Path Planning

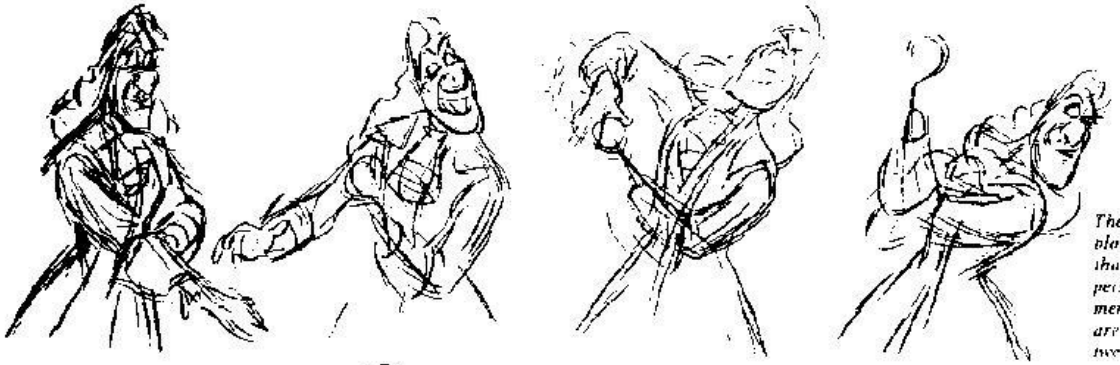
Leo Dorst

2012

7. Put the "Juice" in it.

With all the staging problems solved, the animator can now concentrate on individual actions, timing, expressions, and making the drawings that will give life to the action.

The scene is a close up of Captain Hook telling his valet in the next room of his plan to trick Tinker Bell into revealing the location of Peter Pan's hiding place. During his dialogue, he is putting on his finest clothes, down to a gold-plated hook.

