

Tiebreaking Strategies for A* Search: How to Explore the Final Frontier

15 min + 5 min question

POSTER 4ft (122cm) wide x 6ft (183 cm) tall

Masataro Asai

2nd year in Ph.D course

University of Tokyo

Short talk (15min)

1 Overview

- What I've been doing (5 min)
 - primarily in classical planning
 - **1st paper** : application-oriented macro-related paper
 - **2nd paper** : macro-related paper
 - **3rd paper** : A* tiebreaking paper
- What I'm interested in (10 min)
 - *4th paper* : aiming to be a non ad-hoc macro paper
 - *Theory unifying all satisficing heuristic search*
 - → Hopefully a clean thesis with a consistent story?

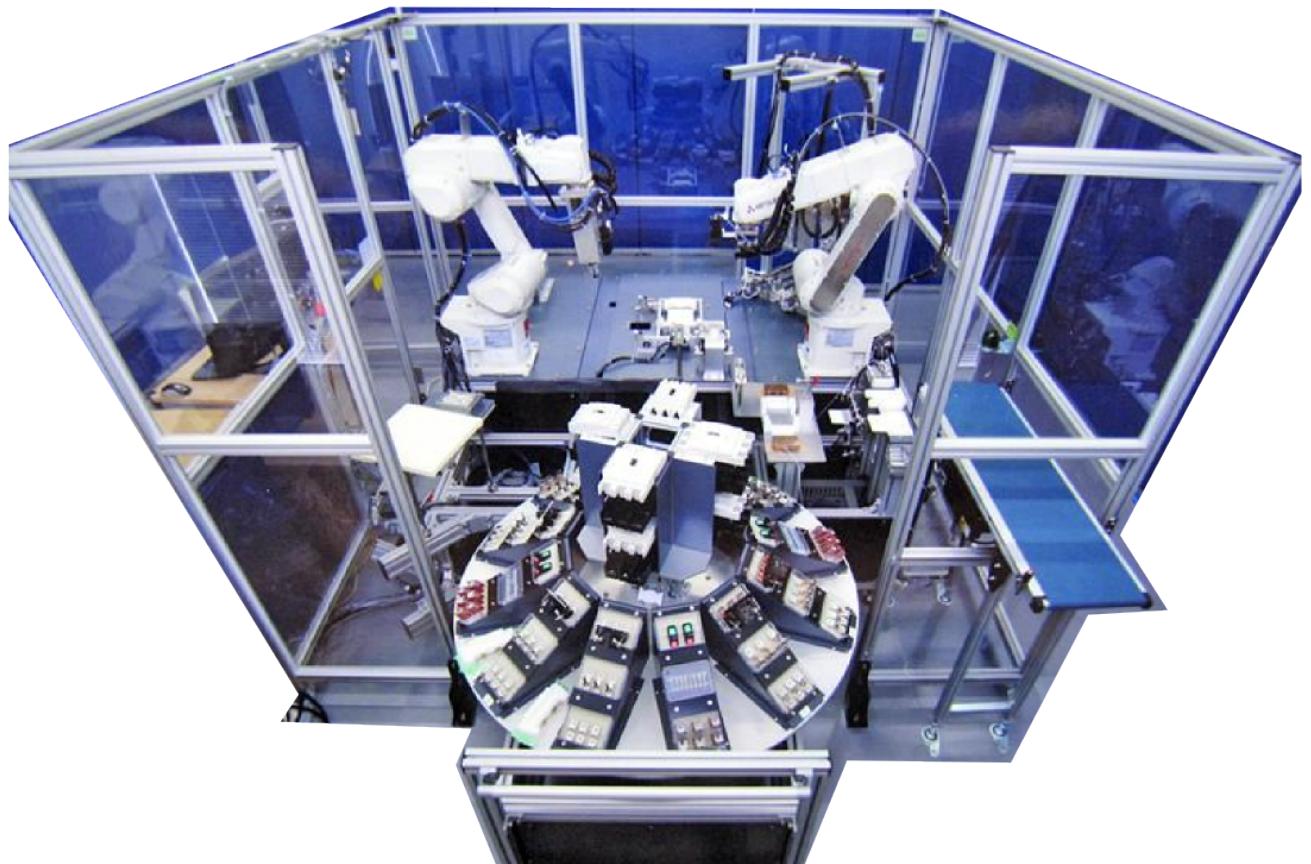
2 Cell-Assembly system

Next I'd like to provide a bit more details of my recent work, only briefly.

In this work, we proposed an automated method for solving large repetitive problems which are easy for human but difficult for programs. It detects a certain kinds of loops based only from the logical relationships between facts and actions.

Asai, M.; Fukunaga, A: 2014. Fully Automated Cyclic Planning for Large-Scale Manufacturing Domains. In ICAPS2014.

Process scheduling w/ organized robotic arms

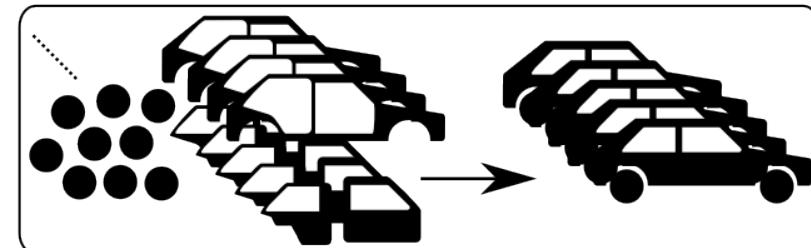
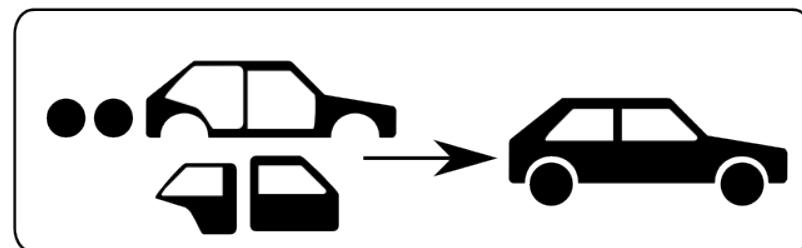
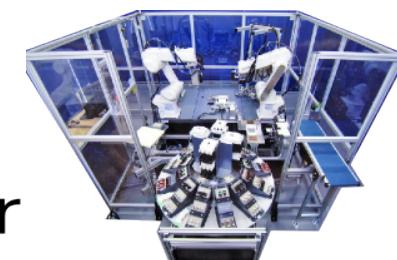


2.1 Issues addressed

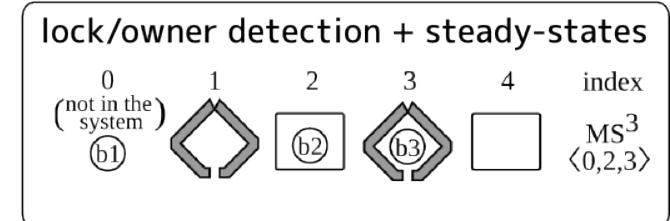
Production scale problems

PDDLs containing 1000 object instances

Repetition should not confuse the planner



Proposed Method:
Detecting one cycle of a loop
(*steady states* of the environment)
and perform Loop-Unrolling



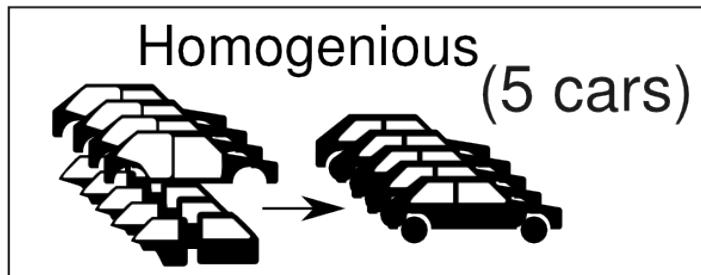
3 ICAPS15 paper

heterogeneous

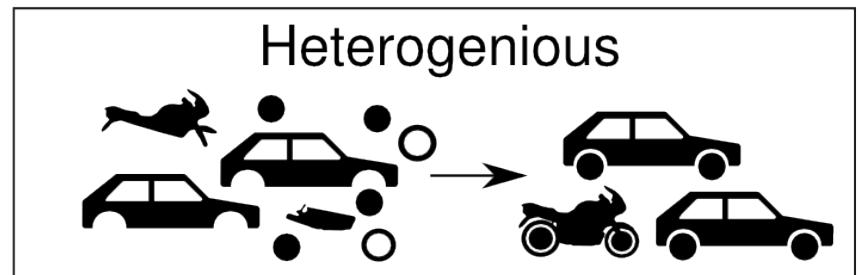
In this work, we generalized the proposed method by detecting and categorizing the logical structure which forms each loop. For example, programs do not know that cars consists of several parts such as doors, engines and tires.

Types of Repetition

ICAPS14

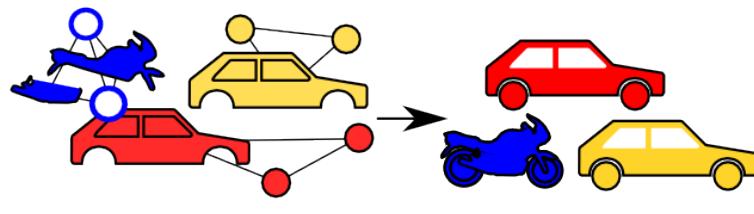


ICAPS15

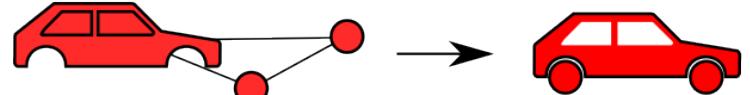


Methods:

1. Detect the object structures from the predicates



2. *long zero-ary macro operators*
 - zero-ary macros: 10-200 ops
 - **specialized** knowledge for each group
e.g. macro encoding a *subplan for a car*



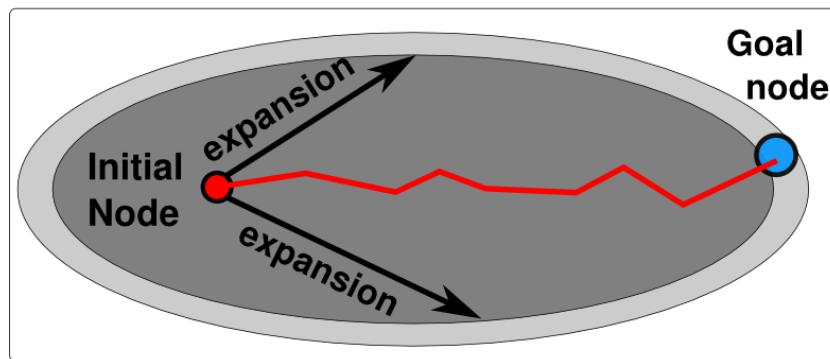
4 AAAI16 paper (visit my 2nd poster session)

*Understanding the search space of A**

- $f > f^*$ (entire search space)
- $f = f^*$ (some nodes are expanded by A*)
- $f < f^*$ (all nodes are expanded by A*)

 Optimal solution

2D pathfinding etc.



