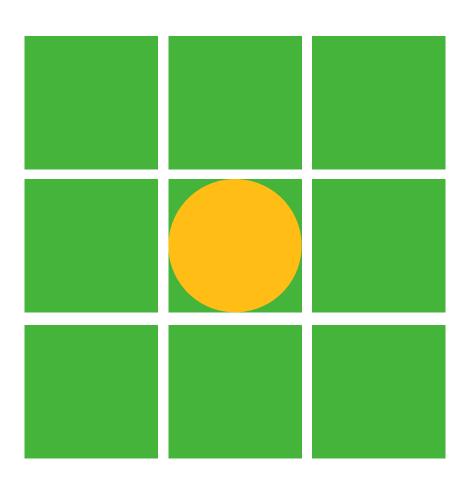


# LMCut Heuristic with Different Precondition Choice Functions Bachelor Thesis Presentation

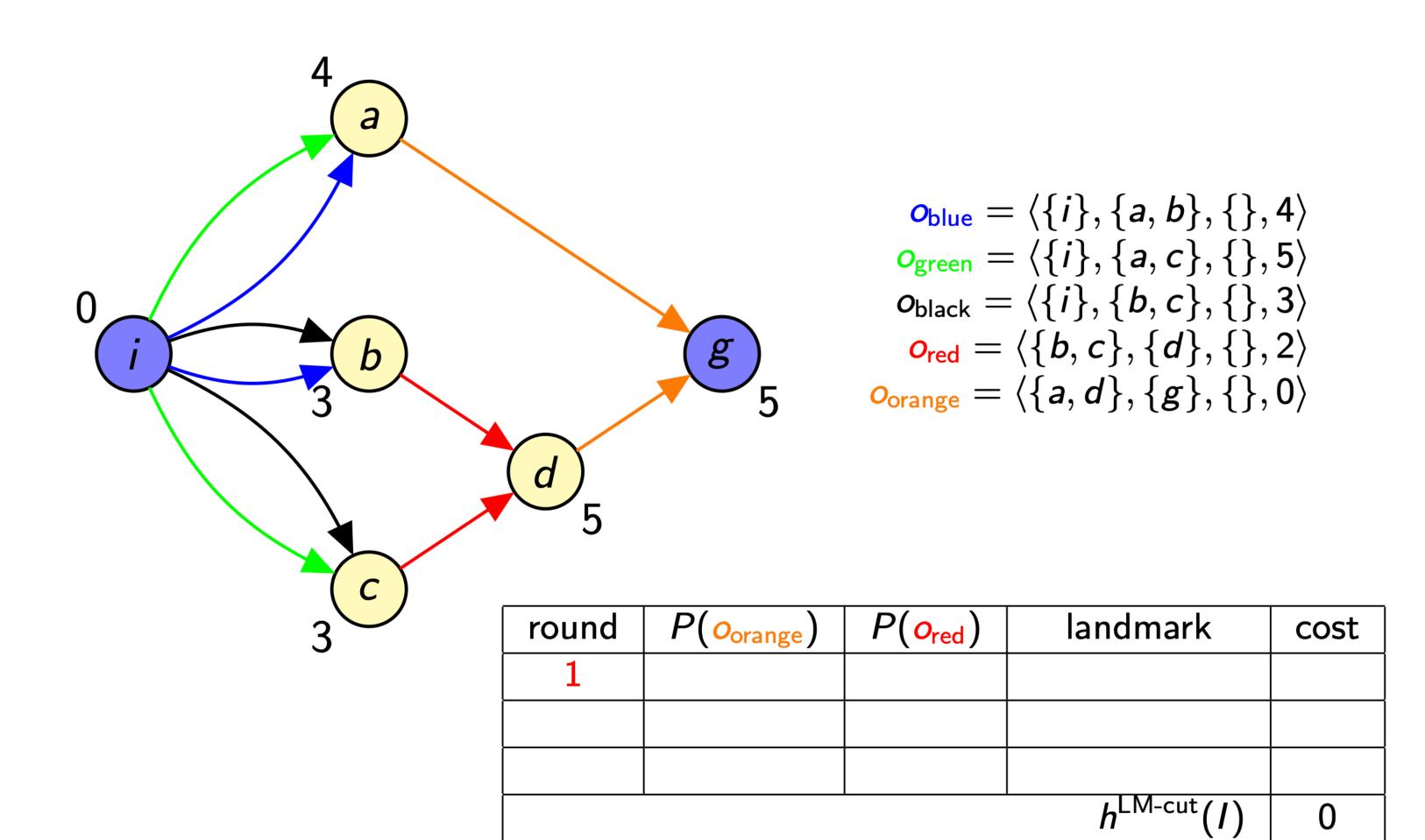
# Quick Story About VisitAll...



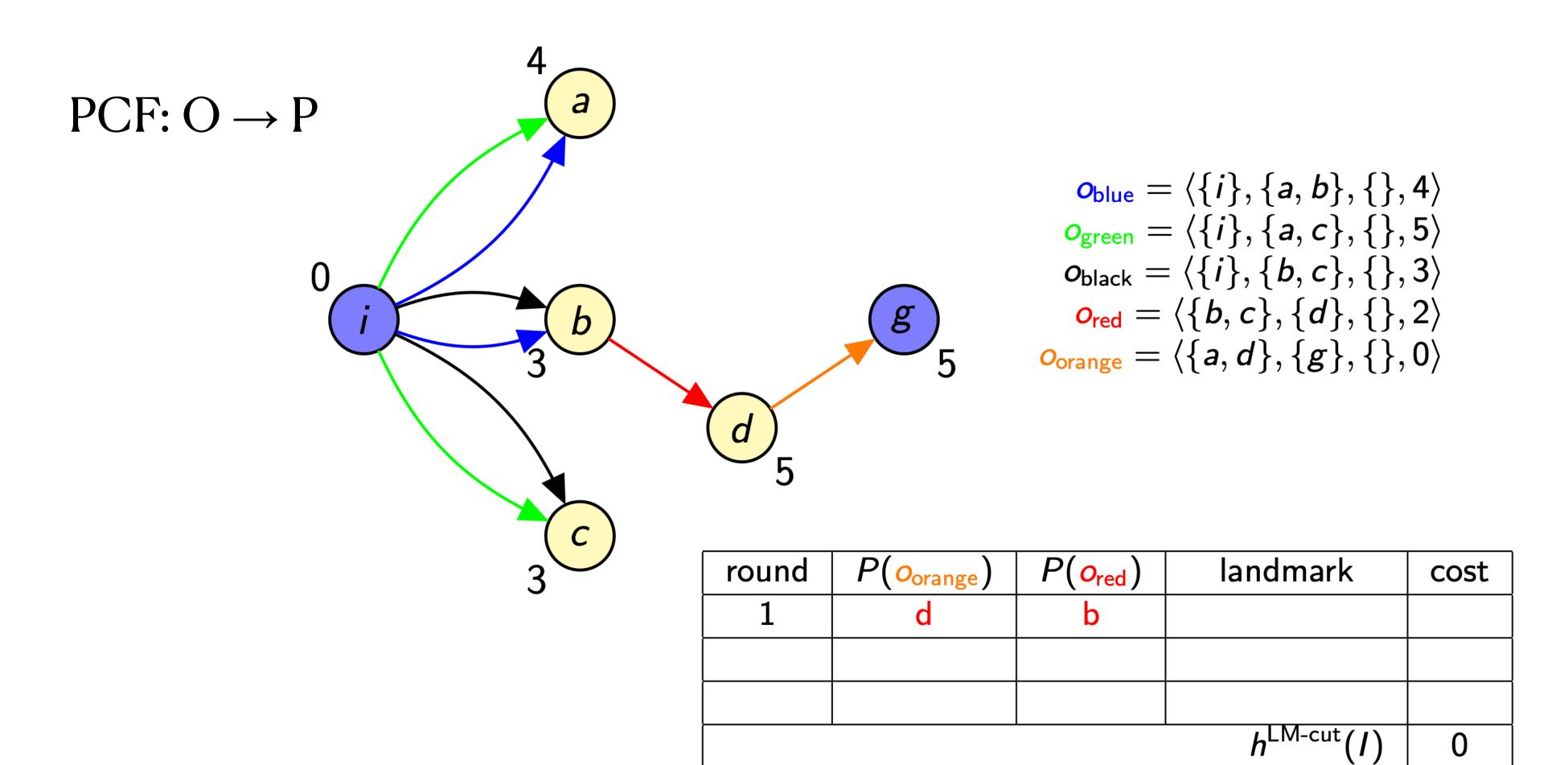
### Introduction

- Background: LMCut Heuristic
- Introduced Changes: Precondition Choice Functions and Tie-Breaking Strategies
- Results und Discussion: Experimental Evaluation and Theory

