Ant Colony Optimization for Path Planning in Search and Rescue Operations

Michael Morin*, Irène Abi-Zeid*, Claude-Guy Quimper**
* Department of Operations and Decision Systems
** Department of Computer Science and Software Engineering
Université Laval, Québec, Canada

UNIVERSITÉ LAVAL
Faculté des sciences de l'administration

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Discrete Optimization

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Michael Morin[a,*], Irène Abi-Zeid[a], Claude-Guy Quimper[b]

[a] *Department of Operations and Decision Systems, Université Laval, Québec, Canada*
[b] *Department of Computer Science and Software Engineering, Université Laval, Québec, Canada*

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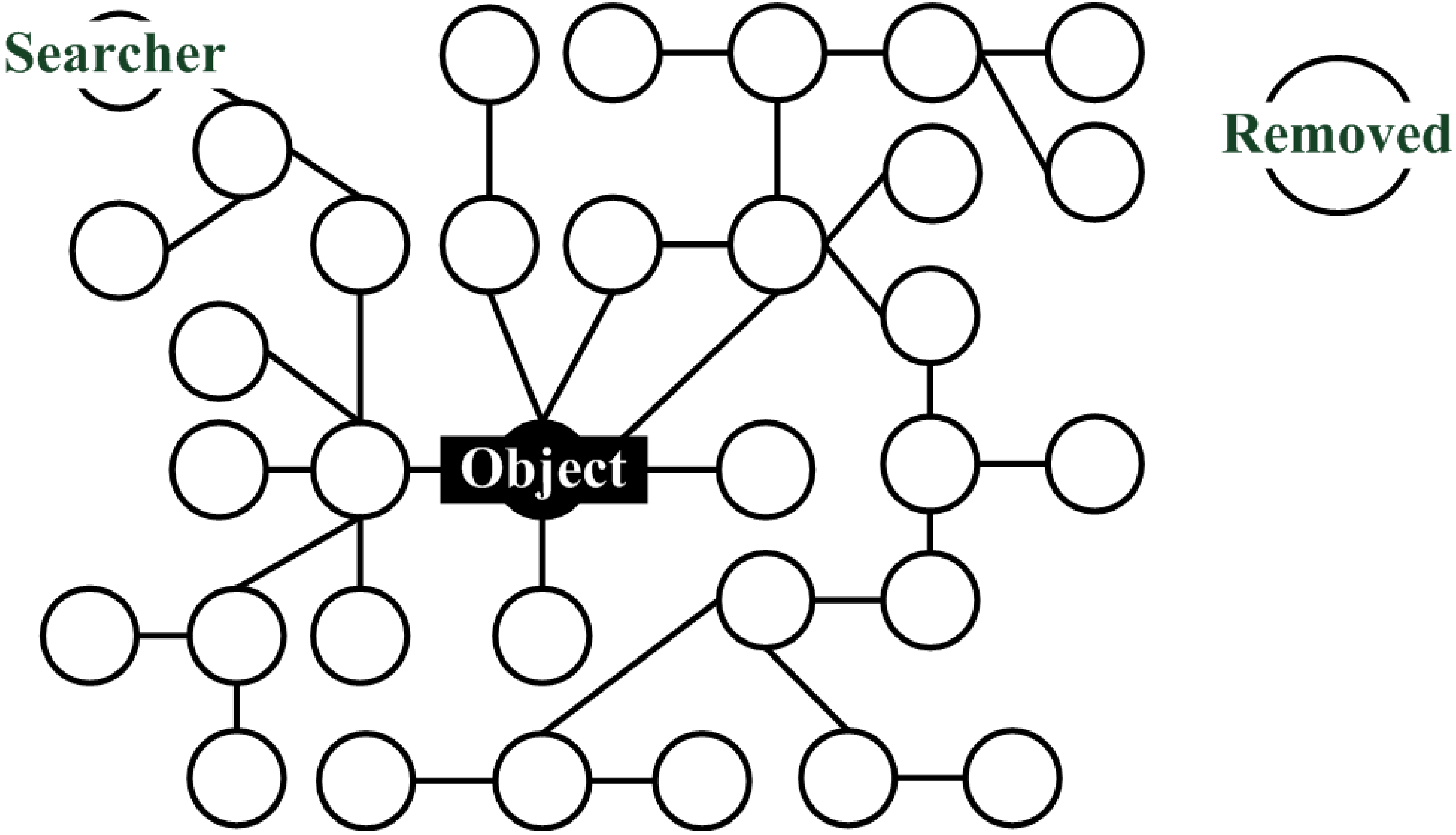
Search theory