Few nodes have $f=f^$*

Tiebreaking not important

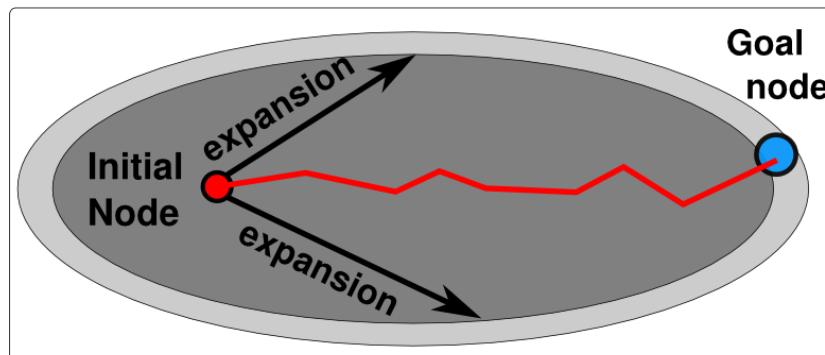
4.1 AAAI16 paper (visit my 2nd poster session)

*Understanding the search space of A**

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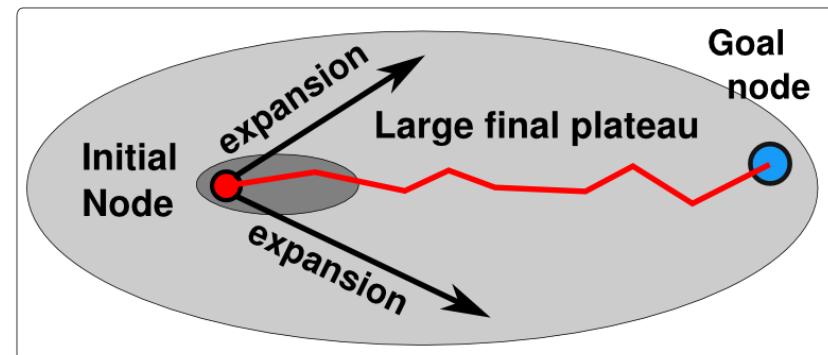
2D pathfinding etc.



Few nodes have $f=f^$*

Tiebreaking not important

Classical Planning

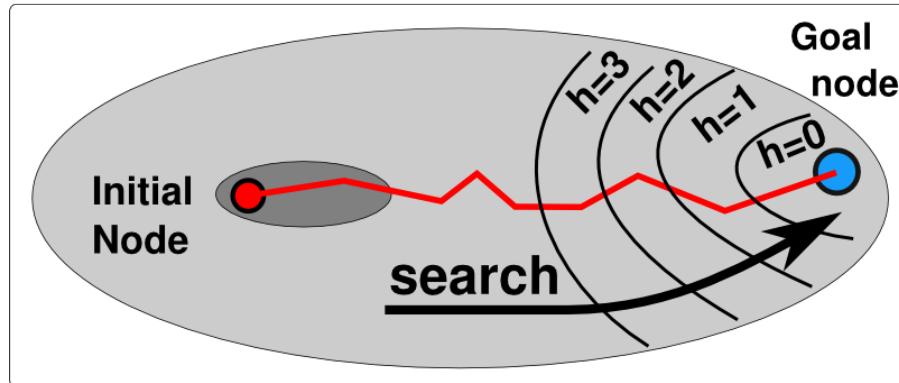


Almost all nodes are $f=f^$*

→ *Tiebreaking has a huge impact*

4.2 Investigating h -tiebreaking in A*

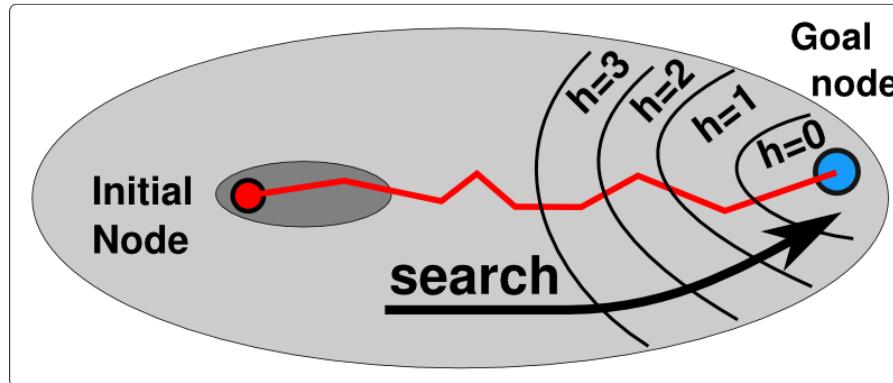
*Domains with strictly
Positive Action Costs only*



*h -based tiebreaking
gives heuristic guidance*

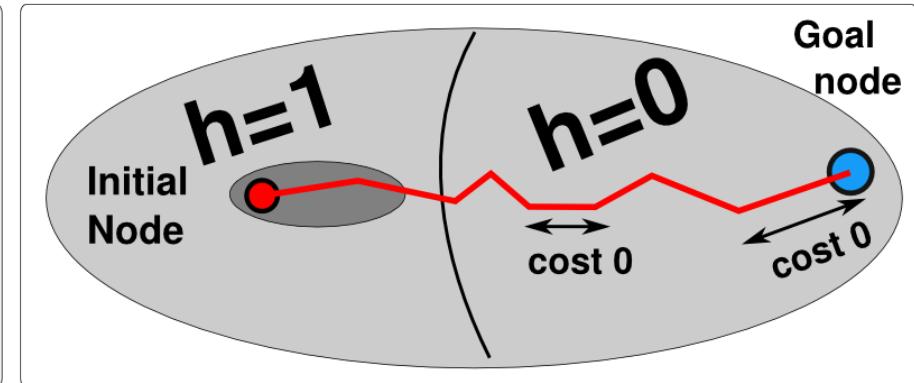
4.3 Investigating h -tiebreaking in A*

*Domains with strictly
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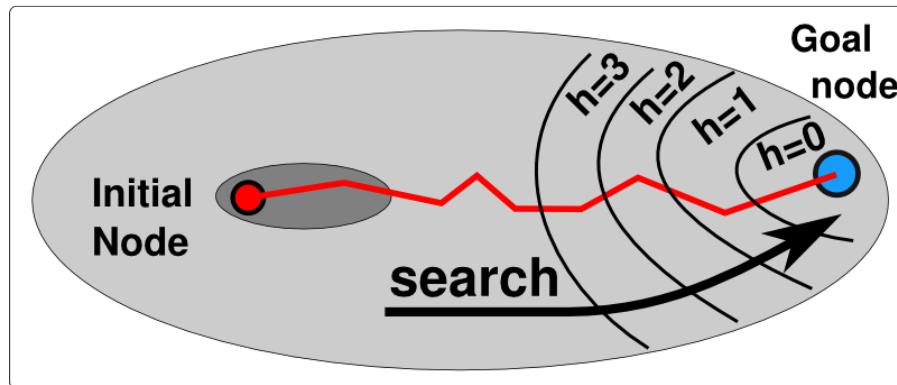
*Domains with
0-cost Actions*



*Has larger h -plateaus
 h -tiebreaking does not work*

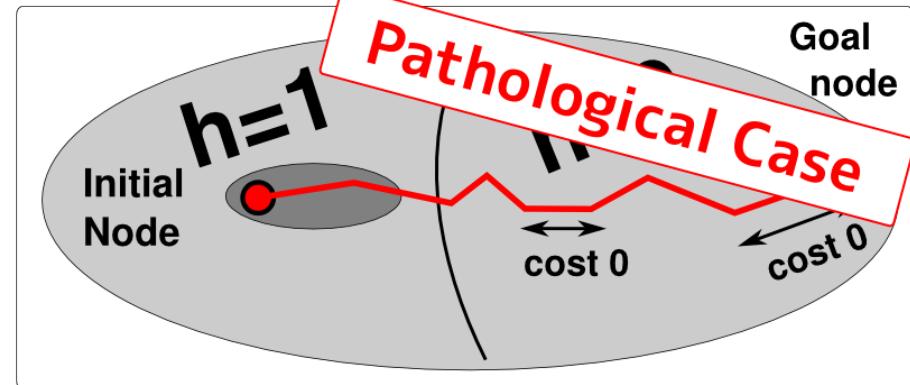
4.4 Investigating h -tiebreaking in A*

*Domains with strictly
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*h -based tiebreaking
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*Domains with
0-cost Actions*

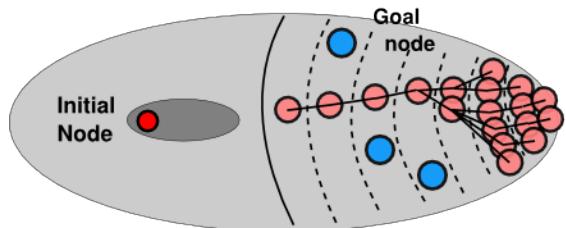


*Enlarge h -plateaus
 h -tiebreaking does not work*

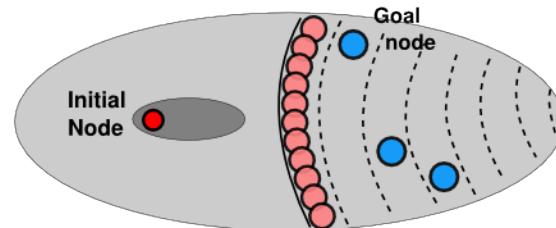
4.5 Investigating $h +$ LIFO/FIFO tiebreaking in A*

