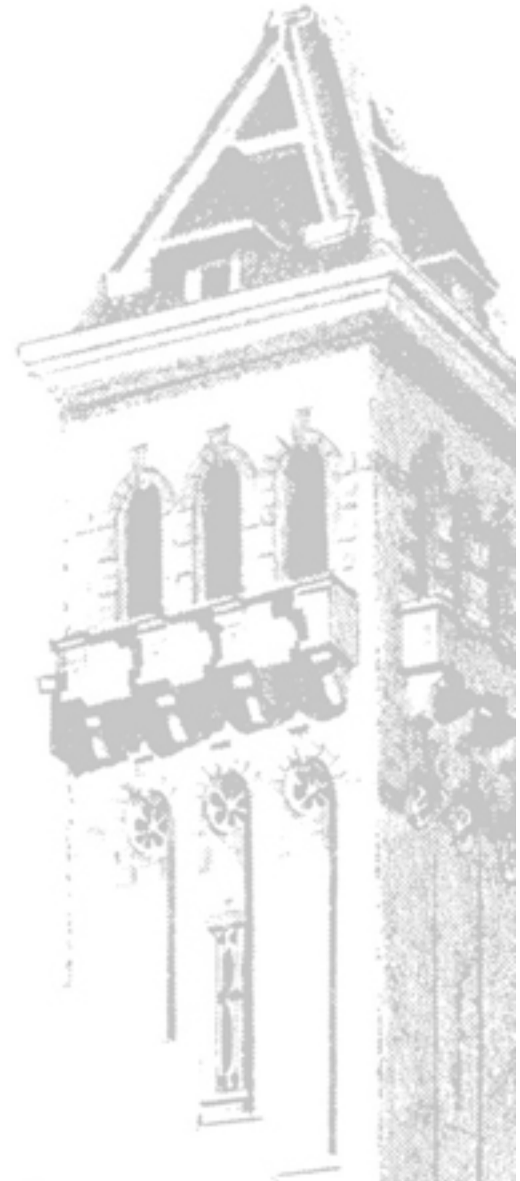
Planning and Acting in Incomplete Domains

Christopher Weber and Daniel Bryce



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Motivation

- Train Agents cheaply
- Perfect Knowledge Engineering is Costly
- Plan and Act with Incomplete Domain Knowledge
- Focus on Incomplete Actions, but complete set of Propositions

Anatomy of an Incomplete Domain

- STRIPS: (P,A,I,G)
  - P: Set of propositions
  - A: Incomplete Actions
    - Known: Preconditions, Adds, Deletes
    - Possible: Preconditions, Adds, Deletes
    - Impossible: Preconditions, Adds, Deletes
  - I: Initial State
  - G: Goal

PARC Printer

```
(:action HtmOverBlack-Move-A4
 :parameters ( ?sheet - sheet_t )
 :precondition (and (clear) (Available HtmOverBlack-RSRC)
                    (Sheetsize ?sheet A4)
                    (Location ?sheet HtmOverBlack_Entry-EndCap_Exit))
 :effect (and (not (Available HtmOverBlack-RSRC))
              (Location ?sheet HtmOverBlack_Exit-Down_TopEntry)
              (not (Location ?sheet HtmOverBlack_Entry-EndCap_Exit))
              (Available HtmOverBlack-RSRC))
 :poss-effect (and (not (clear))))
```

Plan Semantics

- Optimistic:
  - Ignore possible preconditions and deletes.
  - Keep possible adds.
- Pessimistic:
  - Assume possible preconditions and deletes.
  - Ignore possible adds.
- Cautiously Optimistic:
  - Don't assume anything
  - Count models under which plan succeeds

Synthesizing Plans

- Optimistic/Pessimistic
  - Translate Instance to STRIPS instance
    - Use favorite classical planner
- Cautiously Optimistic
  - Translate to Conformant Planning
    - Use favorite Conformant Planner (count models)
  - Default Planner
    - Count models
    - Count failure diagnoses

Conformant Planning

- Action Incompleteness → State Incompleteness
  - New propositions (e.g., pre(a,p), add(b, q), …)
  - Initial Belief State (e.g., unknown(pre(a,p)))
  - Condition each effect on incompleteness
    - -pre(a,p), r, s => g
    - pre(a,p), p, r, s => g
    - add(b,q), m, n => q
- Must be Conformant Probabilistic to count (weighted) models
  - Conformant Non-deterministic requires strong plans

