# ACAI 2015 - Solvers Evaluation

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# Objective of this course

- Highlight the benefit of independent evaluation of constraints-based techniques
- Provide some advices and pitfalls to avoid
- Explain how to read the evaluation results (go beyond the ranking!)
- Focus on the technical issues met when running an evaluation on modern hardware and OS

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Based on our own experience in organizing the SAT, PB or CSP competitions from 2002 to 2012!

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Based on our own experience in organizing the SAT, PB or CSP competitions from 2002 to 2012!
And our experience as participants (Sat4j, ppfolio)

# Outline of the talk

Motivation and conditions of success

Selecting Benchmarks

Ranking solvers

Understanding the results of the evaluation

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# Evaluations: motivation

- Worst-case complexity vs reality: NP-complete does not mean intractable in practice
- Allow to observe specific algorithms implementations on specific benchmarks on specific hardware: produce data for analysis
- Identify which technique/approach is suitable for which benchmarks
- Foster the development of new algorithms
- Expand the application domain: gather new benchmarks

# Evaluations: motivation

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Rankings and winners are a byproduct of the evaluations, not goals to achieve!

# Conditions of success

- Common input/output format for the benchmarks
- Critical mass of solvers
- Critical mass of diverse benchmarks
- Low entry level for participants

There should be publicly available benchmarks and solvers

# Common input/output format for the benchmarks

- Simple to understand and parse for the solver designer
- Simple to understand and generate by the benchmarks provider
- Readable by a human (text based)
- Main issues:
  - not oriented toward the end user
  - not space efficient

# Example: Dimacs format

## Do you understand this?

```
p cnf 4 7
1 2 3 4 0
-1 -2 0
-1 -3 0
-1 -4 0
-2 -3 0
-2 -4 0
-3 -4 0
```

# Example: Dimacs format

## Do you understand this?

```
p cnf 4 7
1 2 3 4 0
-1 -2 0
-1 -3 0
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-2 -3 0
-2 -4 0
-3 -4 0
```

Encode $x_1 + x_2 + x_3 + x_4 = 1$

# Counter-Example: Mancoosi CUDF format

## Does this one look better?

```
package: supersolver
version: 1
depends: minisat

package: minisat
version: 1
conflicts: minisat

package: minisat
version: 2
conflicts: minisat

package: glucose
version: 2
provides: minisat
```

# Benefit of a common input format: program reuse

- for SAT, the second Dimacs challenge (1993) created a common input format
- since then, SAT solvers have been used as black boxes reading Dimacs formatted files
- without black boxes, no Planning as Satisfiability, no Bounded Model Checking, no Chaff ...

Requires also the availability of the solvers for research purposes, ideally in source form: without Grasp, SATO, Relsat available in source, no Chaff!

# Critical mass of solvers

- Need enough participants to simply check the results
- 4/5 research groups working on a specific topic are enough to start an evaluation (MUS/Group-MUS 2011)
- A basic/trivial approach can be used as a witness

Example: SAT,PB,MAXSAT,ASP,SMT,...
Counter-Examples: SAT 2005 non clausal track, SAT 2007 certified unsat track,

# Critical mass of benchmarks

- Variety of benchmarks is key for a good evaluation
- Sources of benchmarks are the biggest bias for an objective evaluation
- Random/Crafted/Application buckets
- New versus known benchmarks (do you allow Machine Learning?)
- Benchmarks coming from companies (e.g. IBM BMC benchmarks)

The more diverse are the benchmarks, the less significant is a global ranking in practice!

# Low entry level for participants

- The SAT competition has been a big success because a master student could write a good SAT solver 10 years ago (e.g. Siege)
- Building a CSP or an Automated Reasoning solver (CASC) is much more evolved
- Recent SAT solvers include many sophisticated techniques (pre/in-processing): raised entry level to at least a PhD
- How to lower the entry level? Minisat Hack (since 2009)!

# Checking solvers answers

Never trust the solvers!

- The answers of the solvers should be checked if possible
  - SAT check that the assignment satisfies all the constraints
  - UNSAT check that no other solver answered correctly SAT
- Sometimes it is quite hard to check answers (e.g. for QBF)
- Over the years, practical solutions appear (DRUP format and checker for logging and check UNSAT proofs in SAT solvers)

# "Incorrect" solvers

There are many reasons why a solver may be found "incorrect" during an evaluation:

- The solver contains at least one bug
- The solver enters a corner case: may be avoided using benchmarks normalization
- The solver does not interpret correctly the input (parsing problem)
- The solver does not interpret correctly the semantic of the input
- There is a problem with the evaluation platform

An incorrect answer does not make automatically the solver buggy!

# Decision vs Optimization

- On decision problems, the solver answers SAT/UNSAT/UNKNOWN
- On decision problems, the solver answers OPT/SAT/UNSAT/UNKNOWN
  - SAT check that the assignment satisfies all the constraints
  - OPT check that no other solver answered correctly a better SAT answer
- The quality of the solution can be taken into account
- Difference between finding the best solution and proving there is no better solution

# Outline

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# Benchmarks categories

| | |
|---|---|
| random | Randomly generated, obey a mathematical model (e.g. Random Uniform 3-SAT) |
| crafted | "Born to be hard" represent known [in]tractable classes of benchmarks (e.g. Pigeon Hole Problem) |
| application | represent modeling of real/artificial problems |

With the usual feature that
$size(crafted) < size(random) << size(application)$ and
$runtime(crafted) > runtime(random) >> runtime(application)$

# Benchmarks hardness

Benchmarks are used to discriminate solvers

- Easy benchmarks (solved by all participants) are of no help*
- Hard benchmarks (solved by no participant) are of no help
- Only the remaining benchmarks (let's call them Medium) are of interest
- Easy/Medium/Hard classification depends on the solvers!

