SCIP Introduction Sep. 26, 2018

Time	Schedule
9:30–11:00	Introduction & Overview (1)
11:00–11:30	Break
11:30–12:30	Introduction & Overview (2)
12:30–14:00	Lunch Break
14:00–15:30	Programming Exercises with PySCIPOpt (first steps)
15:30–16:00	Break
16:00–17:30	Programming Exercises With PySCIPOpt (more realistic examples)

SCIP Introduction at the 3rd IMI-ISM-ZIB Workshop, Tokio, Japan

Introduction to SCIP

Gregor Hendel, hendel@zib.de

SCIP Introduction Day
September 26, 2018
3rd IMI-ISM-ZIB MODAL Workshop

What is SCIP?

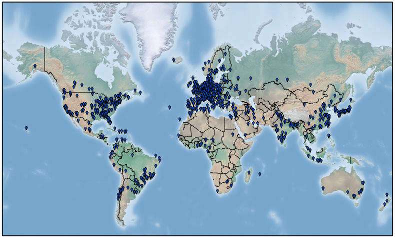
SCIP (Solving Constraint Integer Programs) . . .

- provides a full-scale MIP and MINLP solver,
- is constraint based,
- incorporates
  - MIP features (cutting planes, LP relaxation), and
  - MINLP features (spatial branch-and-bound, OBBT)
  - CP features (domain propagation),
  - SAT-solving features (conflict analysis, restarts),
- is a branch-cut-and-price framework,
- has a modular structure via plugins,
- is free for academic purposes,
- and is available in source-code under `http://scip.zib.de` !

Meet the SCIP Team

31 active developers

- 7 running Bachelor and Master projects
- 16 running PhD projects
- 8 postdocs and professors



4 development centers in Germany

- ZIB: SCIP, SoPlex, UG, ZIMPL
- TU Darmstadt: SCIP and SCIP-SDP
- FAU Erlangen-Nürnberg: SCIP
- RWTH Aachen: GCG

Many international contributors and users

- more than 10 000 downloads per year from 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

Outline

SCIP – Solving Constraint Integer Programs

http://scip.zib.de

SCIP – Solving Constraint Integer Programs

Constraint Integer Programming

The Solving Process of SCIP

Extending SCIP by Plugins

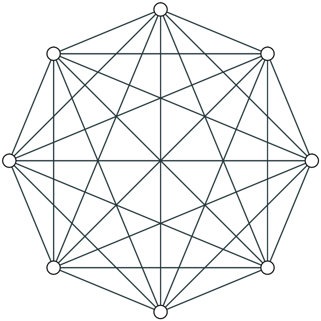
The SCIP Optimization Suite

http://scip.zib.de

An example: the Traveling Salesman Problem

Definition (TSP)
Given a complete graph $G = (V, E)$ and distances d_e for all $e \in E$:

Find a Hamiltonian cycle (cycle containing all nodes, tour) of minimum length.



K_8

Definition (TSP)
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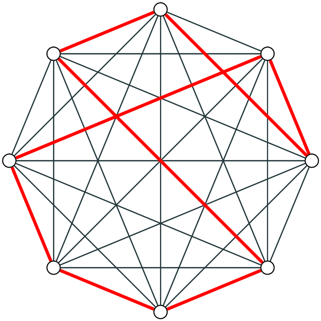


K_8

Definition (TSP)
Given a complete graph $G = (V, E)$ and distances d_e for all $e \in E$:

Find a Hamiltonian cycle (cycle containing all nodes, tour) of minimum length.

What is a Constraint Integer Program?

Mixed Integer Program

Objective function:

- linear function

Feasible set:

- described by linear constraints

Variable domains:

- real or integer values

$$\begin{aligned} \min \quad & c^T x \\ s.t. \quad & Ax \leq b \\ & (x_I, x_C) \in \mathbb{Z}^I \times \mathbb{R}^C \end{aligned}$$

Constraint Program

Objective function:

- arbitrary function

Feasible set:

- given by arbitrary constraints

Variable domains:

- arbitrary (usually finite)

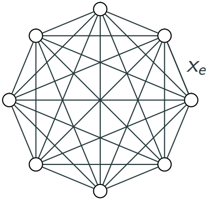
$$\begin{aligned} \min \quad & c(x) \\ s.t. \quad & x \in F \\ & (x_I, x_N) \in \mathbb{Z}^I \times X \end{aligned}$$

Given

- complete graph $G = (V, E)$
- distances $d_e > 0$ for all $e \in E$

Binary variables

- $x_e = 1$ if edge e is used



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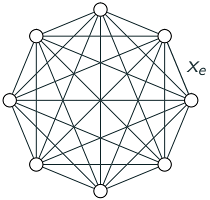
TSP – Integer Programming Formulation

Given

- complete graph $G = (V, E)$
- distances $d_e > 0$ for all $e \in E$

Binary variables

- $x_e = 1$ if edge e is used



K_8

$$\begin{aligned}
\min \quad & \sum_{e \in E} d_e \, x_e & \\
\text{subject to} \quad & \sum_{e \in \delta(v)} x_e = 2 & \forall v \in V \\
& \sum_{e \in \delta(S)} x_e \geq 2 & \forall S \subset V, S \neq \emptyset \\
& x_e \in \{0, 1\} & \forall e \in E
\end{aligned}$$

TSP – Integer Programming Formulation

Given

- complete graph $G = (V, E)$
- distances $d_e > 0$ for all $e \in E$

Binary variables

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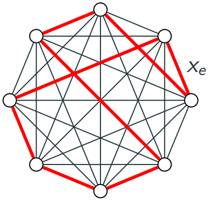


K_8

$$
\begin{array}{llll}
\min & \sum_{e \in E} d_e \, x_e & & \\
\text{subject to} & \sum_{e \in \delta(v)} x_e = 2 & \forall v \in V & \text{node degree} \\
& \sum_{e \in \delta(S)} x_e \geq 2 & \forall S \subset V, S \neq \emptyset & \\
& x_e \in \{0, 1\} & \forall e \in E &
\end{array}
$$

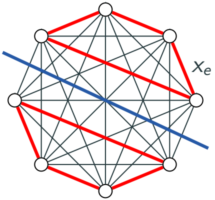
TSP – Integer Programming Formulation

Given

- complete graph $G = (V, E)$
- distances $d_e > 0$ for all $e \in E$

Binary variables

- $x_e = 1$ if edge e is used



K_8

$$
\begin{array}{lll}
\min & \sum_{e \in E} d_e \, x_e & \\
\text{subject to} & \sum_{e \in \delta(v)} x_e = 2 & \forall v \in V \\
 & \sum_{e \in \delta(S)} x_e \geq 2 & \forall S \subset V, S \neq \varnothing \quad \text{subtour elimination} \\
 & x_e \in \{0, 1\} & \forall e \in E
\end{array}
$$

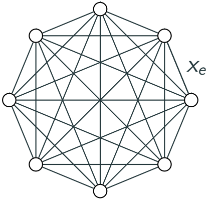
TSP – Integer Programming Formulation

Given

- complete graph $G = (V, E)$
- distances $d_e > 0$ for all $e \in E$

Binary variables

- $x_e = 1$ if edge e is used



K_8

$$\min \sum_{e \in E} d_e x_e \qquad \text{distance}$$

$$\begin{aligned}
\text{subject to} \quad & \sum_{e \in \delta(v)} x_e = 2 && \forall v \in V \\
& \sum_{e \in \delta(S)} x_e \geq 2 && \forall S \subset V, S \neq \emptyset \\
& x_e \in \{0, 1\} && \forall e \in E
\end{aligned}$$

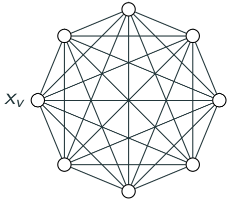
TSP – Constraint Programming Formulation

Given

- complete graph $G = (V, E)$
- for each $e \in E$ a distance $d_e > 0$

Integer variables

- x_v position of $v \in V$ in tour



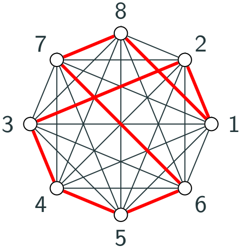
K_8

Given

- complete graph $G = (V, E)$
- for each $e \in E$ a distance $d_e > 0$

Integer variables

- x_v position of $v \in V$ in tour



$$
\begin{aligned}
\min \quad & \text{length}(x_1, \ldots, x_n) \\
\text{subject to} \quad & \text{alldifferent}(x_1, \ldots, x_n) \\
& x_v \in \{1, \ldots, n\} \qquad \forall v \in V
\end{aligned}
$$

Constraint Integer Program

Objective function:

- ▷ linear function

Feasible set:

- ▷ described by arbitrary constraints

Variable domains:

- ▷ real or integer values

$$\begin{array}{ll} \min & c^T x \\ s.t. & x \in F \\ & (x_I, x_C) \in \mathbb{Z}^I \times \mathbb{R}^C \end{array}$$

Remark:

- arbitrary objective or variables modeled by constraints

Constraint Integer Program

Objective function:

▷ linear function

Feasible set:

▷ described by arbitrary constraints

Variable domains:

▷ real or integer values

$$\begin{array}{llll} \min & \sum_{e \in E} d_e\, x_e & & \\ s.t. & \sum_{e \in \delta(v)} x_e & = 2 & \forall\, v \in V \\ & \text{nosubtour}(x) & & \\ & x_e & \in \{0,1\} & \forall\, e \in E \end{array}$$

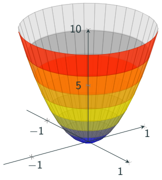
(CIP formulation of TSP)

Single nosubtour constraint rules out subtours (e.g. by domain propagation). It may also separate subtour elimination inequalities.

