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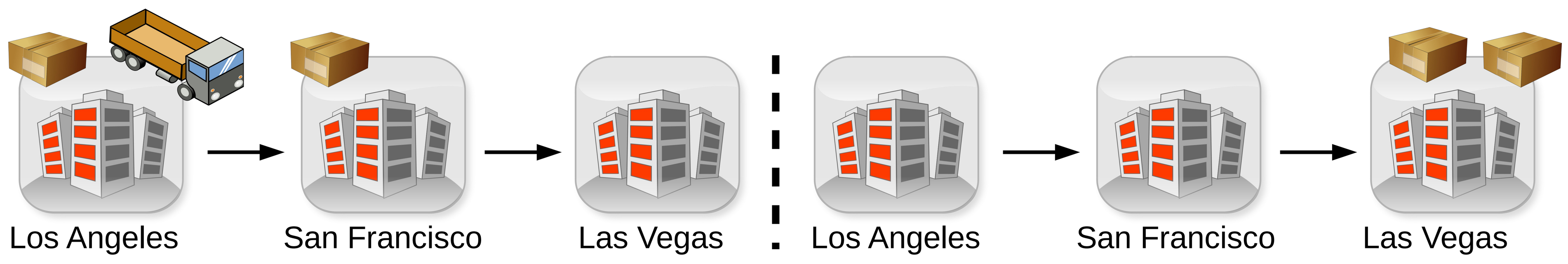
No One SATPlan Encoding To Rule Them All

1. What is Planning?

- World state: instantiation of multivalued state variables
- Actions:
  - require certain values of state variables to be used
  - change values of state variables by their effects
- Objective:
  - Given a set of actions
  - Given an initial state (start) and goal conditions
  - Find a plan (sequence of actions to get from start to goal)

2. Example: delivering 2 packages to Las Vegas



State Variables and their domains:
- Truck location T, dom(T) = {LA, SF, LV}
- Package locations P and Q
  dom(P) = dom(Q) = {LA, SF, LV, Tr}

Initial State: T=LA, P=LA, Q=SF
Goal Conditions: P=LV, Q=LV

Actions:
- move(x,y)=[prec: {T=x}, eff: {T=y}]
- loadP(x)=[prec: {T=x, P=x}, eff: {P=Tr}]
- loadQ(x)=[prec: {T=x, Q=x}, eff: {Q=Tr}]
- dropP(x)=[prec: {T=x, P=Tr}, eff: {P=x}]
- dropQ(x)=[prec: {T=x, Q=Tr}, eff: {Q=x}]

Where x,y are LA, SF, and LV

Plan: loadP(LA), move(LA,SF), loadQ(SF), move(SF,LV), dropP(LV), dropQ(LV)

3. Finding Plans with Satisfiability Solvers

- If the formula F_k is satisfiable then a plan of size k exists
- Solve F_1, F_2, ... until a satisfiable formula F_n is reached
- Use the solution of F_n to construct a plan

BUT HOW?
… should F_k be defined?

4. Enconding Planning as SAT

- The key aspect for the performance
- Many encoding schemes in the last decades
  - Various encodings work well for different problem kinds
  - The aim is to be the best for all

Traditional Approach

BUT is this the best approach?
- We assemble a set of encodings
- Then select the best encoding for a given problem
  - Inspired by sequential portfolios
  - The set of encodings should be diverse
  - The selecting algorithm should be fast and smart (choose well)

NEW!

