A* Tie-Breaking Strategies in Fast Downward

Bachelor's Thesis Presentation

University of Basel

Artificial Intelligence Research Group

University of Basel

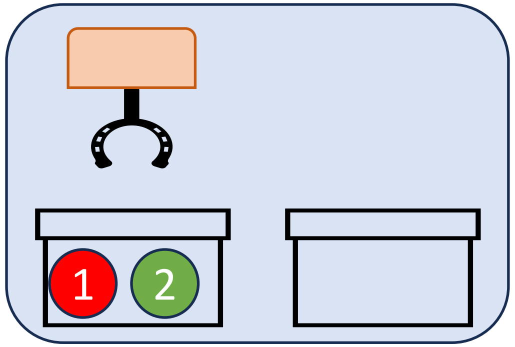
Mirco Franco

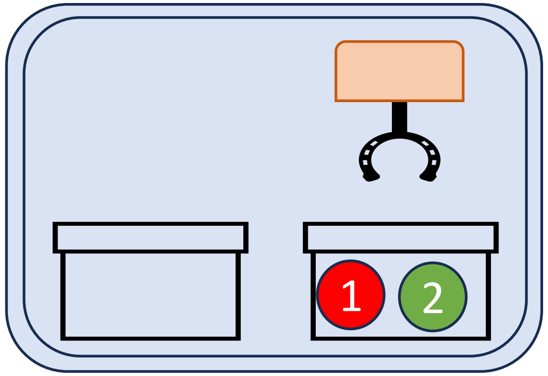
21. July 2025

Overview

- Background
- Tie-Breaking
- Depth-Diversification
- Distance-to-go
- Evaluation
- Conclusion

