Introduction to the SCIP Optimization Suite

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Introduction to the SCIP Optimization Suite

SCIP Optimization Suite

- toolbox for generating and solving constraint integer programs
- free for academic use, available in source code

ZIMPL

- model and generate LPs, MIPs, and MINLPs

SCIP

- MIP, MINLP and CIP solver, branch-cut-and-price framework

SoPlex

- revised primal and dual simplex algorithm

GCG

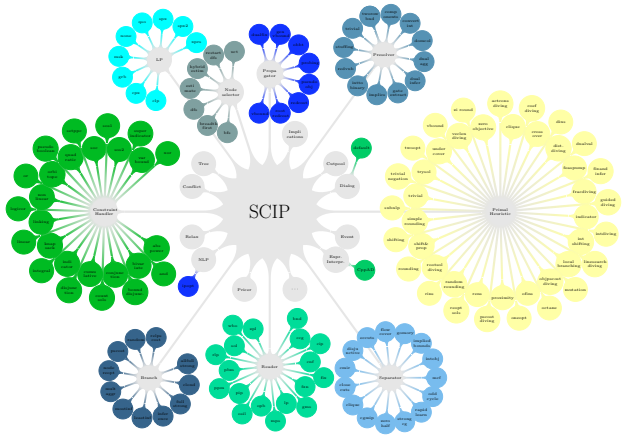
- generic branch-cut-and-price solver

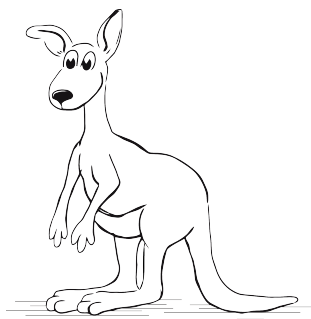
UG

- framework for parallelization of MIP and MINLP solvers

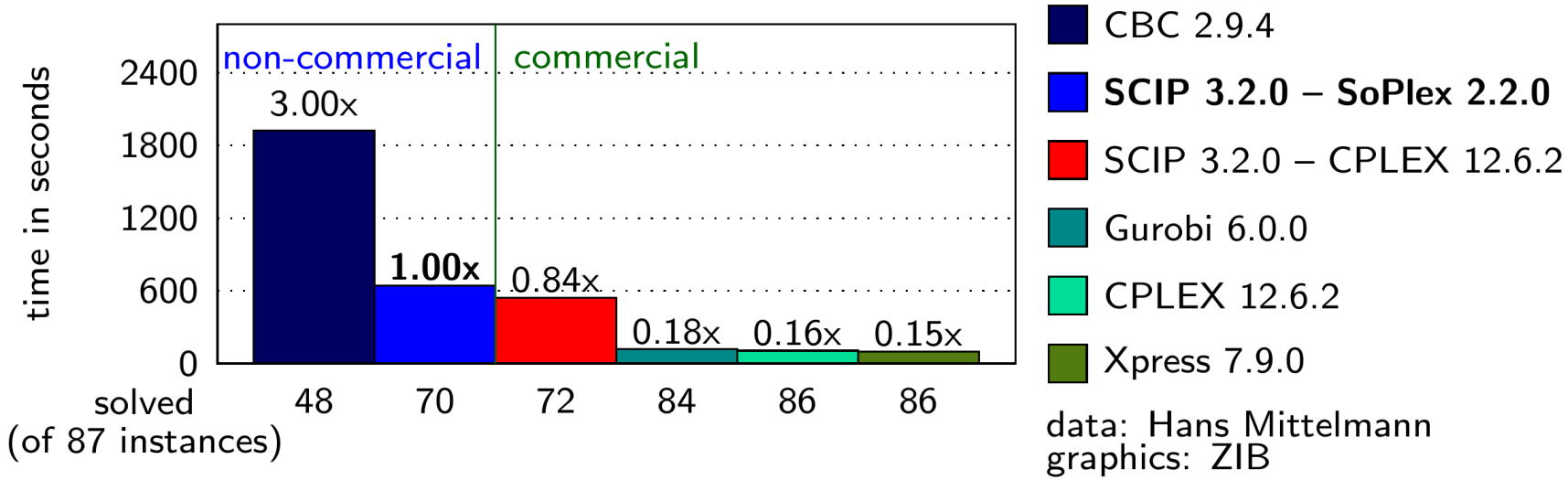
SCIP (Solving Constraint Integer Programs)