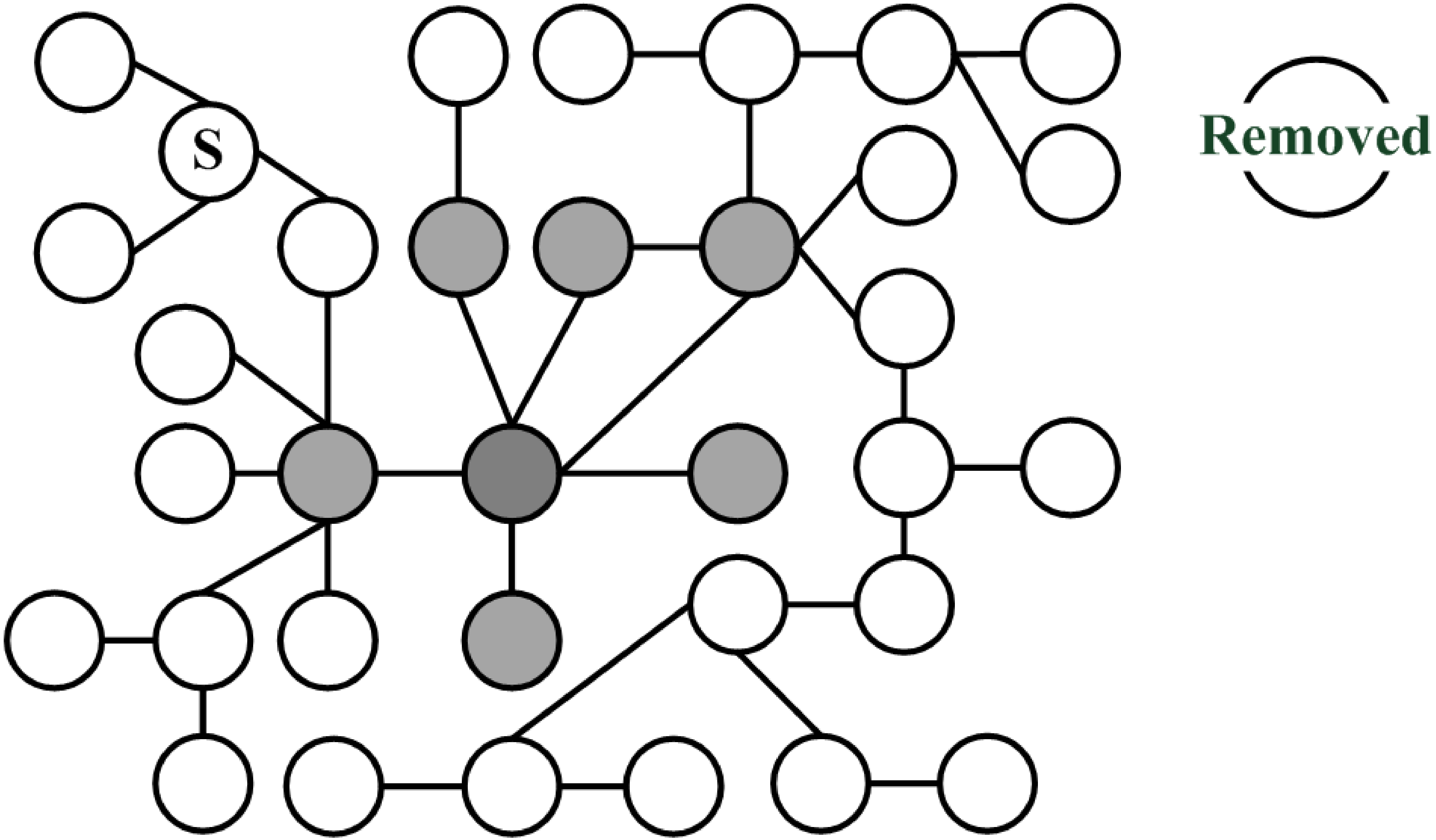
- Also called the Theory of Optimal Search and Screening (first developed by B.O. Koopman in 1946)
- To enhance U-boat search methodologies during the Battle of the Atlantic (1939-1945)
- Main problem classes:
  - Optimal Search Density problems
  - Optimal Searcher Path problems

Path planning in search theory

- Optimal searcher path (OSP) problem
  - Operational-level path planning in graph/grid *search environment*
  - Imperfect detection ⇒ *Probability of Detection*
  - Moving search object ⇒ *Probability of Containment* (whereabouts)
    Motion model
  - Maximize the Cumulative Overall p*robability of Success* (*COS*)

