

Where Ignoring Delete Lists Works, Part II: Causal Graphs

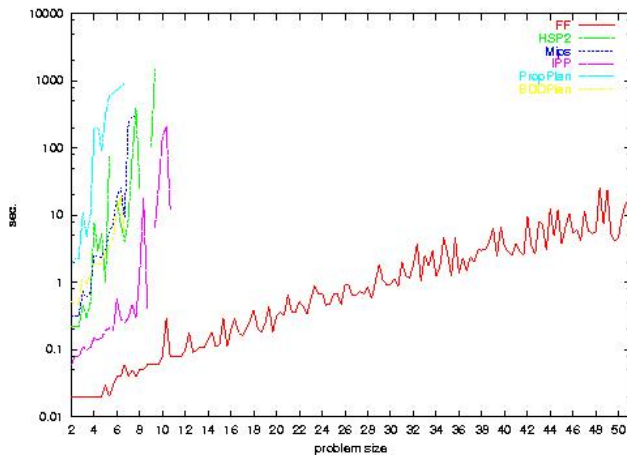
Jörg Hoffmann

INRIA
Nancy, France

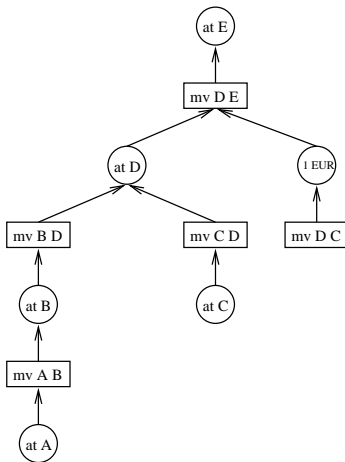
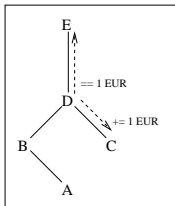
June 14, 2011

- ▶ What happened?
- ▶ On causal graphs and h^+
- ▶ Guaranteed global analysis
- ▶ Approximate local analysis
- ▶ Diagnosis
- ▶ Conclusion

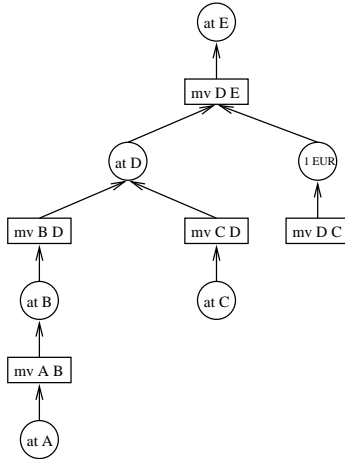
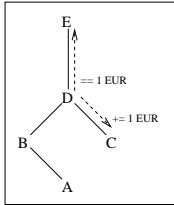
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Can we recognize this automatically?



Can we recognize this automatically?



Works *only* in trivialities; explodes quickly

Time passes ...



← me in 2002

Time passes ...



← me in 2003

Time passes ...



← me in 2004

Time passes ...



Time passes ...



← me in 2006

Time passes ...



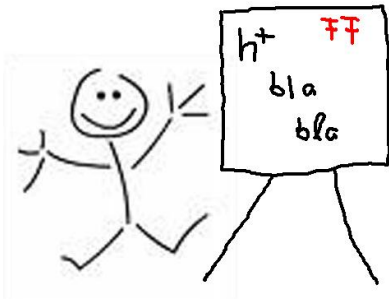
Time passes ...

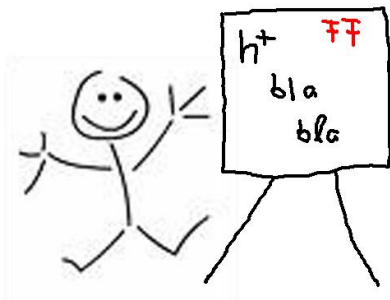


Time passes ...









← Carlos Areces

Luciana
Benotti →



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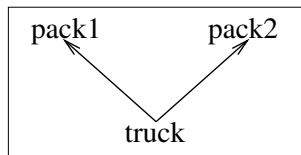
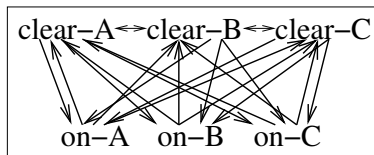
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Jörg: "...  **Causal graphs!!!**



The causal graph of Blocksworld contains cycles; h^+ local minima.