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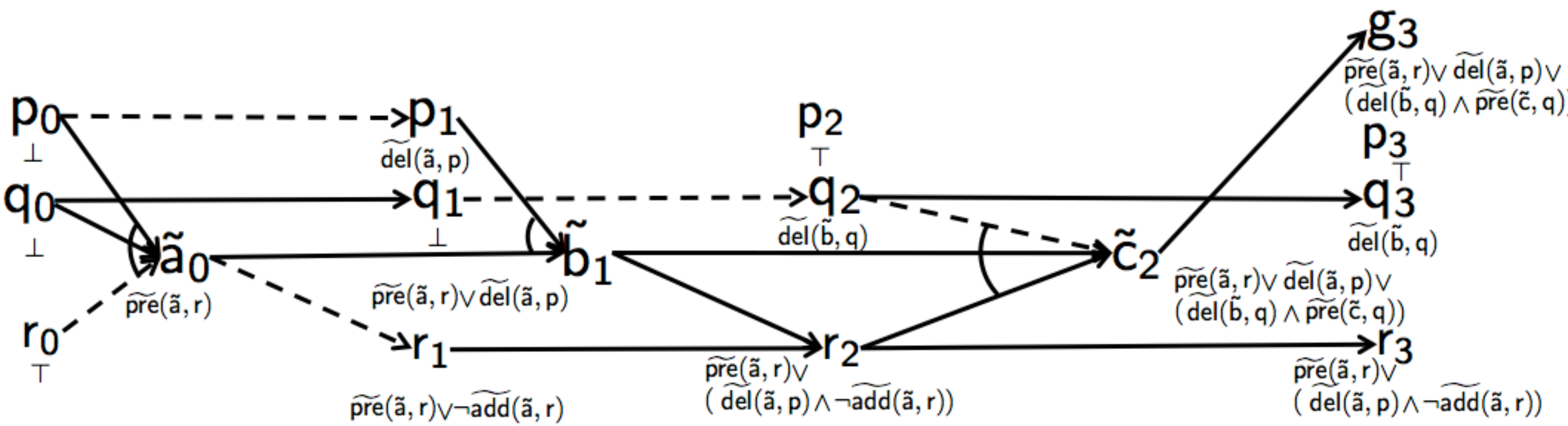
DeFault

- Extend [Garland and Lesh, AAAI02] and [Robertson and Bryce, HDIP09] from single fault to multi-fault.
- Foundations in Model-Based Diagnosis [Reiter, AIJ87] and Assumption-Based Truth Maintenance Systems [de Kleer AIJ86].

Plan Failure Explanations



Propositions = {p,q,r,g}
Incomplete Actions = {a,b,c}
Initial State = {p, q}
Goal = {g}
Incomplete Features = {pre(a, r), add(a, r), del(a, p), del(b, q), pre(c, q)}
Complete Features: pre(a) = {p, q};
pre(b) = {r}, add(b) = {r};
pre(c) = {r}, add(c) = {g}.
State Sequence: (s0 = {p,q}, s1 = {p,q,r}, s2 = {q,r}, s3 = {q,r,g})

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Propagating Failure Explanations

$$d(\tilde{a}_t) = d(\tilde{a}_{t-1}) \vee \bigvee_{p \in \mathrm{pre}(\tilde{a})} d(p_t) \vee \bigvee_{p \in \widetilde{\mathrm{pre}}(\tilde{a}_t)} (d(p_t) \wedge \widetilde{\mathrm{pre}}(\tilde{a}_t, p))$$

$$d(p_{t+1}) = \begin{cases} d(p_t) \wedge d(\tilde{a}_t) & : p \in \mathrm{add}(\tilde{a}_t) \\ d(p_t) \wedge (d(\tilde{a}_t) \vee \neg \widetilde{\mathrm{add}}(\tilde{a}_t, p)) & : p \in \widetilde{\mathrm{add}}(\tilde{a}_t) \\ \top & : p \in \mathrm{del}(\tilde{a}_t) \\ d(p_t) \vee \widetilde{\mathrm{del}}(\tilde{a}_t, p) & : p \in \widetilde{\mathrm{del}}(\tilde{a}_t) \\ d(p_t) & : \mathrm{otherwise} \end{cases}$$

Counting Models and Diagnoses

$$pre(a,r) \vee del(a,p) \vee (del(b,q) \wedge pre(c,q))$$

- Propositional Models: 26
- PI1: 2
- PI2: 1

$$pre(a,r) \vee del(a,p)$$

- Propositional Models: 24
- PI1: 2
- PI2: 0

Models (26834 Incomplete Features)

18012102889058430029072958416000499615620779677228097366088755462667565584997221674103819610797789889939066653095734373653126377973436854598417143324084982234554133305 7
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041830687647219698319135375241621083212938305557294762396