Cumulative in time Across space


Searcher
Object
Removed


S
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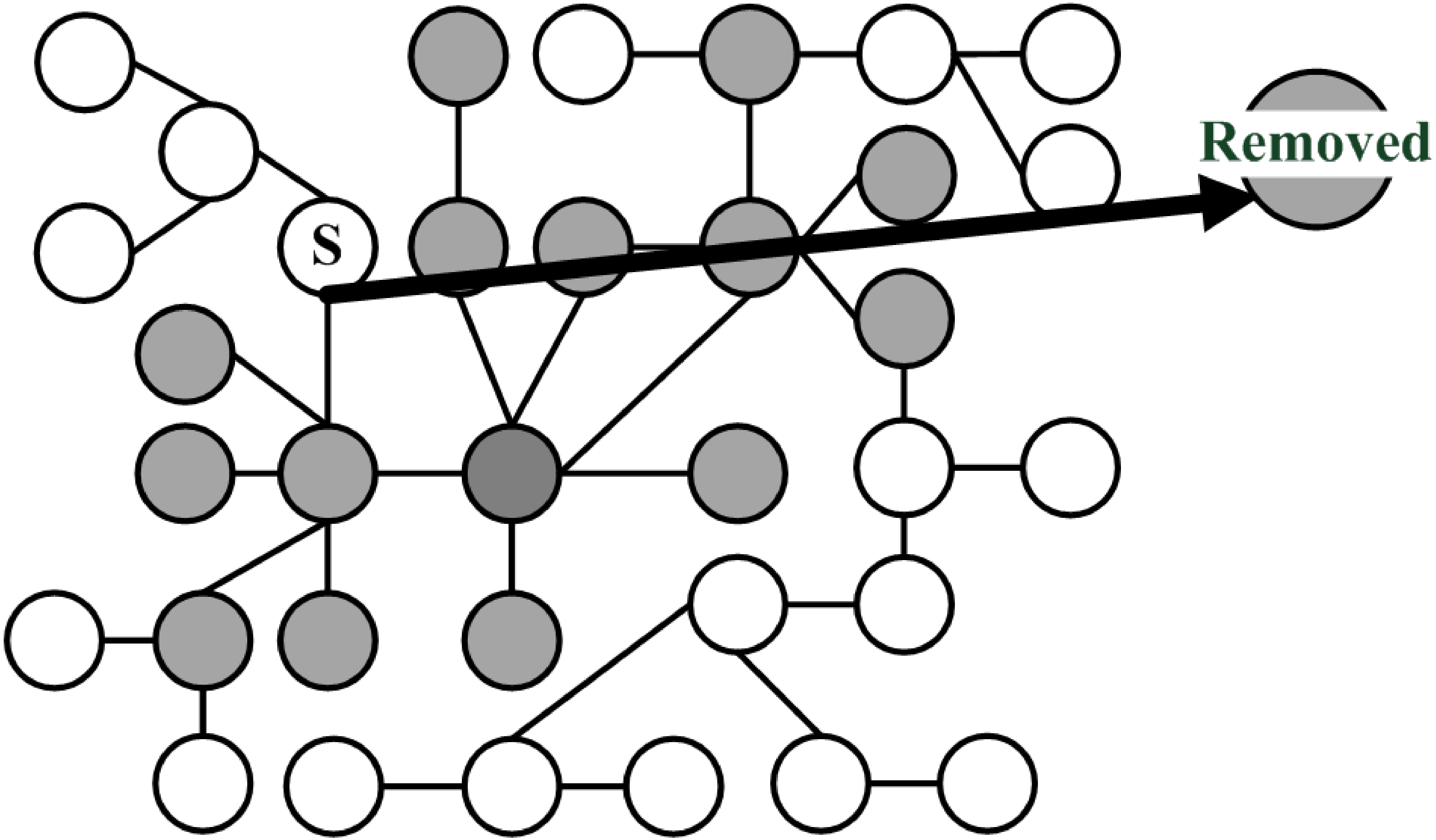
S
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