A Beginner’s Introduction to Heuristic Search Planning

4. Five Families of Heuristics

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Heuristics
Planning as Heuristic Search

- general search algorithm (e.g. A*, greedy best-first search)
- distance estimator (heuristic function)
Desirable Properties of Heuristics for Optimal Planning

heuristic $h$ maps states to numbers in $\mathbb{R}_{\geq 0} \cup \{\infty\}$

Desirable properties for optimal planning:

- **admissibility**: $h(s) \leq h^*(s)$ for all states $s$
- **consistency**: $h(s) \leq \text{cost}(o) + h(s')$ for all state transitions $s \xrightarrow{o} s'$

$h^*$: actual distance to goal ("perfect heuristic")
Desirable property for optimal and satisficing planning:

- **accuracy**: $h(s)$ should be “close” to $h^*(s)$
How do we come up with **precise** estimates in a **domain-independent** fashion?
How to Come Up with Good Heuristics

How do we come up with good heuristics?

A commonly held view:

Inspiration

"I think you should be more explicit here in step two."

Must we wait for inspiration to strike?
How do we come up with good heuristics?

Another commonly held view:

**Perspiration**

“None of my inventions came by accident. I see a worthwhile need to be met and I make trial after trial until it comes. What it boils down to is one per cent inspiration and ninety-nine per cent perspiration.”

— Thomas Alva Edison (1929)

Phrased less positively:

“Throw enough mud at the wall, some of it will stick.”
How to Come Up with Heuristics

How do we come up with good heuristics?

Our recommendation:

Careful Scientific Study

“First, you have to understand the problem.”

— George Pólya (1945)
The Science of Heuristics

Ask (and answer) questions:

- **Dissect existing approaches**: where do they work? Where not? Why and why not?
- Can specific approaches be distilled to **general ideas**? Can general ideas be applied more specifically?
- **Compare existing** approaches: does one dominate another? What do they have in common? How are they different? Can their strengths be combined?
Five Families of Heuristics
How do we come up with heuristics for general problems?

⇝ five major approaches in the literature

- delete relaxation
- abstraction
- critical paths
- landmarks
- network flows
Running Example: FreeCell

image credits: GNOME Project (GNU General Public License)
Heuristics in Fast Downward

When a heuristic is implemented in Fast Downward, we mention its plug-in name.

- Many heuristics have options, sometimes with bad defaults.
- We use dots (e.g., `lmcount(...)`) when options matter a lot.

Want to find out more?

- Check out the cited papers.
- public mailing list
  - link on [http://www.fast-downward.org](http://www.fast-downward.org)
- Ask us!
Planning Heuristics: Delete Relaxation

Five classes of heuristics:

1. Delete Relaxation

Estimate cost to goal by considering simpler planning task without negative side effects of actions.

Example: Delete Relaxation in FreeCell

Problem constraints dropped by the delete relaxation in FreeCell:

- free cells and free tableau positions remain available after moving cards into them
- cards remain movable and remain valid targets for other cards after moving cards on top of them

⇒ more in Part 6
Delete relaxation heuristics in the literature (admissible in red):

- **max heuristic** (Bonet & Geffner, ECP 1999; AIJ 2001)
- **additive heuristic** (Bonet & Geffner, ECP 1999; AIJ 2001)
- **FF heuristic, $h^+$ heuristic** (Hoffmann & Nebel, JAIR 2001)
- **pairwise max heuristic** (Mirkis & Domshlak, ICAPS 2007)
- **set-additive heuristic** (Keyder & Geffner, ECAI 2008)
- **Steiner tree heuristic** (Keyder & Geffner, IJCAI 2009)
- **landmark-cut heuristic** (Helmert & Domshlak, ICAPS 2009)
- **improved LM-Cut** (Bonet & Helmert, ECAI 2010)

**in Fast Downward**

`hmax()`, `add()`, `ff()`, `lmcut()`
Planning Heuristics: Abstraction

Five classes of heuristics:

2. Abstraction

Estimate cost by projecting the state space to a smaller space (applying a graph homomorphism).

