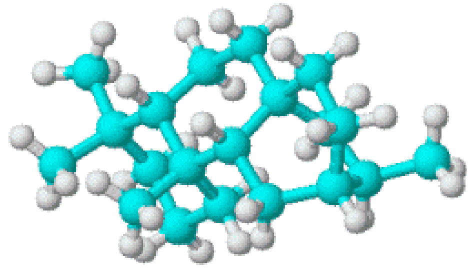
7th GECCO Workshop on Blackbox Optimization Benchmarking (BBOB): Welcome and Introduction to COCO/BBOB

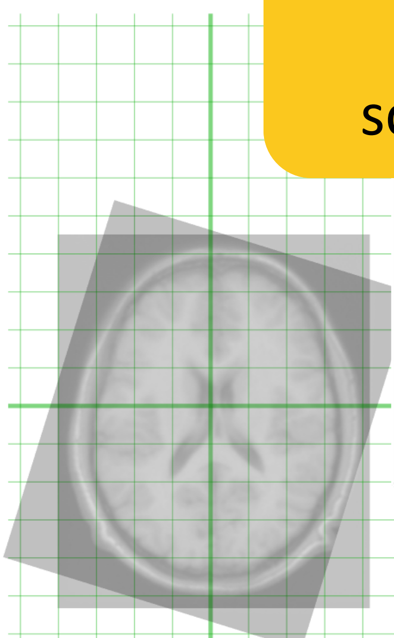
The BBOBies
https://github.com/numbbo/coco

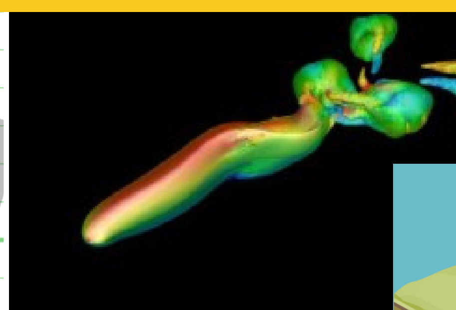
INVENTORS FOR THE DIGITAL WORLD

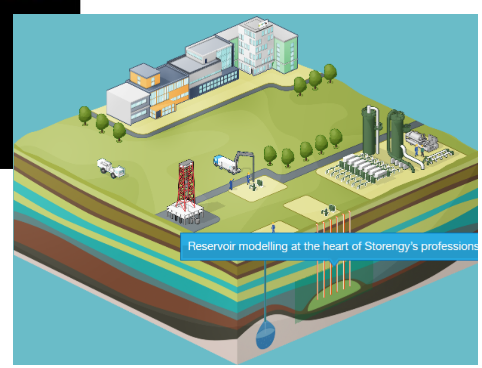
slides based on previous ones by A. Auger, N. Hansen, and D. Brockhoff



challenging optimization problems
appear in many
scientific, technological and industrial domains







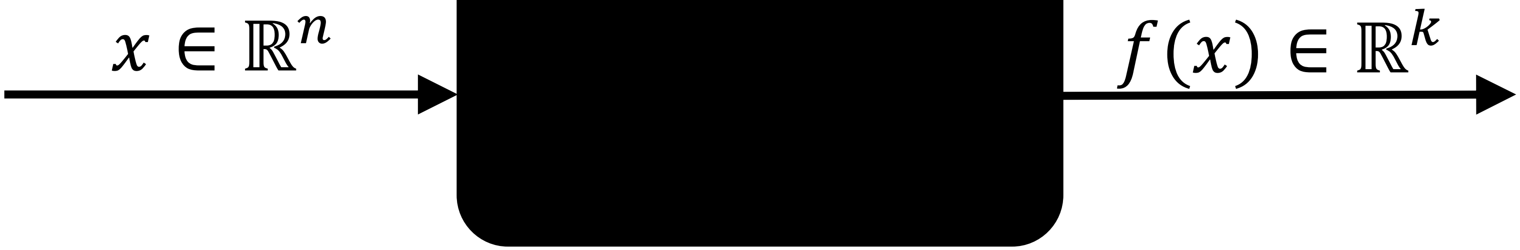
Numerical Blackbox Optimization

Optimize $f : \Omega \subset \mathbb{R}^n \mapsto \mathbb{R}^k$

derivatives not available or not useful

Practical Blackbox Optimization

Given:



Not clear:

which of the many algorithms should I use on my problem?

Numerical Blackbox Optimizers

Deterministic algorithms

Quasi-Newton with estimation of gradient (BFGS) [Broyden et al. 1970]
Simplex downhill [Nelder & Mead 1965]
Pattern search [Hooke and Jeeves 1961]
Trust-region methods (NEWUOA, BOBYQA) [Powell 2006, 2009]

Stochastic (randomized) search methods

Evolutionary Algorithms (continuous domain)

- Differential Evolution [Storn & Price 1997]
- Particle Swarm Optimization [Kennedy & Eberhart 1995]
- **Evolution Strategies, CMA-ES** [Rechenberg 1965, Hansen & Ostermeier 2001]
- Estimation of Distribution Algorithms (EDAs) [Larrañaga, Lozano, 2002]
- Cross Entropy Method (same as EDA) [Rubinstein, Kroese, 2004]
- [Holland 1975, Goldberg 1989]

Simulated annealing [Kirkpatrick et al. 1983]
Simultaneous perturbation stochastic approx. (SPSA) [Spall 2000]

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- choice typically not immediately clear
- although practitioners have knowledge about which difficulties their problem has (e.g. multi-modality, non-separability, ...)

Need: Benchmarking

- understanding of algorithms
- algorithm selection
- putting algorithms to a standardized test
  - simplify judgement
  - simplify comparison
  - regression test under algorithm changes

Kind of everybody has to do it (and it is tedious):

- choosing (and implementing) problems, performance measures, visualization, stat. tests, ...
- running a set of algorithms

that's where COCO and BBOB come into play

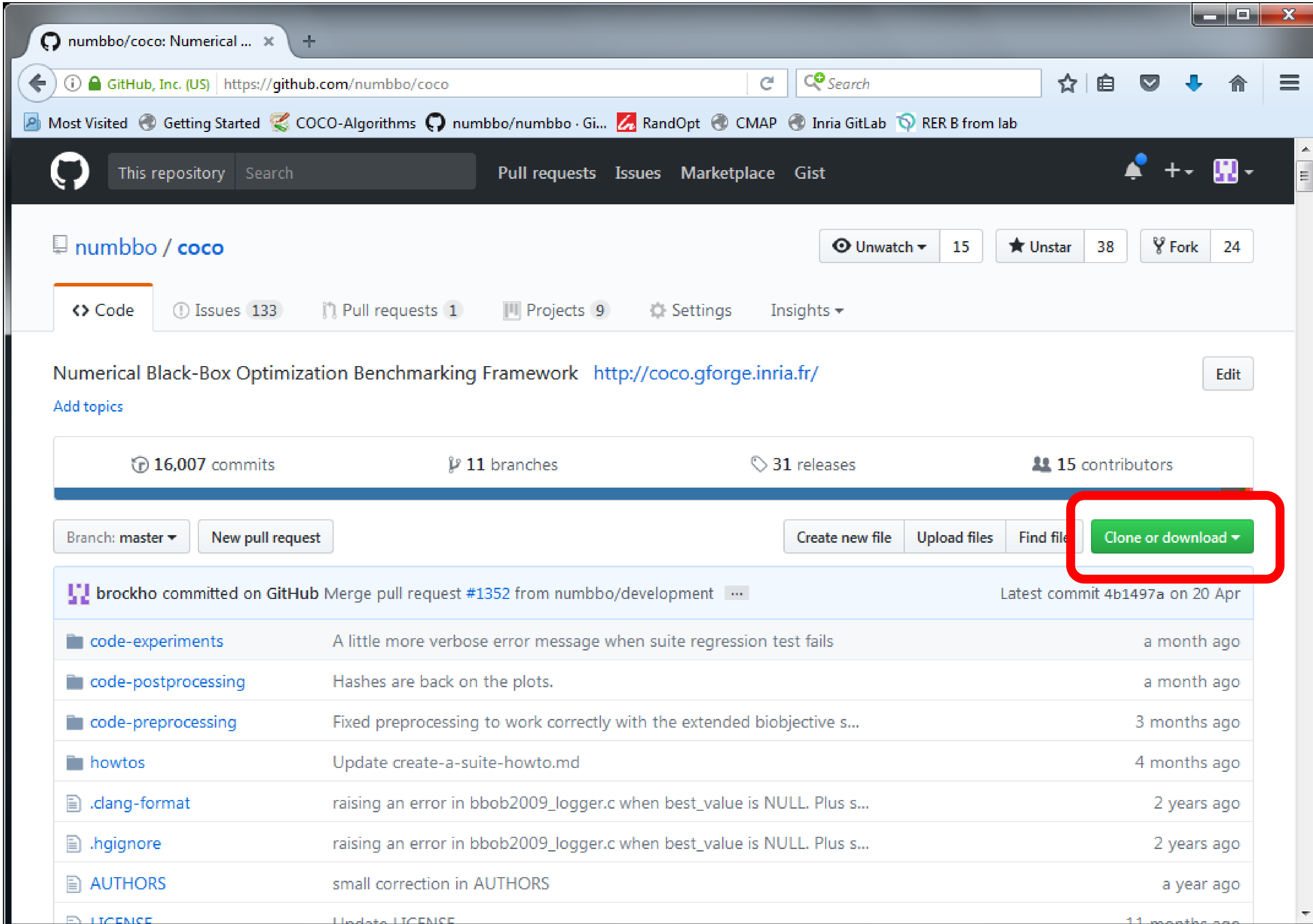
Comparing Continuous Optimizers Platform

`https://github.com/numbbo/coco`

automatized benchmarking

How to benchmark algorithms with COCO?

https://github.com/numbbo/coco



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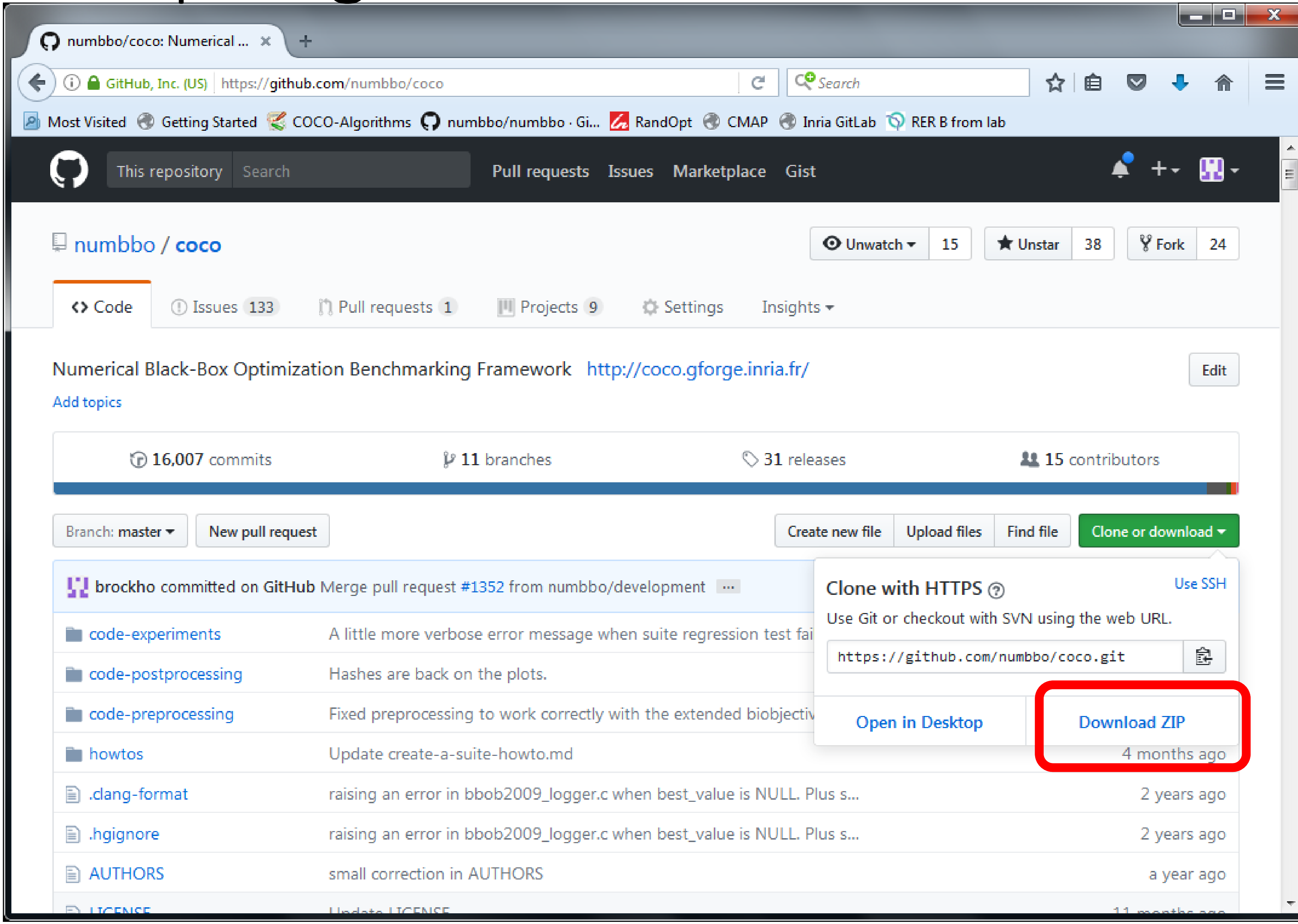

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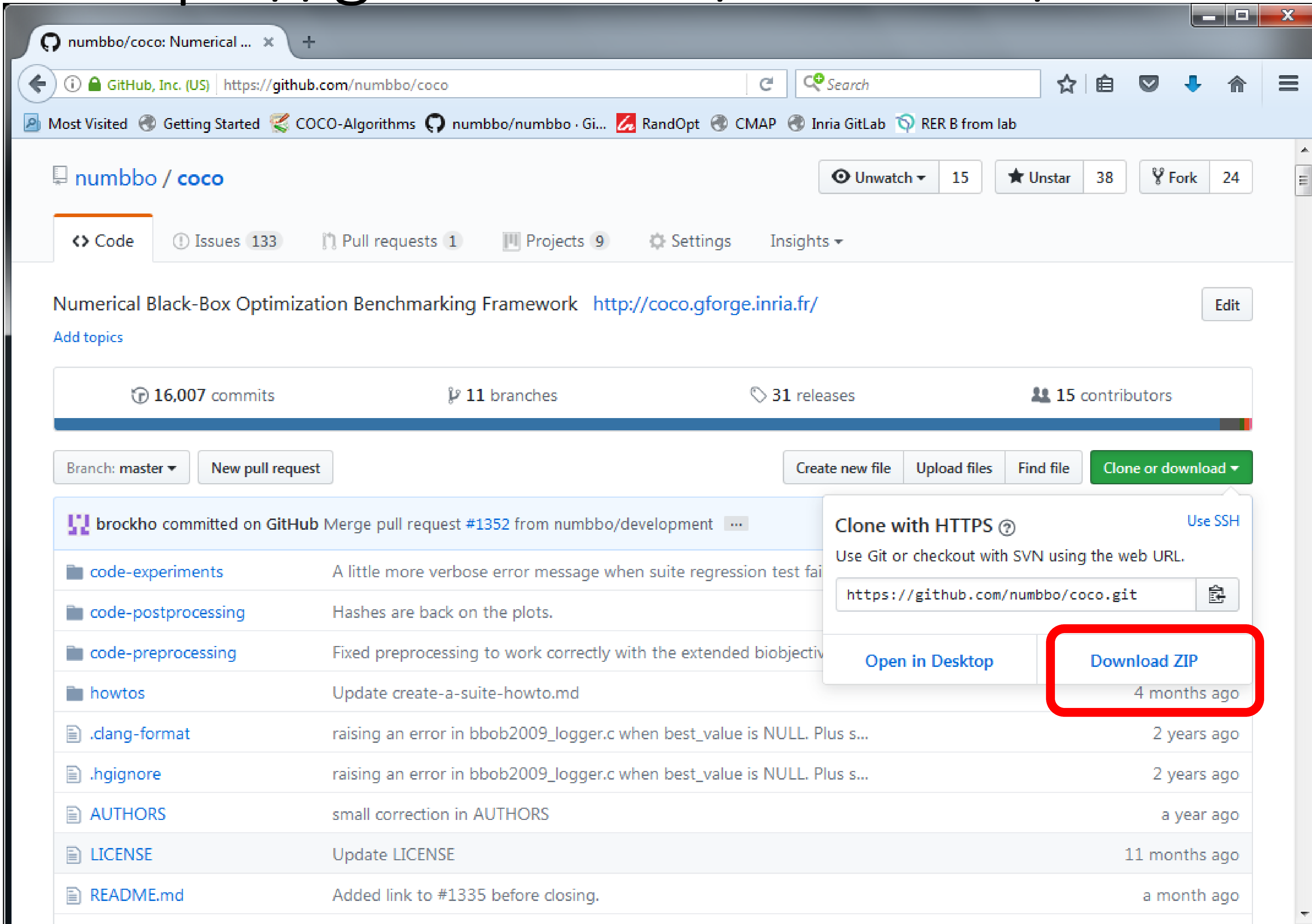

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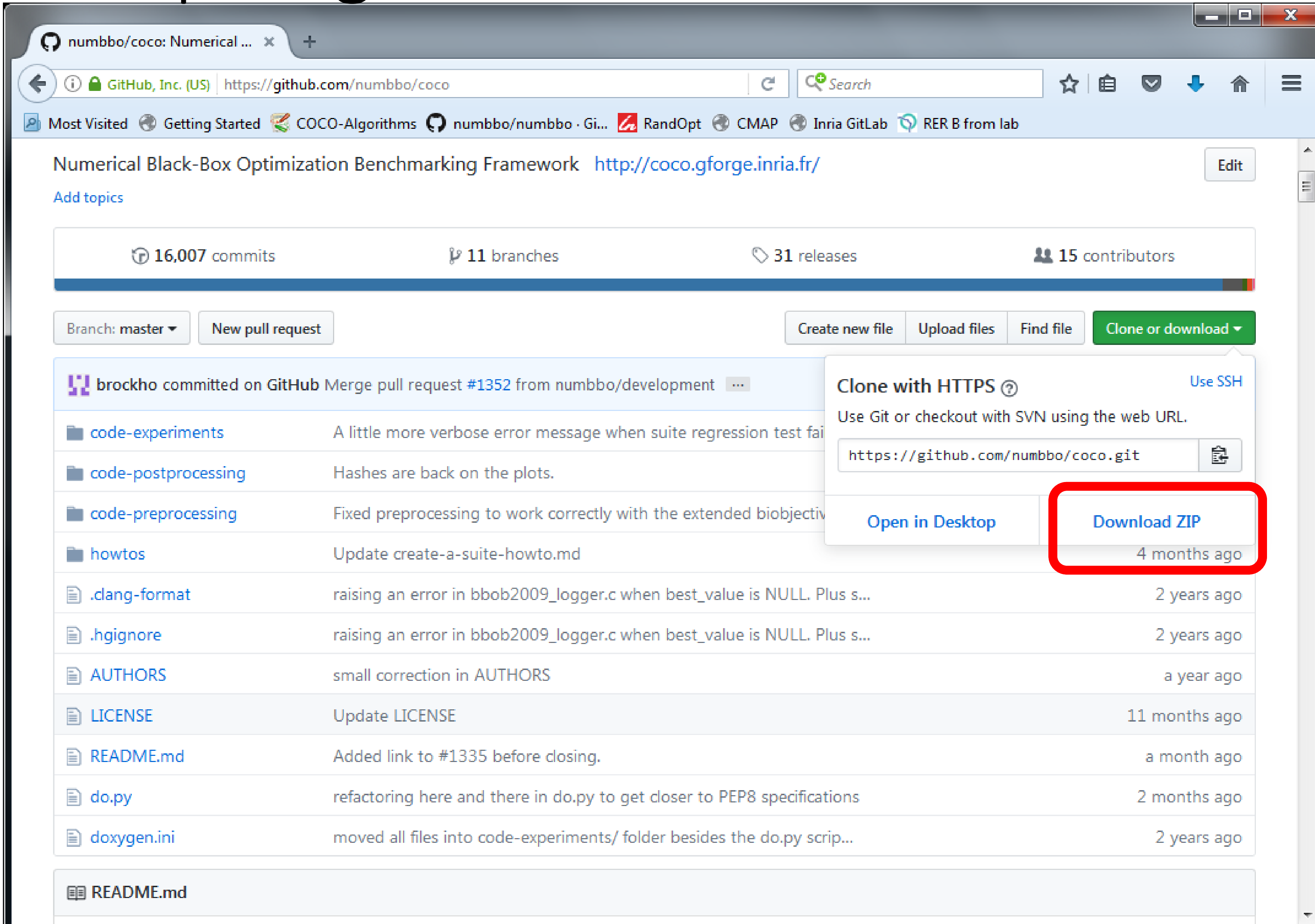