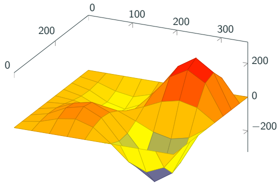
Mixed-Integer Nonlinear Programs (MINLPs)

$$\begin{aligned} \min\ & c^{\mathsf{T}} x & \\ \text{s.t. } & g_k(x) \leq 0 & \forall k \in [m] \\ & x_i \in \mathbb{Z} & \forall i \in \mathcal{I} \subseteq [n] \\ & x_i \in [\ell_i, u_i] & \forall i \in [n] \end{aligned}$$

The functions $g_k \in C^1([\ell, u], \mathbb{R})$ can be



convex or



nonconvex

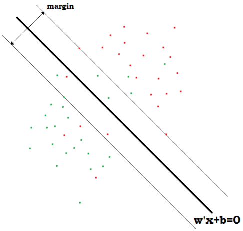
Support Vector Machine, e.g., with ramp loss.

$$\min \frac{w^{\mathsf{T}}w}{2} + \frac{C}{n}\sum_{i=1}^{n}(\xi_i + 2(1 - z_i))$$

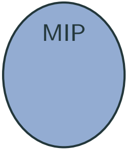
$$\text{s.t. } z_i(y_i(w^{\mathsf{T}}x_i + b) - 1 + \xi_i) \geq 0 \qquad \forall i$$

$$\xi_i \in [0,2], \quad z_i \in \{0,1\} \qquad \forall i$$

$$w \in \mathbb{R}^d, \quad b \in \mathbb{R}$$

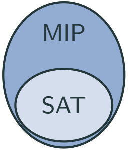


- Mixed Integer Programs



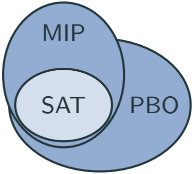
Constraint Integer Programming

- Mixed Integer Programs
- SATisfiability problems



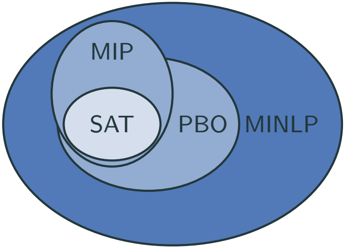
Constraint Integer Programming

- Mixed Integer Programs
- SATisfiability problems
- Pseudo-Boolean Optimization



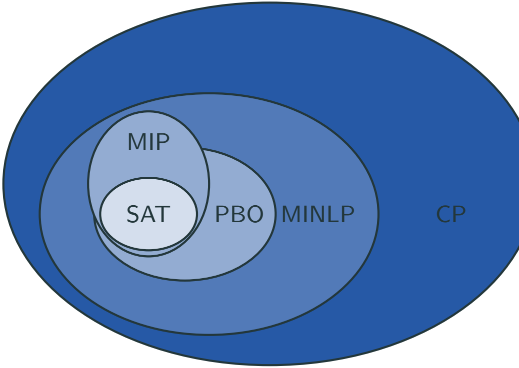
Constraint Integer Programming

- Mixed Integer Programs
- SATisfiability problems
- Pseudo-Boolean Optimization
- Mixed Integer NonIinear Programs



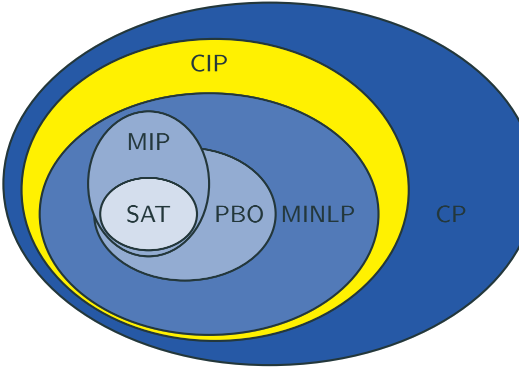
Constraint Integer Programming

- Mixed Integer Programs
- SATisfiability problems
- Pseudo-Boolean Optimization
- Mixed Integer NonIinear Programs
- Constraint Programming



Constraint Integer Programming

- **M**ixed **I**nteger **P**rograms
- **SAT**isfiability problems
- **P**seudo-**B**oolean **O**ptimization
- **M**ixed **I**nteger **N**on**l**inear **P**rograms
- **C**onstraint **P**rogramming
- **C**onstraint **I**nteger **P**rogramming



Constraint Integer Programming

- Mixed Integer Programs
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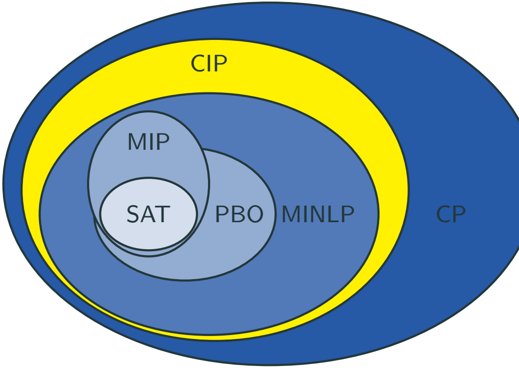
- Constraint Integer Programming



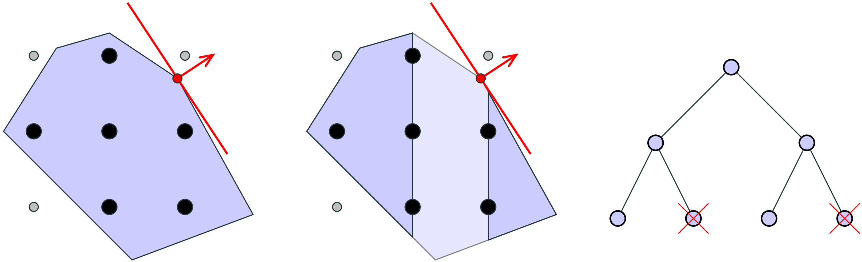
Relation to CP and MIP

- Every MIP is a CIP. *"MIP $\subsetneq$ CIP"*
- Every CP over a finite domain space is a CIP. *"FD $\subsetneq$ CIP"*

SCIP – Solving Constraint Integer Programs

http://scip.zib.de

Branch-and-bound



Basic Workflow

```
read ../check/instances/MIP/bell5.mps
optimize
write solution mysolution.sol
quit
```

Displaying information
Use the `display ...` command to enter the menu and

- obtain `solution` information
- print the current `transproblem` to the console
- display plugin information, e.g., list all available branching rules

Changing Settings
Use the `set ...` command to list the settings menu.

Important Parameters

Numerical parameters
These must be set before reading a problem.

- `numerics/feastol`, default 10^{-6}
- `numerics/epsilon`, default 10^{-9}
- `numerics/infinity`, default 10^{20}

Limits

- `limits/time`
- `limits/nodes`
- `limits/gap`

Randomization

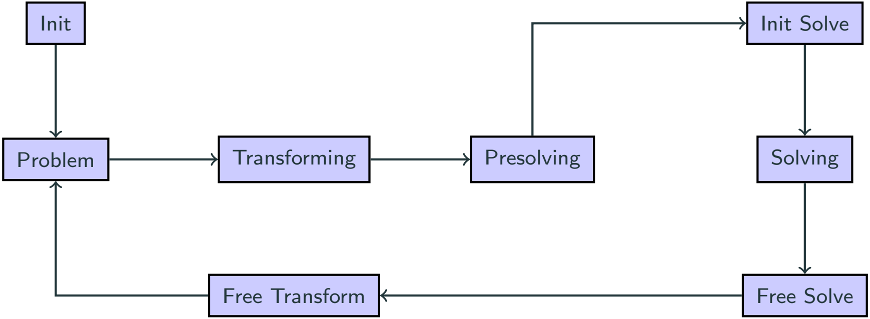
- `randomization/randomseedshift`
- `randomization/lpseed`
- `randomization/permutationseed`

Different Tasks – Different Plugins

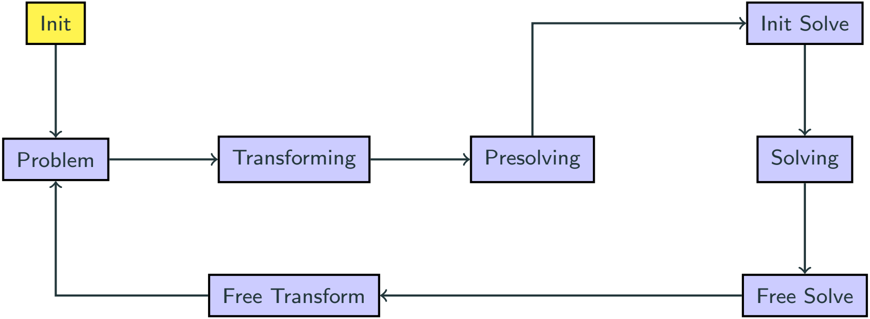
Different plugin classes are responsible of the following tasks.

1. Presolving and node propagation
   - Constraint handlers
   - Presolvers
   - Propagators
2. Separation
   - Constraint handlers
   - Separators
3. Improving solutions
   - Primal heuristics
4. Branching
   - Constraint handlers
   - Branching rules
5. Node selection
   - Node selectors

Operational Stages

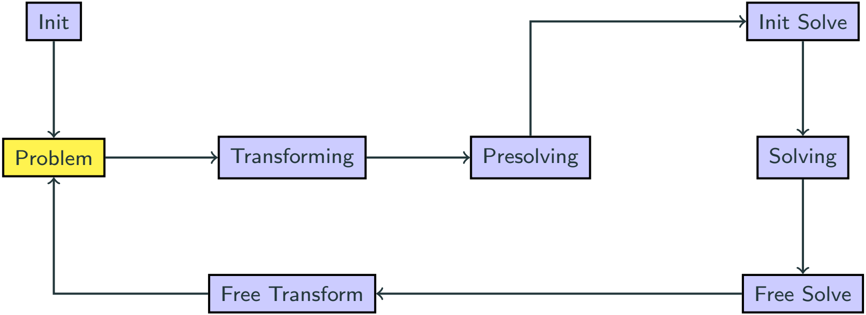


Operational Stages



- Basic data structures are allocated and initialized.
- User includes required plugins (or just takes default plugins).