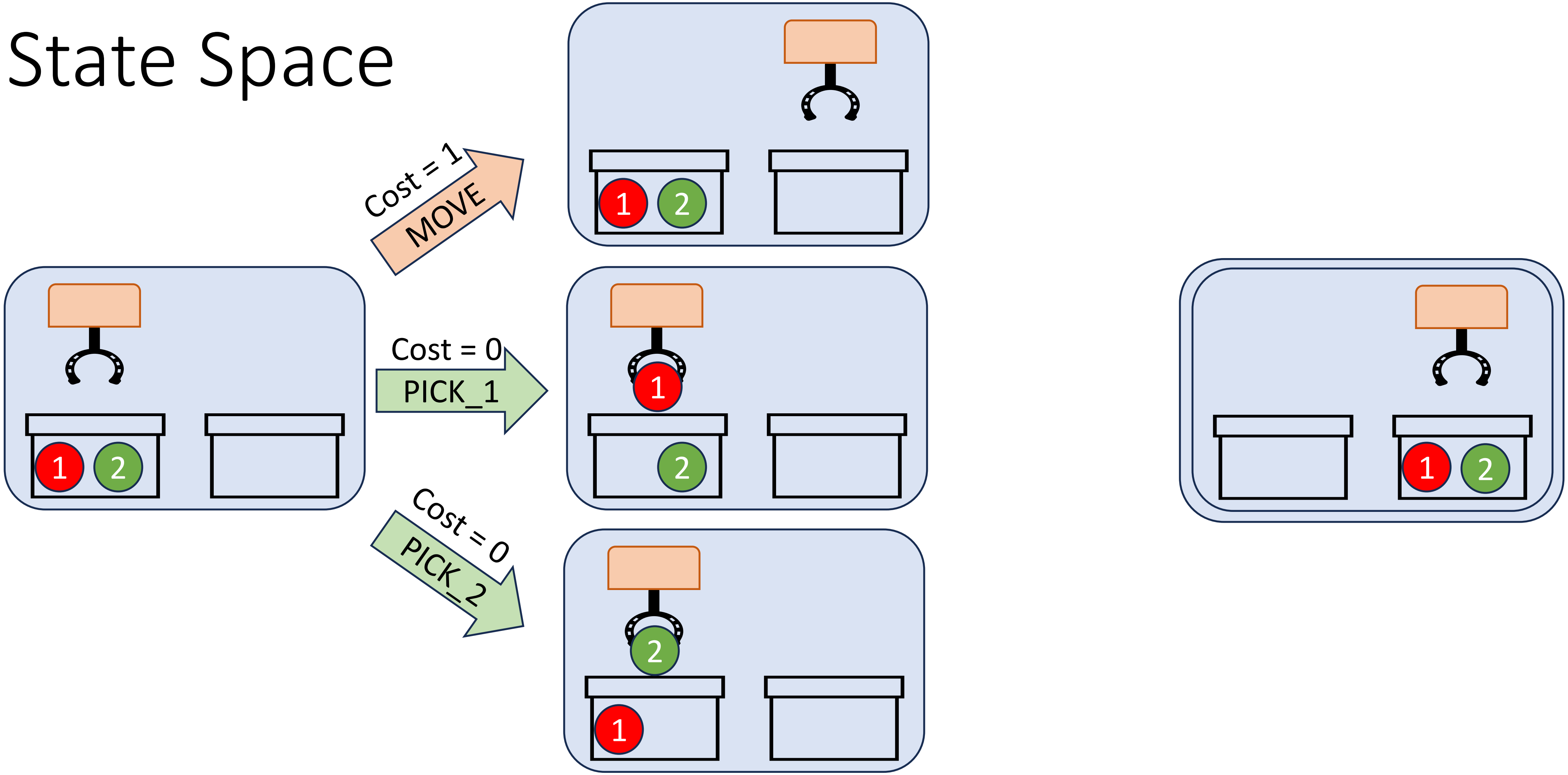
State Space



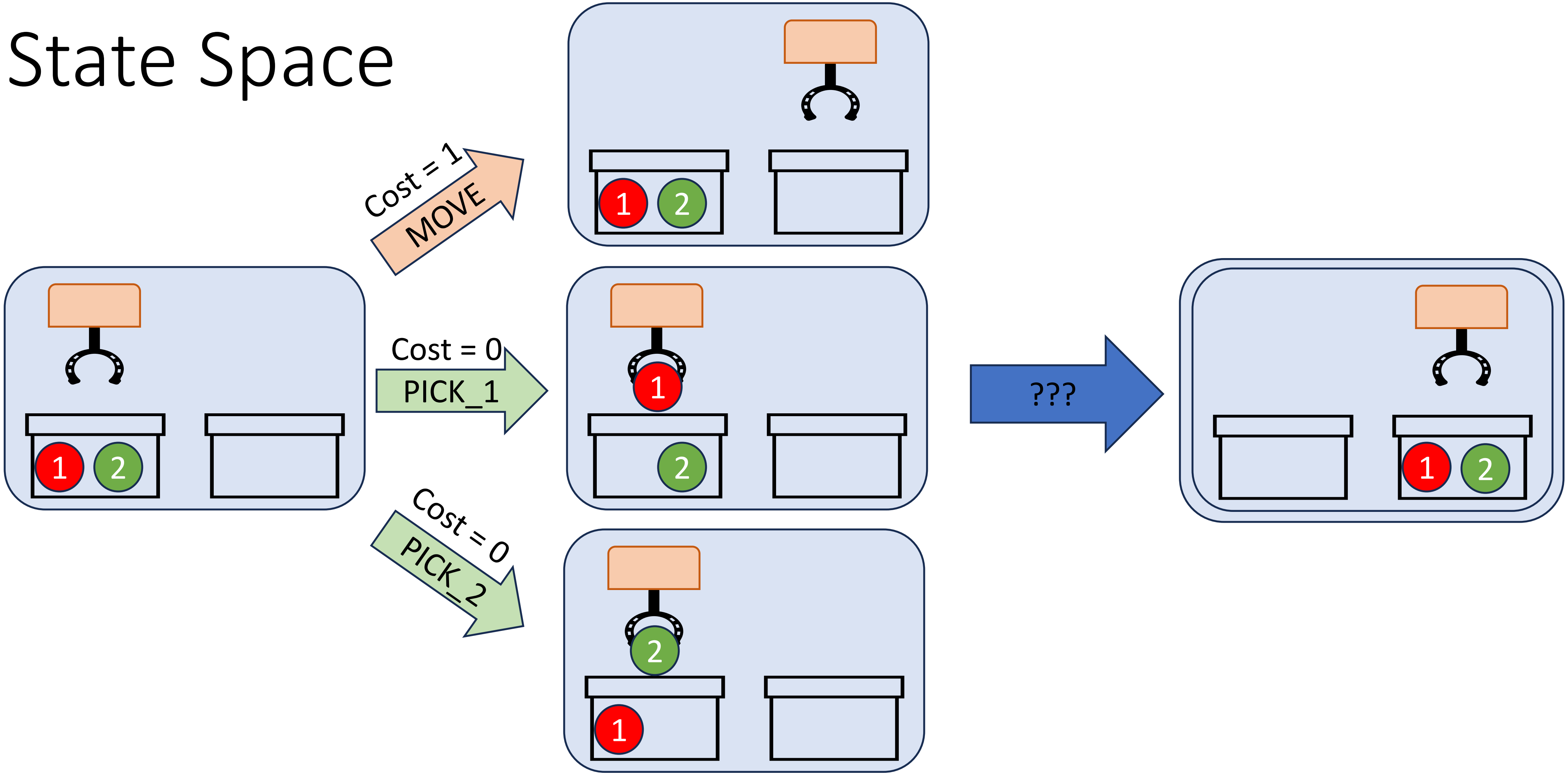


State Space

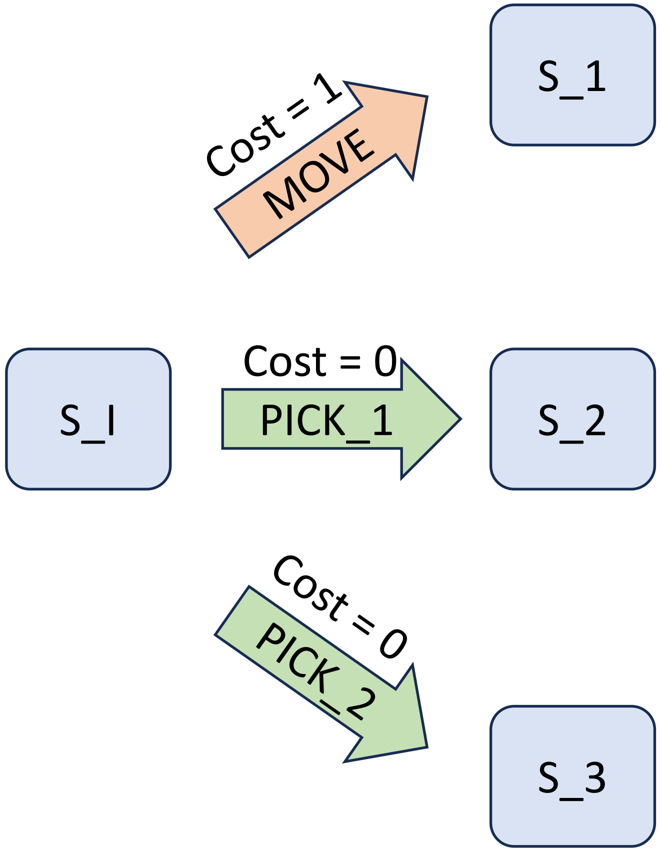
State Space



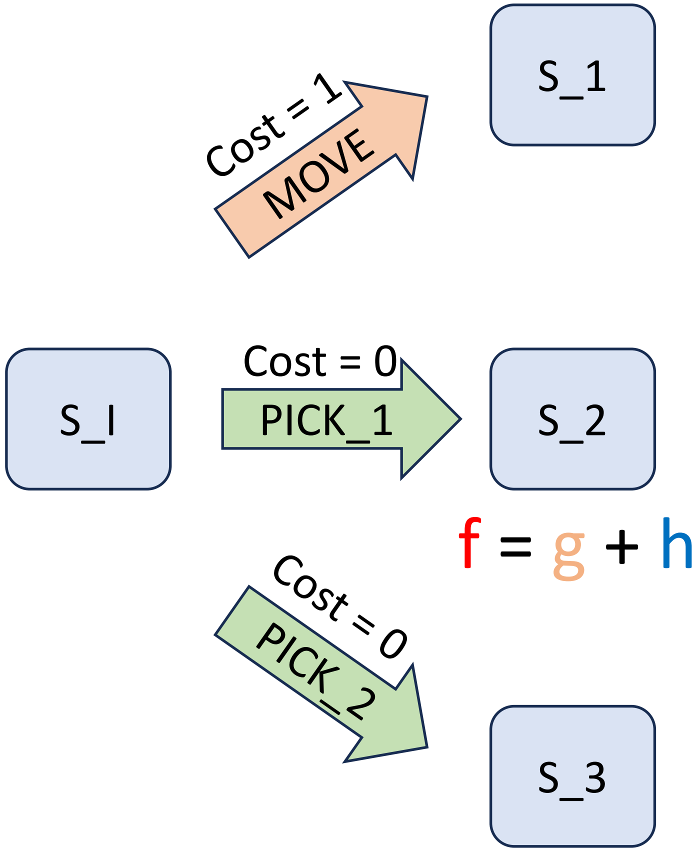
State Space



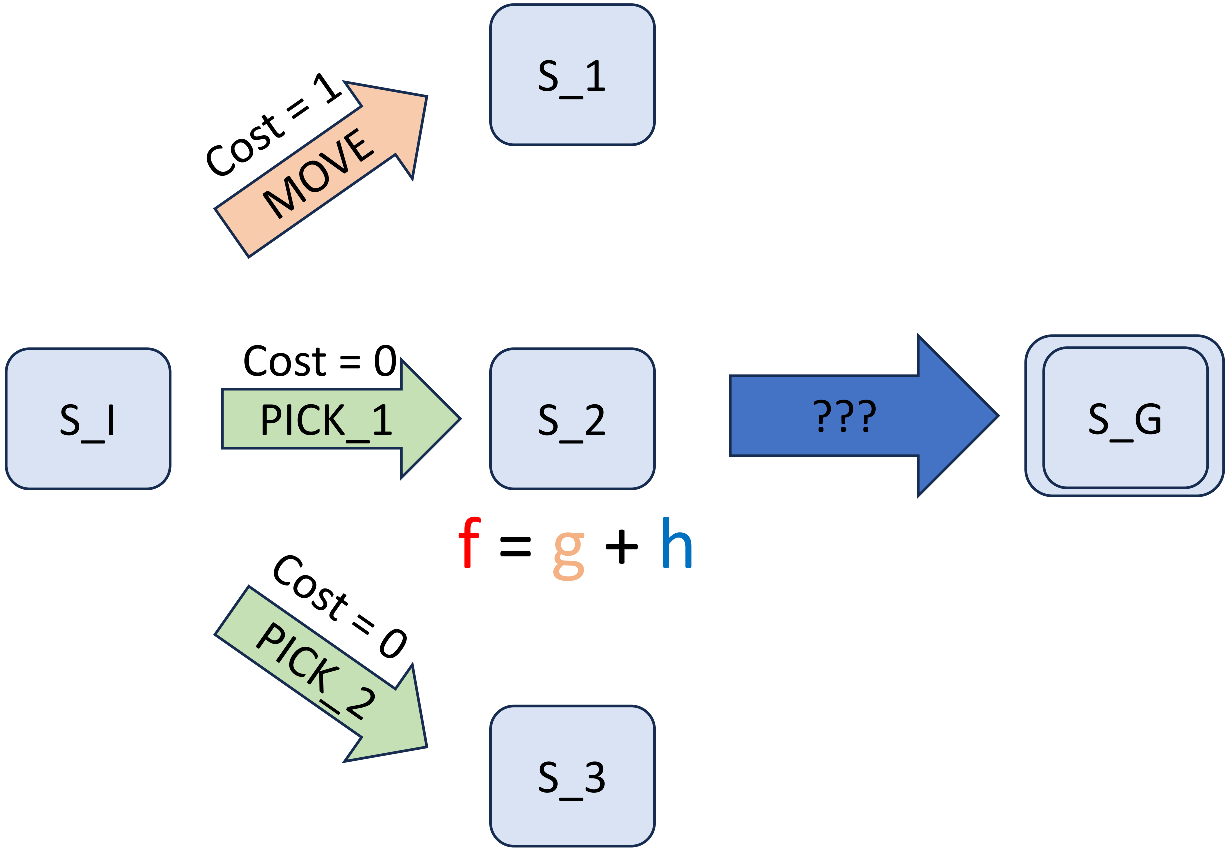
A* search algorithm



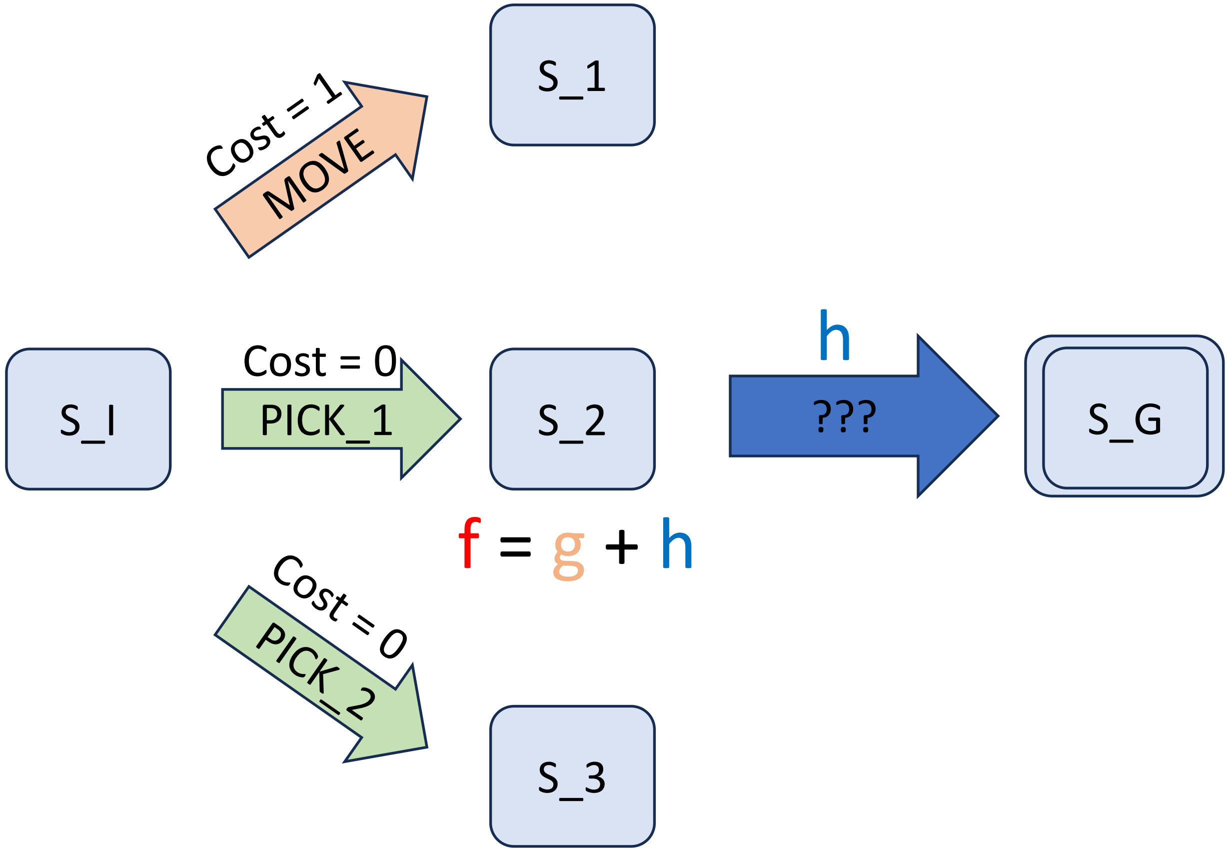
A* search algorithm



A* search algorithm

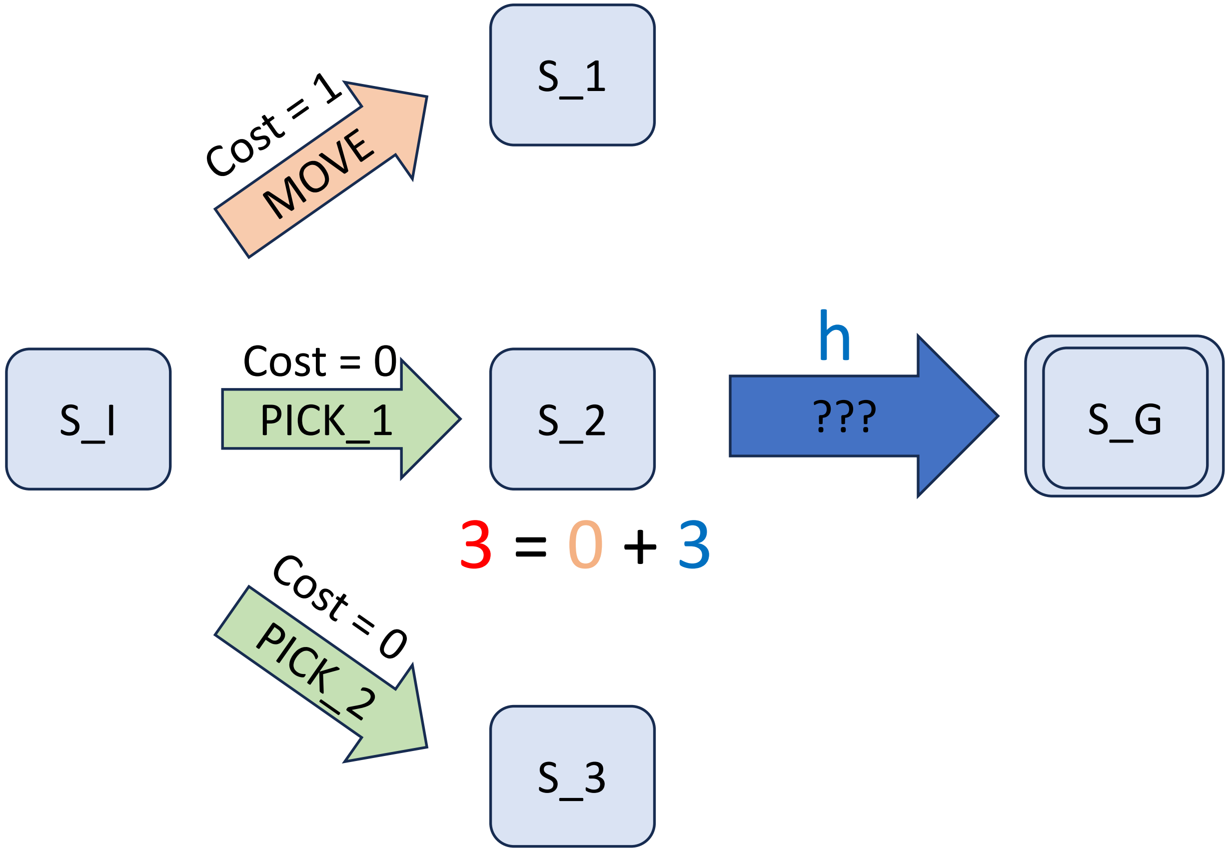


A* search algorithm

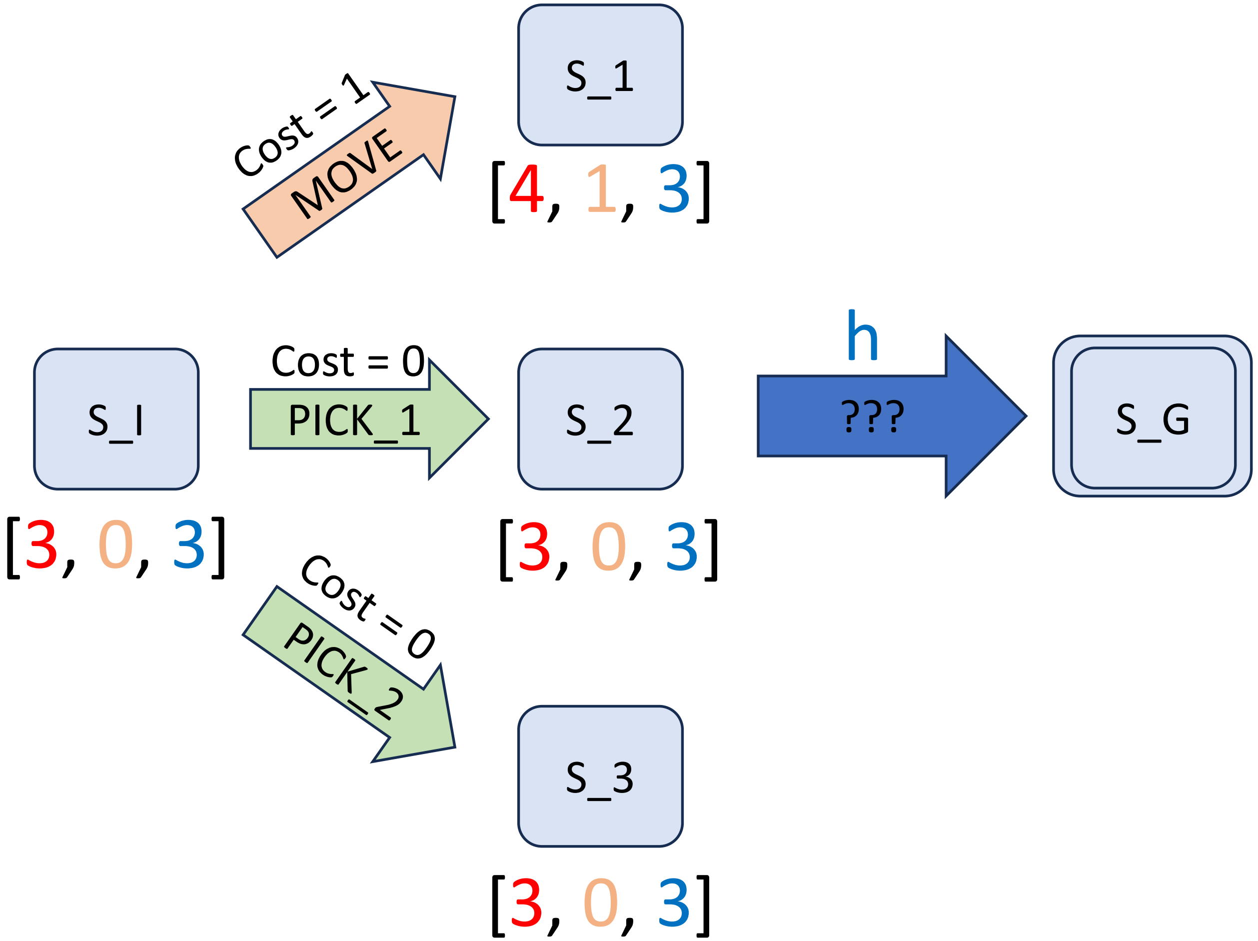


LM-cut and Merge&Shrink are admissible heuristics

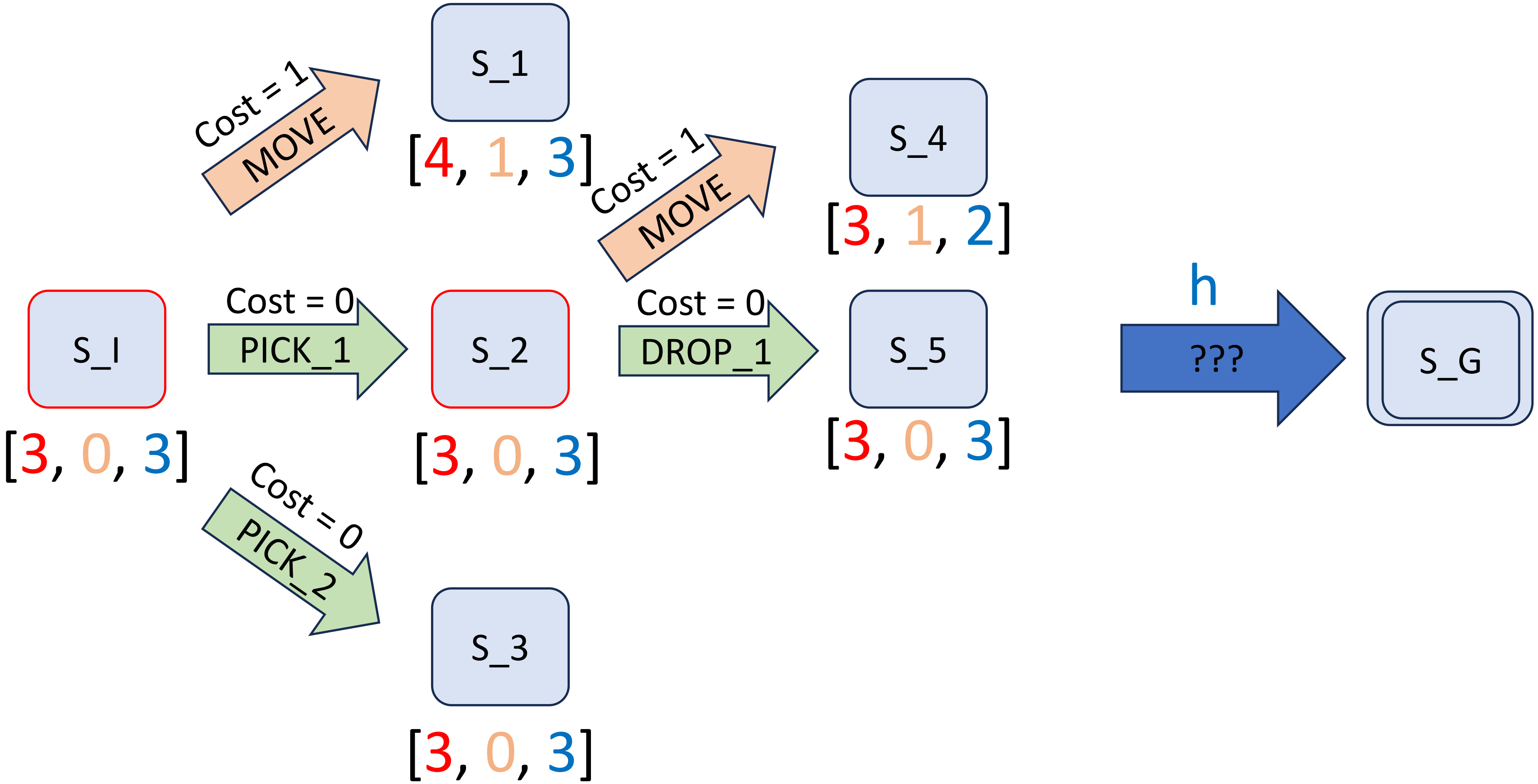
A* search algorithm



A* search algorithm

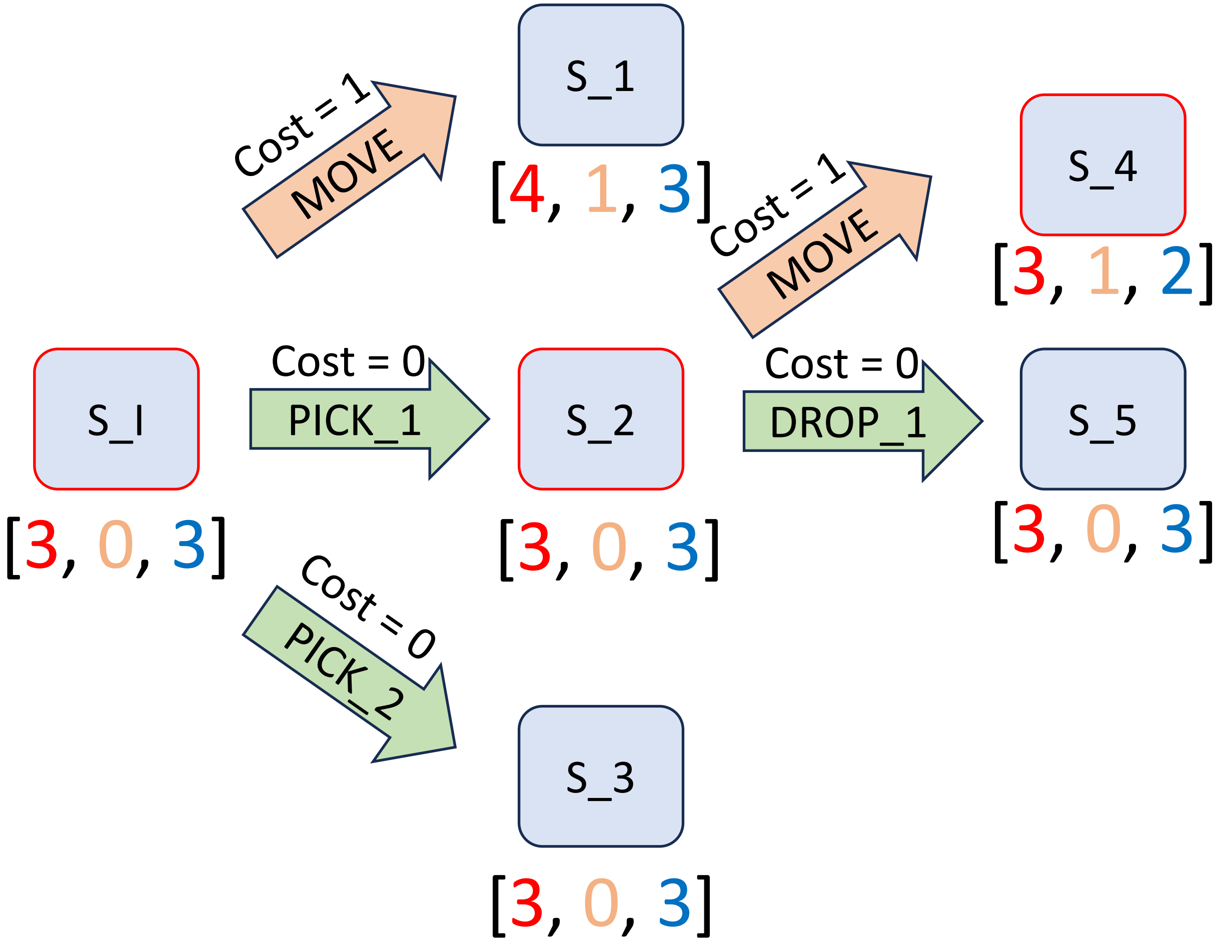


A* search algorithm



A* search algorithm

Configuration:
[f, h, *]



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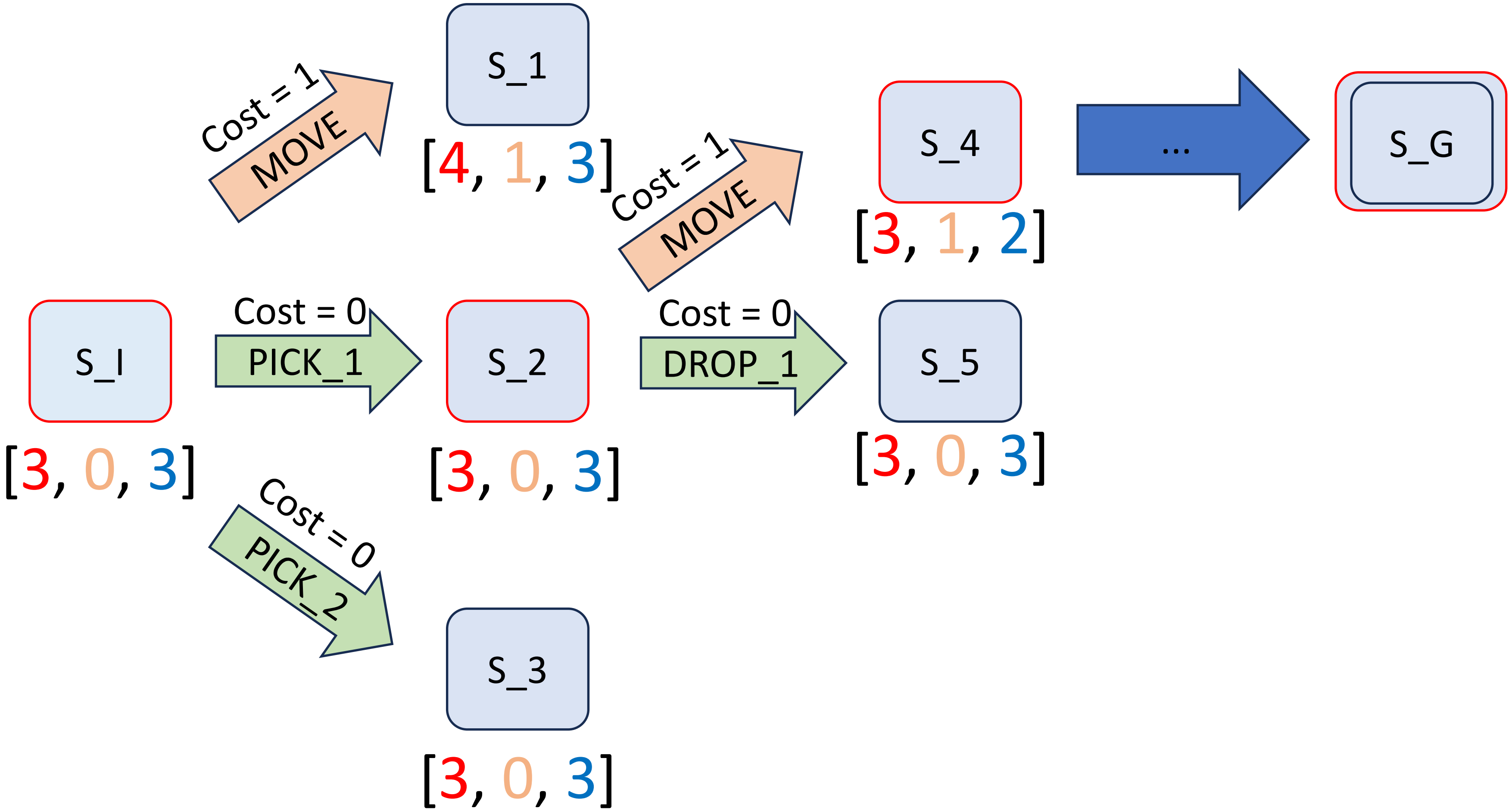
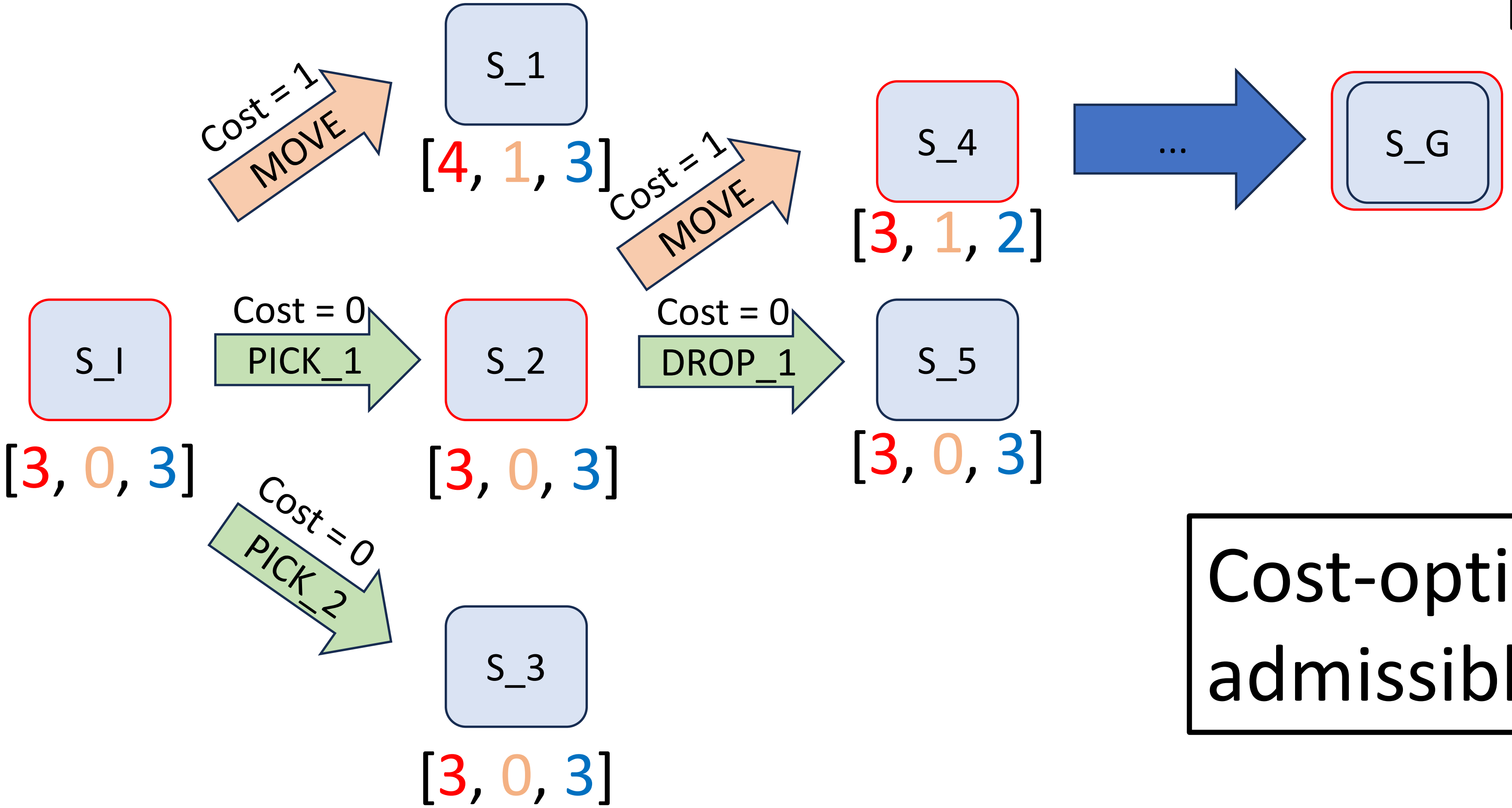
A* search algorithm

Configuration:
[f, h, *]



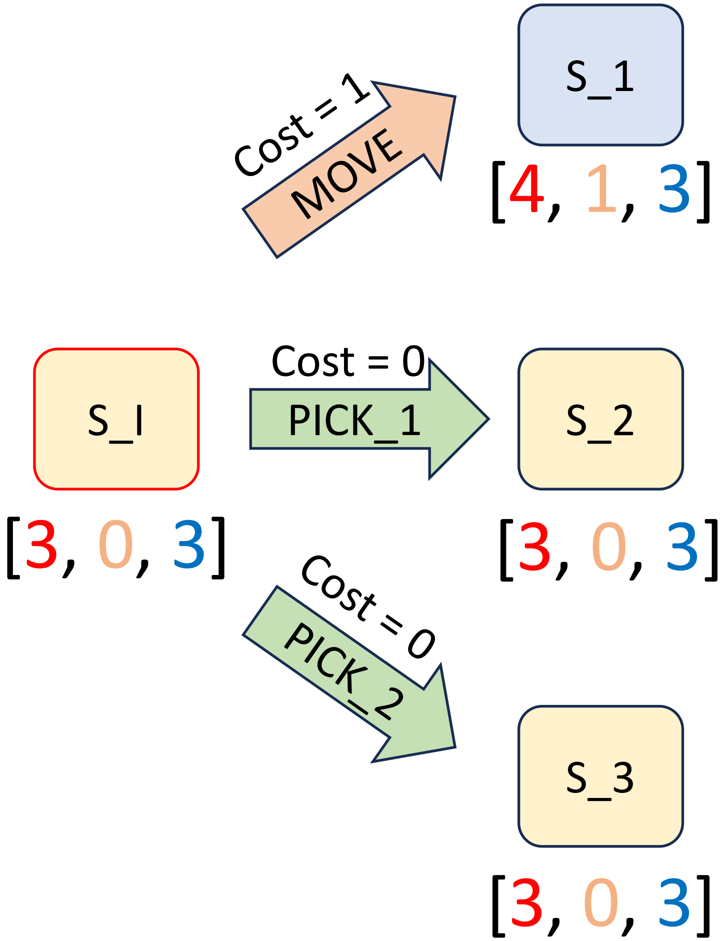
A* search algorithm

Configuration:
[f, h, *]

