Searching Without a Heuristic: Efficient Use of Abstraction

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Supported in part by the DARPA CSSG program, the NSF, and the NSERC.

Good Heuristics are Hard to Find

- Glued 15-puzzle: has unmovable tile
- Manhattan distance admissible
- Glued tile reduces effectiveness
- Natural solution: construct pattern database (PDB)

Start

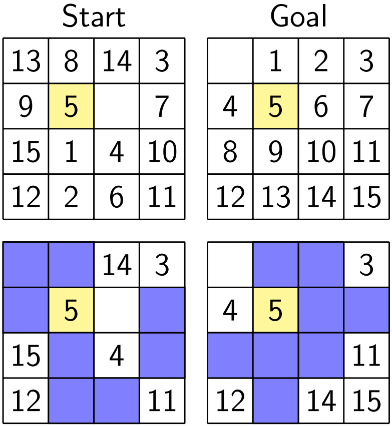
13	8	14	3
9	5		7
15	1	4	10
12	2	6	11

Goal

	1	2	3
4	5	6	7
8	9	10	11
12	13	14	15

Example: Glued 15-Puzzle PDB

- Abstract the puzzle by obscuring tiles
- Enumerate entire abstract state space backward from goal
- Store costs to goal in look-up table
- Use look-up table for heuristic estimates

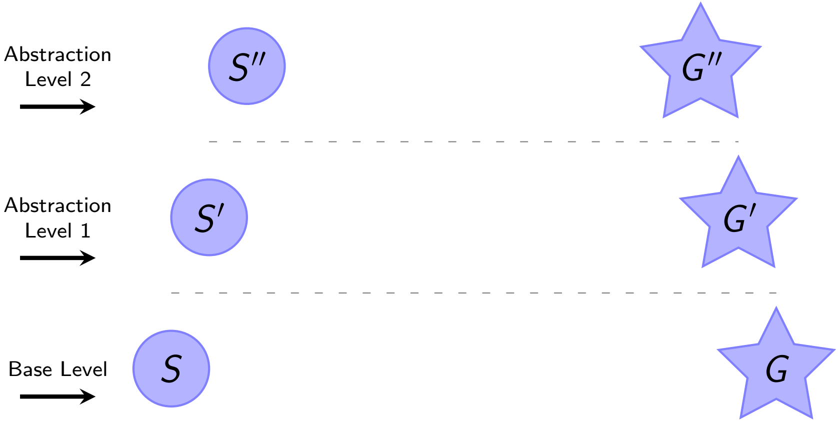


Pattern Database Shortcomings

Disadvantages when solving one or a few instances:

- Must enumerate *entire* abstract space
  - Expensive preprocessing phase
  - Database entry for *every* abstract state
- During single search, most entries go unused
- Database not reusable
  - when goal state changes
  - when operator costs change
- One abstraction for all instances

Hierarchical A* (Holte et al. 1996)



HA* uses a hierarchy of abstractions.

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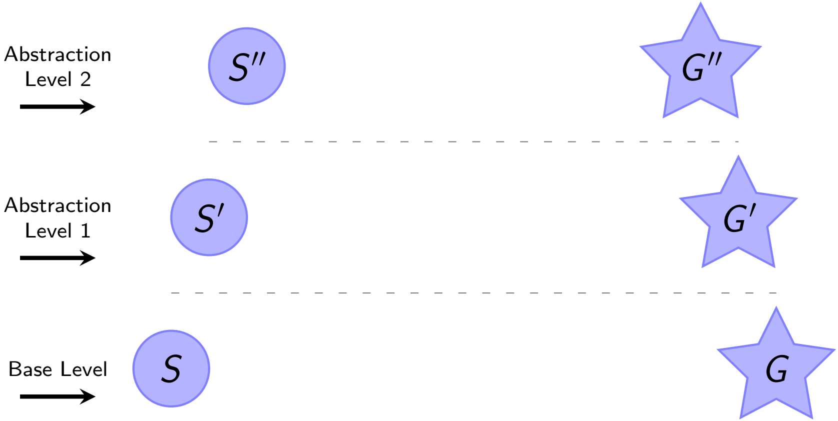

Objective: find the cheapest path from S to G.

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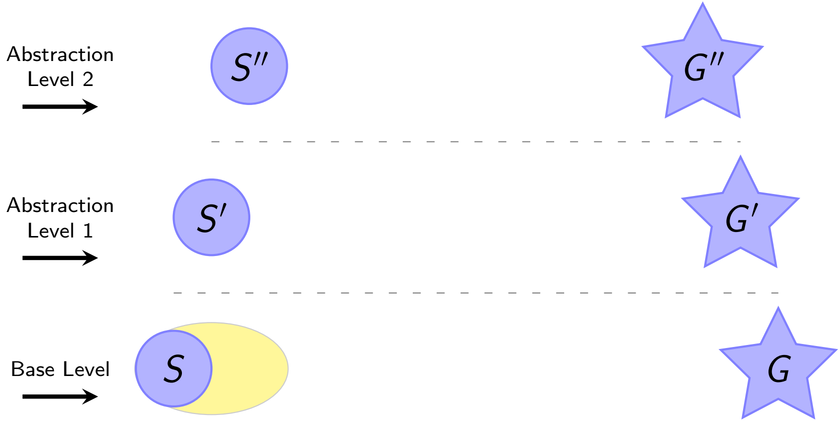

The yellow area represents generated states.

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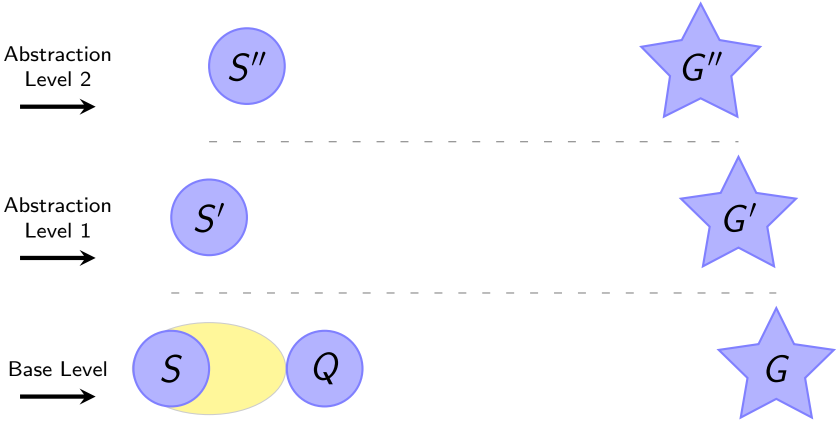
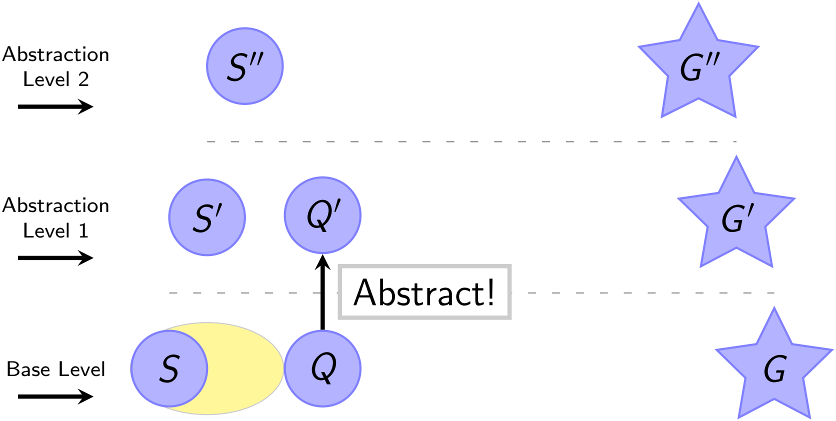


To generate Q, we need to know $h(Q)$.

Hierarchical A* (Holte et al. 1996)



To find $h(Q)$: abstract Q and search at level 1.

