Data-aware coordination with `TRAC`

Artefact submission for the COORDINATION 2024 paper #8

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This document specifies the instructions for the AEC of COORDINATION 2024 for the evaluation of our artefact submission. We set a `Docker` container for `TRAC` in order to simplify the work of the AEC (the `README` file at https://github.com/loctet/TRAC contains the instructions for the manual installation procedure).

1. Installation

Follow the instructions at https://docs.docker.com/ to install `Docker` on your system.

To install and run TRAC using `Docker`:

1. Pull the `Docker` image:

   ```
   docker pull loctet/trac_dafsms:v1
   ```

2. Run the container:

   ```
   docker run -it loctet/trac_dafsms:v1
   ```

   (you might need to run the above commands as `root`). The former command downloads the `Docker` image of `TRAC` while the latter starts a container with an interactive terminal.

2. Reproducibility

2.1 How Table 1 has been created

We now describe how the information in Table 1 of our COORDINATION has been determined.
We recall that Table 1 reports how our framework captures the features of the smart contracts in the Azure repository described at the following links:

- Hello Blockchain
- Simple Marketplace
- Basic Provenance
- Digital Locker
- Refrigerated Transportation
- Asset Transfer
- Room Thermostat
- Defective Component Counter
- Frequent Flyer Rewards Calculator.

For each smart contract, the table below reports

- where the features are met in the `Solidity` implementation in the Azure repository
- the lines in the DAFSM model where the feature is captured (if at all)

Example (link to .sol)	Line in Code for the feature	How TRAC handle it
Simple Marketplace	BI : Lines 21 & 44	BI: Line 1, 2 & 6
Hello Blockchain	BI: Lines 19 & 39	Bi: Line 1 & 3
Bazaar	ICI: BazaarItem (Line 78) ItemList(Line 40) BI : BazaarItem (Line 76) ItemList(Line 33)	
Ping Pong	BI : Line 16 & 67 ICI : Lines 18, 29, 41, 47, 77, 82 & 88	
Defective Component Counter	BI: Line 17 PP: Line 15	BI: Line 1 PP: Line 1
Frequent Flyer Rewards Calculator	BI : Line 20 PP : Line 18	BI: Line 1 PP: Line 1
Room Thermostat	PP : Line 16	PP: Line 1
Asset Transfer	BI : Line 18, PP: Line 49 RR : Lines 97 & 171	BI: Lines 1& 3 PP: Lines 2& 7 RR:

Example (link to .sol)	Line in Code for the feature	How TRAC handle it
Basic Provenance	BI: Line 19 PP: Line 17, 26 RR : Line 38, 51	BI: Line 1 PP: Line 1, 2, 3 RR:
Refrigerated Transportation	BI: Line 32 PP: Line 28, 89 RR : Line 118, 143 MRP : Lines 33, 34, 119 & 142	BI: Line 1 PP: Line 1, 5 & 9 RR: MRP:
Digital Locker	BI : Line 21 PP: Lines 19, 68 RR : Lines 102,126, 127, 139 & 149 MRP : Lines 76, 91	BI: Line 1 PP: Line 1 RR: MRP:

2.2. How to check the well-formedness of the Azure benchmarks

The DAFSM models for each smart contract but for `Bazaar` and `Ping Pong` of the Azure repository can be found in the directory `Examples/dafsms_txt/azure`.

To check a model with `TRAC`, navigate to the directory `src` and execute the `Main.py` as done with the `Docker` commands below on the `simple-marketplace` smart contract:

```
cd src
python3 Main.py --filetype txt "azure/simplemarket_place"
```

The latter command produces the following output

```
--Parsing Txt to generate Json file

Checking the well formness of the model----

(!) Verdict: Well Formed
```

reporting that the DAFSMs for the `simplemarket_place` is well formed. For the other smart contracts it is enough to execute the python script on the corresponding DAFSM.