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Heuristics

- Optimistic/Pessimistic
  - FF Heuristic
- Cautiously Optimistic
  - Propagate PFE's, ignore deletes

$$d(\tilde{a}_{t+k}) = \bigvee_{p \in \mathrm{pre}(\tilde{a})} d(p_{t+k}) \vee \bigvee_{p \in \widetilde{\mathrm{pre}}(\tilde{a})} (d(p_{t+k}) \wedge \widetilde{\mathrm{pre}}(\tilde{a}, p))$$

$$d(p_{t+k+1}) = \begin{cases} d(a_{t+k}(p)) & : p \in \mathrm{add}(a_{t+k}(p)) \\ d(a_{t+k}(p)) \vee \neg\widetilde{\mathrm{add}}(a_{t+k}(p), p) & : p \in \widetilde{\mathrm{add}}(a_{t+k}(p)) \end{cases}$$

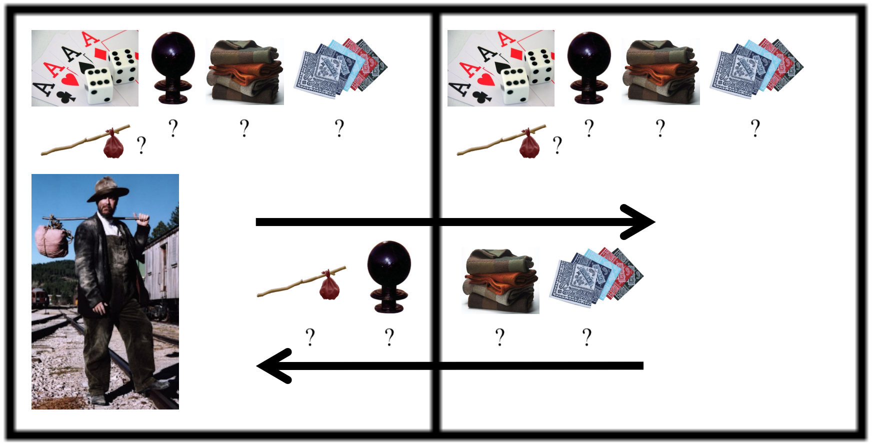
Heuristics Cont'd

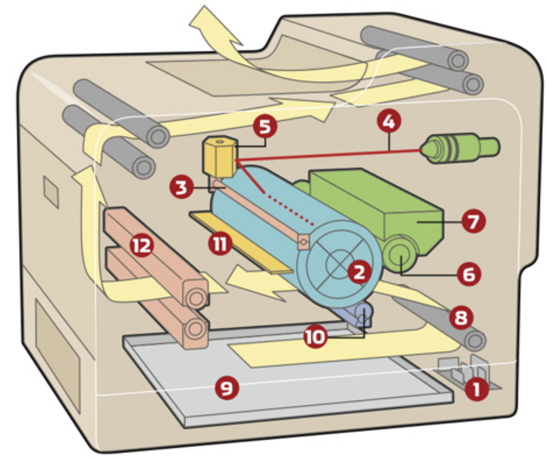
- Select Supporting action for each proposition
  - h^M Fewest Models of effect PFE
  - h^{PI} Fewest Prime Implicants (Diagnoses) of effect PFE
- Extract Relaxed Plan using chosen actions