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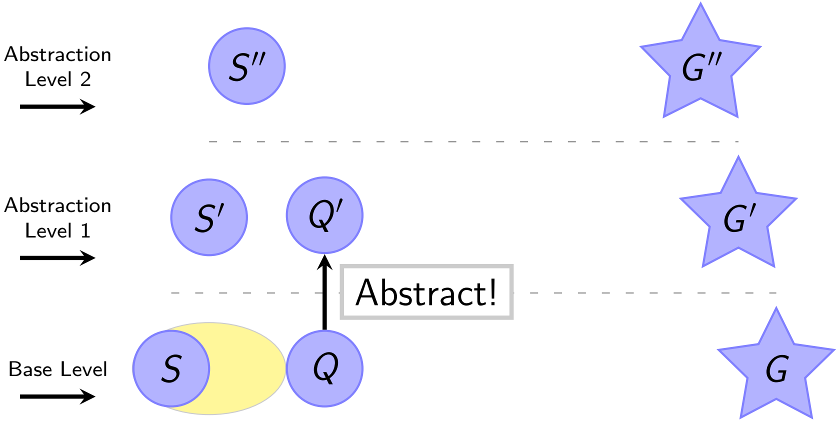
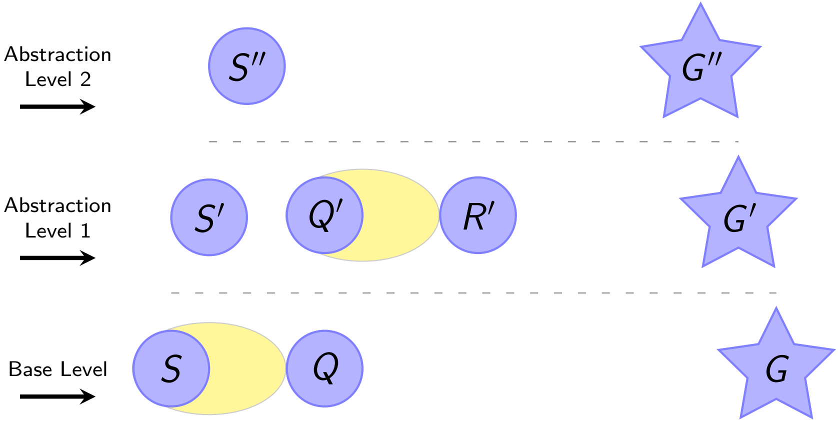


New objective: find cheapest path from Q' to G'.

Hierarchical A* (Holte et al. 1996)



To generate R', we need to know $h(R')$.

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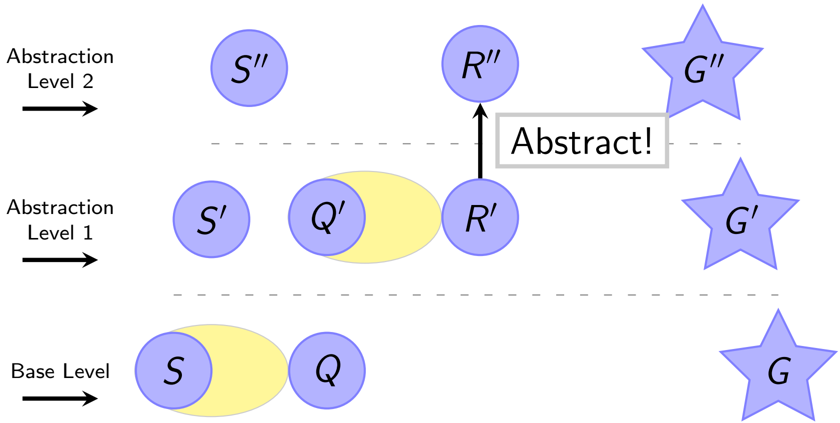
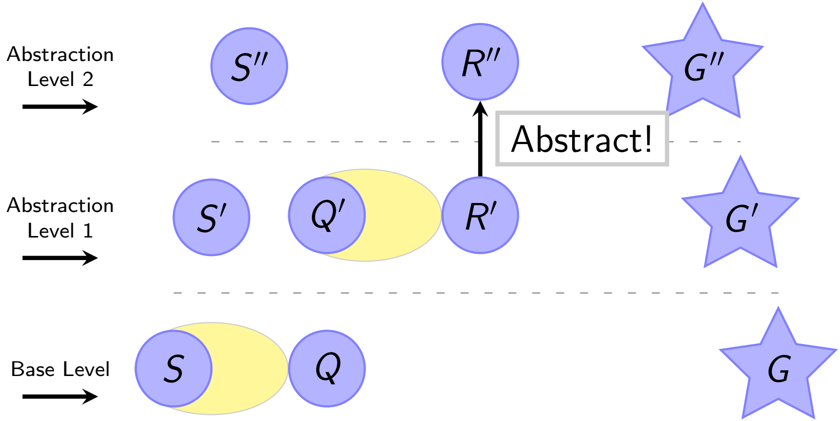


To find $h(R')$: abstract R' and search at level 2.

Hierarchical A* (Holte et al. 1996)



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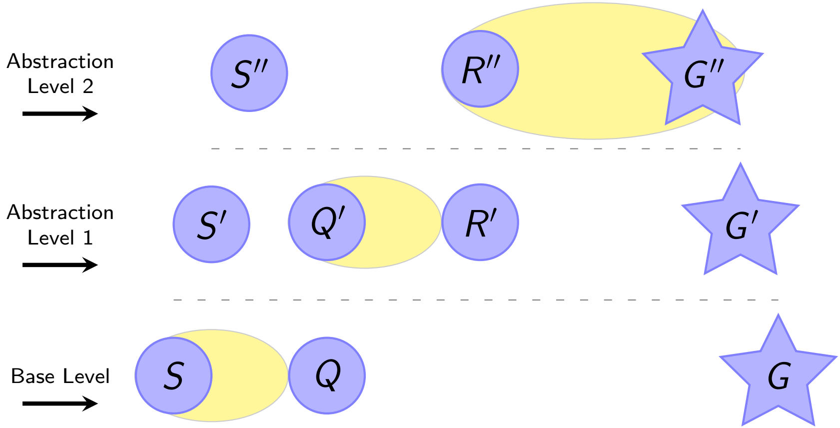
Hierarchical A* (Holte et al. 1996)



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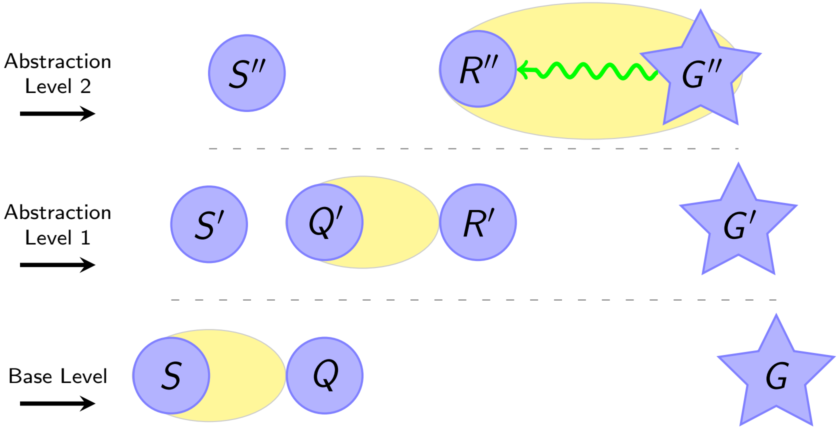
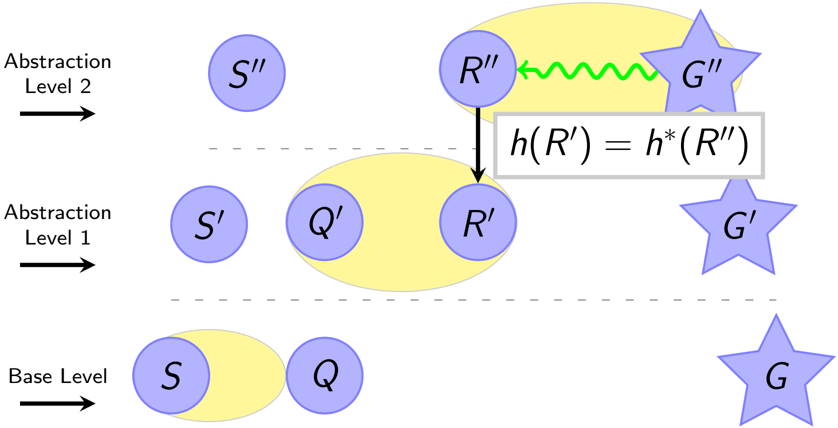