4.4 goal node, init

LIFO=Depth-first could miss the shallow solutions

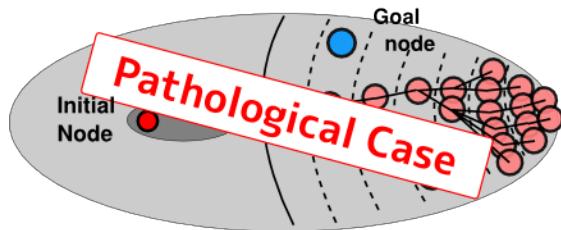


FIFO=Breadth-first doesn't reach solutions

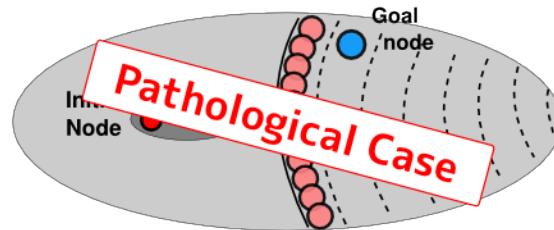


4.6 Investigating $h +$ LIFO/FIFO tiebreaking in A*

LIFO=Depth-first could miss the shallow solutions

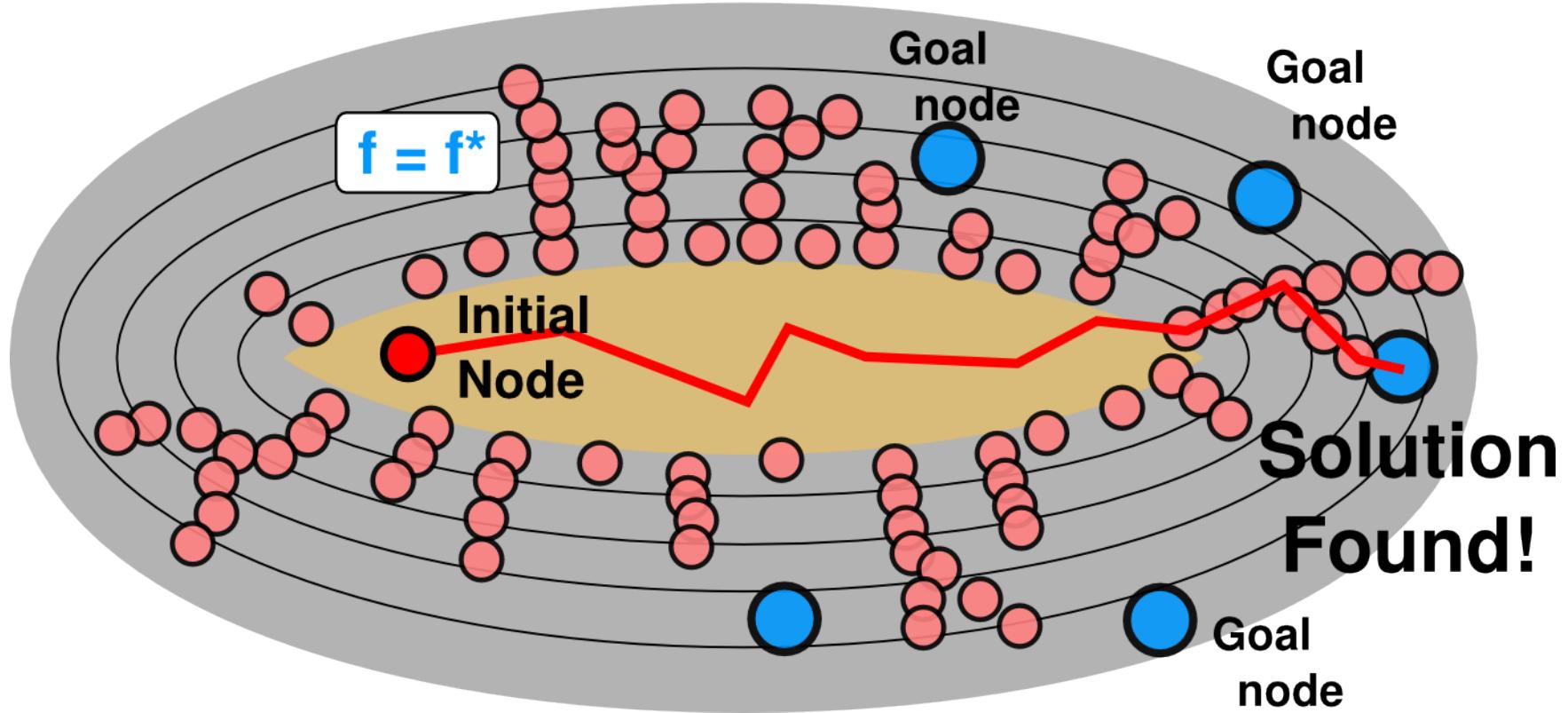


FIFO=Breadth-first doesn't reach solutions



4.7 A* with $h +$ Depth Diversification

Select a depth randomly (Random Depth)
Select a node randomly (Random Order)



and "plateau search = satisficing planning"

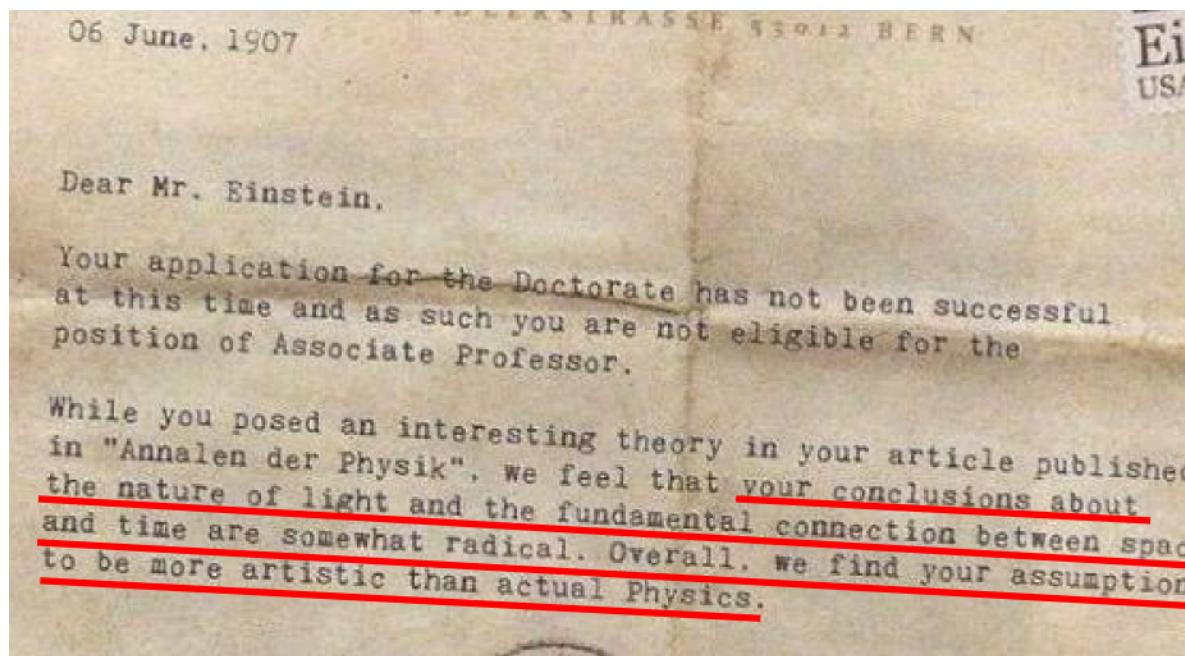
5 Toward Thesis Proposals

- How to make a consistent thesis?
 - Macro papers → satisficing search
 - Tiebreaking papers → optimal search (A^*)
 - I have to **unify them**

6 Inherent Danger of Showing Research Ideas at DC

I am inclined to continuing research after graduation as a PostDoc / maybe in industry, but showing too much unreliable ideas here may cause this:

(just be sure, I'm **not** claiming I am Einstein, no!)