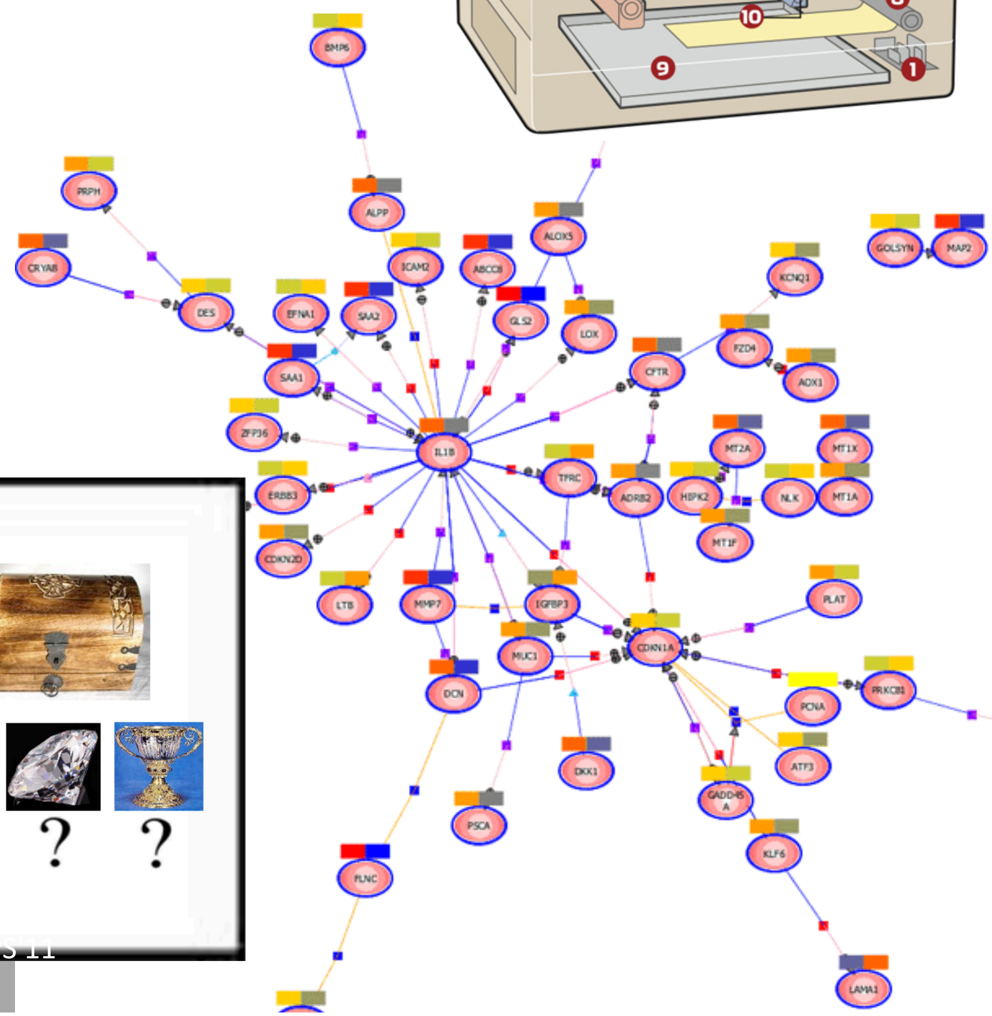
DeFault Planner

- Dual-Queue GBFS w/ Preferred Operators
- Return First Solution
- All code identical except heuristic functions and search nodes
- Compute plan quality after search
- Pure Java
- JDD BDD package