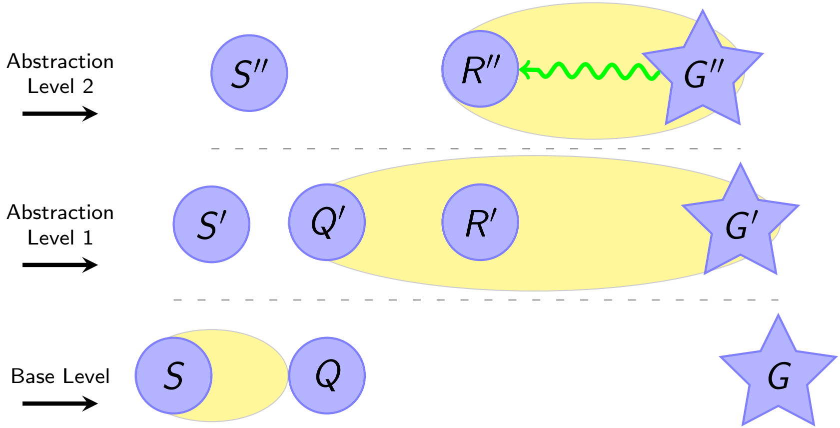
h^* values along the solution path are cached.

Hierarchical A* (Holte et al. 1996)



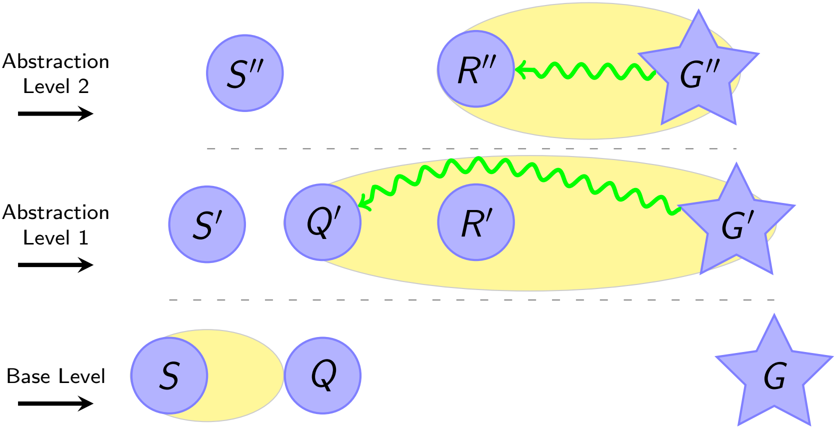
Use cost-to-goal at level 2 as $h(R')$.

Hierarchical A* (Holte et al. 1996)



Eventually the search at level 1 finishes.

Hierarchical A* (Holte et al. 1996)



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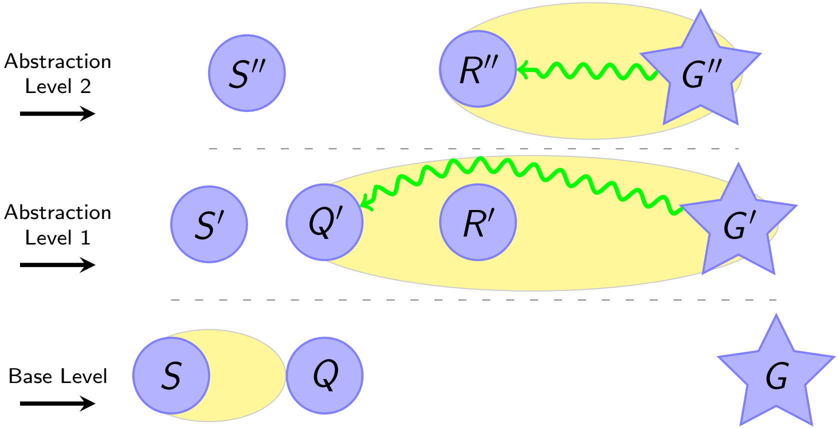
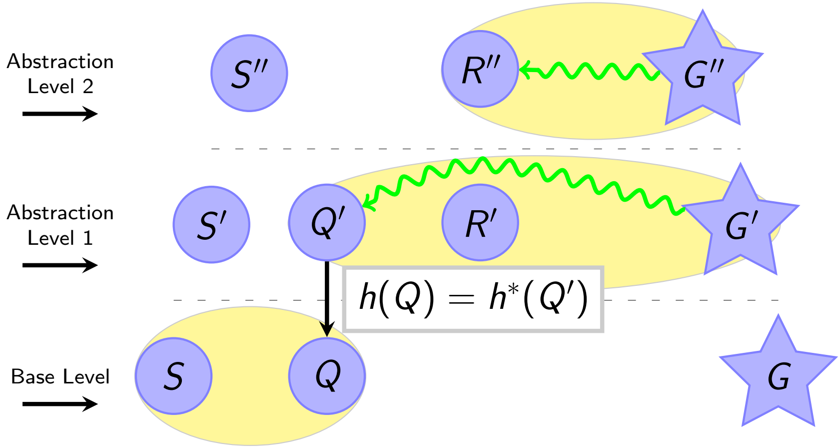


R' is not on the solution path.

Hierarchical A* (Holte et al. 1996)



Use cost-to-goal at level 1 as $h(Q)$.

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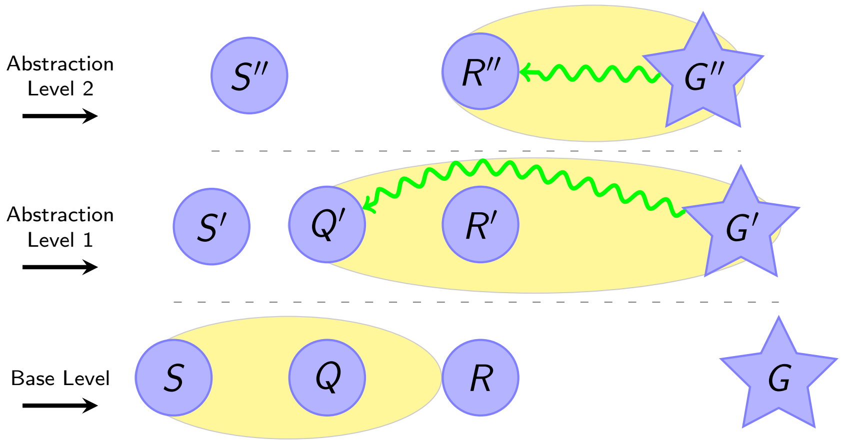

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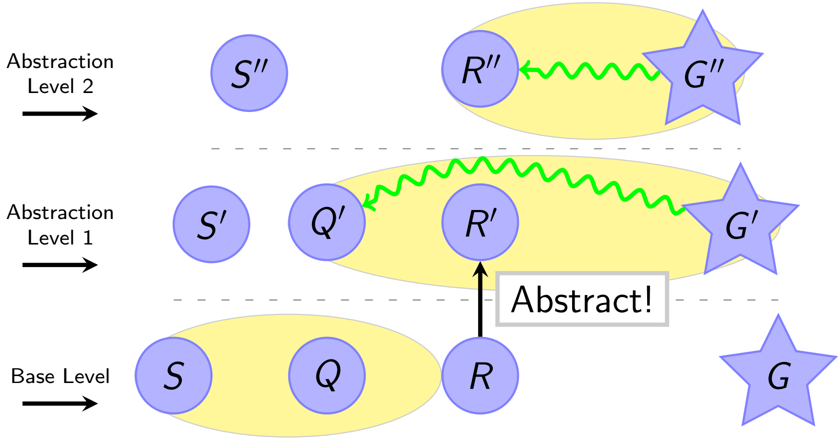