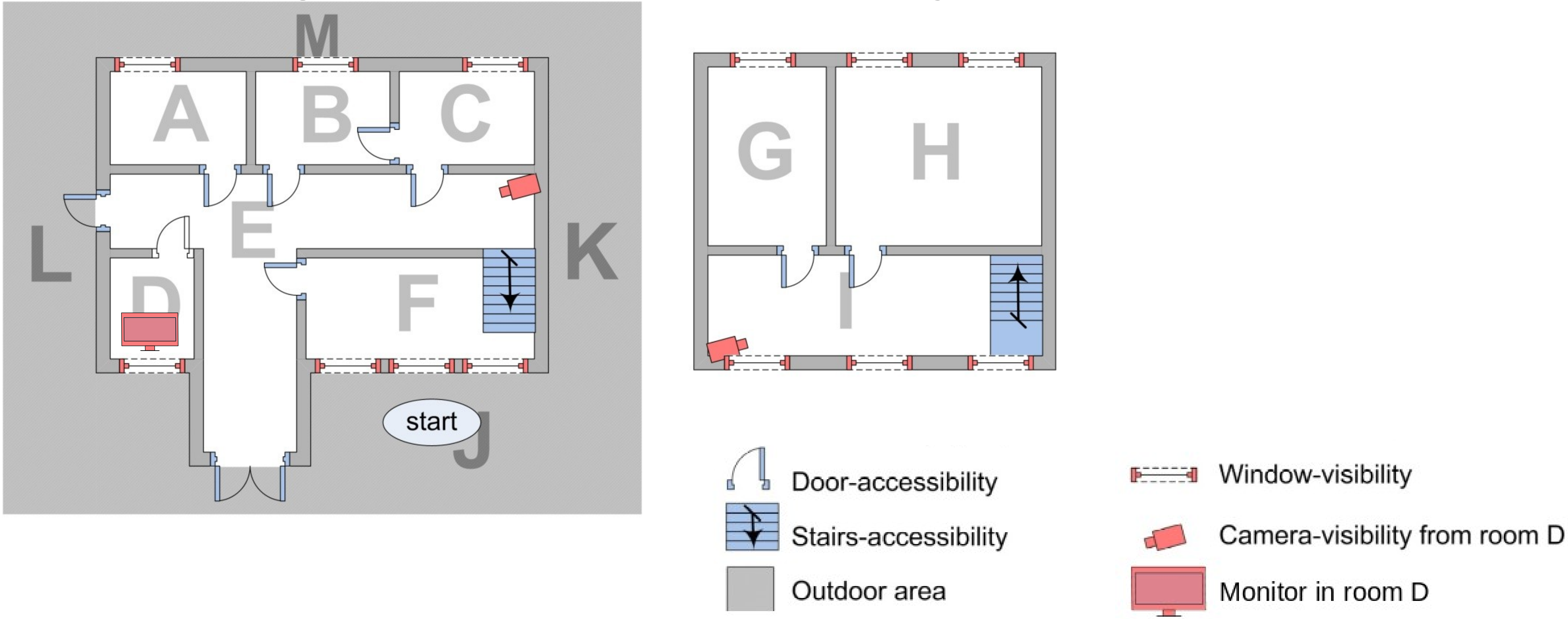
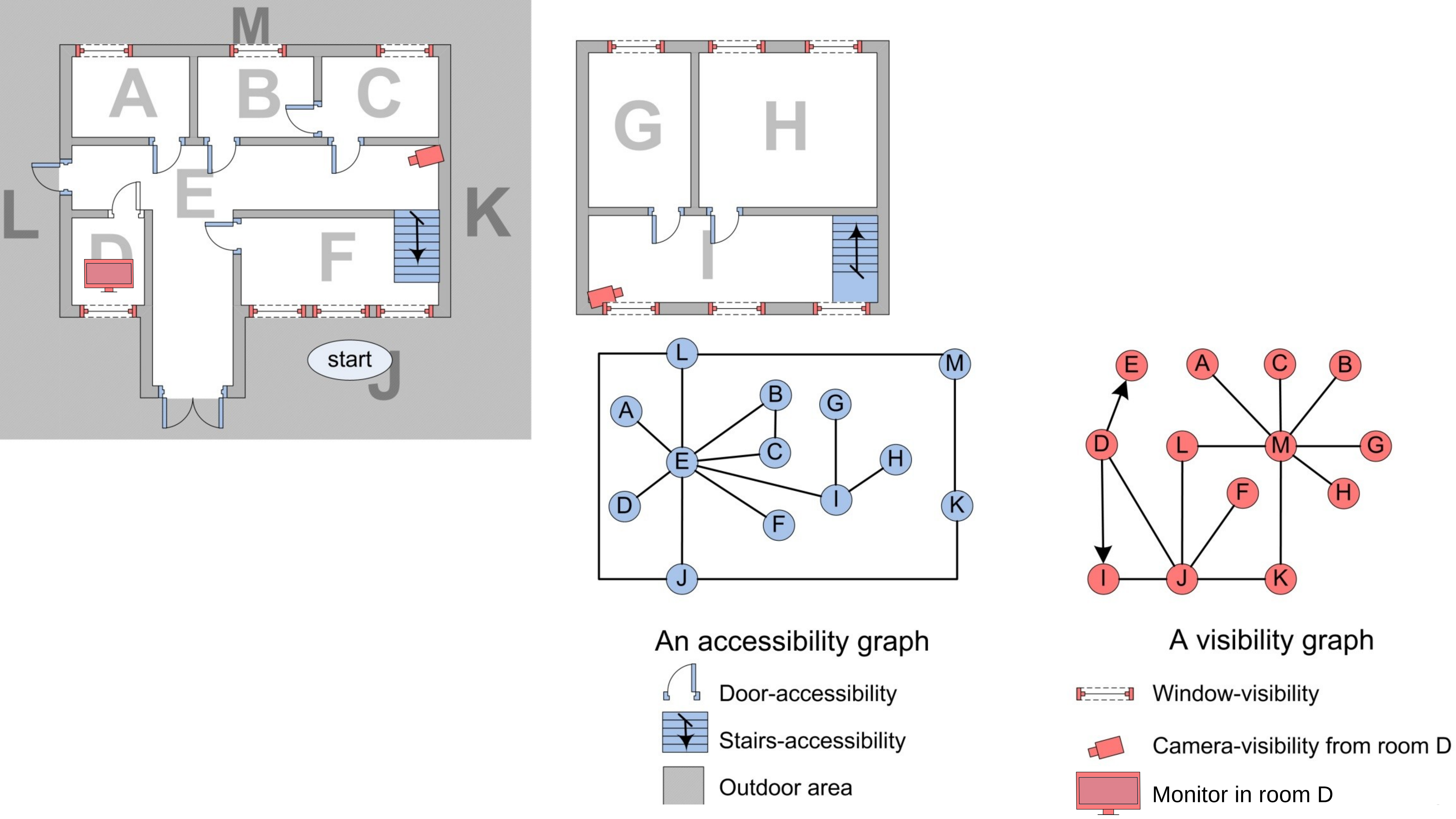
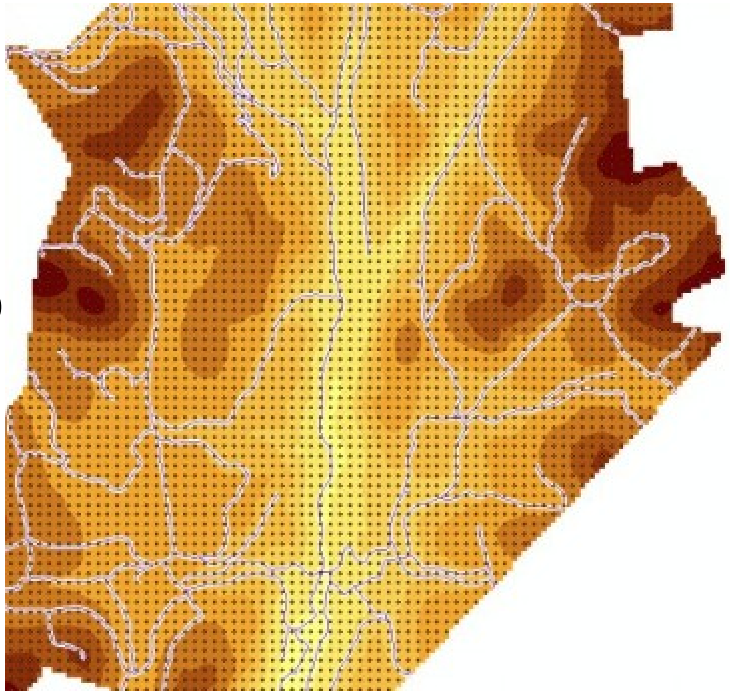
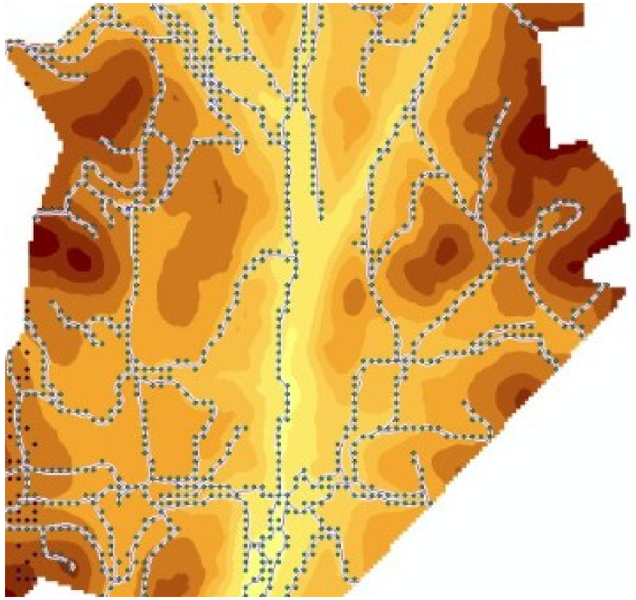
Searching with extended visibility