** may be used to quickly check the answers of the participating solvers*

# State Of The Art (SOTA) (CASC definition)

- The state of the art represents the set of all the benchmarks solved by at least one solver [in a given timeout]
- Improving the SOTA is thus to solve new benchmarks [in a given timeout]
- Improvement can come from faster solvers
- Improvement can come from orthogonal approaches
- Improvement cannot come from portfolio-solvers, i.e. combination of existing solvers

# Benchmarks selection

- Classify benchmarks per categories (origin)
- Benchmarks hardness determined by a selection of existing solvers
- Randomly pick a selection of benchmarks respecting a given ratio of easy/medium/hard benchmarks
  - easy needed to check that those problems are still easy for new techniques
  - medium needed to discriminate solvers
  - hard benchmarks needed to get a chance to improve the state of the art

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# Aim of the ranking

- Order the solvers according to one or several performance criteria
- Spot interesting solvers
- Provide a winner

# Desirable properties

- Should be easy to check
- The score obtained by a solver should not depend on other participating solvers
- Should be able to exhibit "interesting" solvers

# Basic ranking scheme

- Rank the solvers according to the total number of problems solved
- Break ties with CPU-time

Simple lexicographic ranking based on two criteria used for CASC, SAT,...

# Purse-based ranking scheme (SAT COMP. 2005)

**Benchmark purse** to be divided equally among the solvers able to solve it.

**Speed purse** to be divided unequally among the solvers able to solve a given benchmark.

**Series** an extra credit is given for each series solved.

**Solver** his score is the sum of the credits obtained per benchmark solved plus the credits obtained per series solved.

# Purse based ranking: observations

- Easy benchmarks (solved by all solvers) do not provide much credit
- Benchmarks solved by a single solve provide a lot of credit
- Speed purse rewards fast solvers
- Series credit rewards wide scope/multipurpose solvers

Very difficult to check the results

# Penalty-based ranking scheme

(Penalized Average Runtime used in Machine Learning systems)

- Rank the solvers according to CPU-time
- Take a default CPU-time for unsolved benchmarks ($x$ times the timeout)

(PAR10 = take 10 times the timeout as penalty)

# Comparison of those rankings

(see SATSPEC2009 web page for details)

Application benchmarks

| Solver | Solved | CPU time | PAR10 | PAR100 | Purse |
|---|---|---|---|---|---|
| Rsat | **106** | **18043** | **1554043** | **15378043** | **44623** |
| TiniSatELite | 103 | 22193 | 1594193 | 15742193 | 30301 |
| picosat | 103 | 30610 | 1602610 | 15750610 | 25509 |
| minisat | 97 | 20931 | 1664931 | 16460931 | 29714 |

Crafted benchmarks

| Solver | Solved | CPU time | PAR10 | PAR100 | Purse |
|---|---|---|---|---|---|
| minisat | **71** | **13105** | **1573105** | **15613105** | 24601 |
| SATzilla | 69 | 12281 | 1596281 | 15852281 | 30336 |
| MiraXT | 57 | 13929 | 1741929 | 17293929 | 14737 |
| TTS | 37 | 3347 | 1971347 | 19683347 | **36457** |

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# Poor man results of the SAT competition

## SAT 2014 competition

| | |
|---|---|
| Organizing committee | Anton Belov, Daniel Diepold, Marijn Heule, Matti Järvisalo |
| Judges | Pete Manolios, Lakhdar Sais and Peter Stuckey |
| Proceedings | Descriptions of the solvers and benchmarks |
| Benchmarks | Application, Hard combinatorial, Random |
| Solvers | Source code available in EDACC |

| | Application | | | Hard combinatorial | | | Random | | |
|---|---|---|---|---|---|---|---|---|---|
| | Gold | Silver | Bronze | Gold | Silver | Bronze | Gold | Silver | Bronze |
| **Core solvers** | | | | | | | | | |
| SAT+UNSAT | Lingeling | SWDiA5BY | Riss BlackBox | glueSplit_clasp | Lingeling | SparrowToRiss | | | |
| SAT | minisat_blbd | Riss BlackBox | SWDiA5BY | SparrowToRiss | CCAnr+glucose | SGSeq | Dimetheus | BalancedZ | CSCCSat2014 |
| Certified UNSAT | Lingeling (druplig) | glucose | SWDiA5BY | Riss BlackBox | Lingeling (druplig) | glucose | | | |
| **Core solvers, Parallel** | | | | | | | | | |
| SAT+UNSAT | Plingeling | PeneLoPe | Treengeling | Treengeling | Plingeling | pmcSAT 2.0 | | | |
| SAT | | | | | | | pprobSAT | Plingeling | CSCCSat2014 |
| **Minisat hack** | | | | | | | | | |
| SAT+UNSAT | MiniSat_HACK_999ED | minisat_blbd | ROKKminisat | | | | | | |

## SAT 2013 competition

| | |
|---|---|
| Organizing committee | Adrian Balint, Anton Belov, Marijn Heule and Matti Järvisalo |
| Judges | Roberto Sebastiani, Karem A. Sakallah and Youssef Hamadi |
| Proceedings | Descriptions of the solvers and benchmarks |
| Benchmarks | Application, Hard combinatorial, Random |
| Solvers | |

| | Application | | | Hard combinatorial | | | Random | | |
|---|---|---|---|---|---|---|---|---|---|
| | Gold | Silver | Bronze | Gold | Silver | Bronze | Gold | Silver | Bronze |
| **Core solvers** | | | | | | | | | |
| SAT+UNSAT | Lingeling aqw | Lingeling 587f | ZENN 0.1.0 | BreakIDGlucose 1 | gluebit_clasp 1.0 | glucose 2.3 | CSHCrandMC | MIPSat random sat_unsat | march_vfl 1.0 |
| SAT | Lingeling aqw | ZENN 0.1.0 | satUZK 48 | glucose 2.3 | gluebit_clasp 1.0 | BreakIDGlucose 1 | probSAT SC13 | sattime2013 2013 | Ncca+ V 1 |
| Certified UNSAT | glucose 2.3 (certified unsat) | glueminisat-cert-unsat 2.2.7j | Riss3g cert | Riss3g cert | glucose 2.3 (certified unsat) | forl drup-nocachestamp | | | |
| **Core solvers, Parallel** | | | | | | | | | |
| SAT+UNSAT | Plingeling aqw | Treengeling aqw | PeneLoPe 2013 | Treengeling aqw | Plingeling aqw | pmcSAT 1.0 | | | |
| **Minisat hack** | | | | | | | | | |
| SAT+UNSAT | SINNminisat 1.0.0 | minisat_bit 1.0 | MiniGolf prefetch | | | | | | |
| **Open track (multiple solver sources, mixed benchmarks)** | | | | | | | | | |
| | CSHCpar8 | | | MIPSat | | | GlucoRed+March r531 | | |

# Immediate, not obviously visible, results

- Much reliable solvers (e.g. less segmentation fault)
- “More correct" solvers (if bugs are detected they are fixed)
- More reusable solvers (they now agree on the evaluation I/O as well)
- Unique access point to the expected answers for SOTA benchmarks.

