Where Ignoring Delete Lists Works, Part II: Causal Graphs

Jörg Hoffmann

INRIA
Nancy, France

June 14, 2011
Outline

- What happened?
- On causal graphs and $h^+$
- Guaranteed global analysis
- Approximate local analysis
- Diagnosis
- Conclusion
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Where Ignoring Delete Lists Works

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<th>Blocksworld–Arm Depots Driverlog</th>
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</tr>
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<tbody>
<tr>
<td>Hanoi [0] Blocksworld–NoArm [0] Transport [0]</td>
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<thead>
<tr>
<th>local minima ed &lt;= c</th>
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<tbody>
<tr>
<td>undirected</td>
</tr>
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<td>flat ed &lt;= c</td>
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red: no local minima at all under $h^+$
Can we recognize this automatically?

\[
\begin{array}{c}
\text{E} \\
\text{D} \\
\text{B} \\
\text{A}
\end{array}
\xrightarrow{== \ 1 \text{ EUR}}

\begin{array}{c}
\text{D} \\
\text{C}
\end{array}
\xrightarrow{+= \ 1 \text{ EUR}}

\begin{array}{c}
\text{B} \\
\text{C} \\
\text{E}
\end{array}
\xrightarrow{mv \ B \ D}

\begin{array}{c}
\text{D} \\
\text{C}
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\xrightarrow{mv \ D \ E}

\begin{array}{c}
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\end{array}
\xrightarrow{at \ A}

\begin{array}{c}
\text{E}
\end{array}
\xrightarrow{at \ E}

\begin{array}{c}
\text{D}
\end{array}
\xrightarrow{1 \text{ EUR}}
Can we recognize this automatically?

Works only in trivialities; explodes quickly
Time passes ...
Time passes . . .

← me in 2003
Time passes . . .

← me in 2004
Time passes . . .
Time passes ...
Time passes . . .

← me in 2007
Time passes . . .

← me in 2008
Time passes . . .

← me in 2009
Shortly after the presentation. Carlos, Luciana, and Jörg sit around a table. The conversation goes like this:

Carlos/Luciana: “When we made PDDL models, it was very hard to know how to design them so that planners would perform better. Couldn’t one build a tool based on recognizing $h^*$ topology?”

Jörg: “Oh yeah, I already tried that during my PhD, but it didn’t work.”

Carlos/Luciana: “But couldn’t we do something like XYZ?”

Jörg: “Hm I don’t think so.”

Carlos/Luciana: “αβγ maybe?”

... [45 minutes later] ...

Jörg: “Look, just consider Blocksworld and Logistics. One has local minima, the other doesn’t. Still both have deletes.”

Jörg: “And there is no other obvious difference in their structure . . .”

Jörg: “. . . Causal graphs!!!”
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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?
Outline

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

Details:

On causal graphs and $h^+$

Details:


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

Assume optimal relaxed plan $P^+(s)$ for $s$

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Wlog $P^+(s) = \langle R1^+, R2^+, R3^+ \rangle \circ P^+$
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Say $s' := \text{apply}(s, R1, R2, R3)$
CG acyclic & invertibility $\implies$ no local minima under $h^+$

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Wlog $P^+(s) = \langle R1^+, R2^+, R3^+ \rangle \circ P^+$

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

$P^+(s') := \langle L3^+, L2^+, L1^+ \rangle \circ P^+$

apply$(s, R1^+, R2^+, R3^+)[x_1] = \{d_1, d_2, d_3, c_1\} =$

apply$(s', L3^+, L2^+, L1^+)[x_1]$
CG acyclic & invertibility $\implies$ no local minima under $h^+$

Say we're in $s_0$
CG acyclic & invertibility $\iff$ no local minima under $h^+$

Say we’re in $s_0$

$P^+(s_0) = \langle \text{op}_0^+ \rangle \circ P^+$, and (from prev arg) $|P^+(s_0)| \leq |P^+(s)|$
CG acyclic & invertibility $\implies$ no local minima under $h^+$

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$\text{op}_0$ is applicable now, leading to $s_1$
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) $|P^+(s_0)| \leq |P^+(s)|$

- $op_0$ is applicable now, leading to $s_1$

- $P^+(s_1) := P^+$ (remove $op_0$ from $P^+(s_0)$); thus $h^+(s_1) < h^+(s)$!!
What does any of this have to do with causal graphs???
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\( x_0 \) is CG leaf

\[ \Rightarrow \text{moving } x_0 \text{ does not affect relaxed plan, thus applying } op_0 \text{ in } s_0 \text{ decreases } h^+ \]
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”
Is this useful for anything?