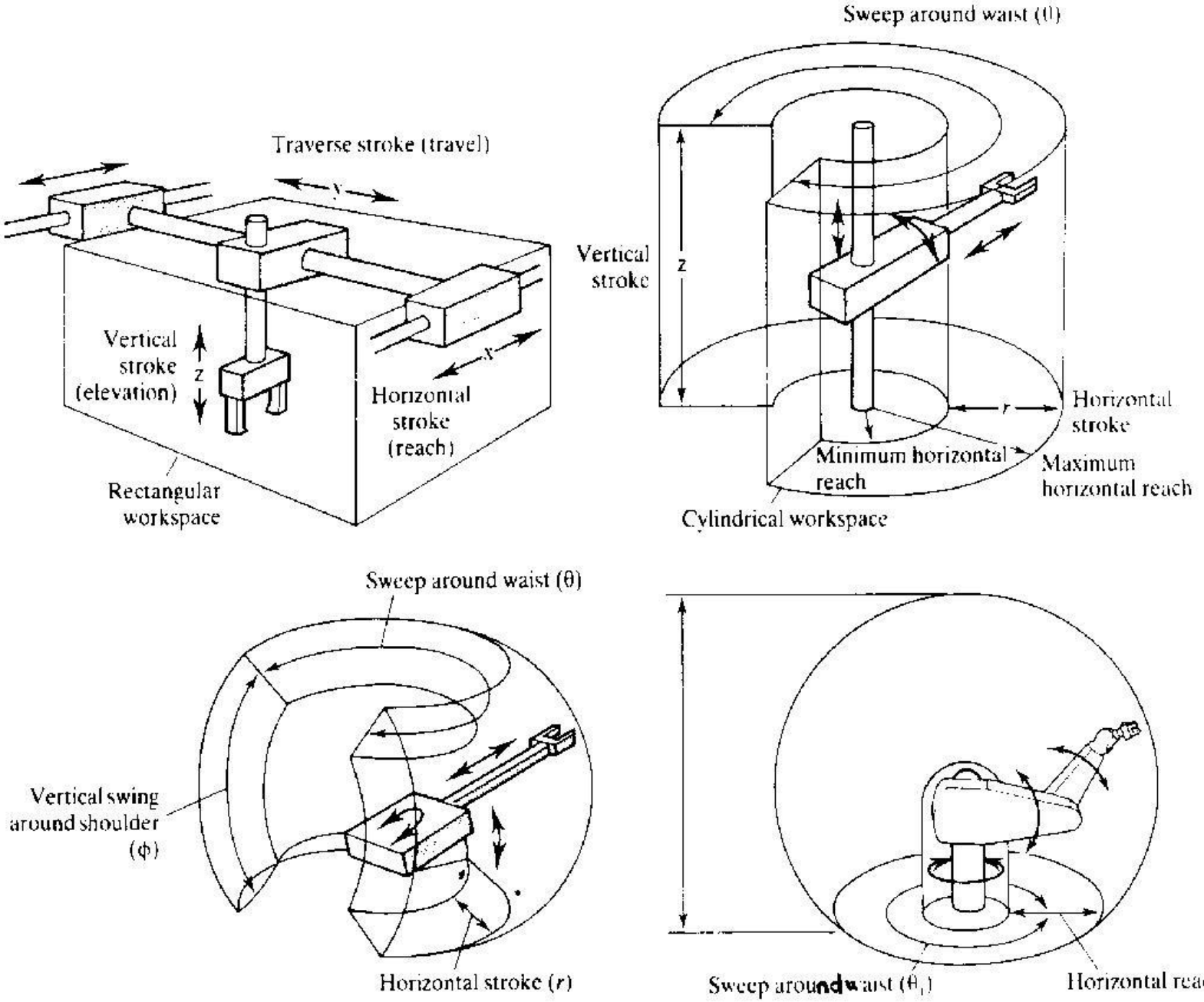


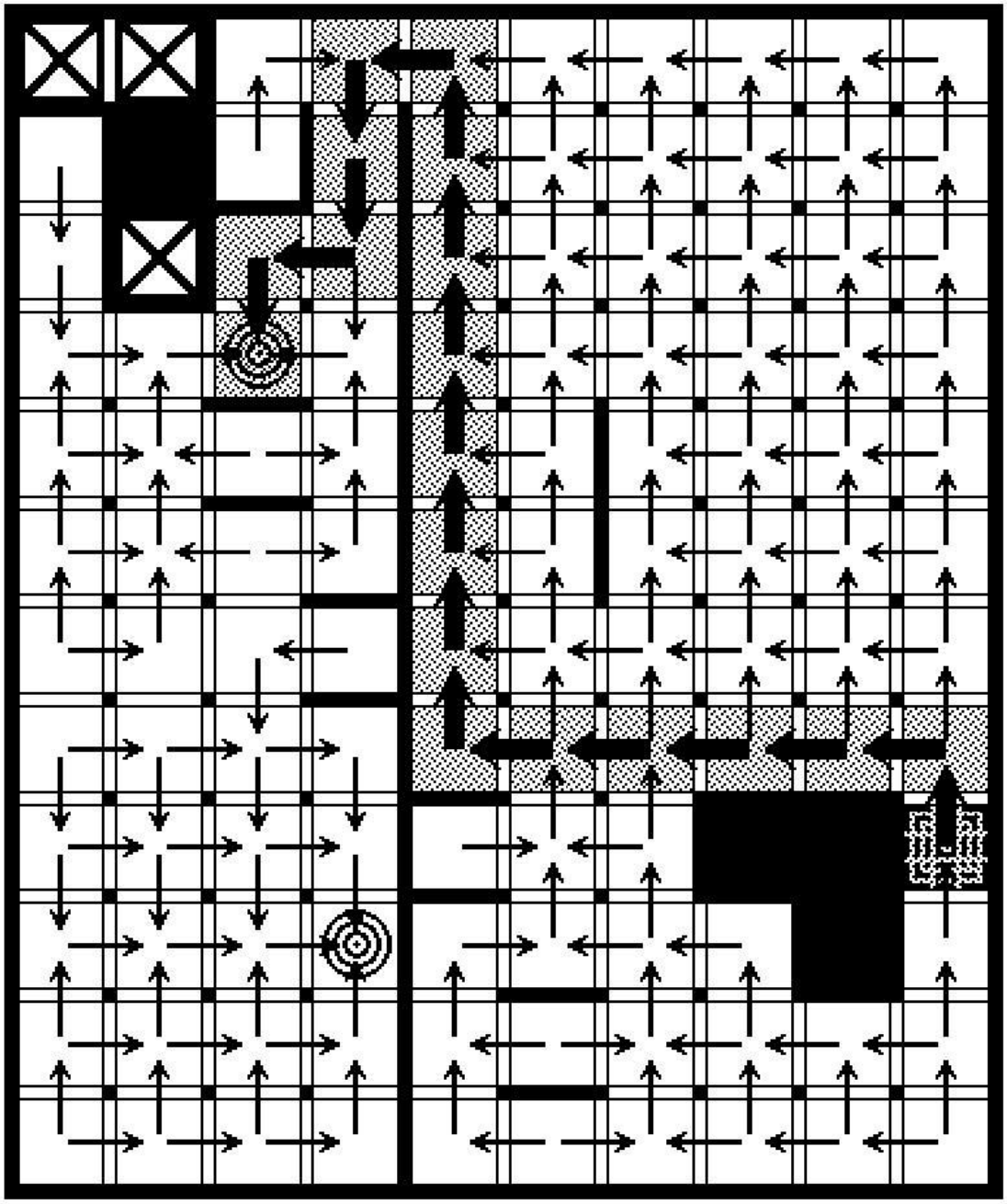
These are the drawings blown up from thumbnails that determine position, perspective size, and movement in the scene. There are twenty-eight frames between drawings 2 and 3.