# Results you will find on presentations, papers

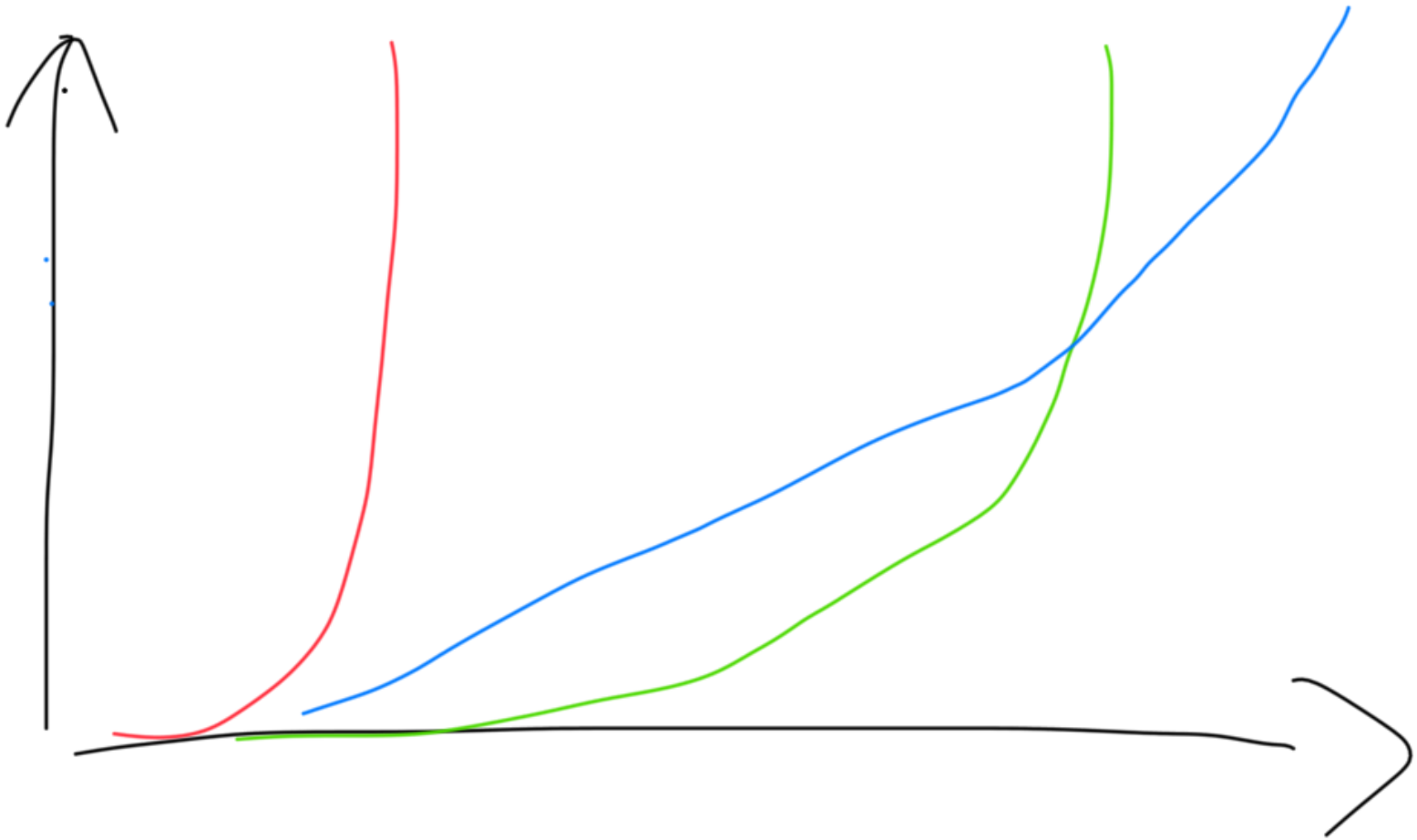
**Cactus plots** visual representation of the distribution of the runtimes of the solvers on solved benchmarks.

- x-axis represents the number of problem solved
- y-axis represents the runtime
- a point represents the number of problems solved within the given runtime

**Scatter plots** Visual comparison of a metric (usually runtime) for two solvers on a given set of benchmarks

- x-axis represents the runtime of solver A
- y-axis represents the runtime of solver B
- a point represents the metrics of solvers A and B for a given benchmark