Example: Abstraction in FreeCell

One possible abstraction for FreeCell: project away all cards that are not 10s, Js, Qs or Ks.

⇒ more in Part 5
Abstraction heuristics in the literature (admissible in red):

- **pattern databases (PDBs)** (Edelkamp, ECP 2001; Haslum et al., AAAI 2007; Pommerening et al., IJCAI 2013)
- **symbolic PDBs** (Edelkamp, AIPS 2002)
- **constrained PDBs** (Haslum et al., AAAI 2005)
- **merge-and-shrink** (Dräger et al., SPIN 2006; Helmert et al., ICAPS 2007; Sievers et al. AAAI, 2014)
- **structural patterns** (Katz & Domshlak, ICAPS 2008)
- **Cartesian abstraction** (Seipp & Helmert, ICAPS 2013; ICAPS 2014)

**in Fast Downward**

pdb(...), zopdbs(...), cpdbs(...), gapdb(...), ipdb(...), merge_and_shrink(...)
Planning Heuristics: Critical Paths

Five classes of heuristics:

3. Critical Paths

Estimate cost by critical path length (makespan) of a concurrent solution for a simplified problem. In the simplification, a set of subgoals is considered reachable when all size-$m$ subsets are reachable; $m \in \mathbb{N}_1$ is a parameter.

Example: Critical Paths in FreeCell

Possible critical path for single subgoals ($h^1$):

- Solving the FreeCell task requires four subgoals: have each of ♦$K$, ♥$K$, ♠$K$, ♣$K$ at foundations
- Follow third subgoal: getting ♠$K$ to foundations requires first having ♠$Q$ at foundations and having ♠$K$ movable.
- Follow second subsubgoal: having ♠$K$ movable requires...
Critical path heuristics in the literature *(admissible in red)*:

- $h^m$ heuristic family *(Haslum & Geffner, AIPS 2000)*
- additive $h^m$ *(Haslum et al., AAAI 2005)*
- additive-disjunctive heuristic graphs *(Coles et al., ICAPS 2008)*

*In Fast Downward*

$h_m(m=2), h_m(m=3), \ldots$

**warning:** very inefficient implementation!
Planning Heuristics: Landmarks

Five classes of heuristics:

4. Landmarks

An action set $A$ is a **landmark** if all plans include an action from $A$. Compute a set of landmarks and use it to derive a cost estimate (e.g., by counting the number of landmarks).

**Example: Landmarks in FreeCell**

Landmarks in FreeCell:

- The set of actions that move the ♥Q to foundations.
- The set of actions that move the ♣7 away from the ♦8.
- ...

↓ more in Part 6
Landmark heuristics in the literature (admissible in red):

- LAMA heuristic (Richter et al., AAAI 2008)
- cost-partitioned landmarks (Karpas & Domshlak, IJCAI 2009)
- conjunctive landmarks (Keyder et al., ECAI 2010)
- landmark-cut heuristic (Helmert & Domshlak, ICAPS 2009)

in Fast Downward

lmcount(...), lmcut()
Planning Heuristics: Network Flows

Five classes of heuristics:

5. Network Flows

In every plan, the number of times each fact is produced vs. the number of times it is consumed must be “balanced”. Solve a linear program encoding this information.

Example: Flow Constraints in FreeCell

Flow constraints in FreeCell:

- Each card is moved into a free cell as often as it is moved out of a free cell.
- Each card is buried in a stack as often as it is uncovered.
- ... 

(Give or take a bit to account for current state and goal.)
Network flow heuristics in the literature (admissible in red):

- **flow heuristic** (van den Briel et al., CP 2007)
- **state equation heuristic** (Bonet, IJCAI 2013)
- **enhanced flow heuristics** (Bonet & van den Briel, ICAPS 2014)
Summary
Summary

• the challenge: precise domain-independent heuristics
• it bears repeating: heuristics can be studied scientifically
• five major approaches in the literature:
  • delete relaxation
  • abstraction
  • critical paths
  • landmarks
  • network flows