Problem Specification



- User creates and modifies the original problem instance.
- Problem creation is usually done in file readers.

Define Variables (LOP Example)

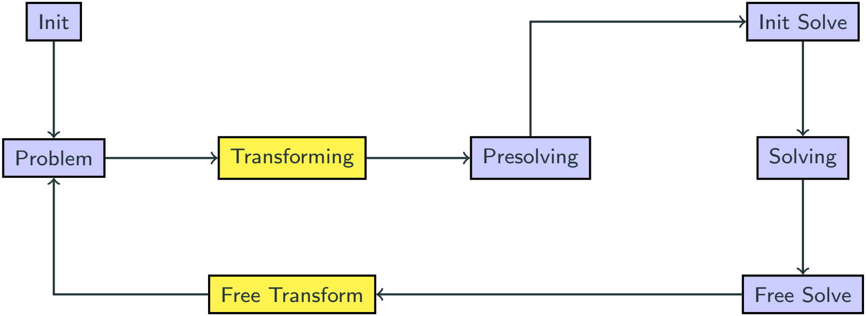
```
SCIP_VAR* var;
SCIP_CALL(                    // return value macro
  SCIPcreateVar(
    scip,                     // SCIP pointer
    &var,                     // save in variable
    "varname",                // pass variable name
    0.0,                      // lower bound
    1.0,                      // upper bound
    length,                   // obj. value
    SCIP_VARTYPE_BINARY,      // type
    TRUE,                     // initial
    FALSE,                    // removable
    NULL, NULL, NULL,         // no callback functions
    NULL                      // no variable data
  )
);
SCIP_CALL( SCIPaddVar(scip, var) );        // add var.
```

TSP: Define Degree Constraints

```
SCIP_CALL( SCIPcreateConsLinear(
    scip,          // SCIP pointer
    &cons,         // save in cons
    "consname",    // name
    nvar,          // number of variables
    vars,          // array of variables
    vals,          // array of values
    2.0,           // left hand side
    2.0,           // right hand side (equation)
    TRUE,          // initial?
    FALSE,         // separate?
    TRUE,          // enforce?
    TRUE,          // check?
    TRUE,          // propagate?
    FALSE,         // local?
    FALSE,         // modifable?
    FALSE,         // dynamic?
    FALSE,         // removable?
    FALSE          // stick at node?
  ));
SCIP_CALL( SCIPaddCons(scip, cons) );      // add constraint
SCIP_CALL( SCIPreleaseCons(scip, &cons) ); // free cons. space
```

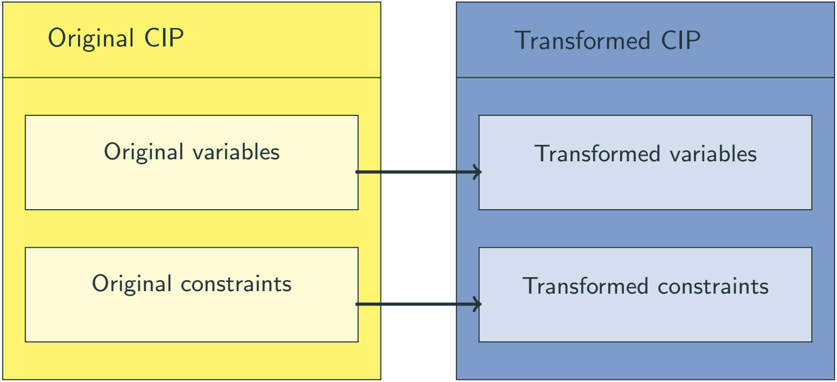
MIPs are specified using linear constraints only (may be "upgraded").

Transformation



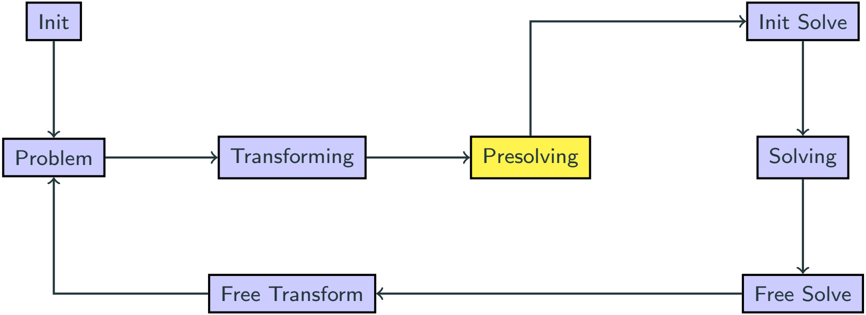
- Creates a working copy of the original problem.

Original and Transformed Problem

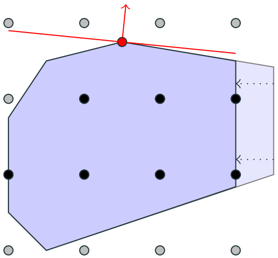


- data is copied into separate memory area
- presolving and solving operate on transformed problem
- original data can only be modified in problem modification stage

Presolving


Init
Problem
Transforming
Presolving
Init Solve
Solving
Free Solve
Free Transform

Presolving



Task

- reduce size of model by removing irrelevant information
- strengthen LP relaxation by exploiting integrality information
- make the LP relaxation numerically more stable
- extract useful information

Primal Reductions:
- based on feasibility reasoning
- no feasible solution is cut off

Dual Reductions:
- consider objective function
- at least one optimal solution remains

Presolving Tips and Parameters

Use `display presolvers` to list all presolvers of SCIP.

Disable Presolving
Disable all presolving for a model

```
set presolving emphasis off
```

Deactivate single techniques

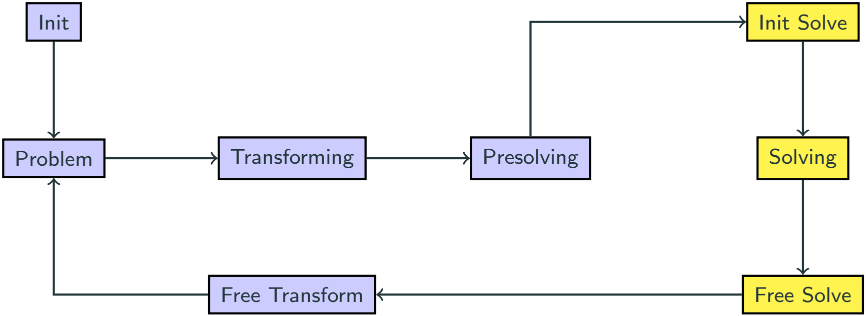
```
set presolving tworowbnd maxrounds 0
set propagating probing maxprerounds 0
set constraints components advanced maxprerounds 0
```

Aggressive Presolving

```
set presolving emphasis aggressive
```

General Rule of Thumb
Only deactivate single presolving techniques if you encounter performance problems.

Solving


Init
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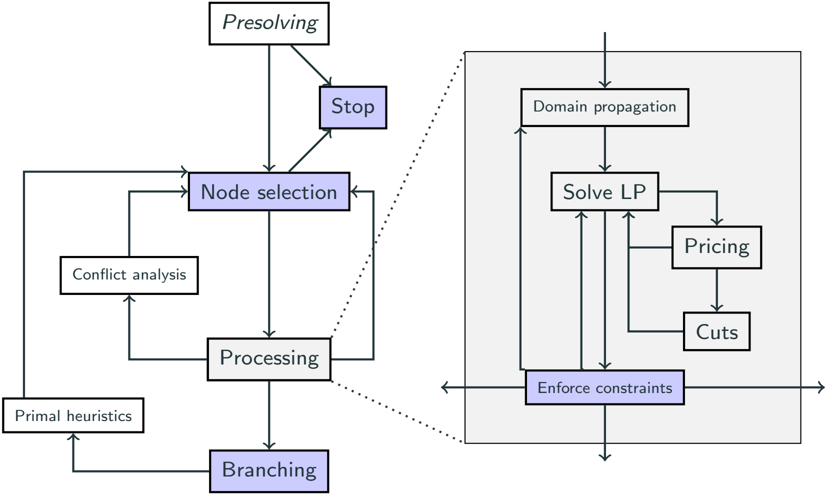
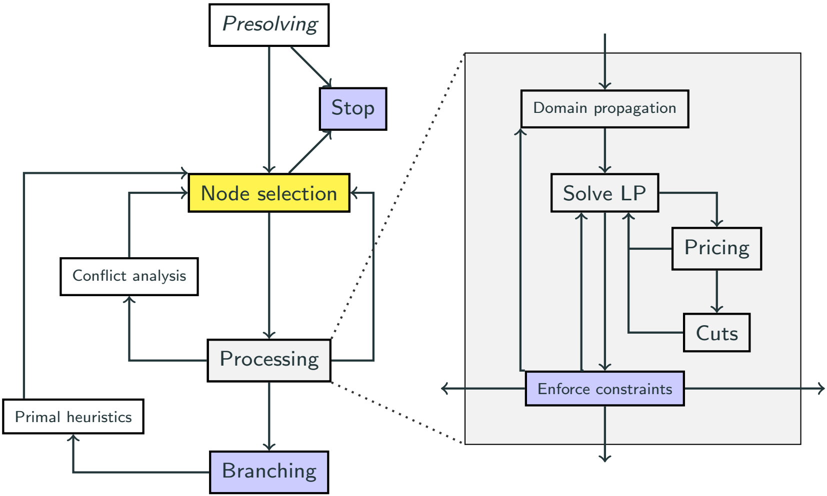
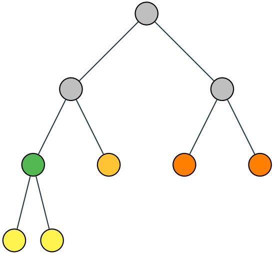
Flow Chart SCIP