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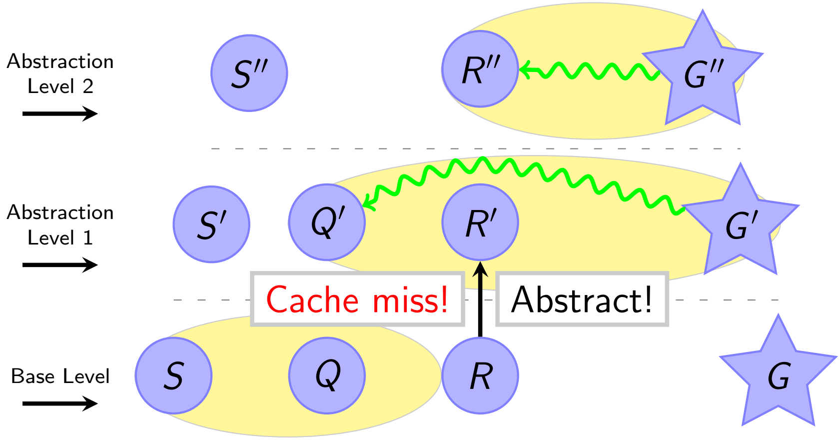
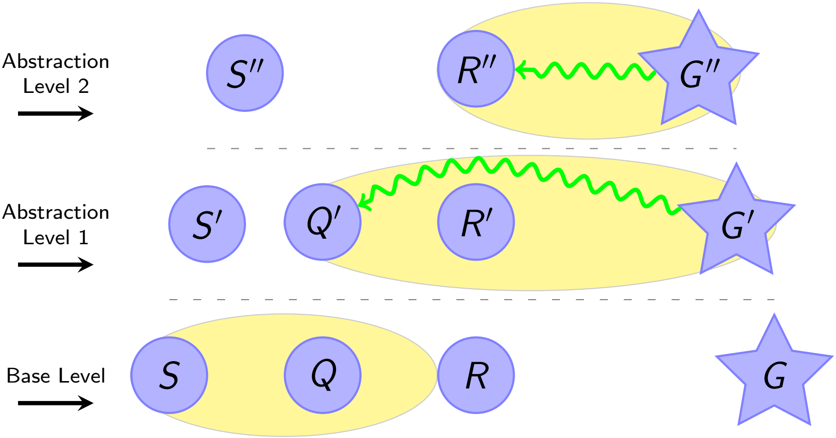


$h^*(R')$ is not cached: must search again.

Hierarchical A* (Holte et al. 1996)



Eventually the search at level 1 finishes.

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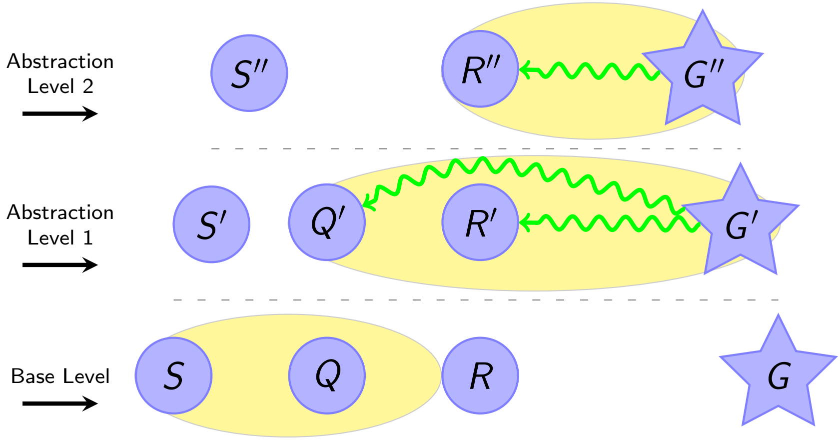

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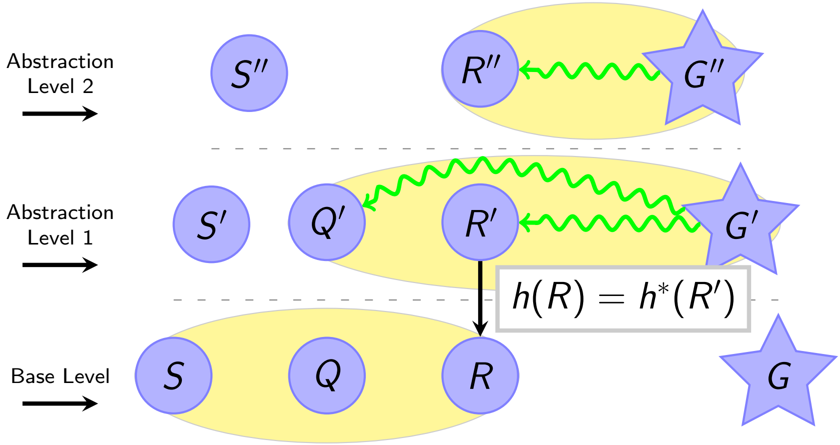

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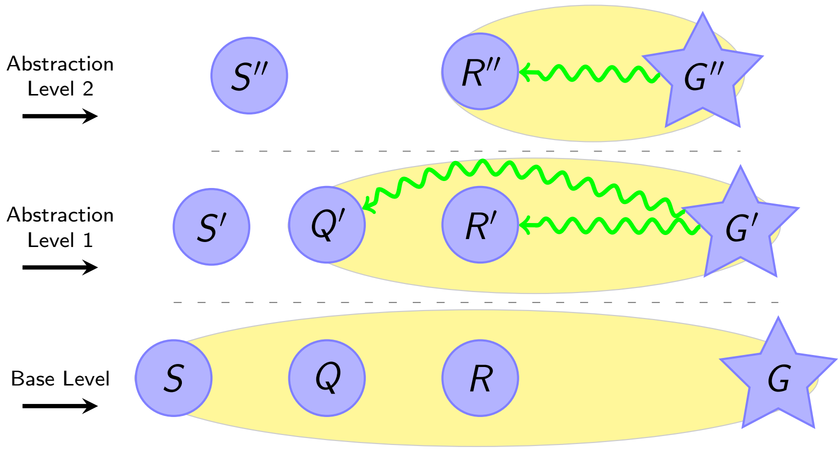


Search proceeds in this manner until finished.

Hierarchical IDA* (Holte et al. 2005)

- Use modified IDA* at each level
- Used effective many-to-one abstractions
- Used instance-specific abstractions
  - specialized to each problem
  - more effective than domain-specific abstraction
- Complicated caching schemes *a la* HA*

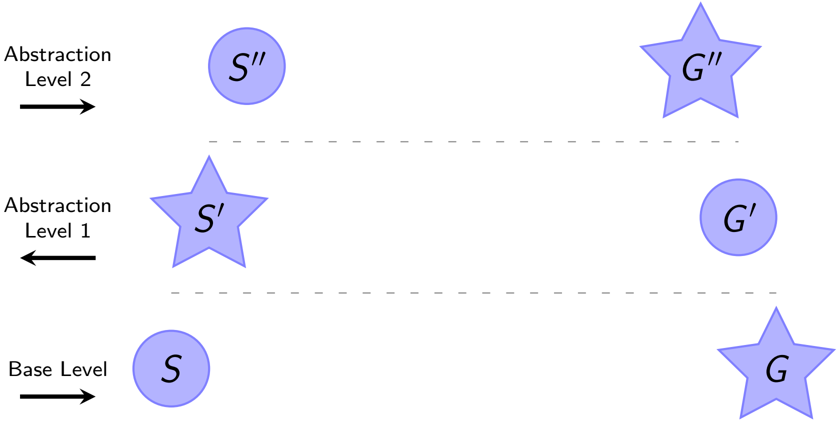
Hierarchical Heuristic Search Benefits

Advantages when solving one or a few instances:

- Abstract space visited lazily
  - No expensive preprocessing!
- Only generates cache entries that are required
- Likely faster & smaller than full PDB
- Natural to use instance-specific abstractions
  - Likely better than domain-specific abstractions

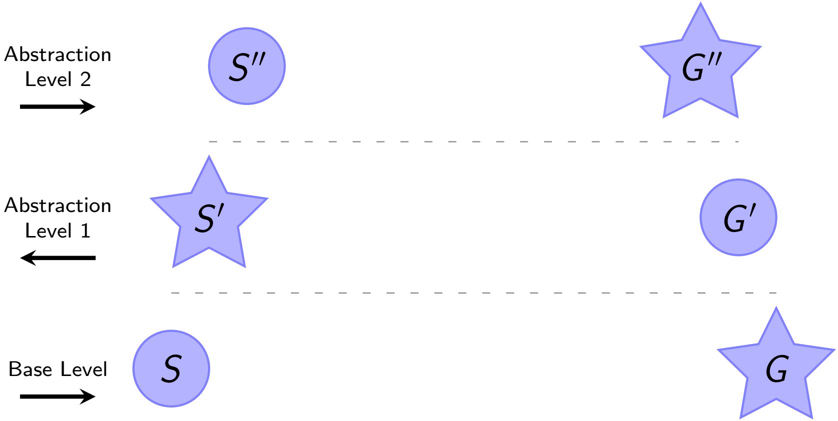
Outline

The Switchback Algorithm



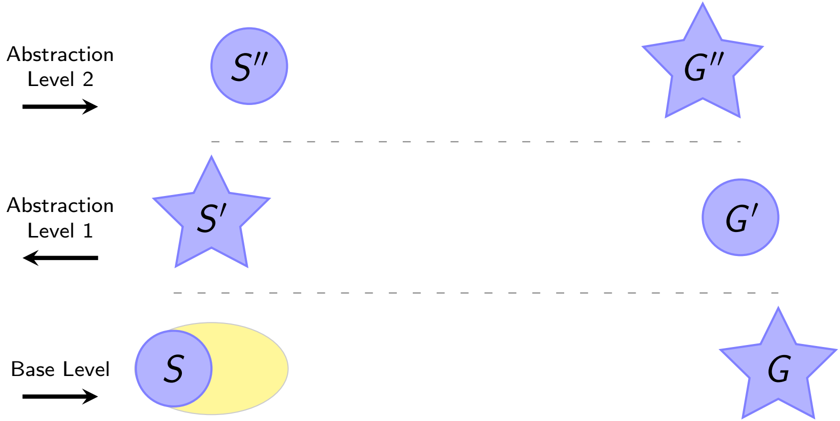
Switchback uses a hierarchy of abstractions.

The Switchback Algorithm



Objective: find the cheapest path from S to G.

The Switchback Algorithm



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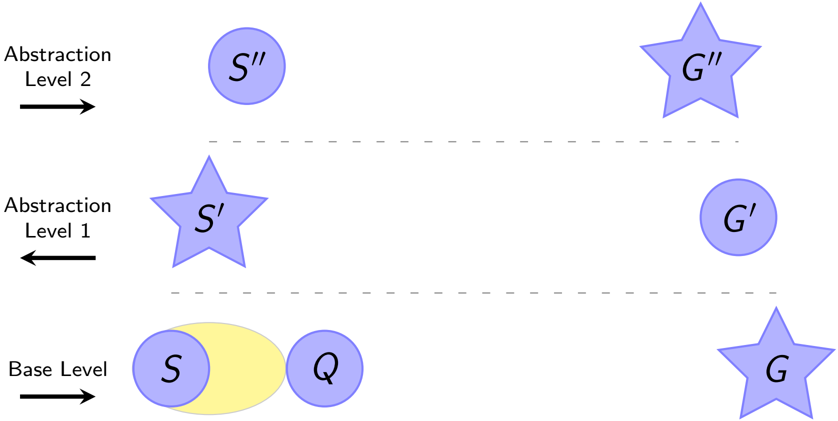
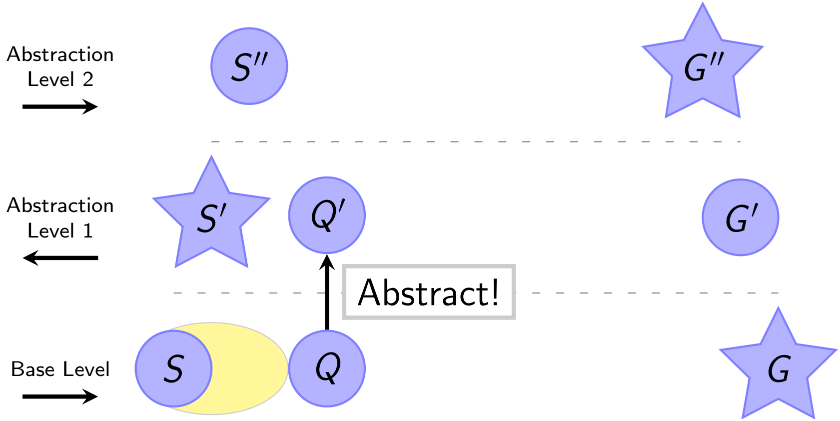


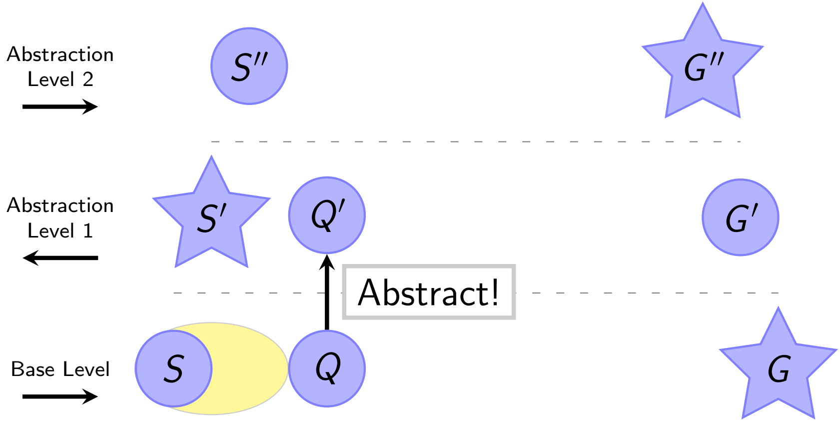
To generate Q, we need to know $h(Q)$.

The Switchback Algorithm



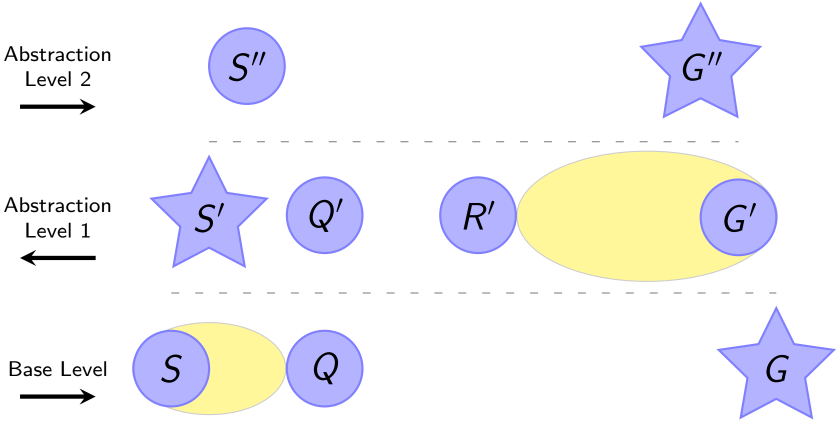
To find $h(Q)$: search backward at level 1.