M
A
B
C
E
L
K
D
F
start
J
G
H
I
An accessibility graph
Door-accessibility
Stairs-accessibility
Outdoor area
A visibility graph
Window-visibility
Camera-visibility from room D
Monitor in room D

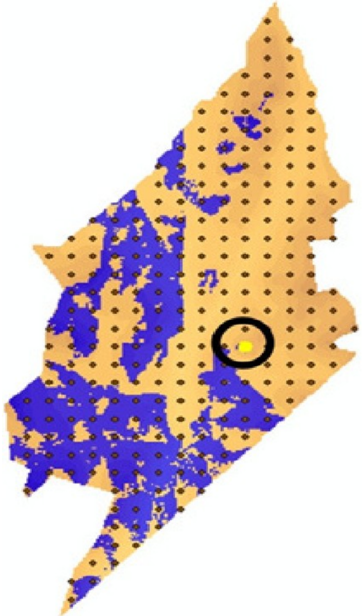
GIS map

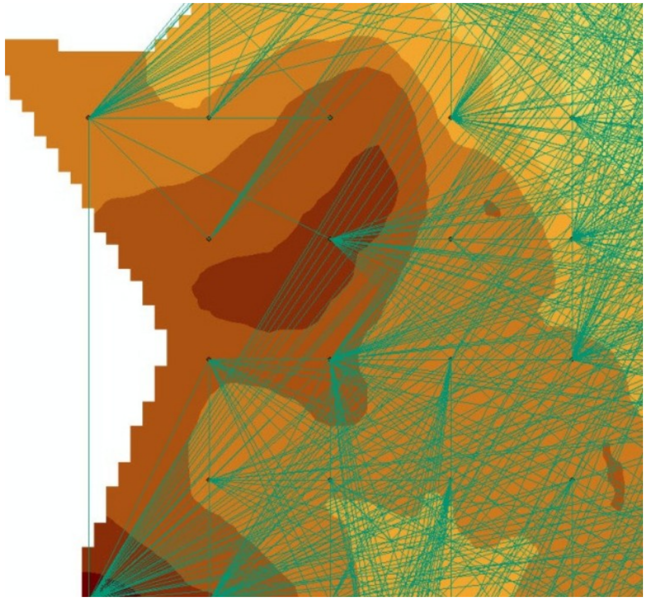




Accessibility graph

Viewshed analysis

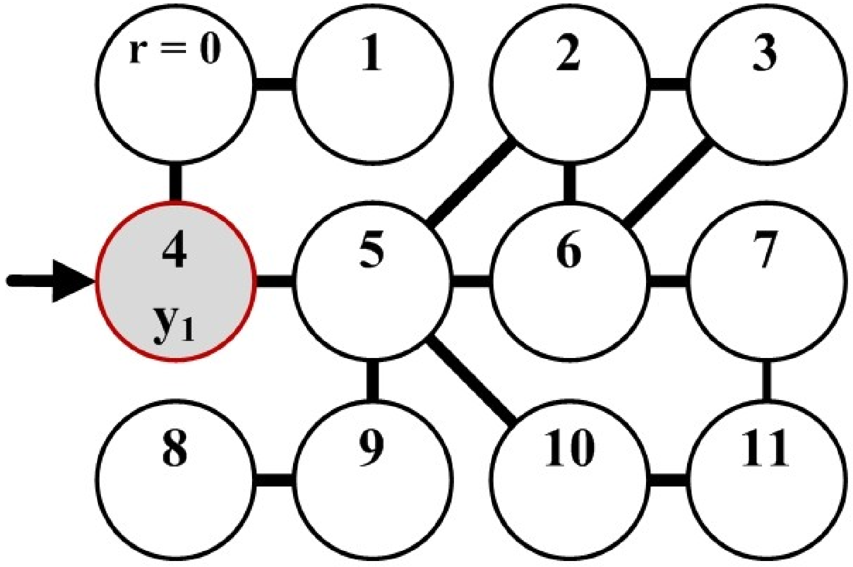




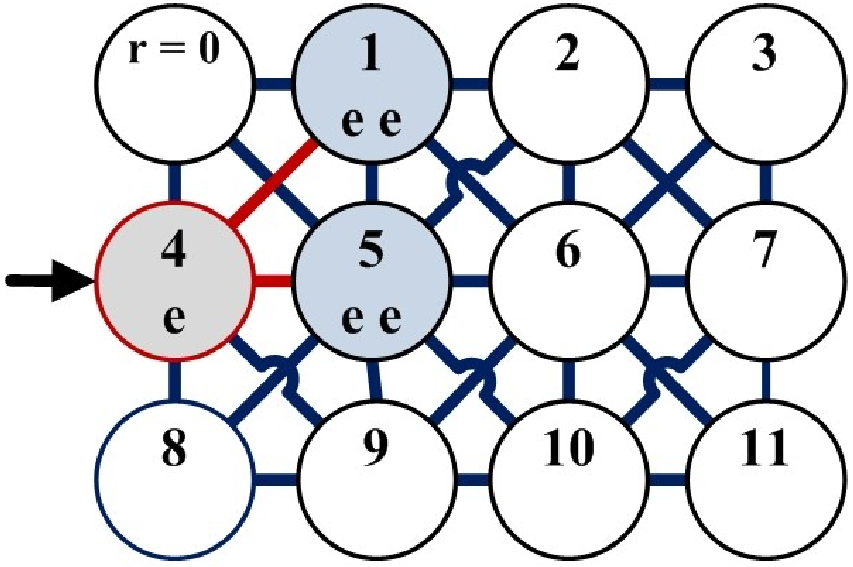
Visibility graph

Optimal Search Path with Visibility (OSPV)

- Search from a distance, ex. number of looks (scans)