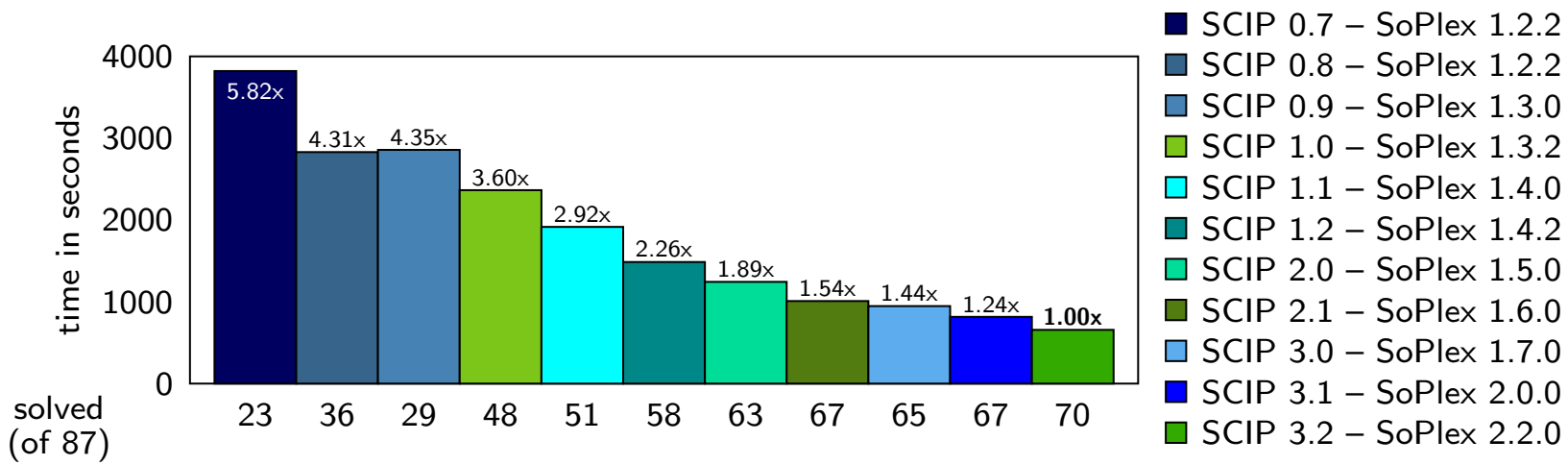
- is a branch-cut-and-price framework,
- is constraint based,
- incorporates
  - CP features (domain propagation),
  - MIP features (cutting planes, LP relaxation),
  - SAT-solving features (conflict analysis, restarts), and
  - MINLP features (expression trees, convex underestimators)
- has a modular structure via plugins,
- provides a full-scale MIP and MINLP solver,
- is free for academic purposes
- has just been released in its new version 3.2





Fastest MIP solver available in Source Code





Benchmark results from Hans Mittelmann, `http://plato.asu.edu/ftp/milpc`

Some facts about SCIP

- documentation and guidelines
  - more than 450 000 lines of C code, 20% documentation with 30 000 assertions and 4 000 debug messages
  - HowTos: plugin types, debugging, automatic testing
  - 9 examples and 4 applications illustrating the use of SCIP
  - active mailing list `scip@zib.de` (300 members)