The Switchback Algorithm



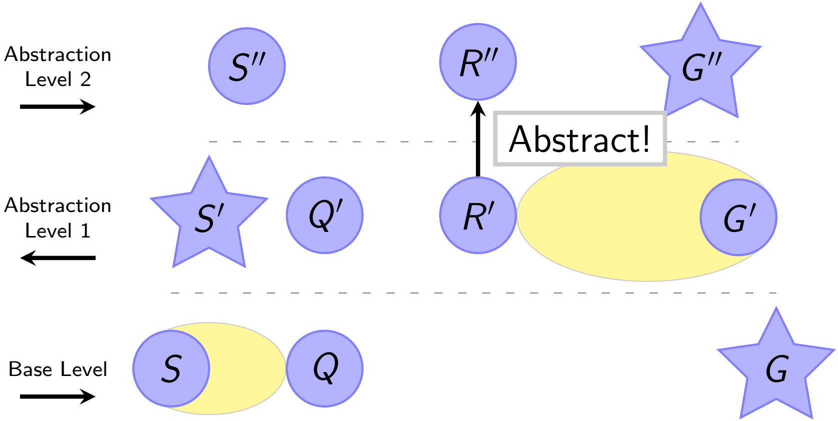
New objective: find cheapest path from G' to Q'.

The Switchback Algorithm



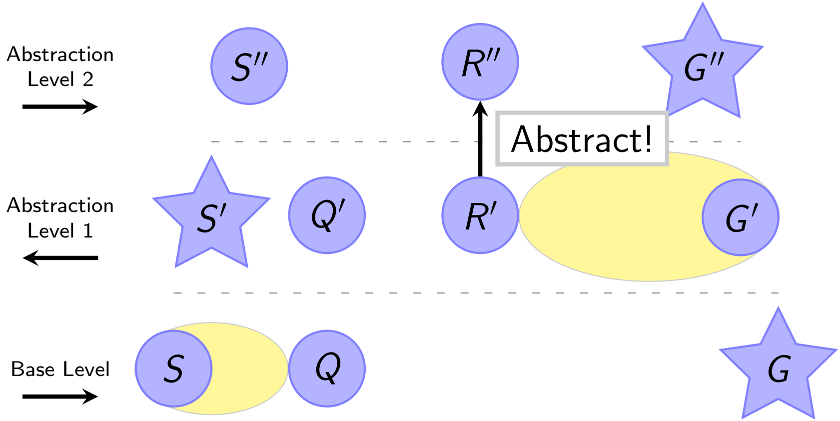
To generate R', we need to know $h(R')$.

The Switchback Algorithm



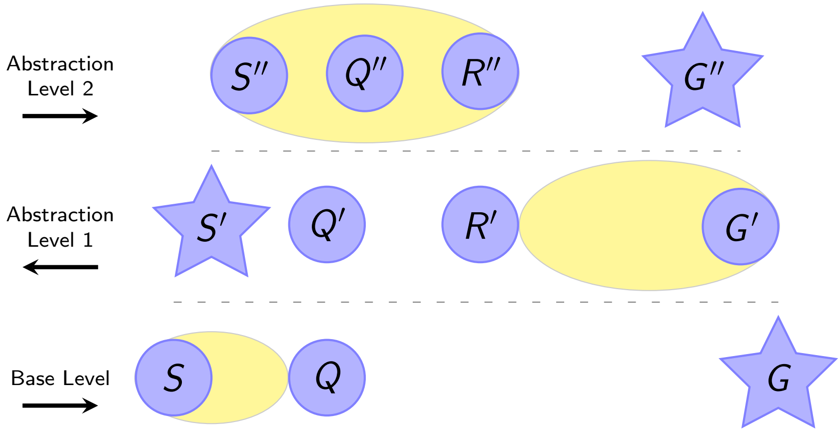
To find $h(R')$: search forward at level 2.

The Switchback Algorithm



New objective: find cheapest path from S'' to R''.

The Switchback Algorithm



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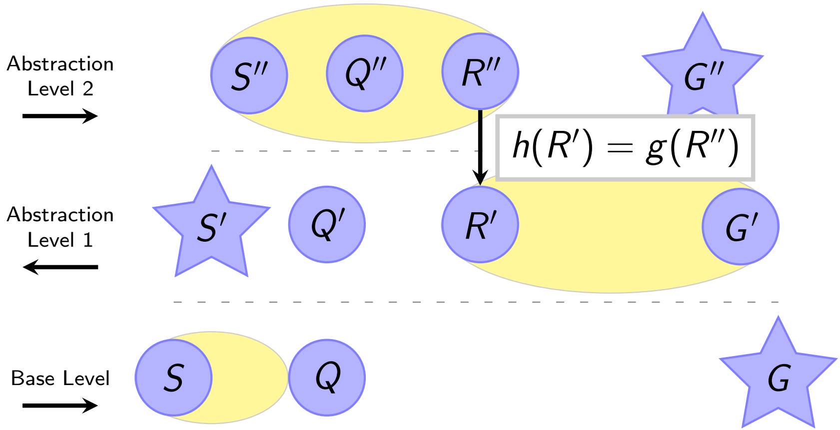
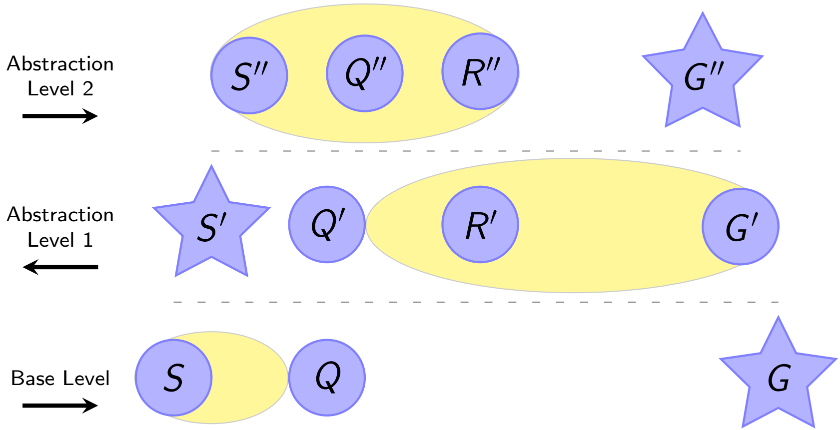


Use cost to R'' at level 2 as $h(R')$.

The Switchback Algorithm



To generate Q', we need to know $h(Q')$.

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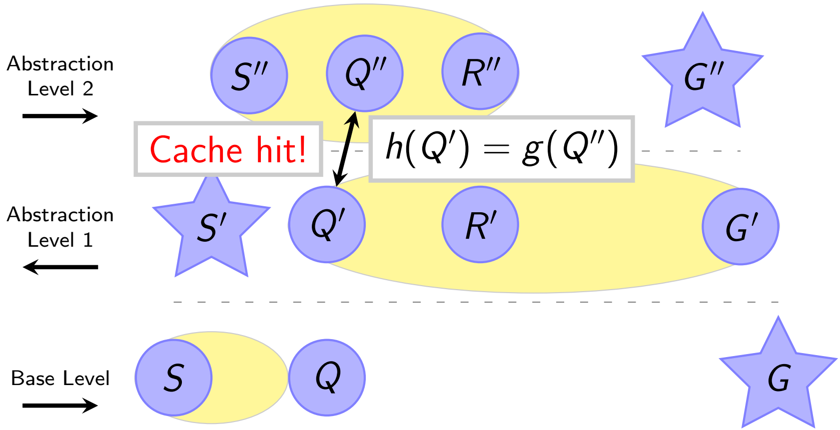
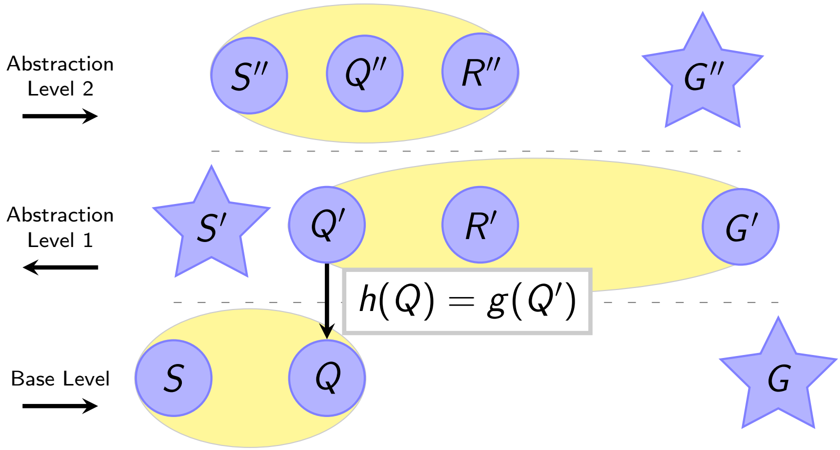