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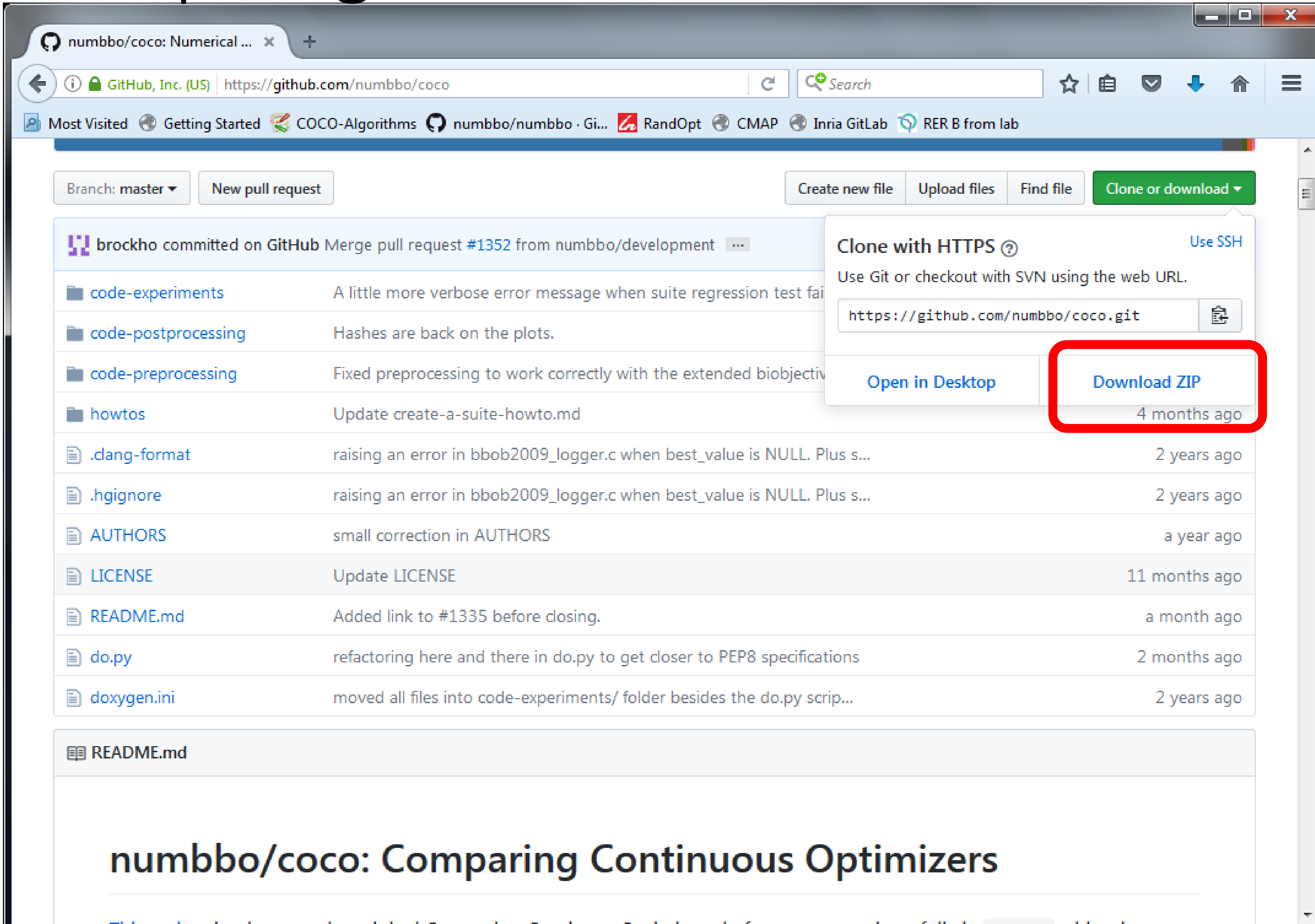

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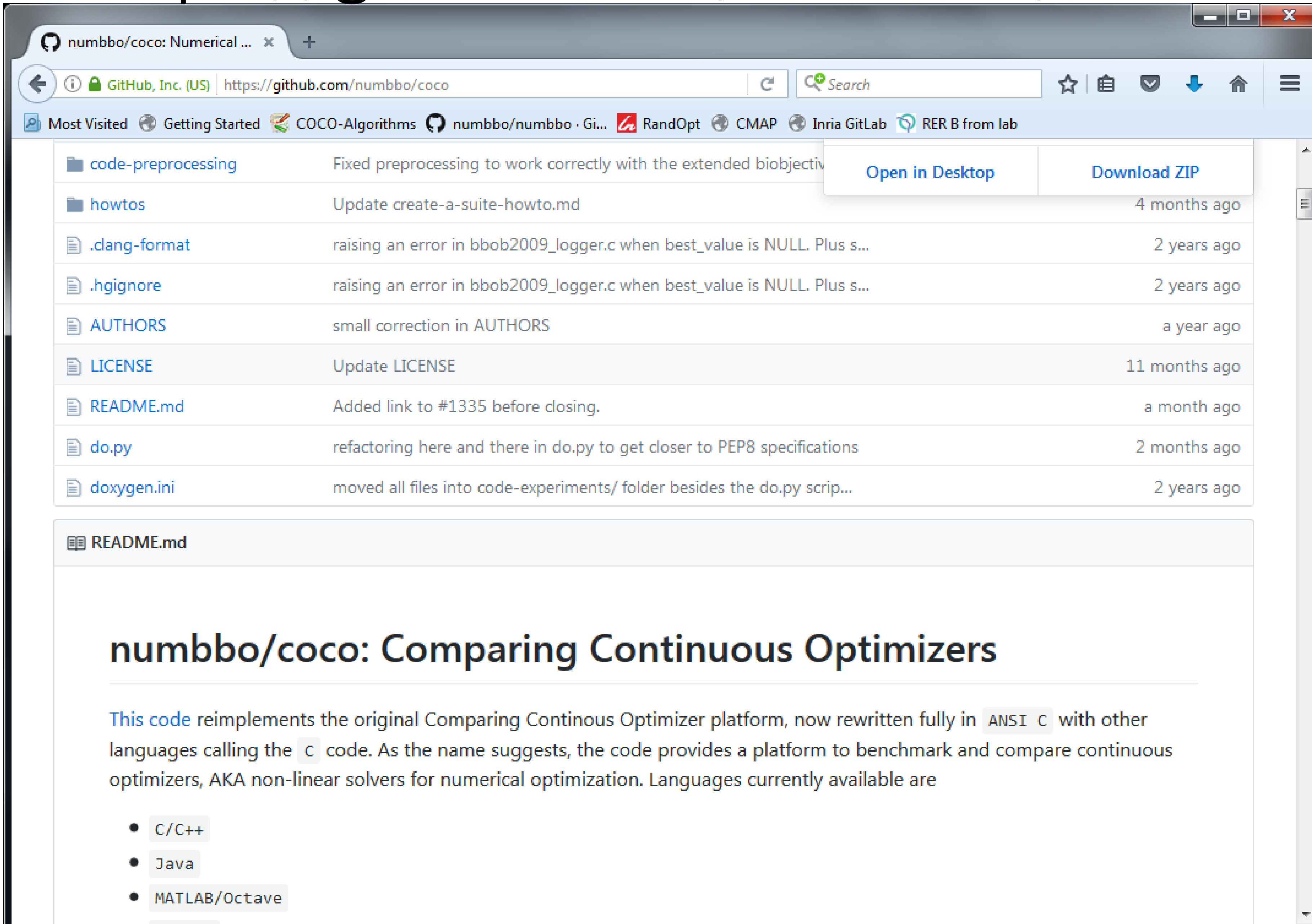

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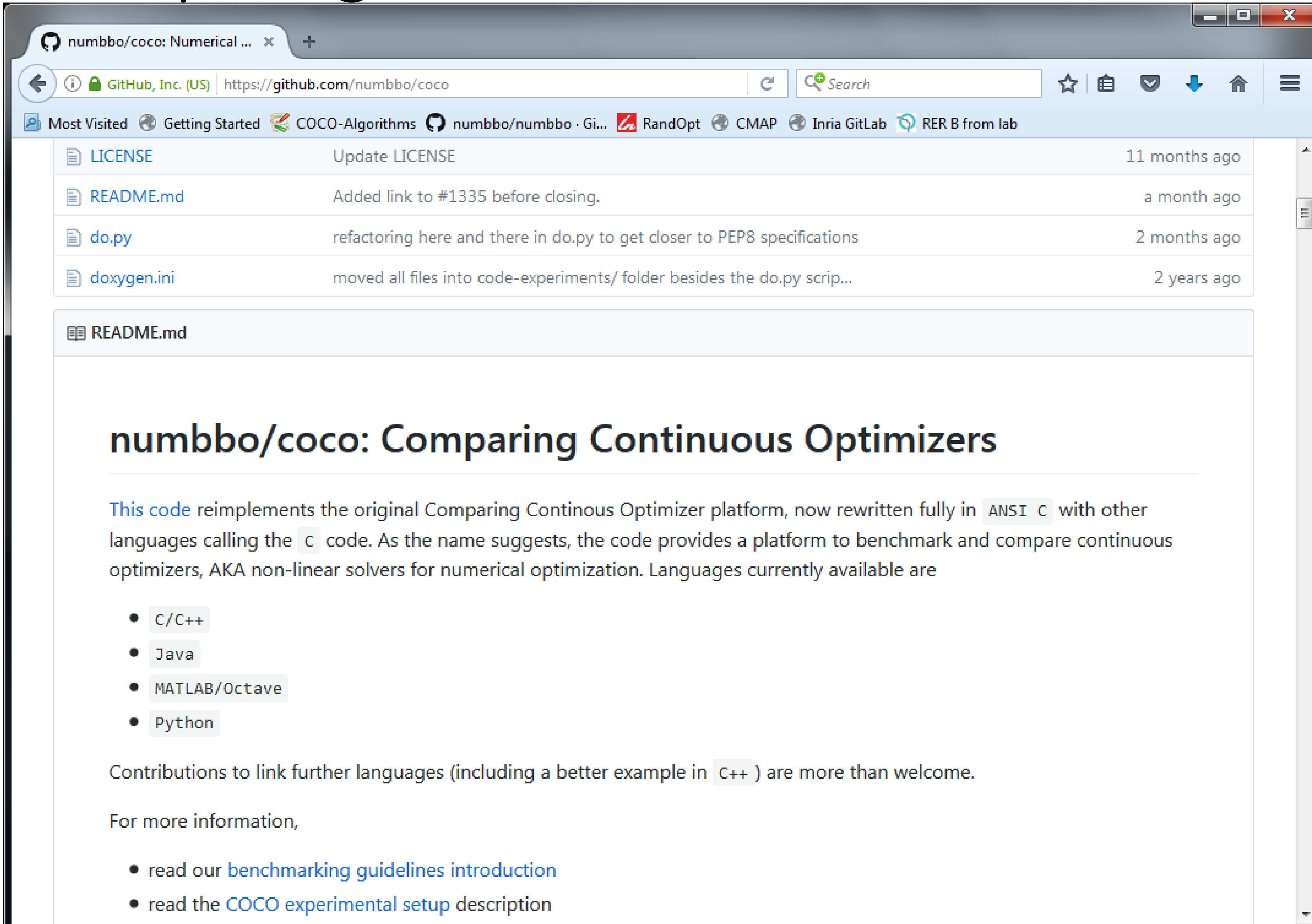

numbbo/coco: Numerical ...

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LICENSE	Update LICENSE	11 months ago
README.md	Added link to #1335 before closing.	a month ago
do.py	refactoring here and there in do.py to get closer to PEP8 specifications	2 months ago
doxygen.ini	moved all files into code-experiments/ folder besides the do.py scrip...	2 years ago

README.md

numbbo/coco: Comparing Continuous Optimizers

This code reimplements the original Comparing Continous Optimizer platform, now rewritten fully in `ANSI C` with other languages calling the `C` code. As the name suggests, the code provides a platform to benchmark and compare continuous optimizers, AKA non-linear solvers for numerical optimization. Languages currently available are

- `C/C++`
- `Java`
- `MATLAB/Octave`
- `Python`

Contributions to link further languages (including a better example in `C++`) are more than welcome.

For more information,

- read our benchmarking guidelines introduction
- read the COCO experimental setup description

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- see the `bbob-biobj` and `bbob-biobj-ext` COCO multi-objective functions testbed documentation and the specificities of the performance assessment for the bi-objective testbeds.
- consult the BBOB workshops series,
- consider to register here for news,
- see the previous COCO home page here and
- see the links below to learn more about the ideas behind CoCO.

https://github.com/numbbo/coco

Getting Started

0. Check out the *Requirements* above.

1. **Download** the COCO framework code from github,

requirements & download

- either by clicking the Download ZIP button and unzip the `zip` file,
- or by typing `git clone https://github.com/numbbo/coco.git`. This way allows to remain up-to-date easily (but needs `git` to be installed). After cloning, `git pull` keeps the code up-to-date with the latest release.

The record of official releases can be found here. The latest release corresponds to the master branch as linked above.

2. In a system shell, **`cd` into** the `coco` or `coco-<version>` folder (framework root), where the file `do.py` can be found. Type, i.e. **execute**, one of the following commands once

```
python do.py run-c
python do.py run-java
python do.py run-matlab
python do.py run-octave
python do.py run-python
```

depending on which language shall be used to run the experiments. `run-*` will build the respective code and run the example experiment once. The build result and the example experiment code can be found under `code-experiments/build/<language>` (`<language>=matlab` for Octave). `python do.py` lists all available commands.

3. On the computer where experiment data shall be post-processed, run

```
python do.py install-postprocessing
```

https://github.com/numbbo/coco

numbbo/coco: Numerical ...

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installation I: experiments

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```

installation II: postprocessing

to (user-locally) install the post-processing. From here on, `do.py` has done its job and is only needed again for updating the builds to a new release.

4. **Copy** the folder `code-experiments/build/YOUR-FAVORITE-LANGUAGE` and its content to another location. In Python it is sufficient to copy the file `example_experiment.py`. Run the example experiment (it already is compiled). As the details vary, see the respective read-me's and/or example experiment files:

- `C` read me and example experiment
- `Java` read me and example experiment
- `Matlab/Octave` read me and example experiment
- `Python` read me and example experiment

If the example experiment runs, **connect** your favorite algorithm to Coco: replace the call to the random search optimizer in the example experiment file by a call to your algorithm (see above). **Update** the output `result_folder`, the `algorithm_name` and `algorithm_info` of the observer options in the example experiment file.

Another entry point for your own experiments can be the `code-experiments/examples` folder.

5. Now you can **run** your favorite algorithm on the `bbob` suite (for single-objective algorithms) or on the `bbob-biobj` and `bbob-biobj-ext` suites (for multi-objective algorithms). Output is automatically generated in the specified data `result_folder`. By now, more suites might be available, see below.

https://github.com/numbbo/coco

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coupling algo + COCO

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example_experiment.c (slightly simplified)

```c
/* Iterate over all problems in the suite */
while ((PROBLEM = coco_suite_get_next_problem(suite, observer)) != NULL)
{
    size_t dimension = coco_problem_get_dimension(PROBLEM);

    /* Run the algorithm at least once */
    for (run = 1; run <= 1 + INDEPENDENT_RESTARTS; run++) {

      size_t evaluations_done = coco_problem_get_evaluations(PROBLEM);
      long evaluations_remaining =
          (long)(dimension * BUDGET_MULTIPLIER) - (long)evaluations_done;

      if (... || (evaluations_remaining <= 0))
        break;

      my_random_search(evaluate_function, dimension,
                       coco_problem_get_number_of_objectives(PROBLEM),
                       coco_problem_get_smallest_values_of_interest(PROBLEM),
                       coco_problem_get_largest_values_of_interest(PROBLEM),
                       (size_t) evaluations_remaining,
                       random_generator);
}
```

numbbo/coco at develop...

GitHub, Inc. (US) https://github.com/numbbo/coco/tree/development

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6. **Postprocess** the data from the results folder by typing

```
python -m cocopp [-o OUTPUT_FOLDERNAME] YOURDAT
```

running the experiment

Any subfolder in the folder arguments will be searched fo n different folders collected under a single "root" `YOURDATAFOLDER` folder. We can also compare more than one algorithm by specifying several data result folders generated by different algorithms.

A folder, `ppdata` by default, will be generated, which contains all output from the post-processing, including an `index.html` file, useful as main entry point to explore the result with a browser. Data might be overwritten, it is therefore useful to change the output folder name with the `-o OUTPUT_FOLDERNAME` option.

A summary pdf can be produced via LaTeX. The corresponding templates can be found in the `code-postprocessing/latex-templates` folder. Basic html output is also available in the result folder of the postprocessing (file `templateBBOBarticle.html`).

7. Once your algorithm runs well, **increase the budget** in your experiment script, if necessary implement randomized independent restarts, and follow the above steps successively until you are happy.

8. The experiments can be **parallelized** with any re-distribution of single problem instances to batches (see `example_experiment.py` for an example). Each batch must write in a different target folder (this should happen automatically). Results of each batch must be kept under their separate folder as is. These folders then must be