Within that area, key drawings are made of just how the hook will be put in place. These drawings are called "extremes" or "keys." The animator controls the timing with charts on the drawing noting the position of the inbetweens in relation to the extremes.

The breakdown man does the main inbetweens that may contain special drawing problems.

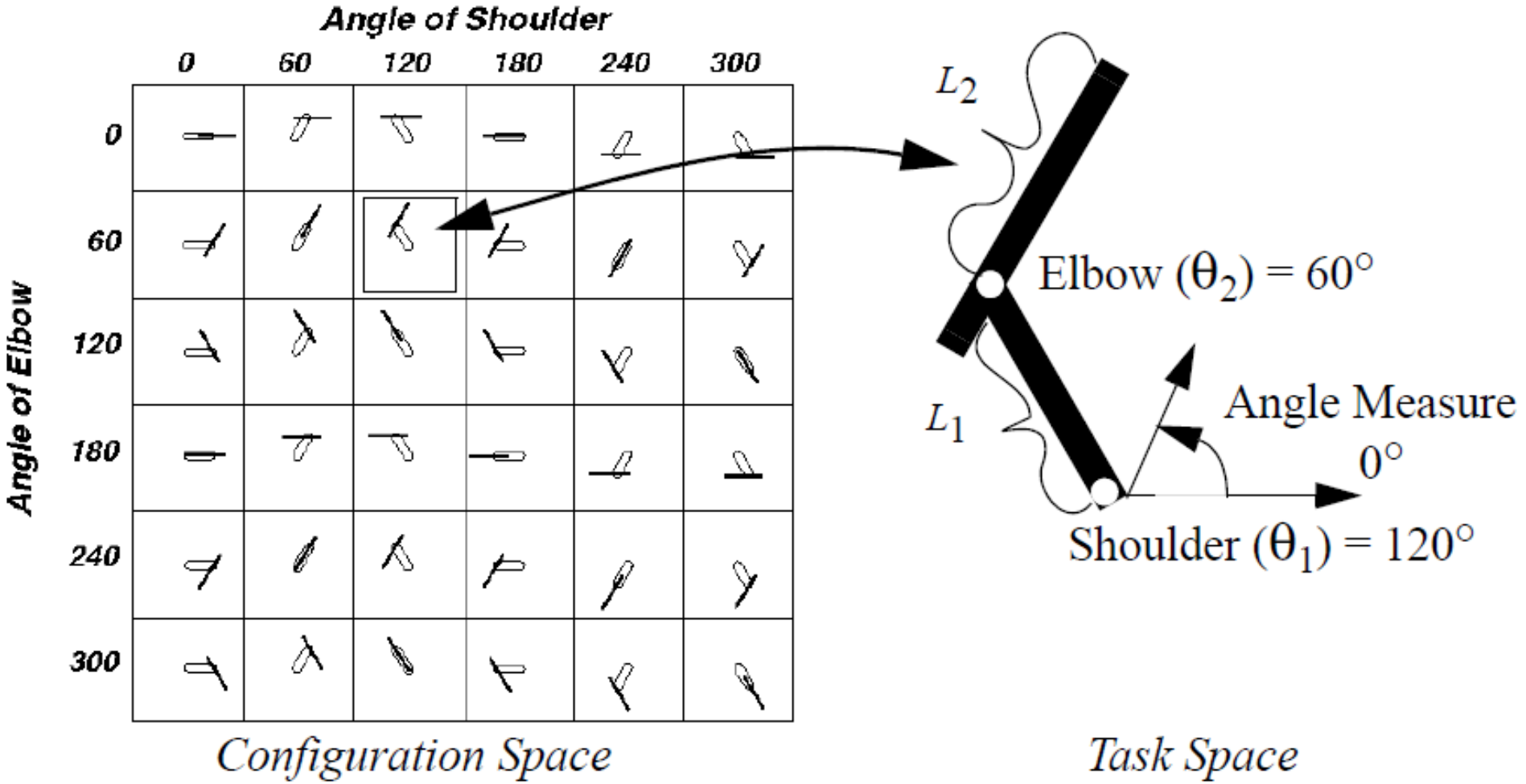
The inbetweener makes the remaining drawings that will complete the scene. In this type of complex and sophisticated action, there are no mechanical inbetweens. Each drawing has to be considered a new phase in the overall action. The cartoon character must be alive on every drawing.

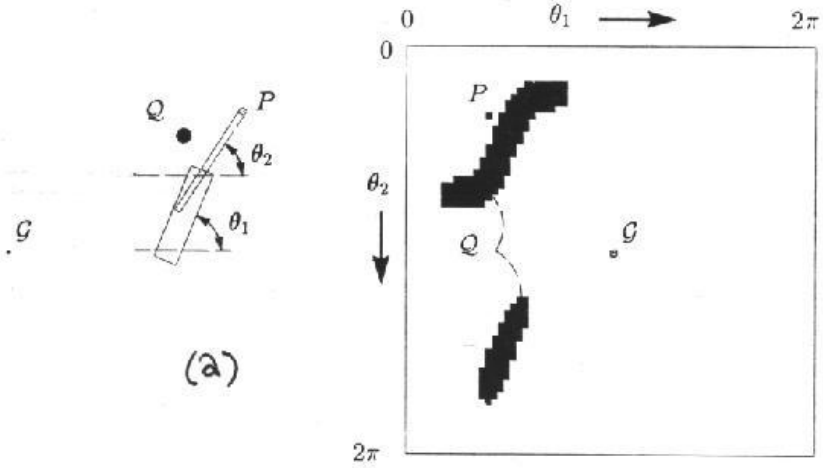

Traverse stroke (travel)
Vertical stroke (elevation)
Horizontal stroke (reach)
Rectangular workspace
Sweep around waist (θ)
Vertical stroke
Horizontal stroke
Minimum horizontal reach
Maximum horizontal reach
Cylindrical workspace
Sweep around waist (θ)
Vertical swing around shoulder (ϕ)
Horizontal stroke (r)
Sweep around waist (θ1)
Horizontal reach