2.3. How to check the randomly generated models

The 135 randomly generated models used in last part of Section 4 of our paper are in `src/Examples/random_txt/tests_dafsm_1` splitted in sub-directories each containing 5 DAFSMs and a `list_of_files_info.csv` file with metadata on the DAFSMs (we detail the metadata in section 4 below). Our performance analysis can be reproduced by executing the following commands in the `Docker`:

```
cd src
python3 Random_exec.py tests_dafsms_1 --number_runs_per_each 10 --
number_test_per_cpu 5 --time_out 300000000000
```

Note that the results may vary due to different hardware/software configurations than those we used (cf. page 12 of the paper).
The latter command above specifies the target directory `tests_dafsms_1`, the number of repetitions for each experiment, the number of experiments analyzed by each cpu, and the time out in nanoseconds. While running the checks further `csv` files will be generated and finally merged into a single file called `src/Examples/random_txt/tests_dafsm_1/merged_list_of_files_info.csv`. Notice if the target directory in the command above is not changed, this `csv` file will be overwritten at each execution. The current content of the `csv` files when starting the `Docker` contains the values plotted in Figures 2 and 3 of our paper .

The plots can be obtained by executing

```
python3 ./plot_data.py examples_1 --file merged_list_of_files_info\
    --field num_states,num_transitions,num_paths\
    --pl_lines
participants_time,non_determinism_time,a_consistency_time,z3_running_time\
    --shape 2d --type_plot scatter
```

in the `Docker`; the plots are `png` images saved in the directory `Examples/random_txt/tests_dafsms_1`.

3. Usage

3.1. Format of DAFSMs

The DAFSMs model (Definition 1 of our paper) is renderer in `TRAC` with a DSL which represents a DAFSM as sequences of lines, each specifying a transition of the DAFSM. We explain the format of transitions through the Simple Market Place contract (→ following Example 1 of our paper), which in our DSL is

```
_ {True} o:O > starts(c,string _description, int _price) {description :=
_description & price := _price} {string description, int price, int offer}
S0
S0 {_offer > 0} b:B > c.makeOffer(int _offer) {offer := _offer} S1
S1 {True} o > c.acceptOffer() {} S2+
S1 {True} o > c.rejectOffer() {} S01
S01 {_offer > 0} any b:B > c.makeOffer(int _offer) {offer := _offer} S1
S01 {_offer > 0} b:B > c.makeOffer(int _offer) {offer := _offer} S1
```

hereafter called `SMP`; the names of states in `SMP` differ from those in Example 1, but this is immaterial for the analysis.

In general, a transition consists of

- a source and a target state; a trailing `+` denotes final states (like `S2+` above)
- a guard specified in the notation of `Z3`
- a qualified participant `p : P` corresponding to ν p : P in the paper , `any p : P`, or just `p`
- a call to an operation of the contract

- a list of `&`-separate assignments.

The first line of `SMP` is a special transition corresponding to the edge entering the initial state in Example 1 barred for

- the fact that the source state is `_` is used to identify the initial state
- the additional `_description` parameter, omitted in the paper for readability

The guard `True` in the transition is the *precondition* while the list of assignments `{description := _description & price := _price}` is followed by an explicit declaration of the contract variables to capture the assumption in the first item of Page 3 of the paper ; the transition introduces a fresh participant `o` with role `O` which renders the object-oriented mechanism described just above Definition 1.

Conventionally, parameters start with `_` to distinguish them from contract variables.

3.2. Examples of non well-formed models

As seen in Section 2.2, `SMP` is well-formed; we now apply `TRAC` to detect non well-formed models. The file `azure/simplemarket_place_edit_1` contains a modified DAFSM obtained by replacing the `acceptOffer` transition of `SMP` with

`S1 {True} x > c.acceptOffer() {} S2+`

Executing in the `Docker`

```
python3 Main.py --filetype txt "azure/simplemarket_place_edit_1"
```

produces

```
The Path : _-starts-S0>S0-makeOffer-S1 does not contain the participant x : []
Error from this stage:S1_acceptOffer()_S2
--For _acceptOffer_0:   Check result ::  False
--- Participants        : False

(!) Verdict: Not Well Formed
```

stating that participant `x` has not been introduced. In fact, the `CallerCheck` finds a path to `S1` where participant `x` is not introduced (first line of the output above) identified in the transition from `S1` to `S2` with label `acceptOffer` (second line of the output). The last three lines of the output inform the user that well formedness does not hold for the use of a non introduced participant.