# How to read a cactus plot



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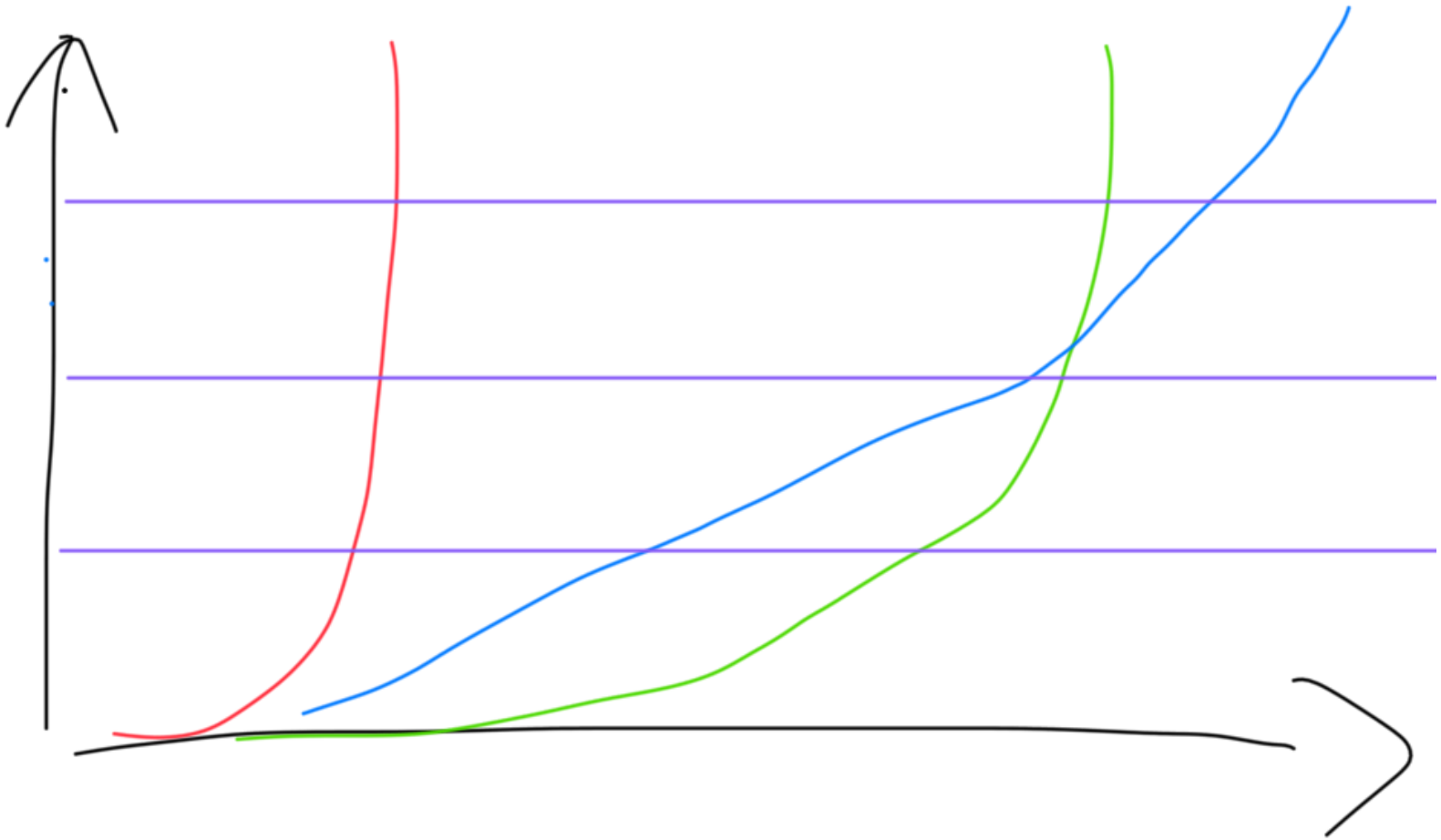
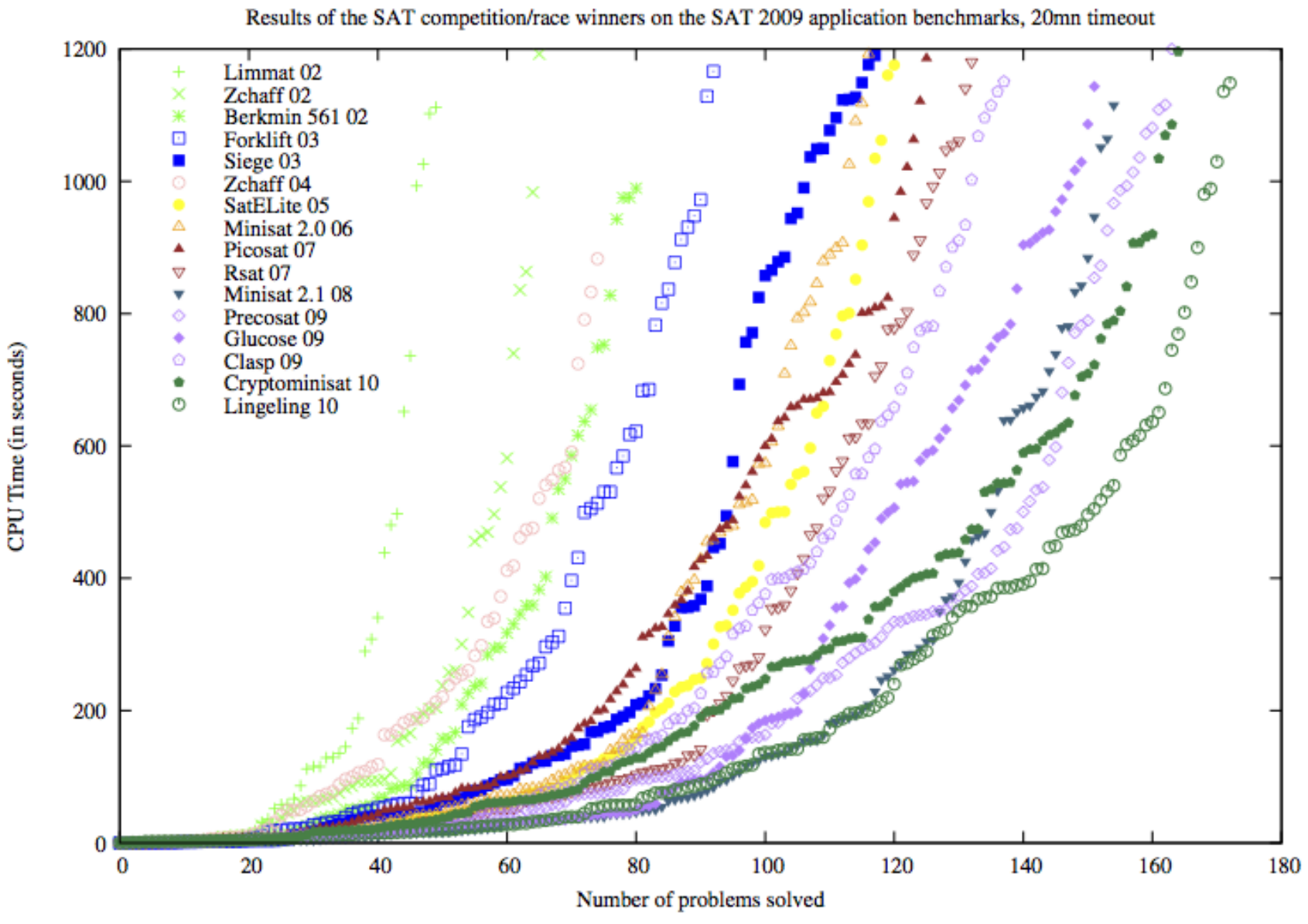


# Example: winners on SAT2009 benchmarks

- Take the winners of the SAT competitions since 2002
- Take the benchmarks of the SAT 2009 competition
- Take the hardware of the SAT 2009 competition (2GB of RAM)
- Observe ...