https://github.com/numbbo/coco

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python -m cocopp [-o OUTPUT_FOLDERNAME] YOURDATAFOLDER [MORE_DATAFOLDERS]
```

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postprocessing

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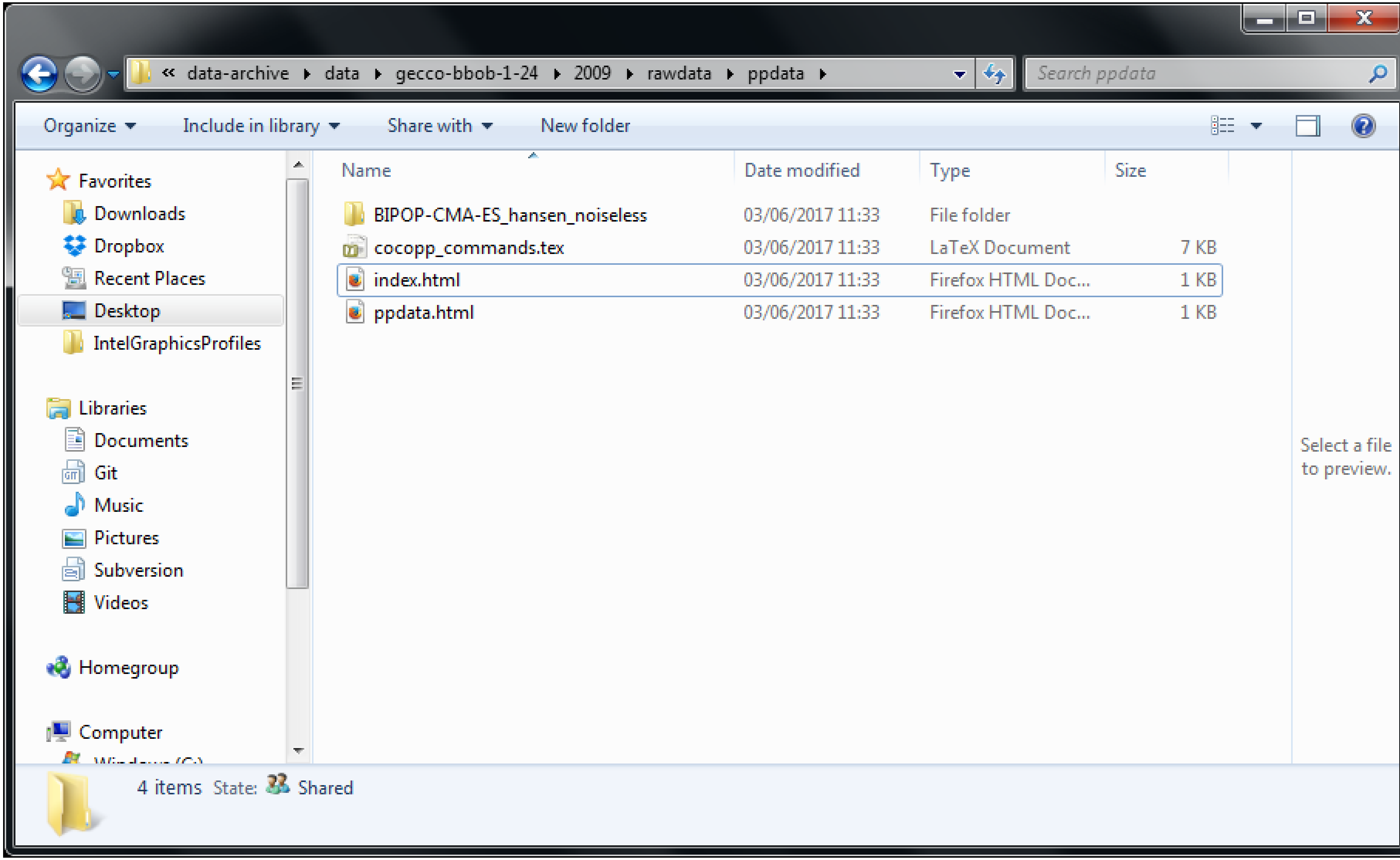
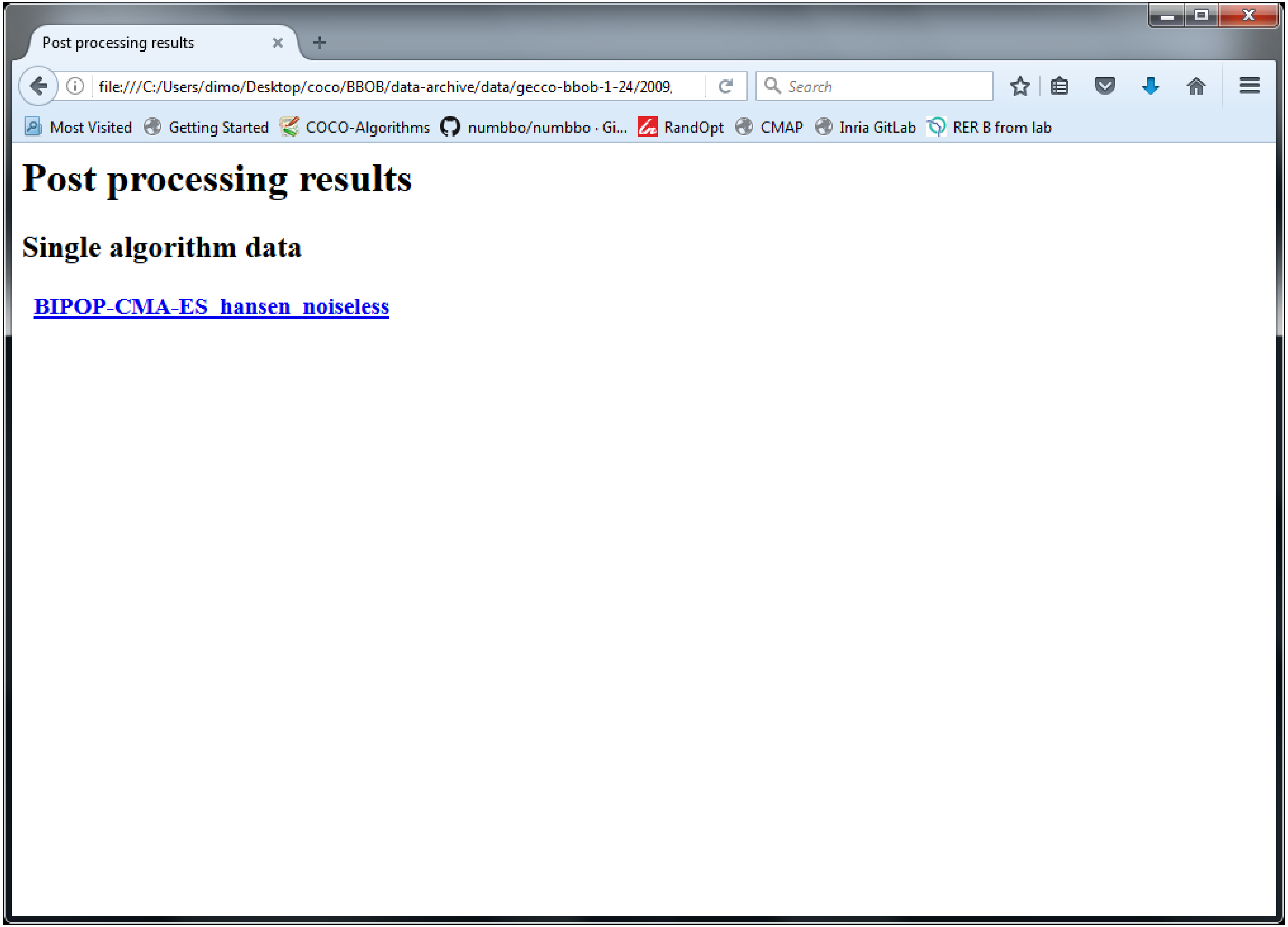
Result Folder



Automatically Generated Results



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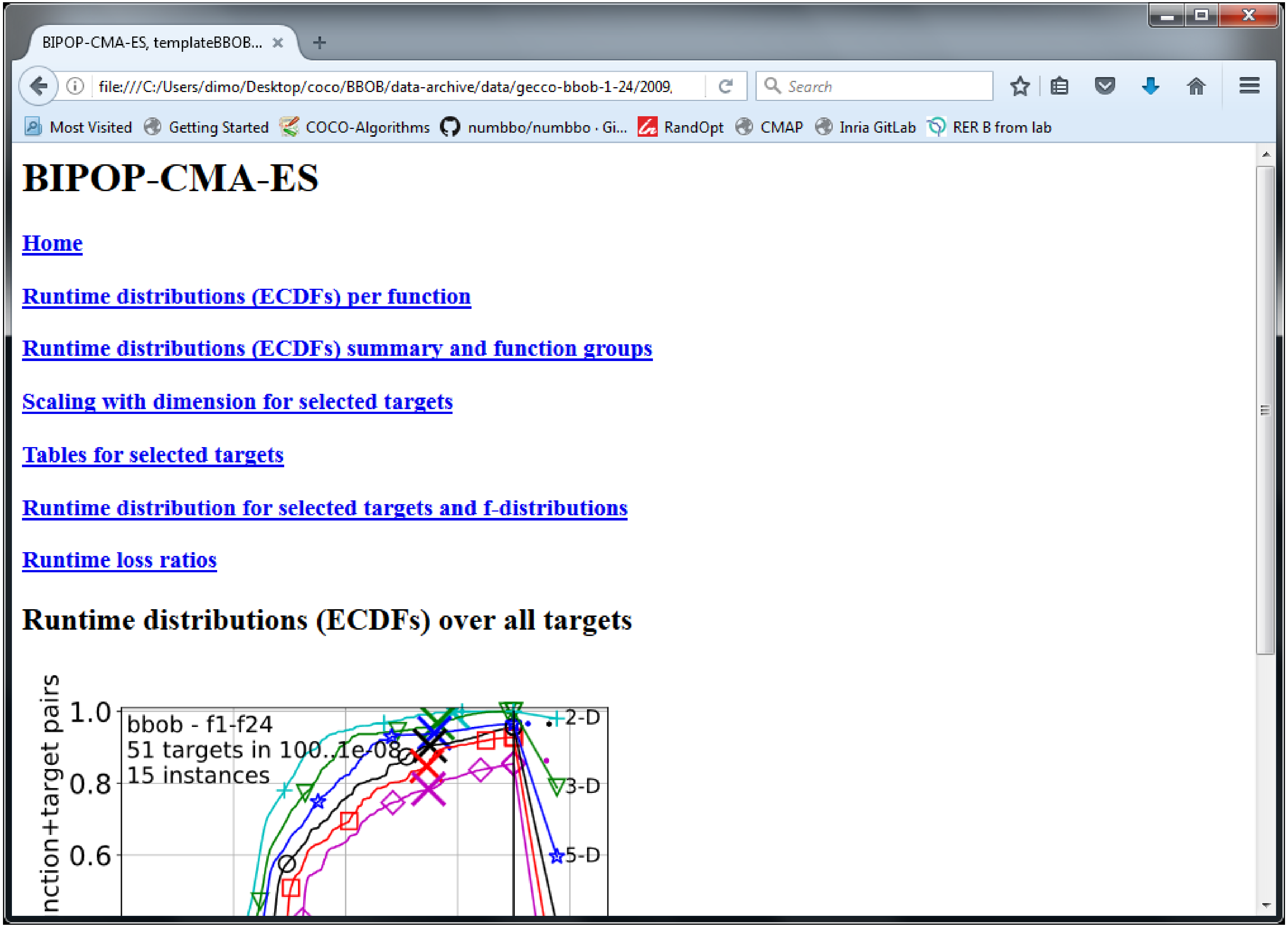

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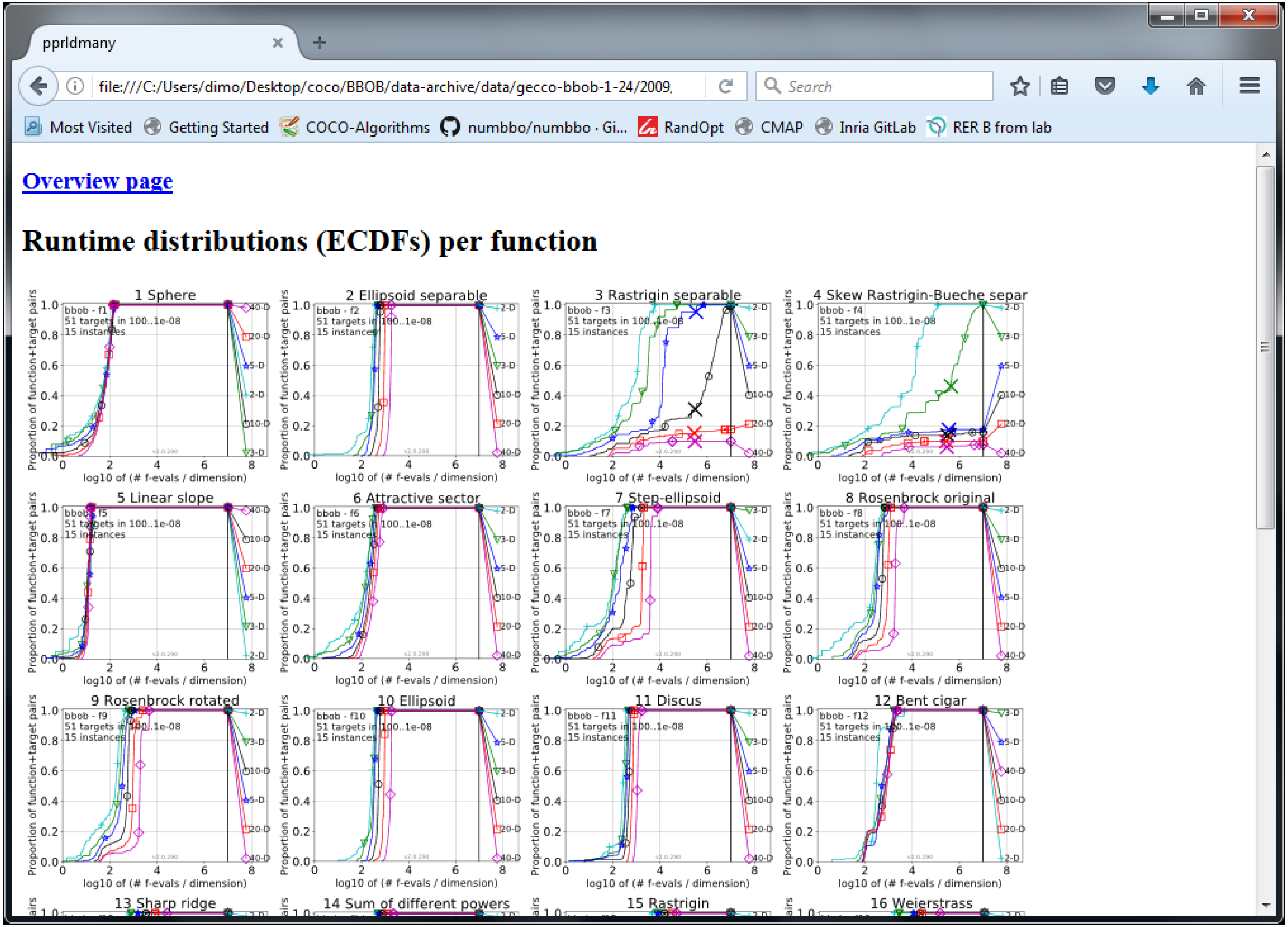

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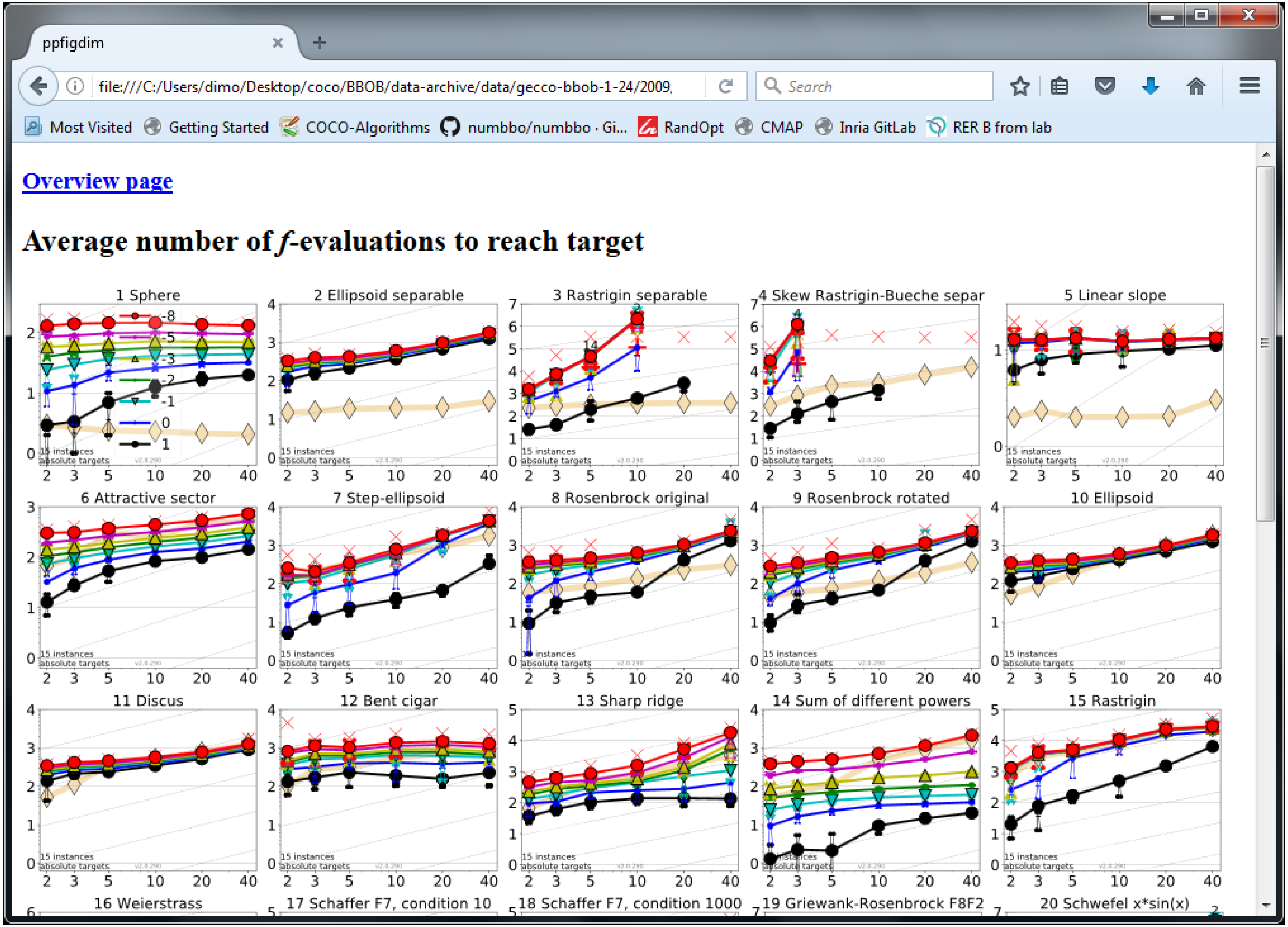


doesn't look too complicated, does it?

[the devil is in the details ☺]

so far (i.e. incl. BBOB-2017):

data for about 170 algorithm variants

(some of which on noisy or multiobjective test functions)

145 workshop papers

by 101 authors from 28 countries

Measuring Performance

On

- real world problems
  - expensive
  - comparison typically limited to certain domains
  - experts have limited interest to publish
- "artificial" benchmark functions
  - cheap
  - controlled
  - data acquisition is comparatively easy
  - problem of representativeness

Test Functions

- define the "scientific question"

the relevance can hardly be overestimated

- should represent "reality"
- are often too simple?

remind separability

- a number of testbeds are around

- account for invariance properties

prediction of performance is based on “similarity”,
ideally equivalence classes of functions

Available Test Suites in COCO

• bbob	24 noiseless fcts	140+ algo data sets
• bbob-noisy	30 noisy fcts	40+ algo data sets
• bbob-biobj	55 bi-objective fcts	15 algo data sets

Under development:

- extended bi-objective suite (bbob-biobj-ext)
- large-scale version of bbob (bbob-largescale)
- constrained test suite (bbob-constrained)

Long-term goals:

- combining difficulties