- interface and usability
  - user-friendly interactive shell
  - interfaces to AMPL, GAMS, ZIMPL, MATLAB, Python and Java
  - C++ wrapper classes
  - LP solvers: CLP, CPLEX, Gurobi, MOSEK, QSopt, SoPlex, Xpress
  - over 1 600 parameters and 15 emphasis settings

The SCIP Community

- 27 active developers
  - 4 running Bachelor and Master projects
  - 15 running PhD projects
  - 8 postdocs and professors
- 4 development centers in Germany
  - Aachen: GCG
  - Berlin: SCIP, SoPlex, UG, ZIMPL
  - Darmstadt: SCIP and SCIP-SDP
  - Erlangen-Nürnberg: SCIP

- many international contributors and users
  - more than 8 000 downloads per year from over 100 countries
- careers
  - 10 awards for Masters and PhD theses: MOS, EURO, GOR, DMV
  - 7 former developers are now building commercial optimization software at CPLEX, FICO Xpress, Gurobi, MOSEK, and GAMS

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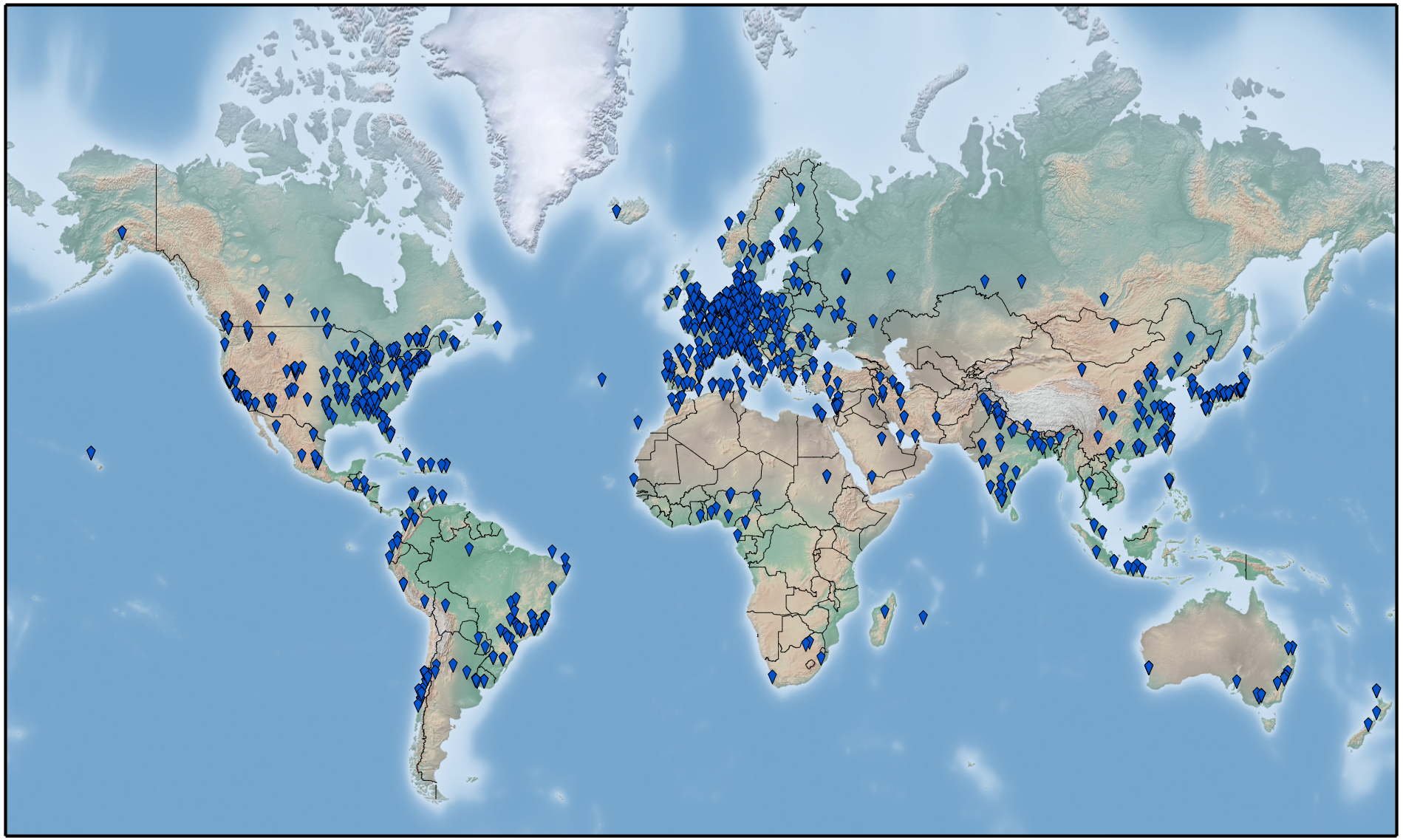
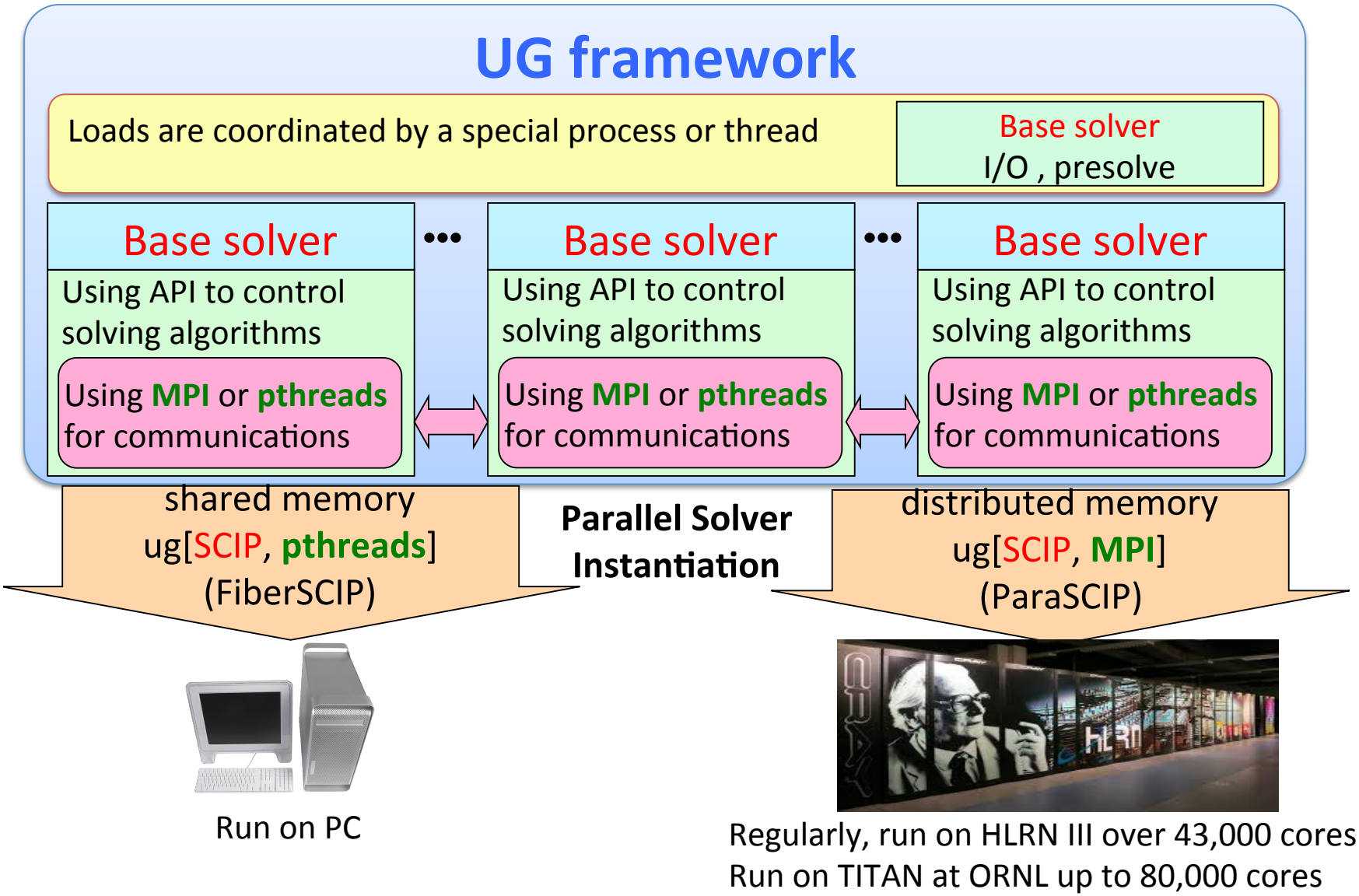