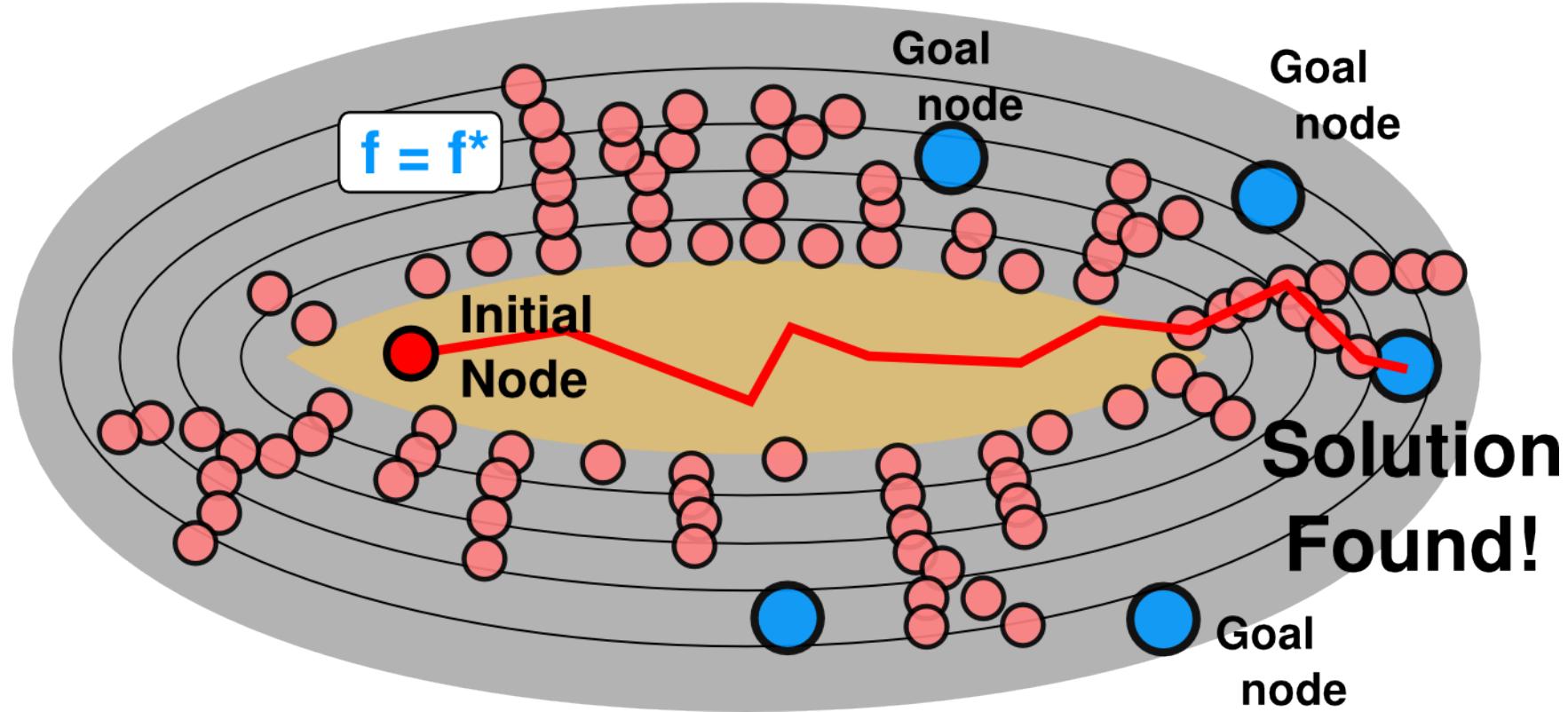


7 Danger Zone!

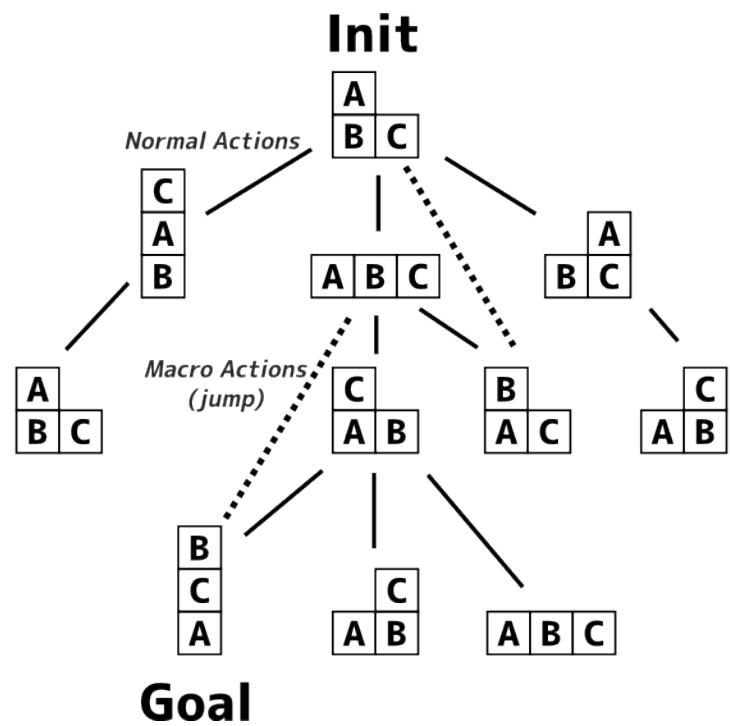
Research IDEAs : not yet fully developped

8 Background 1: A* [RD RO] paper was about search space

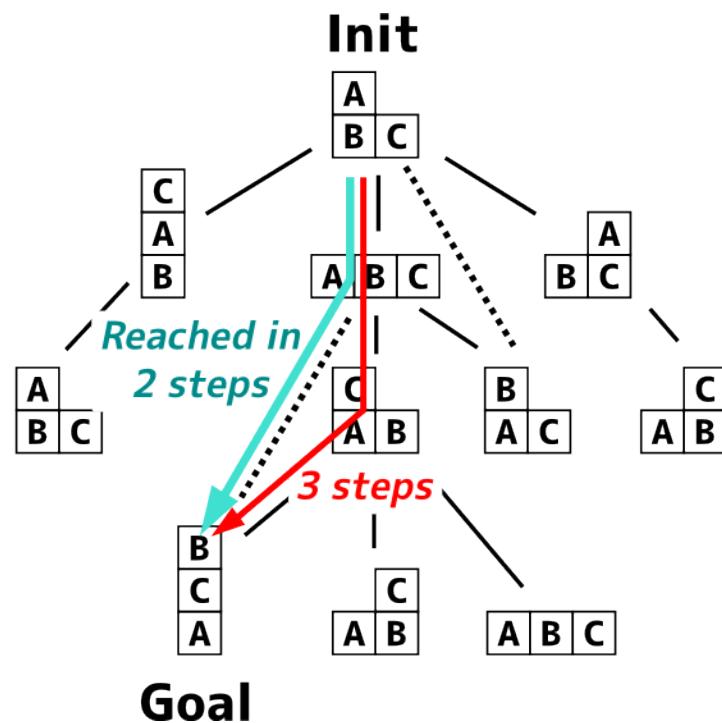
Select a depth randomly (Random Depth)
Select a node randomly (Random Order)



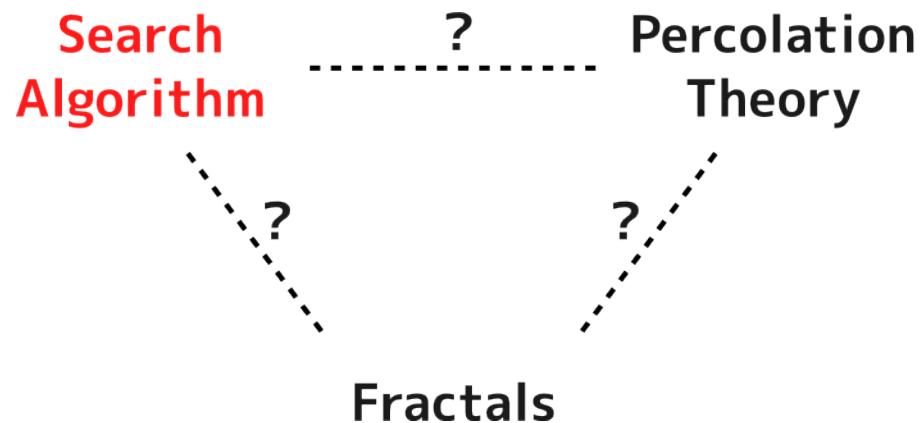
9 Background 2: Macro operators changes the search space structure



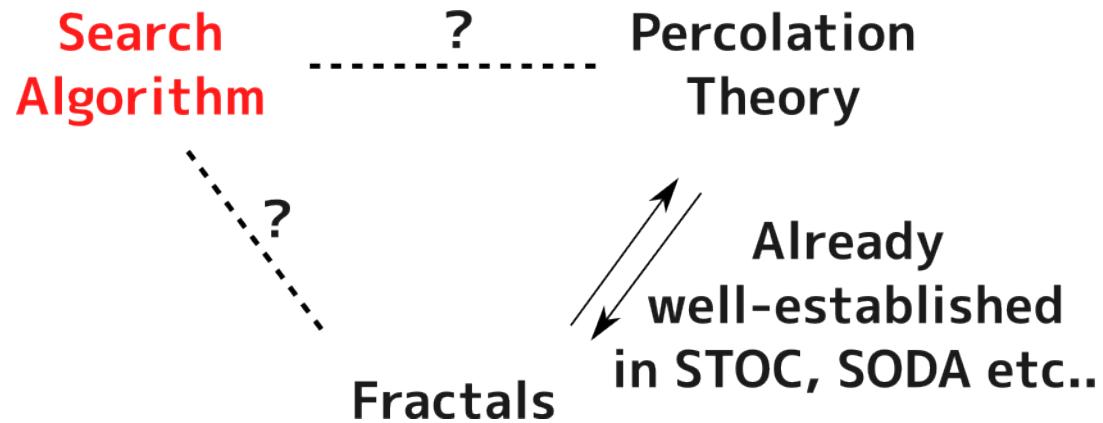
10 Background 2: Macro operators changes the search space structure



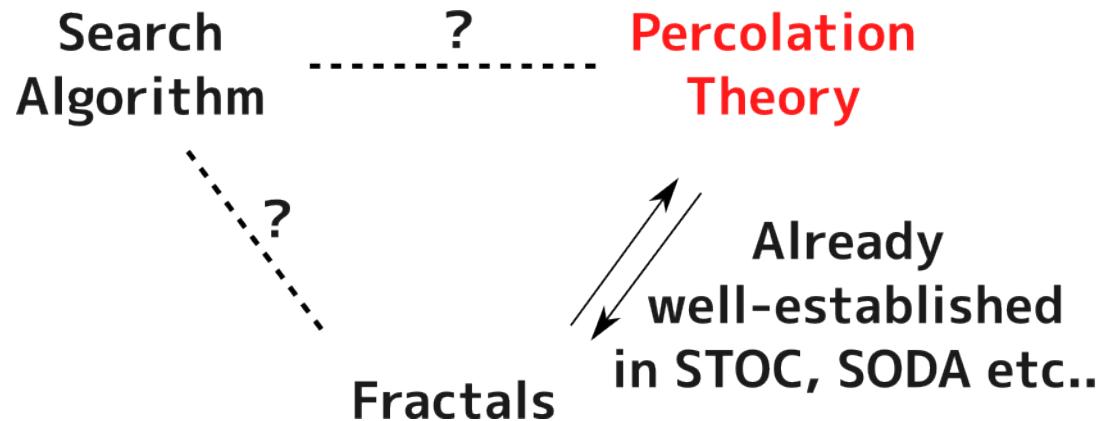
11 Unifying Framework : Discuss Search Space Theoretically