- almost real-world problems
- real-world problems

How Do We Measure Performance?

Meaningful quantitative measure

- quantitative on the ratio scale (highest possible)

  "algo A is two *times* better than algo B" is a meaningful statement
- assume a wide range of values
- meaningful (interpretable) with regard to the real world

  possible to transfer from benchmarking to real world

runtime or first hitting time is the prime candidate
(we don't have many choices anyway)

How Do We Measure Performance?

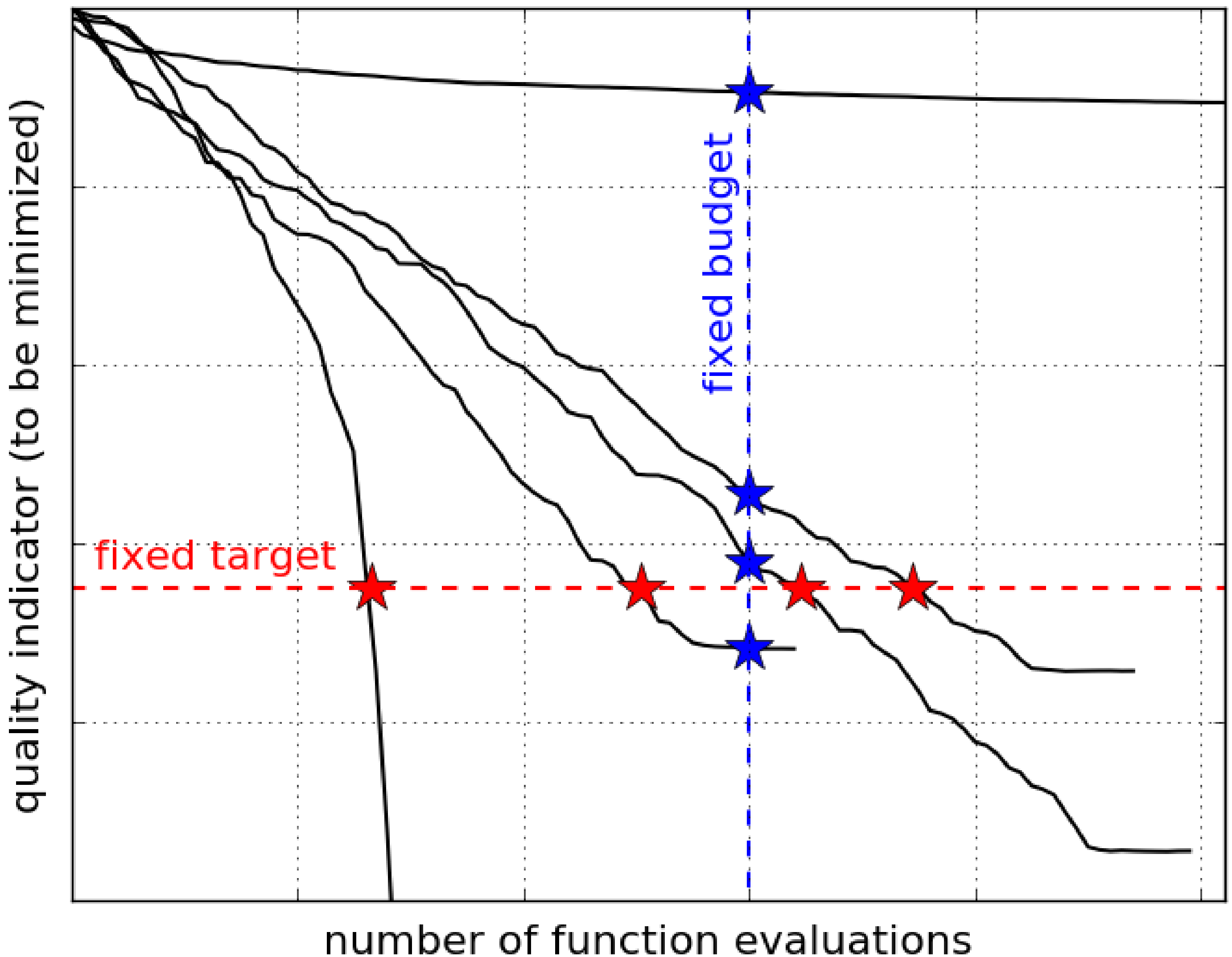
Two objectives:

- Find solution with small(est possible) function/indicator value
- With the least possible search costs (number of function evaluations)

For measuring performance: fix one and measure the other

Measuring Performance Empirically

convergence graphs is all we have to start with...

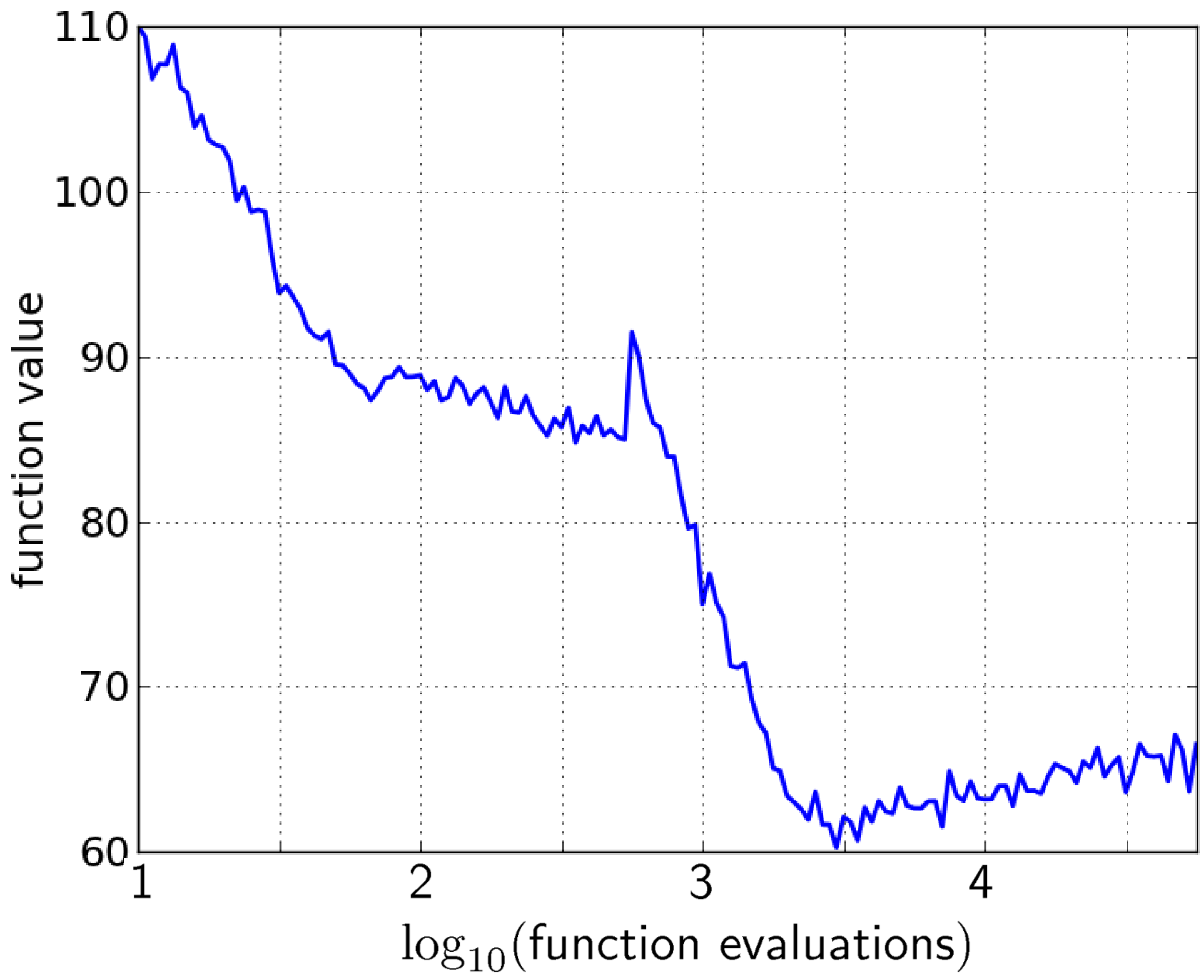


ECDF:

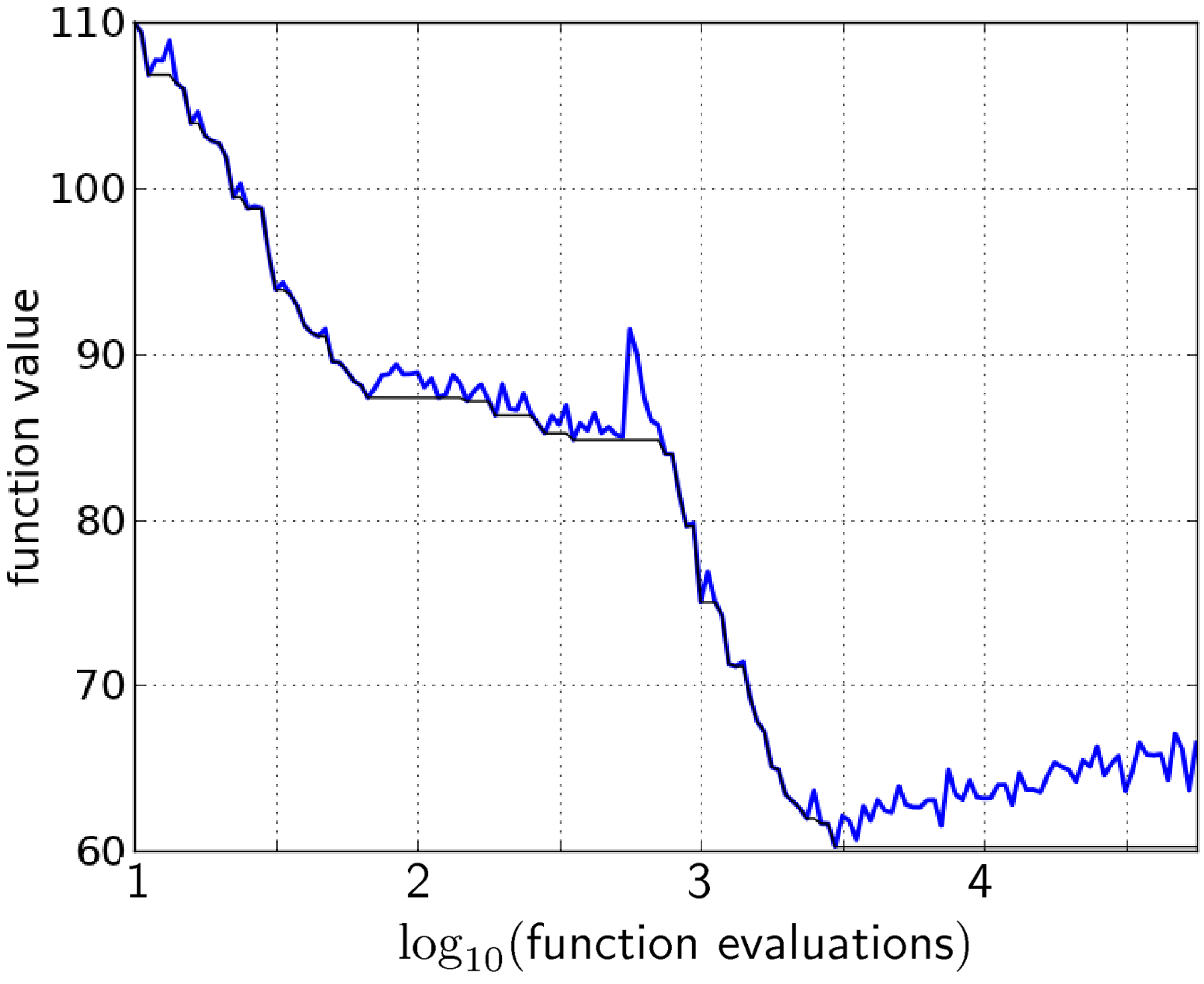
Empirical Cumulative Distribution Function of the Runtime

[aka data profile]

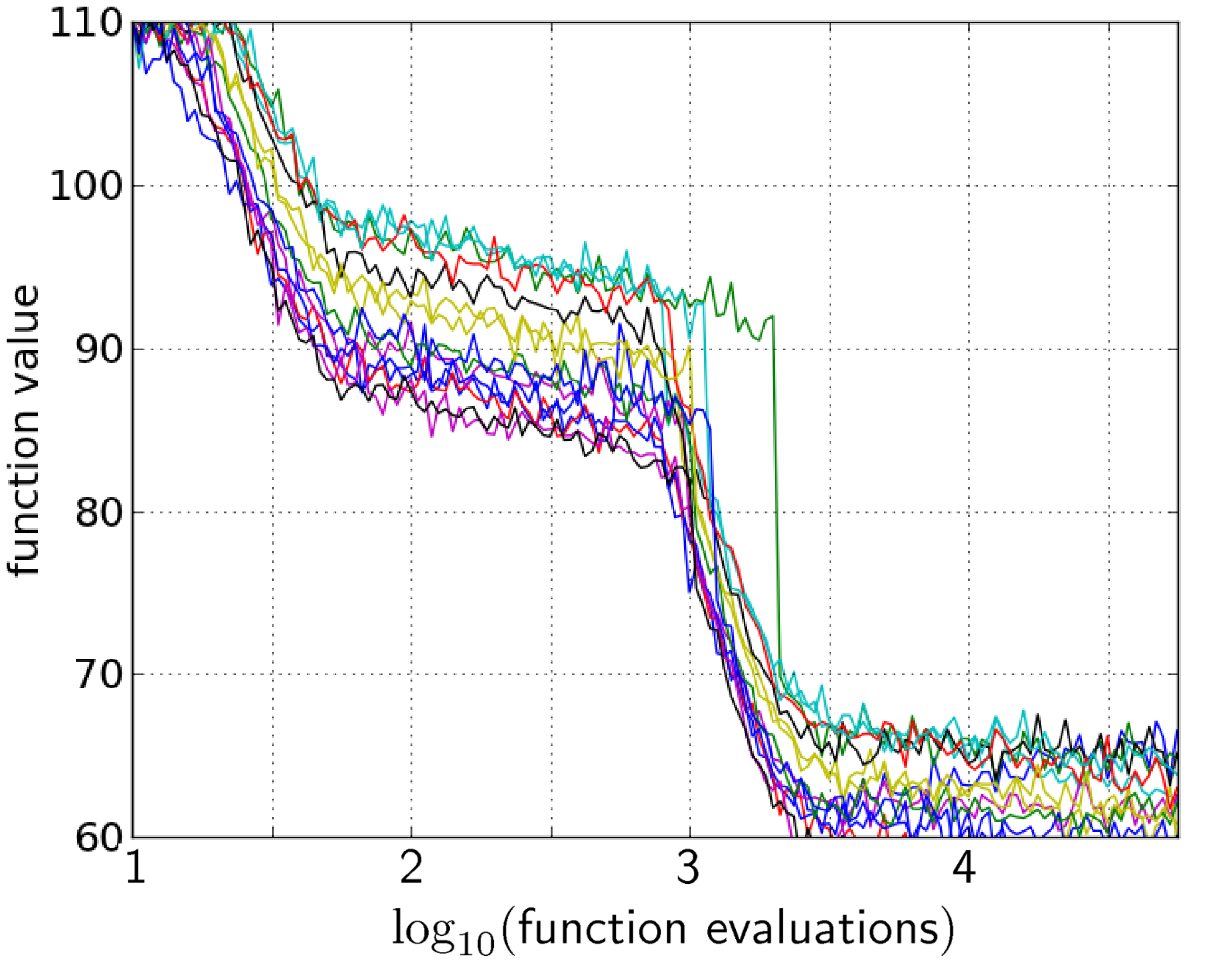
A Convergence Graph



First Hitting Time is Monotonous

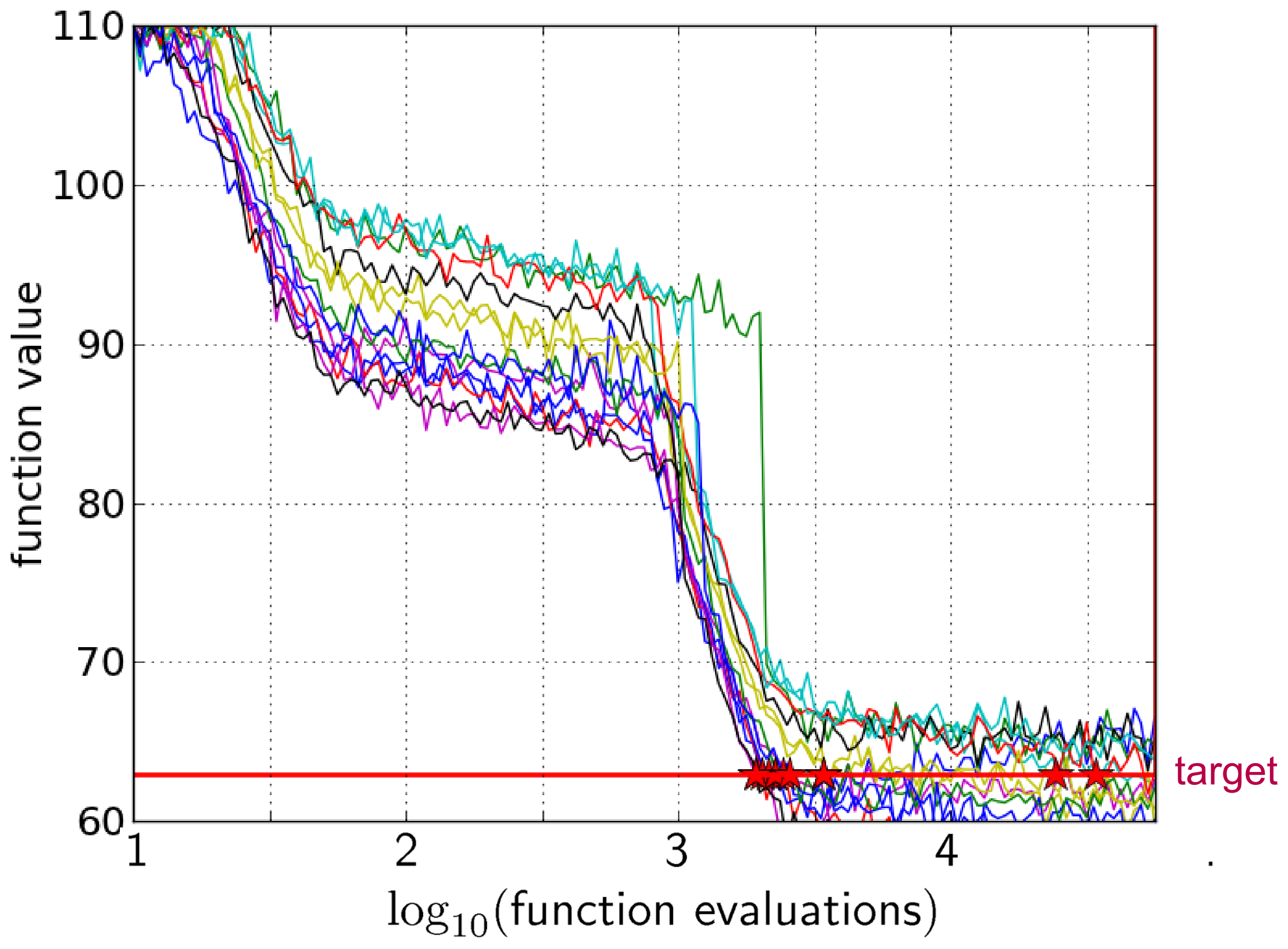


15 Runs

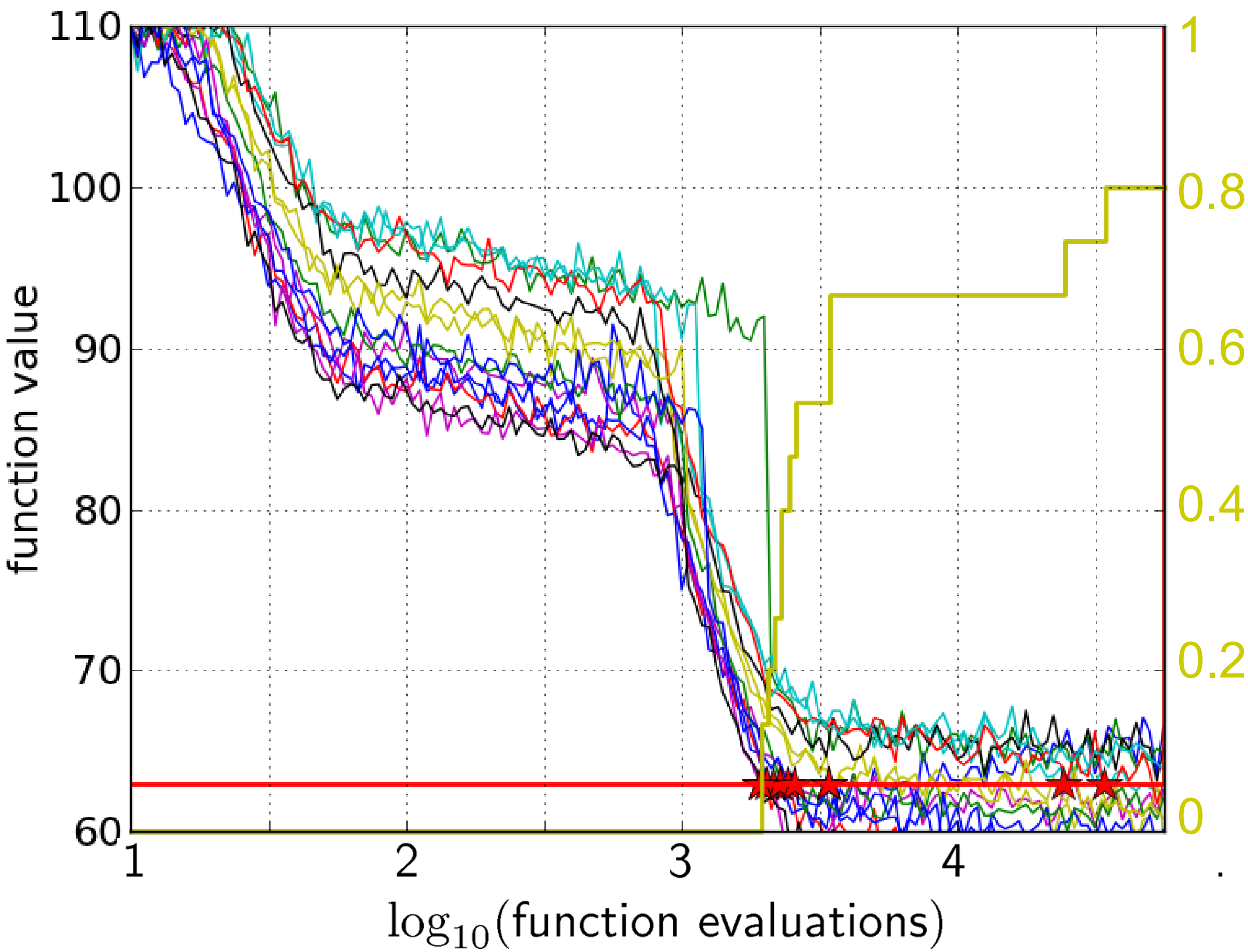


110
100
90
80
70
60
function value
1
2
3
4
$\log_{10}$(function evaluations)

15 Runs ≤ 15 Runtime Data Points



Empirical Cumulative Distribution

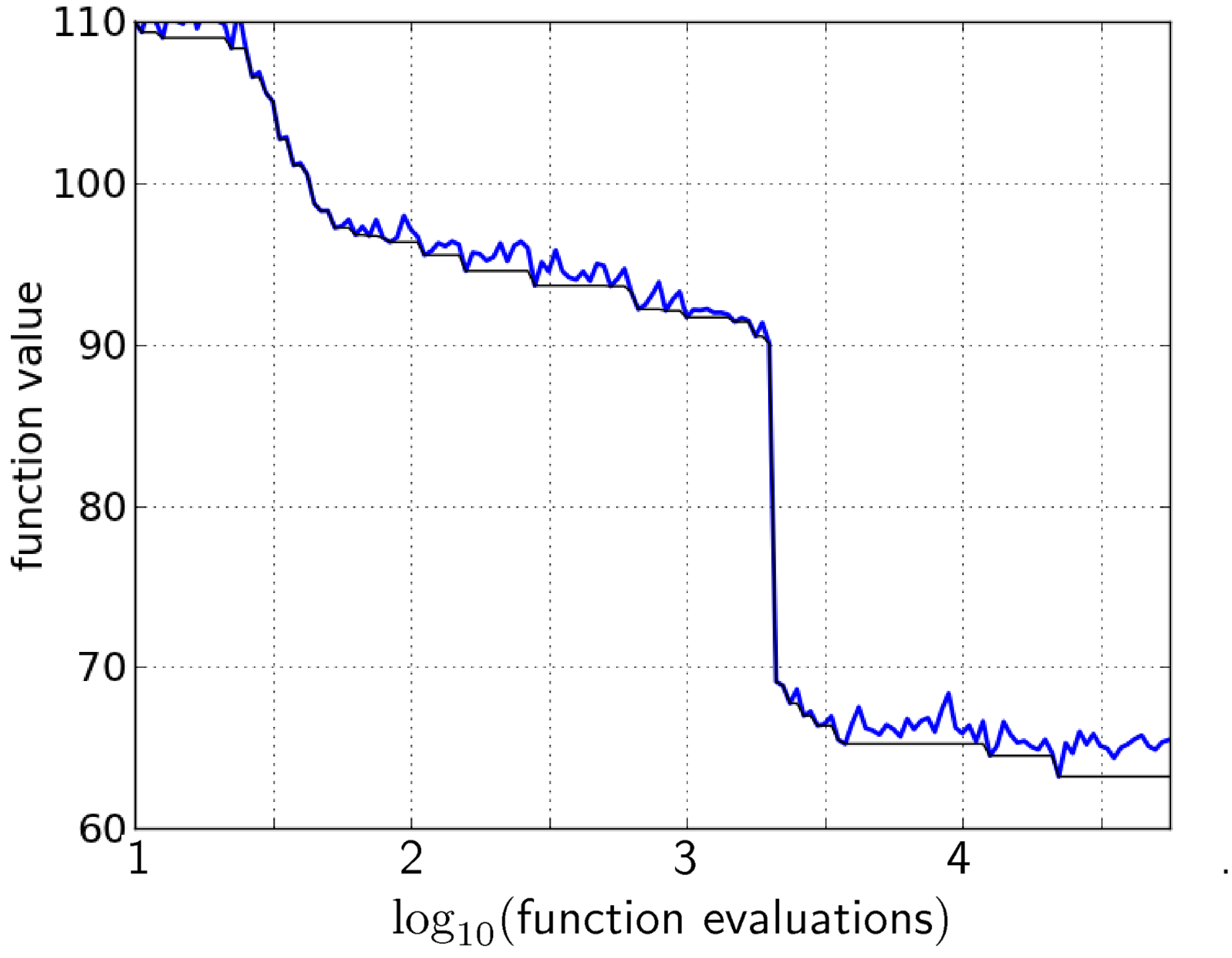


the ECDF of run lengths to reach the target

- has for each data point a vertical step of constant size
- displays for each x-value (budget) the count of observations to the left (first hitting times)

e.g. 60% of the runs need between 2000 and 4000 evaluations
80% of the runs reached the target

Reconstructing A Single Run



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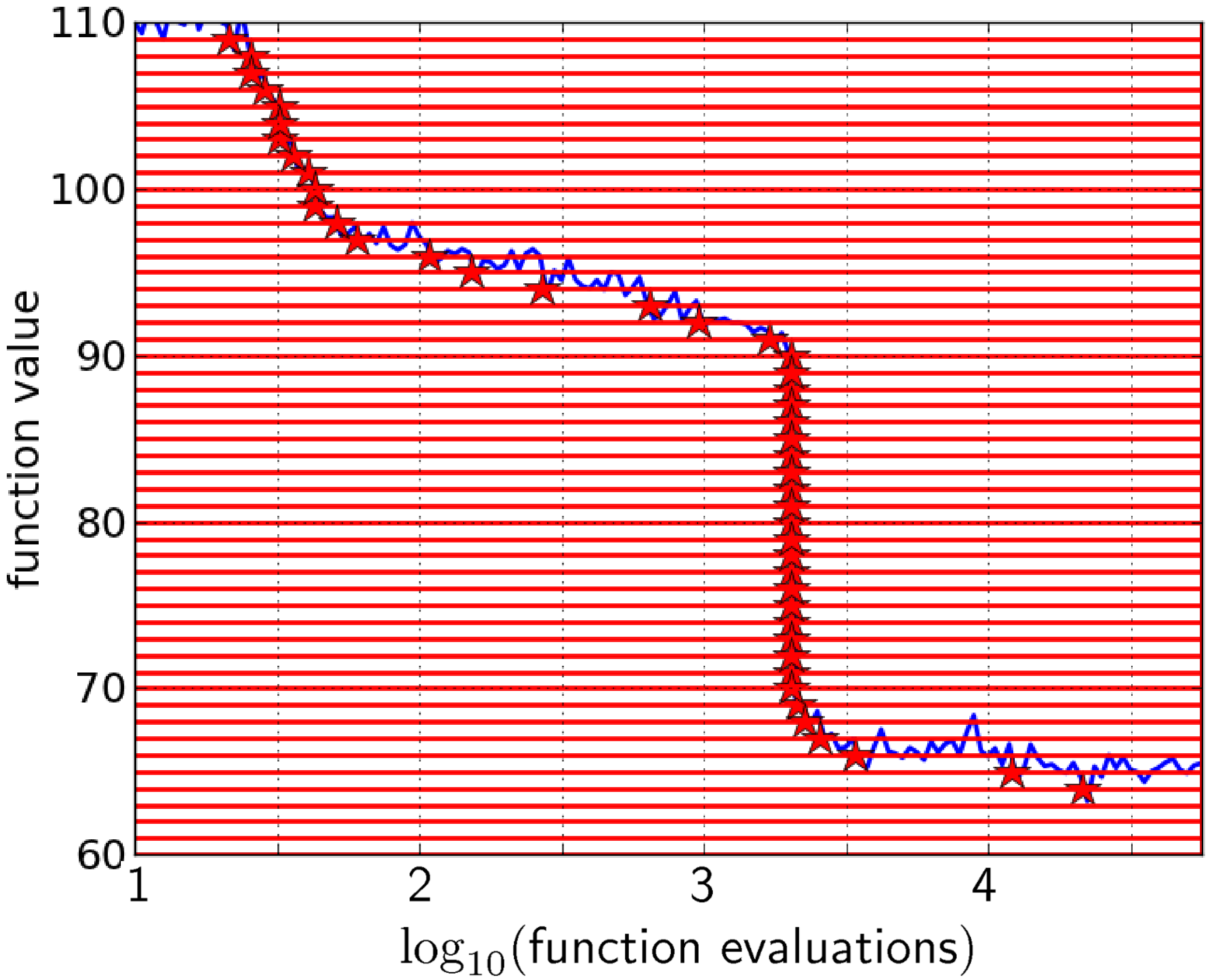
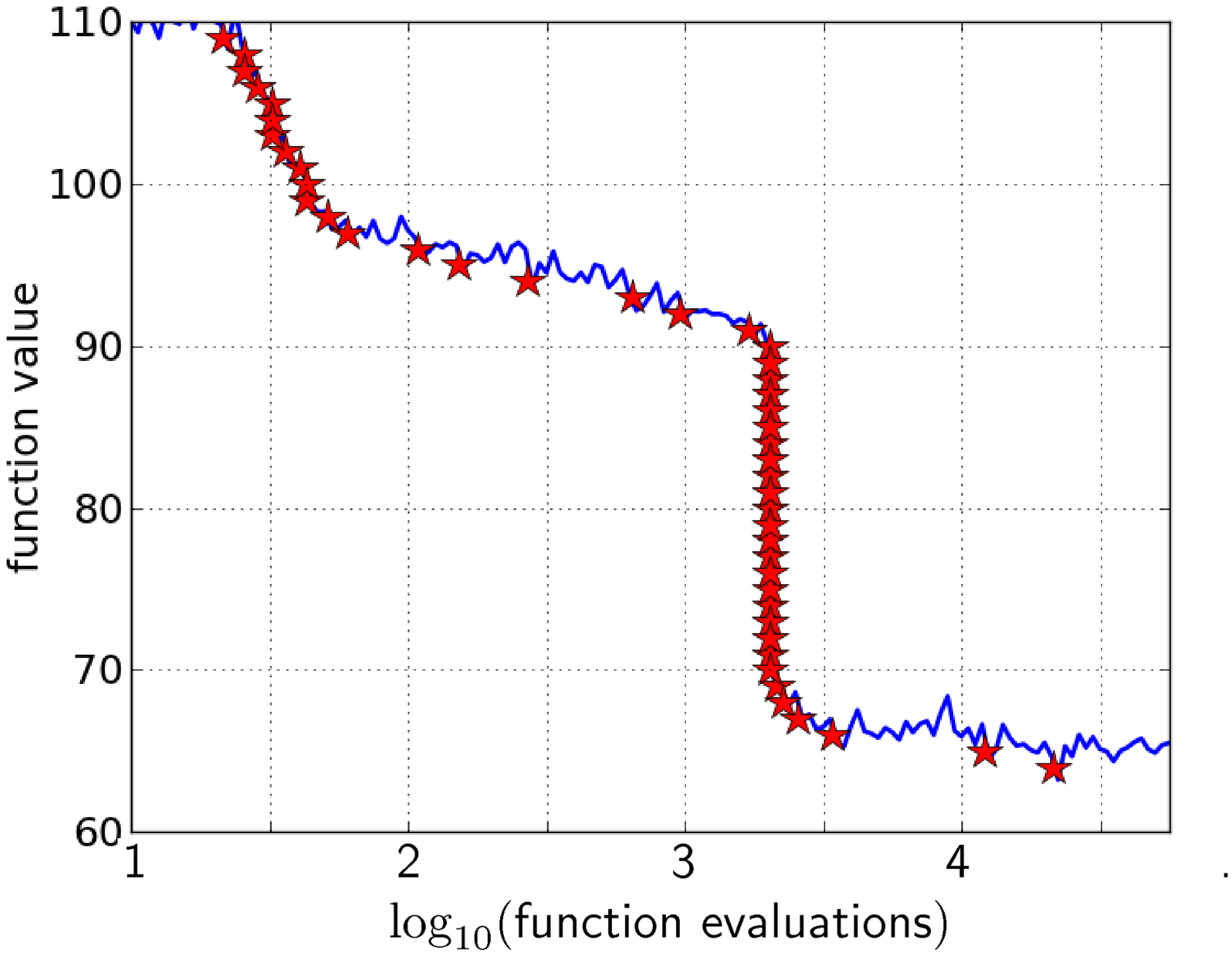
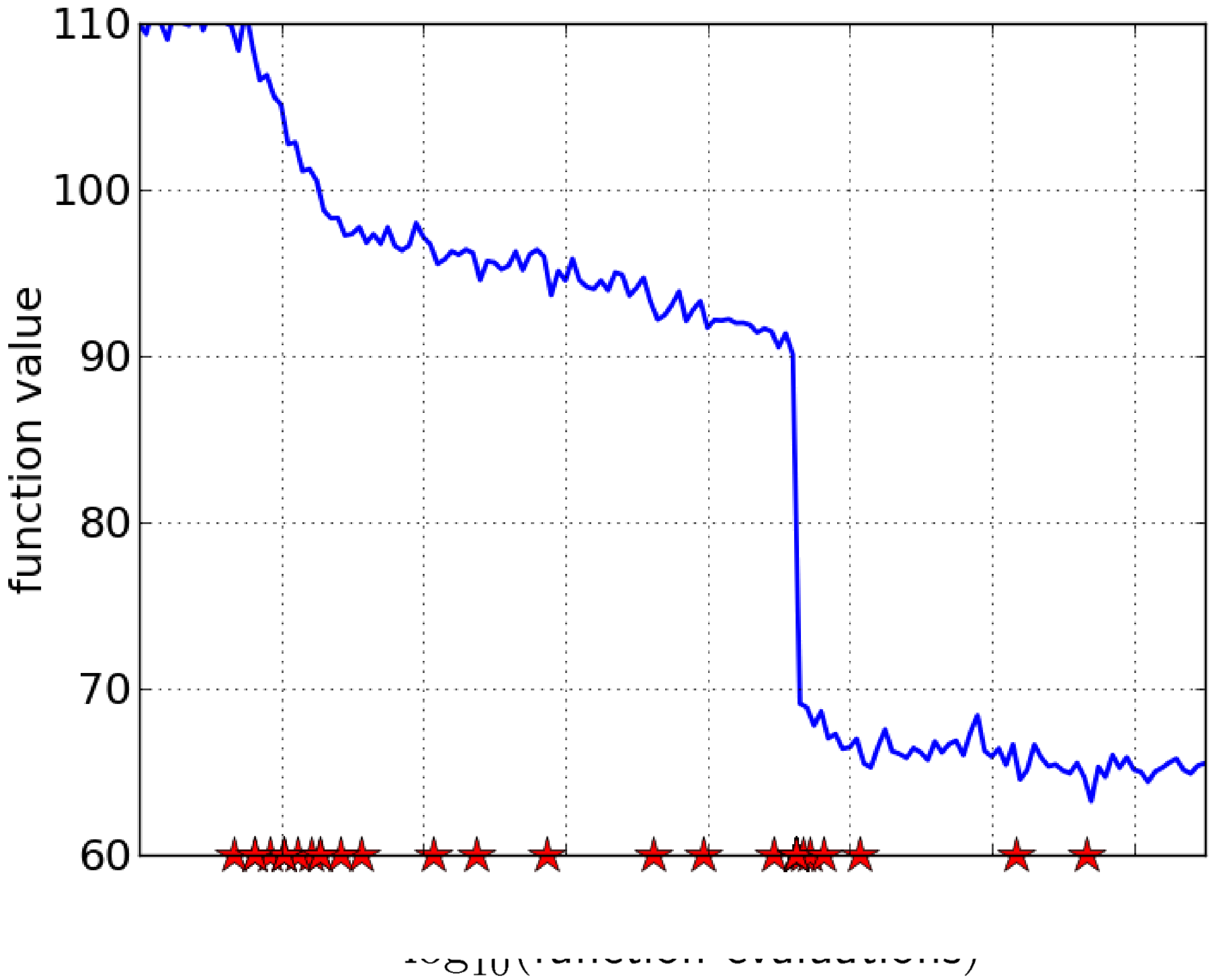


50 equally spaced targets

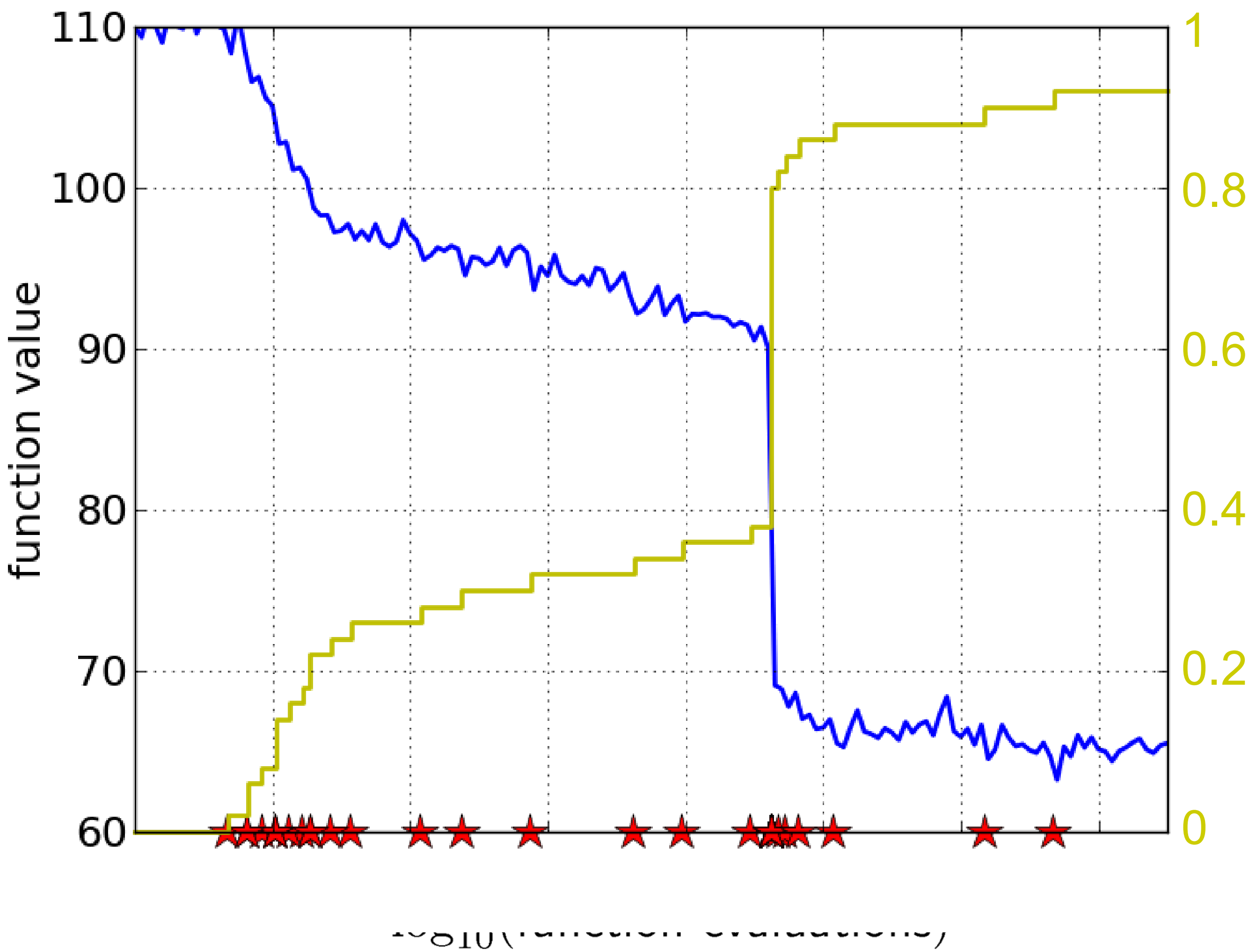