Threat to validity:
winners after 2009 may have been trained on those benchmarks
the hardware does no longer represent a desktop computer

# Example: winners on SAT2009 benchmarks



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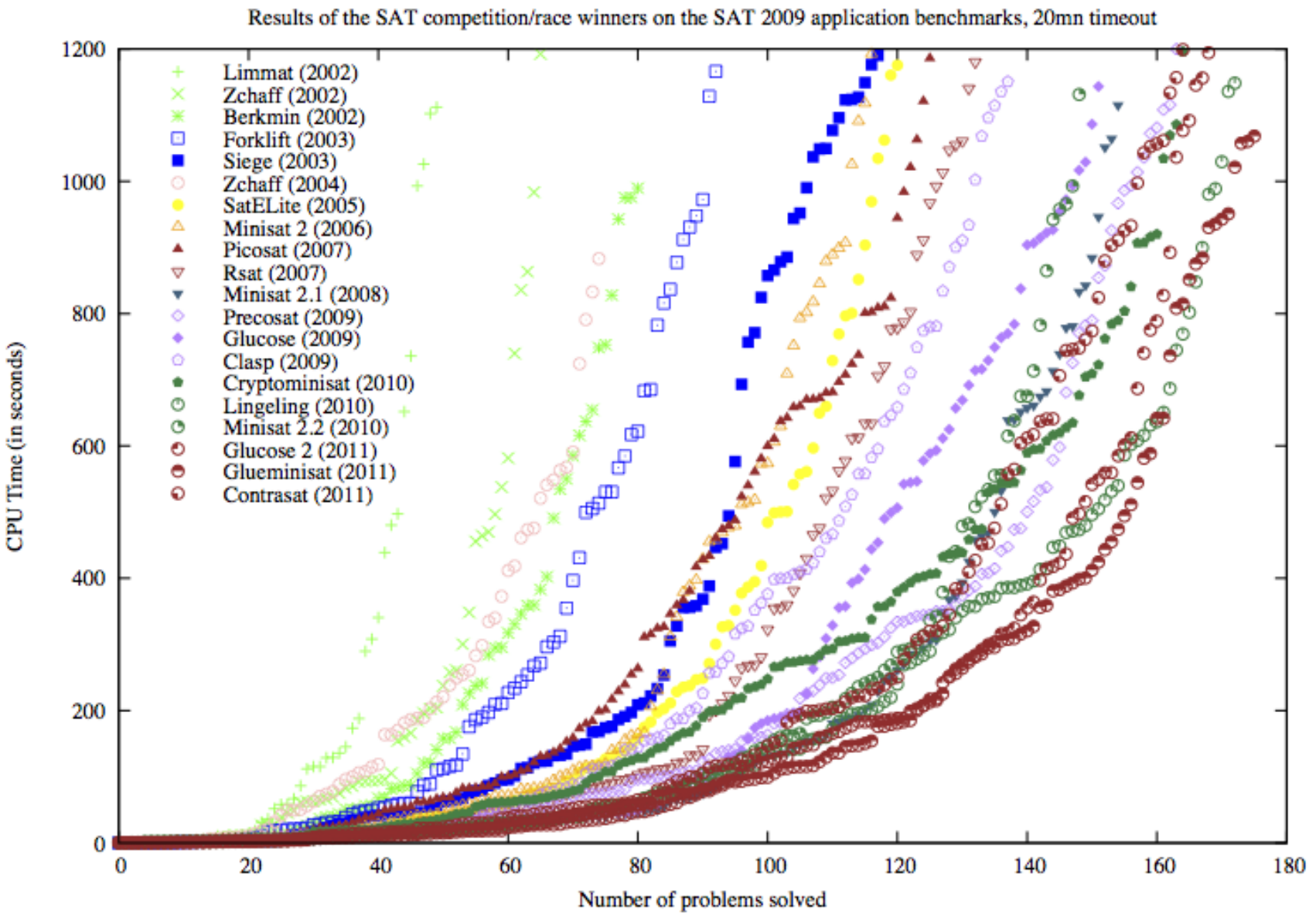