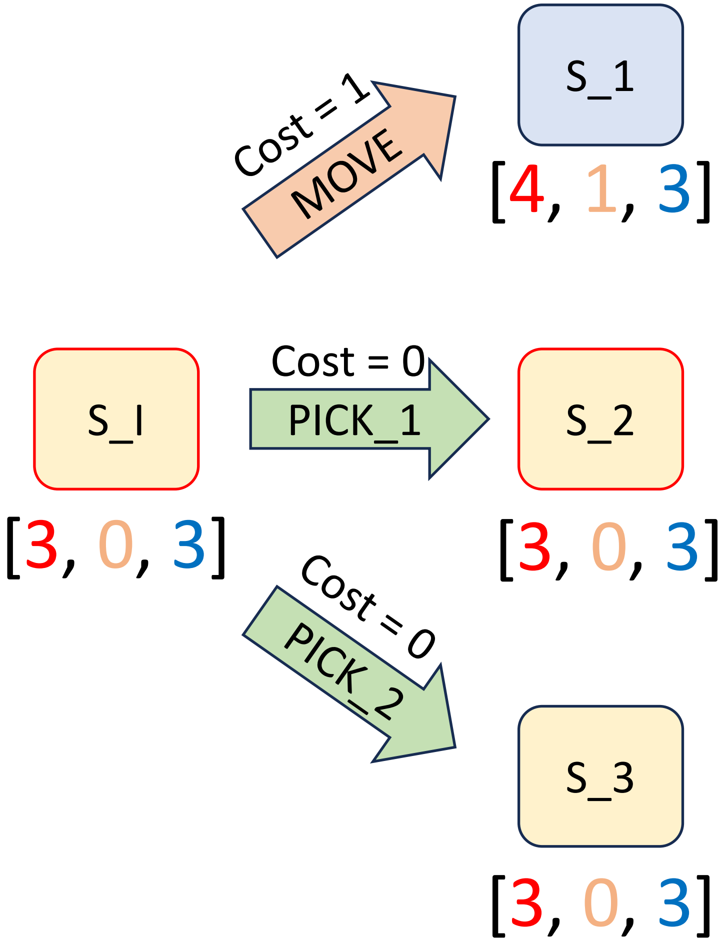


Cost-optimal with admissible heuristics

Tie-Breaking



Tie-Breaking



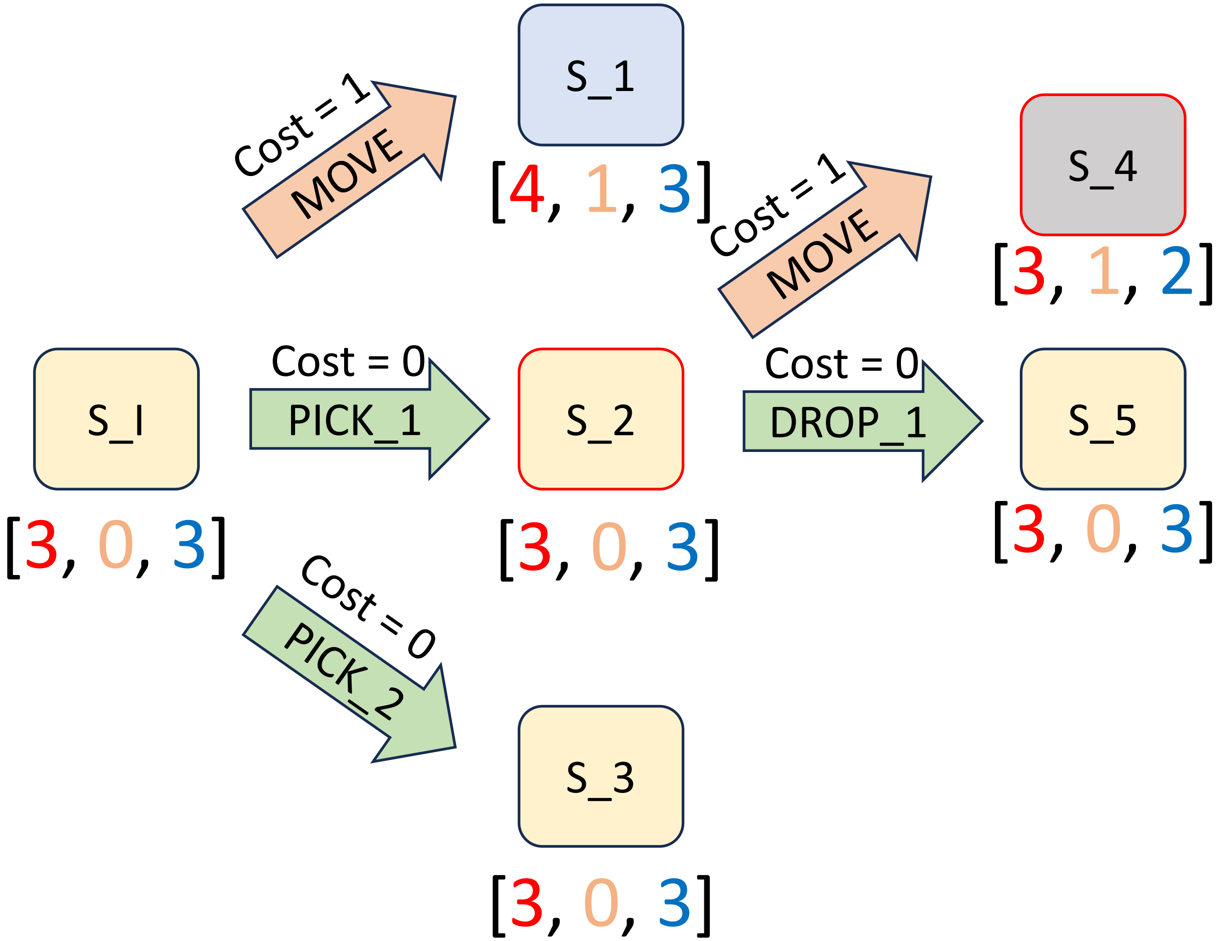
Default Tie-Breaker:

FIFO

LIFO

Random

Tie-Breaking



Configuration:

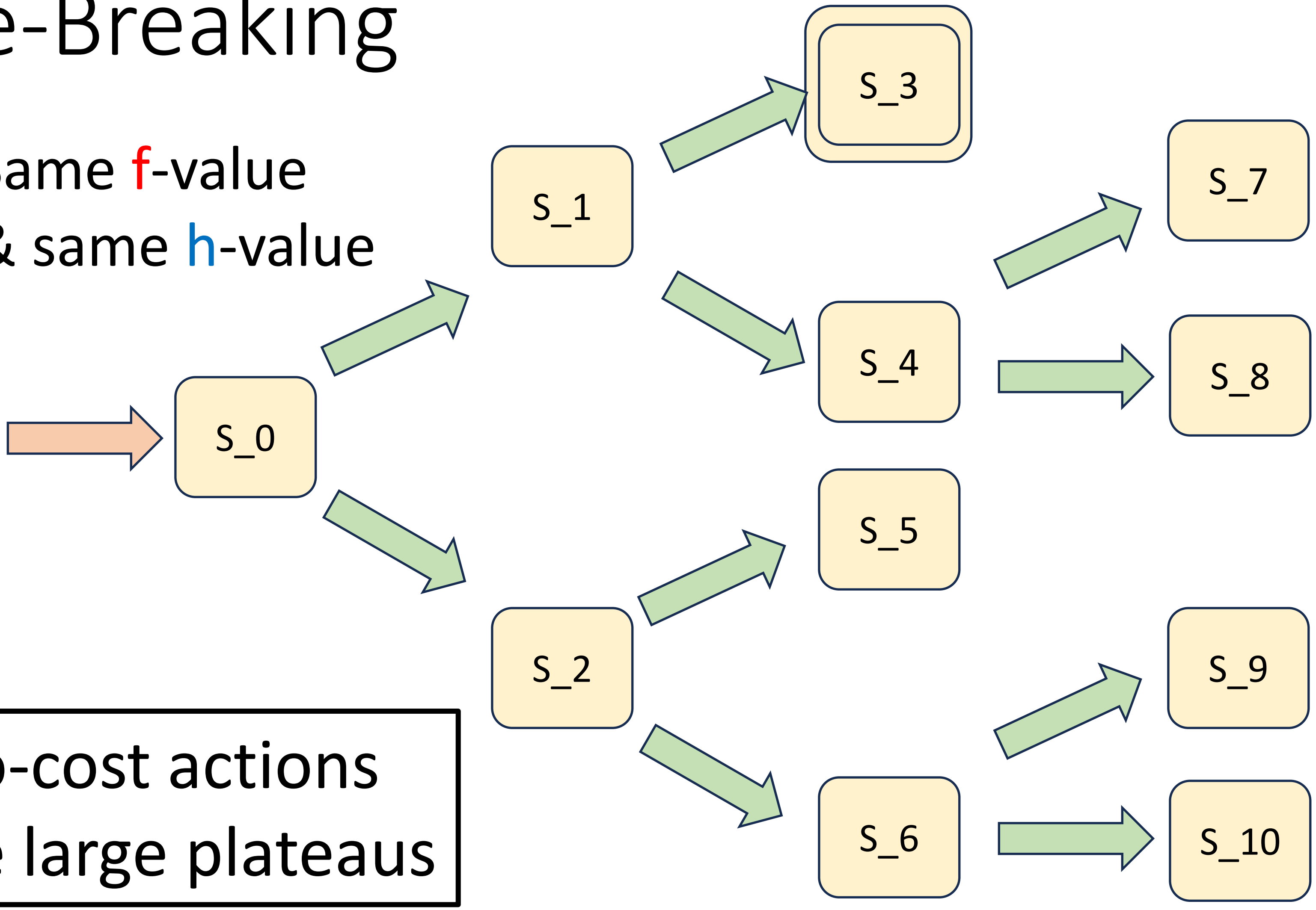
[f, h, FIFO]

[f, h, LIFO]

[f, h, RO]

Tie-Breaking

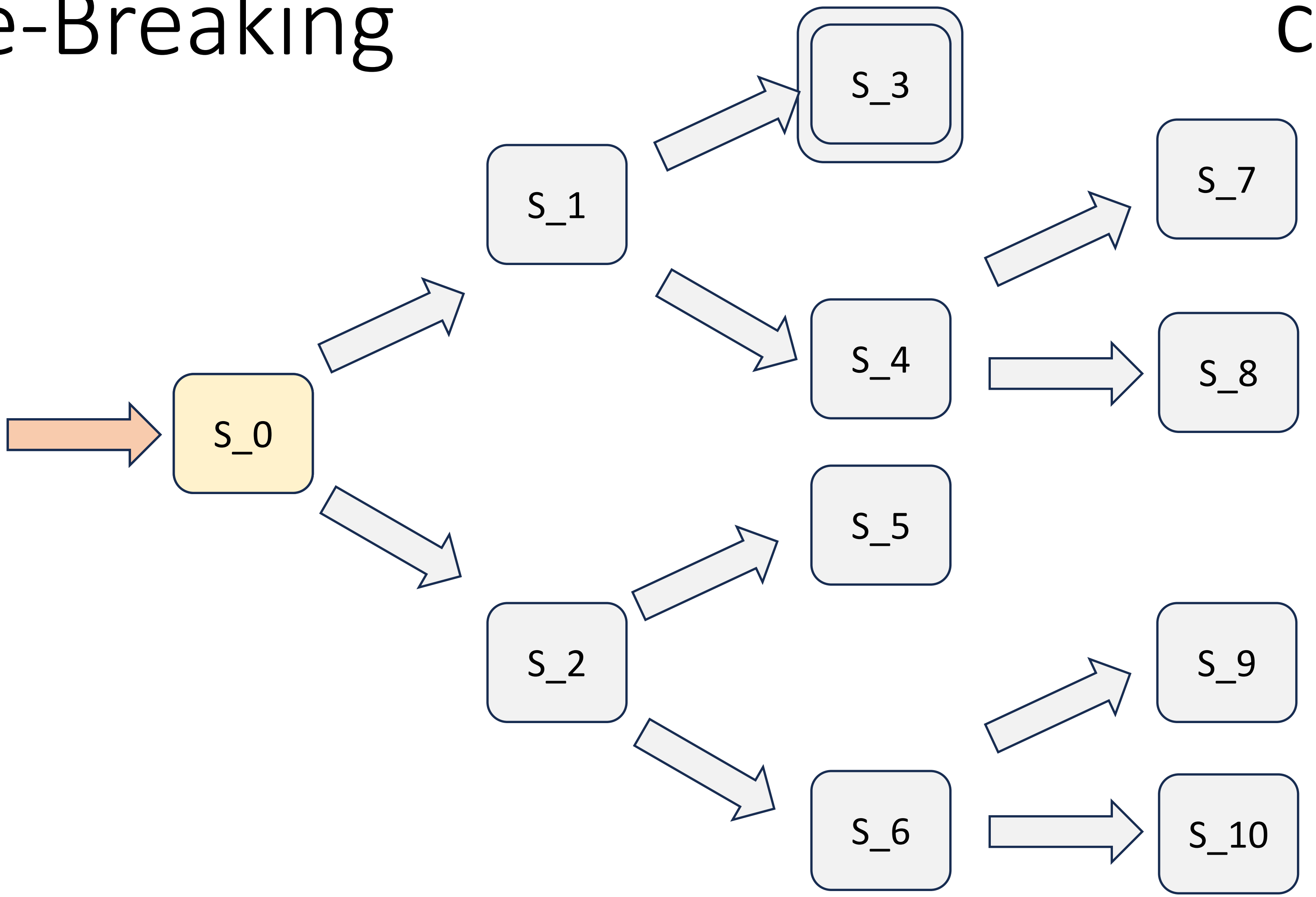
Same f-value
& same h-value



Zero-cost actions create large plateaus

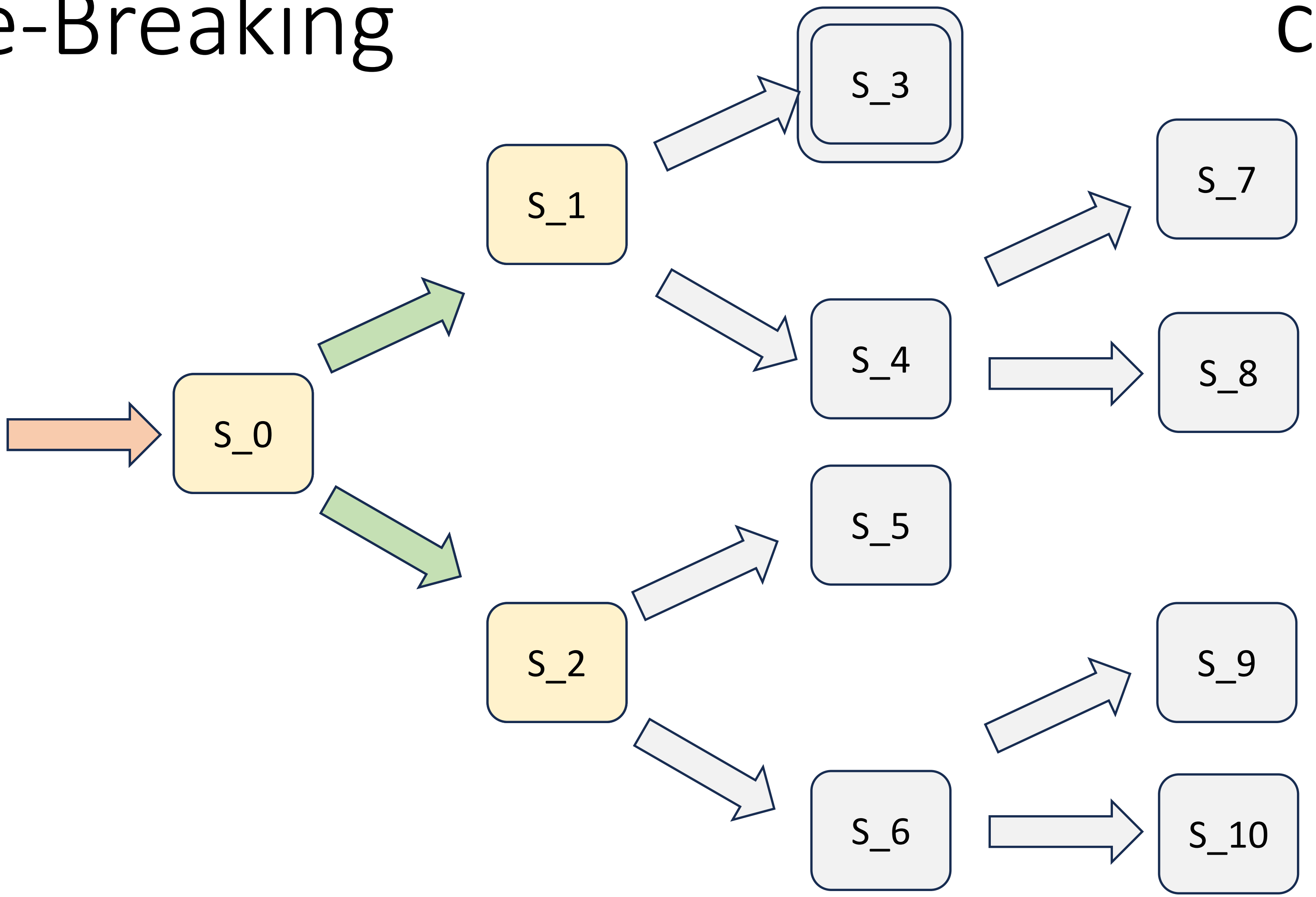
Tie-Breaking

Configuration:
[f, h, FIFO]



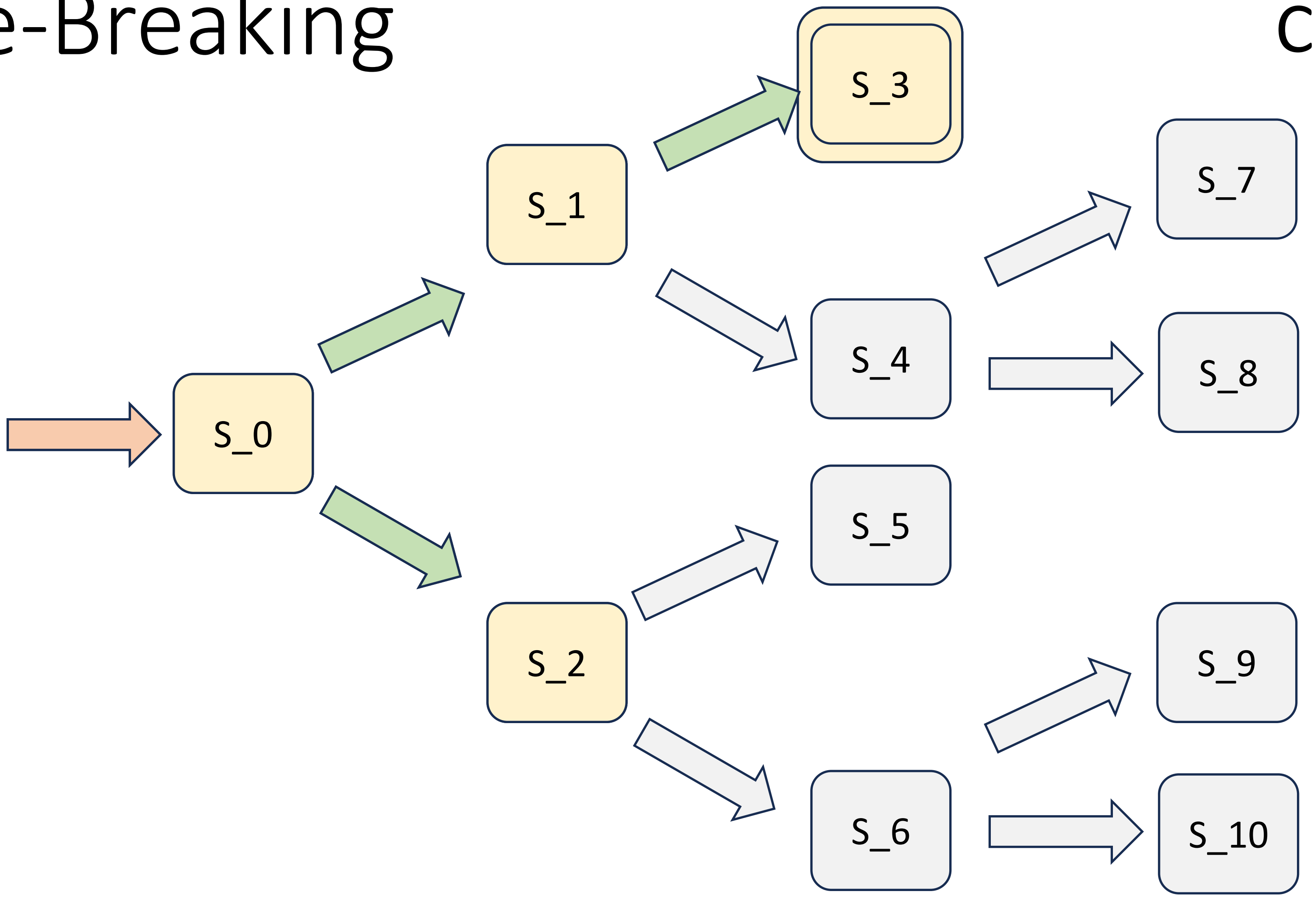
Tie-Breaking

Configuration:
[f, h, FIFO]



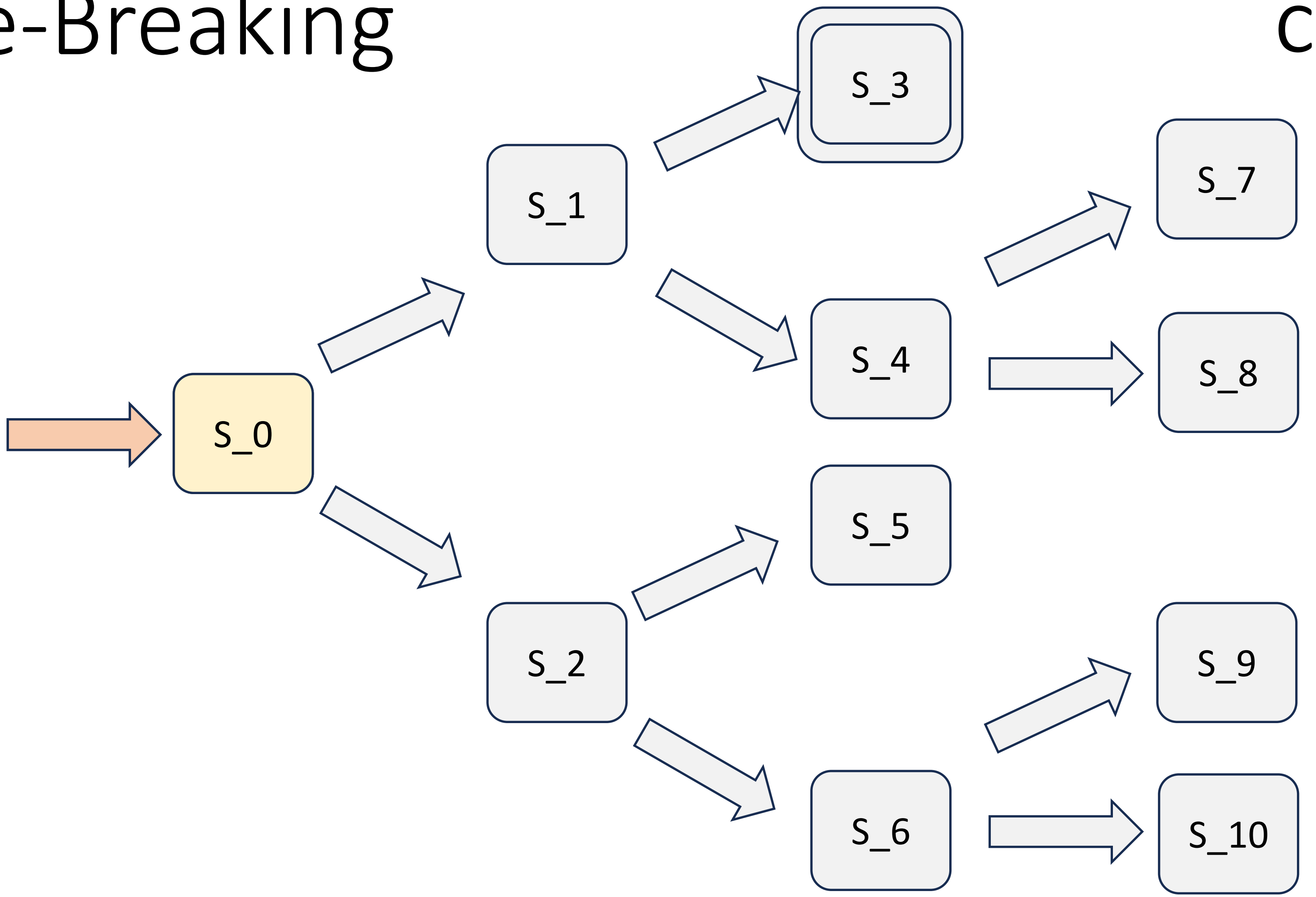
Tie-Breaking

Configuration:
[f, h, FIFO]