That of Logistics doesn't; h^+ no local minima.

Is there a general phenomenon behind this?

- ▶ What happened?
- ▶ **On causal graphs and h^+**
- ▶ Guaranteed global analysis
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Details:

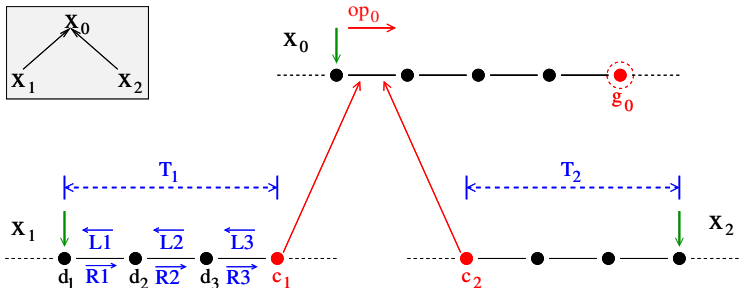
[J. Hoffmann (2011). *Analyzing Search Topology Without Running Any Search: On the Connection Between Causal Graphs and h^+* . Journal of Artificial Intelligence Research, Volume 41: 155-229. **June 2nd** 😊]

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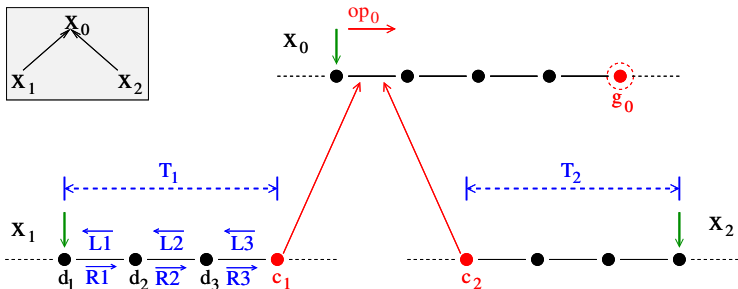
CG acyclic & invertibility \implies no local minima under h^+

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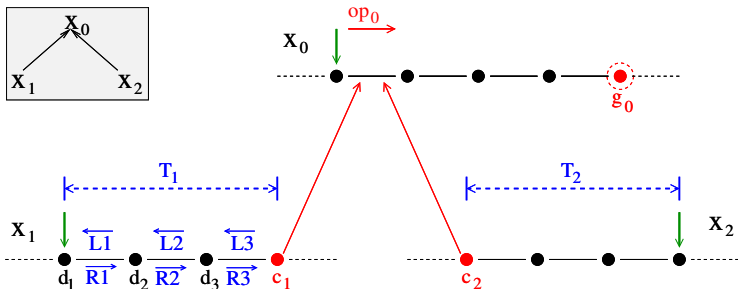
- ▶ Finite-domain vars (“SAS⁺”) x_0, x_1, x_2
- ▶ Domain transition graphs
- ▶ Causal graph: top left
- ▶ Transitions invertible + no side effects
- ▶ **Red**: need this; **Blue**: how to get it; **Green**: where we are (state s)
- ▶ **“Start” state s is not a local minimum!**
- ▶ **State s_0 : $x_1 = c_1$ and $x_2 = c_2$**

CG acyclic & invertibility \implies no local minima under h^+



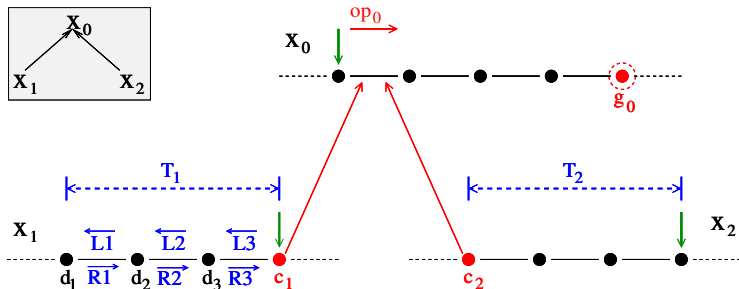
- ▶ Assume optimal relaxed plan $P^+(s)$ for s
- ▶ $P^+(s)$ must achieve c_1, c_2 via some paths T_1, T_2
- ▶ **If we remain within these paths, h^+ never increases!**