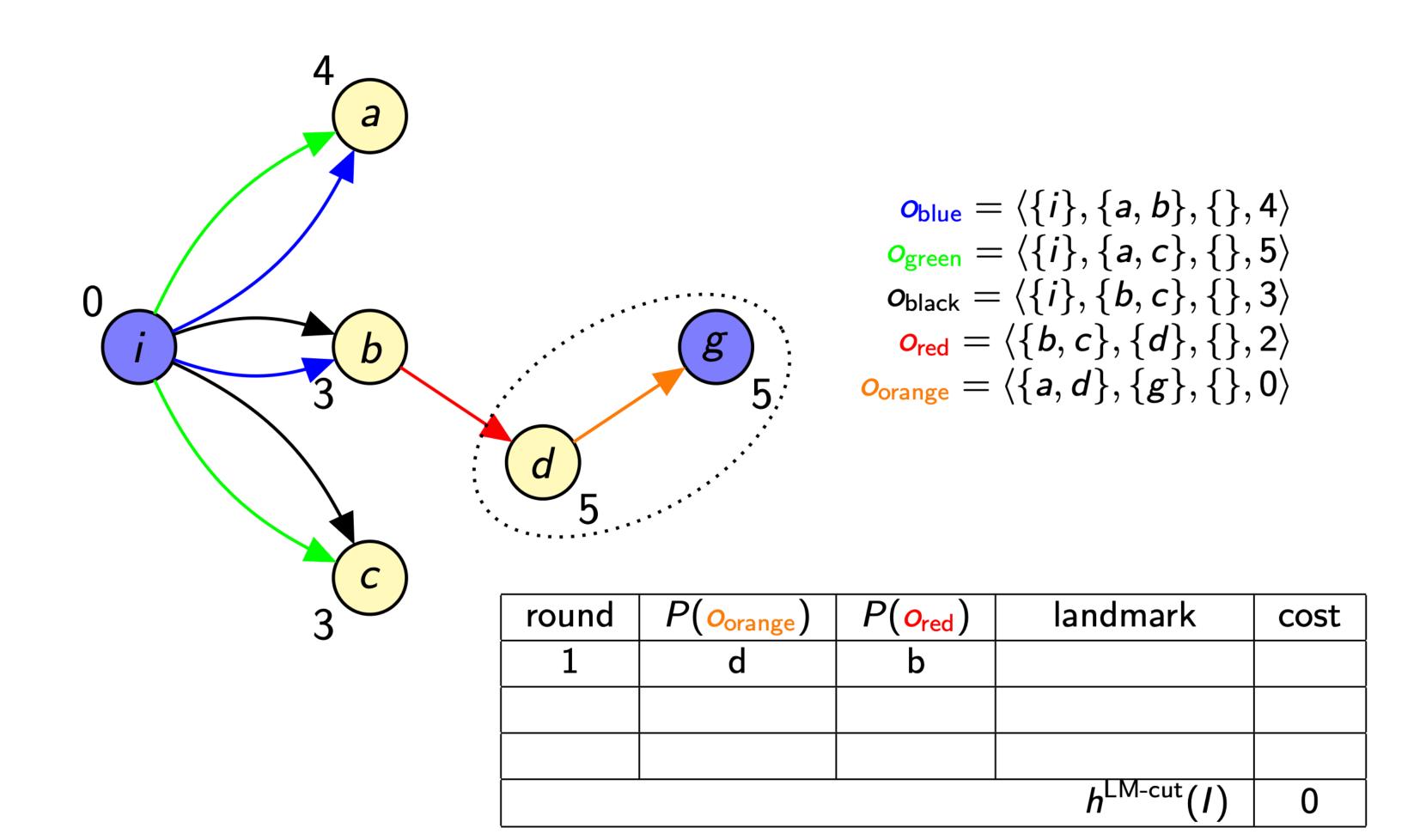
### 1. Compute h<sup>max</sup> values of the variables