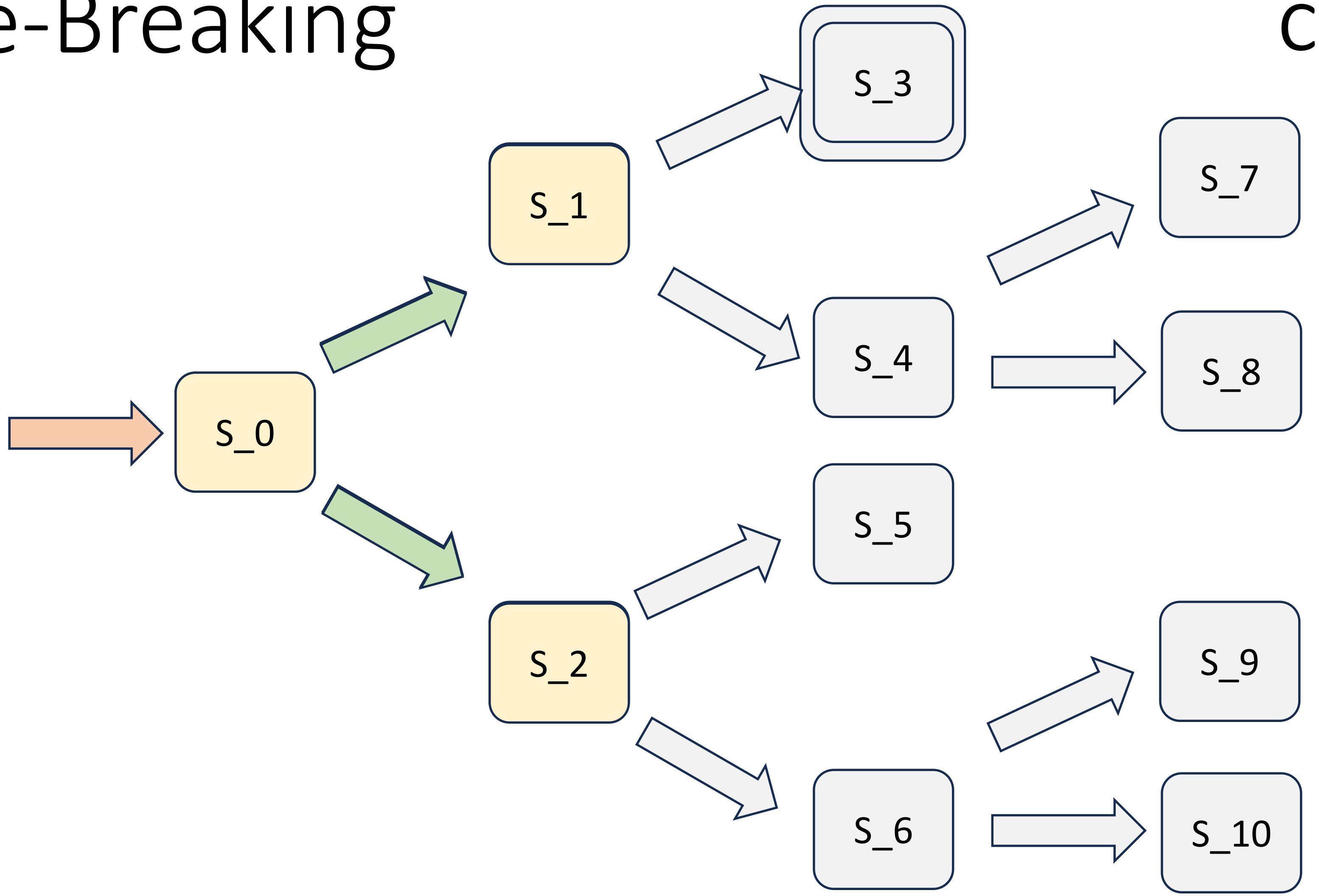
Tie-Breaking

Configuration:
[f, h, LIFO]



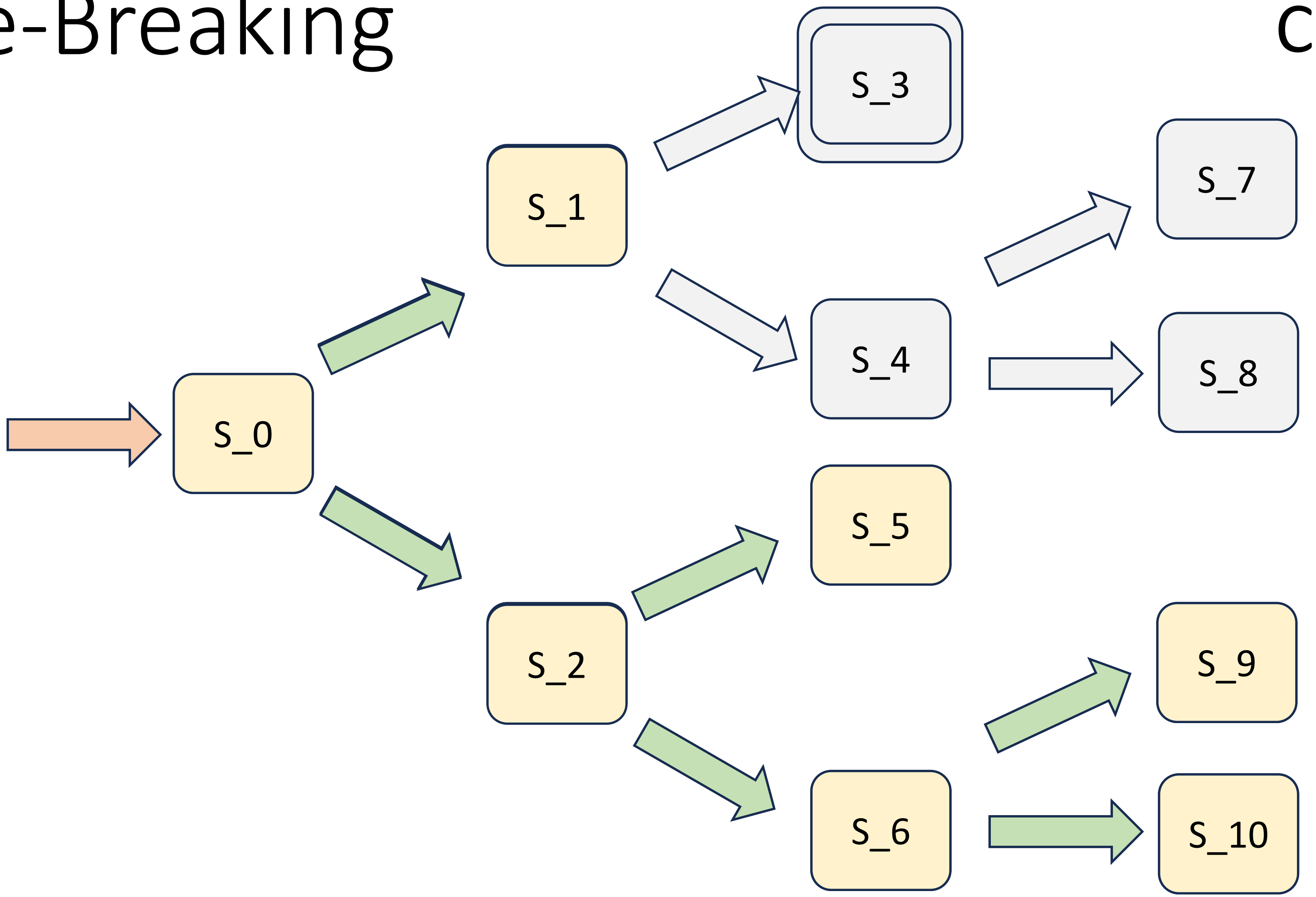
Tie-Breaking

Configuration:
[f, h, LIFO]



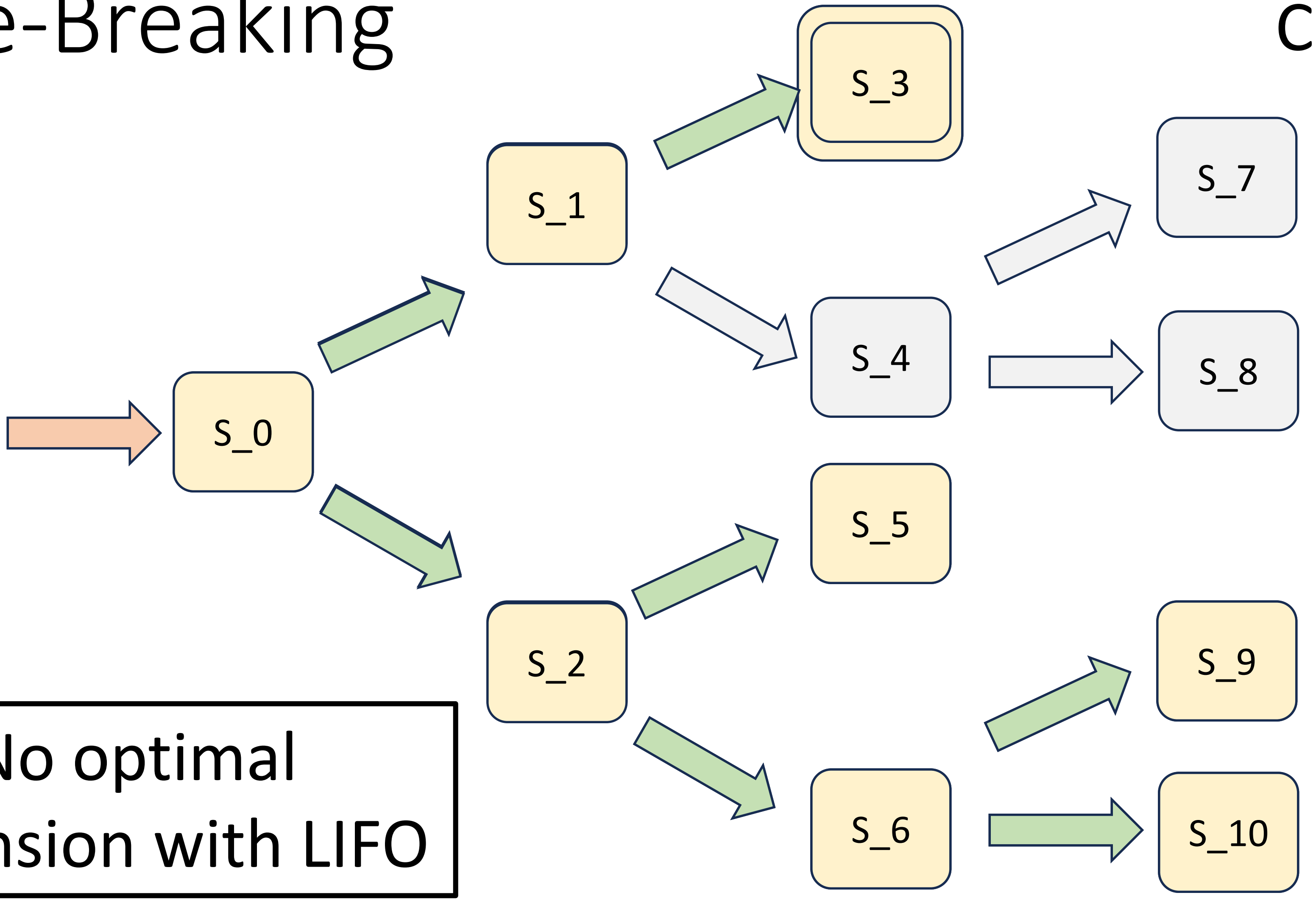
Tie-Breaking

Configuration:
[f, h, LIFO]



Tie-Breaking

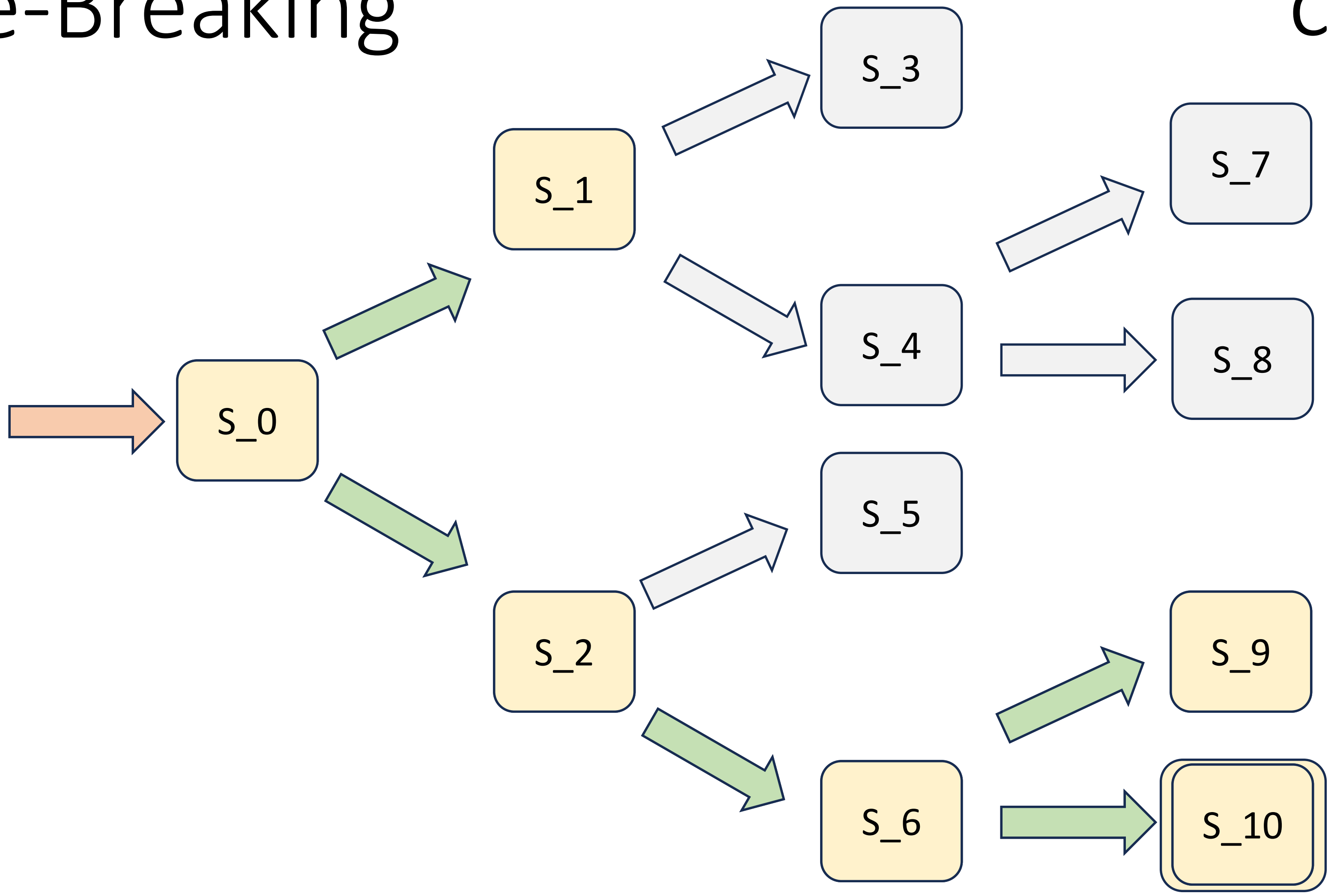
Configuration:
[f, h, LIFO]



No optimal expansion with LIFO

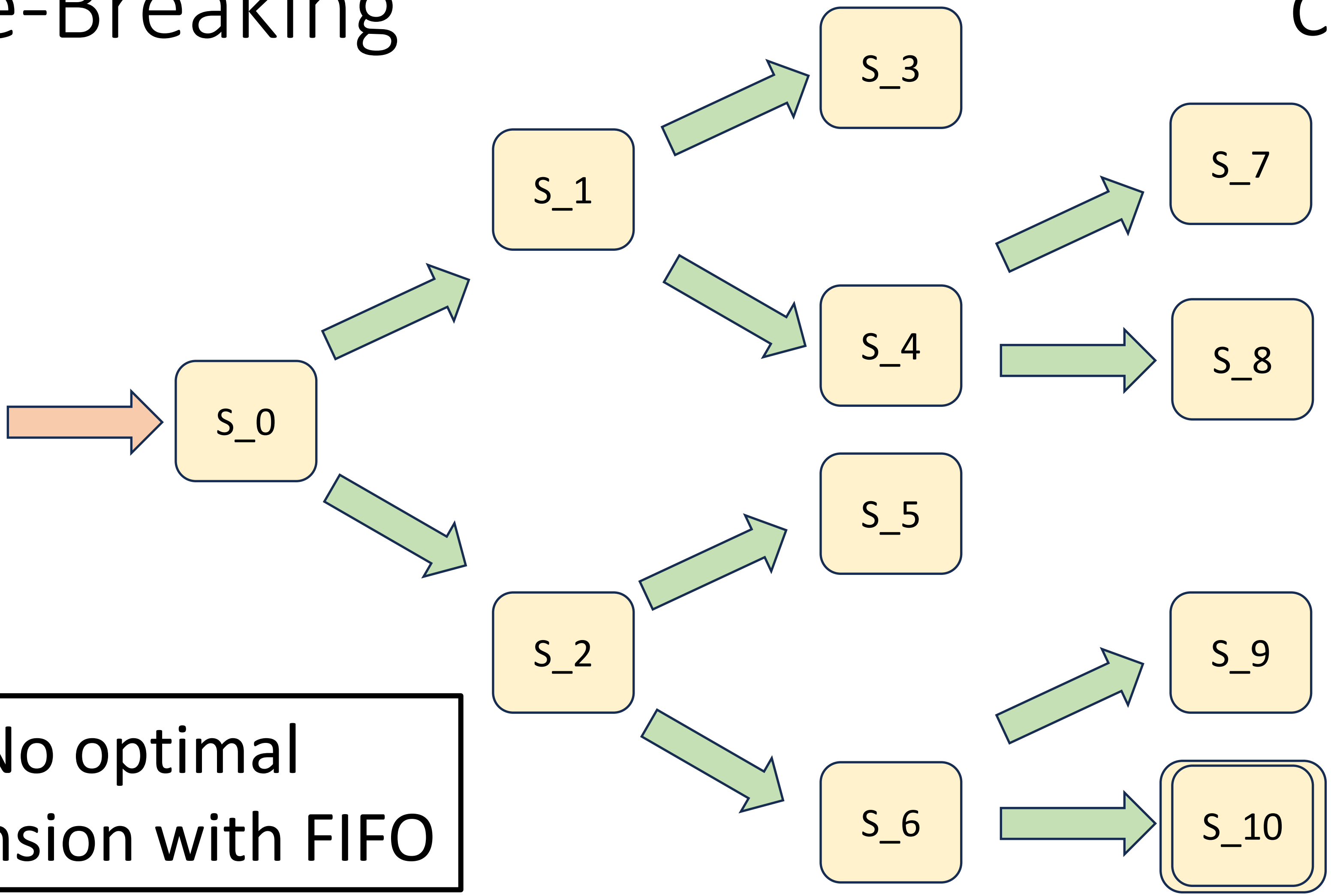
Tie-Breaking

Configuration:
[f, h, LIFO]



Tie-Breaking

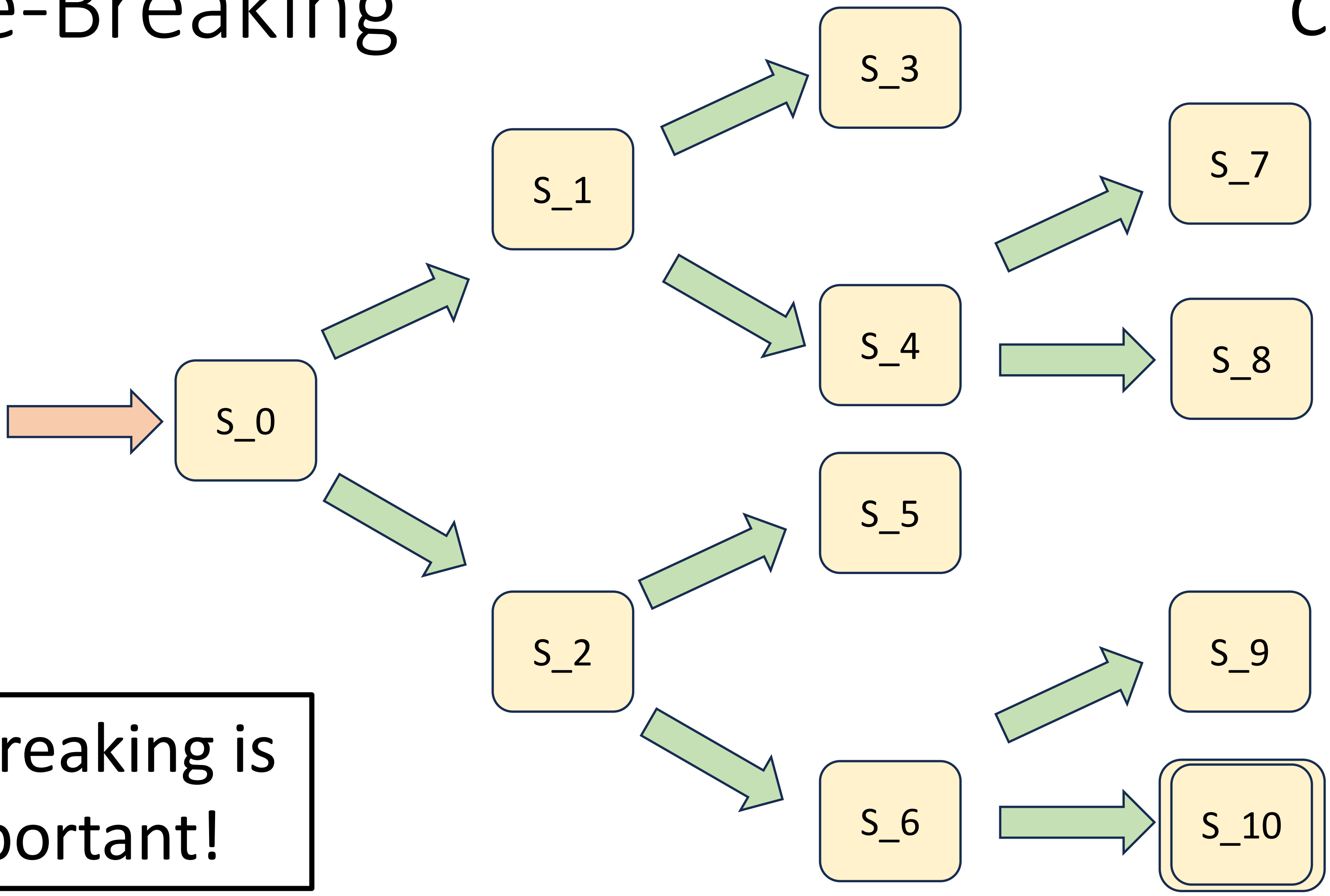
Configuration:
[f, h, FIFO]