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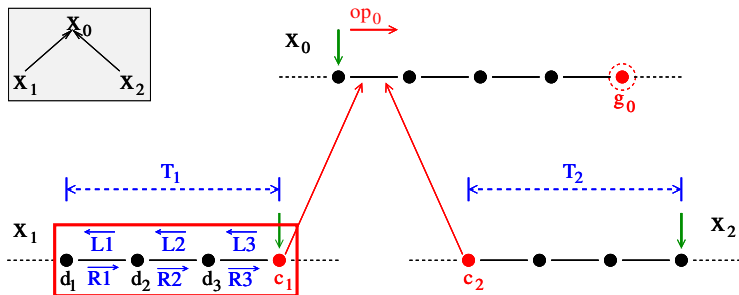
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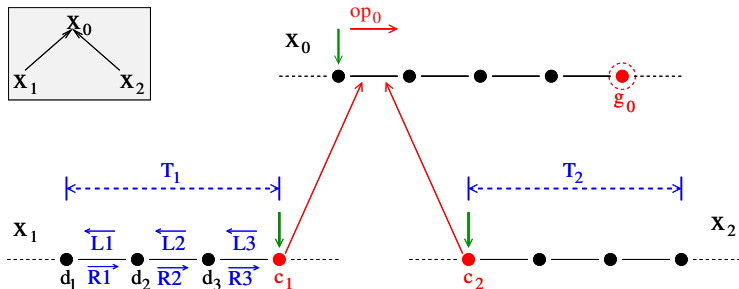
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- ▶ Say $s' := \text{apply}(s, R1, R2, R3)$

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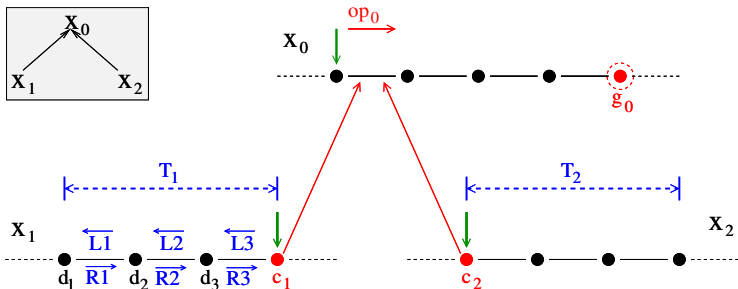
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- ▶ Say $s' := \text{apply}(s, R1, R2, R3)$
- ▶ $P^+(s') := \langle L3^+, L2^+, L1^+ \rangle \circ P^+$
- ▶ $\text{apply}(s, R1^+, R2^+, R3^+)[x_1] = \{d_1, d_2, d_3, c_1\} =$
 $\text{apply}(s', L3^+, L2^+, L1^+)[x_1]$

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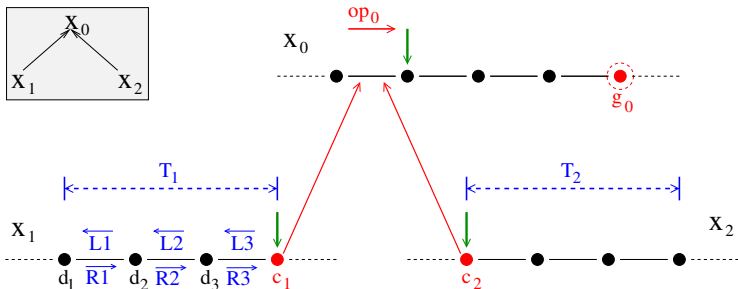
► Say we're in s_0