UG – Ubiquity Generator

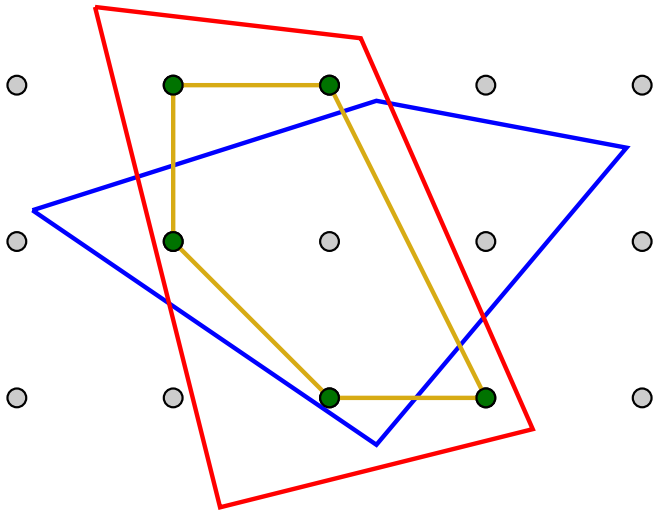


Run on PC

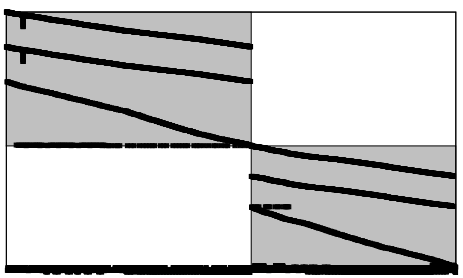
Regularly, run on HLRN III over 43,000 cores
Run on TITAN at ORNL up to 80,000 cores

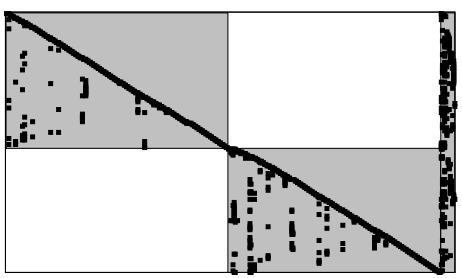
GCG – Generic Column Generation

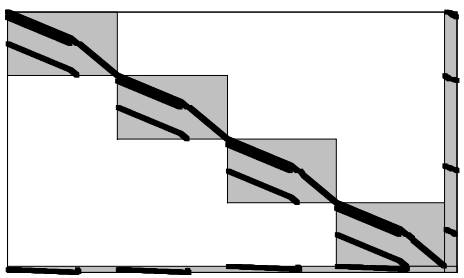
- Goal of GCG:
  - extend branch-cut-and-price framework SCIP to generic solver
  - based on Dantzig-Wolfe decomposition
  - easy use of branch-cut-and-price



- How does it work?
  - structure of problem provided or detected
  - pricing problems solved as general MIPs