Reconstructing A Single Run



Reconstructing A Single Run

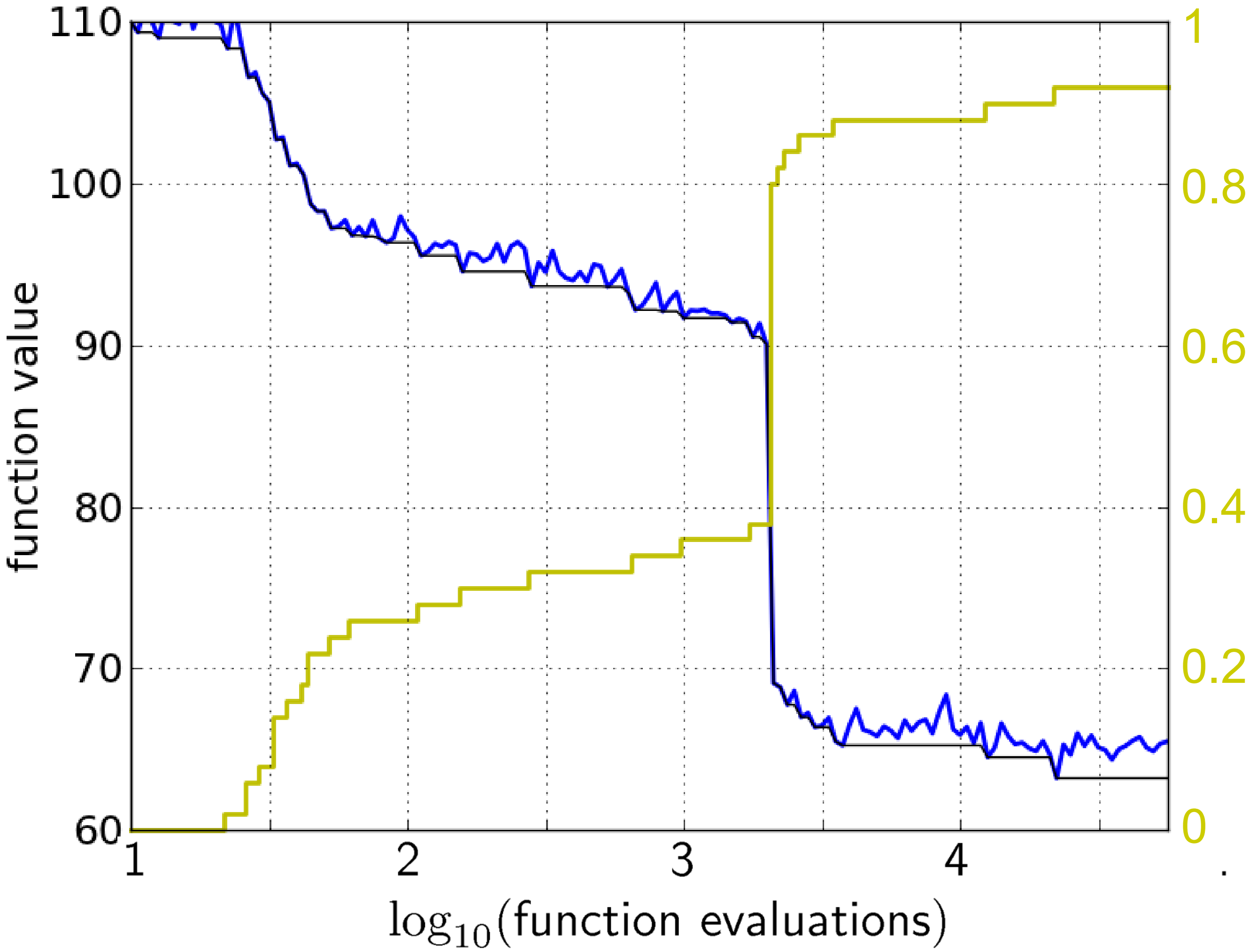


Reconstructing A Single Run



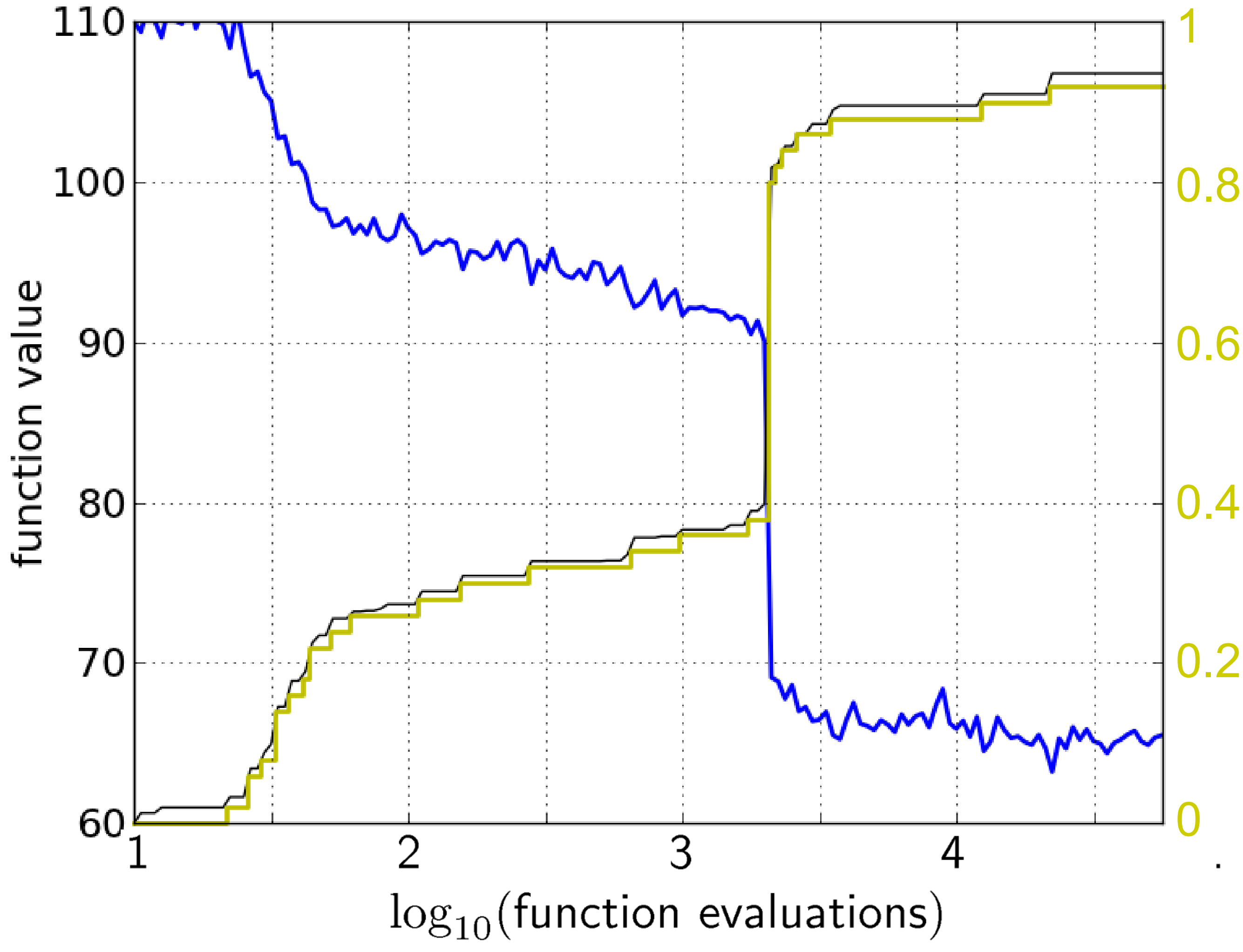
ıe empirical CDF makes a step for each star, is monotonous and displays for each budget the fraction of targets achieved within the budget

Reconstructing A Single Run



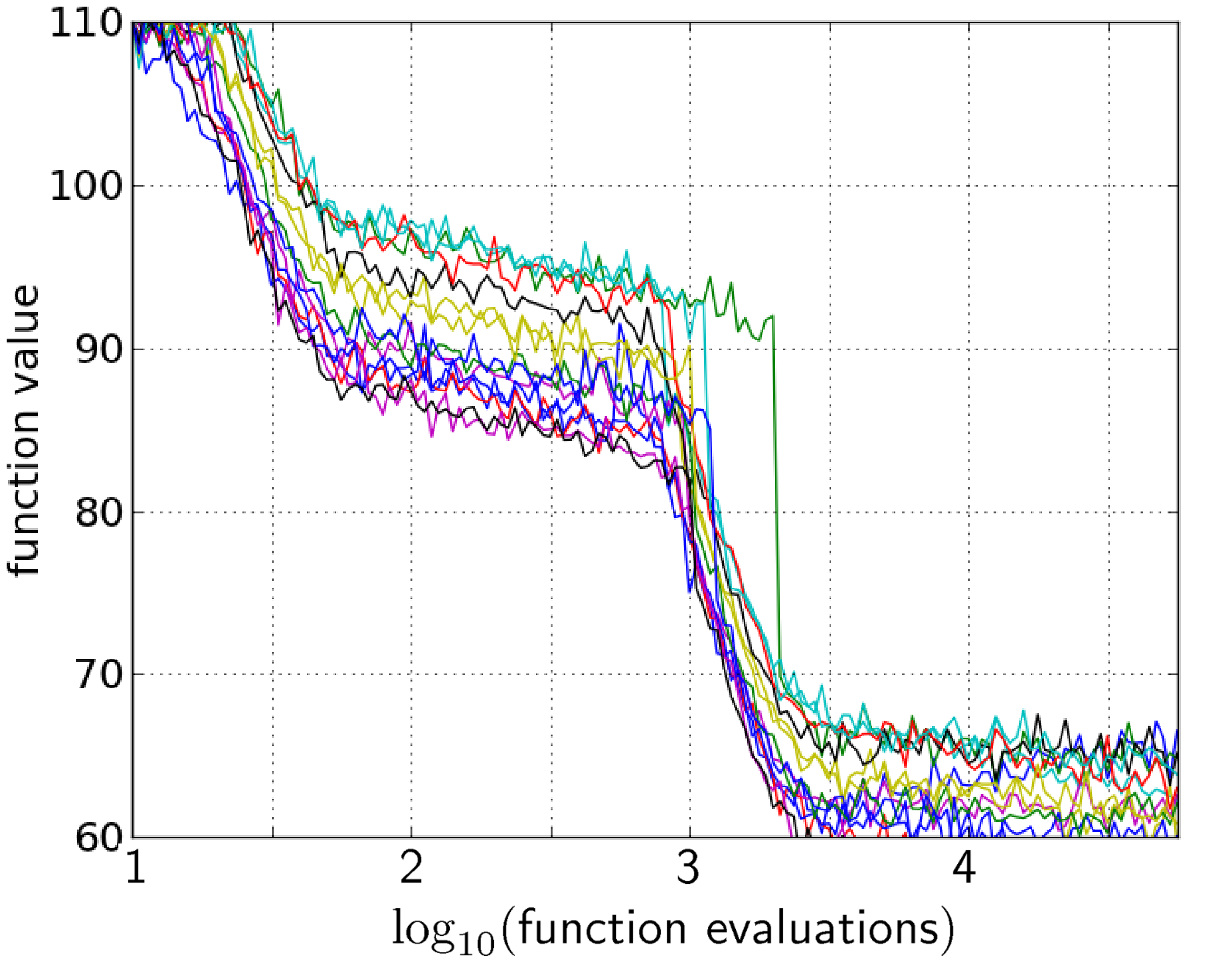
the ECDF recovers the monotonous graph, discretised and flipped

Reconstructing A Single Run



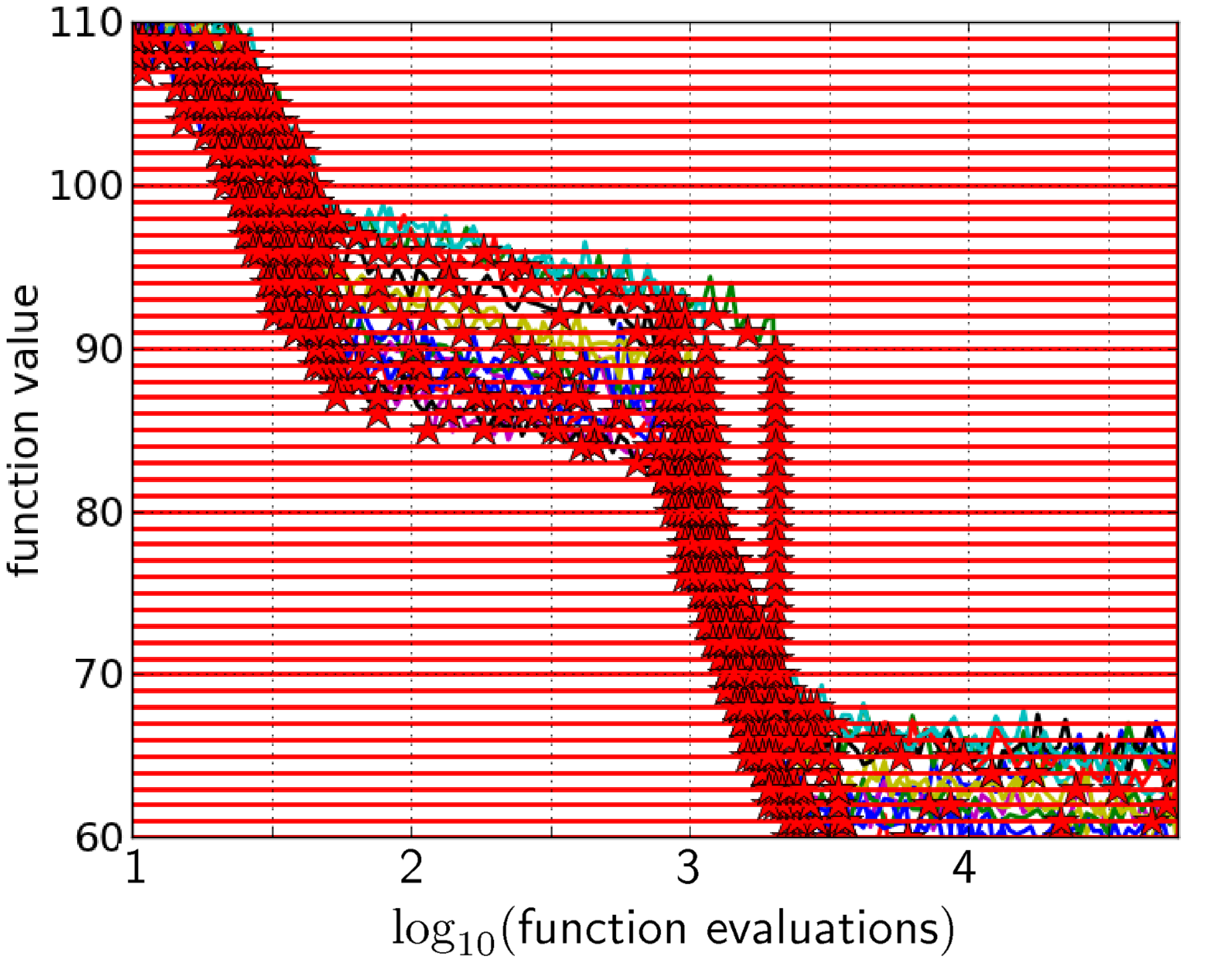
the ECDF recovers the monotonous graph, discretised and flipped

Aggregation



15 runs

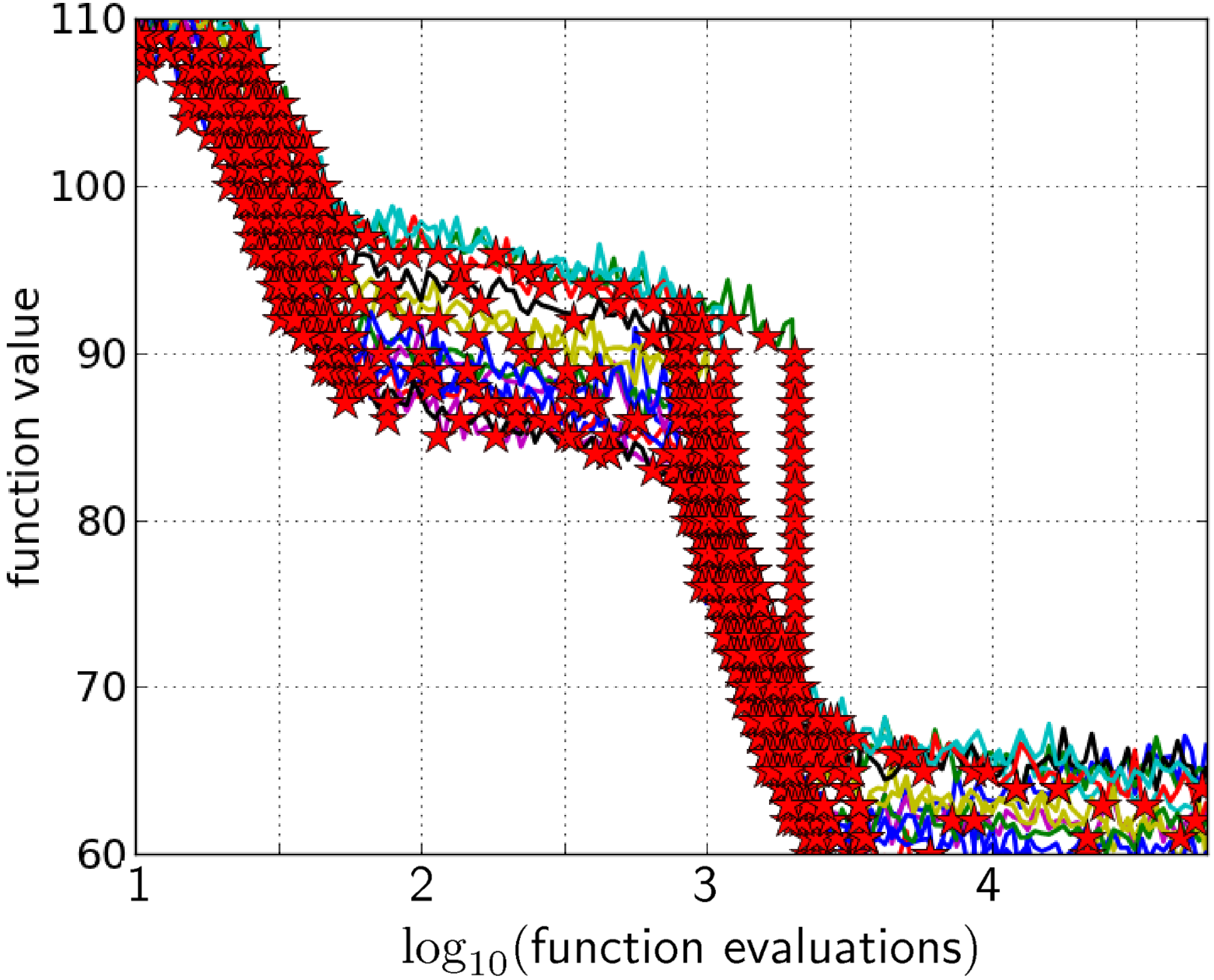
Aggregation



15 runs

50 targets

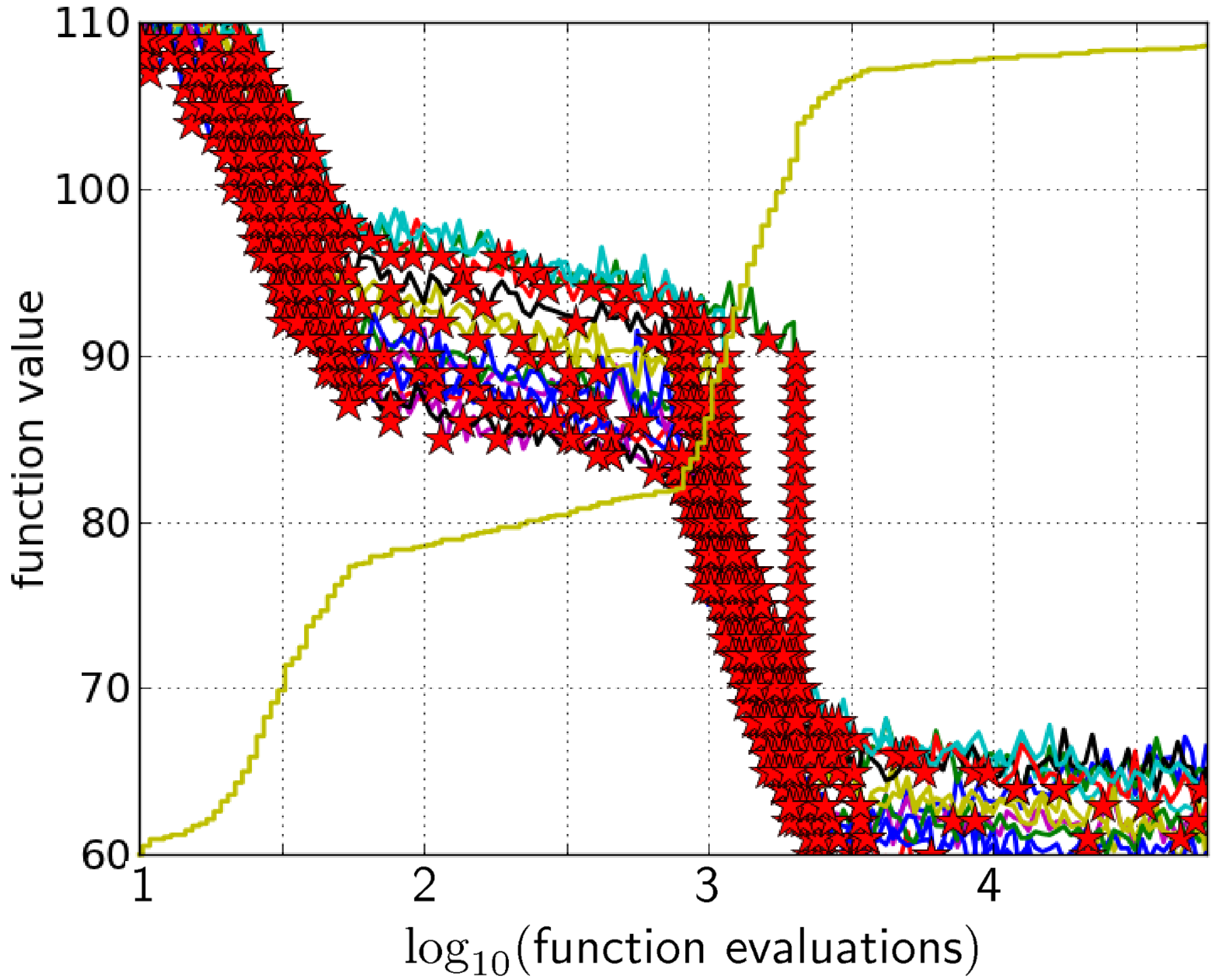
Aggregation



15 runs

50 targets

Aggregation

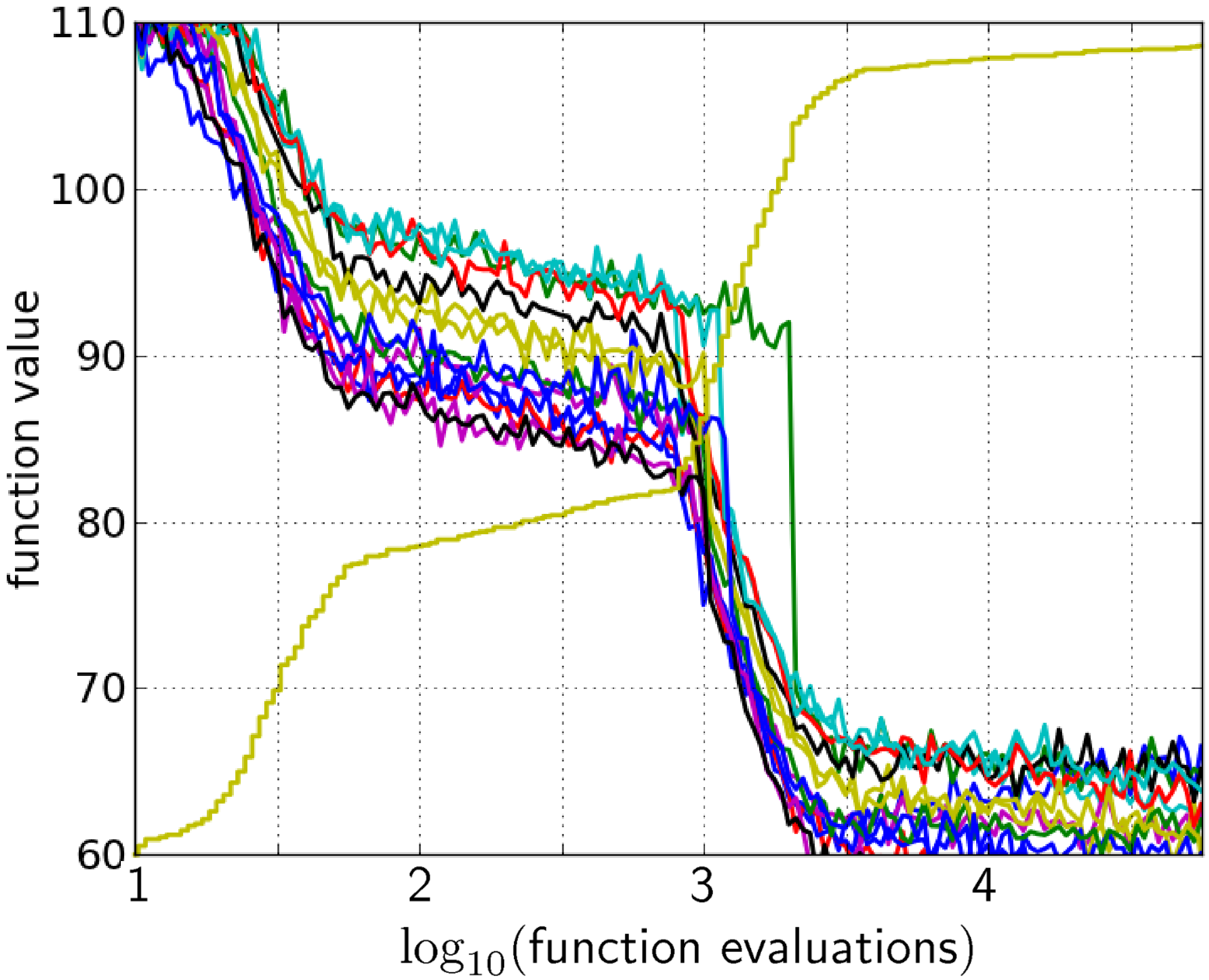


15 runs

50 targets

ECDF with 750 steps

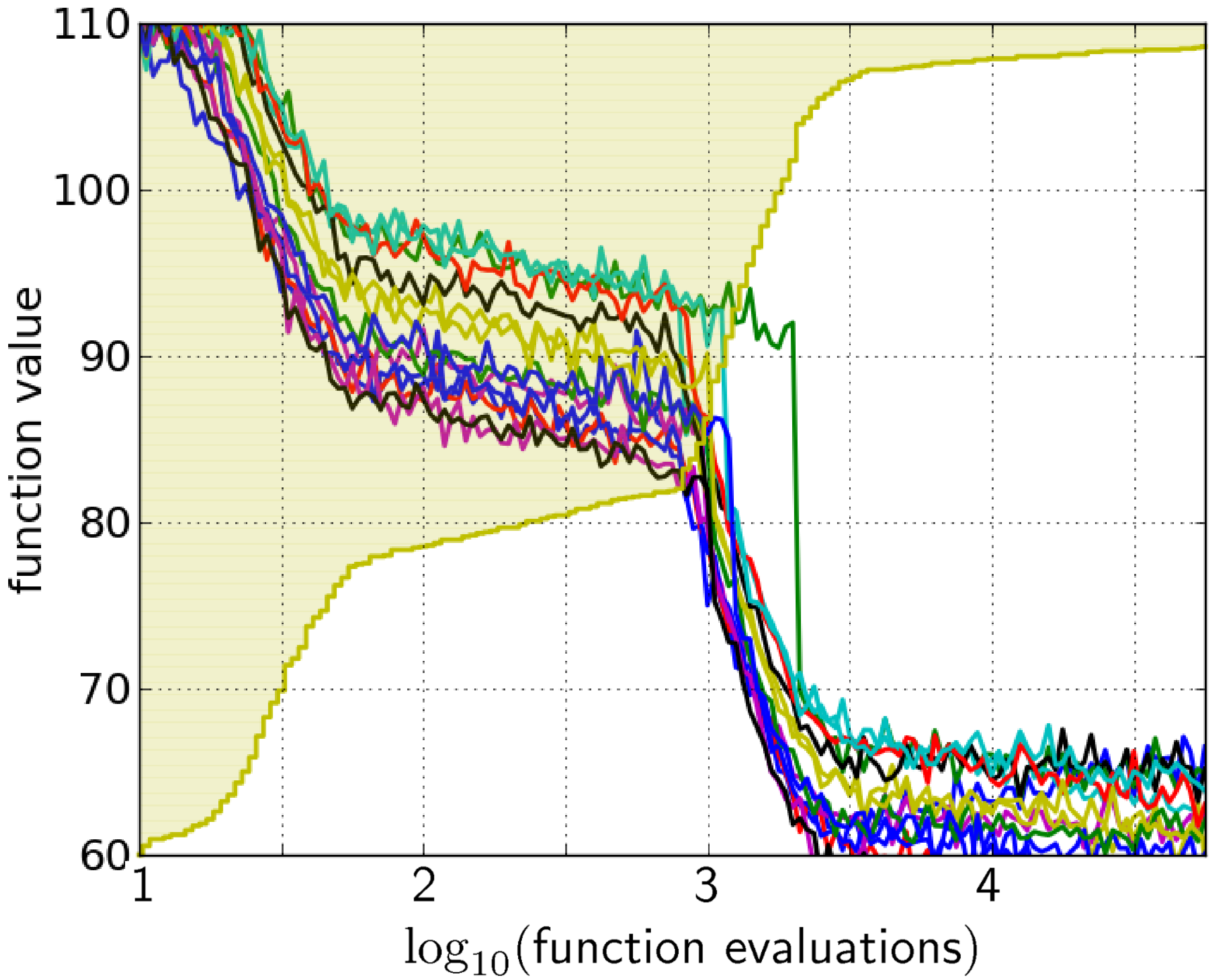
Aggregation



50 targets from 15 runs

...integrated in a single graph

Interpretation



50 targets from 15 runs integrated in a single graph

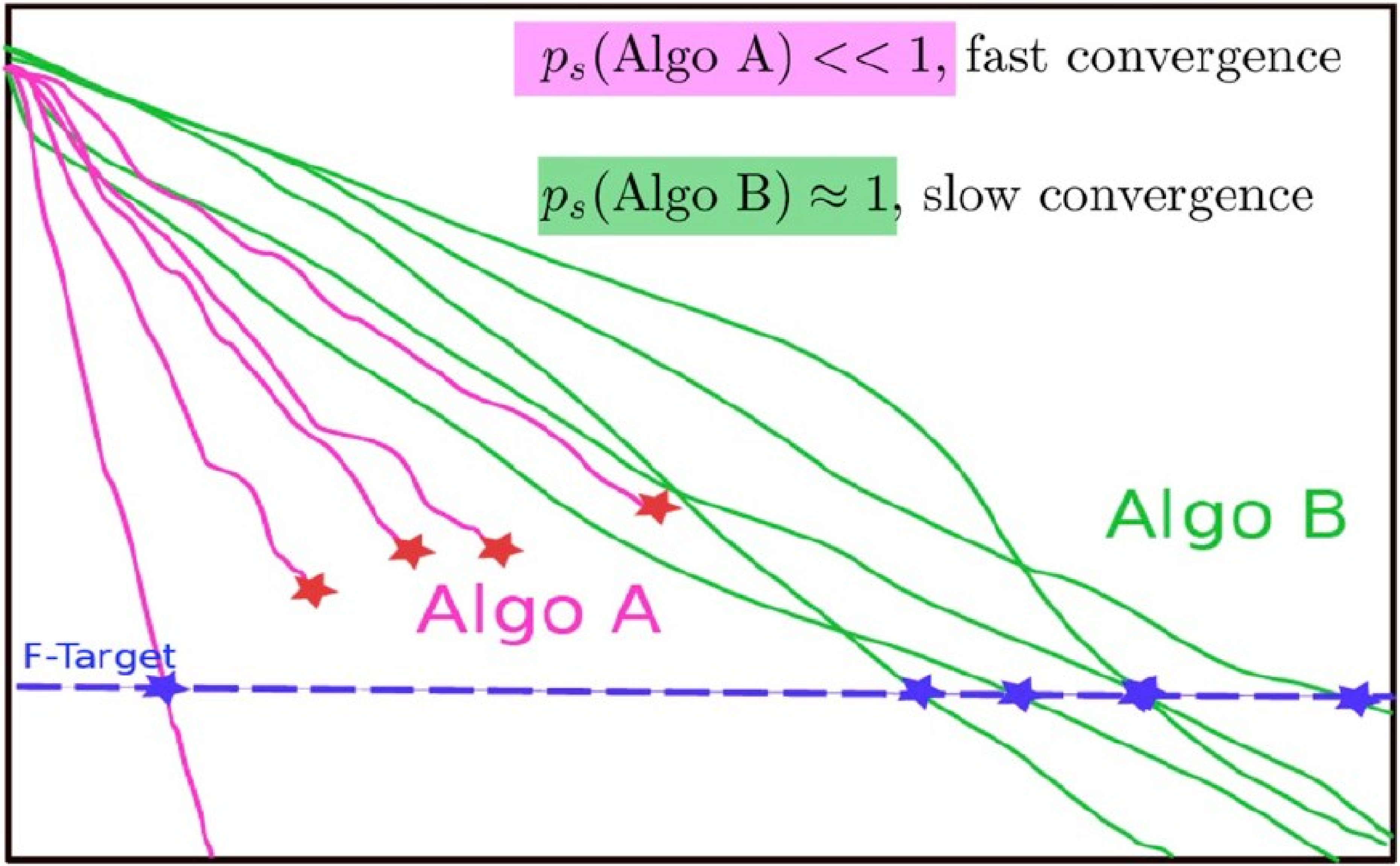
area over the ECDF curve

=

average log runtime

(or geometric avg. runtime) over all targets (difficult and easy) and all runs

Fixed-target: Measuring Runtime



Fixed-target: Measuring Runtime

- Algo Restart A:

RT^r_A

p_s(Algo Restart A) = 1

- Algo Restart B:

RT^r_B

p_s(Algo Restart A) = 1

Fixed-target: Measuring Runtime

- Expected running time of the restarted algorithm:

$$E[RT^r] = \frac{1 - p_s}{p_s} E\left[RT_{unsuccessful}\right] + E[RT_{successful}]$$

- Estimator average running time (aRT):

$$\widehat{p_s} = \frac{\#\text{successes}}{\#\text{runs}}$$

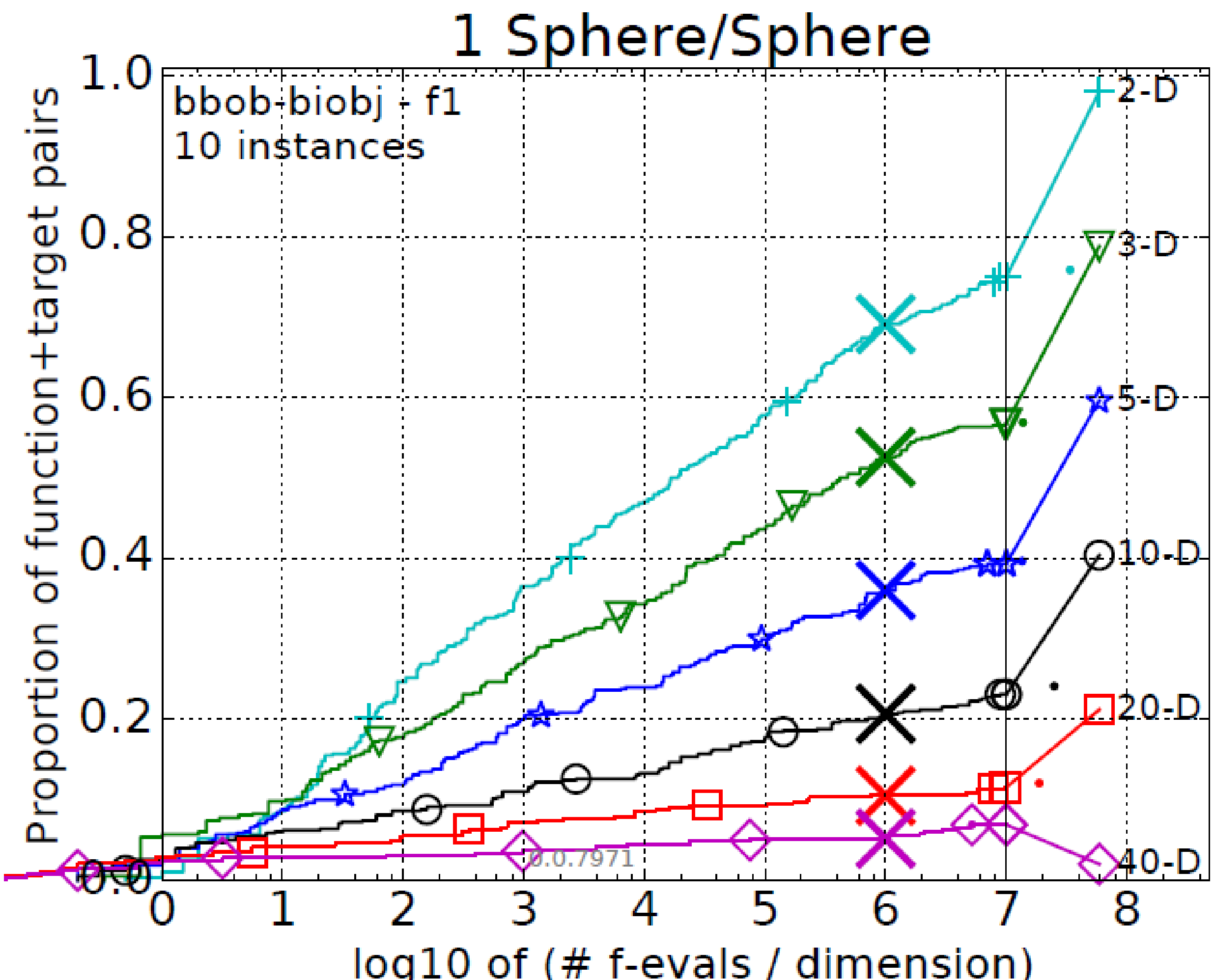
$$\widehat{RT_{unsucc}} = \text{Average evals of unsuccessful runs}$$

$$\widehat{RT_{succ}} = \text{Average evals of successful runs}$$

$$aRT = \frac{\text{total }\#\text{evals}}{\#\text{successes}}$$

ECDFs with Simulated Restarts

What we typically plot are ECDFs of the simulated restarted algorithms:

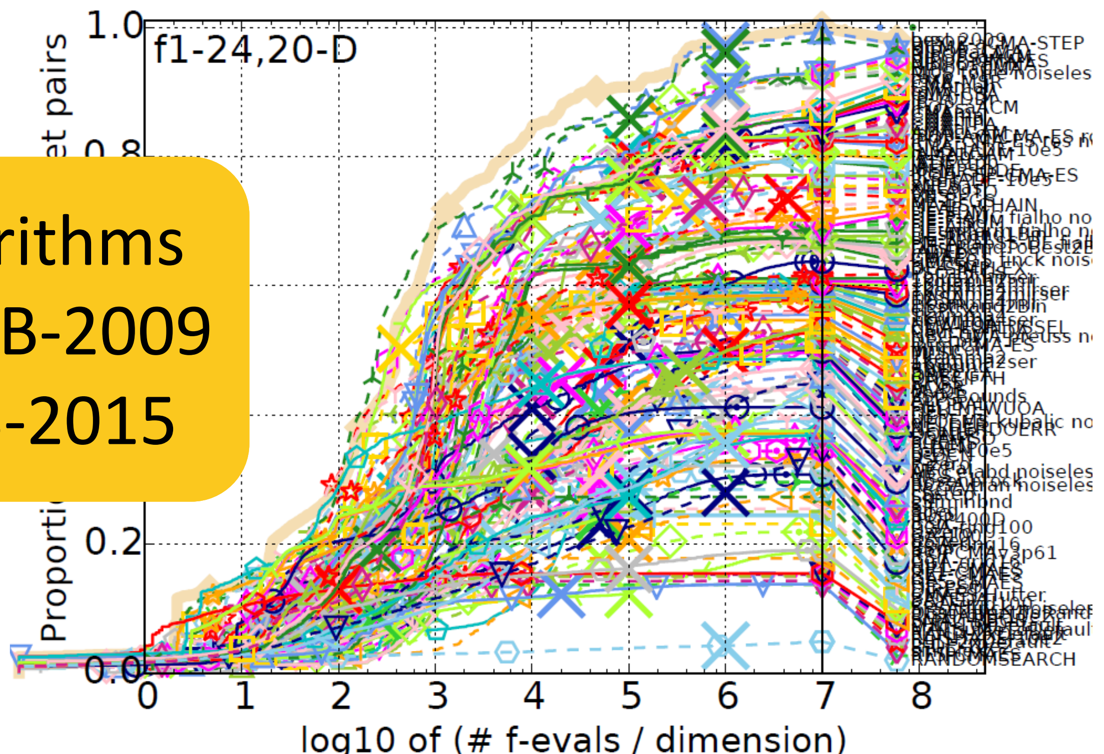


Worth to Note: ECDFs in COCO

In COCO, ECDF graphs

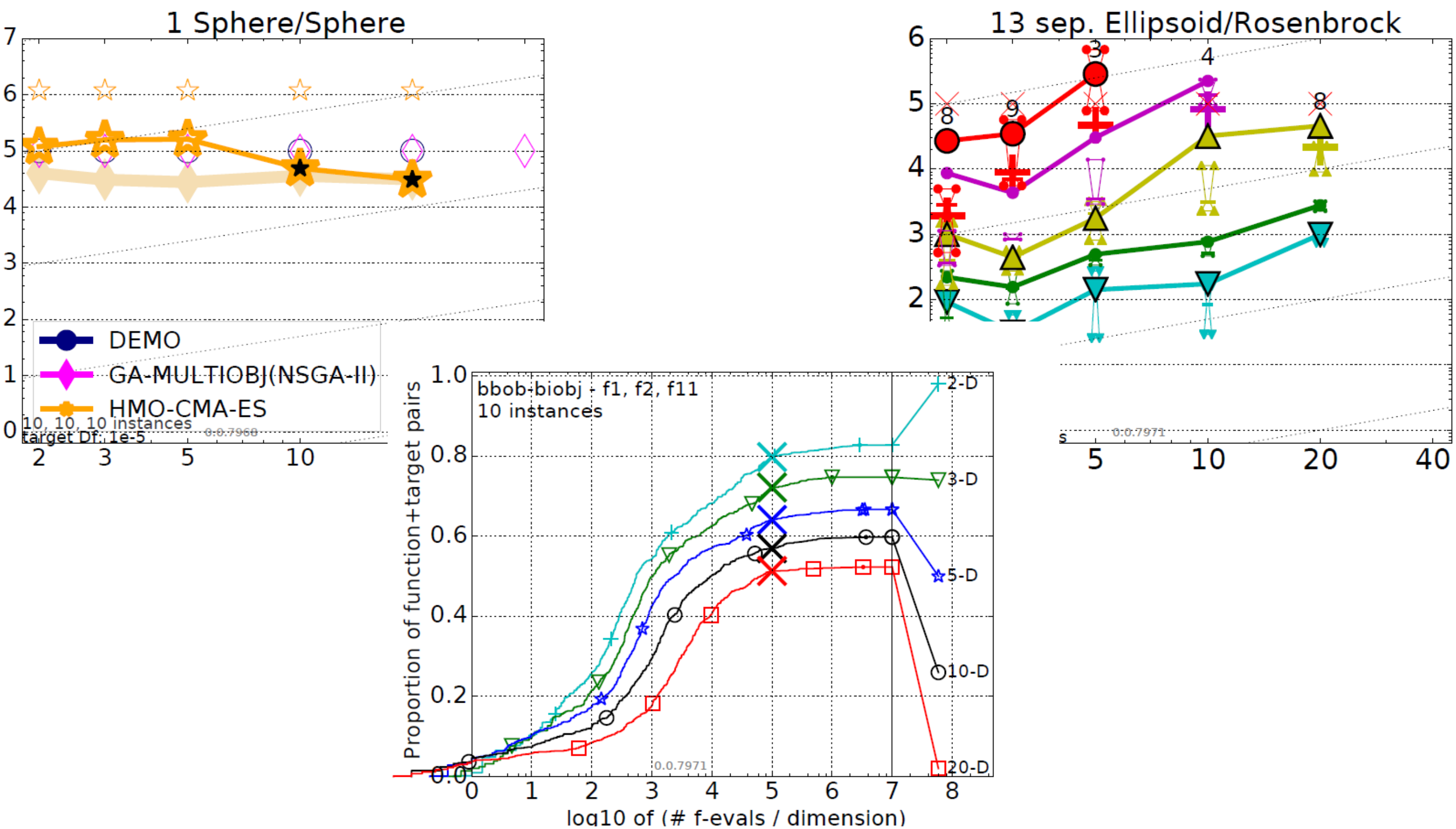
- never aggregate over dimension
    - but often over targets and functions
- can show data of more than 1 algorithm at a time

150 algorithms from BBOB-2009 till BBOB-2015



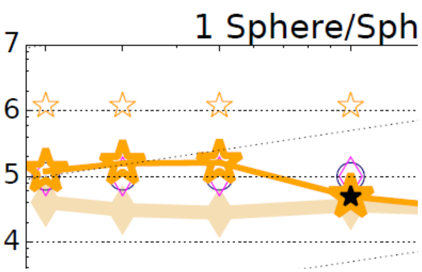
More Automated Plots...

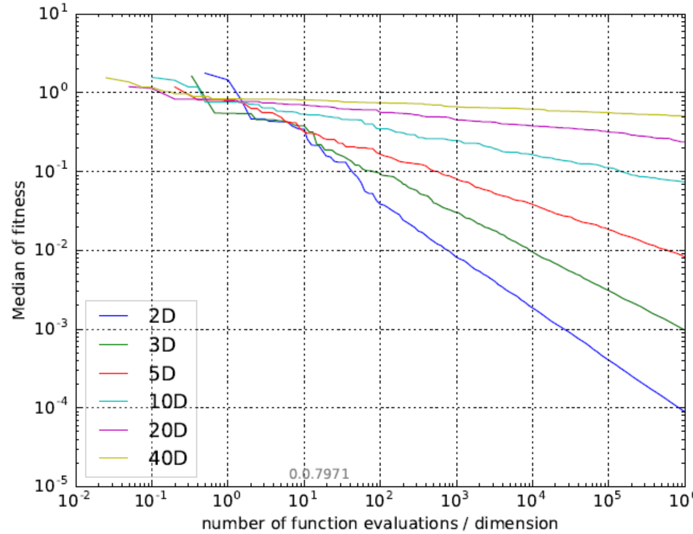
...but no time to explain them here ☹

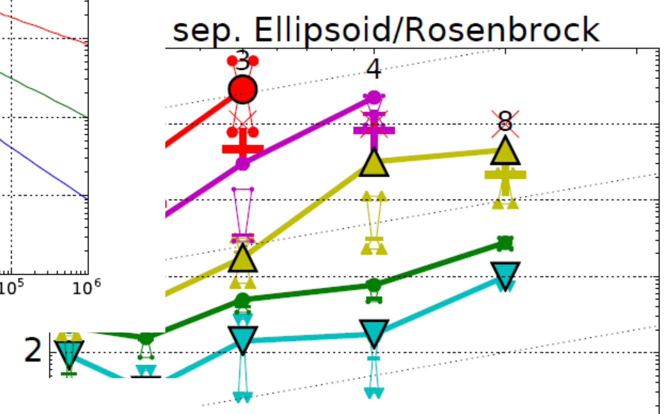


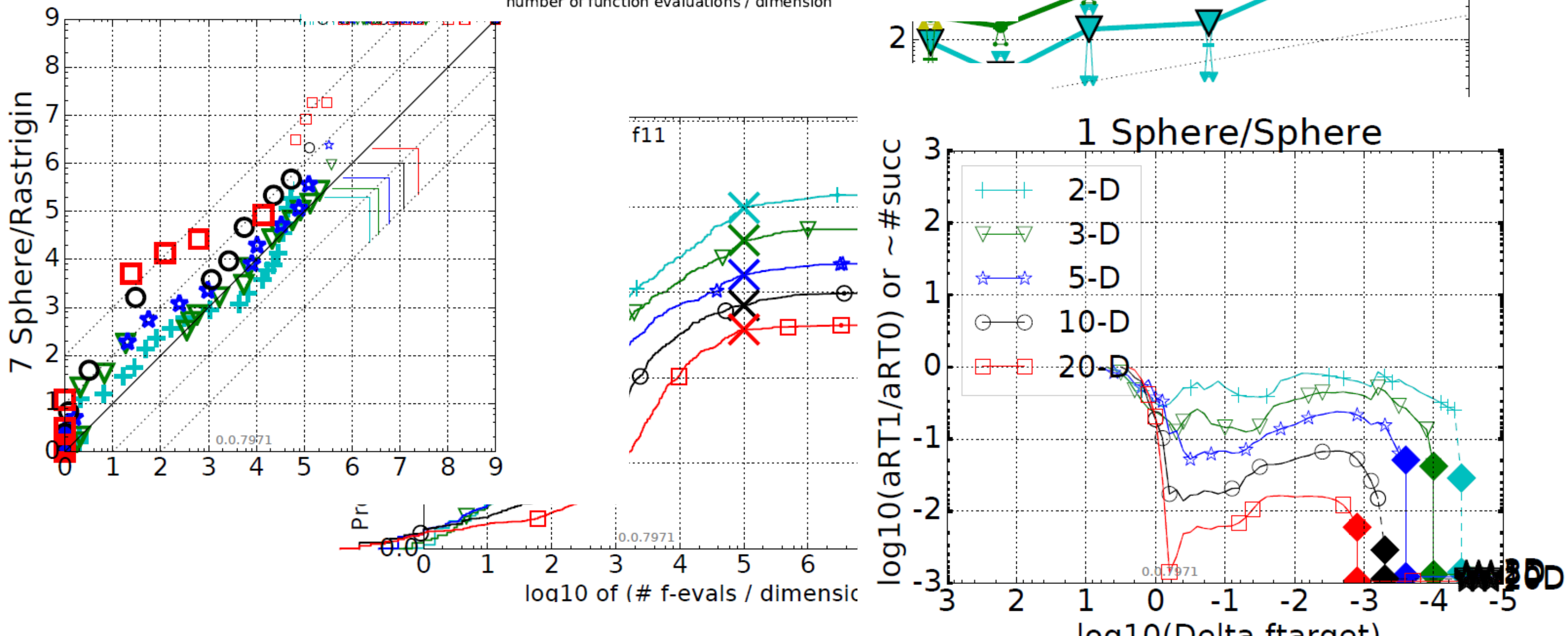
More Automated Plots...

...but no time t









The BBOB functions

bbob Testbed

- 24 functions in 5 groups:

1 Separable Functions	
f1	Sphere Function
f2	Ellipsoidal Function
f3	Rastrigin Function
f4	Büche-Rastrigin Function
f5	Linear Slope
2 Functions with low or moderate conditioning	
f6	Attractive Sector Function
f7	Step Ellipsoidal Function
f8	Rosenbrock Function, original
f9	Rosenbrock Function, rotated
3 Functions with high conditioning and unimodal	
f10	Ellipsoidal Function
f11	Discus Function
f12	Bent Cigar Function
f13	Sharp Ridge Function
f14	Different Powers Function

4 Multi-modal functions with adequate global structure	
f15	Rastrigin Function
f16	Weierstrass Function
f17	Schaffers F7 Function
f18	Schaffers F7 Functions, moderately ill-conditioned
f19	Composite Griewank-Rosenbrock Function F8F2
5 Multi-modal functions with weak global structure	
f20	Schwefel Function
f21	Gallagher's Gaussian 101-me Peaks Function
f22	Gallagher's Gaussian 21-hi Peaks Function
f23	Katsuura Function
f24	Lunacek bi-Rastrigin Function

- 6 dimensions: 2, 3, 5, 10, 20, (40 optional)

Notion of Instances

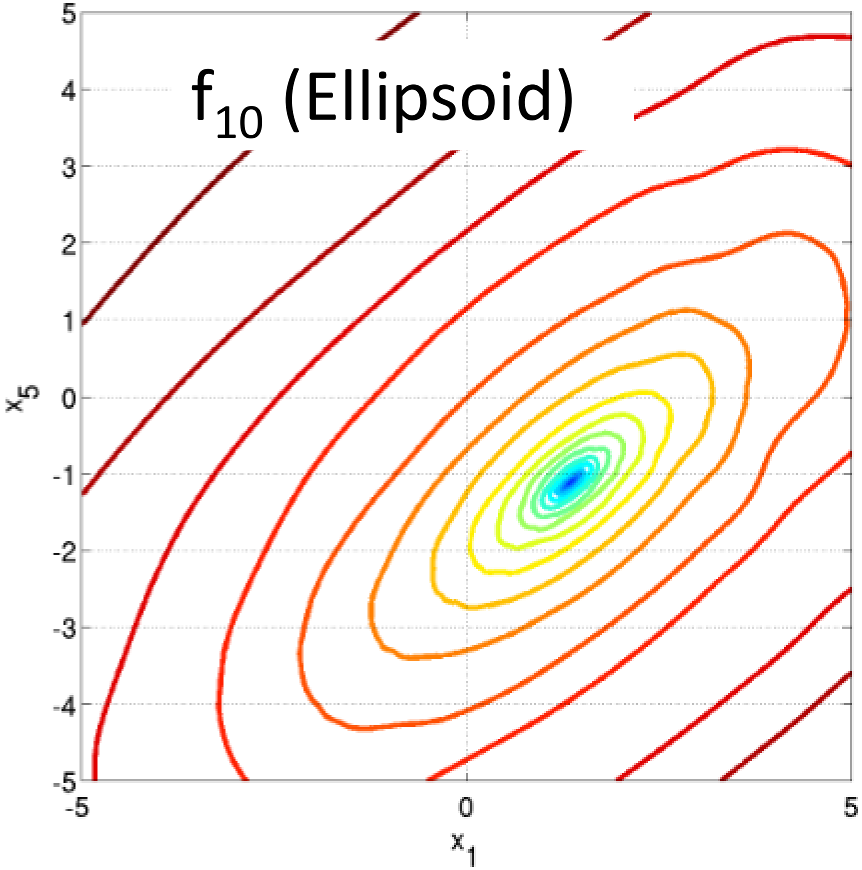
- All COCO problems come in form of instances
  - e.g. as translated/rotated versions of the same function
- Prescribed instances typically change from year to year
  - avoid overfitting
  - 5 instances are always kept the same

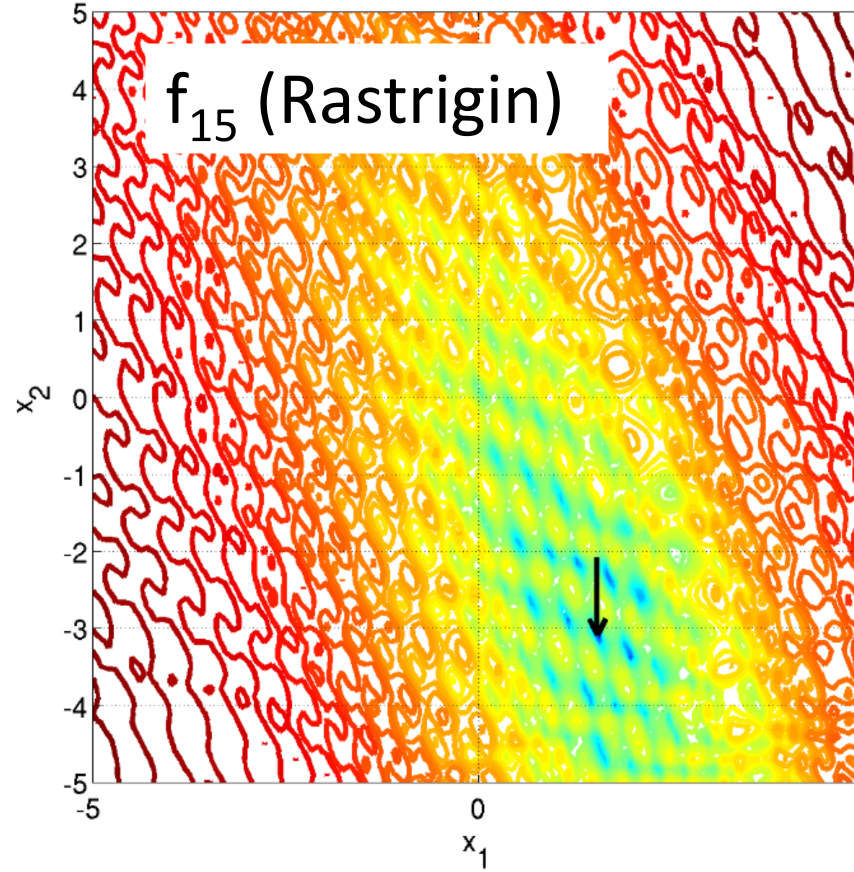