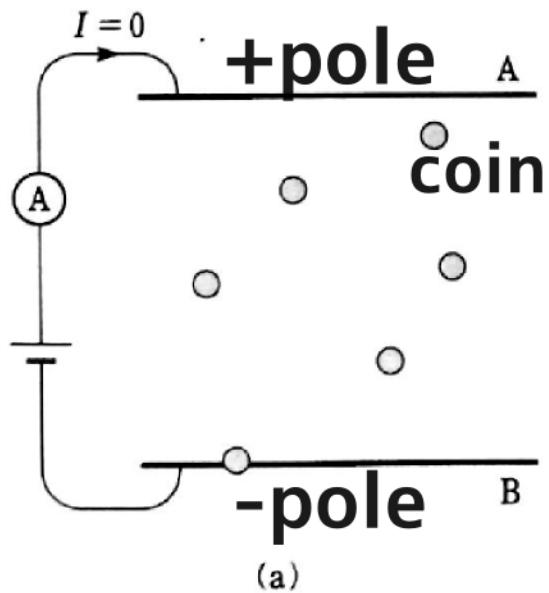
12 Unifying Framework : Discuss Search Space Theoretically



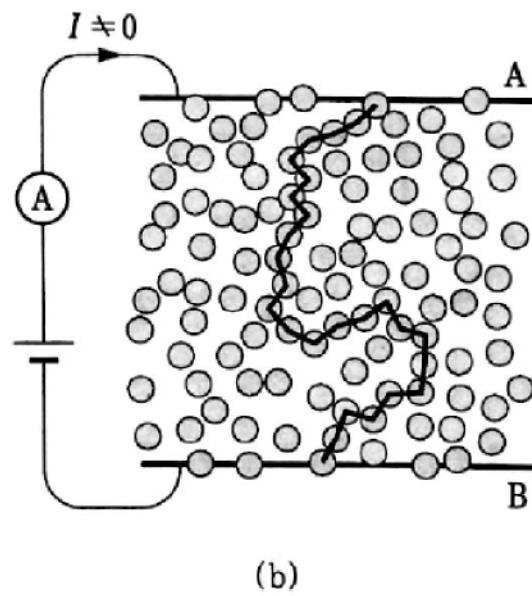
13 Unifying Framework : Discuss Search Space Theoretically



14 Percolation Theory – Toward Planning Complexity



(a)

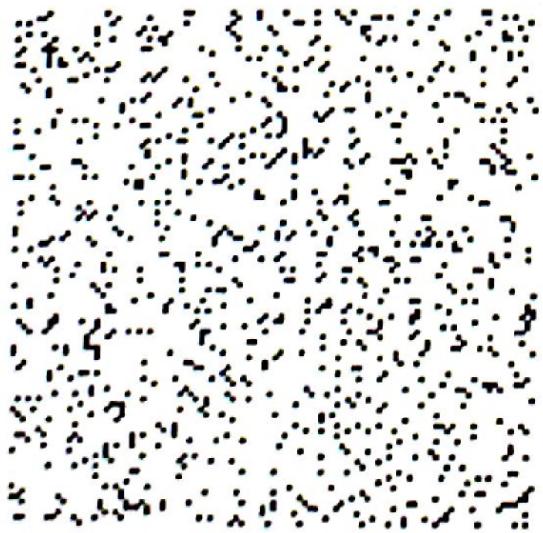


(b)

At what density
does a circuit emerge?

14.1 Occupation Ratio r

occupied node = black
unoccupied node = white



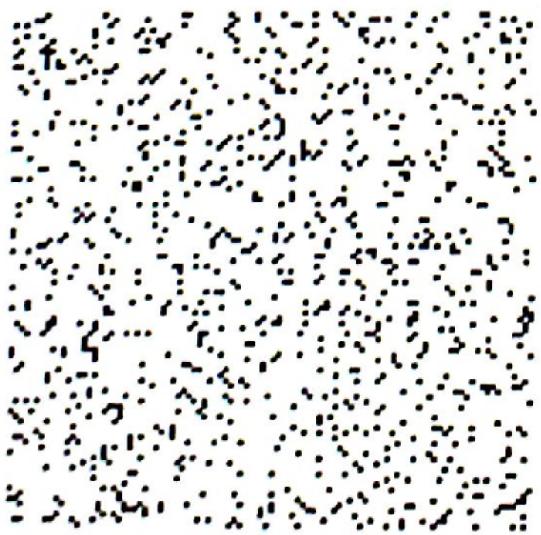
$r=0.1$



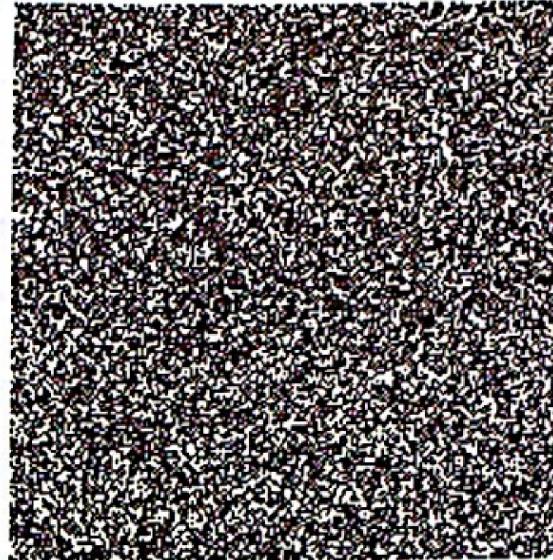
$r=0.9$

14.2 Occupation Ratio r

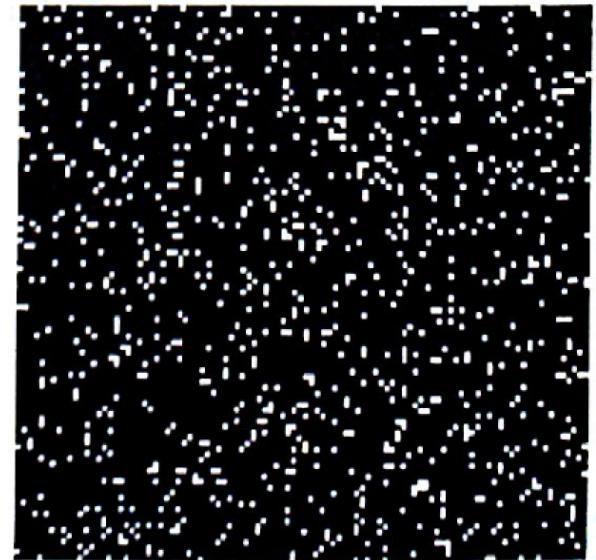
occupied node = black
unoccupied node = white



$r=0.1$



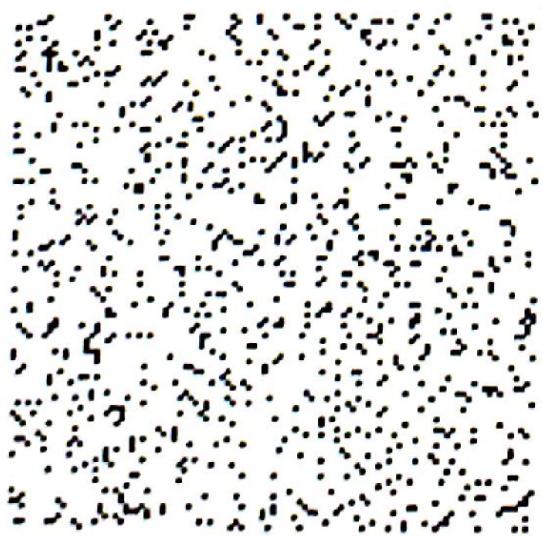
$r=r_c=0.5928$



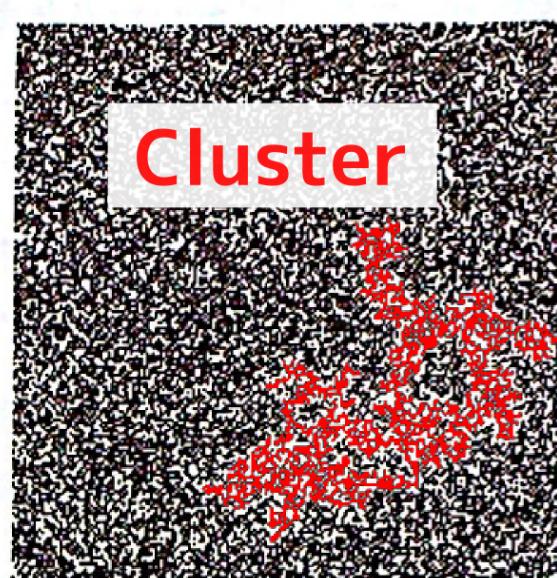
$r=0.9$

14.3 Occupation Ratio r

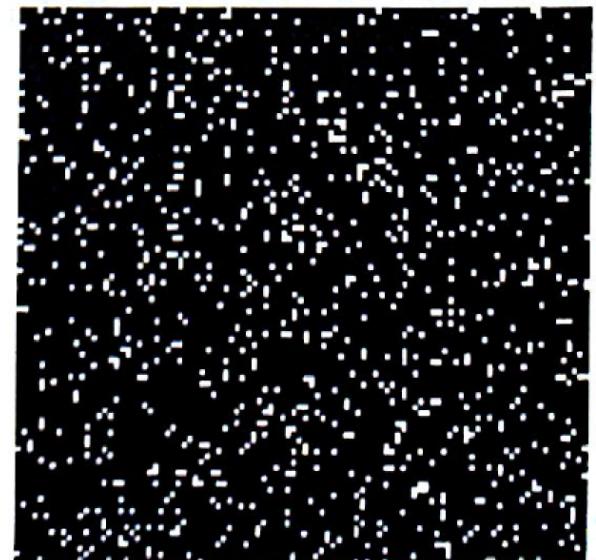
occupied node = black
unoccupied node = white