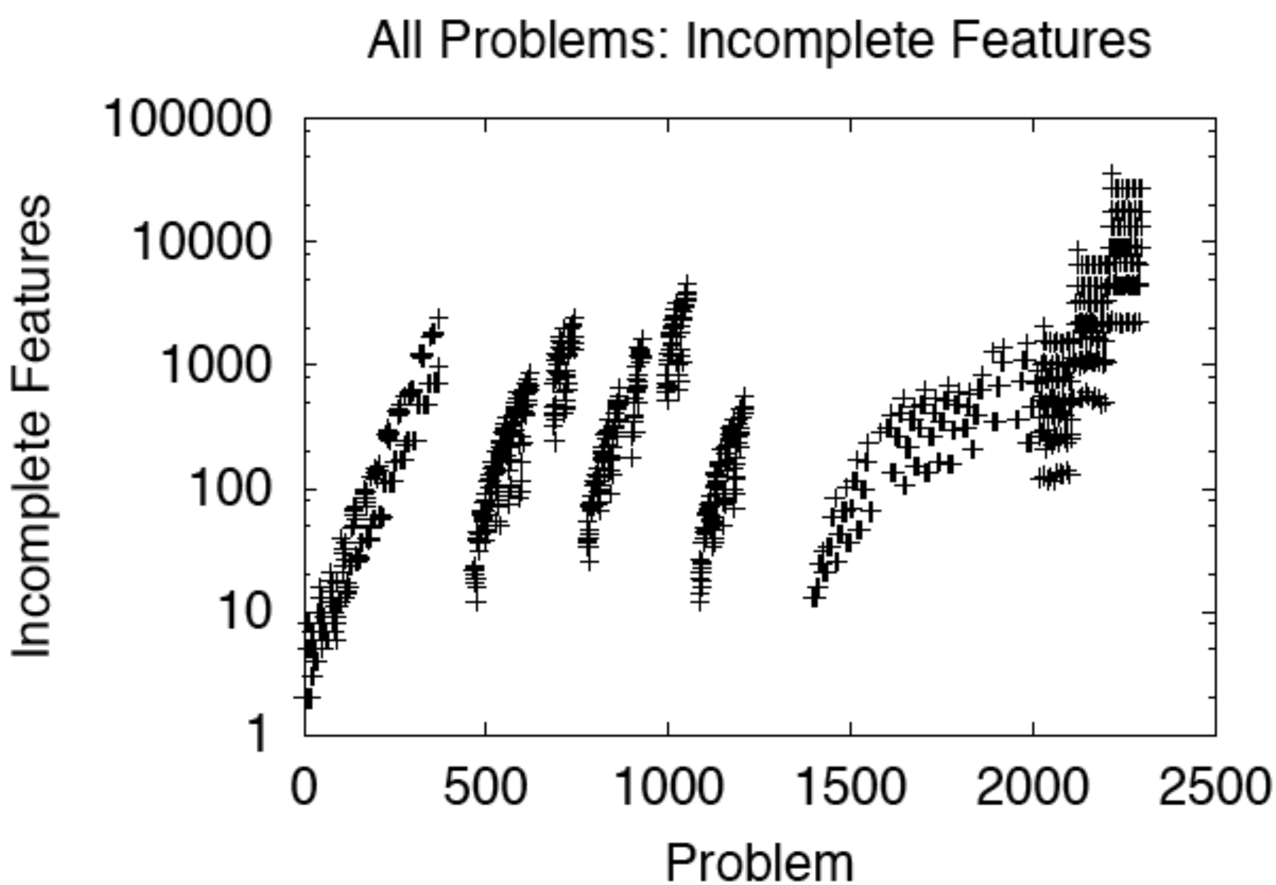
Domains







Incomplete Features



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Questions

- Q1: Does reasoning about incompleteness lead to high quality plans?
- Q2: Does counting prime implicants perform better than counting models?
- Q3: As the number of incomplete features grows, does stronger reasoning about incompleteness help?

Q1: Quality

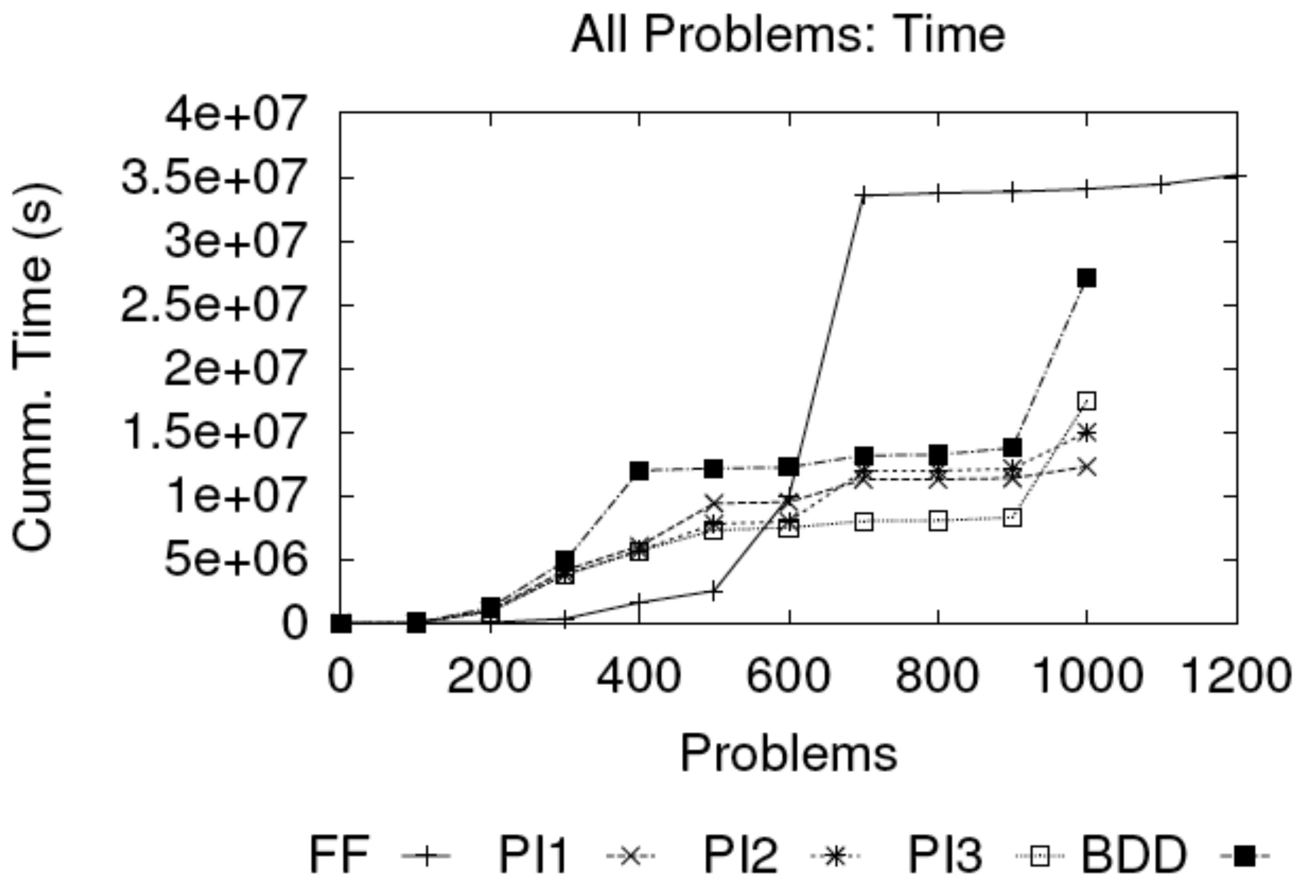
	FF	PI1	PI2	PI3	BDD
FF	0	148	157	158	121
PI1	**603**	0	**82**	**80**	**204**
PI2	**591**	75	0	48	**205**
PI3	**564**	59	**52**	0	**194**
BDD	**494**	185	189	186	0