No optimal expansion with FIFO

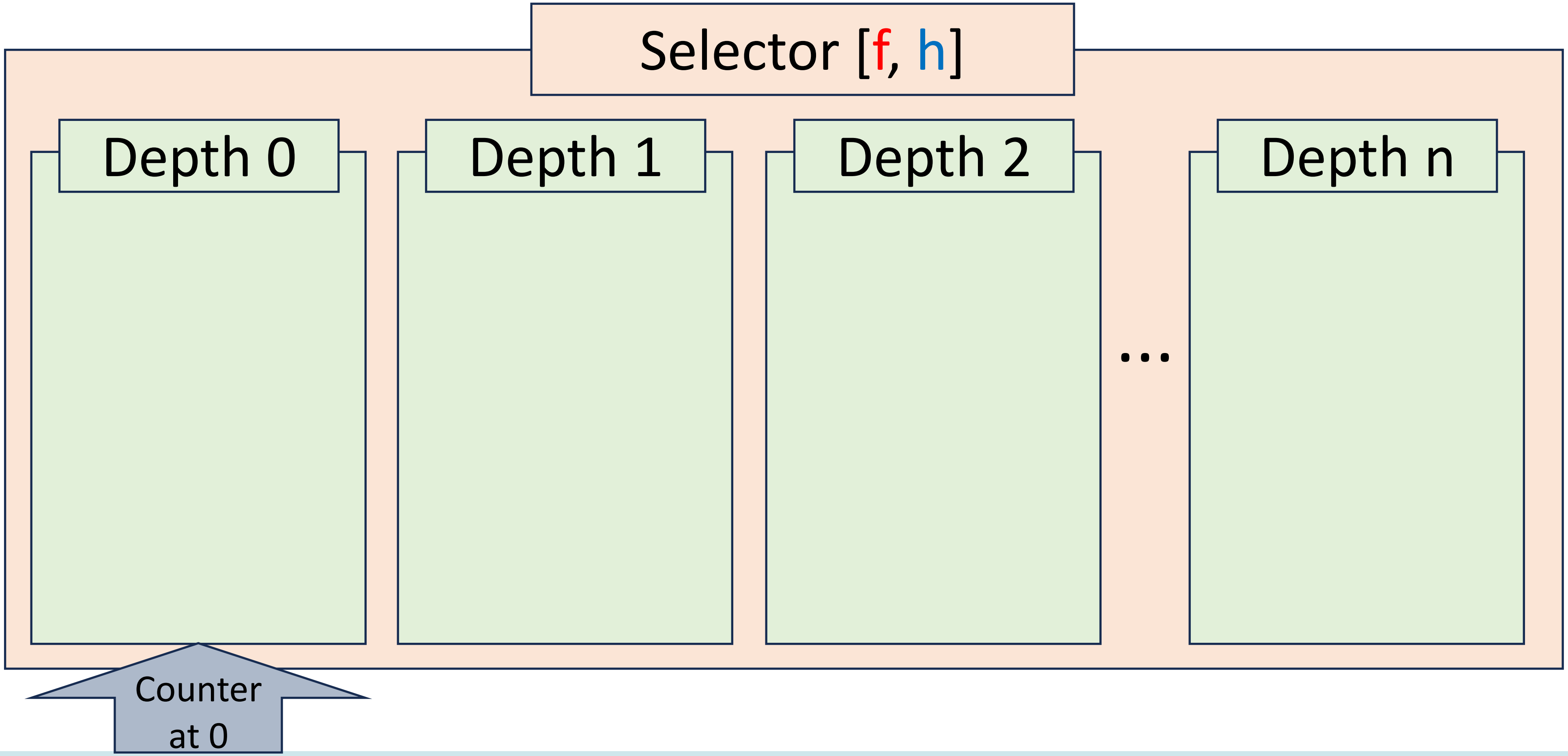
Tie-Breaking

Configuration:
[f, h, FIFO]

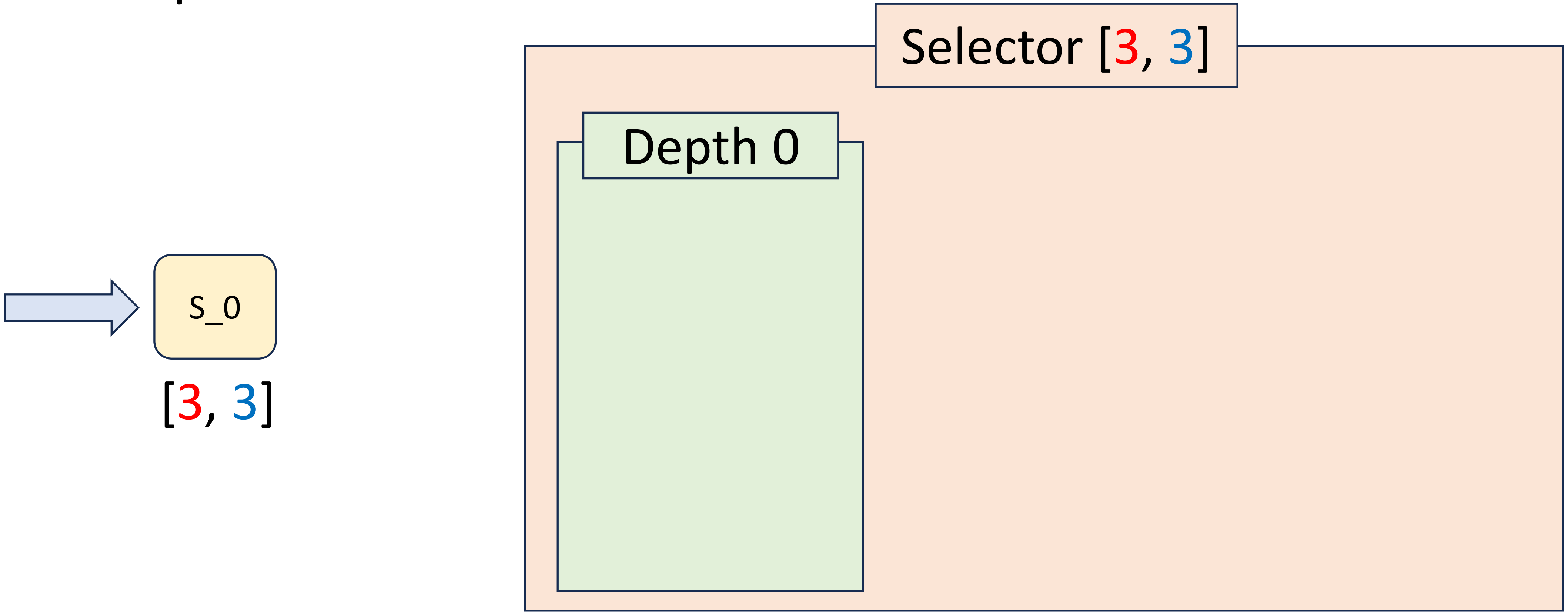


Tie-Breaking is important!

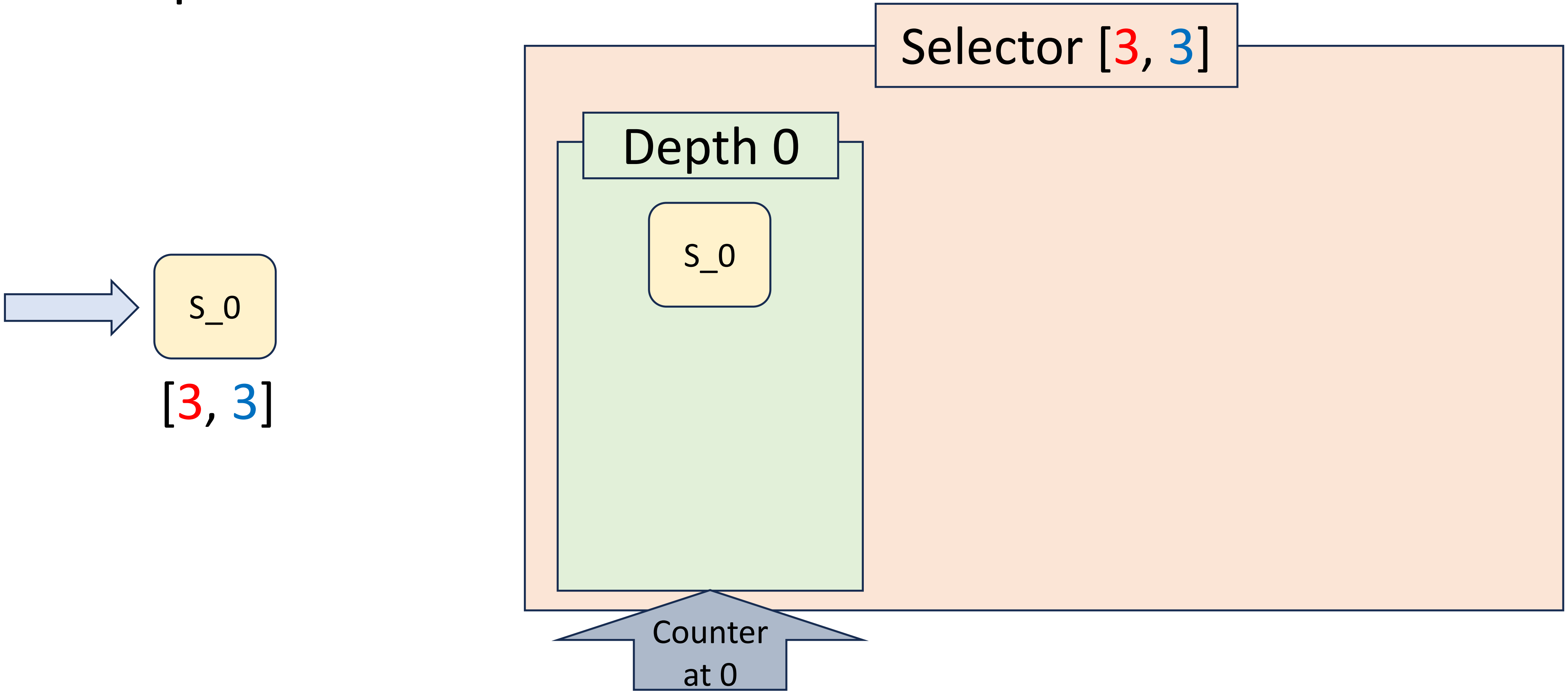
Depth-Diversification



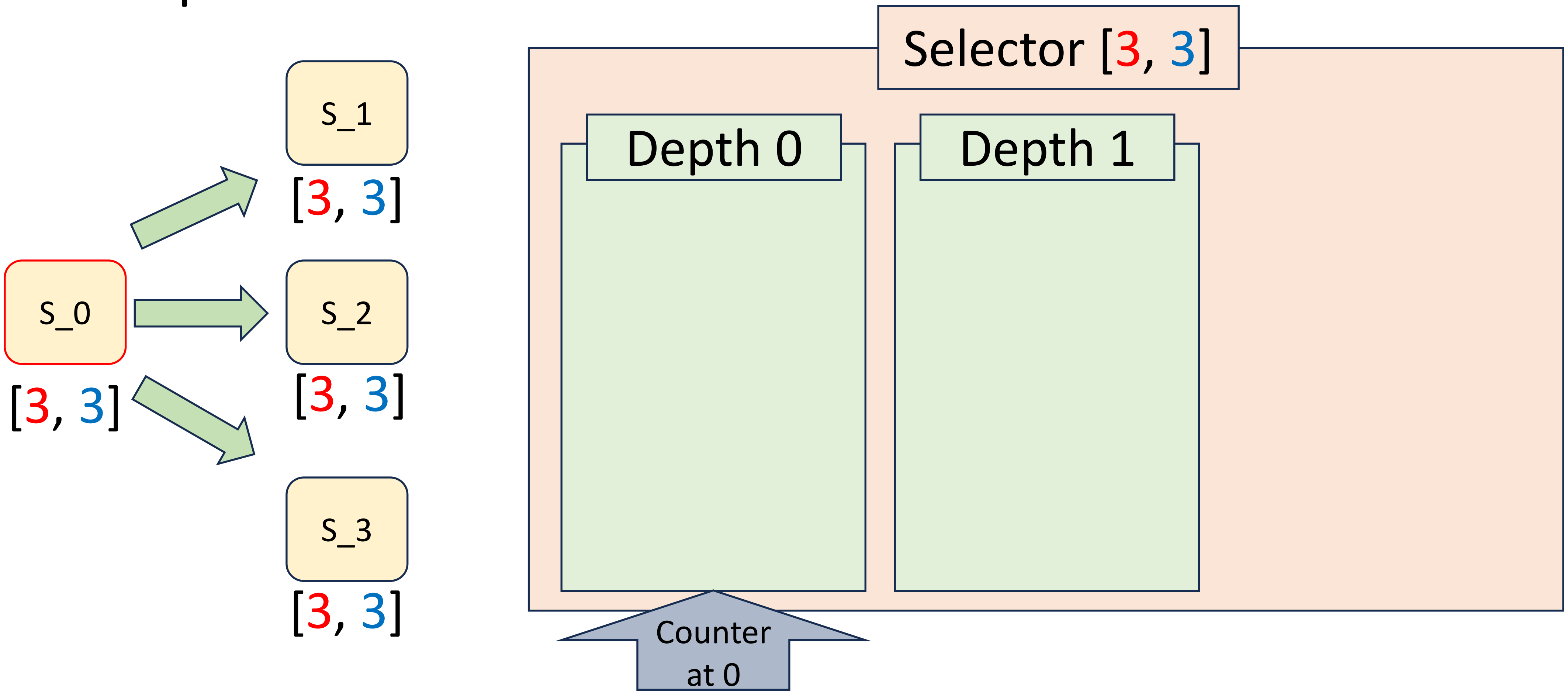
Depth-Diversification



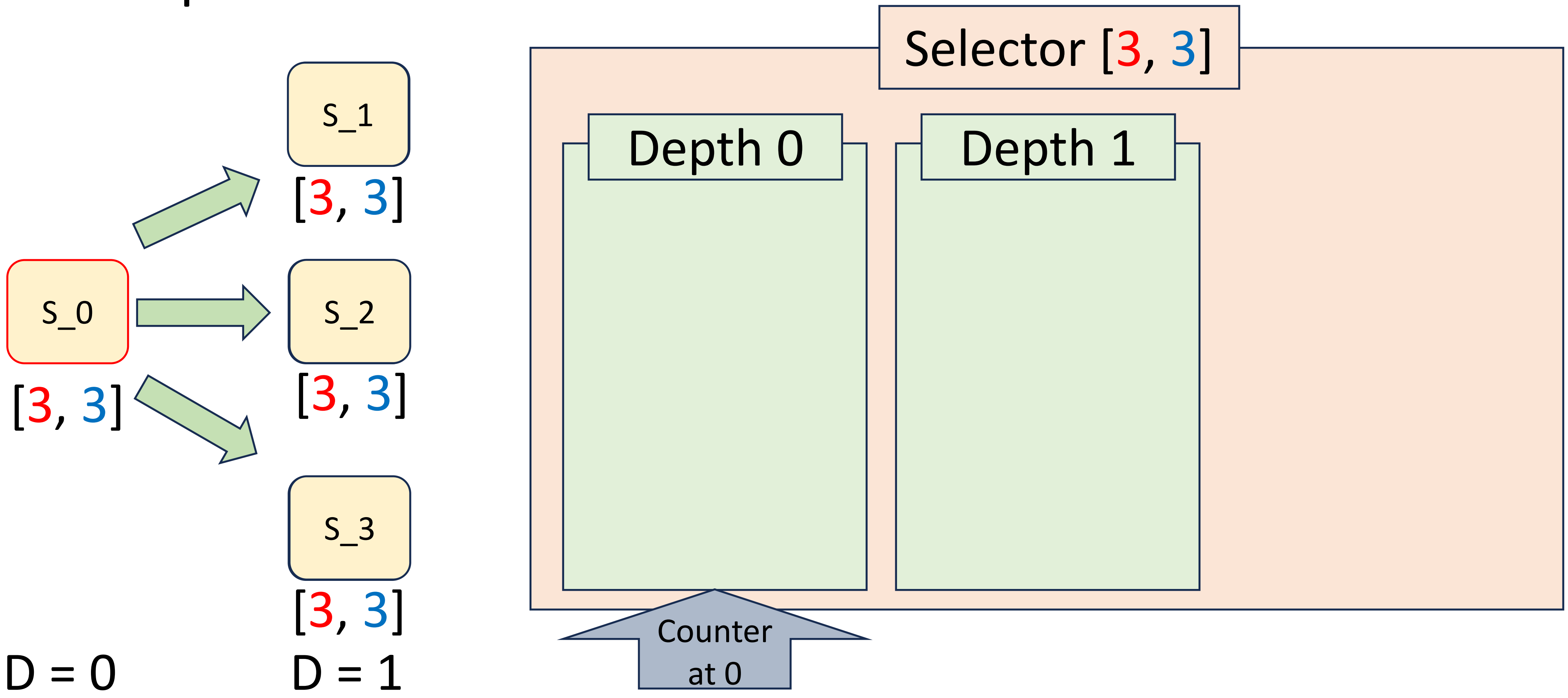
Depth-Diversification



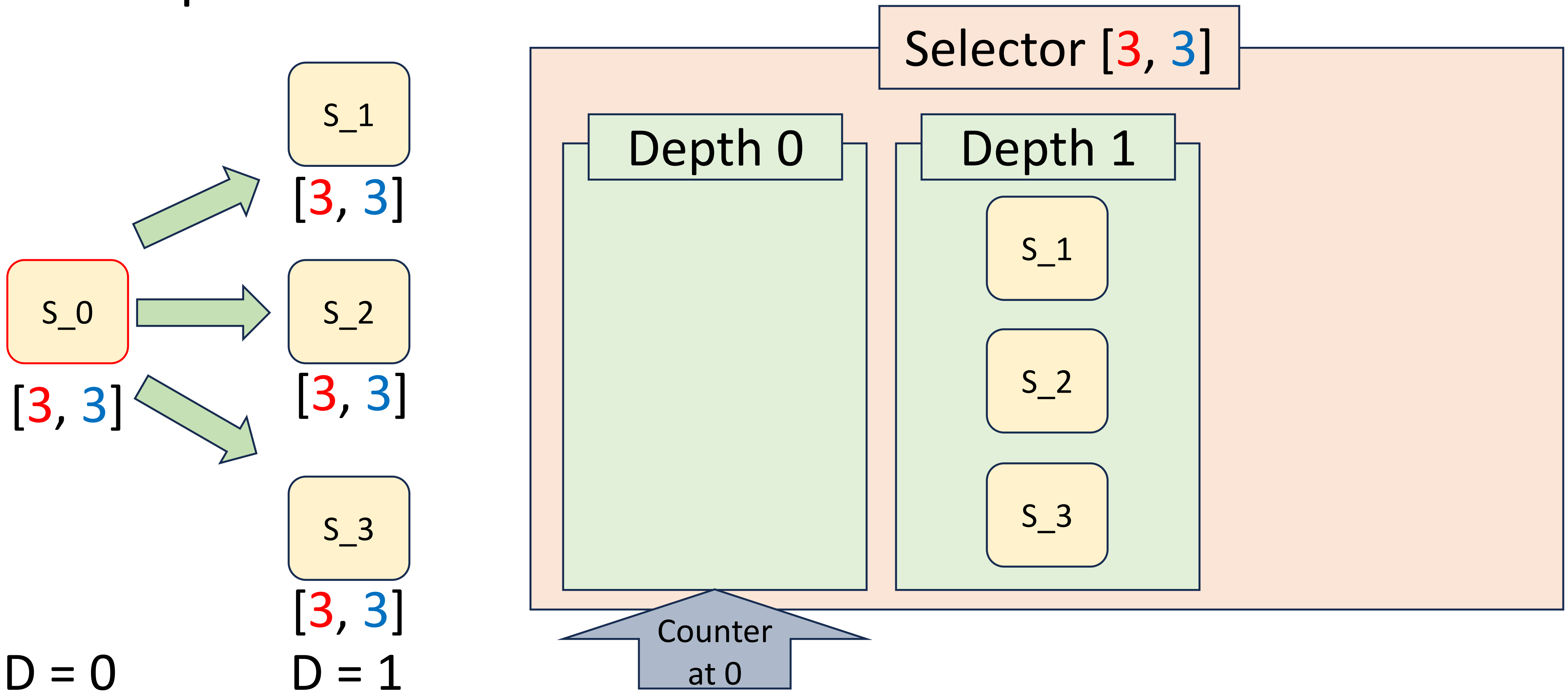
Depth-Diversification



Depth-Diversification

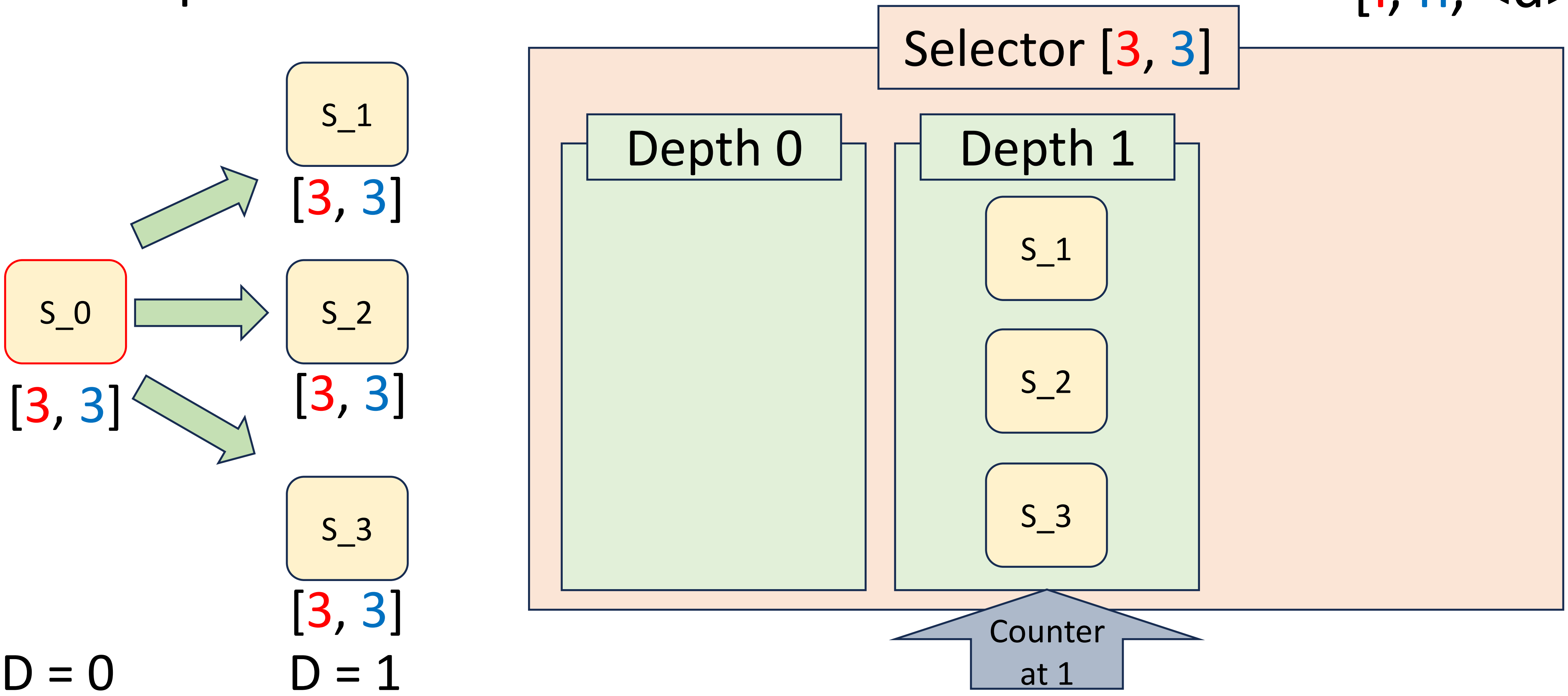


Depth-Diversification



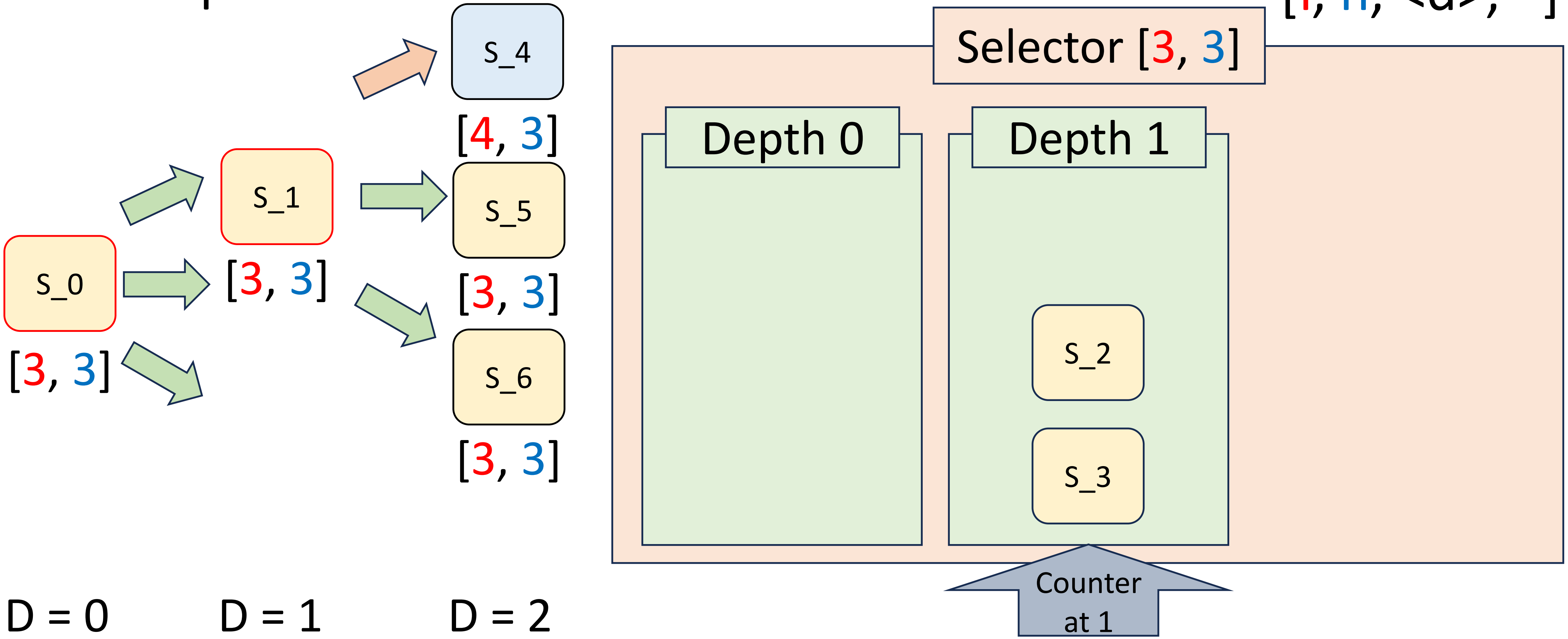
Depth-Diversification

Configuration:
[f, h, <d>, *]