The file `azure/simplemarket_place_edit_2` modifies `SMP` by replacing the transitions `acceptOffer` and `rejectOffer` respectively with

S1 {False} o > c.acceptOffer() {} S01 and S1 {False} o > c.rejectOffer() {} S01

Executing now the command below in the `Docker`

```
python3 Main.py --filetype txt "azure/simplemarket_place_edit_2"
```

produces

```
Error from this state:S01_makeOffer(int _offer)_S1
--For _makeOffer_0:   Check result ::  False
--- A-Consistency: False

Simplification of the of the negation of the formula:  Not(And(Not(_offer <= 0),
offer == _offer))  ::  True

(!) Verdict: Not Well Formed
```

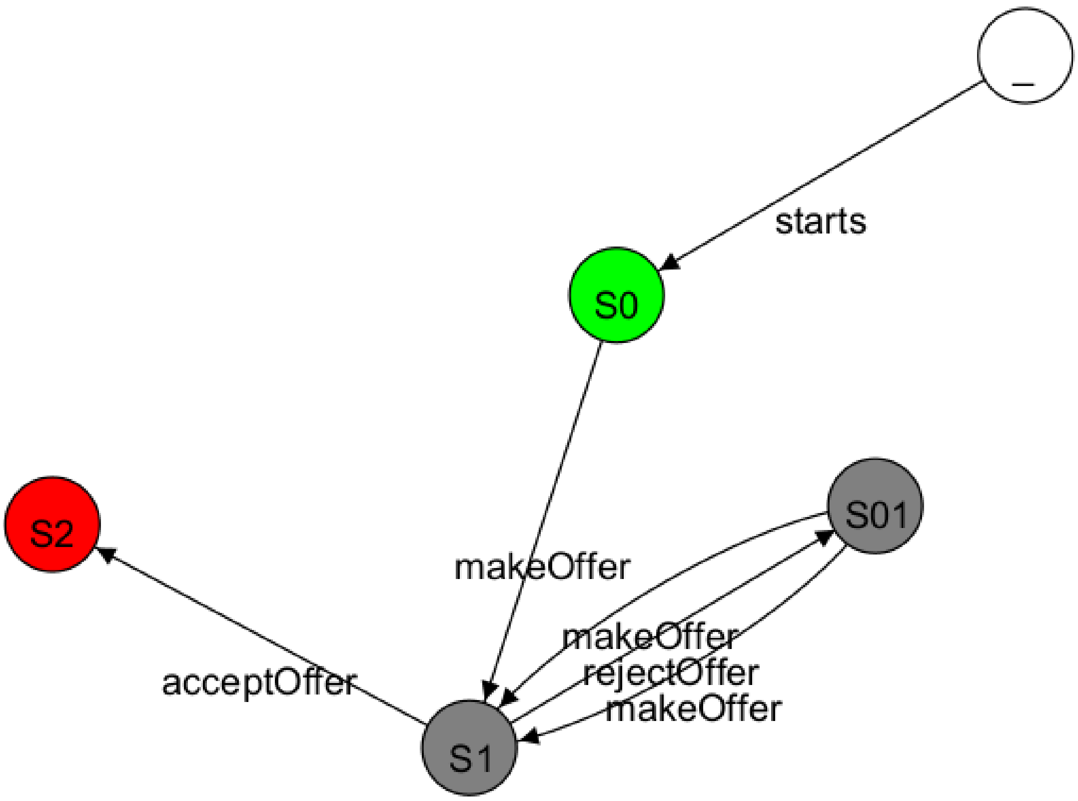
which tells that consistency is violated by the transition

```
S0 {_offer > 0} b:B > c.makeOffer(int _offer) {offer := _offer} S1
```

The simplification operated by `Z3` on the negation of the formula in the last but one line of the output yields (the formula) `True`.

The `Main.py` script used above accepts the `check_type <chk>` optional parameters where `<chk>` can take two qualifiers; `check_type` defaults to `1` which checks well-formedness and can be set to `fsm` to generate a visual representation of a DAFSM as a `png` file.