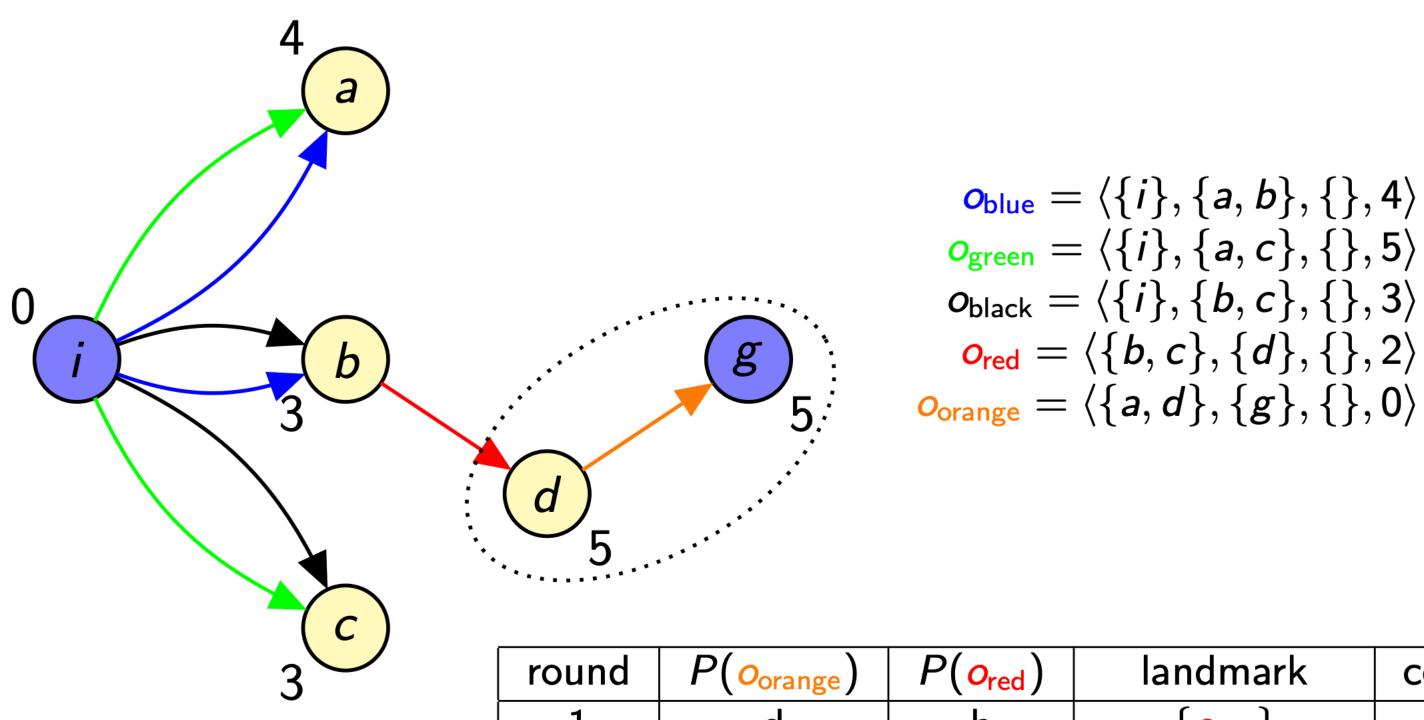
### 2. Compute justification graph



#### 3. Determine Goal Zone

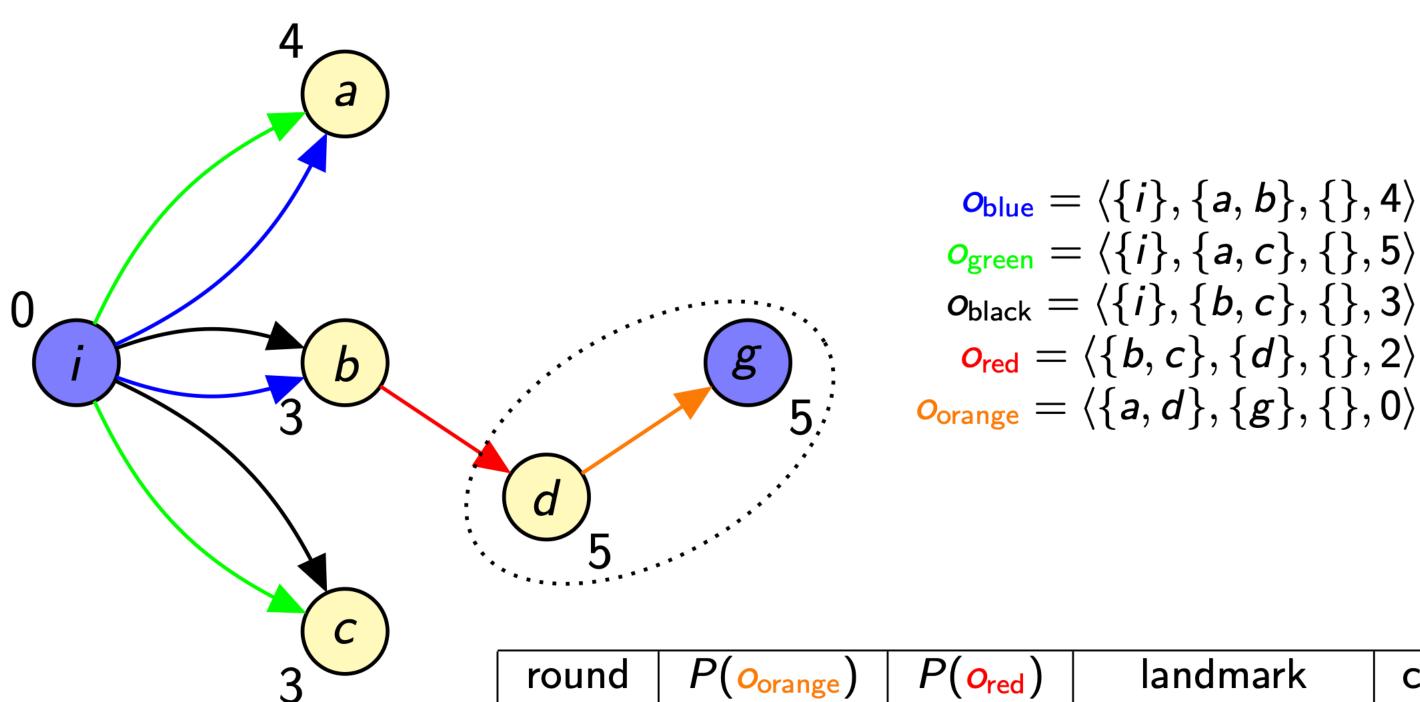


### 4. Compute Cut

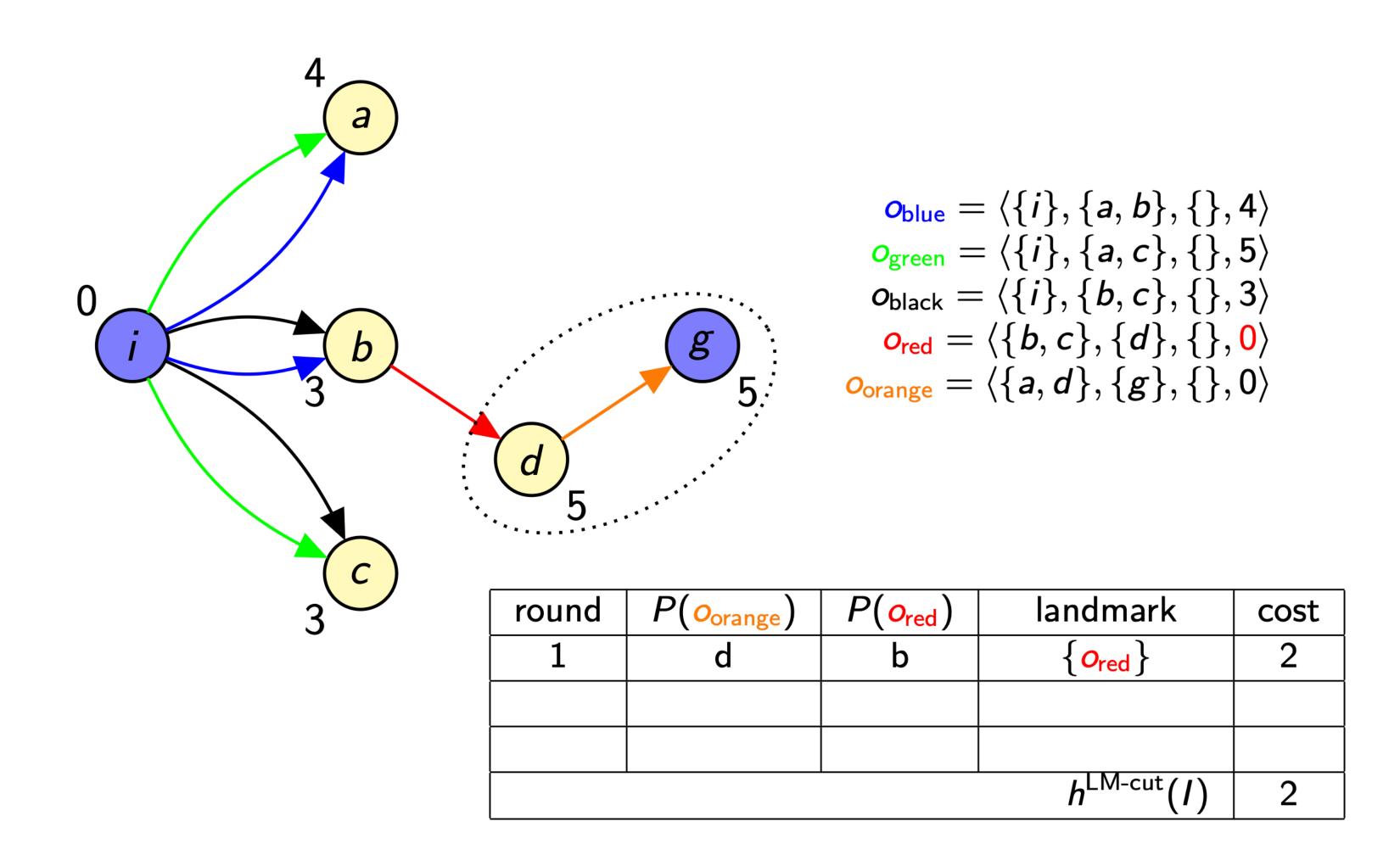


round	$P(o_{orange})$	$P(o_{red})$	landmark	cost
1	d	b	$\left\{ {\color{red}o_{red}}  ight\}$	2
			$h^{LM-cut}(I)$	0

5. Increase h<sup>LMCut</sup>(I) by cost(L)



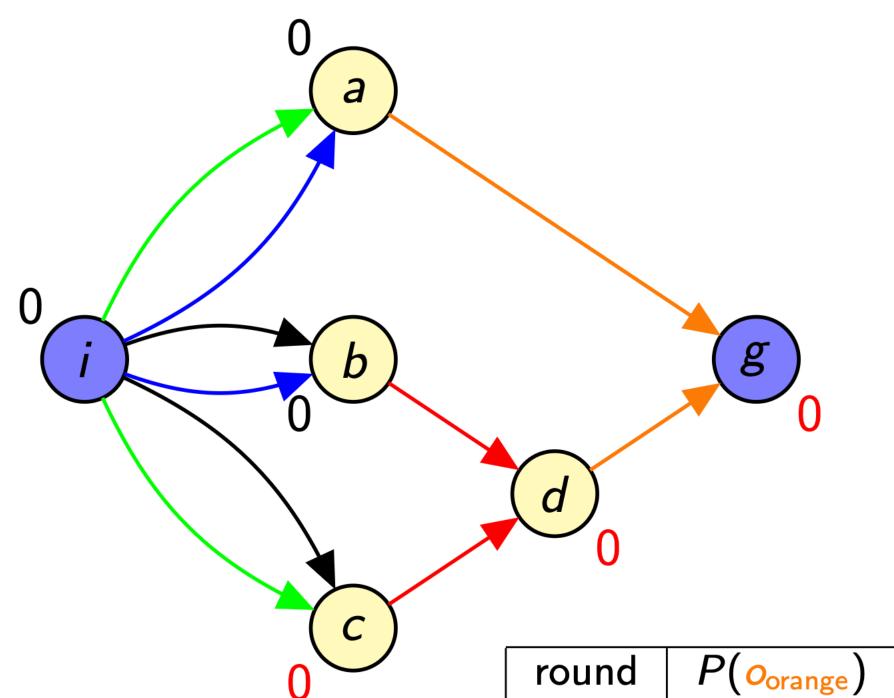
6. Decrease cost(o) by cost(L) for all  $o \in L$ 



**Continue iterating** 

SRC: https://ai.dmi.unibas.ch/\_files/teaching/hs23/po/slides/po-go5.pdf

1. Compute  $h^{max}$  values of the variables. Stop if  $h^{max}(g) = 0$ .



$$o_{
m blue} = \langle \{i\}, \{a, b\}, \{\}, 0 \rangle$$
 $o_{
m green} = \langle \{i\}, \{a, c\}, \{\}, 0 \rangle$ 
 $o_{
m black} = \langle \{i\}, \{b, c\}, \{\}, 2 \rangle$ 
 $o_{
m red} = \langle \{b, c\}, \{d\}, \{\}, 0 \rangle$ 
 $o_{
m orange} = \langle \{a, d\}, \{g\}, \{\}, 0 \rangle$ 

round	$P(o_{orange})$	$P(o_{red})$	landmark	cost
1	d	b	$\{o_{red}\}$	2
2	а	b	{o <sub>green</sub> , o <sub>blue</sub> }	4
3	d	С	$\{o_{green}, o_{black}\}$	1
			$h^{LM-cut}(I)$	7

#### **Precondition Choice Functions**

• PCFrd: Completely Random Choice

#### **Precondition Choice Functions**

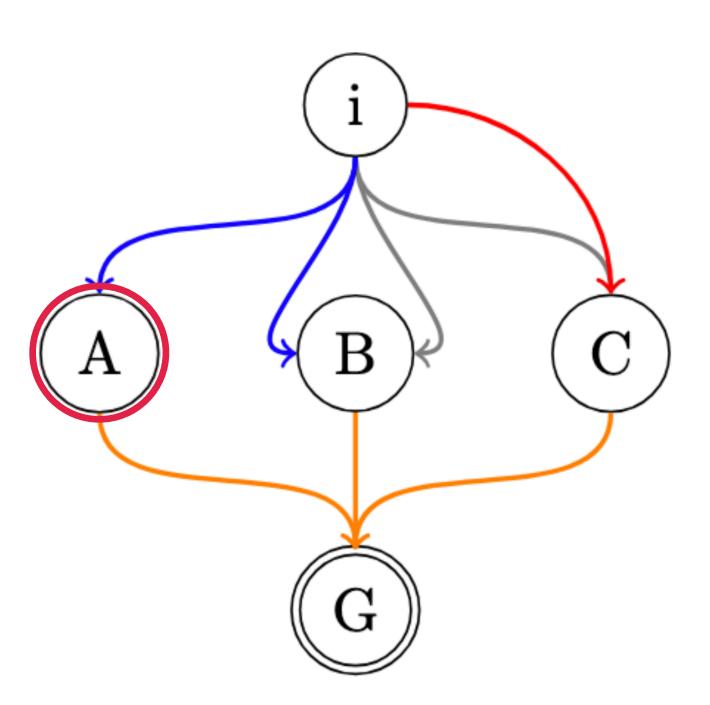
- PCFrd: Completely Random Choice
- PCFrd-max: Random Choice With hmax as Termination Criterion