Flow Chart SCIP





Techniques

- basic rules
  - depth first search (DFS)
    $\rightarrow$ early feasible solutions
  - best bound search (BBS)
    $\rightarrow$ improve dual bound
  - best estimate search (BES)
    $\rightarrow$ improve primal bound

- combinations
  - BBS or BES with plunging
  - hybrid BES/BBS
  - interleaved BES/BBS

Task

- improve primal bound
- keep comp. effort small
- improve global dual bound

Node Selection Tips and Parameters

Available Node Selectors

```
display nodeselectors

node selector std priority memsave prio  description
------------- ------------ ------------  -----------
estimate            200000          100  best estimate search
bfs                 100000            0  best first search
...
dfs                      0       100000  depth first search
```

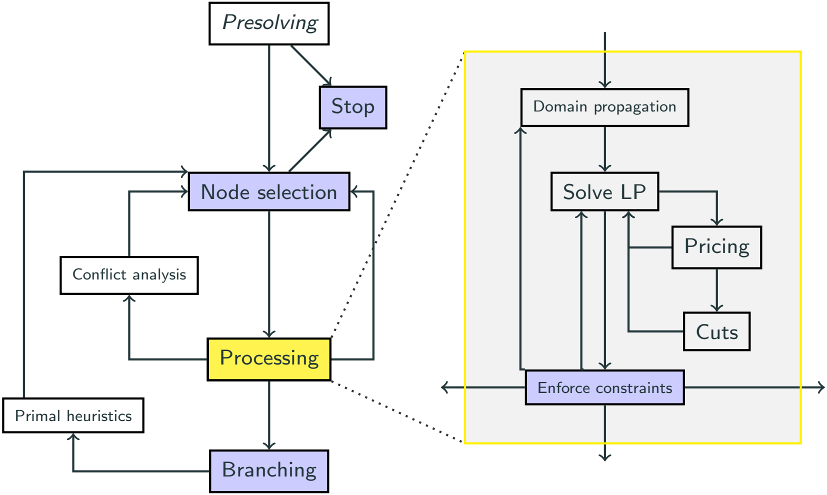
Switching Node Selectors

Only the node selector with highest standard priority is active. Use

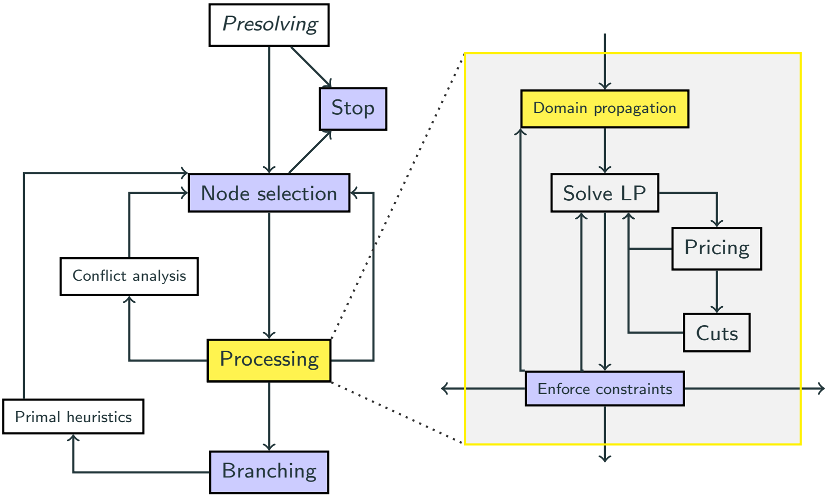
```
set nodeselection dfs stdpriority 1000000
```

to activate depth first search also in non-memsave mode.

Flow Chart SCIP



Flow Chart SCIP



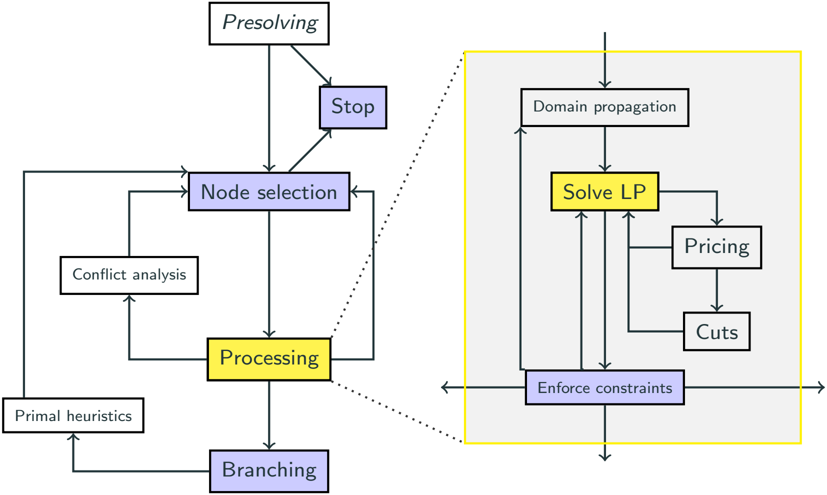
Domain Propagation

Task

- simplify model locally
- improve local dual bound
- detect infeasibility

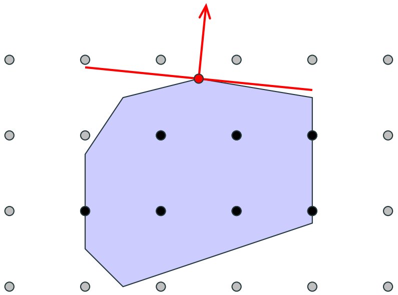
Techniques

- constraint specific
  - each cons handler may provide a propagation routine
  - reduced presolving (usually)
- dual propagation
  - root reduced cost strengthening
  - objective function
- special structures
  - variable bounds



Presolving
Stop
Node selection
Conflict analysis
Processing
Primal heuristics
Branching
Domain propagation
Solve LP
Pricing
Cuts
Enforce constraints

LP Solving



- LP solver is a black box
- interface to different LP solvers: SoPlex, CPLEX, XPress, Gurobi, CLP, ...
- primal/dual simplex
- barrier with/without crossover

- feasibility double-checked by SCIP
- condition number check
- resolution by changing parameters: scaling, tolerances, solving from scratch, other simplex

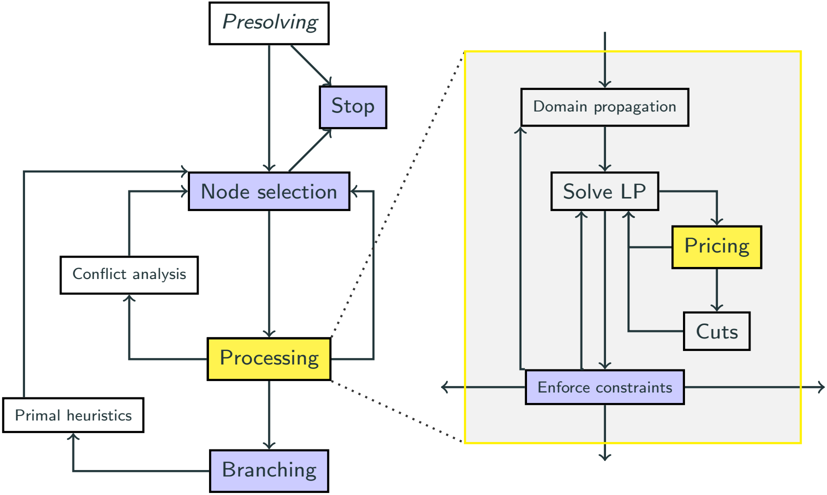
LP Solving Tips and Parameters

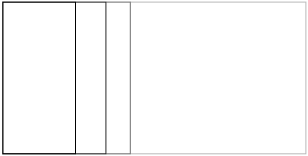
Most Important LP Parameters

- `lp/initalgorithm`, `lp/resolvealgorithm`
  - Primal/Dual Simplex Algorithm
  - Barrier w and w/o crossover
- `lp/pricing`
  - normally LP solver specific default
  - Devex
  - Steepest edge
  - Quick start steepest edge
- `lp/threads`

Slow LP performance is a blocker for the solving process and can sometimes be manually tuned significantly.