5. Four Kinds of SATPlan Encodings

- Based on restrictions on actions in a single step:
  - Forall-Step – most strict
  - Exists-Step
  - Relaxed Exists-Step
  - Relaxed Relaxed Exists-Step (R^2 Exists-Step) – least strict

	$\forall$	$\exists$	$R\exists$	$R^2\exists$
All possible orderings $\trianglelefteq$ of the sets A_j make valid plans	√			
Each action $a \in A_j$ is applicable in the state s_j	√	√		
The effects of all actions $a \in A_j$ are applied in s_{j+1}	√	√	√	
There exists an ordering $\trianglelefteq$ of the sets A_j to make a valid plan	√	√	√	√

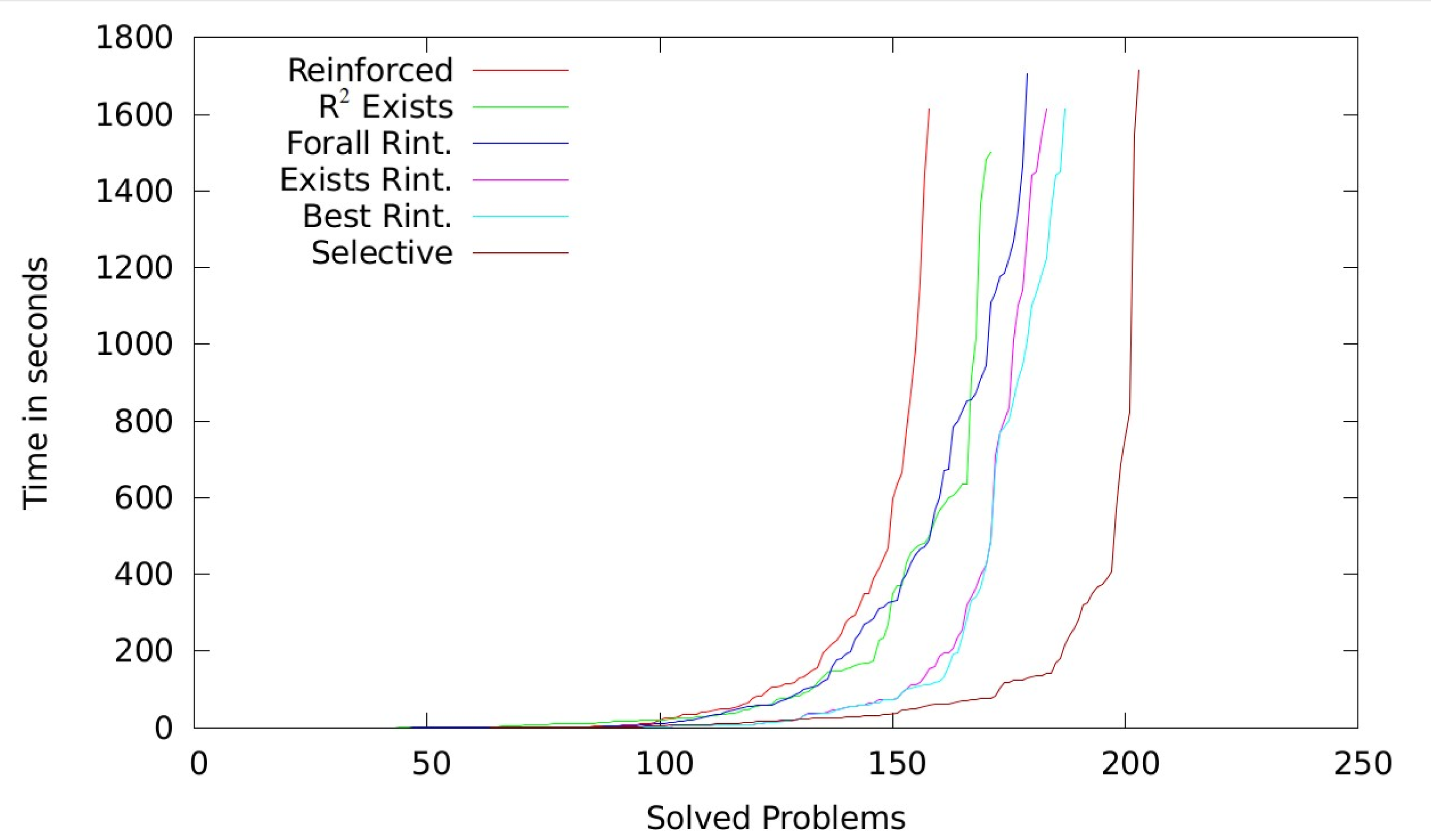
- To be diverse we choose a Forall-Step encoding (**Reinforced**) and the **R^2 Exists-Step** encoding

