

# Data-aware coordination with TRAC

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## 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).

References to our paper submitted at COORDINATION 2024 are marked with a .

## 1. Installation

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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

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### 2.1 How Table 1 has been created

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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
<a href="#">Simple Marketplace</a>	BI : Lines 21 & 44	BI: <a href="#">Line 1, 2 &amp; 6</a>
<a href="#">Hello Blockchain</a>	BI: Lines 19 & 39	Bi: <a href="#">Line 1 &amp; 3</a>
<a href="#">Bazaar</a>	ICI: BazaarItem (Line 78) ItemList(Line 40) BI : BazaarItem (Line 76) ItemList(Line 33)	
<a href="#">Ping Pong</a>	BI : Line 16 & 67 ICI : Lines 18, 29, 41, 47, 77, 82 & 88	
<a href="#">Defective Component Counter</a>	BI: Line 17 PP: Line 15	BI: <a href="#">Line 1</a> PP: <a href="#">Line 1</a>
<a href="#">Frequent Flyer Rewards Calculator</a>	BI : Line 20 PP : Line 18	BI: <a href="#">Line 1</a> PP: <a href="#">Line 1</a>
<a href="#">Room Thermostat</a>	PP : Line 16	PP: <a href="#">Line 1</a>
<a href="#">Asset Transfer</a>	BI : Line 18, PP: Line 49 RR : Lines 97 & 171	BI: <a href="#">Lines 1&amp; 3</a> PP: <a href="#">Lines 2&amp; 7</a> RR:
<a href="#">Basic Provenance</a>	BI: Line 19 PP: Line 17, 26 RR : Line 38, 51	BI: <a href="#">Line 1</a> PP: <a href="#">Line 1, 2, 3</a> RR:
<a href="#">Refrigerated Transportation</a>	BI: Line 32 PP: Line 28, 89 RR : Line 118, 143 MRP : Lines 33, 34, 119 & 142	BI: <a href="#">Line 1</a> PP: <a href="#">Line 1, 5 &amp; 9</a> RR: MRP:
<a href="#">Digital Locker</a>	BI : Line 21 PP: Lines 19, 68 RR : Lines 102,126, 127, 139 & 149 MRP : Lines 76, 91	BI: <a href="#">Line 1</a> PP: <a href="#">Line 1</a> 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 `src/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 `azure/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 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).

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.
```

### Warning:

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.

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  
`src/Examples/random_txt/tests_dafsms_1`.

## 3. Usage

### 3.1. Format of DAFSMs

The DAFSMs model (Definition 1 ) is rendered 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 Marketplace contract (following Example 1 ), which in our DSL is

```
_ {True} o:0 > 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  $\nu p : P$ , `any p : P`, or just `p` (Definition 1 )
- 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 ; the transition introduces a fresh participant `o` with role `0` 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
```

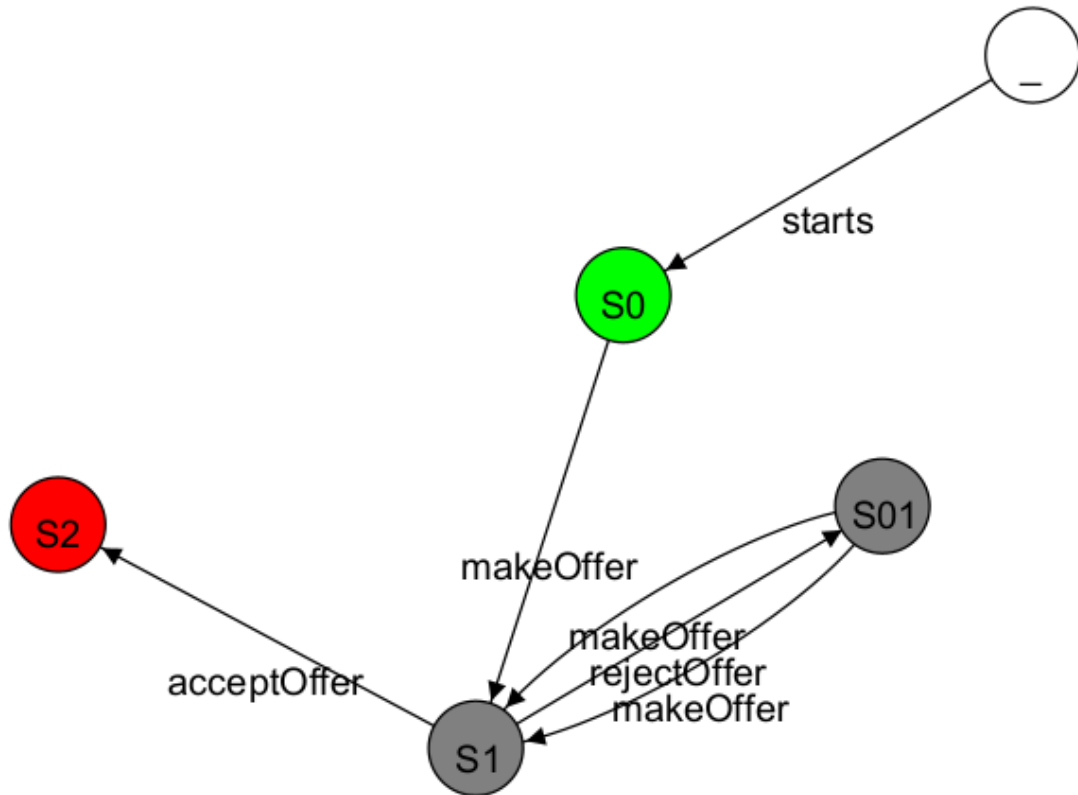
which tells that consistency is violated by the transition

```
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



(labels are simplified for readability). The description in Section 3.1 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 `src/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 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 , 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 `src/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 Section 4 .

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 `src/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

`src/Examples/random_txt/<subdir>/list_of_files_info.csv`, allocates 5 models to each CPU and performs the check as described in Section 4. Each CPU will output a `csv` file `src/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 `src/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 `src/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 `src/Examples/random_txt/<subdir>/list_of_files_info.csv` (default: `False`)

To preserve data `Random_exec.py` stores results in `src/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 `src/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 `src/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 using the `Main.py` on the file where the DAFSM is stored and specifying an alternative base directory that can be set in `src/Settings.py` if the default one (`src/Examples/dafsms_txt`) 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`.