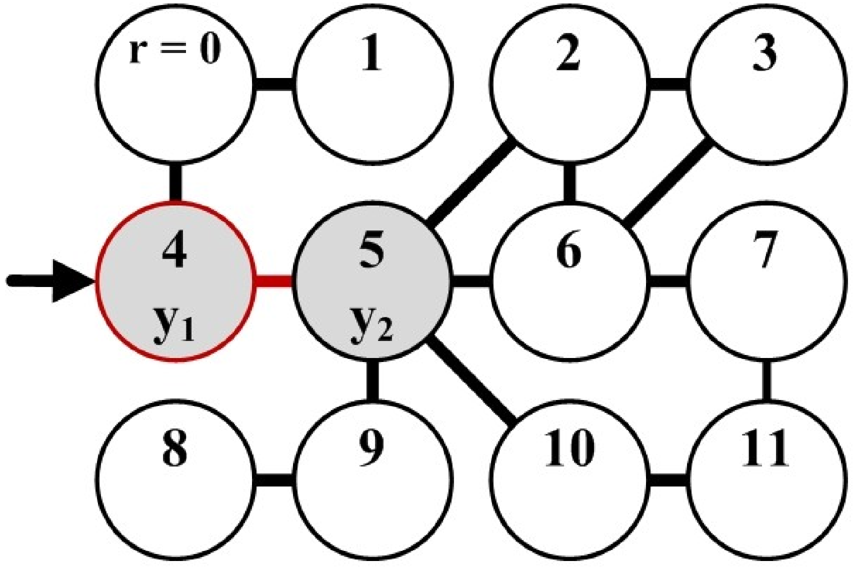
$t = 1, T = 6$



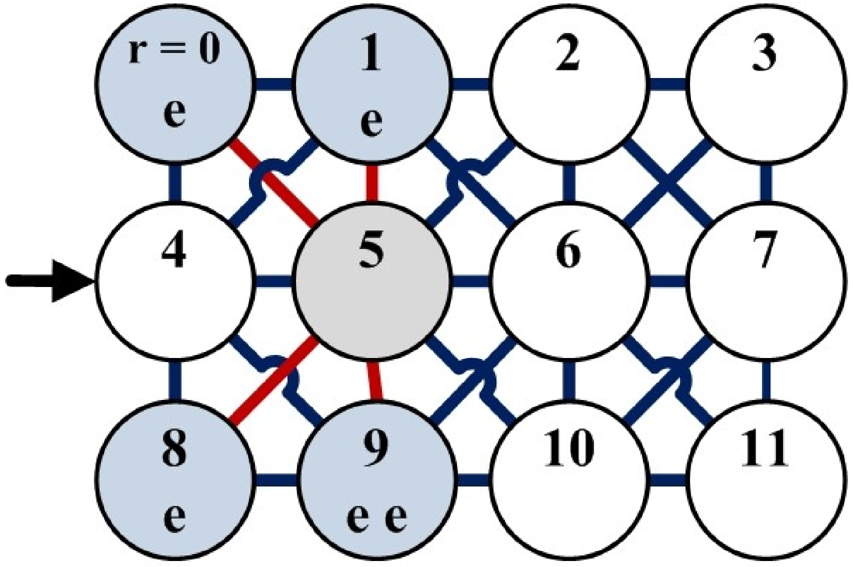
$t = 1, Q = 5$

Optimal Search Path with Visibility (OSPV)

- Search from a distance, ex. number of looks (scans)



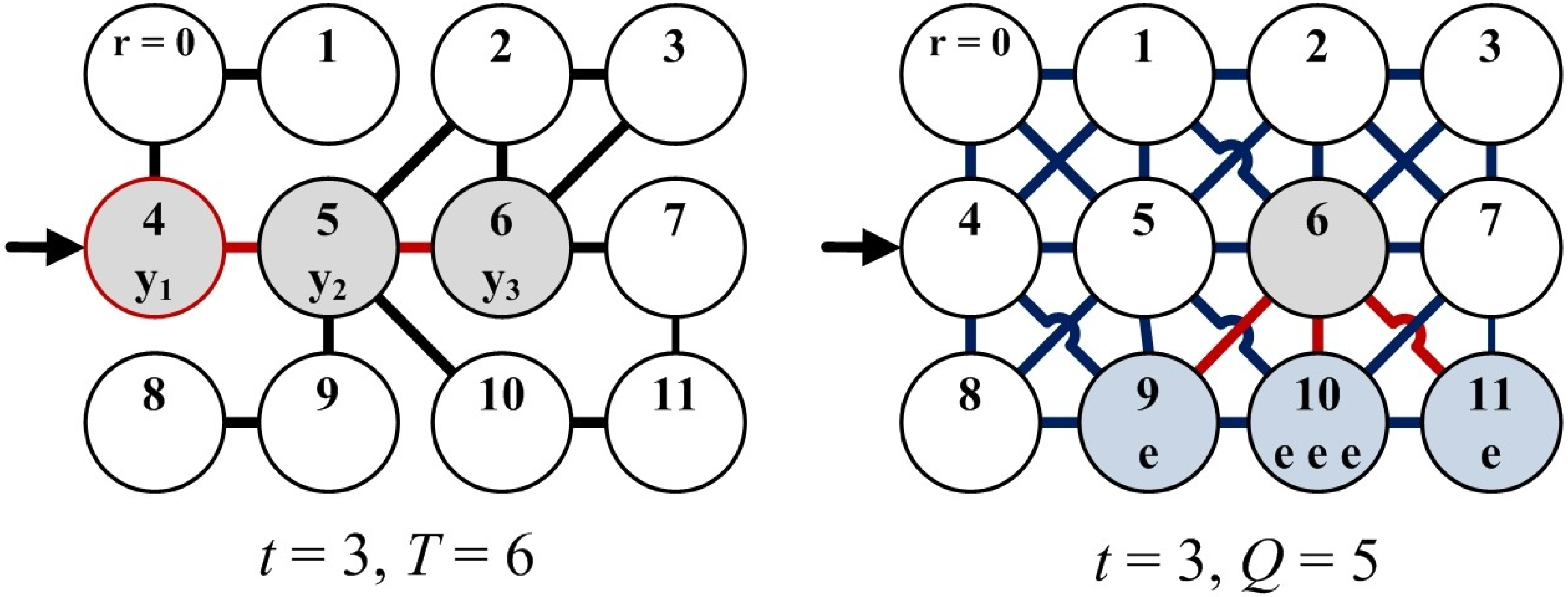
$t = 2, T = 6$



$t = 2, Q = 5$

Optimal Search Path with Visibility (OSPV)