$r=0.1$



$r=r_c=0.5928$



$r=0.9$

14.4 Phase Transition

Probability p of
↑ two nodes
having a path

$p=1$

$p=0$

$r=0$

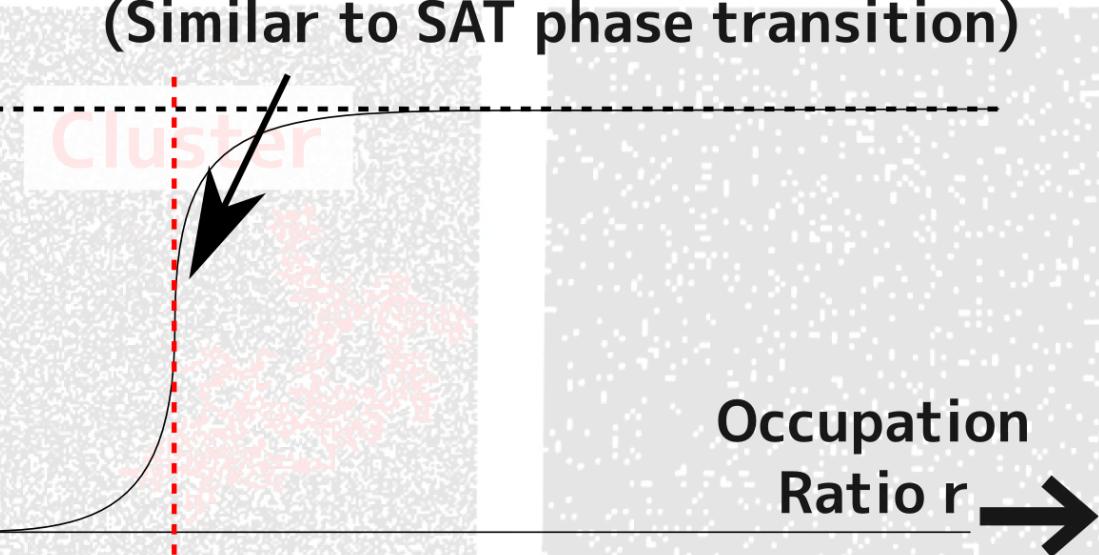
$r=0.1$

Becomes Increasingly Difficult to
determine the connectivity of 2 nodes
(Similar to SAT phase transition)

$r=r_c$

Occupation
Ratio r

$r=0.9$



14.5 Open Question

- What is the occupation ratio of the search space of particular search algorithm?
- Does the same theory holds for heuristic search?
 - c.f. (Rintanen 2004) on phase transition in STRIPS
- Does **Junk Macros** changes the occupation ratio ?
 - Purely randomly generated, un-opinionated macros

14.6 Preliminary results on Junk Macros

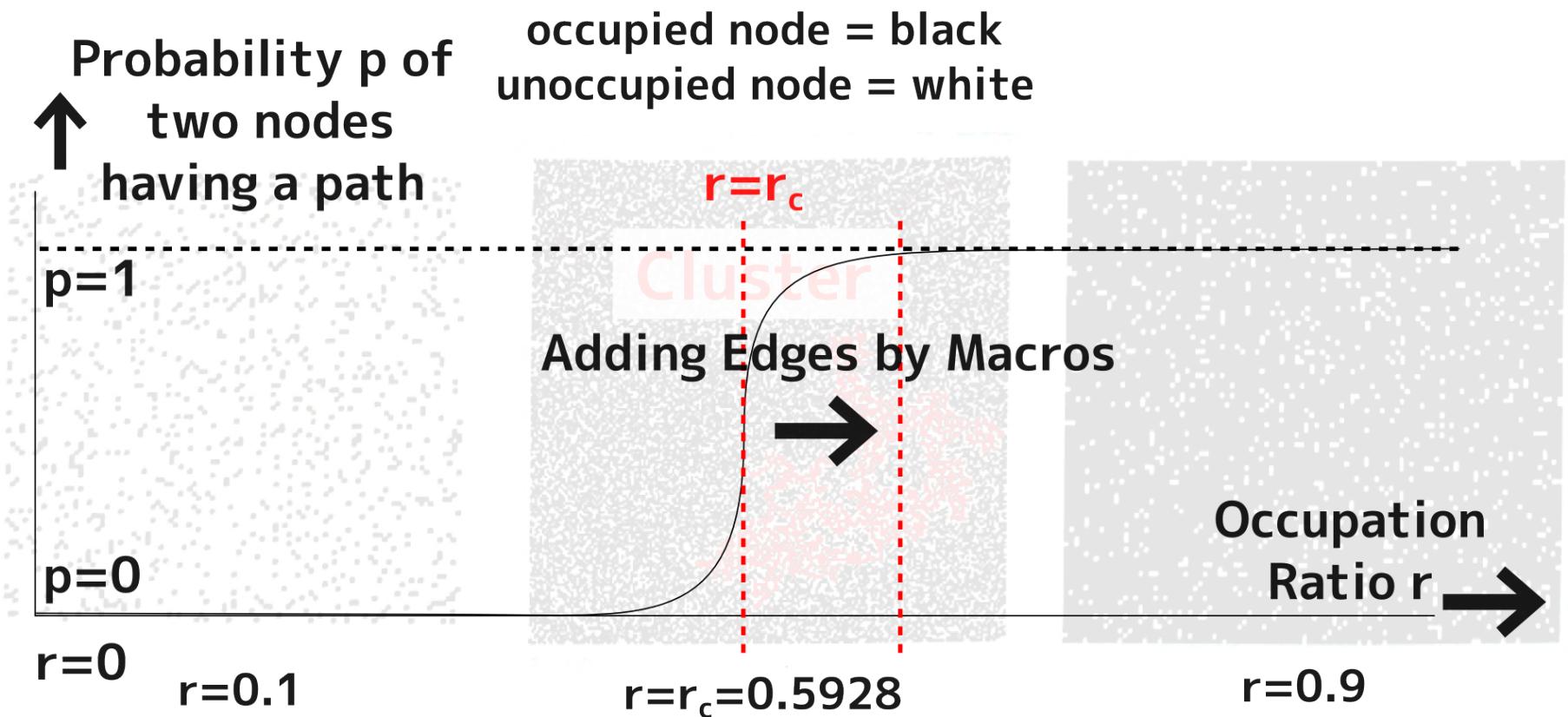
junk macros reduces number of evaluations

(LAMA) Domain	L	Preprocess [sec]	Search [sec]	Total [sec]	Eval [node]
airport	8	112 (1.1)	355 (.50)	467 (.57)	→ 280721 (.74)
cybersec	8	2217 (.91)	3	2220 (.91)	3309
depot	8	22	4	22	
driverlog	5	4	1	4	
hanoi	2	2	1	2	
mystery	5	87 (1.4)	160 (1.0)	247 (1.2)	2643 (.08)
pipesworld-t	8	304 (1.5)	893 (2.1)	1197 (1.7)	355576 (.89)
rovers	2	331 (1.1)	114 (.96)	445 (1.0)	→ 87475 (.90)
transport-sat11	2	205 (1.3)	630 (2.0)	835 (1.8)	47244 (.47)

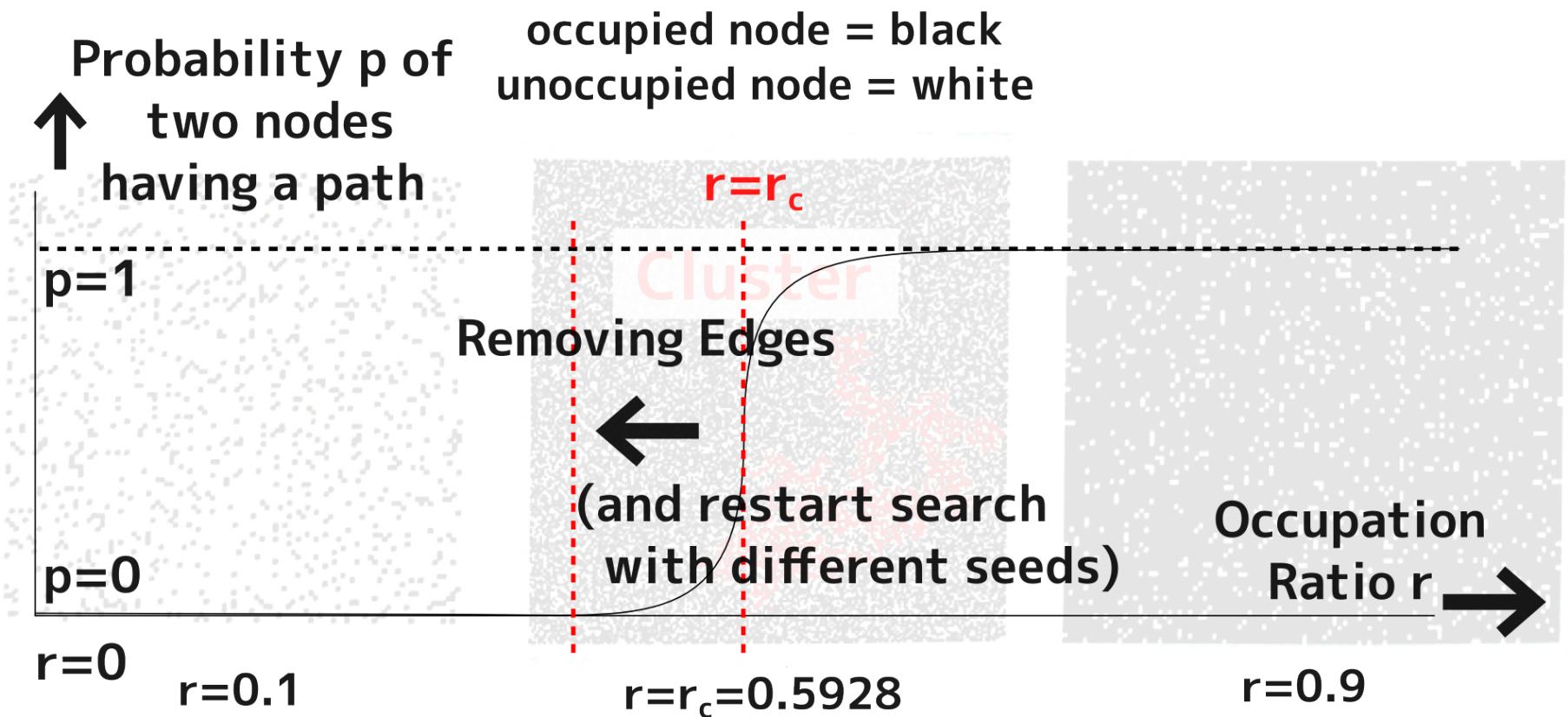
Random junk macros reduce the number of evaluations compared to w/o macros

Table 2: Selective results showing the improvements by junk macros of length L , using LAMA planner. Each cell shows the sum over all instances in the domain solved by all configurations, averaged by the 10 runs. Ratios relative to LAMA are shown, e.g., “(.86)” means the ratio compared to LAMA is 0.86. **Improvement/degradation** are tested with statistical significance ($p < 0.001$).