Flow Chart SCIP





Branch-and-Price

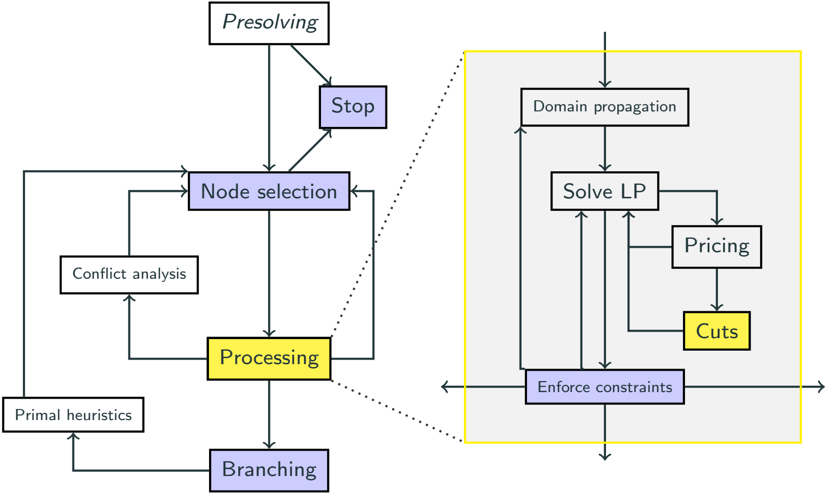
- huge number of variables
- start with subset
- add others, when needed

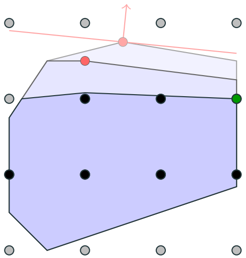
Pricing

- find variable with negative reduced costs
- or prove that there exists none
- typically problem specific

- dynamic aging of variables
- problem variable pricer to add them again
- early branching possible
- lazy variable bounds

Flow Chart SCIP





Task

- strengthen relaxation
- add valid constraints
- generate on demand

Techniques

- general cuts
  - complemented MIR cuts
  - Gomory mixed integer cuts
  - strong Chvátal-Gomory cuts
  - implied bound cuts
  - reduced cost strengthening
- problem specific cuts
  - 0-1 knapsack problem
  - stable set problem
  - 0-1 single node flow problem

Feasible region: ($b \in \mathbb{Z}_+$, $a_j \in \mathbb{Z}_+ \quad \forall\, j \in N$)

$$X^{BK} := \{\ x \in \{0,1\}^n \ :\ \sum_{j \in N} a_j x_j \leq b\ \}$$

Minimal Cover: $C \subseteq N$

- $\sum_{j \in C} \quad a_j > b$
- $\sum_{j \in C \setminus \{i\}} a_j \leq b \quad \forall\, i \in C$

Minimal Cover Inequality

$$\sum_{j \in C} x_j \leq |C| - 1$$

$5x_1 + 6x_2 + 2x_3 + 2x_4 \leq 8$

Minimal cover:
$C = \{2, 3, 4\}$

Minimal cover inequality:
$x_2 + x_3 + x_4 \leq 2$

Separation Tips and Parameters

Disable/Speed up/Emphasize All Separation

```
set separating emphasis off/fast/aggressive
```

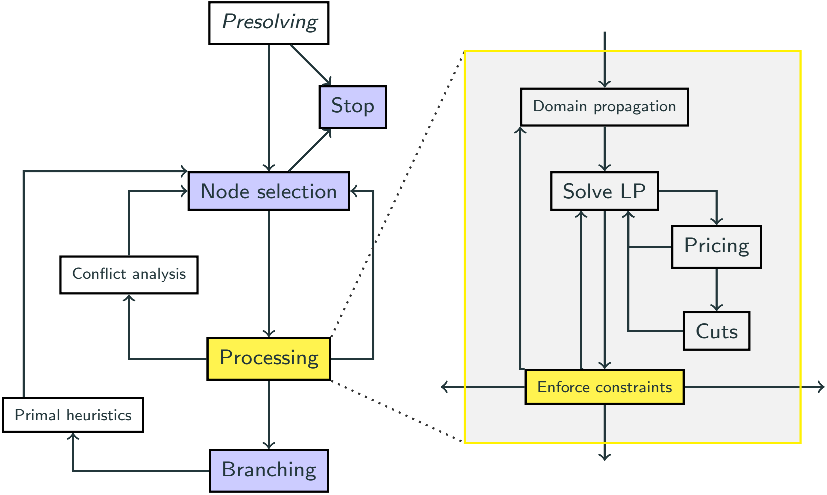
Disable Single Separation Techniques

```
set separating clique freq -1
set constraints cardinality sepafreq -1
```

Some Important Parameters

- `separating/maxcuts`, `separating/maxcutsroot`
- `separating/maxrounds`, `separating/maxroundsroot`
- `separating/maxstallrounds`, `separating/maxstallroundsroot`

Flow Chart SCIP



Constraint Enforcement

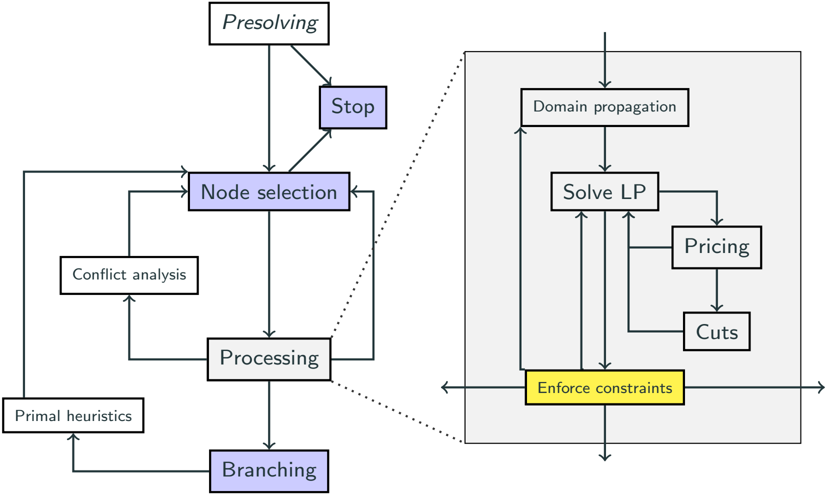
LP solution may violate a constraint not contained in the relaxation.

Enforcing is necessary for a correct implementation!

Constraint handler resolves the infeasibility by ...

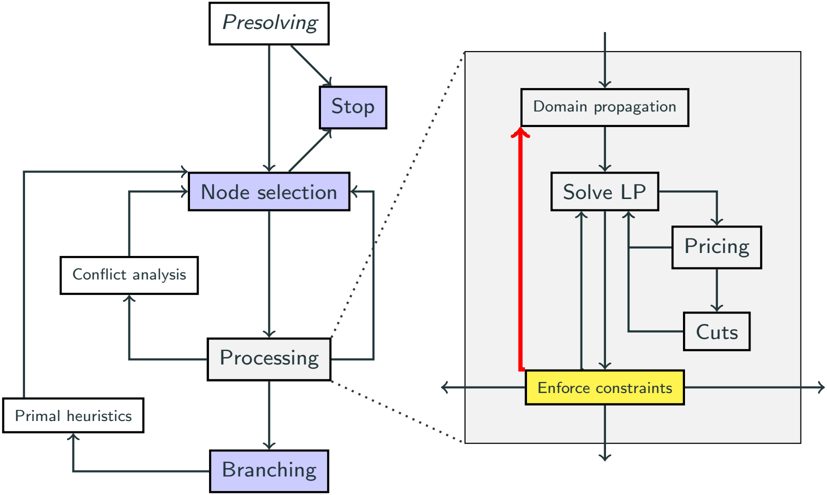
- Reducing a variable's domain,
- Separating a cutting plane (may use integrality),
- Adding a (local) constraint,
- Creating a branching,
- Concluding that the subproblem is infeasible and can be cut off, or
- Just saying "solution infeasible".

Constraint Enforcement



- Reduced domain
- Added constraint
- Added cut
- Branched
- Cutoff
- Infeasible
- Feasible

Constraint Enforcement



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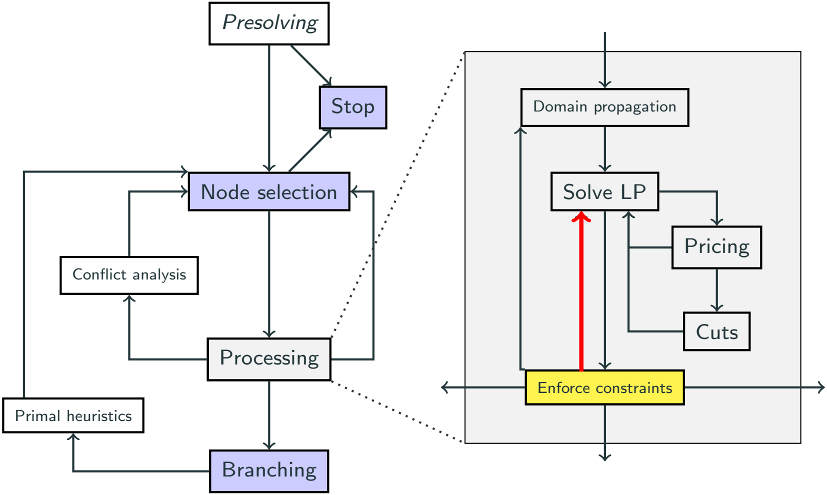

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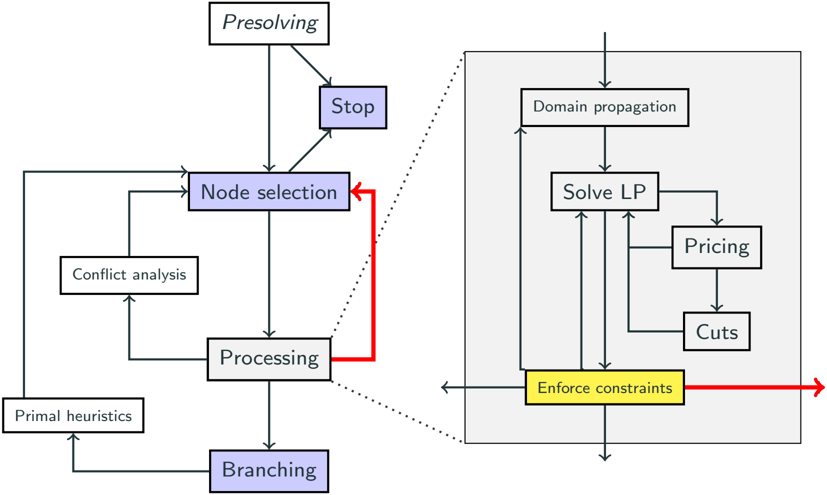