- Search from a distance, ex. number of looks (scans)



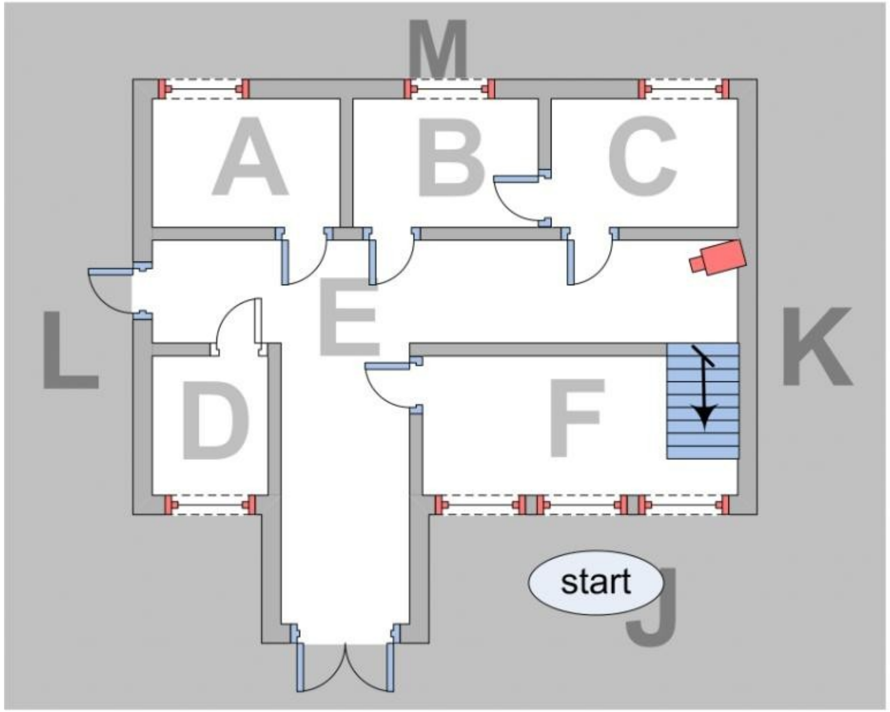
Ant Search Path with Visibility

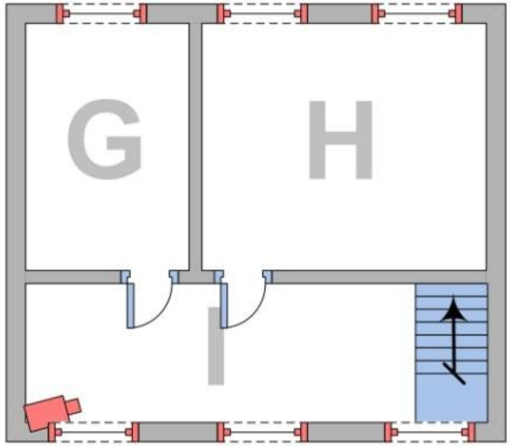
Algorithm 1: ASPV($Ospv$, C, ρ)

Input: An OSPV problem $Ospv$, the size of the colony C, and the evaporation rate ρ.
Output: The incumbent search plan P^{best}.

begin
  $\tau^{\text{path}}, \tau^{\text{eff}} \leftarrow$ `Initialize()` ;
  while *stopping criterion is not met* **do**
    $\mathcal{C} \leftarrow$ `Generate()` ;
    $P^{\text{best}}, \tau^{\text{path}}, \tau^{\text{eff}} \leftarrow$ `Update()` ;
  end
  return P^{best} ;
end

2 types of decision = 2 pheromone tables





T	Path's pheromone values												
1	A	B	C	D	E	F	G	H	I	**J**	K	L	M
2	A	B	C	D	**E**	F	G	H	I	J	K	L	M
3	A	B	C	D	E	F	G	H	**I**	J	K	L	M
4	A	B	C	D	E	F	G	**H**	I	J	K	L	M

T	Effort's pheromone values												
1	A	B	C	D	E	**F**	G	H	I	J	K	L	M
2	A	B	C	D	**E**	F	G	H	I	J	K	L	M
3	A	B	C	D	E	F	G	H	I	**J**	K	L	M
4	A	B	C	D	E	F	G	**H**	I	J	K	L	M

Components = 96 variants of the algorithm

Type	Name	Name
Initialization	iU: Uniform iR: Random	iO: OSPV
Updates	uAA: All-Ants uIB: Iteration-best uRB: Restart-best	uGB: Global-best uORBU: On restart-best upd. uOGBU: On global-best upd.
Restarts	rG: Geometric rL: Luby	rN: Without
Boosting	bY: With	bN: Without

1 initialization component is problem specific

Components = 96 variants of the algorithm

Type	Name	Name
Initialization	iU: Uniform iR: Random	iO: OSPV
Updates	uAA: All-Ants uIB: Iteration-best uRB: Restart-best	uGB: Global-best uORBU: On restart-best upd. uOGBU: On global-best upd.
Restarts	rG: Geometric rL: Luby	rN: Without
Boosting	bY: With	bN: Without

2 update components used only with restart

Components = 96 variants of the algorithm

Type	Name	Name
Initialization	iU: Uniform iR: Random	iO: OSPV
Updates	uAA: All-Ants uIB: Iteration-best uRB: Restart-best	uGB: Global-best uORBU: On restart-best upd. uOGBU: On global-best upd.
Restarts	rG: Geometric rL: Luby	rN: Without
Boosting	bY: With	bN: Without