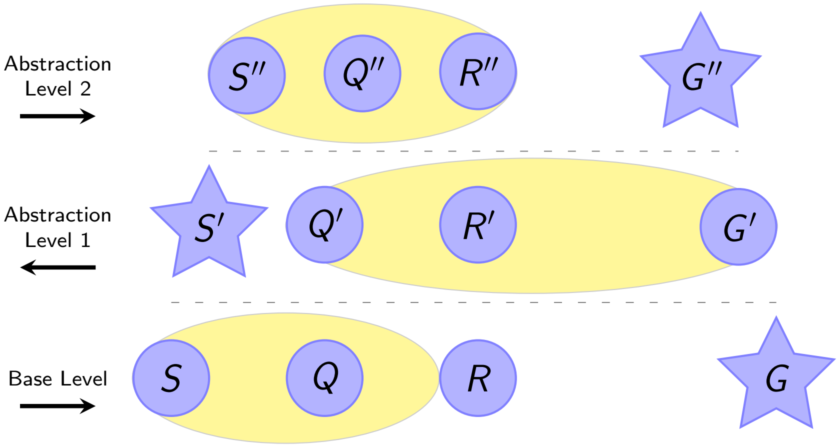
To find $h(Q')$: use cached cost to Q''.

The Switchback Algorithm



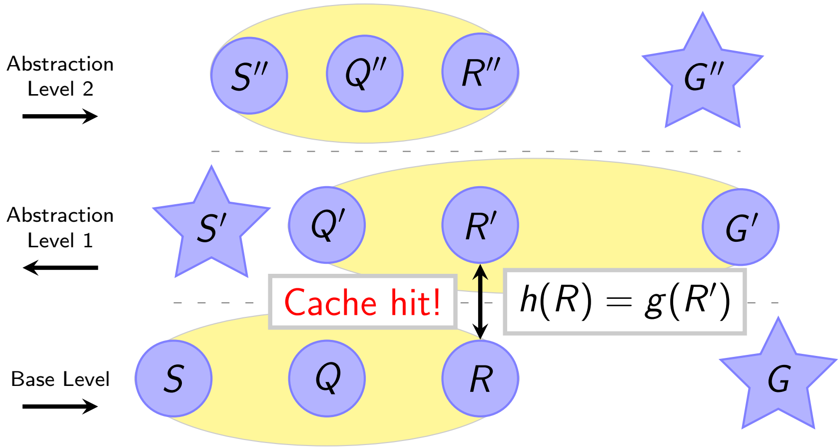
Use cost to Q' at level 1 as $h(Q)$.

The Switchback Algorithm



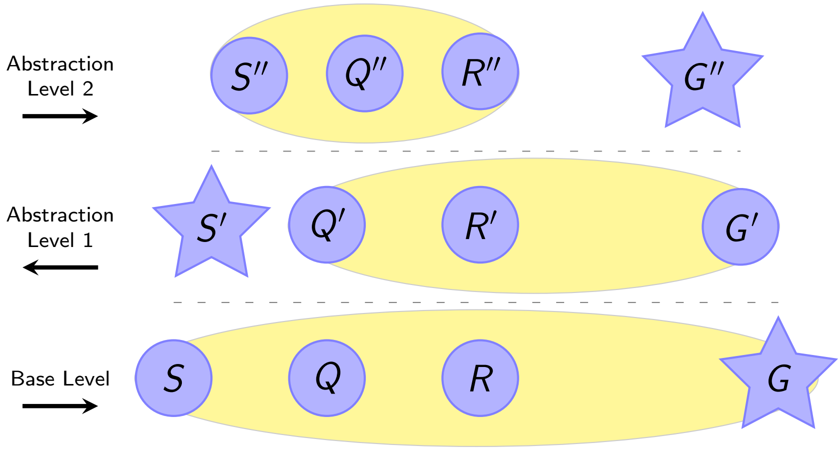
To generate R, we need to know $h(R)$.

The Switchback Algorithm



To find $h(R)$: use cached cost to R'.

The Switchback Algorithm



Search proceeds in this manner until finished.

Properties of Switchback

- Complete: terminates with solution if one exists
- Admissible: finds optimal solutions
- Efficient: expands states at most once
- See paper for details!

Outline

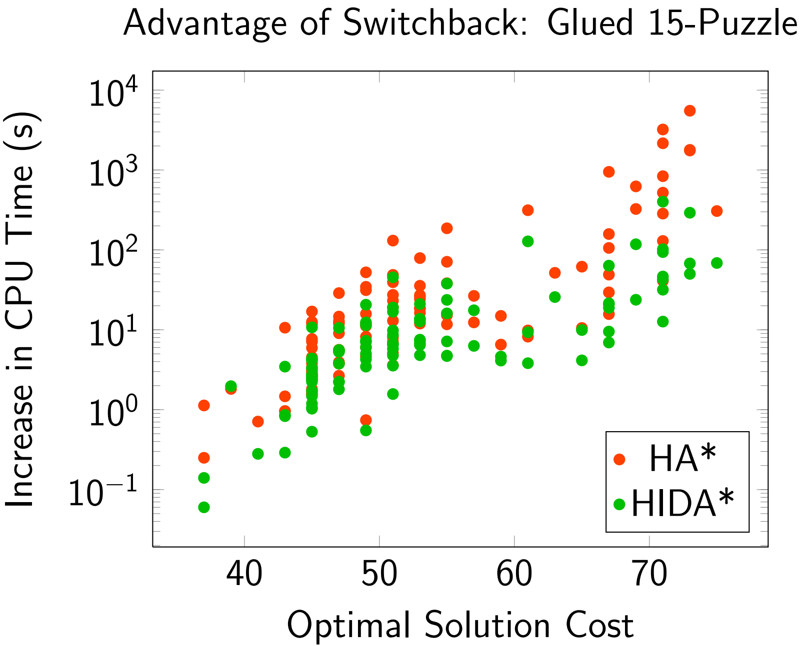
Experimental Setup

- HA*, HIDA*, and Switchback
- Several semi-standard domains
- Used custom abstraction hierarchies given by Holte et al. (2005)
- C++ implementation
- 47 GB memory limit, no time limit

Experimental Results: Glued 15-Puzzle

Averages from 100 instances

	CPU Time (s)		Nodes Gen. (M)	
Algorithm	Mean	Max	Mean	Max
Switchback	5	70	6	77
HA*	137	3286	12	99
HIDA*	21	172	20	132


Advantage of Switchback: Glued 15-Puzzle
Increase in CPU Time (s)
10^4
10^3
10^2
10^1
10^0
10^{-1}
40
50
60
70
Optimal Solution Cost
HA*
HIDA*