#### **Precondition Choice Functions**

- PCFrd: Completely Random Choice
- PCFrd-max: Random Choice With hmax as Termination Criterion
- PCFhadd: Choosing Preconditions Based on hadd

### **Tie-Breaking Strategies**

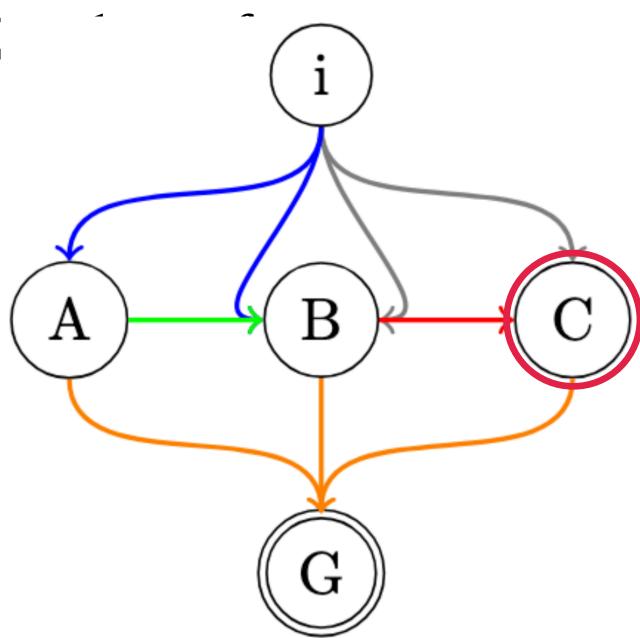
• PCF<sub>e-min</sub>: Favor Preconditions being Effect of Lowest Number of Operators



### **Tie-Breaking Strategies**

• PCF<sub>e-min</sub>: Favor Preconditions being Effect of Lowest Number of Operators

• PCF<sub>p-min</sub>: Favor Preconditions being Precondition of Lowest N



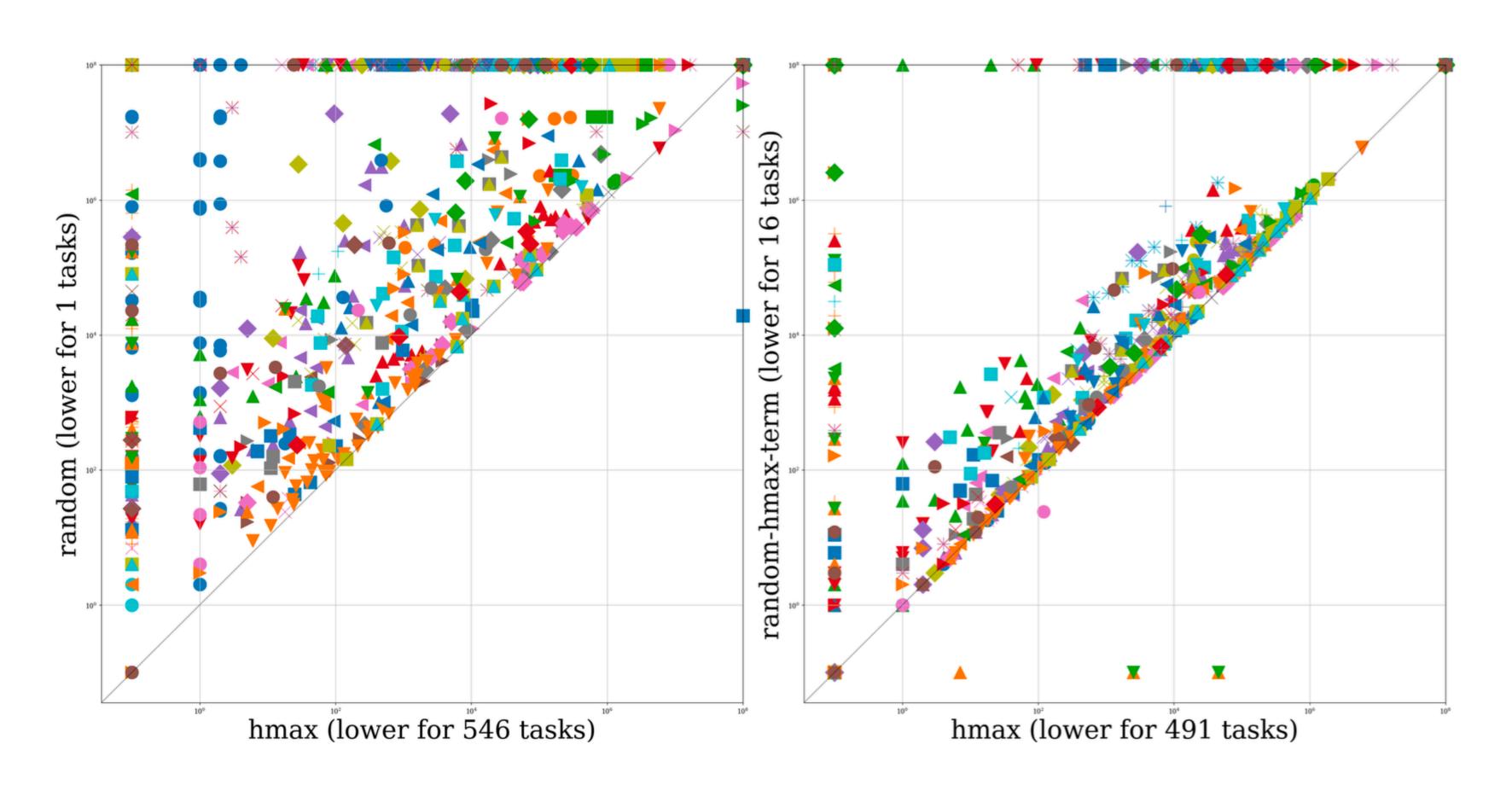
### **Tie-Breaking Strategies**

- PCF<sub>e-min</sub>: Favor Preconditions being Effect of Lowest Number of Operators
- PCF<sub>p-min</sub>: Favor Preconditions being Precondition of Lowest Number of Operators
- PCF<sub>unused</sub>: Favor Unused Preconditions

### **Tie-Breaking Strategies**

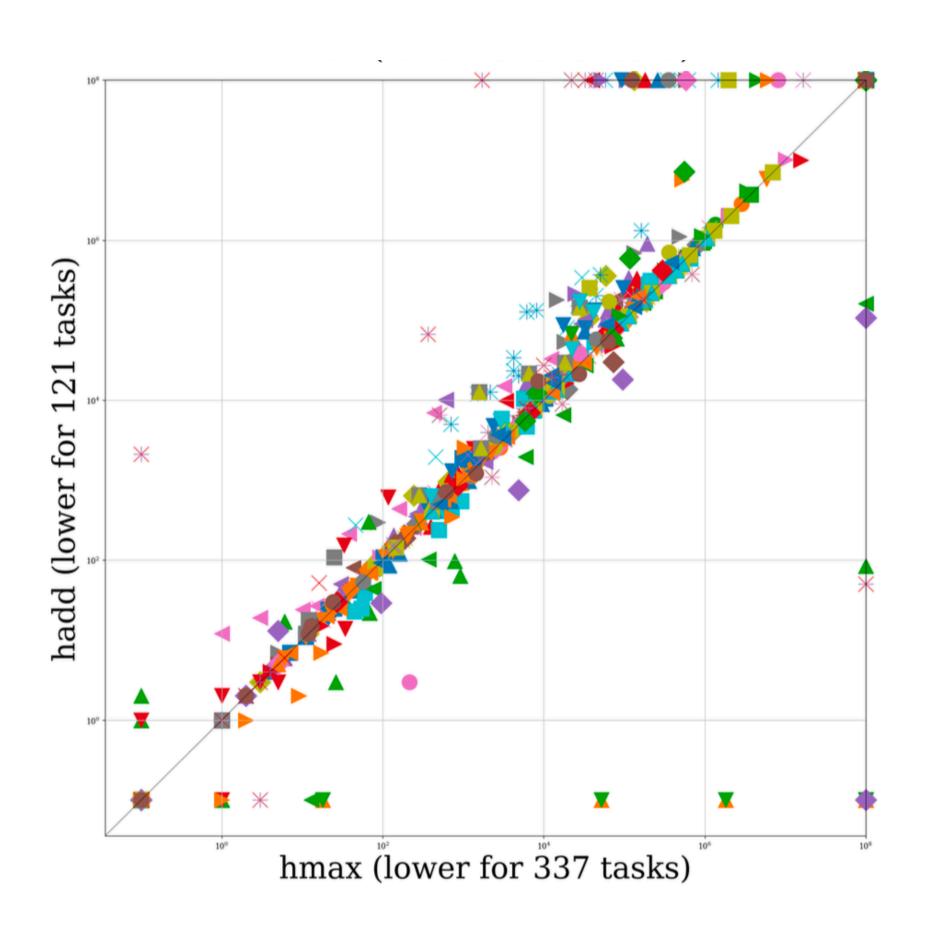
- PCF<sub>e-min</sub>: Favor Preconditions being Effect of Lowest Number of Operators
- PCF<sub>p-min</sub>: Favor Preconditions being Precondition of Lowest Number of Operators
- PCF<sub>unused</sub>: Favor Unused Preconditions
- PCF<sub>unused-n</sub>: Favor Less Frequently Used Preconditions