Q2: Counting Performance

Domain	FF	PI1	PI2	PI3	BDD	POND
PARCprinter 0.25	130	83	85	**86**	80	10
PARCprinter 0.5	130	87	**88**	87	80	0
PARCprinter 0.75	130	82	**83**	81	80	0
PARCprinter 1.0	13	**10**	9	9	8	0
Parcprinter	403	262	**265**	263	248	10
Barter 0.25	150	106	128	**129**	108	60
Barter 0.5	150	134	**137**	134	118	45
Barter 0.75	150	**140**	138	137	111	27
Barter 1.0	15	**14**	**14**	**14**	11	2
Barter	465	394	**417**	414	348	155
Pathways 0.25	160	**40**	**40**	**40**	**40**	19
Pathways 0.5	160	**70**	60	50	60	13
Pathways 0.75	170	**60**	50	40	**60**	12
Pathways 1.0	19	5	6	6	**7**	2
Pathways	509	**175**	156	136	167	46

Domain	FF	PI1	PI2	PI3	BDD	POND
Bridges1 0.25	33	**19**	**19**	**19**	**19**	2
Bridges1 0.5	33	**15**	**15**	**15**	**15**	2
Bridges1 0.75	32	**18**	17	17	**18**	2
Bridges1 1.0	4	**2**	**2**	1	**2**	1
Bridges2 0.25	29	15	**16**	**16**	**16**	3
Bridges2 0.5	31	16	12	12	**19**	3
Bridges2 0.75	31	13	14	15	**16**	2
Bridges2 1.0	4	1	1	0	**2**	1
Bridges3 0.25	36	25	25	25	**26**	1
Bridges3 0.5	37	22	22	22	**23**	2
Bridges3 0.75	38	**25**	**25**	24	**25**	1
Bridges3 1.0	4	**3**	**3**	**3**	2	1
Bridges	312	174	171	169	**183**	21
Total	1689	1005	**1009**	982	946	232

Q2: Counting Performance



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Q3: Counting and Features

Domain	FF	PI1	PI2	PI3	BDD	POND
PARCprinter 0.25	130	83	85	**86**	80	10
PARCprinter 0.5	130	87	**88**	87	80	0
PARCprinter 0.75	130	82	**83**	81	80	0
PARCprinter 1.0	13	**10**	9	9	8	0
Parcprinter	403	262	**265**	263	248	10
Barter 0.25	150	106	128	**129**	108	60
Barter 0.5	150	134	**137**	134	118	45
Barter 0.75	150	**140**	138	137	111	27
Barter 1.0	15	**14**	**14**	**14**	11	2
Barter	465	394	**417**	414	348	155
Pathways 0.25	160	**40**	**40**	**40**	**40**	19
Pathways 0.5	160	**70**	60	50	60	13
Pathways 0.75	170	**60**	50	40	**60**	12
Pathways 1.0	19	5	6	6	**7**	2
Pathways	509	**175**	156	136	167	46

Domain	FF	PI1	PI2	PI3	BDD	POND
Bridges1 0.25	33	**19**	**19**	**19**	**19**	2
Bridges1 0.5	33	**15**	**15**	**15**	**15**	2
Bridges1 0.75	32	**18**	17	17	**18**	2
Bridges1 1.0	4	**2**	**2**	1	**2**	1
Bridges2 0.25	29	15	**16**	**16**	**16**	3
Bridges2 0.5	31	16	12	12	**19**	3
Bridges2 0.75	31	13	14	15	**16**	2
Bridges2 1.0	4	1	1	0	**2**	1
Bridges3 0.25	36	25	25	25	**26**	1
Bridges3 0.5	37	22	22	22	**23**	2
Bridges3 0.75	38	**25**	**25**	24	**25**	1
Bridges3 1.0	4	**3**	**3**	**3**	2	1
Bridges	312	174	171	169	**183**	21
Total	1689	1005	**1009**	982	946	232