The image below for `SMP` is generated by invoking the `GraphStream` library (https://graphstream-project.org/) from our `GraphGen` component according to Figure 1 in the paper



(labels are simplified for readability). The description in Section 3.1 of the paper wrongly states that `GraphGen` is "a third-party component", but in fact it should read that `GraphGen` is a wrapper to invoke `GraphStream`. Unfortunately, the image cannot be visualised from inside the `Docker` because `GraphGen` uses the functionality of `GraphStream` that displays the graph in an interactive window. So, to see the model it is necessary to use `TRAC` from outside the `Docker`.

3.3. Commands for performance evaluation

To evaluate the performances of `TRAC`, we created a randomizer that contains a generator of random models in our DSL, a program that applies `TRAC` on the generated models, and a visualiser to plot data from `csv` files. In the following, we explain how to perform each step.

Generating random examples

The following command generates 100 random models, saves them in the directory `Examples/random_txt/your_sub_dir_name`, checks for the well-formedness of the models, and collects performance data in `csv` files:

```
python3 Generate_examples.py --directory your_sub_dir_name --num_tests 100
```

The generation process can be customised setting optional parameters of `Generate_examples.py`; if not specified, all but the last four parameters default to randomly generated values:

- `--num_tests <num>` the number of tests to generate
- `--num_states <num>` the number of states per test
- `--num_actions <num>` is the number of actions
- `--num_vars <num>` is the number of variables
- `--max_num_transitions <num>` is the maximal number of transitions that should be at least the number of states (minus 1)
- `--max_branching_factor <num>` is the maximum branching factor that should be greater or equal to 1; in corner cases, the branching factor is predominant and may lead to exceeding the maximum number of transitions
- `--num_participants <num>` is the maximum number of participant variables
- `--steps <num>` the increment steps for generating tests (meaningful only if `--incremental_gen` below is set to true; default: `10`)
- `--incremental_gen [True|False]` enables/disables incremental generation of models (default: `False`)
- `--merge_only_csv [True|False]` if set to `True` merges results into a single `csv` file; all other parameters are ignored when this is flag is used (default: `False`)
- `--num_example_for_each <num>` is the number of models to generate for each configuration (default: `5`).

To generate the models used in Section 4 of the paper , we ran the following command:

```
python3 Generate_examples.py --directory tests_dafsms_1 --steps 5 --
num_example_for_each 5\
    --num_tests 30 --incremental_gen True
```

Warning: the directory `Examples/random_txt/tests_dafsms_1` in the `Docker` is populated with the models and `csv` files generated for the experiments reported in the paper . Executing the command above in the `Docker` would overwrite the files generated for the experiments in our paper .

Well-formedness check of the models starts immediately after the generation phase is completed. The results of each check are stored in a `csv` file together with metadata for the performance evaluation. (The full description of the metadata is in section 4 below.)

It is possible to check existing generated models stored in `Examples/random_txt/<subdir>` with the following command

```
python3 Random_exec.py <subdir> --number_test_per_cpu 5 --number_runs_per_each
10\
    --time_out 300000000000
```

where

- `--number_test_per_cpu <num>` determines how many tests are to run in parallel per CPU (default: `5`)
- `--number_runs_per_each <num>` specifies how many times to run each model check (default: `10`)
- `--time_out <num>` sets a timeout limit to perform each model check (default: `300000000000`).

The command above reads the metadata in `Examples/random_txt/<subdir>/list_of_files_info.csv`, allocates 5 models to each CPU and performs the check as described in Section 4 of the paper . Each CPU will output a `csv` file `Examples/random_txt/<subdir>/list_of_files_info_<id>.csv` for each model `<id>` assigned to the CPU. All `csv` files are merged into the file `Examples/random_txt/<subdir>/merged_list_of_files_info.csv` upon completion of the evaluation.

The checking process can be customized by setting the following optional parameters:

- `--merge_csv [True|False]` if set to `True`, merges THE generated `csv` files into `Examples/random_txt/<subdir>/merged_list_of_files_info.csv` (default: `False`)
- `--add_path [True|False]` if set to `True`, counts the number path for each model in the `Examples/random_txt/<subdir>/list_of_files_info.csv` (default: `False`)

To preserve data `Random_exec.py` stores results in `Examples/random_txt/<subdir>/<time>` where `<time>` is the time when the execution started.