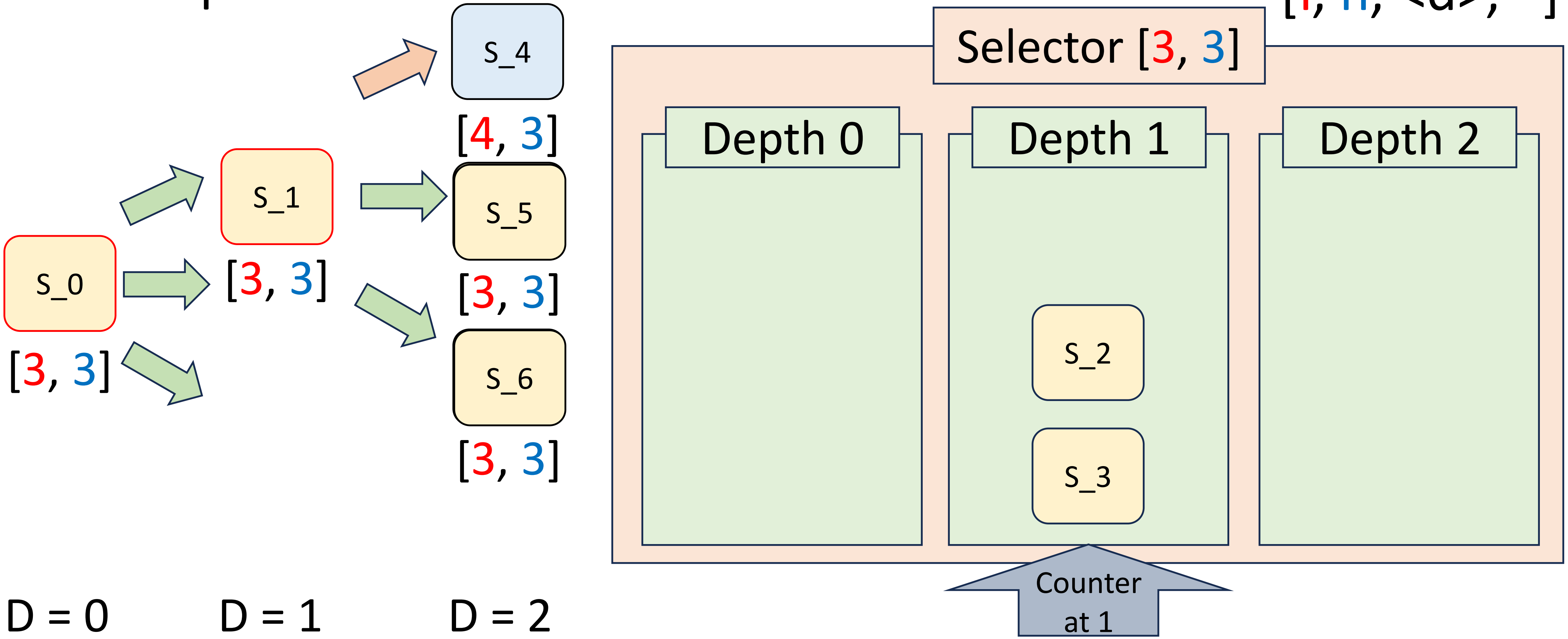
Depth-Diversification

Configuration:
[f, h, <d>, *]



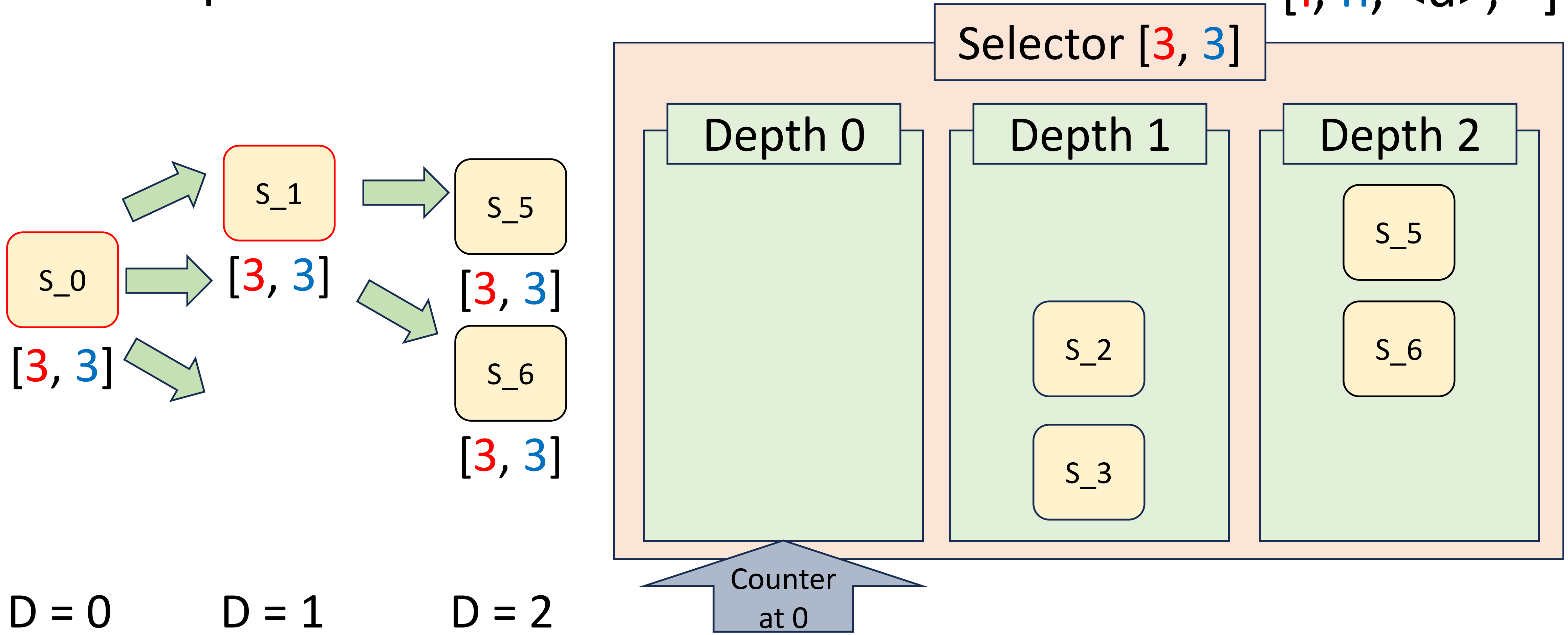
Depth-Diversification

Configuration:
[f, h, <d>, *]



Depth-Diversification

Configuration:
[f, h, <d>, *]



Depth-Diversification

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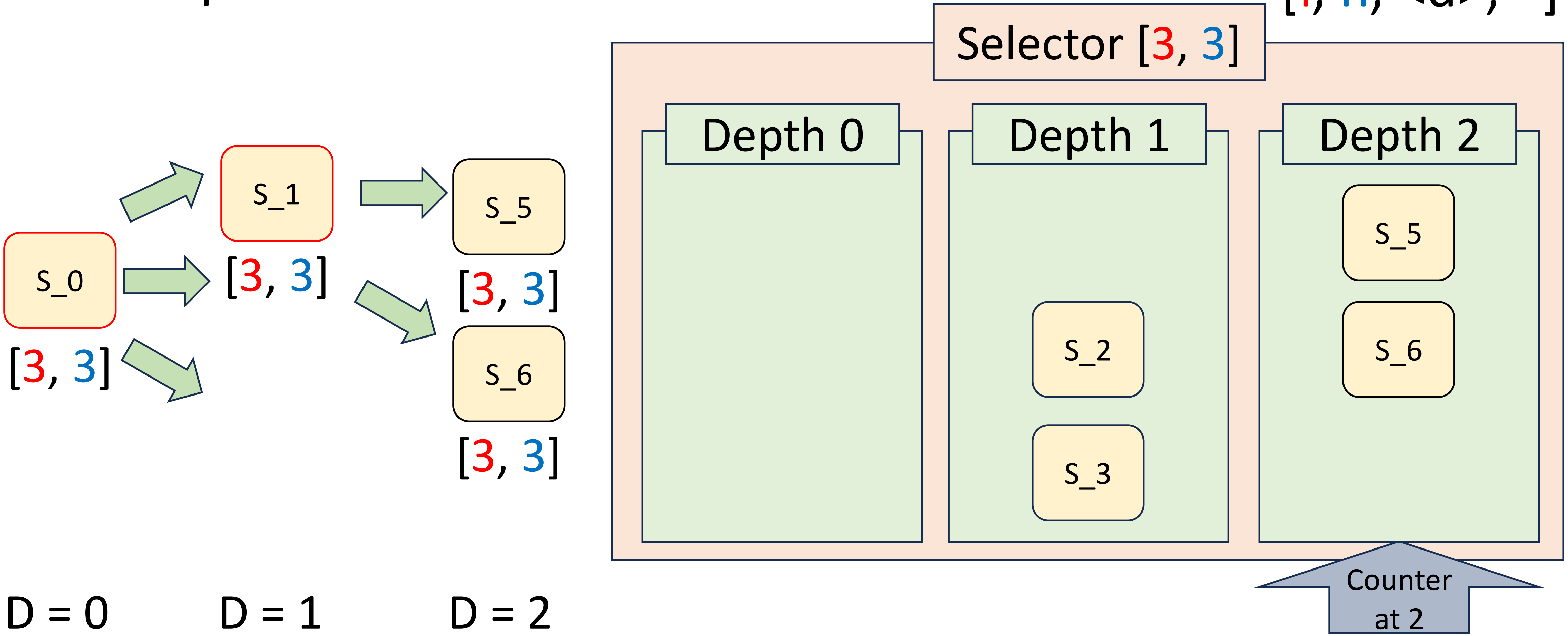
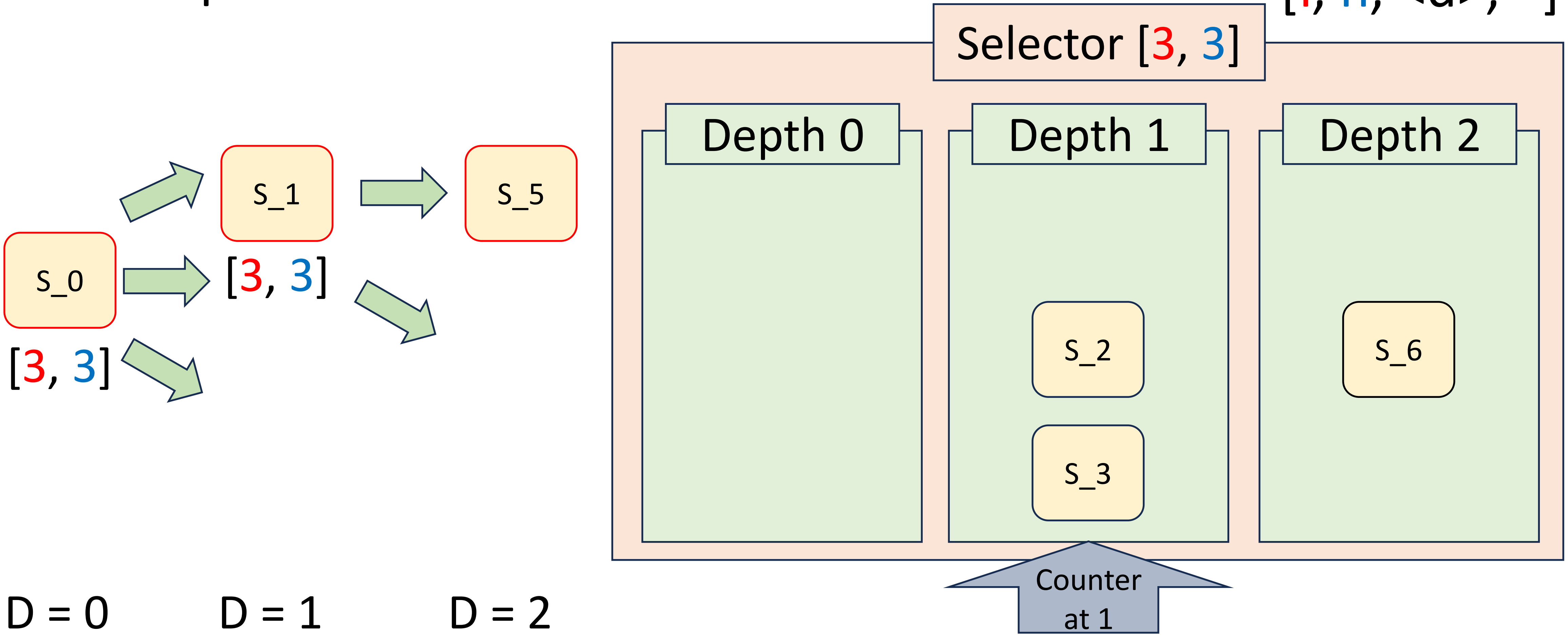
[f, h, <d>, *]



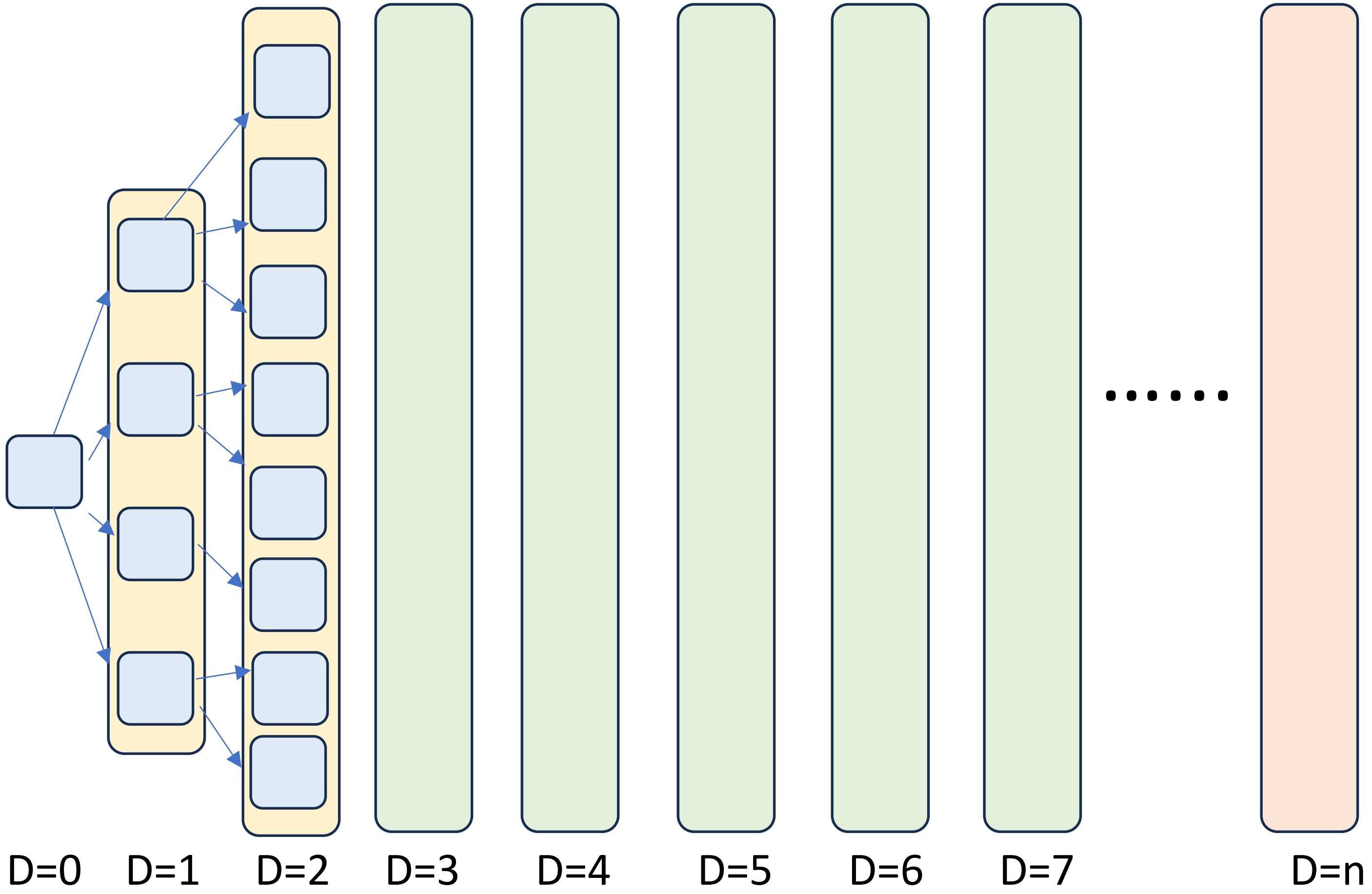
Depth-Diversification

Configuration:
[f, h, <d>, *]



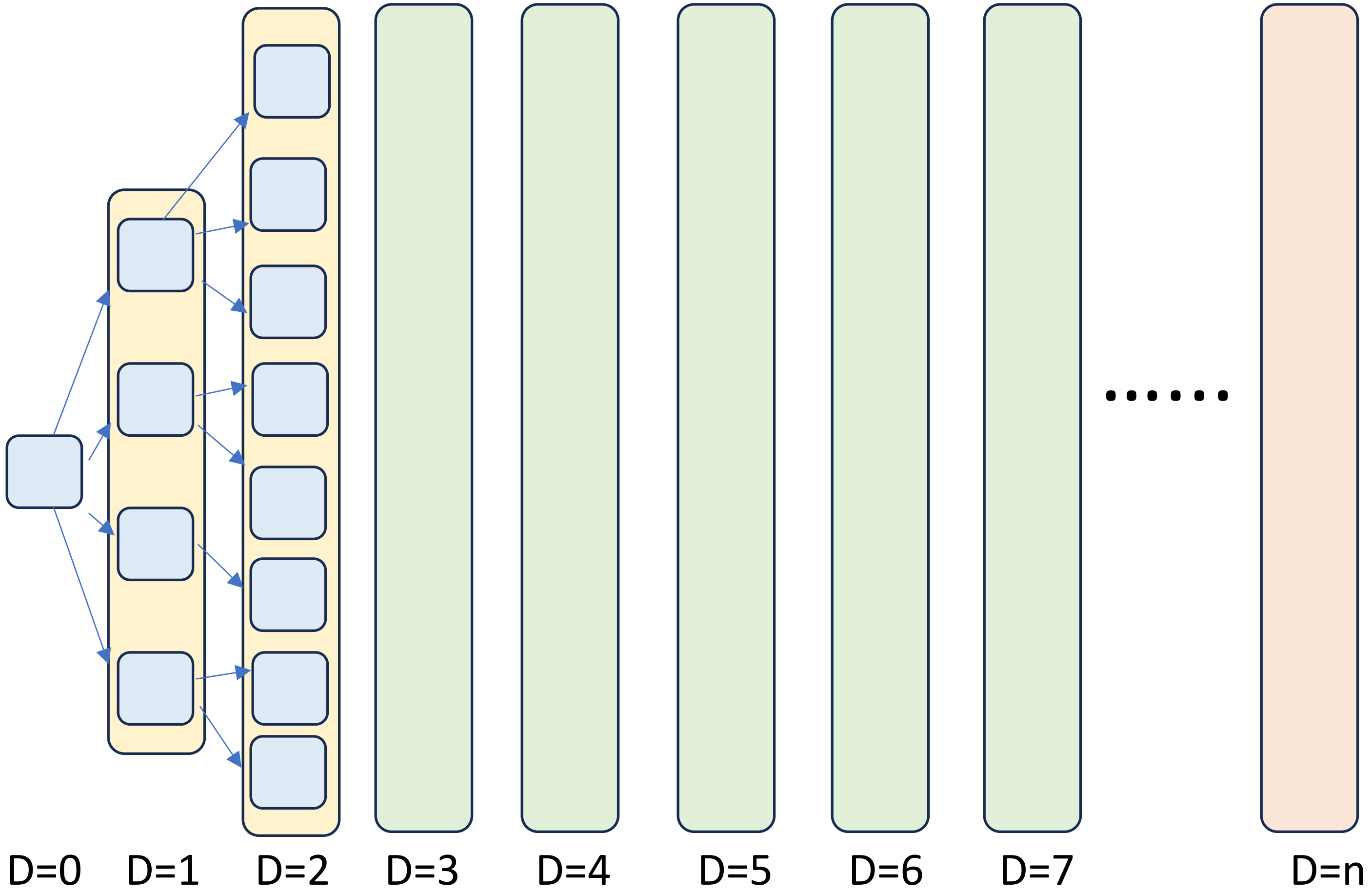
Depth-Diversification

Configuration:
[f, h, <d>, *]