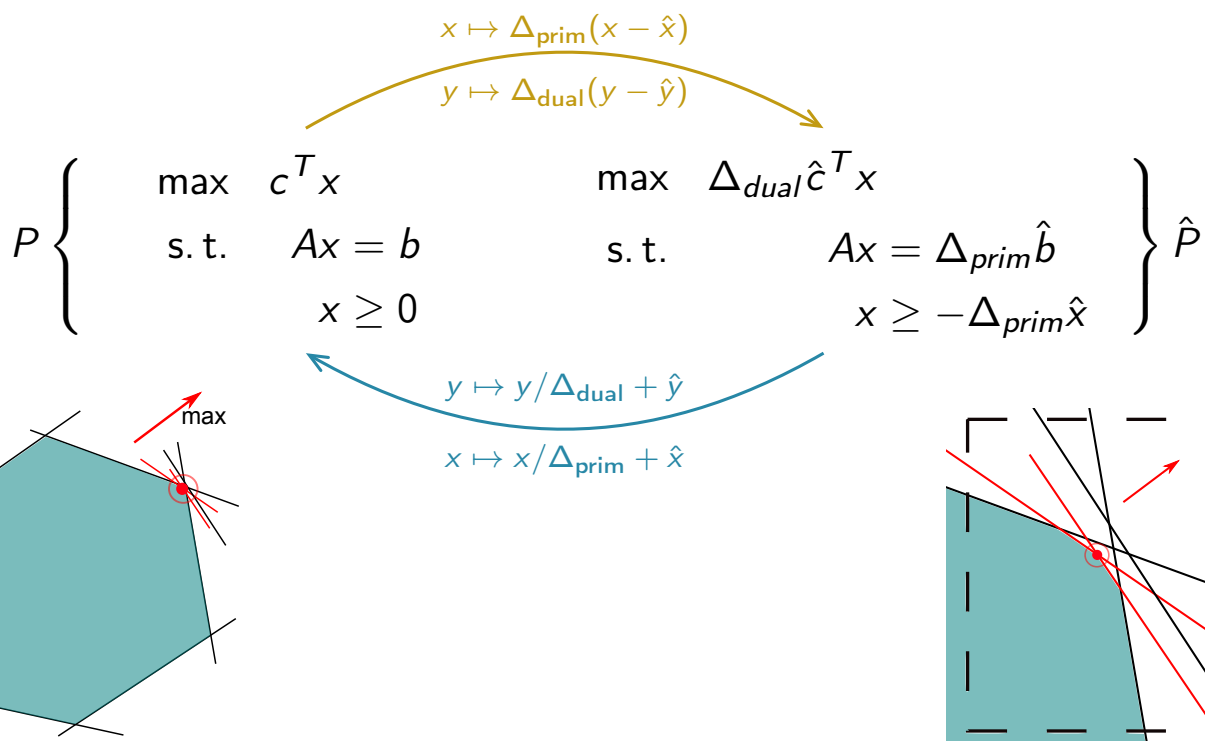






SoPlex – Sequential object-oriented simplex

- implementation of the revised simplex algorithm
- primal and dual solving routines for linear programs
- iterative refinement to overcome numerical problems
  - ▷ fast and accurate solutions by repeated floating-point solves



Most basic Linux commands

- SCIP is a command line tool:
  - no GUI (graphical user interface)
  - completely controlled from the console

- some Linux console commands:

`cd <dir>`	change current directory/navigate through directories
`cd ..`	move one directory up
`ls`	list contents of current directory
`rm <file>`	delete `<file>`
`cp <f1> <f2>`	copy `<f1>` to `<f2>`
`less <file>`	show contents of `<file>` (for text files, `q` to quit)
`./<binary>`	execute file `<binary>`

Installing SCIP

basic requirements:

- C/C++ compiler
- LP solver

- everything you need for a basic installation is contained in the SCIP Optimization Suite
- extract the package and type make:
  1. `tar -xvf scipoptsuite-3.2.0.tgz`
  2. `make`

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- will most likely not work on a standard Linux installation...
- additional packages/third-party software is required to fully enjoy SCIP
- carefully read the error messages to see what is missing

Third party software

- ZLIB
  - necessary to load compressed problem files
- Readline
  - comfortable interactive shell (tab-completion, command history, ...)
- GMP
  - Gnu Multiple Precision library
  - allows for higher precision arithmetic
- ncurses
  - necessary for output formatting
- ...