### **Replacing Precondition Choice Functions**



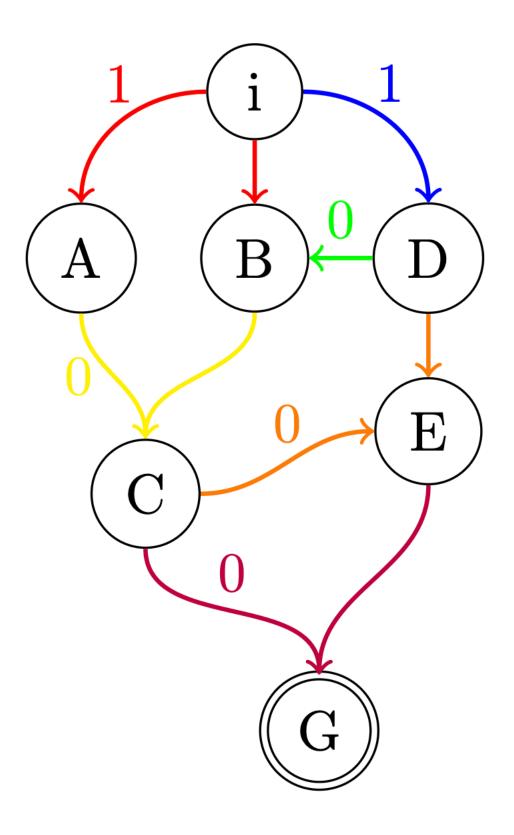
Node Expansions Until Last Jump

### **Replacing Precondition Choice Functions**



Node Expansions Until Last Jump

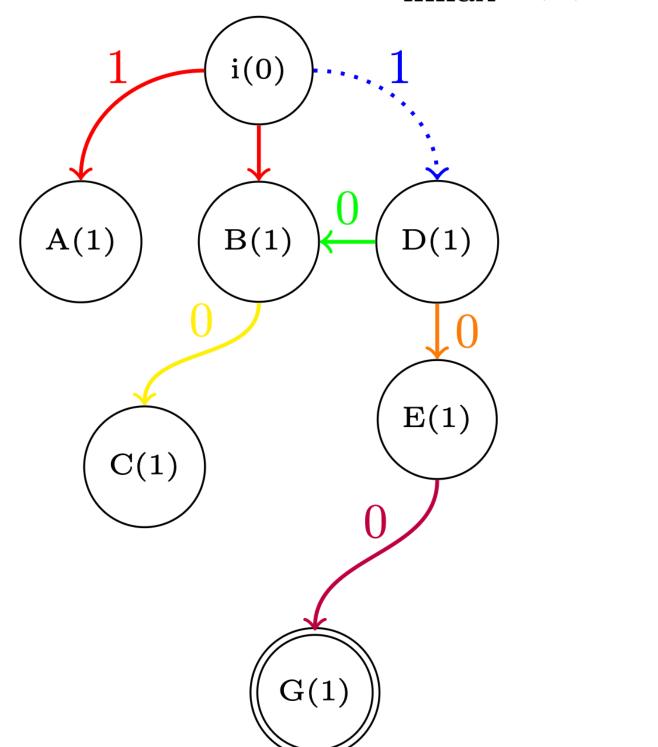
### **Example For Different Outcomes Using Same Tie-Breaking**



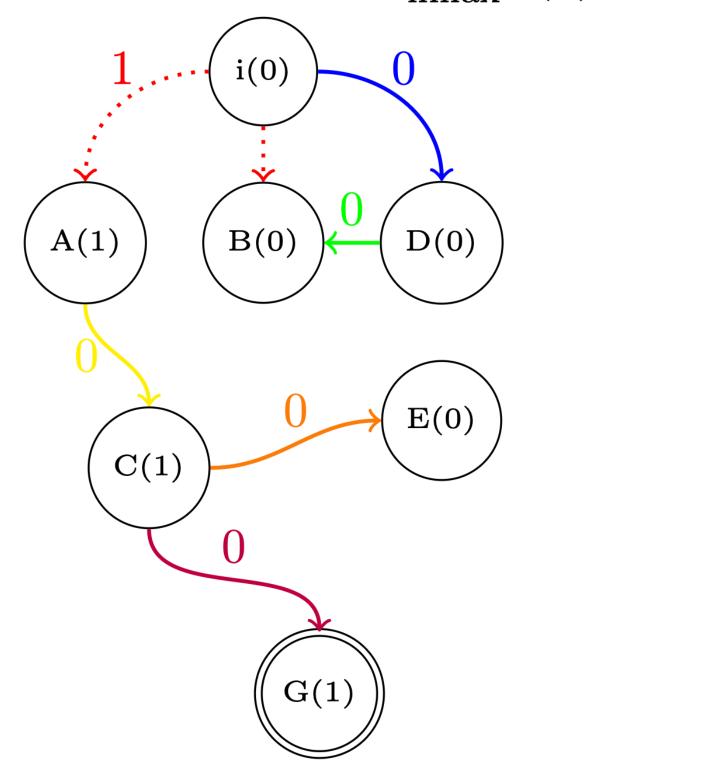
$$egin{aligned} o_{red} &= \langle \{i\}, \{A, B\}, \{\}, 1 
angle \ o_{blue} &= \langle \{i\}, \{D\}, \{\}, 1 
angle \ o_{yellow} &= \langle \{A, B\}, \{C\}, \{\}, 0 
angle \ o_{green} &= \langle \{D\}, \{B\}, \{\}, 0 
angle \ o_{orange} &= \langle \{C, D\}, \{E\}, \{\}, 0 
angle \ o_{purple} &= \langle \{C, E\}, \{G\}, \{\}, 0 
angle \end{aligned}$$