Depth-Diversification

Configuration:
[f, h, <d>, *]

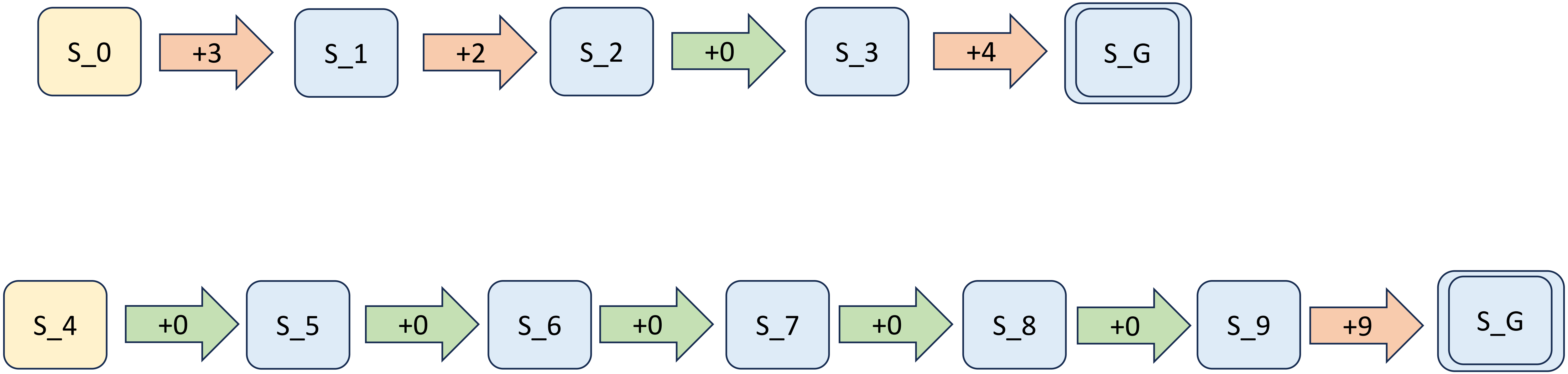


FIFO best for

LIFO best for

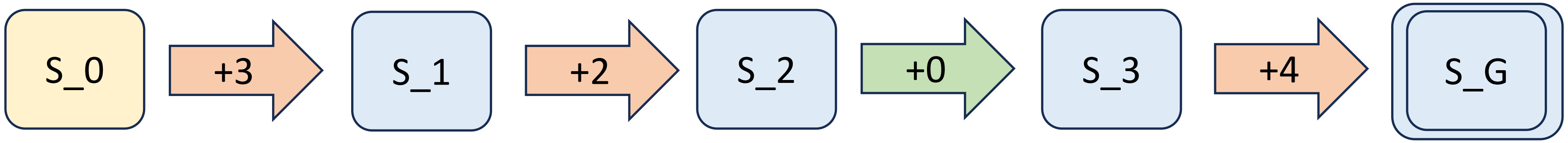
<d> best for

Distance-to-go

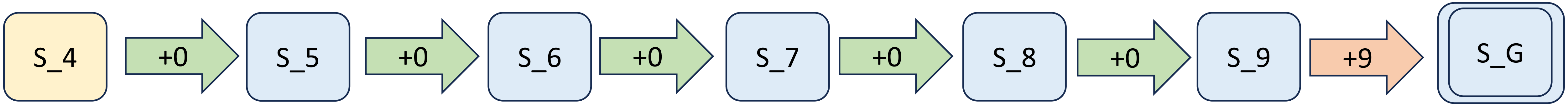


Distance-to-go

Original heuristic h approximates:
3 + 2 + 0 + 4 = 9

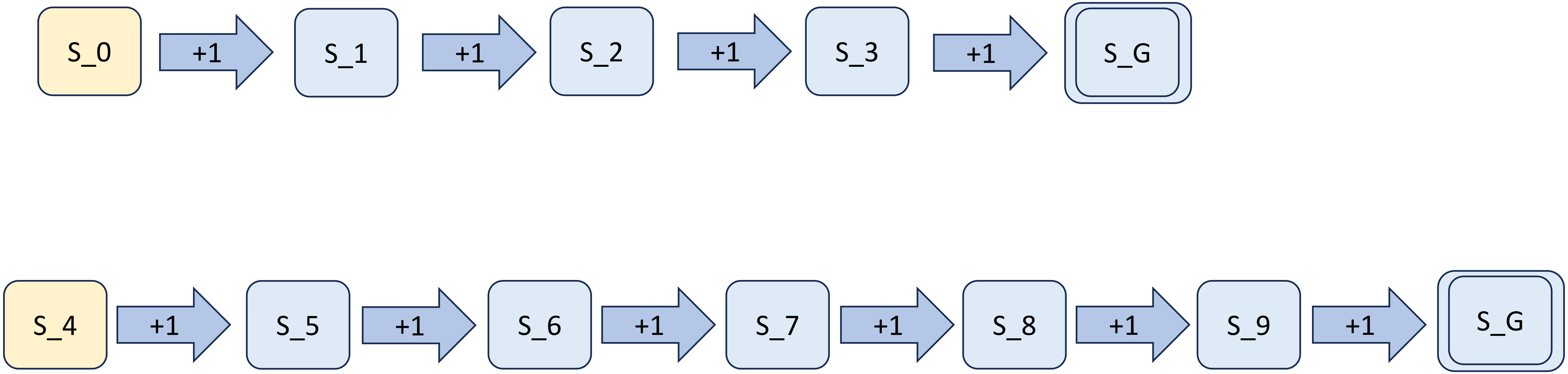


Original heuristic h approximates:
0 + 0 + 0 + 0 + 0 + 9 = 9



Distance-to-go

Configuration:
[f, h^,*]



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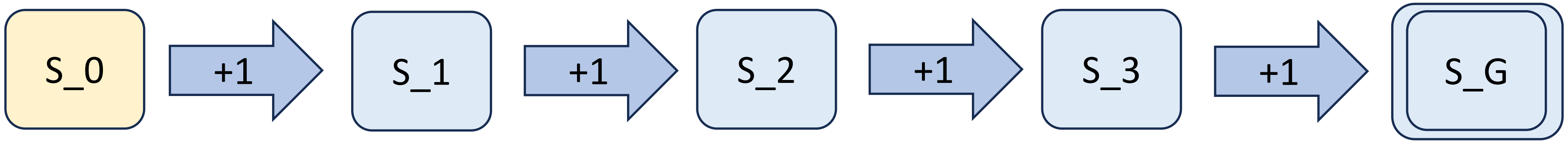
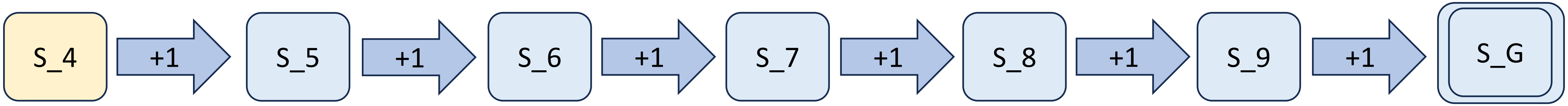
Distance-to-go

Distance-to-go variant h^
estimates: 4 steps



Distance-to-go variant h^
estimates: 6 steps



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Evaluation

Standard IPC-domains

- 1’104 instances
- Few zero-cost actions

Zero-cost domains

- 620 instances
- Only one non-zero action per domain
- Modified domains to emphasize tie-breaking

Configuration

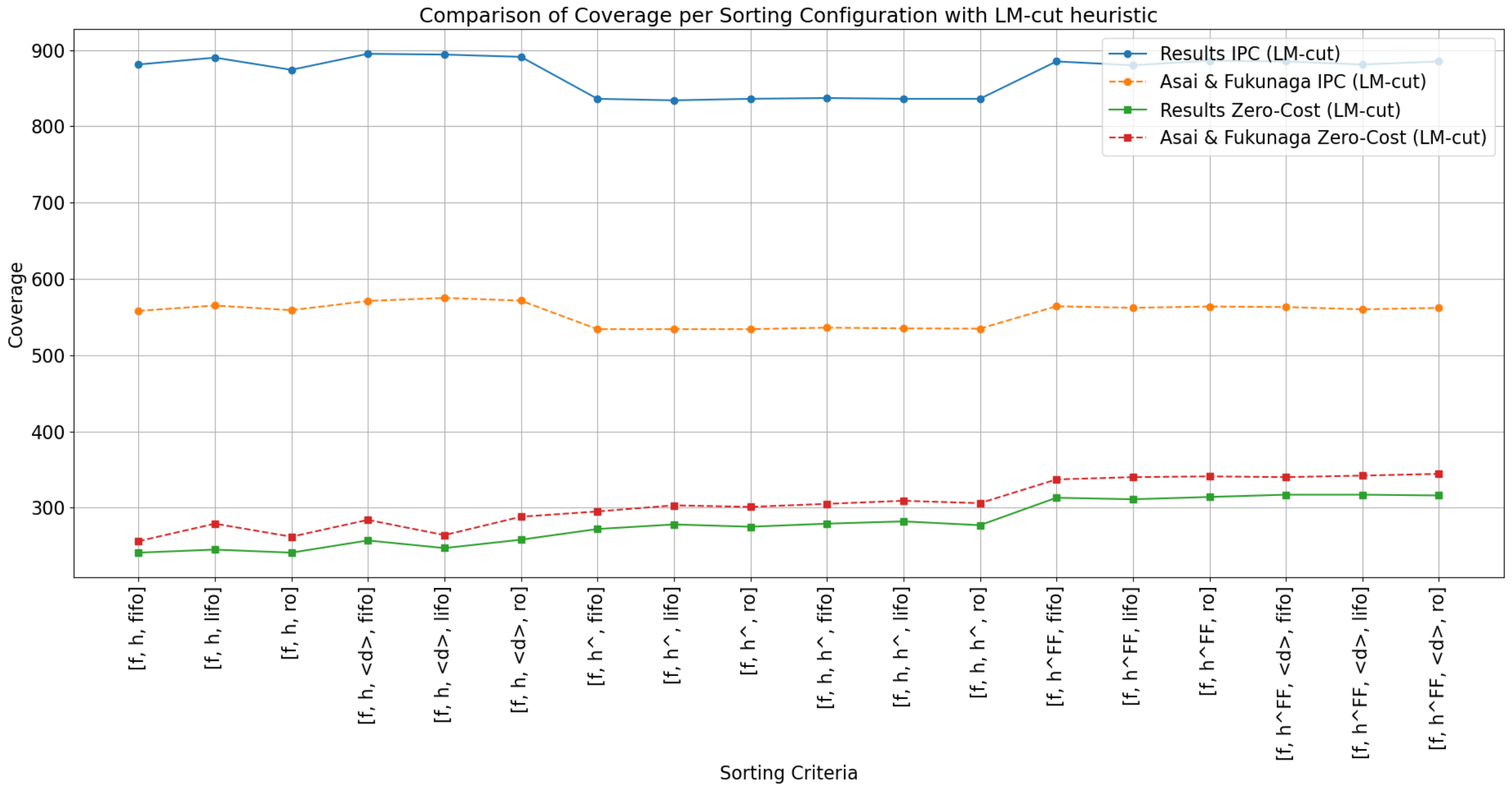
- Baseline:
  - [f, h, *]
  - [f, h, <d>, *]
- Distance-to-go:
  - [f, h^, *]
  - [f, h, h^, *]
  - [f, h^-FF, *]
- Distance + Depth:
  - [f, h^-FF, <d>, *]

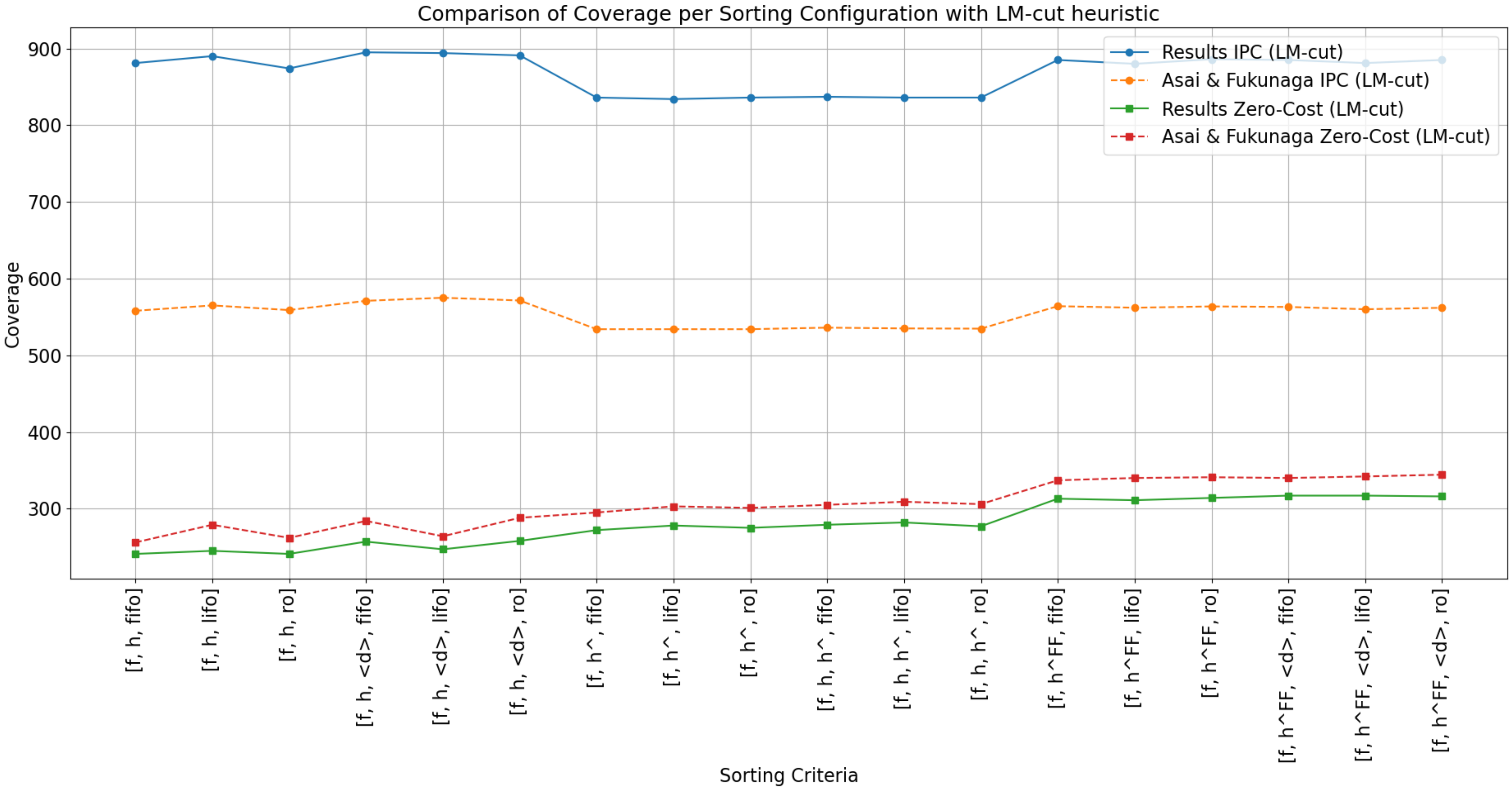
Configuration

- Baseline:
  - [f, h, *]
  - [f, h, <d>, *]
- Distance-to-go:
  - [f, h^, *]
  - [f, h, h^, *]
  - [f, h^-FF, *]
- Distance + Depth:
  - [f, h^-FF, <d>, *]

FF-heuristic is not admissible but achieves good estimates

Results LM-cut

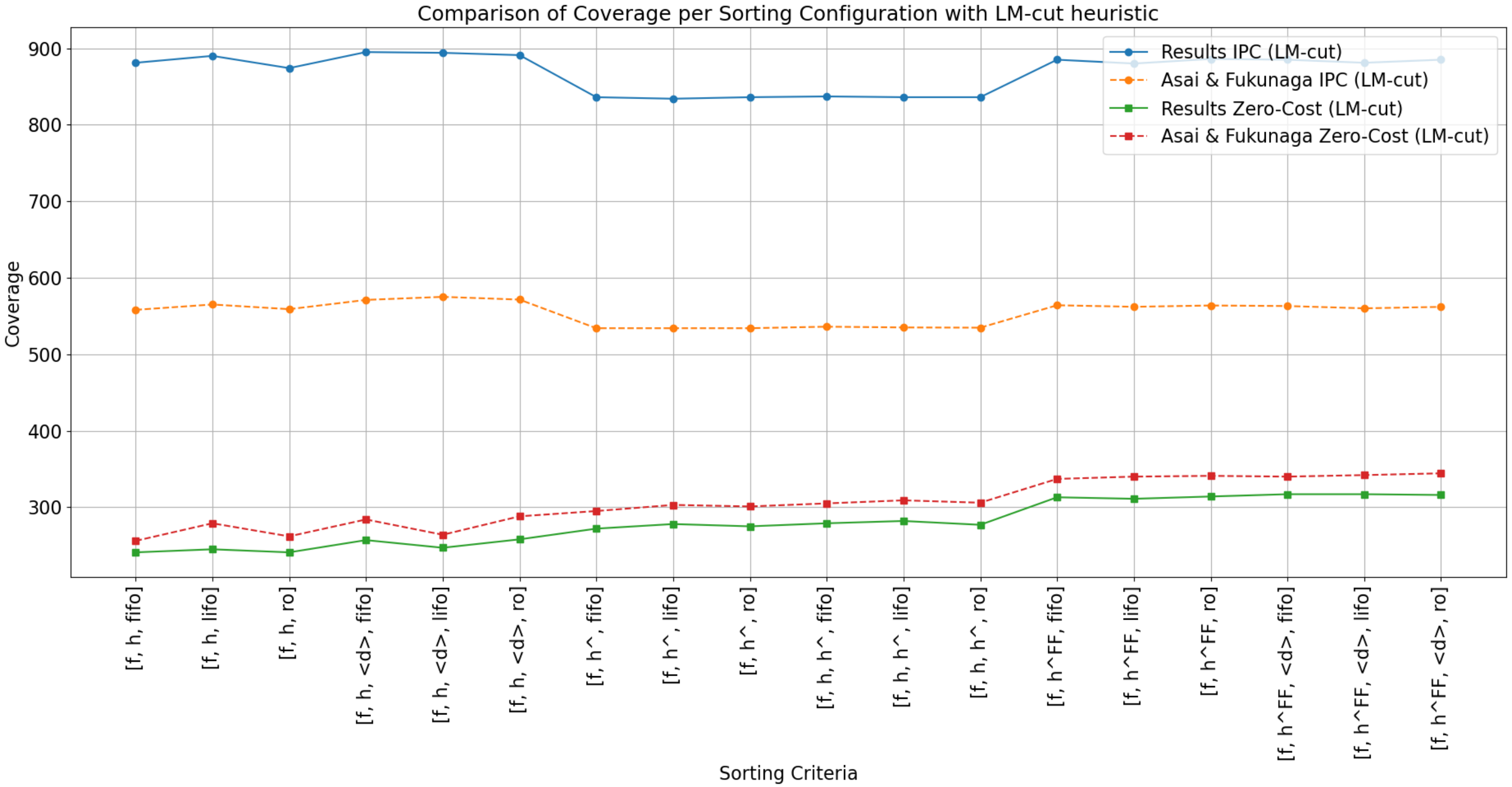




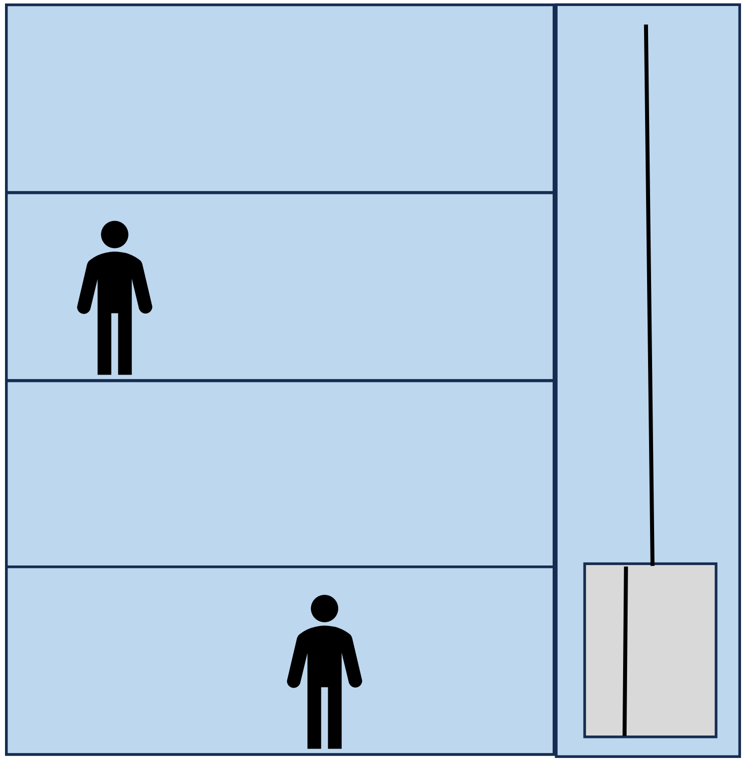
Comparison of Coverage per Sorting Configuration with LM-cut heuristic
Results IPC (LM-cut)
Asai & Fukunaga IPC (LM-cut)
Results Zero-Cost (LM-cut)
Asai & Fukunaga Zero-Cost (LM-cut)
Coverage
900
800
700
600
500
400
300
[f, h, fifo]
[f, h, lifo]
[f, h, ro]
[f, h, <d>, fifo]
[f, h, <d>, lifo]
[f, h, <d>, ro]
[f, h^, fifo]
[f, h^, lifo]
[f, h^, ro]
[f, h, h^, fifo]
[f, h, h^, lifo]
[f, h, h^, ro]
[f, h^FF, fifo]
[f, h^FF, lifo]
[f, h^FF, ro]
[f, h^FF, <d>, fifo]
[f, h^FF, <d>, lifo]
[f, h^FF, <d>, ro]
Sorting Criteria

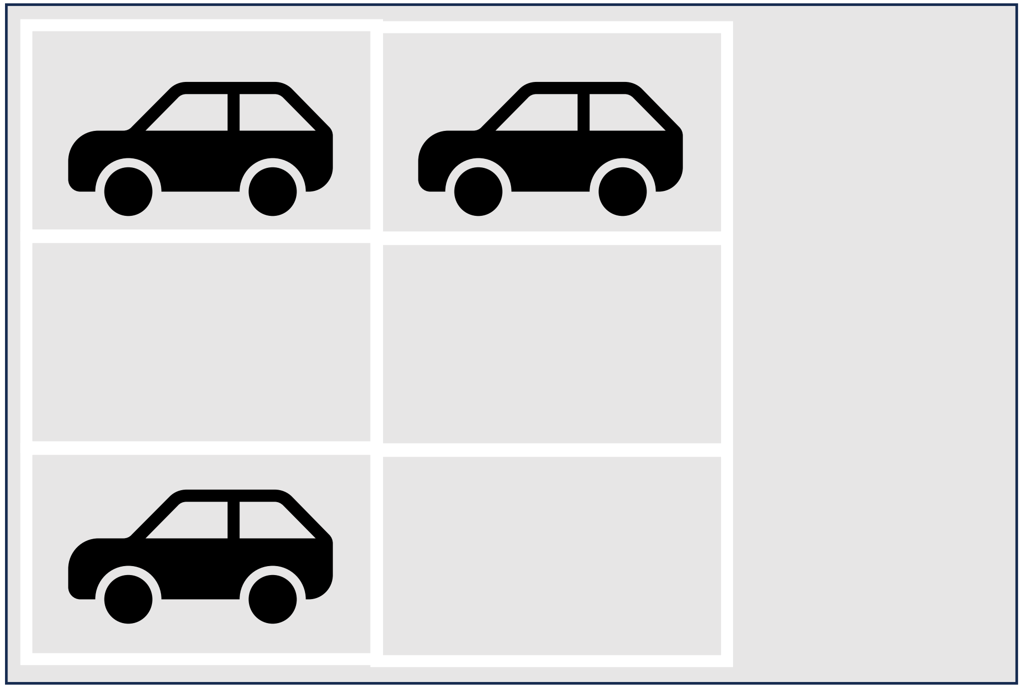
Results LM-cut

- [f, h^-FF, <d>, *] (Zero-cost)
- [f, h, <d>, *] (IPC)