14.7 Macros may be shifting to the right

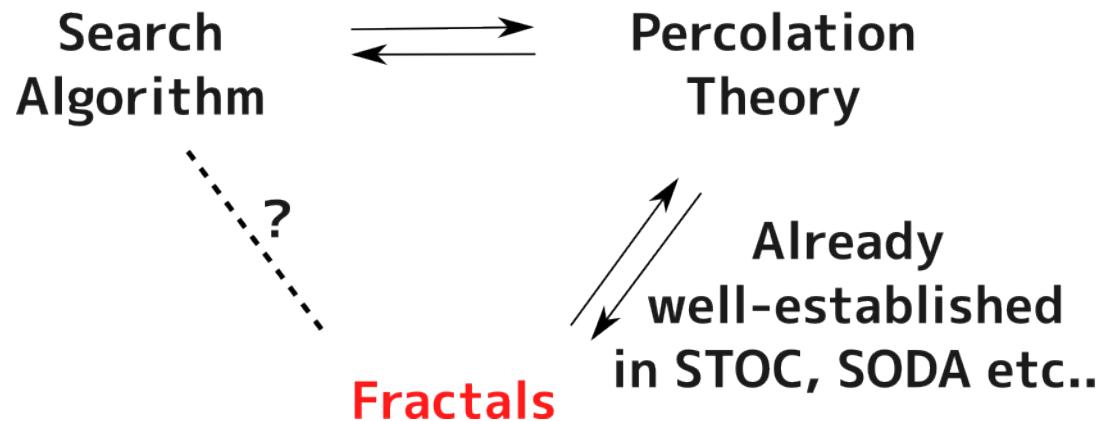


14.8 Opposite : Randomly removing edges — shifting to the left

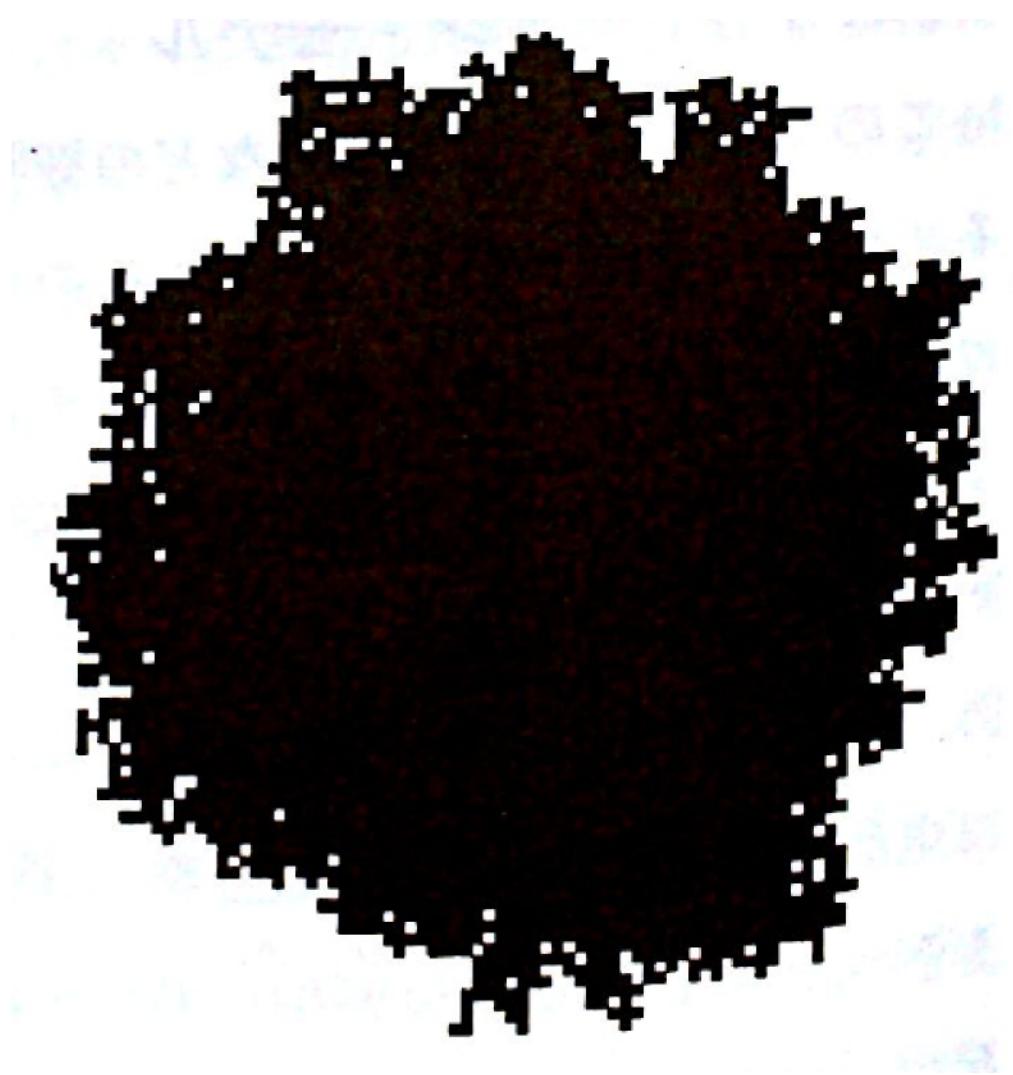


Quickly finding UNSAT, iterate with different random seeds?

