` directory, use the following commands to install DiVinE:

- `mkdir _build && cd _build`
- `cmake .. -DGUI=OFF -DRX_PATH= -DCMAKE_INSTALL_PREFIX=install -DMURPHI=OFF`
- `make`
- `make install`

(see `http://fmt.cs.utwente.nl/tools/ltsmin/#divine`) Here, `install` is a directory (included in the PATH) where to install DiVinE.

The source code for LTSMIN is available at:

`https://github.com/vbloemen/ltsmin/tree/vincent3`

In the `ltsmin` directory, use the following commands to install LTSMIN:

- `git submodule update --init`
- `./ltsminreconf`
- `./configure --prefix=install`
- `make && make install`

(see also `http://fmt.cs.utwente.nl/tools/ltsmin/`) Here, `install` is a directory (included in the PATH) where to install LTSMIN. To test whether LTSMIN has been installed correctly, in the `experiments/graphs` directory, use the command `dve2lts-mc --strategy=ufscc -s28 beem/adding.3.dve`. This runs the UFSCC algorithm on the `adding.3` graph. If successful, various performance statistics should be printed on the standard output (for instance `total scc count: 1894376`).

A.3.2 Installing Hong-UFSCC

The source code for the HONG-UFSCC tool is available at Github:

`https://github.com/vbloemen/hong-ufscc.git`

In the `hong-ufscc` directory, the code is compiled with the command: `make`. If successful, the current directory now contains an executable: `scc`. Calling `scc` with no parameters will print the help message, which describes the options. To make this executable usable for the experiments, please make sure that the directory containing the `scc` executable is included in the PATH.

A.4 Experiment workflow

The experiments can be executed with the provided bash script from the Github project (`bench.sh`).

The procedure to perform all experiments from the paper is as follows:

1. Install LTSMIN and HONG-UFSCC (see App. A.3).
2. Copy the offline input graphs from the zip file to the directories:
    - `experiments/graphs/real-offline`
    - `experiments/graphs/constructed-offline`
3. `cd experiments`
4. Run `./bench.sh` to perform all experiments,

The `bench.sh` script will iterate over all files in the subdirectories of `experiments/graphs` and perform a sequence of experiments for each of these graphs. For each experiment, the program is called (LTSMIN or HONG-UFSCC) with as arguments the number of processor instances, the algorithm to be used, and the input graph. The output of the program is stored in a temporary file and analyzed by `experiments/parse-output.py`. This Python script will then parse the output file and append the results in the corresponding CSV file in the `experiments/results` directory.

For the results in the paper, we ran all experiments 50 times. The `bench.sh` script is set up to run the experiments 10 times (which should be a sufficient number to obtain meaningful results).

Specific experiments: The `bench.sh` script has been set up such that it can be easily modified to perform an experiment on a single graph, using a algorithm, using a specific number of cores, or combinations of these aspects.

A.5 Evaluation and expected result

After performing the experiments, the CSV files in the directory `experiments/results` should contain performance information for each test (one row per test). We provide three Python scripts to translate the CSV data to Latex files, which can consecutively be compiled to PDF files. The `parse-csv.sh` script provides examples on how to use these Python scripts. We show how to use these scripts as follows:

- `python csv2graph.py INFILE MODEL`, this generates the Latex code to create a graph that depicts how the performance times for all tested algorithms change when increasing the number of cores, on the graph MODEL obtained from the CSV file INFILE.
- `python csv2graph.py INFILE MODEL ALG N` this generates the Latex code to create a graph that depicts the relative performance (speedup) of all tested algorithms compared to a baseline (algorithm ALG, using N cores), on the graph MODEL obtained from the CSV file INFILE.
- `python csv2table.py INFILE` this generates the Latex code to create a table that depicts the performance times for the tested algorithms (using 64 cores) and the relative performance of

UFSCC compared to the others, on all graphs from the CSV file INFILE.

- `python csv2scatter.py INFILE ALG1 WORKERS1 ALG2 WORKERS2`, this generates the Latex code to create a scatterplot that compares the relative performance of algorithm ALG1 using WORKERS1 cores with ALG2 using WORKERS2 cores.

Expected results: The expected results for all performed experiments should be similar to those provided in the directory `experiments/results-paper`. We expect similar *relative* performance of the algorithms. We assume that the absolute performance times are too dependent on the specifics of the used hardware for valid comparison. The suggested method to make this comparison is by running `csv2table.py` and `csv2scatter.py` on each CSV file in the directories `experiments/results` and `experiments/results-paper`. We expect to observe that:

- On `beem` graphs, UFSCC (using 64 cores) is typically 10 to 30 times faster compared Tarjan's algorithm

- On `beem` graphs, UFSCC (using 64 cores) is compared to Renault's algorithm (using 64 cores) at worst 0.7 times as fast and for half of the graph instances UFSCC is more than 10 times faster. We consider this result to be the main selling point for our algorithm.

- The speedup graphs for the `beem-selected` and `synthetic` graphs should look similar to those from the `results-paper` directory.

- On the `constructed-offline` graphs that correspond the `beem-selected` ones, UFSCC is expected to perform slightly outperform Hong 's algorithm. and Tarjan's algorithm. Also, Tarjan's algorithm is expected to outperform UFSCC for most of the graphs.

- On the `real-offline` graphs, UFSCC outperforms Tarjan's algorithm, but Hong's algorithm outperforms UFSCC (except for `wiki-links`).

- We expect that some failed experiments, especially for experiments on `constructed-offline` graphs using Hong's algorithm. We have also observed a few failures for Renault's algorithm. We refer to the contents of the `experiments/failures` directory for the failed experiments.

References

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