- You need the respective developer versions, indicated by `-devel` or `-dev` in your favorite package manager!

Alternative

What if you cannot install a package?

- most features can be disabled to solve installation problems:
  - `make ZLIB=false`
  - `make READLINE=false`
  - `make GMP=false`

- ZIMPL has additional requirements: `bison`, `flex`
- in case you cannot install ZIMPL:
  `make ZIMPL=false`

... even more options

- SCIP supports several different LP solvers:

SoPlex (default):	`make LPS=spx`
IBM CPLEX:	`make LPS=cpx`
FICO Xpress:	`make LPS=xprs`
Gurobi:	`make LPS=grb`
CoinOR CLP:	`make LPS=clp`
Mosek:	`make LPS=msk`
QSopt:	`make LPS=qso`
improved SoPlex interface:	`make LPS=spx2`

- for MINLP we recommend you install and use `Ipopt`
  - `make IPOPT=true`
  - a working installation of `Ipopt` is required (not covered here)
- give your binary a descriptive name:
  - `make VERSION=awesome-new-feature`
  - defaults to the current version number

Debugging with SCIP

SCIP can be compiled and run in debug mode

- 30 000 asserts will be checked
- additional checks will be performed
- more warnings may be printed
- debug information is available for `gdb`
- slower than the optimized mode (`OPT=opt`)
- useful when writing new code and when hunting for bugs

- `make OPT=dbg`

Examples/Applications contained in SCIP

- show how SCIP can be used and
  provide starting points for future developments
- examples:
  - Branch-and-Price
  - Branch-and-Cut
  - Callable Library
  - ...
- applications:
  - Coloring
  - Scheduler
  - Multi-objective Optimization
  - Steiner Tree Problem
- every example/application has its own Makefile
- go to `examples/` or `applications/` and type `make`
- code usually relies on a compiled main SCIP

Beyond SCIP...

- GCG, a generic column generation solver, can be compiled with `make gcg`
  - relies on bliss – for graph computations
- UG, the parallelization framework, can be compiled with `make ug`
  - default is to build FiberSCIP, a shared memory parallel SCIP extension

How to use the shell

- navigate to your SCIP installation: `cd projects/scip`
- start SCIP: `./bin/scip`
  (when installed globally just type: `scip`)
- display available commands: `help`
- commands in `<...>` open a new set of commands
  - press ⏎ to return to home menu
- commands can be shortened, but need to be unique:
  e.g. `o[ptimize]` or `q[uit]`
- cycle through previous commands with ↑ and ↓
- `Tab` completion (⇥), e.g. for finding files quickly, is also available
  (requires the `readline` package)

SCIP as a shell program

- run `./bin/scip --help` to see available options
- example:
  `./bin/scip -s fast.set -f mip.lp -l out.log`
- all commands from the interactive shell can be chained together in one call with `-c`:
  `./bin/scip -c "read mip.lp opt disp stat q"`

Modifying the Output

- customize (almost) everything with `SCIP> set display`

`freq`	in-/decrease frequency of node information line
`lpinfo`	enable output of LP solver
`verblevel`	change overall verbosity
	adjust which columns to display/hide
	...