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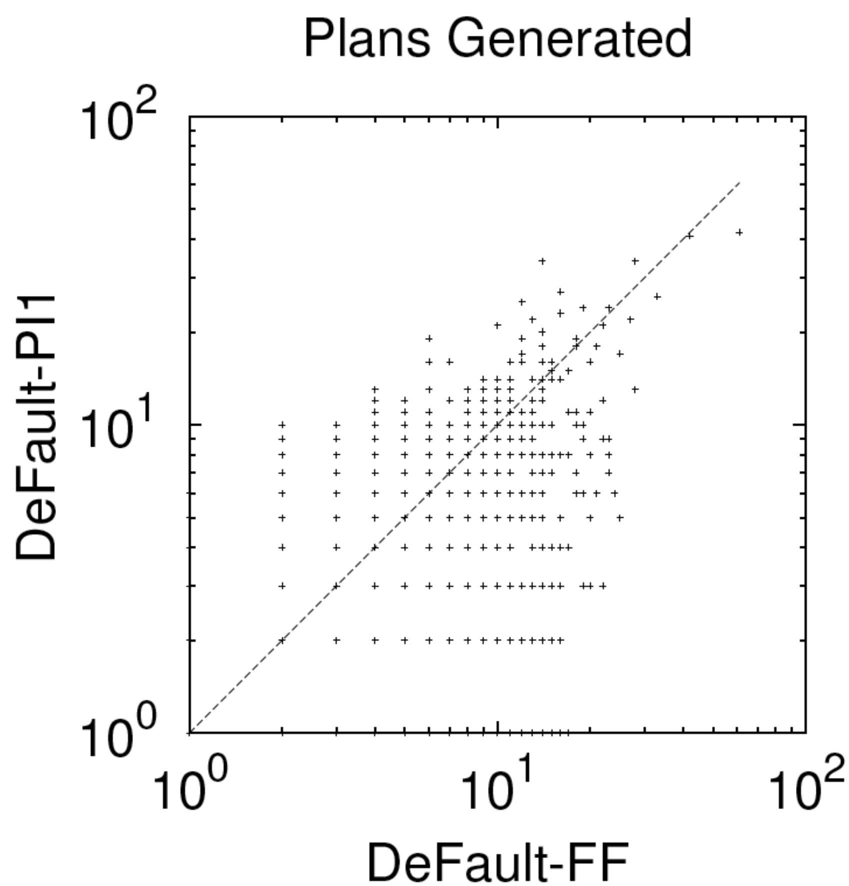
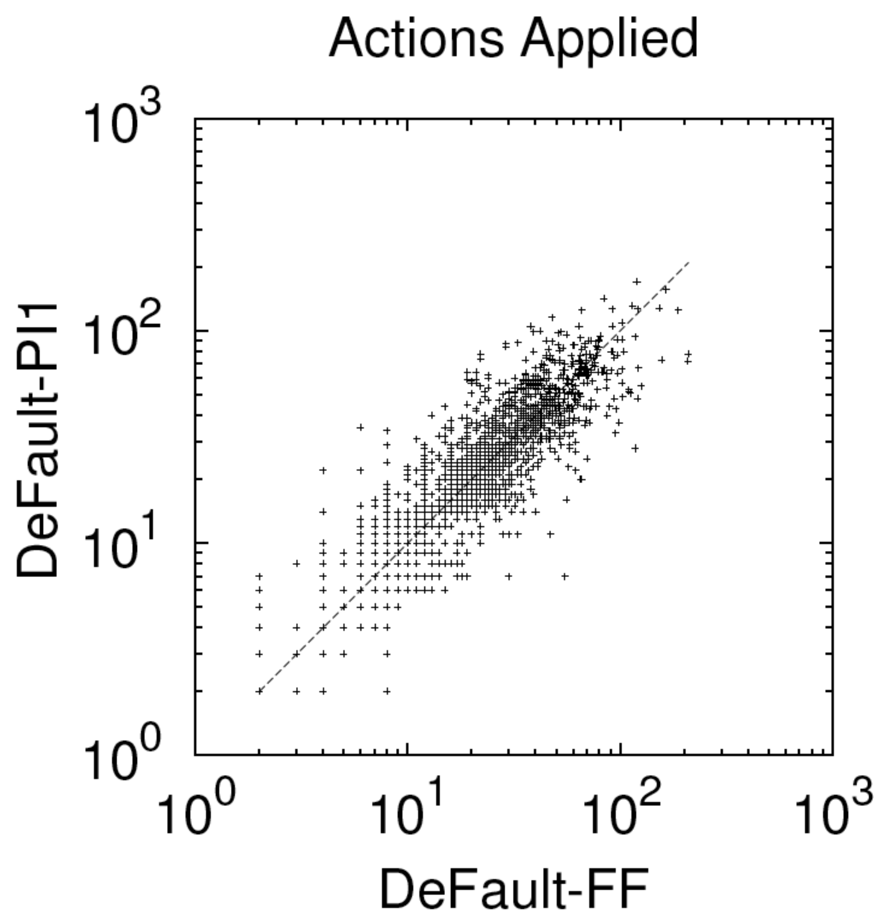
Execution in Incomplete Domains