### **LMCuthmax**

Iteration 1:  $h_{\text{hmax}}^{\text{LMCut}}(I) = 1$ 

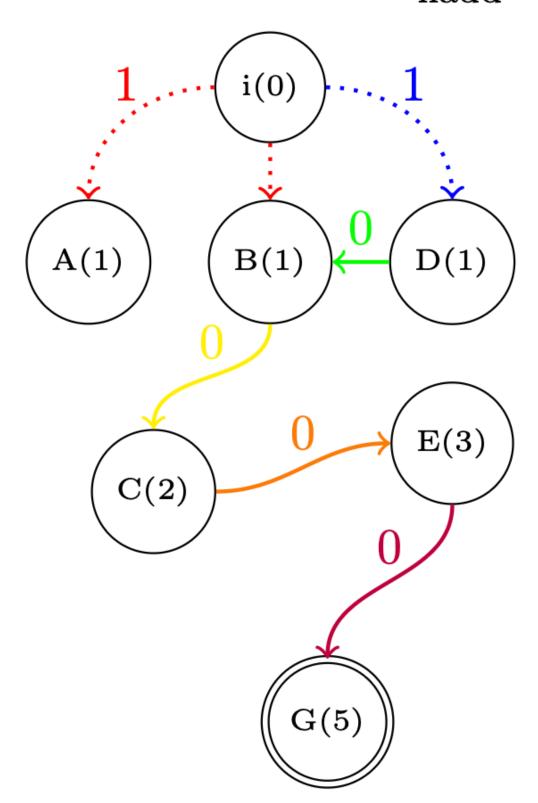


Iteration 2:  $h_{\text{hmax}}^{\text{LMCut}}(I) = 2$ 

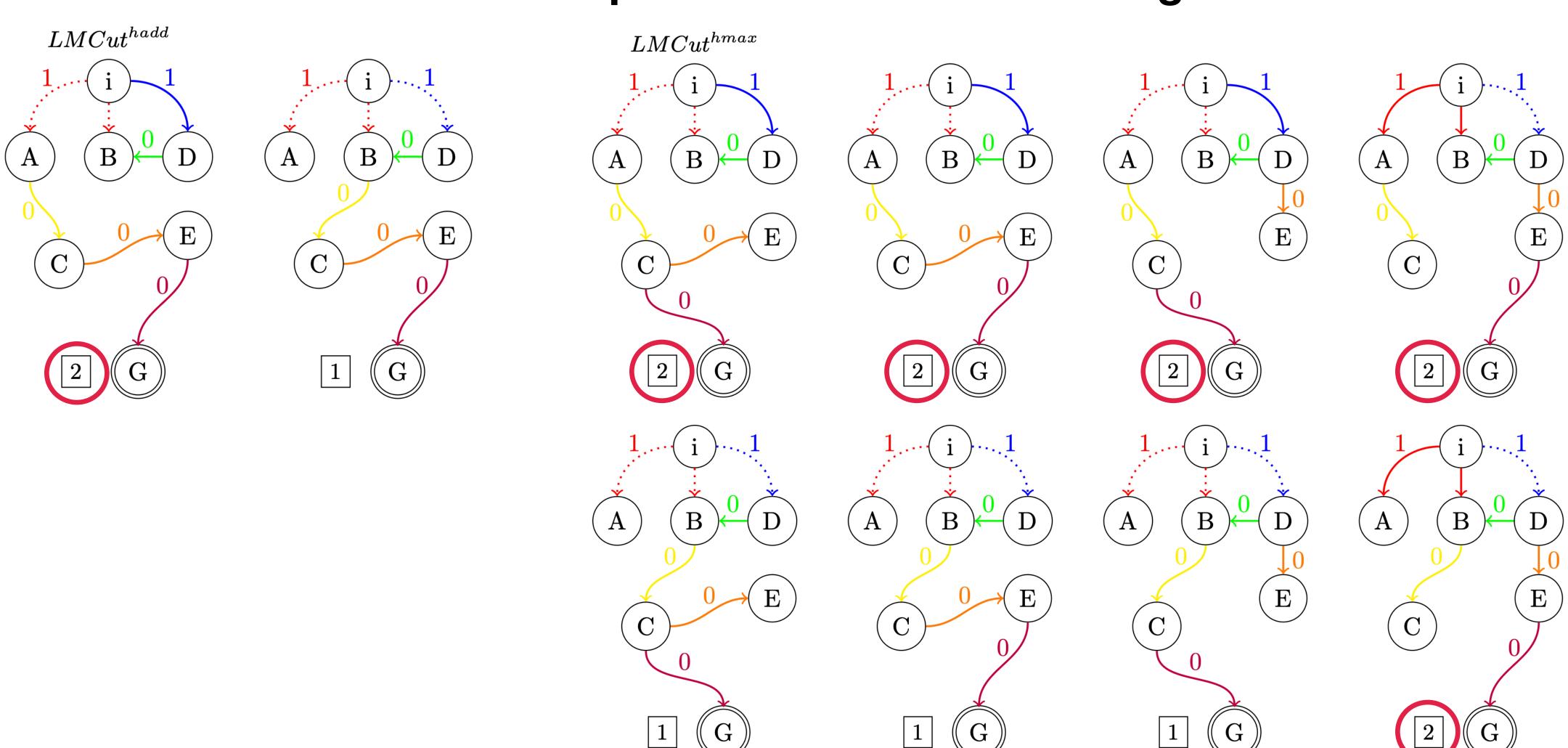


### **LMCut**hadd

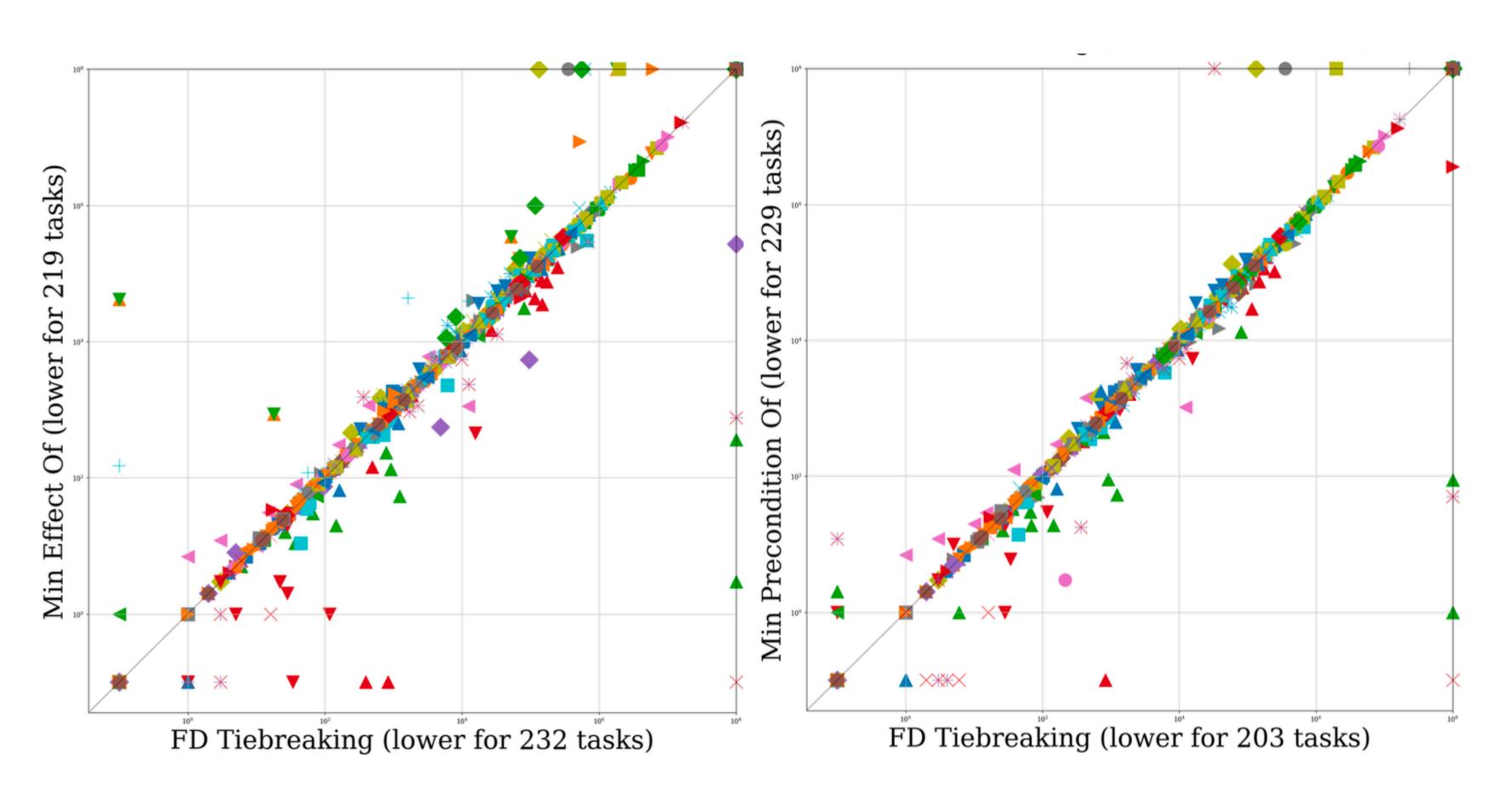
Iteration 1:  $h_{\text{hadd}}^{\text{LMCut}}(I) = 1$ 