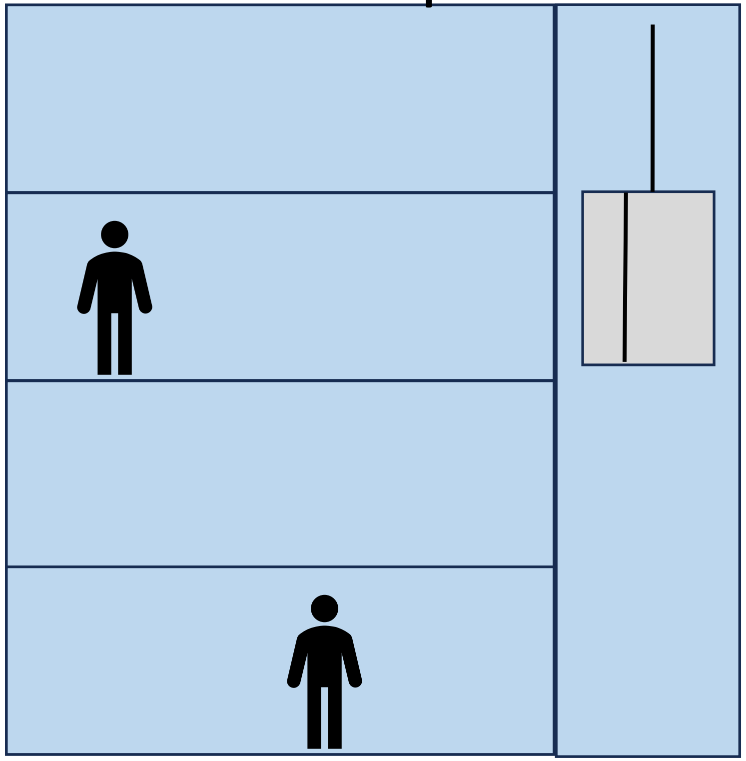
ELEVATORS-UP & PARKING-MOVECC domain



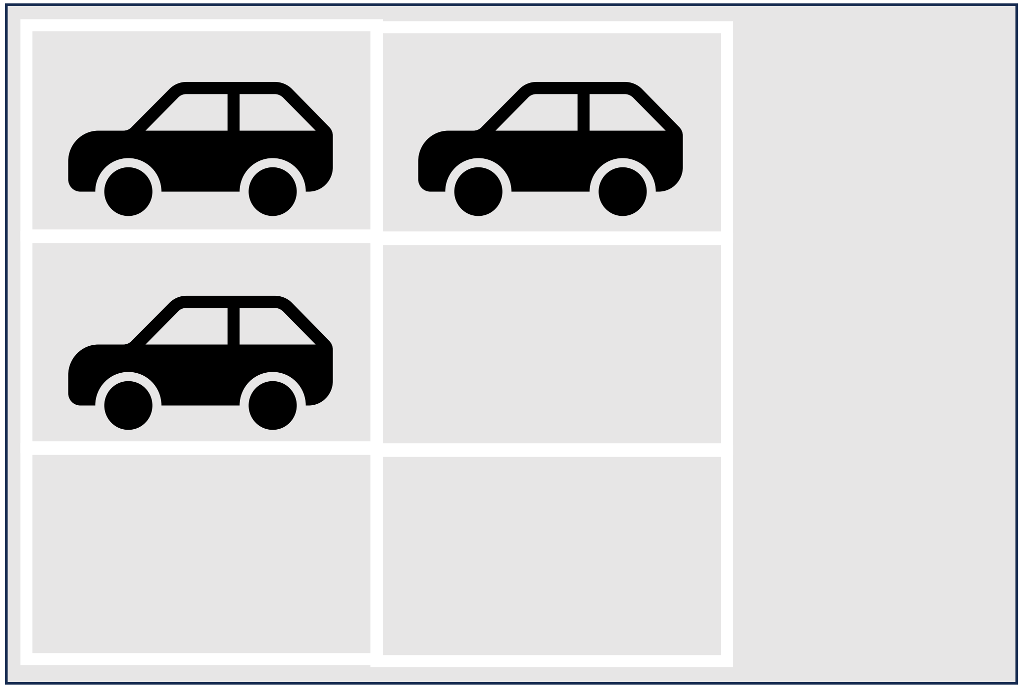


ELEVATORS-UP & PARKING-MOVECC domain

move-up-fast



move-curb-to-curb

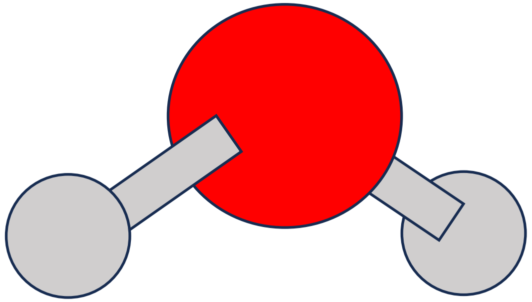


ELEVATORS-UP & PARKING-MOVECC domain

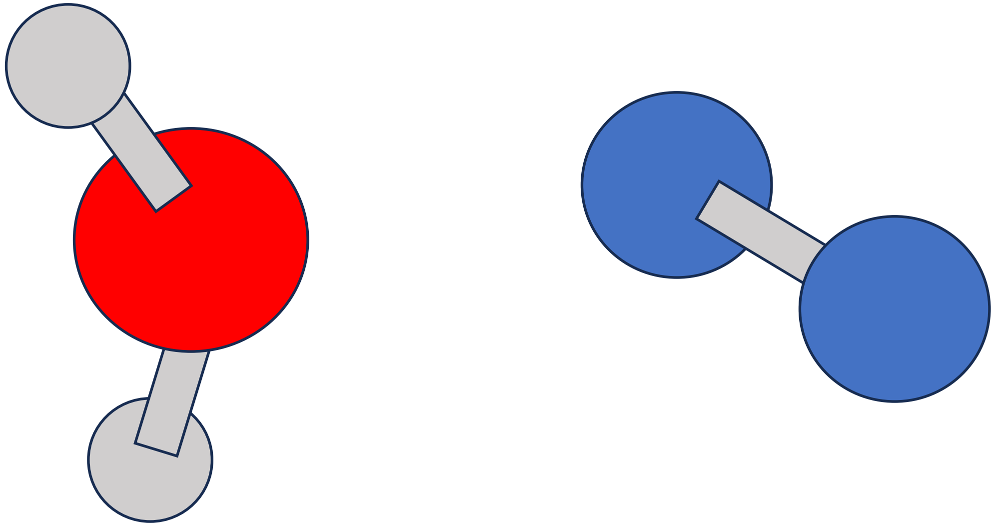
- Total cost of zero
- Baseline: 7/20 and 0/20 instances solved
- Distance-to-go & Depth: 20/20 and 20/20

PATHWAYS-FUEL domain

synthesize (zero-cost)

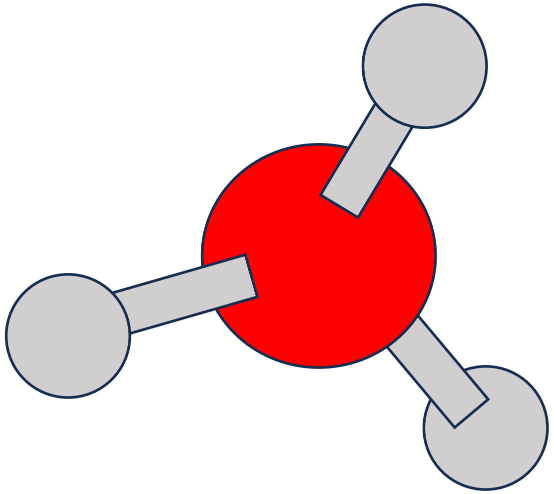


associate (cost = 1)



PATHWAYS-FUEL domain

synthesize (zero-cost)



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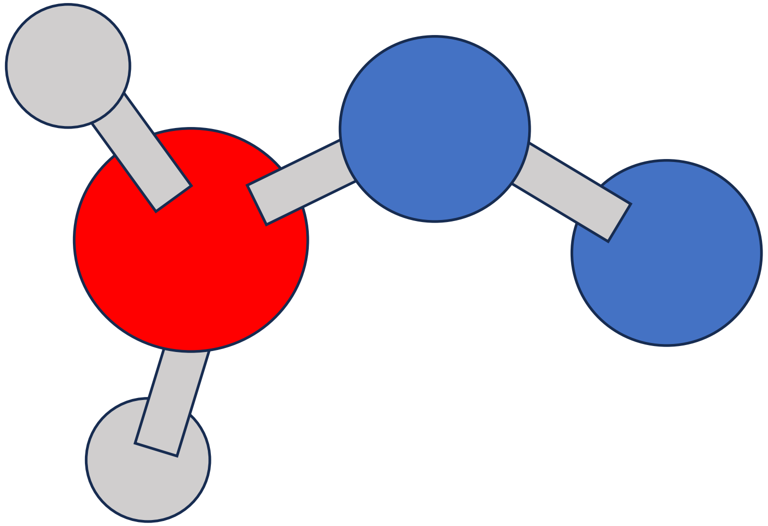
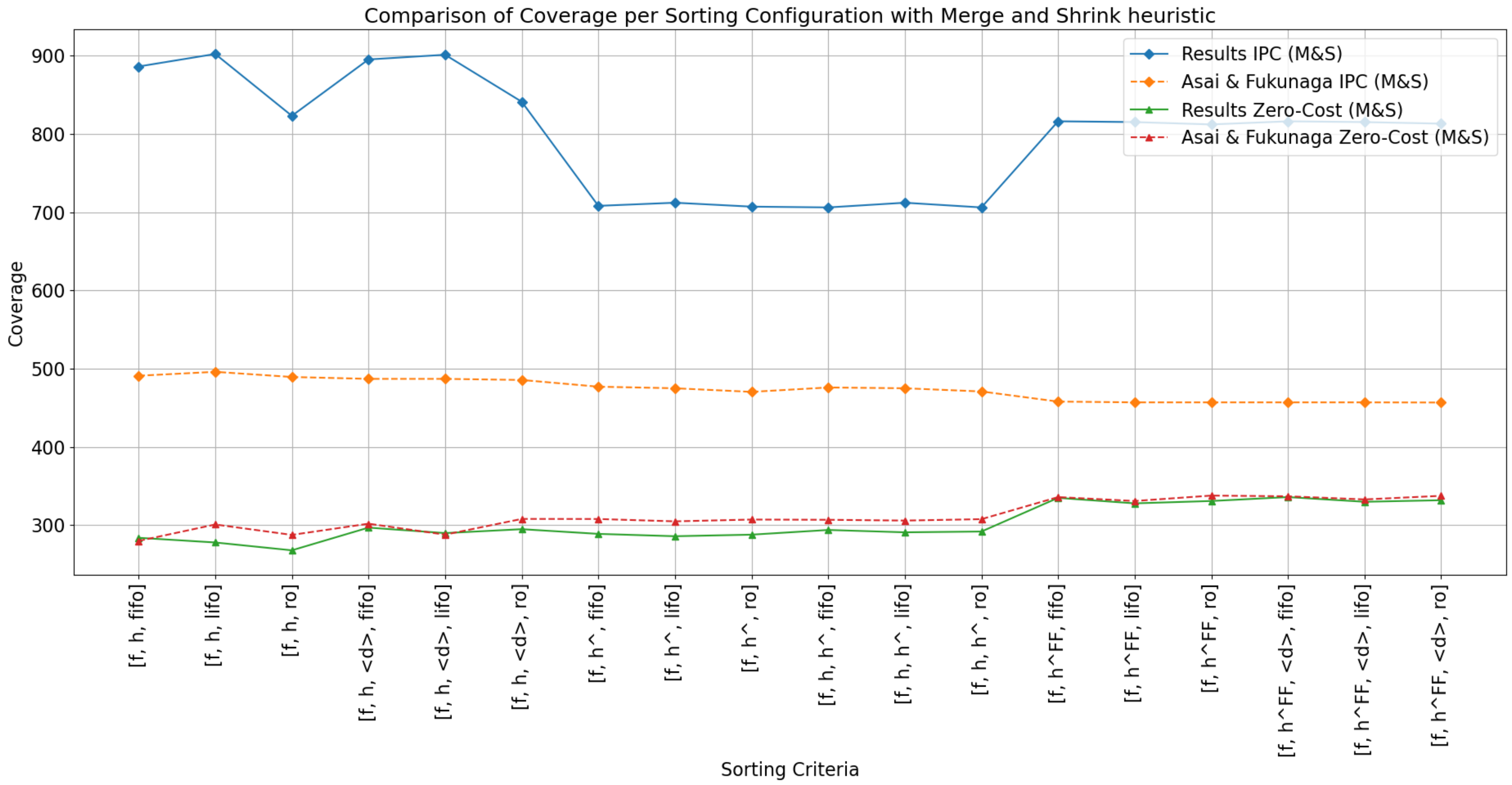
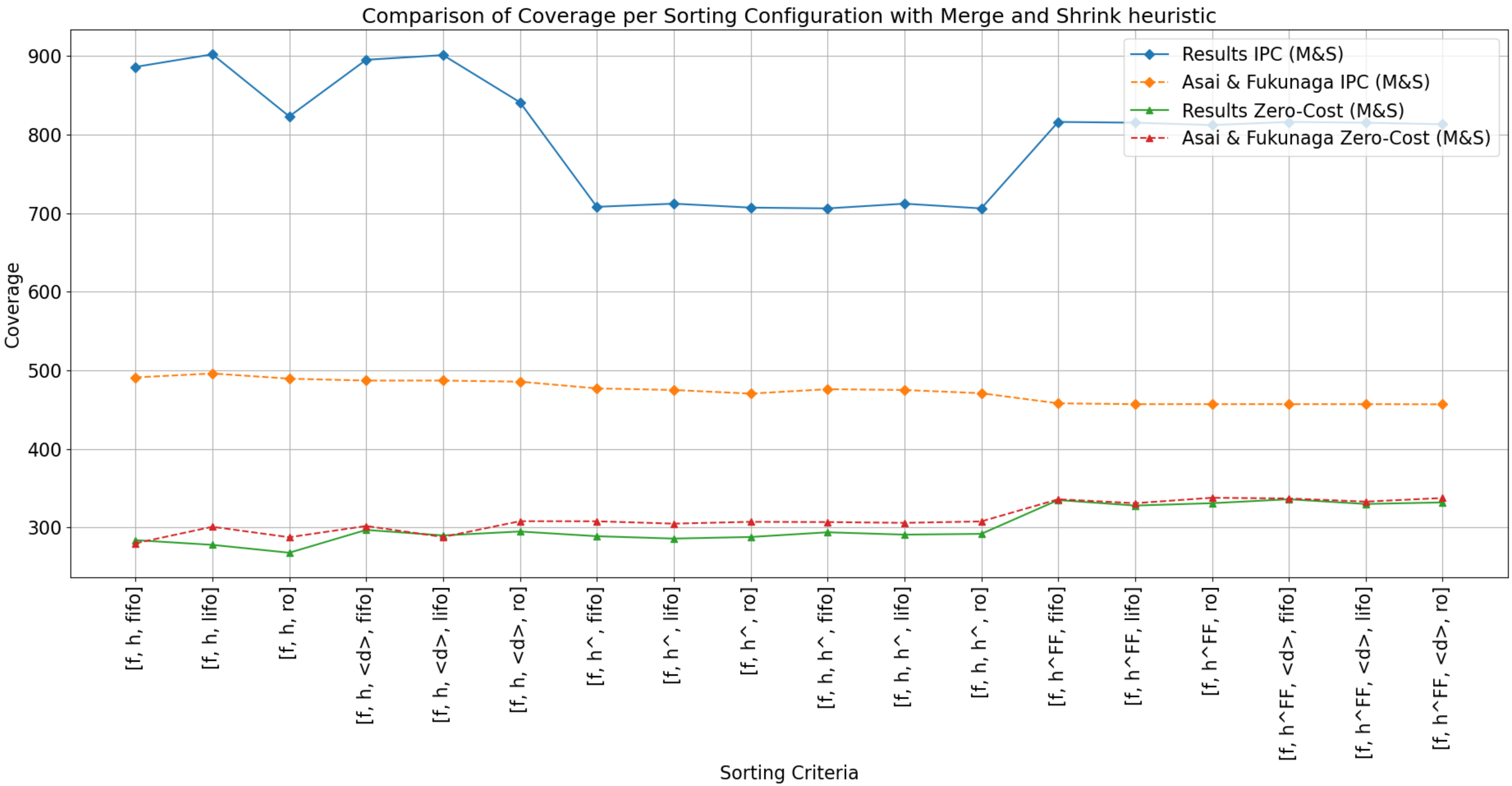


PATHWAYS-FUEL domain

Configurations	FIFO	LIFO	Random	Factor
[f, h, *]	4’173’908	**290**	566’145.80	× 14’392.78
[f, h, <d>, *]	325’339	**423**	1’114’393.50	× 2’634.50
[f, h^, *]	**55**	156’712	39’234.50	× 2’849.31
[f, h, h^, *]	**43**	156’712	none	× 3’644.47
[f, h^-FF, <d>, *]	**31**	**31**	31.80	× 1.02

Results Merge&Shrink

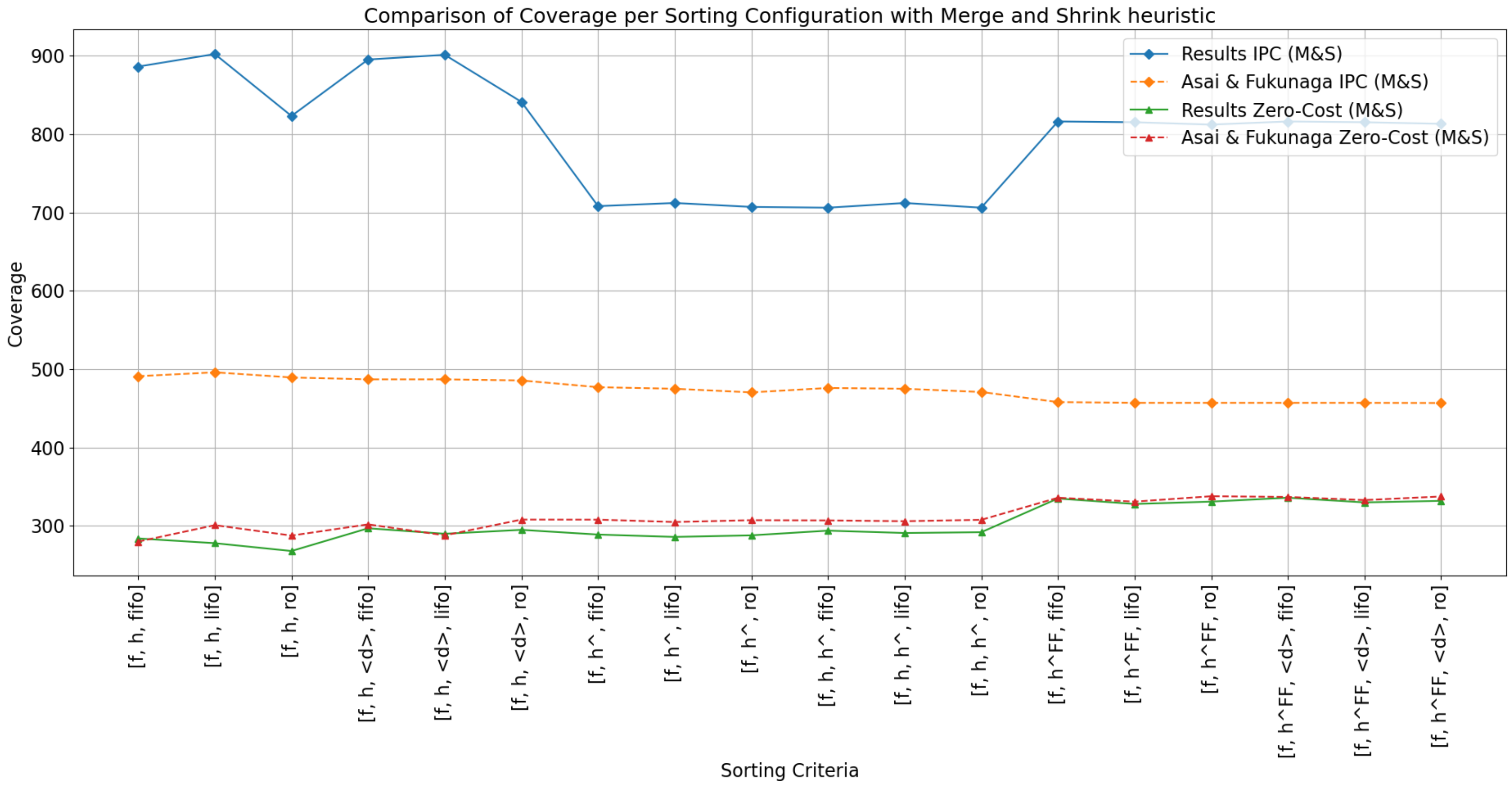




Comparison of Coverage per Sorting Configuration with Merge and Shrink heuristic
Results IPC (M&S)
Asai & Fukunaga IPC (M&S)
Results Zero-Cost (M&S)
Asai & Fukunaga Zero-Cost (M&S)
Coverage
900
800
700
600
500
400
300
Sorting Criteria
[f, h, fifo]
[f, h, lifo]
[f, h, ro]
[f, h, <d>, fifo]
[f, h, <d>, lifo]
[f, h, <d>, ro]
[f, h^, fifo]
[f, h^, lifo]
[f, h^, ro]
[f, h, h^, fifo]
[f, h, h^, lifo]
[f, h, h^, ro]
[f, h^FF, fifo]
[f, h^FF, lifo]
[f, h^FF, ro]
[f, h^FF, <d>, fifo]
[f, h^FF, <d>, lifo]
[f, h^FF, <d>, ro]

Results Merge&Shrink

- [f, h^-FF, <d>, *] (Zero-cost)
- [f, h, <d>, *] (IPC)



Conclusion

- Default Tie-breaking give optimal expansion only in corner cases
- Zero-cost actions create large plateaus
- Depth-Diversification + Distance-to-go heuristics improve coverage
- Final Tie-breaker is important

Future Work

- Cost adaption approach (Corrêa et al)
- Compare heuristics
- Depth-Diversification with randomizer instead of counter