- [Chang and Amir, ICAPS06]
  - Plan optimistically much like a classical planner
  - Learn adds and dels
  - Emphasizes Compact Filtering
- Goalie
  - Plan with DeFault
  - Learn pre, add, and dels
  - Emphasizes Robust Planning
- Q4: Does reasoning about incompleteness reduce the number of execution failures during execution?

Q4: Planner Invocations



Actions Applied



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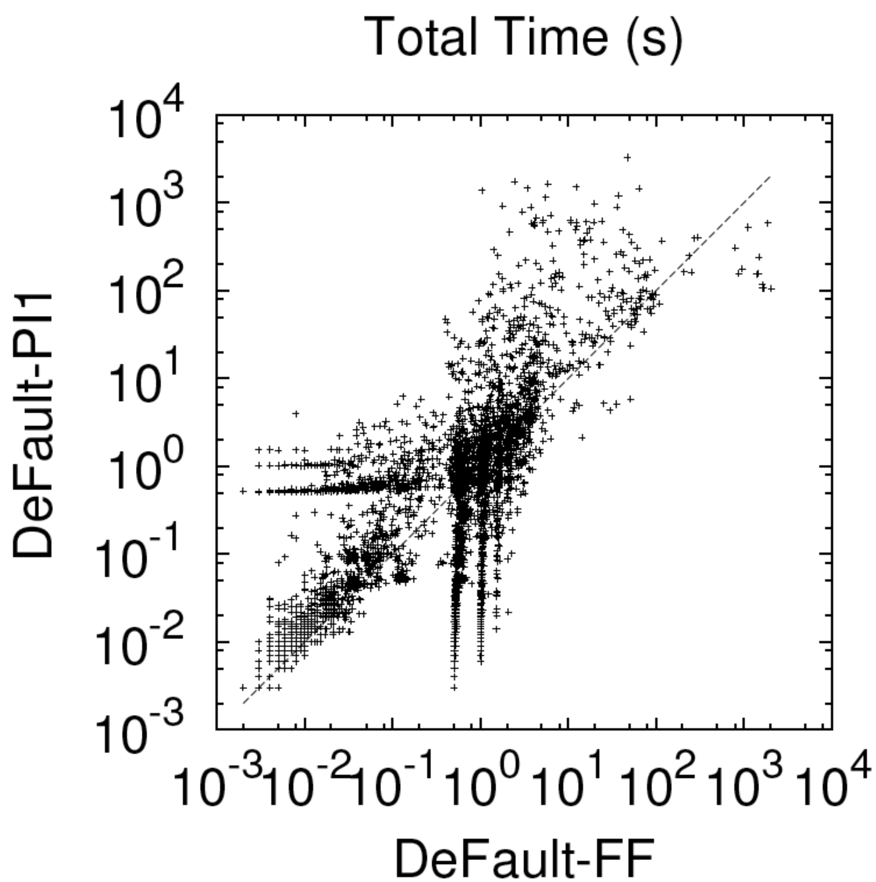
Total Time



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Summary

- First approach to planning in incomplete STRIPS domains
- Counting diagnoses (PIs) is faster than model counting and returns comparable quality plans
- Executing robust Incomplete plans requires less re-planning

Future Work

- More types of models
  - Conditional Effects, Temporal, First-Order, …
- Correlated Incompleteness
- Priors
- Alternative Representations of Failure Expl.
- Approximate Belief States
- Knowledge Acquisition

Thanks

DeFault and Goalie Java source code and domain generators available online

http://www.cs.usu.edu/~danbryce/software/default.jar