15 Unifying Framework : Discuss Search Space Theoretically

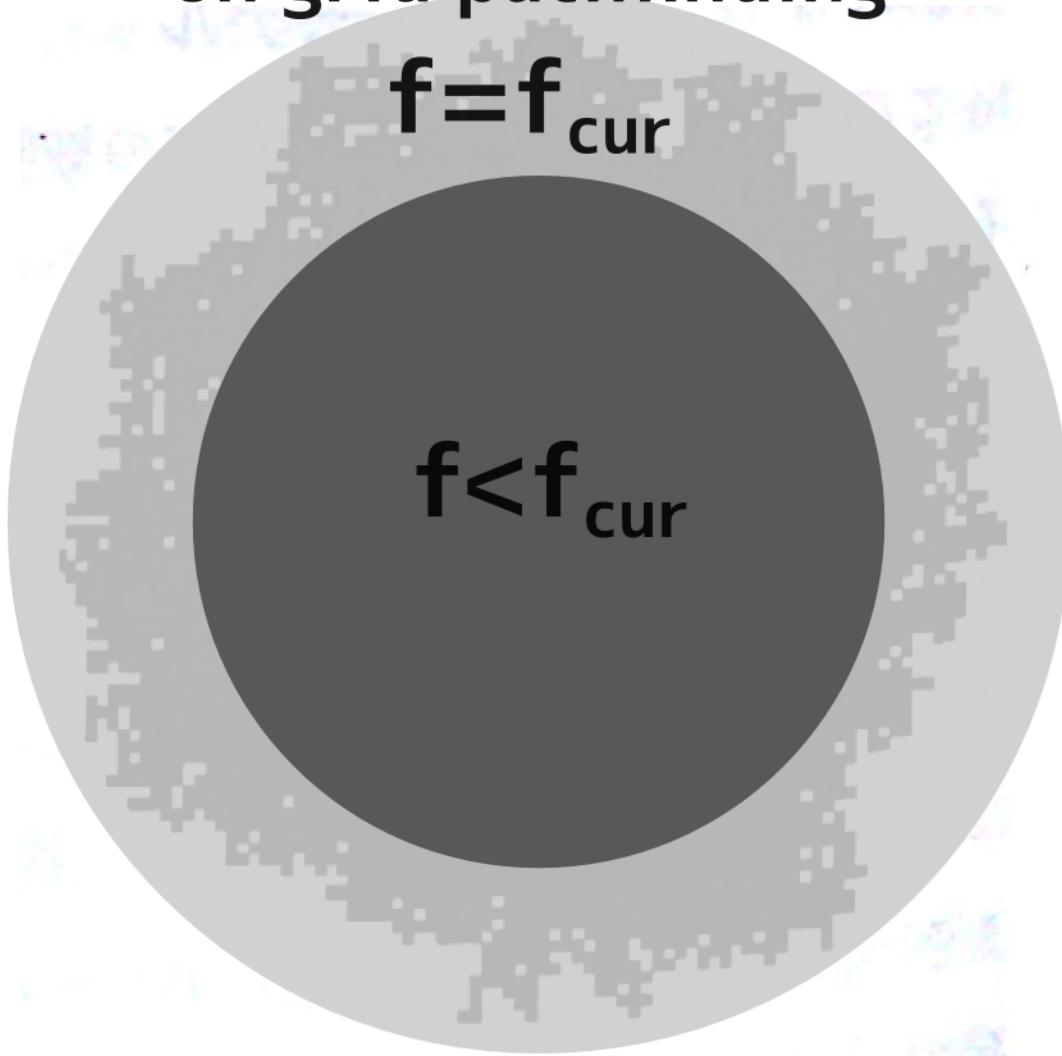


16 Fractals



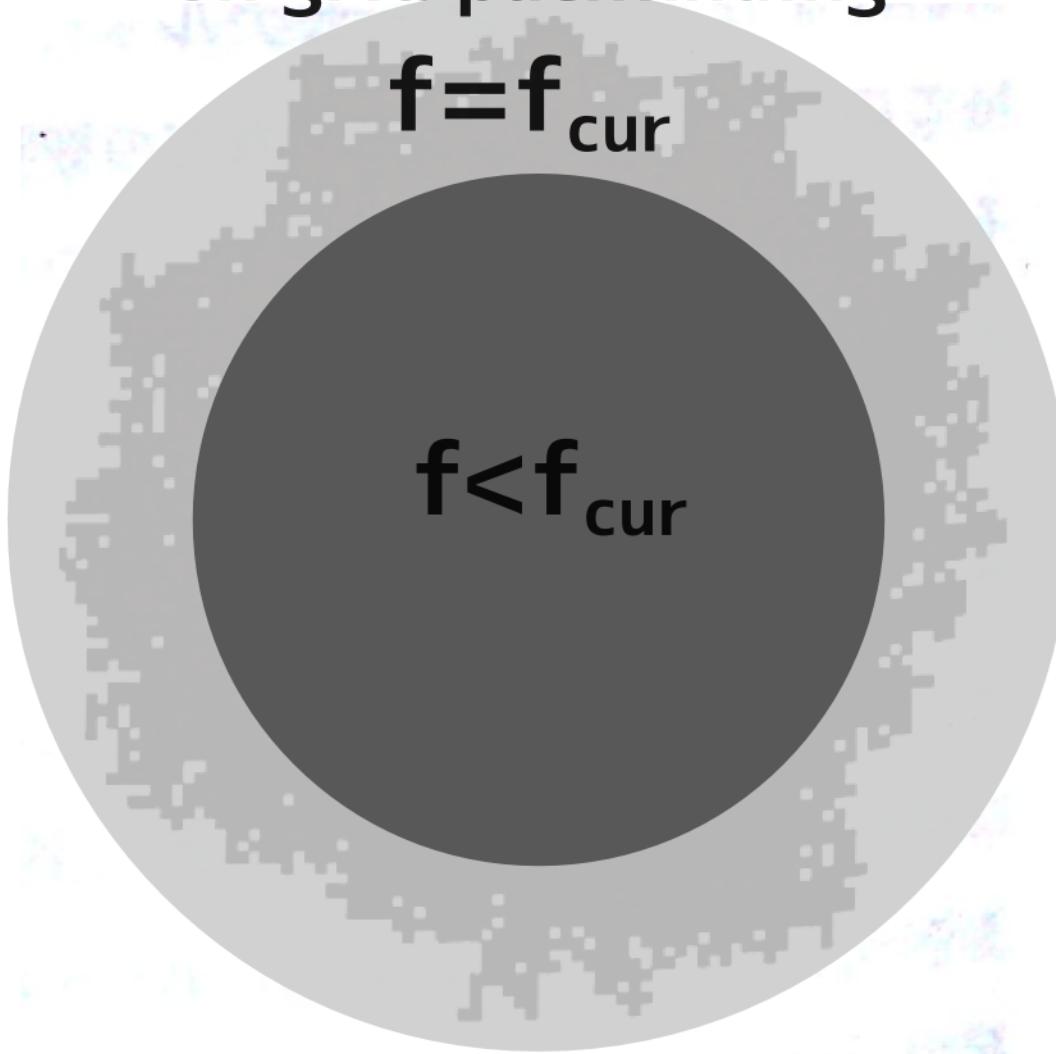
16.1 Fractals

node expansion by A*
with [h, RD, RO] tiebreaking
on grid pathfinding



16.2 Fractals

node expansion by A*
with [h, RD, ~~RC~~] tiebreaking
on grid pathfinding

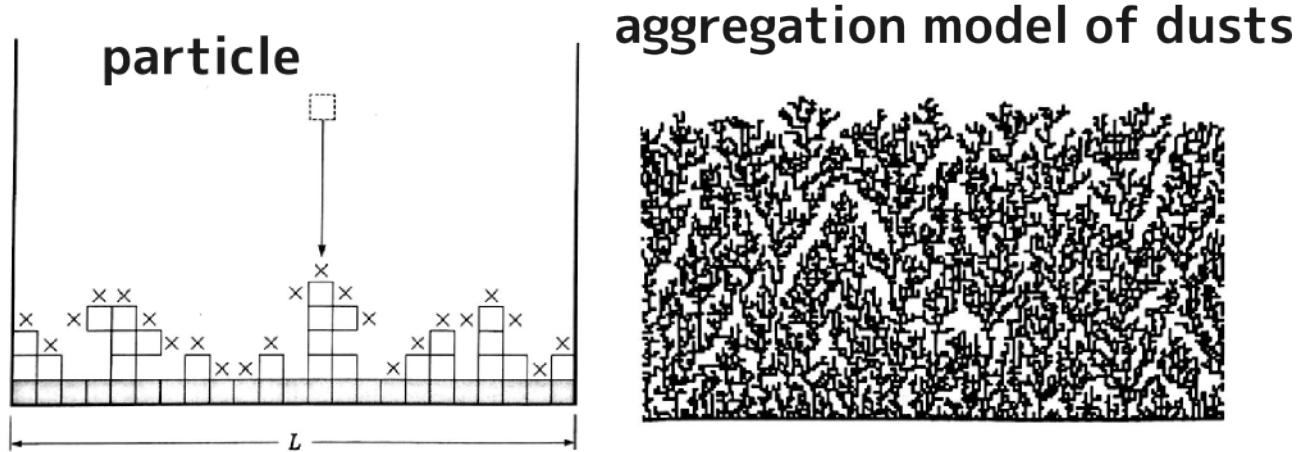


Eden growth model
(citation)

Famous example
of surface fractal

16.3 Famous Fractals (BA)

Ballistic Aggregation model



16.4 Connections between Fractals and Search Algorithms

Different growth model Different expansion model



??? model

↔

A* + LIFO



??? model

↔

A* + FIFO



Eden model
(surface fractal)

↔

A* + [RD,RO]



BA model
(surface fractal)

↔

New algorithm?



DLA model
(fractal)

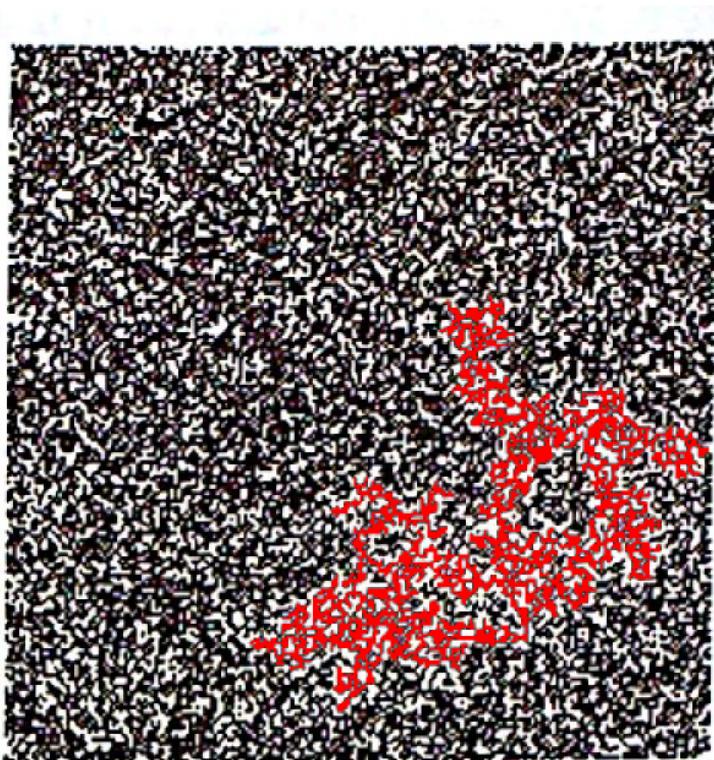
↔

New algorithm?

*Problem: Allegy toward
Nature-inspired algorithms*

Let's make it look more sensible

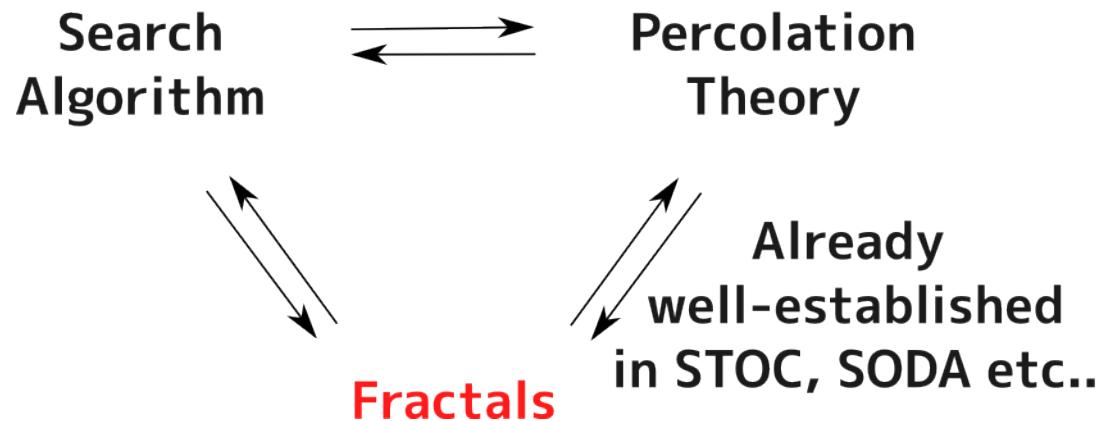
16.5 Connections between Fractals and Percolation



Fractal dimension
of the **red cluster**

$$D \cong \begin{cases} 1.89 & (d = 2) \text{ 2D grid} \\ 2.53 & (d = 3) \text{ 3D grid} \end{cases}$$

17 Unifying Framework : Discuss Search Space Theoretically



18 Possible Benefits:

- More theories about macro operators. Only thing we know:
 - **"Increases branching factor"**
 - **!= effective** branching factor by heuristic search
- Understand Search Algorithms by the **shape of the explored space**
 - What is the fundamental difference between 2 algorithms?

19 Conclusion

Apply Percolation Theory / Fractals to macros / search algorithms

- Analyze macros analyze ICAPS15 macros????
- Analyze search algorithm behavior

→ Unified, consistent thesis!