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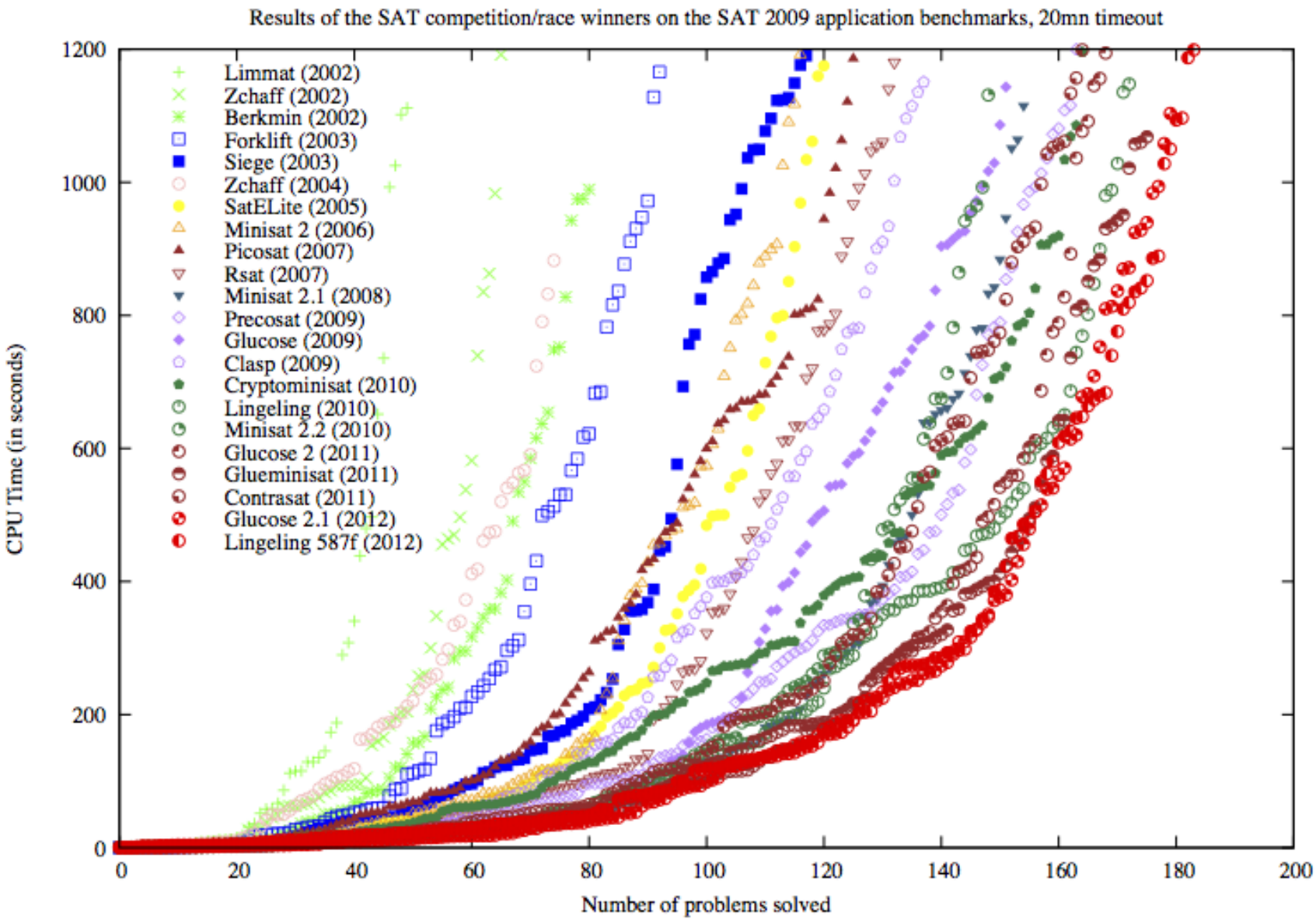
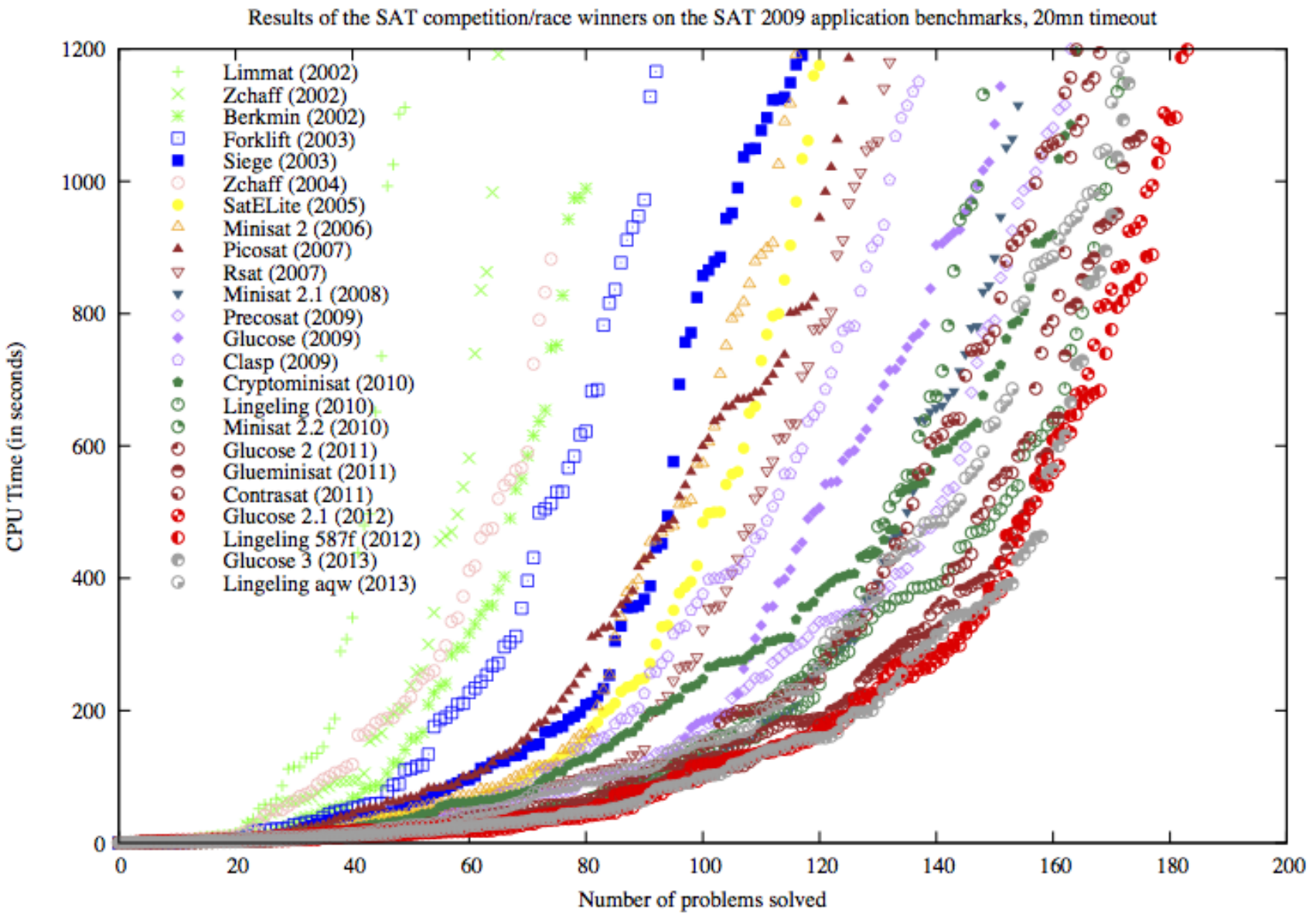
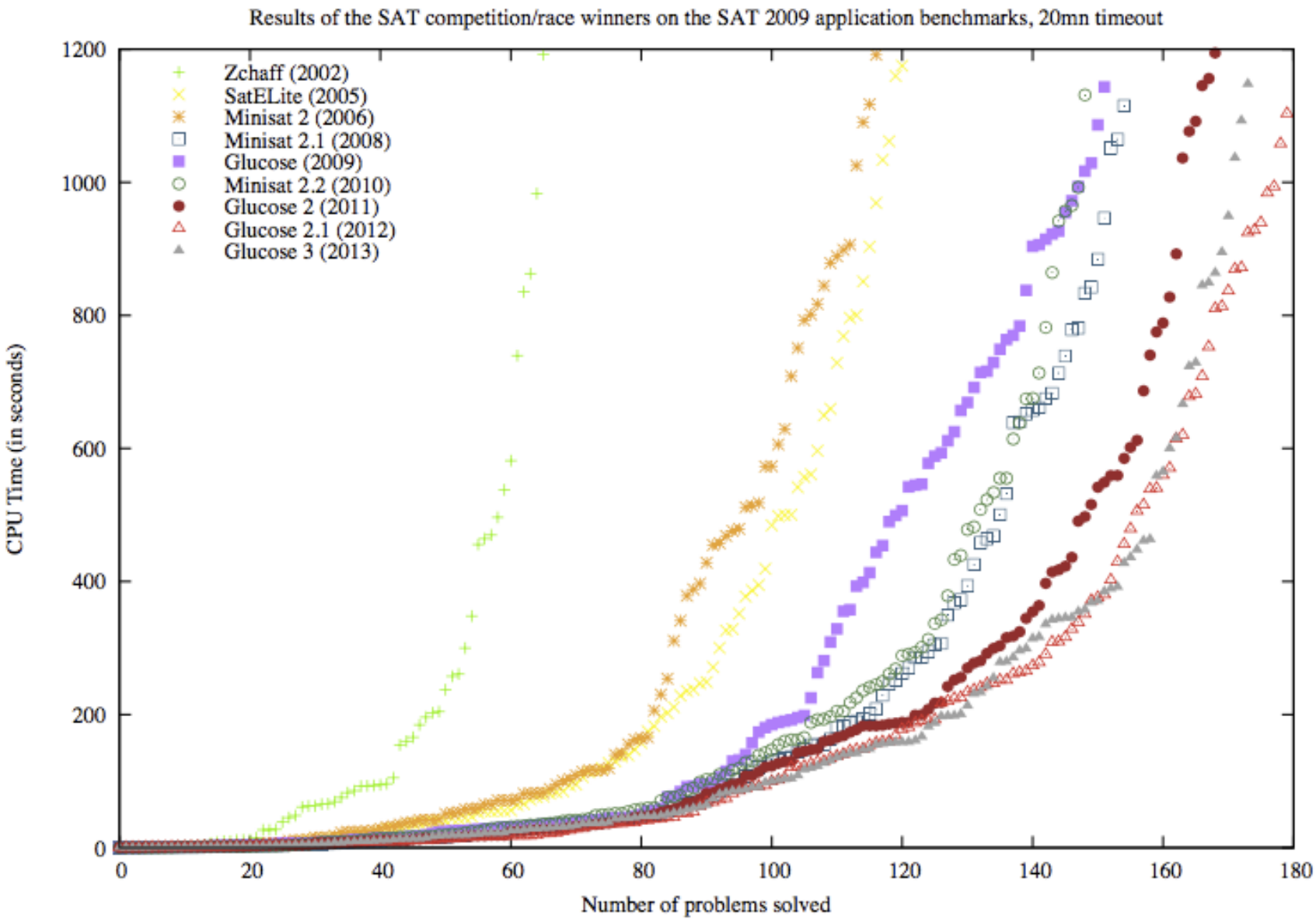