### Justification Graphs for All Valid Tie Breakings

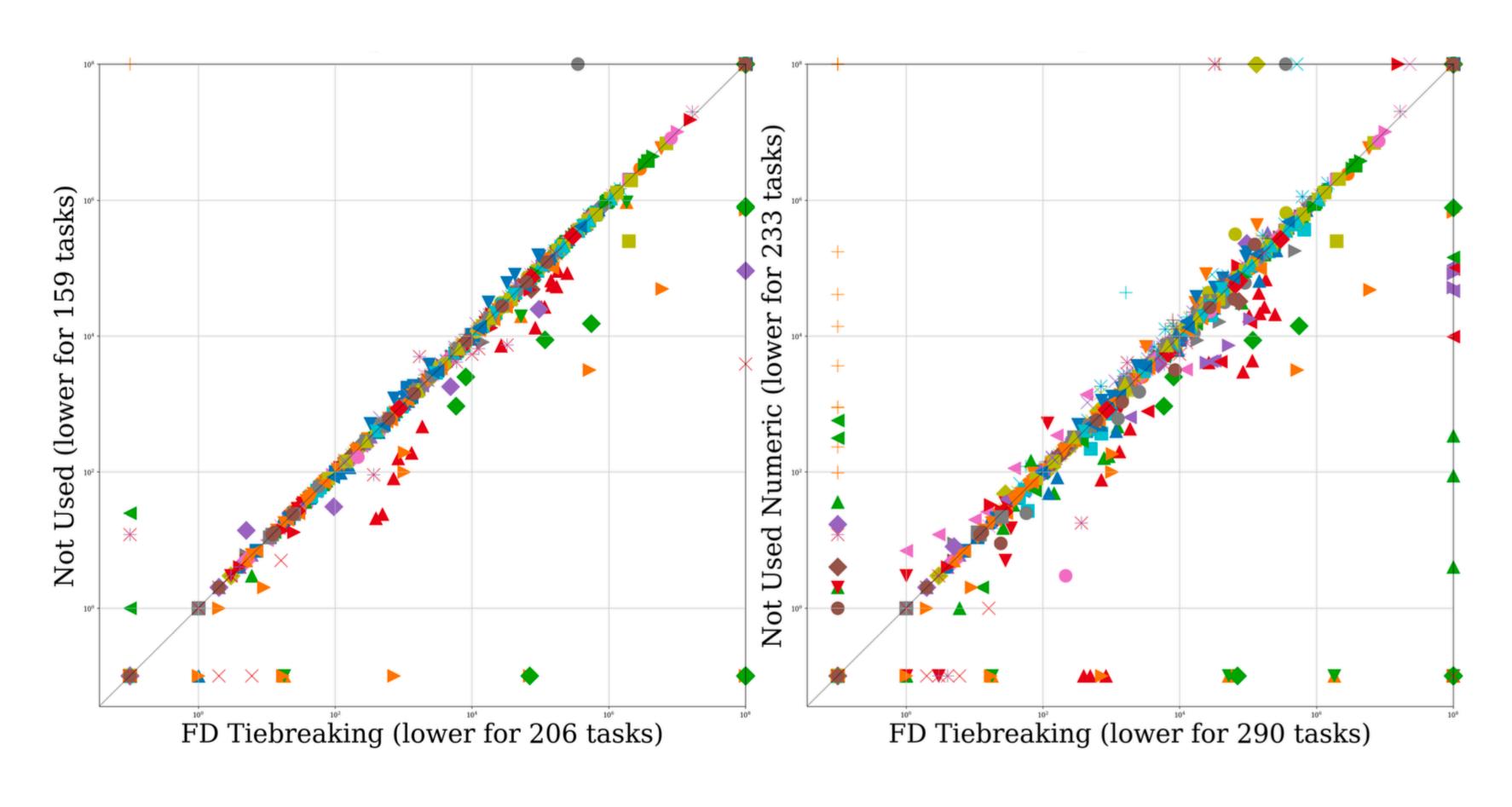


### **Tie-Breaking Strategies**



Node Expansions Until Last Jump

### **Tie-Breaking Strategies**



Node Expansions Until Last Jump

# Selected Precondition Goal Zone Cut Set Operators

### **Tie-Breaking Strategies**

### LMCut<sub>default</sub>

i	=	1
9		?
4	1	
1	0	1
2	1	2

$$egin{array}{c|cccc} i = 4 \\ \hline 1 & 1 & 1 \\ \hline 1 & 0 & 1 \\ \hline 2 & 1 & 1 \\ \hline \end{array}$$

$$i = 6$$
 $0 + 1$ 
 $0 + 4$ 
 $0 + 0$ 

$$egin{array}{c|cccc} i &= 7 \\ \hline 0 & 0 & 0 \\ \hline 0 & 0 & 0 \\ \hline 0 & 0 & 0 \\ \hline \end{array}$$

$$egin{array}{c|c} i = 2 \ \hline 1 & 1 & 2 \ \hline 1 & 0 & 1 \ \hline 2 & 1 & 2 \ \hline \end{array}$$

=	3
1	1
0	1-+
1	2
	1 0 1

$$egin{array}{c|cccc} i = 4 \\ \hline 1 & 1 & 1 \\ \hline 1 & 0 & 1 \\ \hline 2 & 1 & 1 \\ \hline \end{array}$$

$$egin{array}{c|c} i = 5 \\ \hline 1 & 1 & 1 \\ \hline 1 & 0 & 1 \\ \hline 1 & 1 & 1 \\ \hline \end{array}$$

1	=	$\mathbf{o}$
1_	*	$\mathbf{f}$
1	0	0
1	1	<b>0</b>

$$egin{array}{c|cccc} i &= 7 \\ \hline 0 & 0 & 0 \\ \hline 1 & 1 & 0 \\ \hline \end{array}$$

$$egin{array}{c|cccc} i = 8 \\ \hline 0 & 0 & 0 \\ \hline 0 & 0 & 0 \\ \hline 0 & 1 & 0 \\ \hline \end{array}$$

### **Tie-Breaking Strategies**

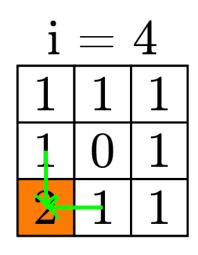
Selected Precondition
Goal Zone
Cut Set Operators

### LMCut<sub>default</sub>

# 

i		2
1	1-	2
1	0	1
2	1	2

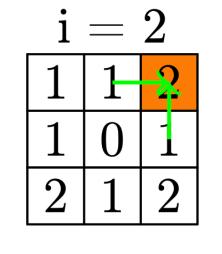
#### Initial state



i	=	5
1	1	1
	<b>6</b>	1
1	K	1

$$i = 6$$
 $0 \quad 1$ 
 $0 \quad 0$ 
 $0 \quad 0$ 
 $0 \quad 0$ 

$$egin{array}{c|c} i = 7 \\ \hline 0 & 0 & 0 \\ \hline 0 & 0 & 0 \\ \hline 0 & 0 & 0 \\ \hline \end{array}$$



$$egin{array}{c|c} i = 3 \ 1 & 1 \ 1 \ 1 & 1 \ 2 & 1 & 2 \ \end{array}$$

$$egin{array}{c|cccc} i = 4 \\ \hline 1 & 1 & 1 \\ \hline 1 & 0 & 1 \\ \hline 2 & 1 & 1 \\ \hline \end{array}$$

$$egin{array}{c|cccc} i = 5 \\ \hline 1 & 1 & 1 \\ \hline 1 & 0 & 1 \\ \hline 1 & 1 & 1 \\ \hline \end{array}$$

$$egin{array}{c|cccc} i = 7 \\ \hline 0 & 0 & 0 \\ \hline 2 & 0 & 0 \\ \hline 1 & 1 & 0 \\ \hline \end{array}$$

$$egin{array}{c|cccc} i = 8 \\ \hline 0 & 0 & 0 \\ \hline 0 & 0 & 0 \\ \hline 0 & 1 & 0 \\ \hline \end{array}$$

$$i = 9$$
 $0 \ 0 \ 0$ 
 $0 \ 0 \ 0$ 
 $0 \ 0 \ 0$ 

# Selected Precondition Goal Zone Cut Set Operators

### **Tie-Breaking Strategies**

### LMCut<sub>default</sub>

# 

i	=	2
$\boxed{1}$	1-	2
1	0	1
2	1	2

i = 5

i = 6

0

$$egin{array}{c|cccc} i = 4 \\ \hline 1 & 1 & 1 \\ \hline 1 & 0 & 1 \\ \hline 2 & 1 & 1 \\ \hline \end{array}$$

Retake same proposition...

$$egin{array}{c|c} i = 1 \\ \hline 2 & 1 & 2 \\ \hline 1 & 0 & 1 \\ \hline 2 & 1 & 2 \\ \hline \end{array}$$

i	=	3
1	1	1
1	0	1
$\boxed{2}$	1	2

$$egin{array}{c|cccc} i = 4 \\ \hline 1 & 1 & 1 \\ \hline 1 & 0 & 1 \\ \hline 2 & 1 & 1 \\ \hline \end{array}$$

$$egin{array}{c|cccc} i = 5 \\ \hline 1 & 1 & 1 \\ \hline 1 & 0 & 1 \\ \hline 1 & 1 & 1 \\ \hline \end{array}$$

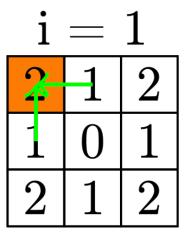
i	=	6
1	X	0
1	0	0
1	1	0

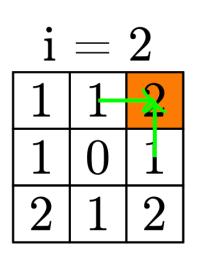
$$egin{array}{c|cccc} 1 &= 9 \\ \hline 0 & 0 & 0 \\ \hline 0 & 0 & 0 \\ \hline 0 & 0 & 0 \\ \hline \end{array}$$

### **Tie-Breaking Strategies**

Selected Precondition Goal Zone Cut Set Operators

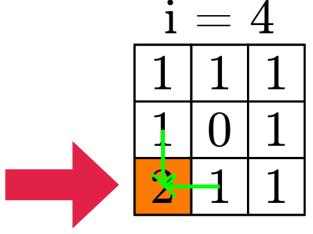
### LMCut<sub>default</sub>

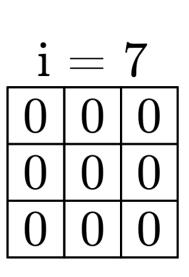




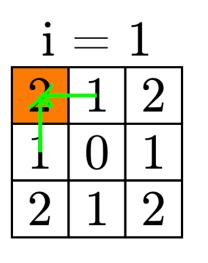
i = 5

i = 6





i = 7 ... with two zero cost operators from prev. iteration...



i	=	2
1	1	2
1	0	1
2	1	2

1		3
1	1	1
1	0	1
$\boxed{2}$	1	2

$$egin{array}{c|cccc} i = 4 \\ \hline 1 & 1 & 1 \\ \hline 1 & 0 & 1 \\ \hline 2 & 1 & 1 \\ \hline \end{array}$$

$$egin{array}{c|c} i = 5 \\ \hline 1 & 1 & 1 \\ \hline 1 & 0 & 1 \\ \hline 1 & 1 & 1 \\ \hline \end{array}$$

i	=	6
1	×	0
1	0	0
1	1	0

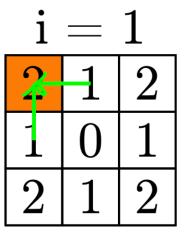
$$egin{array}{c|c} i = 7 \\ \hline 0 & 0 & 0 \\ \hline 2 & 0 & 0 \\ \hline 1 & 1 & 0 \\ \hline \end{array}$$

$$egin{array}{c|cccc} 1 &= 9 \\ \hline 0 & 0 & 0 \\ \hline 0 & 0 & 0 \\ \hline 0 & 0 & 0 \\ \hline \end{array}$$