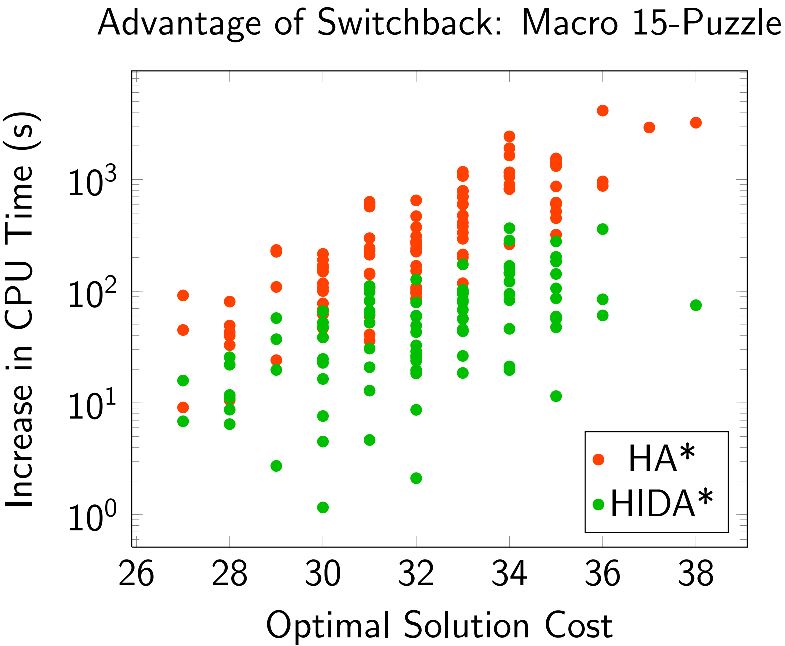
The Macro Tiles Puzzle

- Sliding tile puzzle variant
- Multiple tiles can be moved in one step
- Manhattan distance inadmissible
- Shallower solutions
- Higher branching factor
- More transpositions in state graph

Experimental Results: Macro 15-Puzzle

Averages from 100 instances

	CPU Time (s)		Nodes Gen. (M)	
Algorithm	Mean	Max	Mean	Max
Switchback	161	1127	182	948
HA*	708	4647	236	1074
HIDA*	223	1202	350	1746



Advantage of Switchback: Macro 15-Puzzle
Increase in CPU Time (s)
10^0
10^1
10^2
10^3
26
28
30
32
34
36
38
Optimal Solution Cost
HA*
HIDA*

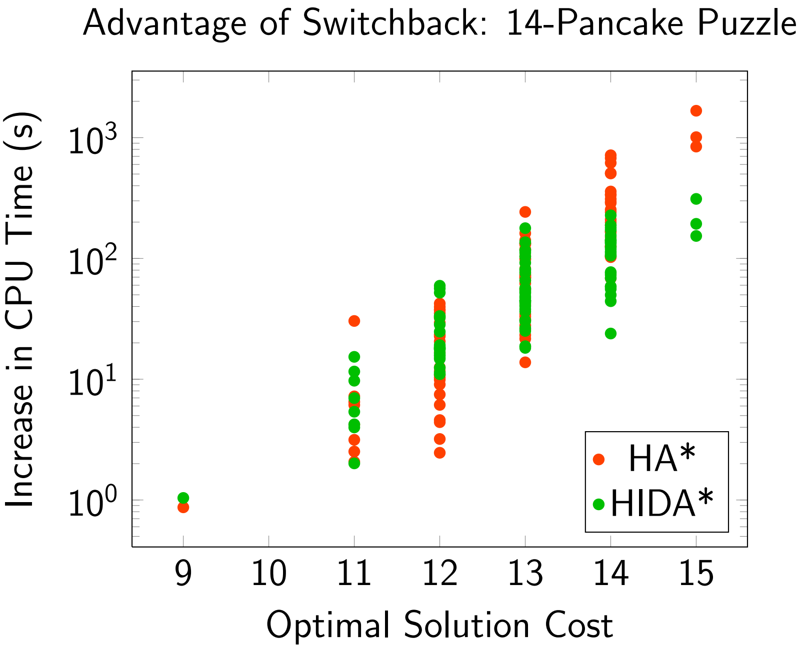
The Pancake Puzzle

- $\boxed{4 \mid 3 \mid 2 \mid 1 \mid 5} \rightarrow \boxed{1 \mid 2 \mid 3 \mid 4 \mid 5}$
- Goal: arrange numbers in order
- Can flip prefixes of the sequence
- Shallow solutions
- High branching factor

Experimental Results: 14-Pancake Puzzle

Averages from 100 instances

	CPU Time (s)		Nodes Gen. (M)	
Algorithm	Mean	Max	Mean	Max
Switchback	22	114	29	123
HA*	168	1772	38	156
HIDA*	89	401	87	311



Advantage of Switchback: 14-Pancake Puzzle
Increase in CPU Time (s)
10^0
10^1
10^2
10^3
9
10
11
12
13
14
15
Optimal Solution Cost
HA*
HIDA*

Summary

- Hierarchical search is an alternative to PDBs
  - Fills cache lazily
  - Can solve many problems in time to build PDB
  - Natural to use instance-specific abstractions
  - No cached heuristic values wasted

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- Switchback is a better hierarchical search
  - avoids abstract state re-expansion
  - simple caching scheme
  - easy to implement

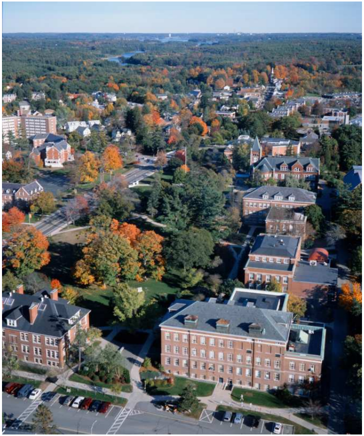
Summary

- Hierarchical search is an alternative to PDBs
  - Fills cache lazily
  - Can solve many problems in time to build PDB
  - Natural to use instance-specific abstractions
  - No cached heuristic values wasted
- Switchback is a better hierarchical search
  - avoids abstract state re-expansion
  - simple caching scheme
  - easy to implement
- Switchback should be widely applicable
  - when predecessor states easily computed
  - when good abstraction hierarchy available

The University of New Hampshire

Tell your students to apply to grad school in CS at UNH!

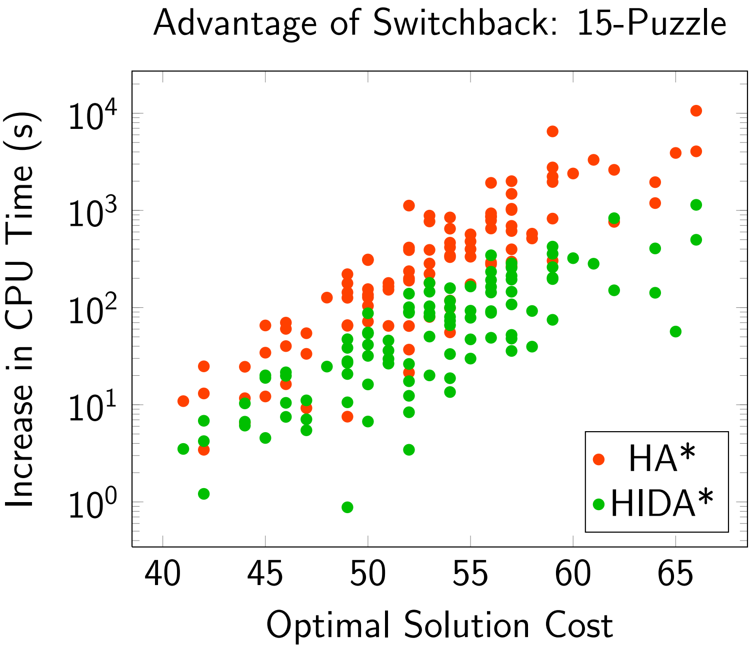
- friendly faculty
- funding
- individual attention
- beautiful campus
- low cost of living
- easy access to Boston, White Mountains
- strong in AI, infoviz, networking



Experimental Results: 15-Puzzle

Averages from 100 instances

	CPU Time (s)		Nodes Gen. (M)	
Algorithm	Mean	Max	Mean	Max
Switchback	83	1422	65	713
HA*	831	12034	110	1222
HIDA*	194	2563	197	2158


Advantage of Switchback: 15-Puzzle
Increase in CPU Time (s)
10^4
10^3
10^2
10^1
10^0
40
45
50
55
60
65
Optimal Solution Cost
HA*
HIDA*