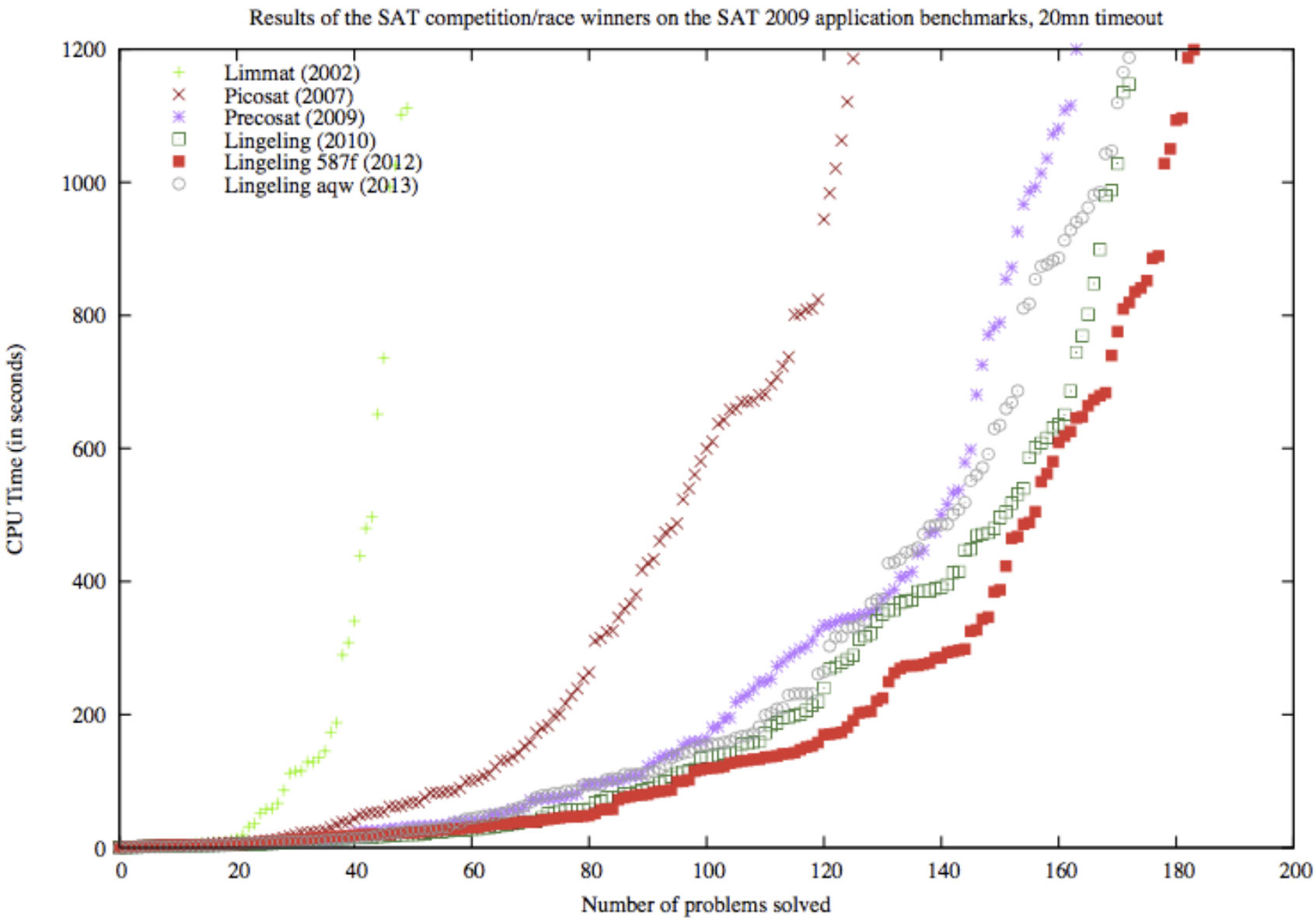
# Example: winners on SAT2009 benchmarks