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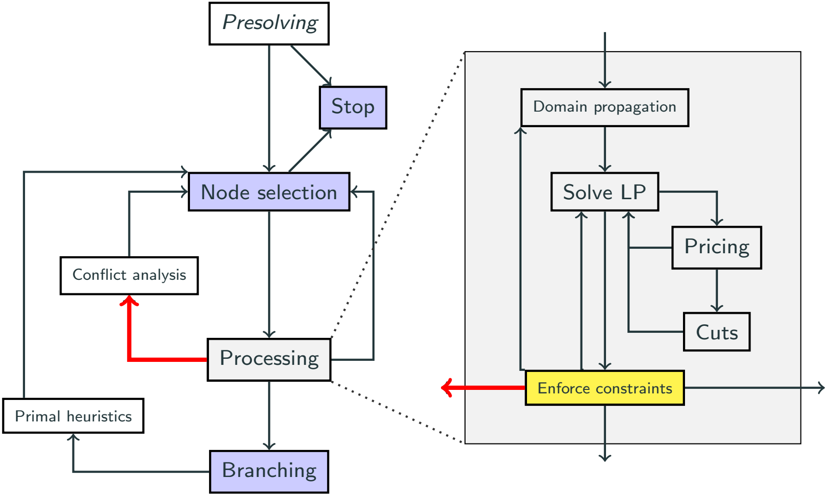

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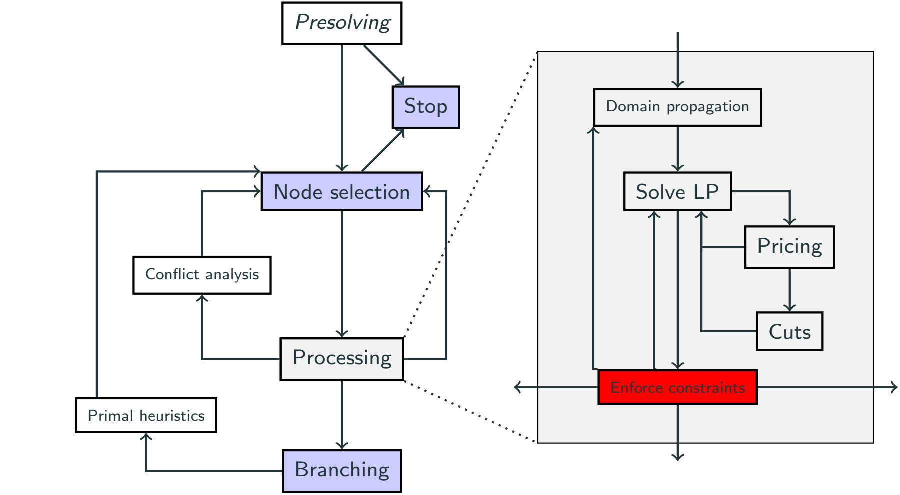

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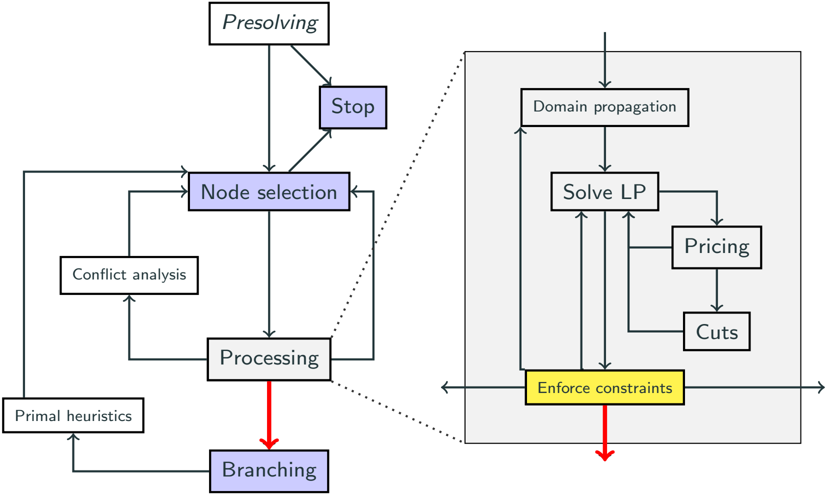

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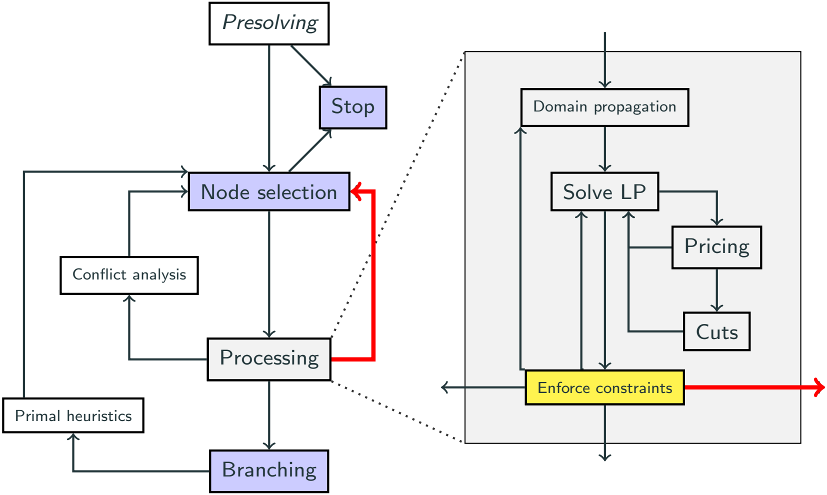

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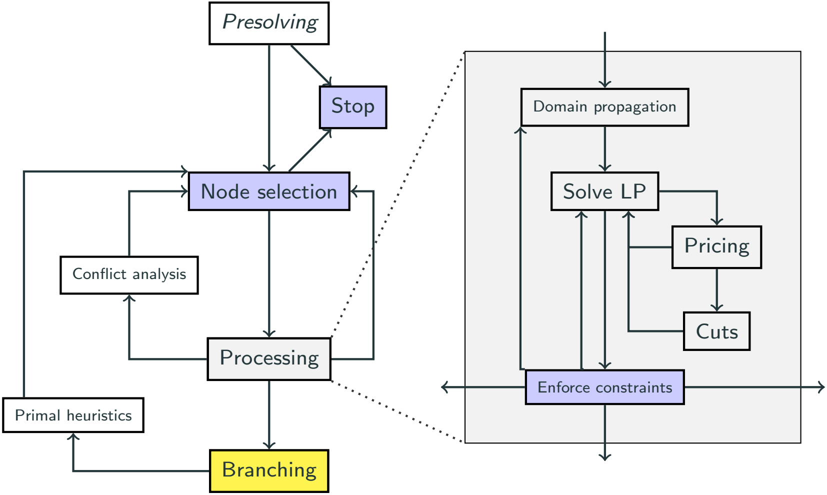
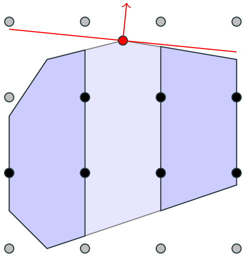
Flow Chart SCIP



Branching Rules



Task

- divide into (disjoint) subproblems
- improve local bounds

Techniques

- branching on variables
  - most infeasible
  - least infeasible
  - random branching
  - strong branching
  - pseudocost
  - reliability
  - VSIDS
  - hybrid reliability/inference
- branching on constraints
  - SOS1
  - SOS2

Branching Rule Tips and Parameters

Branching Rule Selection
Branching rules are applied in decreasing order of priority.

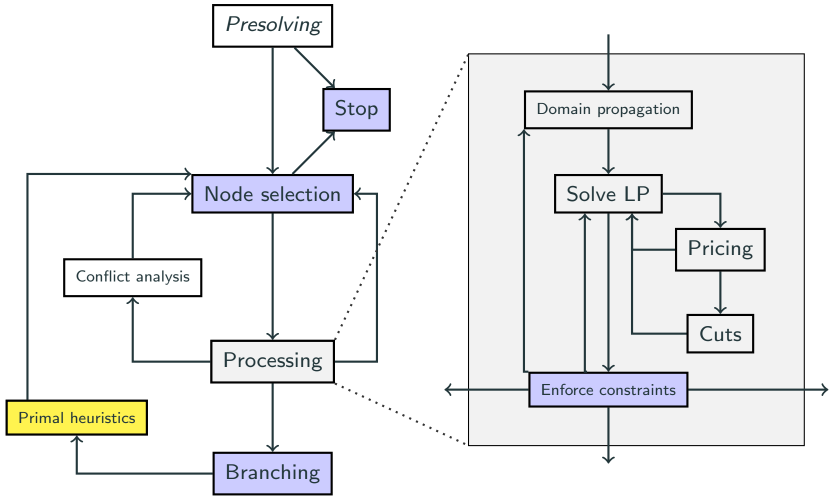
```
SCIP> display branching

 branching rule         priority  maxdepth  maxbddist
 ---------------        --------  --------  ---------
 relpscost                 10000        -1     100.0%
 pscost                     2000        -1     100.0%
 inference                  1000        -1     100.0%
 mostinf                     100        -1     100.0%
```

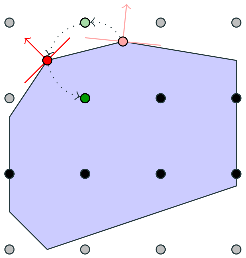
Reliability Branching Parameters
All parameters prefixed with `branching/relpscost/`

- `sbiterquot`, `sbiterofs` to increase the budget for strong branching
- `minreliable` (= 1), `maxreliable` (= 5) to increase threshold to consider pseudo costs as reliable

Flow Chart SCIP



Primal Heuristics



Task

- improve primal bound
- effective on average
- guide remaining search

Techniques

- structure-based
  - clique
  - variable bounds
- rounding
  - possibly solve final LP
- diving
  - least infeasible
  - guided
- objective diving
  - objective feasibility pump
- Large Neighborhood Search
  - RINS, local branching
  - RENS
  - Adaptive LNS
  - Completion of partial solutions