Data are plotted using `Plot_data.py`

```
python3 Plot_data.py <directory> --shape <shape> [--file <file_name>] [--fields
<fields_to_plot>]\
    [--pl_lines <lines_to_plot>] [--type_plot <plot_type>]
```

where

- `<directory>` is the sub-directory of `Examples/random_txt/<subdir>/` containing the `csv` files
- `--shape [2d|3d]` sets the plot shape
- `--file <str>` specify the name of the `csv` file (without the extension) (default: `merged_list_of_files_info`)

- `--fields <list>` sets the column(s) in the `csv` file to plot (default: `num_states`)
- `--pl_lines <list>` defines a comma-separated list of performance indicators to plot against the list set in `--fields` (default: `participants_time, non-determinism_time, a-consistency-time`)
- `--type_plot [line|scatter|bar]` chooses the type of 2D plot (default: `line`)
- `--scale [log|linear]` scale of the y-axis (default: `log`).

To generate the plots of section 4 of the paper , we ran the following commands:

```
python3 Plot_data.py tests_dafsms_1 --file merged_list_of_files_info\
    --field num_states,num_transitions,num_paths\
    --pl_lines
participants_time,non_determinism_time,a_consistency_time,z3_running_time\
    --shape 2d --type_plot scatter --scale linear

python3 Plot_data.py tests_dafsms_1 --file merged_list_of_files_info\
    --field num_states,num_transitions,num_paths\
    --pl_lines
participants_time,non_determinism_time,a_consistency_time,z3_running_time\
    --shape 2d --type_plot scatter --scale log
```

All generated plots are stored in the directory `Examples/random_txt/test_dafsms_1/`. To visualise these plots it is necessary to copy them to a directory outside of `Docker` executing the following commands from a non-docker shell:

```
docker ps
docker cp <containerID>:/home/TRAC/src/Examples/random_txt/<directory>
<localPath>
```

where `containerID` is the `Docker` identity of the `loctet/trac_dafsms:v1` image returned by the `docker ps` command, `<localPath>` is the path outside `Docker` where plots should be copied.

3.4. Run your own examples

Designing some DAFSM and checking them can be done by executing (`python3 Main.py --filetype txt "file_name"`) where `file_name` is the file where the DAFSM is stored and specifying an alternative base directory `<directory>` if the default one is not used.

Further models can be found in `src/Examples/other_tests`.

Additional settings can be configured in the file `src/Settings.py`. This includes default directories and other parameters for various commands. For more detailed information about these settings, refer to the [full documentation].

4. Further information

Below is the description of the header of the `csv` files:

- `path` the path to the model file
- `num_states` number of states
- `num_actions` number of actions

- `num_vars` number of variables
- `max_branching_factor` maximum branching factor
- `num_participants` number of participants
- `num_transitions` number of transitions
- `seed_num` seed number used for randomization
- `min_param_num` actual minimum number of parameters
- `average_param_num` actual average number of parameters
- `max_param_num` actual maximum number of parameters
- `min_bf_num` actual minimum number of branching factors
- `average_bf_num` actual average number of branching factors
- `max_bf_num` actual maximum number of branching factors
- `num_paths` number of paths
- `verdict` verdict of the verification process
- `participants_time` time taken for checking participants
- `non_determinism_time` time taken for non-determinism check
- `a_consistency_time` time taken for action consistency check
- `f_building_time` time taken for formula building
- `building_time` time taken for building
- `z3_running_time` time taken for running Z3
- `total` total time taken for the process
- `is_time_out` indicates if there was a timeout during processing.

The complete documentation of `TRAC` includes detailed code explanations and usage instructions. After downloading, unzip the file to access the Sphinx-generated documentation. This documentation is available at GitHub repository and provides further insights on features of `TRAC`.

Commands `Main.py`, `Generate_examples.py`, `Random_exec.py`, and `Plot_data.py` feature a `--help` option, e.g.,

```
python3 Main.py --help
```

prints a description of the available options and the usage of `Main.py`.