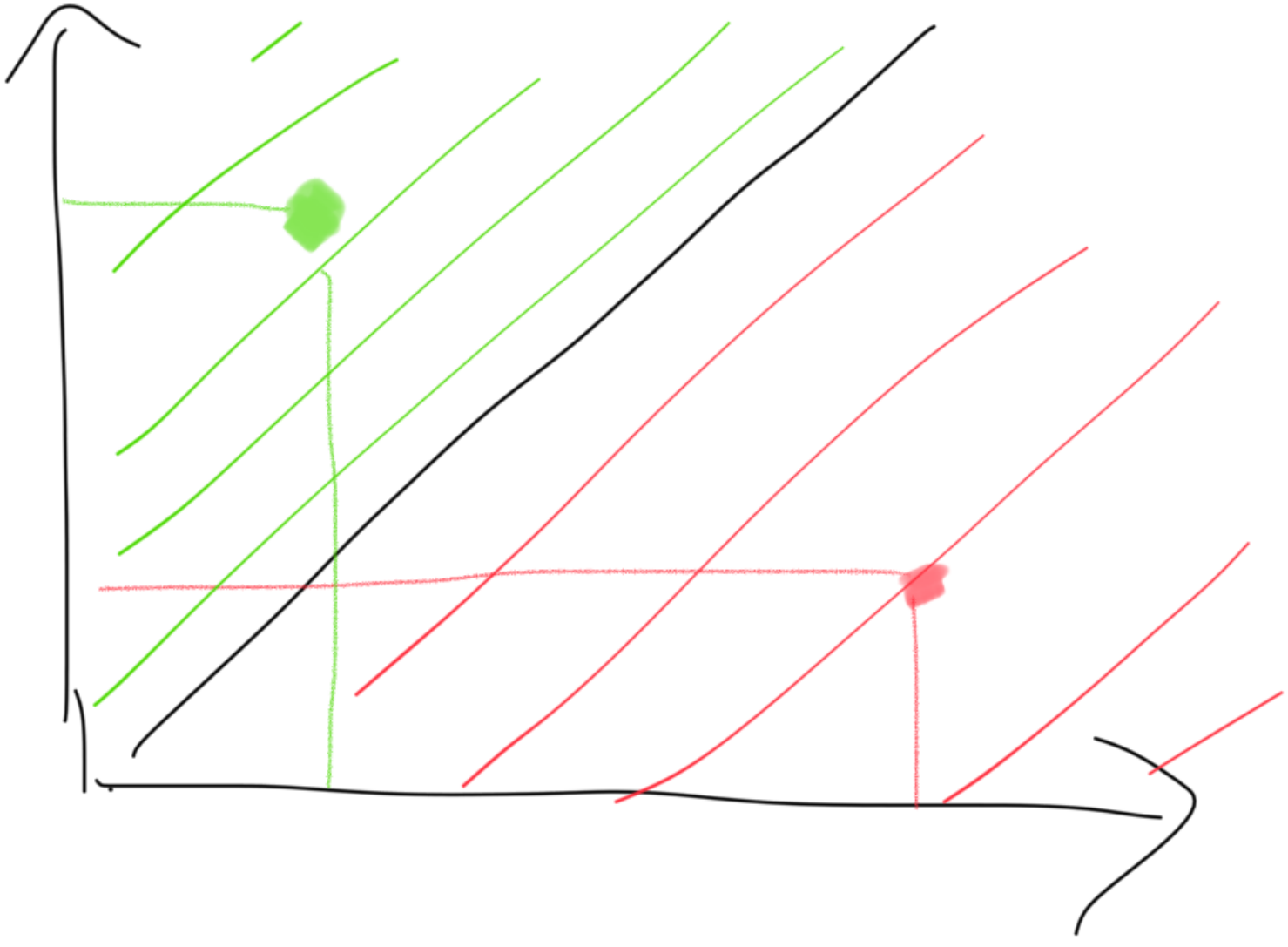
# Glucose


Results of the SAT competition/race winners on the SAT 2009 application benchmarks, 20mn timeout
Zchaff (2002)
SatELite (2005)
Minisat 2 (2006)
Minisat 2.1 (2008)
Glucose (2009)
Minisat 2.2 (2010)
Glucose 2 (2011)
Glucose 2.1 (2012)
Glucose 3 (2013)
CPU Time (in seconds)
Number of problems solved
0
200
400
600
800
1000
1200
0
20
40
60
80
100
120
140
160
180

# Armin's Biere solvers



# How to read a scatter plot



# Example: Armin's Biere POS15 presentation