CG acyclic & invertibility \implies no local minima under h^+



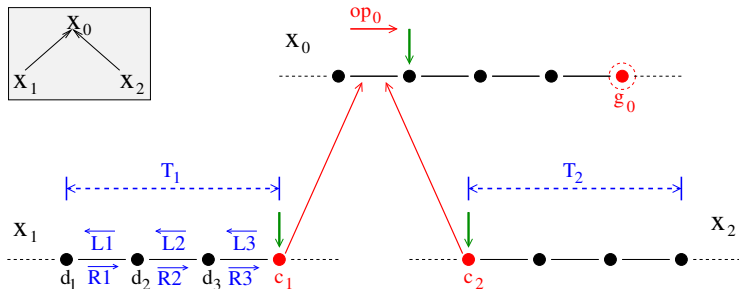
- ▶ Say we're in s_0
- ▶ $P^+(s_0) = \langle op_0^+ \rangle \circ P^+$, and (from prev arg) $|P^+(s_0)| \leq |P^+(s)|$

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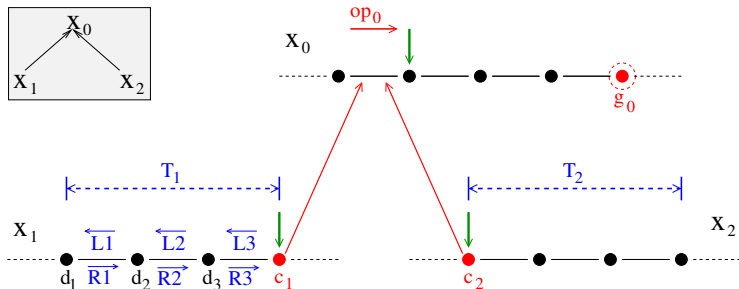
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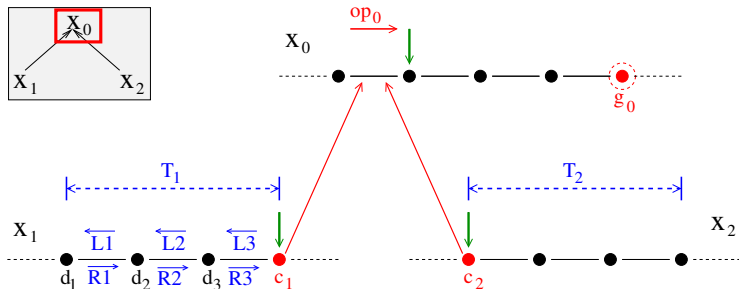
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- ▶ op_0 is applicable now, leading to s_1
- ▶ $P^+(s_1) := P^+$ (remove op_0 from $P^+(s_0)$); thus $h^+(s_1) < h^+(s)!!$

CG acyclic & invertibility \implies no local minima under h^+



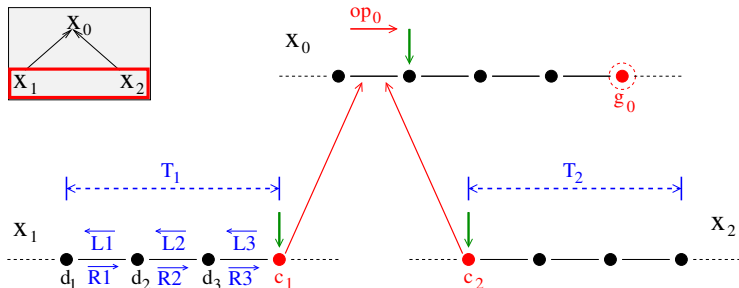
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- ▶ x_0 is **CG leaf**
 \implies moving x_0 does not affect relaxed plan, thus applying op_0 in s_0 decreases h^+

CG acyclic & invertibility \implies no local minima under h^+



- ▶ *What does any of this have to do with causal graphs???*
- ▶ x_0 is **CG leaf**
 \implies moving x_0 does not affect relaxed plan, thus applying op_0 in s_0 decreases h^+
- ▶ Moving x_0 involves **only CG predecessors**; if those have invertible transitions & no cyclic dependencies
 \implies can construct path to s_0 with non-increasing h^+

Is this useful for anything?