- **Domain analysis!**
- **TorchLight**
- Long-term goal: “automatic Hoffmann”
- Guaranteed global analysis
- Approximate local analysis
- Diagnosis

⇒ TorchLight demo today 17:30 – 20:00
Outline

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

- 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
Outline

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

- 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
Approximate local analysis

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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
### Success rate: average per-domain from single sample state per-instance

<table>
<thead>
<tr>
<th>Domain</th>
<th>Success Rate</th>
</tr>
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<tbody>
<tr>
<td>Zenotravel</td>
<td>[95]</td>
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<tr>
<td>Satellite</td>
<td>[81]</td>
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<tr>
<td>Rovers</td>
<td>[76]</td>
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<td>PSR</td>
<td>[60]</td>
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<td>Pipesworld–Tank</td>
<td>[57]</td>
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<td>Pipesworld–NoTank</td>
<td>[50]</td>
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<tr>
<td>Mystery</td>
<td>[49]</td>
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<td>Mprime</td>
<td>[40]</td>
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<td>Freecell</td>
<td>[39]</td>
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<td>Blocksworld–NoArm</td>
<td>[30]</td>
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<td>Grid</td>
<td>[23]</td>
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<td>Driverlog</td>
<td>[22]</td>
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<td>Depots</td>
<td>[10]</td>
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<td>Blocksworld–Arm</td>
<td>[5]</td>
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<tr>
<td>Airport</td>
<td>[0]</td>
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<td>Hanoi</td>
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<td>Tyreworld</td>
<td>[100]</td>
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<td>Transport</td>
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<td>Simple–Tsp</td>
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<td>Movie</td>
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<td>Miconic–STRIPS</td>
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<td>Ferry</td>
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<td>[100]</td>
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<td>Blocksworld–NoArm</td>
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Hoffmann vs. TorchLight

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

Hanoi [0], Airport [0], Blocksworld–Arm [30], Mystery [39], Pipesworld–Tank [40], Mprime [49], PSR [50], Freecell [56], Blocksworld–NoArm [57], Pipesworld–NoTank [76], Grid [80], Depots [81], Zenotravel [95]

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

Tyreworld [100], Transport [100], Simple–Tsp [100], Satellite [100], Rovers [100], Movie [100], Miconic–STRIPS [100], Logistics [100], Gripper [100], Ferry [100], Elevators [100], Driverlog [100]

Not all domains are “fully recognized” . . .

... mostly because Hoffmann is too optimistic
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| Transport       | Transport [100]         |          |
| Simple−Tsp      | Simple−Tsp [100]        |          |
| Movie           | Satellite [100]         |          |
| Miconic−STRIPS  | Rovers [100]            |          |
| Logistics       | Movie [100]             |          |
| Hanoi           | Miconic−STRIPS [100]    |          |
| Gripper         | Logistics [100]         |          |
| Grid            | Gripper [100]           |          |
| Ferry           | Ferry [100]             |          |
| Elevators       | Elevators [100]         |          |
| Blocksworld−NoArm | Driverlog [100]    |          |

Some new domains are “fully recognized” . . .

. . . mostly because Hoffmann is too pessimistic
Success rates are more than a "yes/no" answer!
Outline

- What happened?
- On causal graphs and $h^+$
- Guaranteed global analysis
- Approximate local analysis
- Diagnosis
- Conclusion
Which domain aspects cause local minima?
▶ Which domain aspects cause local minima?

▶ Which unsatisfied conditions caused the analysis to fail?
Diagnosis

- Which domain aspects cause local minima?
- 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!
Outline

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- **Conclusion**
Conclusion

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

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

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- Strengthen global analysis with complementary techniques
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Using TorchLight:

- Relaxed plan analysis $\implies$ macro actions
- Performance prediction (even online during search)
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Thanks. Questions?

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