6. Guessing action ordering for R^2 Exists-Step

- We need to guess the order of actions in a resulting plan.
- We compared a few heuristics, the best are
  - TSort – topological sorting of action interactions
  - Input – the order of actions in the problem definition

Domain	TSort #P/Mks	$TSort^{-1}$ #P/Mks	Input #P/Mks	$Input^{-1}$ #P/Mks	Random #P/Mks
barman	**4**/36	2/29	**4**/60	2/28	1/11
elevators	**20**/85	**20**/99	**20**/106	**20**/79	**20**/75
floortile	17/158	**18**/185	16/149	**18**/178	**18**/167
nomystery	3/14	4/20	3/13	**6**/33	3/14
openstacks	12/75	13/66	**20**/59	5/43	10/57
parcprinter	**20**/30	**20**/249	**20**/88	**20**/186	**20**/140
parking	0/0	0/0	0/0	0/0	0/0
pegsol	**19**/158	18/155	12/147	16/142	18/152
scanalyzer	6/11	**9**/16	7/12	6/13	6/12
sokoban	**1**/17	**1**/19	**1**/18	**1**/17	**1**/19
tidybot	**1**/1	**1**/1	**1**/1	**1**/1	**1**/1
transport	5/20	6/40	8/44	**9**/57	4/19
visitall	**20**/34	12/113	9/55	9/49	12/80
woodwork	**20**/33	**20**/57	**20**/58	**20**/30	**20**/40
Total	**148**	144	141	133	134

Domain	Reinf	$R^2\exists$	Sel	R∀	R∃	R*
barman	4	8	**9**	8	4	8
elevators	**20**	**20**	**20**	**20**	**20**	**20**
floortile	18	18	18	16	**20**	**20**
nomystery	**20**	6	**20**	**20**	**20**	**20**
openstacks	0	15	**20**	0	0	0
parcprinter	**20**	**20**	**20**	**20**	**20**	**20**
parking	0	0	0	0	0	0
pegsol	10	**19**	**19**	11	12	12
scanalyzer	15	9	15	17	**18**	**18**
sokoban	2	2	2	**6**	**6**	**6**
tidybot	2	2	2	13	**15**	**15**
transport	18	13	**19**	18	18	18
visitall	10	**20**	**20**	11	11	11
woodworking	**20**	**20**	**20**	**20**	**20**	**20**
Total	159	172	**204**	180	184	188



7. Encoding Selection Rule

- A transition = change of a state variable
- The set of transitions is defined by the actions
- The selection heuristic is based on
  - The number of transitions (per variable)
  - The number of parallel steps in the plan (makespan)
- The heuristic rule used in our (**Selective**) encoding:

```
T = #transitions / #stateVariables
IF T > 10 THEN
 use the Reinforced encoding
ELSE IF makespan is even THEN
 use R²Exists-Step with TSort ordering
ELSE
use R²Exists-Step with Input ordering
```

8. Experiments

- Compared:
  - Selective encoding and its components (Reinforced and R^2 Exists)
  - State-of-the-art encodings of Rintanen and their optimal combination (R*)
- Benchmark problems: IPC 2011, each domain contains 20 problems
- Sat Solver: Lingeling (version ats)
- PC: Intel i7 920 cpu @2.67 Ghz and 6 GB of memory

9. Conclusion

- Combining diverse encodings works very well
- Just combining the best encodings (of Rintanen) is not the best approach
- Action ordering has huge impact on R^2 Exists encoding
- The presented method is very simple yet experimental results are great
- Future Work: More diverse set of encodings, smarter selection heuristics

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