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- ▶ **Domain analysis!**
- ▶ TorchLight
- ▶ Long-term goal: “automatic Hoffmann”



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- ▶ **Domain analysis!**
- ▶ TorchLight
- ▶ Long-term goal: “automatic Hoffmann”

- ▶ Guaranteed global analysis
- ▶ Approximate local analysis
- ▶ Diagnosis

⇒ TorchLight demo today 17:30 – 20:00



- ▶ What happened?
- ▶ On causal graphs and h^+
- ▶ **Guaranteed global analysis**
- ▶ Approximate local analysis
- ▶ Diagnosis
- ▶ Conclusion

- ▶ Prove absence of local minima & global bound on lookahead
- ▶ Criterion strictly more general than what we just saw
- ▶ Allows e.g. non-unary operators, provided any side-effects are “harmless”

- ▶ Recognizes Logistics, Miconic-STRIPS, Movie, SimpleTSP
- ▶ Does not recognize anything else just yet ... [$\frac{4}{12}$ domains]

- ▶ What happened?
- ▶ On causal graphs and h^+
- ▶ Guaranteed global analysis
- ▶ **Approximate local analysis**
- ▶ Diagnosis
- ▶ Conclusion

- ▶ Local: *Is state s not a local minimum?*
- ▶ Analyze relaxed plan $P^+(s)$
- ▶ Answer “yes” guaranteed correct **if $P^+(s)$ is optimal**
- ▶ Theoretically, given optimal $P^+(s)$ as input, recognizes Ferry, Gripper, Elevators, Transport [+ global = $\frac{8}{12}$ domains]
- ▶ Randomly sample states; fraction of “yes”: **success rate**

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- ▶ Randomly sample states; fraction of “yes”: **success rate**
- ▶ Disclaimer:
 - ▶ Success rates can also be obtained by trivial search probing
 - ▶ Strong theoretical differences; some differences in benchmarks

Hoffmann vs. TorchLight

Zenotravel
Satellite
Rovers
PSR
Pipesworld–Tank
Pipesworld–NoTank
Mystery
Mprime
Freecell
Driverlog
Depots
Blocksworld–Arm
Airport

Tyreworld
Transport
Simple–Tsp
Movie
Miconic–STRIPS
Logistics
Hanoi
Gripper
Grid
Ferry
Elevators
Blocksworld–NoArm

Hanoi [0]
Airport [0]
Blocksworld–Arm [30]
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Pipesworld–Tank [40]
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PSR [50]
Freecell [56]
Blocksworld–NoArm [57]
Pipesworld–NoTank [76]
Grid [80]
Depots [81]
Zenotravel [95]

Tyreworld [100]
Transport [100]
Simple–Tsp [100]
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Rovers [100]
Movie [100]
Miconic–STRIPS [100]
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- ▶ Success rate: average per-domain from single sample state per-instance

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- ▶ Not all domains are “fully recognized” ...
- ▶ ... mostly because Hoffmann is too optimistic

Hoffmann vs. TorchLight

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- ▶ Some new domains are “fully recognized” ...
- ▶ ... mostly because Hoffmann is too pessimistic

Hoffmann vs. TorchLight

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► Success rates are more than a “yes/no” answer!

- ▶ What happened?
- ▶ On causal graphs and h^+
- ▶ Guaranteed global analysis
- ▶ Approximate local analysis
- ▶ **Diagnosis**
- ▶ Conclusion

- ▶ *Which domain aspects cause local minima?*

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- ▶ *Which unsatisfied conditions caused the analysis to fail?*

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- ▶ *Which unsatisfied conditions caused the analysis to fail?*
- ▶ Operator-name/predicate pairs (op, P) where op effect on P prevented use as successful op_0 in approximate local analysis
- ▶ Zenotravel: *“fly,fuel-level”*
- ▶ Mystery/Mprime: *“feast,locale”*
- ▶ Satellite: *“switch-on,calibrated”*
- ▶ Rovers: *“take-image,calibrated”*
- ▶ This is merely a first-shot technique!

- ▶ What happened?
- ▶ On causal graphs and h^+
- ▶ Guaranteed global analysis
- ▶ Approximate local analysis
- ▶ Diagnosis
- ▶ **Conclusion**





Improving TorchLight:

- ▶ Strengthen global analysis with complementary techniques
- ▶ Derive “good case” characterizations from local analysis?

Using TorchLight:

- ▶ Relaxed plan analysis \implies macro actions
- ▶ Performance prediction (even online during search)
- ▶ Abstract by removing (some) harmful effects (diagnosis!)
- ▶ Modeling support for planning end-users (diagnosis!)

Thanks. Questions?

p.s. There is an error in these slides. Where?