Plus:

- the bbob functions are locally perturbed by non-linear transformations

Notion of Instances

- All COCO problems come in form of instances





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`bbob-noisy` Testbed

- 30 functions with various kinds of noise types and strengths
  - 3 noise types: Gaussian, uniform, and seldom Cauchy
  - Functions with moderate noise
  - Functions with severe noise
  - Highly multi-modal functions with severe noise
  - `bbob` functions included: Sphere, Rosenbrock, Step ellipsoid, Ellipsoid, Different Powers, Schaffers' F7, Composite Griewank-Rosenbrock
- 6 dimensions: 2, 3, 5, 10, 20, (40 optional)

bbob-biobj Testbed

- 55 functions by combining 2 **bbob** functions

1 Separable Functions	
f1	Sphere Function ✓
f2	Ellipsoidal Function ✓
f3	Rastrigin Function
f4	Büche-Rastrigin Function
f5	Linear Slope
2 Functions with low or moderate conditioning	
f6	Attractive Sector Function ✓
f7	Step Ellipsoidal Function
f8	Rosenbrock Function, original ✓
f9	Rosenbrock Function, rotated
3 Functions with high conditioning and unimodal	
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f13	Sharp Ridge Function ✓
f14	Different Powers Function ✓

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bbob-biobj Testbed

- 55 functions by combining 2 **bbob** functions

1 Separable Functions	
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f13	Sharp Ridge Function ✓
f14	Different Powers Function ✓

4 Multi-modal functions with adequate global structure	
f15	Rastrigin Function ✓
f16	Weierstrass Function
f17	Schaffers F7 Function ✓

	f_1	f_2	f_6	f_8	f_{13}	f_{14}	f_{15}	f_{17}	f_{20}	f_{21}
f_1	f1	f2	f3	f4	f5	f6	f7	f8	f9	f10
f_2		f11	f12	f13	f14	f15	f16	f17	f18	f19
f_6			f20	f21	f22	f23	f24	f25	f26	f27
f_8				f28	f29	f30	f31	f32	f33	f34
f_{13}					f35	f36	f37	f38	f39	f40
f_{14}						f41	f42	f43	f44	f45
f_{15}							f46	f47	f48	f49
f_{17}								f50	f51	f52
f_{20}									f53	f54
f_{21}										f55