Primal Heuristics Tips and Parameters

Disable/Speed Up/Emphasize Heuristics

```
set heuristics emphasis off/fast/aggressive
```

Disable an individual heuristic via

```
set heuristics feaspump freq -1
```

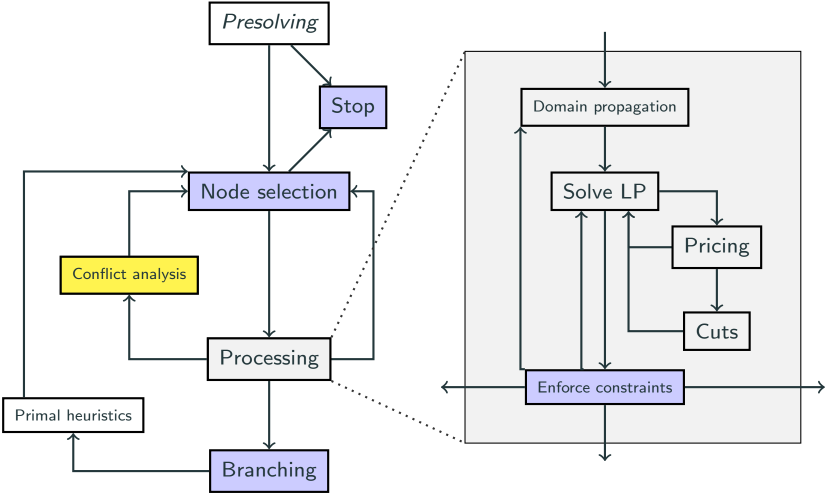
Important Parameters

- `heuristics/alns/nodesofs`, `heuristics/alns/nodesquot` to increase the computational budget of this LNS technique
- `heuristics/guideddiving/... lpsolvefreq`, `maxlpiterofs` `maxlpiterquot` to control the LP solving during this diving technique

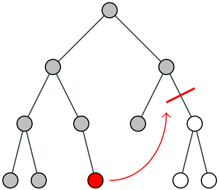
Advice

Use emphasis settings. Do not attempt to individually tune heuristics by hand.

Flow Chart SCIP



Conflict Analysis



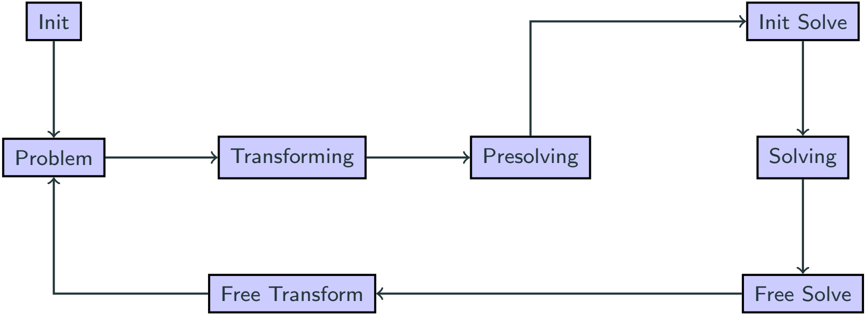
Task

- Analyze infeasibility
- Derive valid constraints
- Help to prune other nodes

Techniques

- Analyze:
  - Propagation conflicts
  - Infeasible LPs
  - Bound-exceeding LPs
  - Strong branching conflicts
- Detection:
  - Cut in conflict graph
  - LP: Dual ray heuristic
- Use conflicts:
  - Only for propagation
  - As cutting planes

Operational Stages



SCIP – Solving Constraint Integer Programs

http://scip.zib.de

The SCIP C API

- C code and documentation
  - more than 800 000 lines of C code, 20% documentation
  - over 50 000 assertions and 5 000 debug messages
  - HowTos: plugins types, debugging, automatic testing
  - 10 examples illustrating the use of SCIP
  - 5 problem specific SCIP applications to solve Coloring, Steiner Tree, or Multiobjective problems.
- Interface and usability
  - Cross-platform availability due to CMake
  - user-friendly interactive shell
  - C++ wrapper classes
  - LP solvers: SoPlex, CPLEX, Gurobi, Xpress, CLP, MOSEK, QSopt
  - NLP solvers: IPOPT, FilterSQP, WORHP
  - over 2 300 parameters and 15 emphasis settings

Interfaces to SCIP

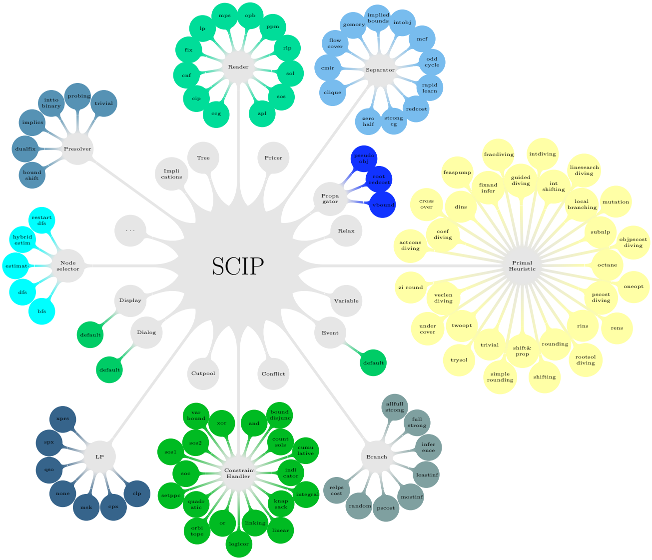
- interactive shell supports 10 different input formats
  → cip, cnf, flatzinc, rlp, lp, mps, opb, pip, wbo, zimpl
- C API/callable library
- C++ wrapper classes
- Python interface
- Java JNI interface
- AMPL
- GAMS
- Matlab (see also OPTI toolbox, `http://www.i2c2.aut.ac.nz/Wiki/OPTI/`)

Getting help

If you should ever get stuck, you can ...

1. type `help` in the interactive shell
2. read the documentation `http://scip.zib.de/doc/html`
   → FAQ, HowTos for each plugin type, debugging, automatic testing, ...
3. active mailing list scip@zib.de (350+ members)
   - search the mailing list archive (append site:listserv/pipermail/scip)
   - register `http://listserv.zib.de/mailman/listinfo/scip/` and post
4. search or post on Stack Overflow using the tag `scip` (more than 100 questions already answered)

Structure of SCIP



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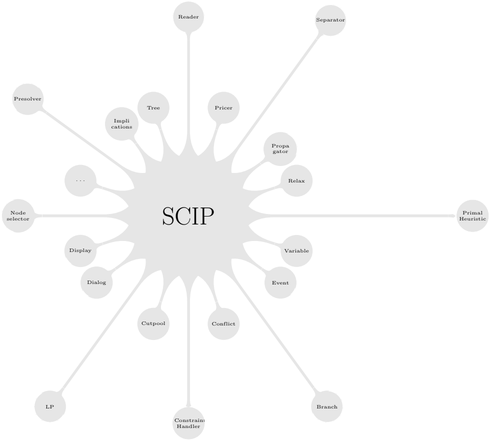

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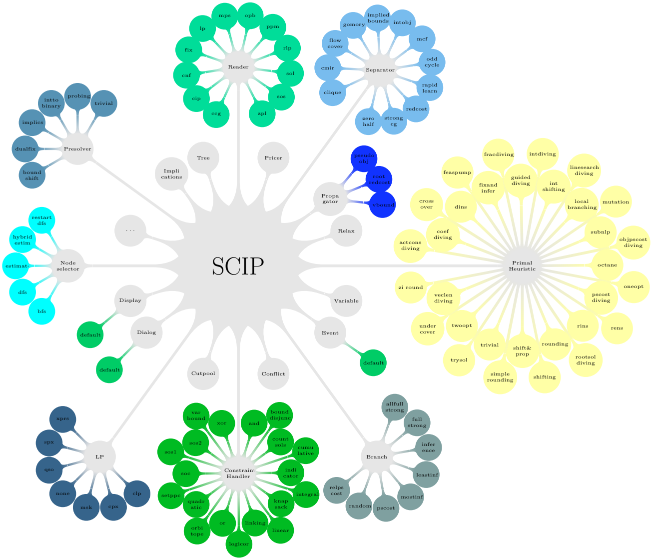

Plugin based design

SCIP core

- branching tree
- variables
- conflict analysis
- solution pool
- cut pool
- statistics
- clique table
- implication graph
- ...