Parameters

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Good news:

- SCIP's default settings are already pretty good!
- SCIP has several emphasis/meta settings to simplify tuning (these will modify multiple parameters at once)
  - `SCIP> set presol emph {off|fast|aggressive}`
  - `SCIP> set heur emph {off|fast|aggressive}`
  - `SCIP> set sepa emph {off|fast|aggressive}`
  - `SCIP> set emphasis ...` → *next slide*

Emphasis Settings

- `SCIP> set emphasis ...`

`feasibility`	for finding feasible solutions quickly
`optimality`	focus on proving optimality
`easycip`	for small and easy problems
`hardlp`	avoid solving many LP relaxations
`cpsolver`	rely on CP techniques instead of MIP
`counter`	for counting all feasible solutions

Analyzing a Run

- most important tool is the statistics output:
  `SCIP> display statistics`
- running times of (almost) all components can be compared

How to use the information?

- Check for long running heuristics that don't find a solution!
- Are cut generators too costly or are more cuts necessary to increase the dual bound?
- ...

Working with Settings Files

- SCIP can save the current settings to a file:
  - either all of them: `SCIP> set save <file.set>`
  - or only the modified ones: `SCIP> set diffsave <file.set>`
- load a settings file:
  - `SCIP> set load <file.set>`
- settings files can also be modified by hand
- if a file called `scip.set` is present in SCIP's home directory, it is automatically loaded

Customizing Parameters

Example: Presolving

- `SCIP> read check/instances/MIP/bell5.mps`
  (models a fiber optic design network)
- disable presolving and compare with default
- `SCIP> set presol emph off`

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- presolving reduces the problem size
- smaller problems are usually easier to solve

Example: Node Selection

- `SCIP> read check/instances/MIP/dcmulti.mps`
  (models multi-period facility location problem)
- try different rules, e.g. depth-first search and breadth-first-search
- `SCIP> set nodesel dfs stdprio 1000000`
- `SCIP> set nodesel breadthfirst stdprio 1000000`

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- node selection rules
  - determine the order of open node processing
  - influence when solutions are found and how many nodes are needed

Example: Separating

- `SCIP> read check/instances/MIP/gt2.mps`
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- `SCIP> read check/instances/MIP/gt2.mps`
  (models truck routing problem)
- disable separation and compare with default

- cutting planes help to improve the dual bound
- Generating too many cuts can be costly!

Example: Branching

- `SCIP> read check/instances/MIP/enigma.mps`
- try different rules and find one that needs 50% more/less nodes than default
- `SCIP> set branching leastinf prio 1000000`
- branching rules determine on which fractional variable to branch

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- `SCIP> set branching leastinf prio 1000000`
- branching rules determine on which fractional variable to branch

- `leastinf` branching is very bad
- `fullstrong` branching is very good

Testing Environment

- SCIP package provides many scripts to make testing easy
- general setup:
  - set of instances put together in a test set:
    `check/testset/short.test`
  - verify solution values:
    `check/testset/short.solu` (optional)
  - run SCIP on the entire test set:
    (use the same options as for compiling)
    `make test TEST=short`
  - test non-default parameters:
    `make test TEST=short SETTINGS=heuristics-off`
  - use the interactive shell to create a new settings file
  - settings file needs to be placed in `settings/`

Default Values

```
      TEST = short
       OPT = opt
  SETTINGS = default
   VERSION = 3.2.0
       LPS = spx
       GMP = true
     ZIMPL = true
  READLINE = true
      ZLIB = true
     IPOPT = false
      TIME = 3600 (sec)
       MEM = 6144 (MB)
```

Output of a single test run

- `.out` file:
  concatenation of all logfiles
- `.err` file:
  concatenation of all occured errors/warnings
- `.set` file:
  copy of the used settings
- `.res` file:
  concise summary of test run
- `.tex` file:
  LaTeX table of results
- `.pav` file:
  machine readable table of results

- all files are stored in `check/results/`:

```
check.short.scip-3.2.0.linux.x86_64.gnu.opt.spx.opt49.default.out
```

Compare multiple runs

- multiple runs over the same test set can be compared
- use `check/allcmpres.sh`:
  1. `cd check`
  2. `./allcmpres.sh results/check.1.res results/check.2.res`

- more than two result files can be compared
- typical use cases:
  - compare different settings
  - compare different versions
  - ...