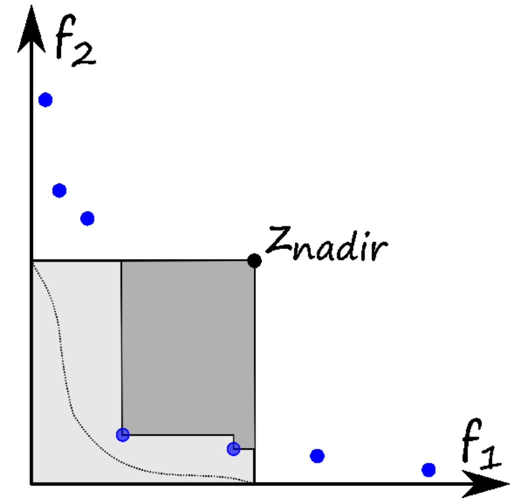
Bi-objective Performance Assessment

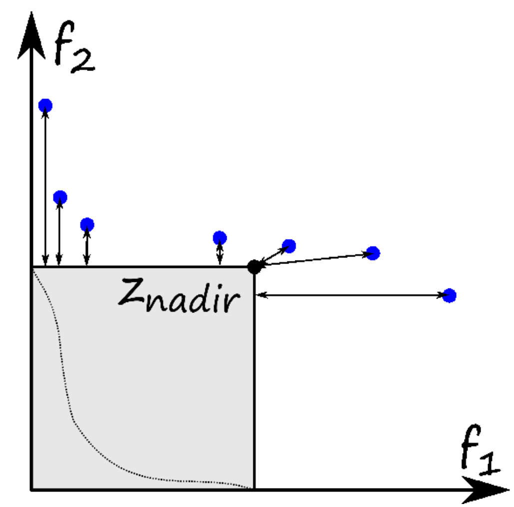
algorithm quality =

normalized* hypervolume (HV)
of all non-dominated solutions
if a point dominates nadir

closest normalized* negative distance
to region of interest $[0,1]^2$
if no point dominates nadir

* such that ideal=[0,0] and nadir=[1,1]





Bi-objective Performance Assessment

We measure runtimes to reach (HV indicator) targets:

- relative to a reference set, given as the best Pareto front approximation known (since exact Pareto set not known)

  `current_best` values incl. all non-dominated points found by the 15 workshop algos of BBOB-2016

- actual absolute hypervolume targets used are

  HV(refset) – targetprecision

with 58 fixed targetprecisions between 1 and -10^{-4} (same for all functions, dimensions, and instances) in the displays

and now?

BBOB-2017

Session I	
08:30 - 09:05	The BBOBies: Introduction to Blackbox Optimization Benchmarking
09:05 - 09:30	Simon Wessing*: Benchmarking the SMS-EMOA with Self-adaptation on the bbob-biobj Test Suite
09:30 - 09:55	Mario García-Valdez* and Juan-J. Merelo: Benchmarking a Pool-Based Execution with GA and PSO Workers on the BBOB Noiseless Testbed
09:55 - 10:20	Zbynek Pitra*, Lukas Bajer, Jakub Repicky, and Martin Holena: Comparison of Ordinal and Metric Gaussian Process Regression as Surrogate Models for CMA Evolution Strategy
Session II	
10:40 - 10:50	The BBOBies: Session Introduction
10:50 - 11:15	Dogan Aydin* and Gurcan Yavuz: Self-adaptive Search Equation-Based Artificial Bee Colony Algorithm with CMA-ES on the Noiseless BBOB Testbed
11:15 - 11:40	Duc Manh Nguyen and Nikolaus Hansen*: Benchmarking CMAES-APOP on the BBOB Noiseless Testbed
11:40 - 12:05	Takahiro Yamaguchi and Youhei Akimoto*: Benchmarking the Novel CMA-ES Restart Strategy Using the Search History on the BBOB Noiseless Testbed
12:05 - 12:30	The BBOBies: Wrap-up and Open Discussion

http://coco.gforge.inria.fr/