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Plugins

- external callback objects
- interact with the framework through a very detailed interface

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Plugins

- external callback objects
- interact with the framework through a very detailed interface
- SCIP knows for each plugin type:
  - the number of available plugins
  - priority defining the calling order (usually)
- SCIP does not know any structure behind a plugin

$\Rightarrow$ plugins are black boxes for the SCIP core

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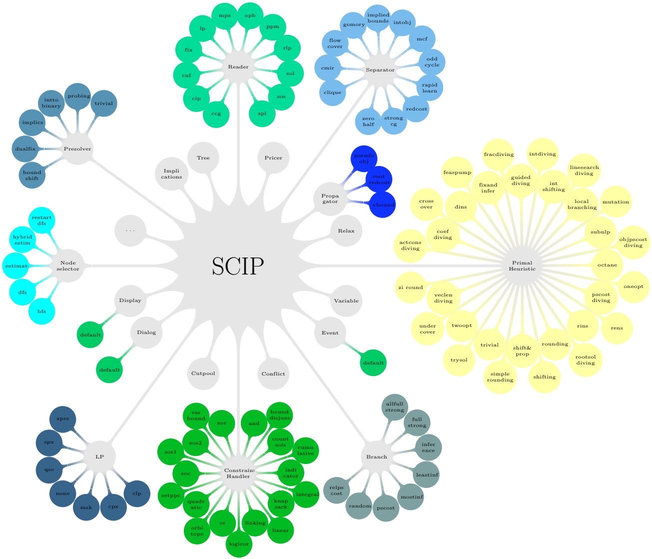
$\Rightarrow$ plugins are black boxes for the SCIP core

$\Rightarrow$ Very flexible branch-and-bound based search algorithm

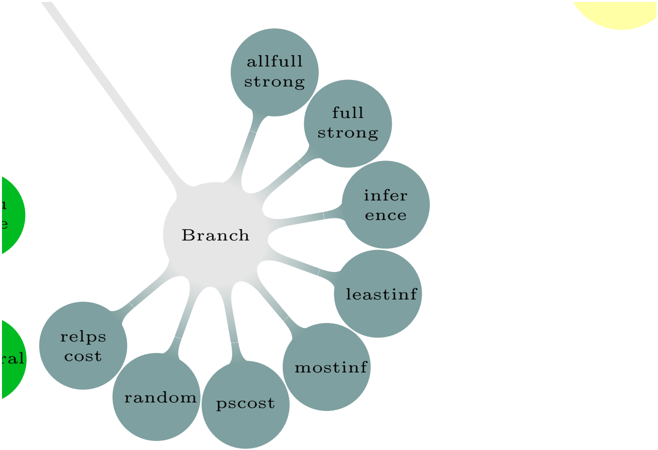
Types of Plugins

- Constraint handler: assures feasibility, strengthens formulation
- Separator: adds cuts, improves dual bound
- Pricer: allows dynamic generation of variables
- Heuristic: searches solutions, improves primal bound
- Branching rule: how to divide the problem?
- Node selection: which subproblem should be regarded next?
- Presolver: simplifies the problem in advance, strengthens structure
- Propagator: simplifies problem, improves dual bound locally
- Reader: reads problems from different formats
- Event handler: catches events (e.g., bound changes, new solutions)
- Display: allows modification of output
- ...

A closer look: branching rules



A closer look: branching rules



What does SCIP know about branching rules?

- SCIP knows the number of available branching rules
- each branching rule has a priority
- SCIP calls the branching rule in decreasing order of priority
- the interface defines the possible results of a call:
  - branched
  - reduced domains
  - added constraints
  - detected cutoff
  - did not run

How does SCIP call a branching rule?

```
/* start timing */
SCIPclockStart(branchrule->branchclock, set);

/* call external method */
SCIP_CALL( branchrule->branchexeclp(set->scip, branchrule,
   allowaddcons, result) );

/* stop timing */
SCIPclockStop(branchrule->branchclock, set);

/* evaluate result */
if( *result != SCIP_CUTOFF
   && *result != SCIP_CONSADDED
   && *result != SCIP_REDUCEDDOM
   && *result != SCIP_SEPARATED
   && *result != SCIP_BRANCHED
   && *result != SCIP_DIDNOTRUN )
{
   SCIPerrorMessage(
      "branching␣rule␣<%s>␣returned␣invalid␣result␣code␣<%d>␣from␣LP␣\
␣␣␣␣␣␣␣solution␣branching\n",
      branchrule->name, *result);
   return SCIP_INVALIDRESULT;
}
```

What can a plugin access?

Plugins are allowed to access all global (core) information

- branching tree
- variables
- conflict analysis
- solution pool
- cut pool
- statistics
- clique table
- implication graph
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Branching Rules

- LP solution
- variables
- statistics

Constraint Handlers

Constraint handlers

- most powerful plugins in SCIP
- define the feasible region
- a single constraint may represent a whole set of inequalities

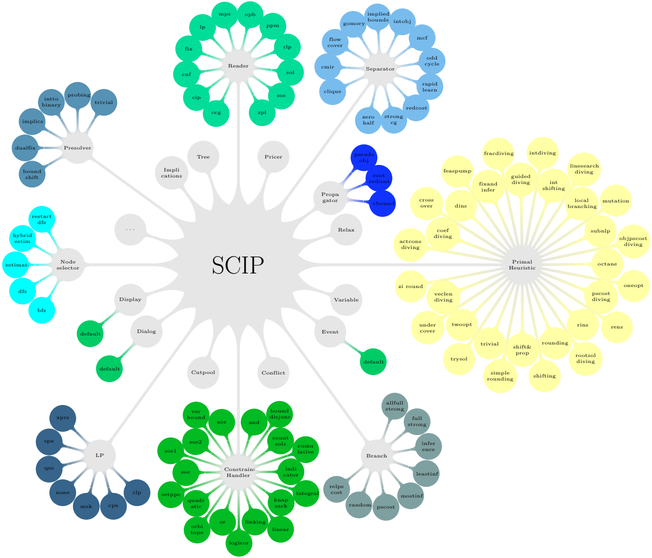
Functions

- check and enforce feasibility of solutions
- can add linear representation to LP relaxation
- constraint-specific presolving, domain propagation, separation

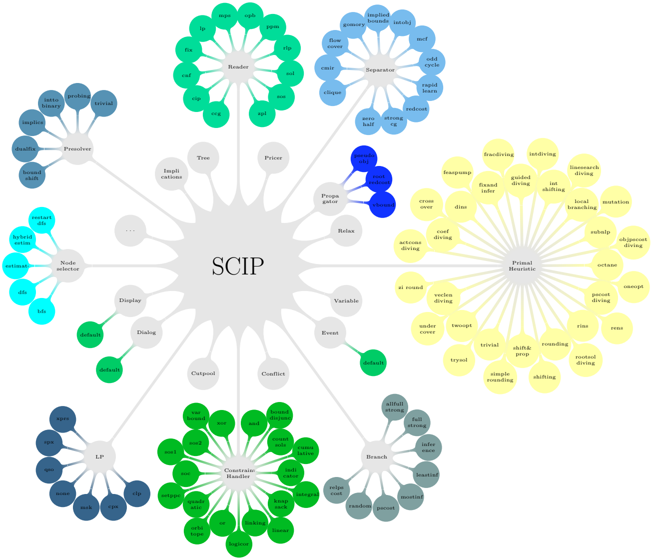
Result

- SCIP is constraint based
    - Advantage: flexibility
    - Disadvantage: limited global view

Default Plugins



Extending SCIP



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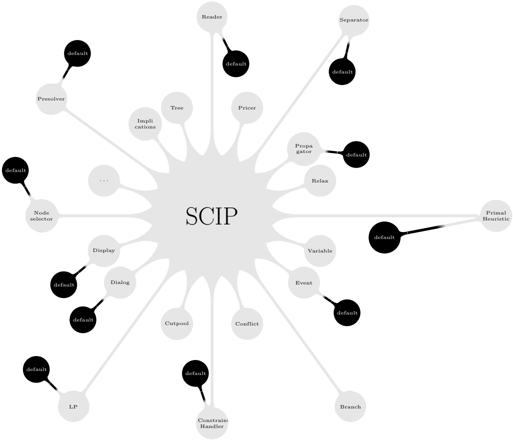
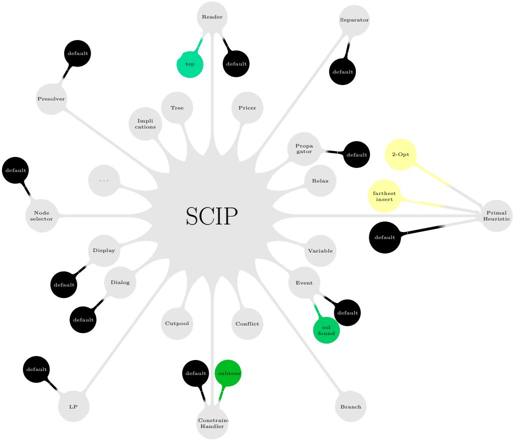
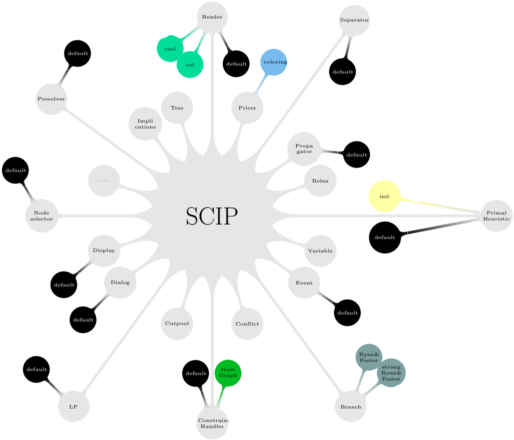


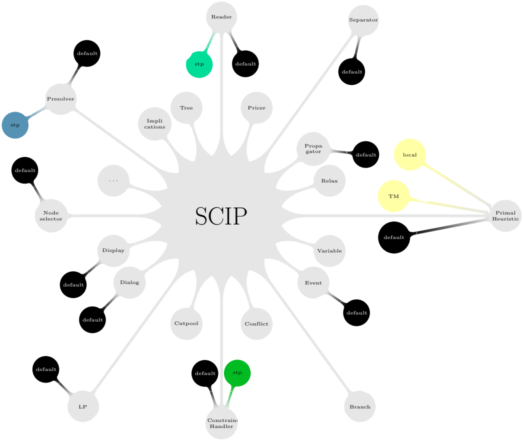
Extending SCIP: TSP



Extending SCIP: Coloring



Extending SCIP: STP



SCIP – Solving Constraint Integer Programs

http://scip.zib.de

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

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

Wrap-up

How to solve your MINLP optimization problem:

- write down the mathematical description
- modeling language, e.g., ZIMPL, generates input for MINLP solver
- SCIP can even read ZIMPL files directly

MIP and MINLP solving

- ... is a bag of tricks
- new tricks are introduced almost every day
- advantages of SCIP
  - open source, you can see everything that happens
  - hundreds of parameters to play with
  - broad scope
  - easily extendable