Who Said we Need to Relax All Variables?

Michael Katz, et al. 2013

Red-Black Planning

- Only relax some variables (colored red)
  - Accumulate values monotonically (delete-relaxed)
- Keep other variables unrelaxed (colored black)
  - Their values change back and forth
- Balancing computational complexity and heuristic accuracy

Achieving computational efficiency

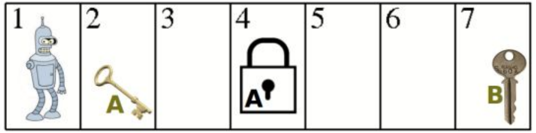
- Number of black variables
  - Limit the number of black variables to a fixed number
- Domain size of black variables
  - Limit the size of the domain for each black variable
- Fewer realistic constraints that must be maintained explicitly

Polynomial-Time Result

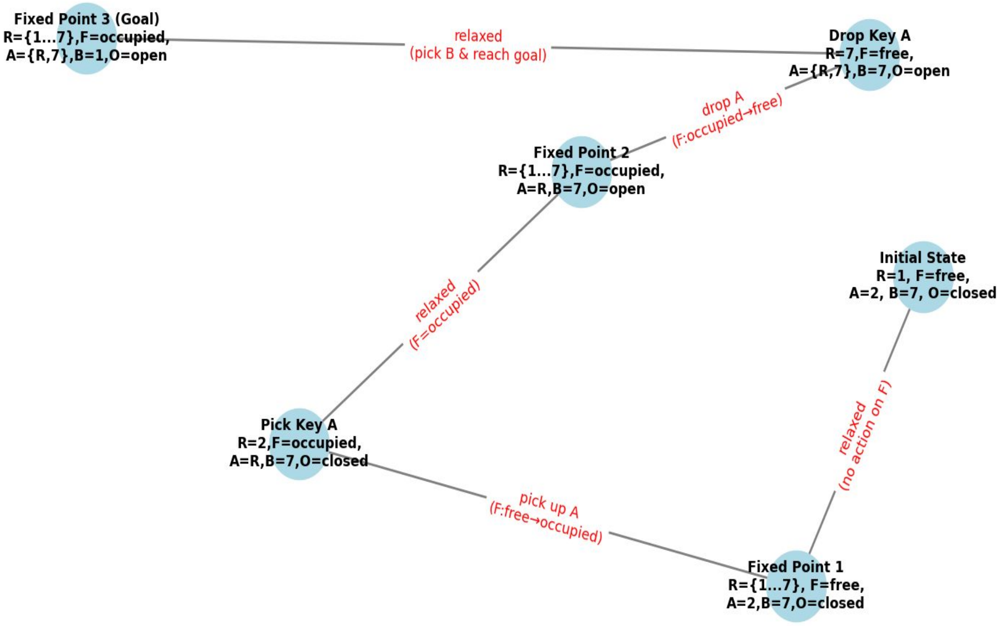
Theorem 1:

Planning for RB tasks with a fixed number of black variables, each having a fixed-size domain, is solvable in polynomial time.

Single Black Variable Case



Hand status F is the only black variable



Algorithm : RB2-PLANGEN(Π)

main

$/\!/\ \Pi = \langle \{v_0\}, V^{\mathsf{R}}, A, I, G \rangle$

$R \leftarrow I$

$R \leftarrow R \cup \text{RelaxedFixedPoint}(A_\emptyset \cup A_{I[v_0]})$

if $G \subseteq R$

  then return "*solvable*"

for $I[v_0] \neq d \in \mathcal{D}(v_0), a_1 \in A_{I[v_0] \to d}$ s.t. $\mathsf{pre}(a_1) \subseteq R$

do
- $R \leftarrow R[\![a_1]\!]$
- $R \leftarrow R \cup \text{RelaxedFixedPoint}(A_\emptyset \cup A_d)$
- **if** $G \subseteq R$
  - **then return** "*solvable*"
- **for** $a_2 \in A_{d \to I[v_0]}$ s.t. $\mathsf{pre}(a_2) \subseteq R$
- **do**
  - everywhere in Π and R,
    replace $I[v_0]$ and d with a new value $d_{\{I[v_0],d\}}$
  - $R \leftarrow R \cup \text{RelaxedFixedPoint}(A)$
  - **if** $G \subseteq R$
    - **then return** "*solvable*"

return "*unsolvable*"

Limitations of Polynomial-Time Result

- **Theorem 2**: Plan existence for RB tasks with a fixed number of black variables is NP-complete
  - Fixed number of black variables, unbounded domains -> NP-complete

- **Theorem 3**: Plan existence for RB tasks where all black variables have fixed-size domains is PSPACE-complete
  - Unbounded number of black variables, fixed-size domains -> PSPACE-complete

Practical Heuristic Computation

- Full delete-relaxation heuristics **underestimate** true planning costs
- Red-Black heuristics substantially improve heuristic accuracy
  - Directly computing the optimal RB heuristic is NP-hard
  - Focus only on tractable fragments

Perfect Red-Black Heuristics

- **Identifying useful, tractable fragments**
  - **rSCC** (Reversible Strongly Connected Components)
    - Solvable in polynomial-time
- A Simple Condition for Perfect Red-Black Heuristics
  - **Lemma 4**: If the chosen red variables have no influence on other variables, the RB heuristic will produce perfect estimates.

How the perfect heuristic condition applies to IPC Benchmarks

- LOGISTICS, MICONIC: Relaxing variables representing object/passenger locations
- SATELLITE: Relaxing variables for capturing image-taking tasks, while leaving satellite status variables black
- VISIT-ALL: Choose visited variables to be red

Conclusion

- Benefit of Red-Black heuristics
- Identifying which variables to relax - Lemma 4
- Exploiting selective relaxations is a promising direction