### **Tie-Breaking Strategies**

Selected Precondition Goal Zone Cut Set Operators

### LMCut<sub>default</sub>

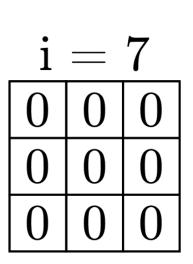


$$egin{array}{c|cccc} i = 3 \\ \hline 1 & 1 & 1 \\ \hline 1 & 0 & 1 \\ \hline 2 & 1 & 2 \\ \hline \end{array}$$

i = 6

0 4

$$egin{array}{c|cccc} i = 4 \\ \hline 1 & 1 & 1 \\ \hline 1 & 0 & 1 \\ \hline 2 & 1 & 1 \\ \hline \end{array}$$



 $\frac{i=7}{0 \mid 0 \mid 0}$  ... leads to growing goal zone...

$$egin{array}{c|cccc} i &= 1 & & & \\ \hline 2 & 1 & 2 & & \\ \hline 1 & 0 & 1 & & \\ \hline 2 & 1 & 2 & & \\ \hline \end{array}$$

$$egin{array}{c|c} i = 2 \ \hline 1 & 1 & 2 \ \hline 1 & 0 & 1 \ \hline 2 & 1 & 2 \ \hline \end{array}$$

i	=	3
1	1	1
1	0	1
$\overline{2}$	1	2

$$egin{array}{c|c} i = 4 \\ \hline 1 & 1 & 1 \\ \hline 1 & 0 & 1 \\ \hline 2 & 1 & 1 \\ \hline \end{array}$$

$$egin{array}{c|c} i = 5 \ \hline 1 & 1 & 1 \ \hline 1 & 0 & 1 \ \hline 1 & 1 & 1 \ \hline \end{array}$$

$$\begin{array}{c|cccc}
 1 & = 0 \\
 \hline
 1 & 0 \\
 \hline
 1 & 0 & 0 \\
 \hline
 1 & 1 & 0 \\
 \end{array}$$

$$egin{array}{c|cccc} i &= 7 \\ \hline 0 & 0 & 0 \\ \hline 1 & 1 & 0 \\ \hline \end{array}$$

$$egin{array}{c|cccc} i = 8 \\ \hline 0 & 0 & 0 \\ \hline 0 & 0 & 0 \\ \hline 0 & 1 & 0 \\ \hline \end{array}$$

$$egin{array}{c|c} i = 9 \\ \hline 0 & 0 & 0 \\ \hline 0 & 0 & 0 \\ \hline 0 & 0 & 0 \\ \hline \end{array}$$

# Goal Zone Cut Set Operators

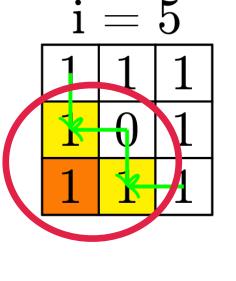
Selected Precondition

### **Tie-Breaking Strategies**

### LMCut<sub>default</sub>

# 

$$egin{array}{c|cccc} i = 4 \\ \hline 1 & 1 & 1 \\ \hline 1 & 0 & 1 \\ \hline 2 & 1 & 1 \\ \hline \end{array}$$



$$i = 6$$
 $0 \quad 1$ 
 $0 \quad 0 \quad 1$ 
 $0 \quad 0 \quad 0$ 

... thus, larger cut set.

$$egin{array}{c|c} i = 2 \\ \hline 1 & 1 & 2 \\ \hline 1 & 0 & 1 \\ \hline 2 & 1 & 2 \\ \hline \end{array}$$

1 1
<u> </u>
$0 \mid 1$
1 2

$$egin{array}{c|c} i = 4 \\ \hline 1 & 1 & 1 \\ \hline 1 & 0 & 1 \\ \hline 2 & 1 & 1 \\ \hline \end{array}$$

$$egin{array}{c|c} i = 5 \\ \hline 1 & 1 & 1 \\ \hline 1 & 0 & 1 \\ \hline 1 & 1 & 1 \\ \hline \end{array}$$

$$egin{array}{c|c} i = 7 \\ \hline 0 & 0 & 0 \\ \hline 1 & 1 & 0 \\ \hline \end{array}$$

$$egin{array}{c|cccc} i = 8 \\ \hline 0 & 0 & 0 \\ \hline 0 & 0 & 0 \\ \hline 0 & 1 & 0 \\ \hline \end{array}$$

$$i = 9$$
 $0 \ 0 \ 0$ 
 $0 \ 0 \ 0$ 
 $0 \ 0 \ 0$ 

# Goal Zone Cut Set Operators

Selected Precondition

### **Tie-Breaking Strategies**

### LMCut<sub>default</sub>

i	=	1
2	1	2
-	$\overline{0}$	<u> </u>
		1
2	$\mid 1 \mid$	2

$$egin{array}{c|c} i = 2 \\ \hline 1 & 1 & 2 \\ \hline 1 & 0 & 1 \\ \hline 2 & 1 & 2 \\ \hline \end{array}$$

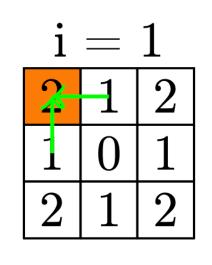
$$egin{array}{c|cccc} i = 3 \\ \hline 1 & 1 & 1 \\ \hline 1 & 0 & 1 \\ \hline 2 & 1 & 2 \\ \hline \end{array}$$

$$egin{array}{c|c} i = 4 \\ \hline 1 & 1 & 1 \\ 1 & 0 & 1 \\ \hline 2 & 1 & 1 \\ \hline \end{array}$$

$$egin{array}{c|cccc} i = 5 \\ 1 & 1 & 1 \\ \hline 1 & 1 & 1 \\ \hline \end{array}$$

$$i = 6$$
 $0 + 1$ 
 $0 + 4$ 
 $0 + 0$ 
 $0 + 4$ 

$$egin{array}{c|c} i = 7 \\ \hline 0 & 0 & 0 \\ \hline 0 & 0 & 0 \\ \hline 0 & 0 & 0 \\ \hline \end{array}$$



1 1
<u> </u>
$0 \mid 1$
1 2

$$egin{array}{c|cccc} i = 4 \\ \hline 1 & 1 & 1 \\ \hline 1 & 0 & 1 \\ \hline 2 & 1 & 1 \\ \hline \end{array}$$

i	=	6
1	×	0
1	0	0
1	1	0

$$egin{array}{c|cccc} i &= 7 \\ \hline 0 & 0 & 0 \\ \hline 1 & 1 & 0 \\ \hline \end{array}$$

$$i = 8$$
 $0 \ 0 \ 0$ 
 $0 \ 0$ 
 $0 \ 0$ 

$$i = 9$$
 $0 \ 0 \ 0$ 
 $0 \ 0 \ 0$ 
 $0 \ 0 \ 0$ 

### **Tie-Breaking Strategies**

Selected Precondition
Goal Zone
Cut Set Operators

### LMCut<sub>default</sub>

i	_	1
<b>C</b>	7	2
1	0	1
2	1	2

$$egin{array}{c|c} i = 2 \\ \hline 1 & 1 & 2 \\ \hline 1 & 0 & 1 \\ \hline 2 & 1 & 2 \\ \hline \end{array}$$

$$egin{array}{c|c} i = 3 \\ \hline 1 & 1 & 1 \\ \hline 1 & 0 & 1 \\ \hline 2 & 1 & 2 \\ \hline \end{array}$$

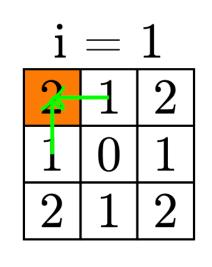
$$egin{array}{c|cccc} i = 4 \\ \hline 1 & 1 & 1 \\ \hline 1 & 0 & 1 \\ \hline 2 & 1 & 1 \\ \hline \end{array}$$

$$egin{array}{c|cccc} i = 5 \\ \hline 1 & 1 & 1 \\ \hline 1 & 0 & 1 \\ \hline 1 & 1 & 1 \\ \hline \end{array}$$

$$i = 6$$
 $0 \quad 1$ 
 $0 \quad 0$ 
 $0 \quad 0$ 

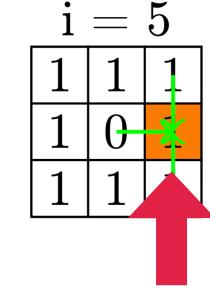
$$egin{array}{c|c} i = 7 \\ \hline 0 & 0 & 0 \\ \hline 0 & 0 & 0 \\ \hline 0 & 0 & 0 \\ \hline \end{array}$$

### LMCut<sub>unused</sub>



=	3
1	1
0	1
1	2
	1 0 1

$$egin{array}{c|cccc} i = 4 \\ \hline 1 & 1 & 1 \\ \hline 1 & 0 & 1 \\ \hline 2 & 1 & 1 \\ \hline \end{array}$$



ĺ		
1	¥	
1	0	
1	1	

Prevent retaking same precondition

$$egin{array}{c|c} i = 7 \\ \hline 0 & 0 & 0 \\ \hline 2 & 0 & 0 \\ \hline 1 & 1 & 0 \\ \hline \end{array}$$

$$i = 8$$
 $0 \ 0 \ 0$ 
 $0 \ 0$ 
 $0 \ 0$ 

$$egin{array}{c|c} i = 9 \\ \hline 0 & 0 & 0 \\ \hline 0 & 0 & 0 \\ \hline 0 & 0 & 0 \\ \hline \end{array}$$

# Thanks!

**Questions?**