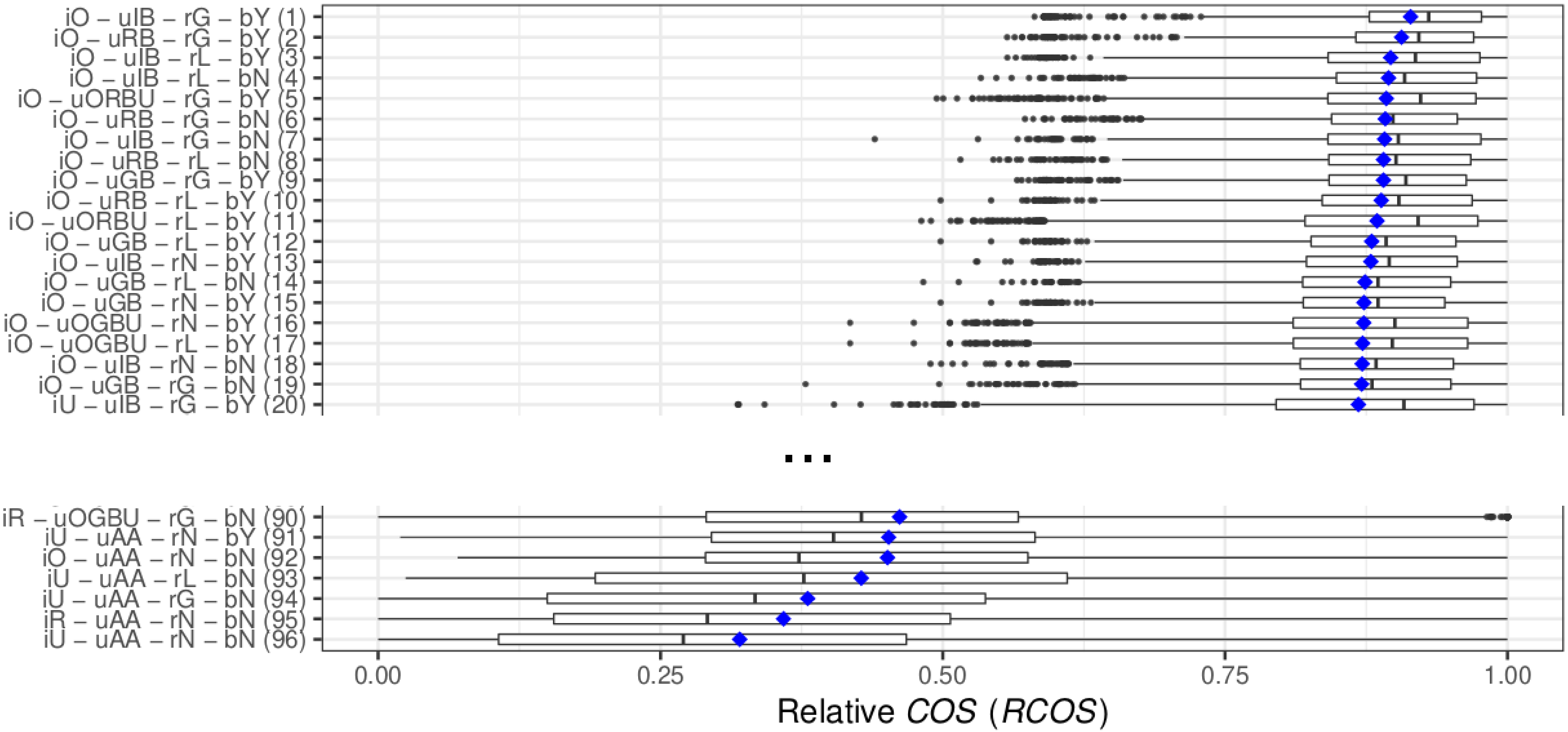
2 restart strategies based on the number of iterations without improvement

Components = 96 variants of the algorithm

Type	Name	Name
Initialization	iU: Uniform iR: Random	iO: OSPV
Updates	uAA: All-Ants uIB: Iteration-best uRB: Restart-best	uGB: Global-best uORBU: On restart-best upd. uOGBU: On global-best upd.
Restarts	rG: Geometric rL: Luby	rN: Without
Boosting	bY: With	bN: Without

Boosting use a greedy solution to increase the pheromone

100 random instances, Q ϵ {1, 2, ..., 5}, T ϵ {4, 9, 16, ... 121}



Relative Cumulative Overall Probability of Success (50 instances)

		Number of scans (Q)				
Method	T	1	2	3	4	5
iO - uIB - rG - bY	9	[*1*, *1*]	[.99, .99]	[*1*, *1*]	[**.97**, **.97**]	[**1**, **1**]
	25	[.96, .98]	[**.95**, **.97**]	[**.94**, **.96**]	[**.9**, **.92**]	[*.94*, *.96*]
	49	[**.97**, **.97**]	[**.96**, **.97**]	[**.96**, **.97**]	[**.97**, **.98**]	[**.95**, **.96**]
	81	[**.88**, **.90**]	[**.92**, **.94**]	[**.95**, **.96**]	[**.97**, **.98**]	[**.97**, **.98**]
	121	[**.82**, **.86**]	[*.87*, *.90*]	[**.95**, **.96**]	[**.92**, **.93**]	[**.94**, **.95**]
Greedy	9	.98	.95	.96	.89	.94
	25	.47	.89	.92	.89	*.96*
	49	.66	.68	.92	.93	.80
	81	.64	.35	.58	.81	.93
	121	.49	*.87*	.35	.80	.82
Best of CPLEX	9	*1*	**1**	*1*	.87	.88
	25	**1**	.35	.41	.30	–
	≥ 36	–	–	–	–	–

Empirical contributions to ACO

- Problem-specific pheromone initialization works
- Restarts pay
- Targeted pheromone updates using quality candidates are best (especially *iteration-best* in our case)
- Boosting may be beneficial

Contributions to search operations planning

- Optimal search path:

  - More flexible with the « V » for visibility
  - So far : ASPV is the best algorithm for the OSPV

- We made steps in the direction of lower-level path planning for operational systems

Version of record:

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