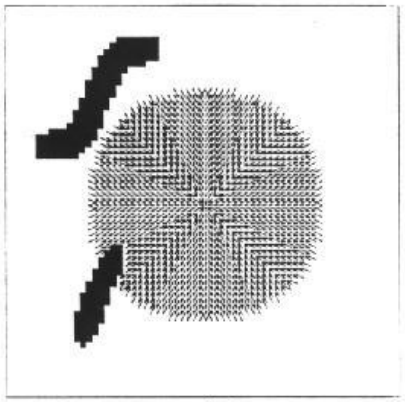


A*-procedure

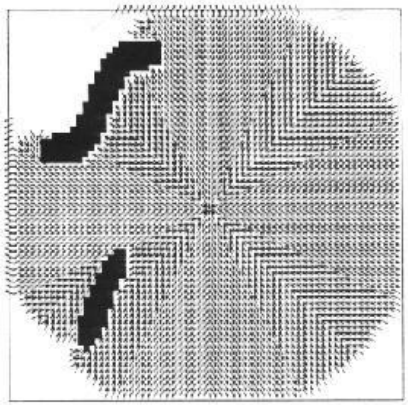
- Refer to A* slides


Angle of Shoulder
0
60
120
180
240
300
Angle of Elbow
0
60
120
180
240
300
Configuration Space
L_2
L_1
Elbow (θ_2) = 60°
Angle Measure
0°
Shoulder (θ_1) = 120°
Task Space

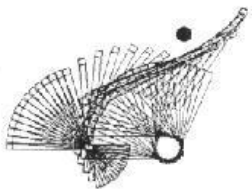

Q
P
θ_2
θ_1
$\mathcal{G}$
(a)
0
θ_1
2π
0
P
θ_2
Q
$\mathcal{G}$
2π

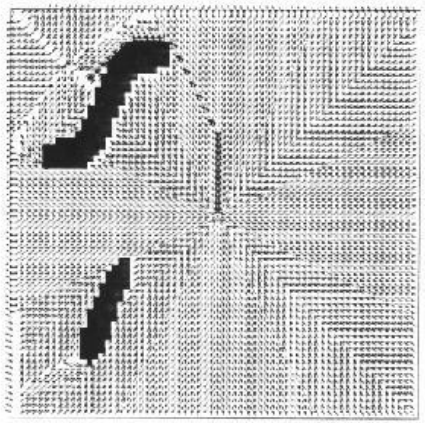


(c)

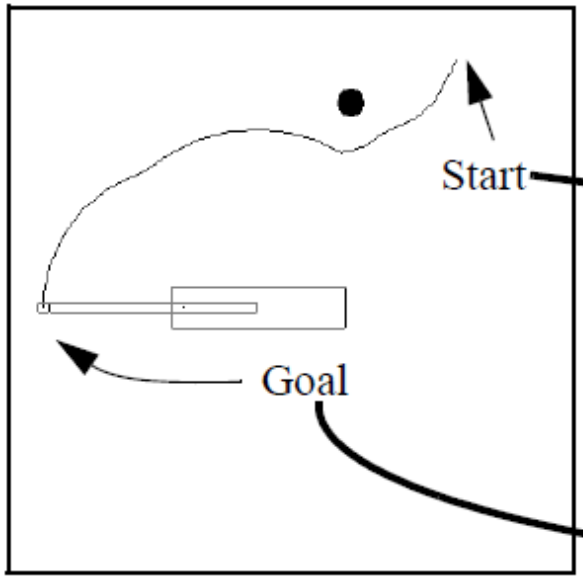


(d)



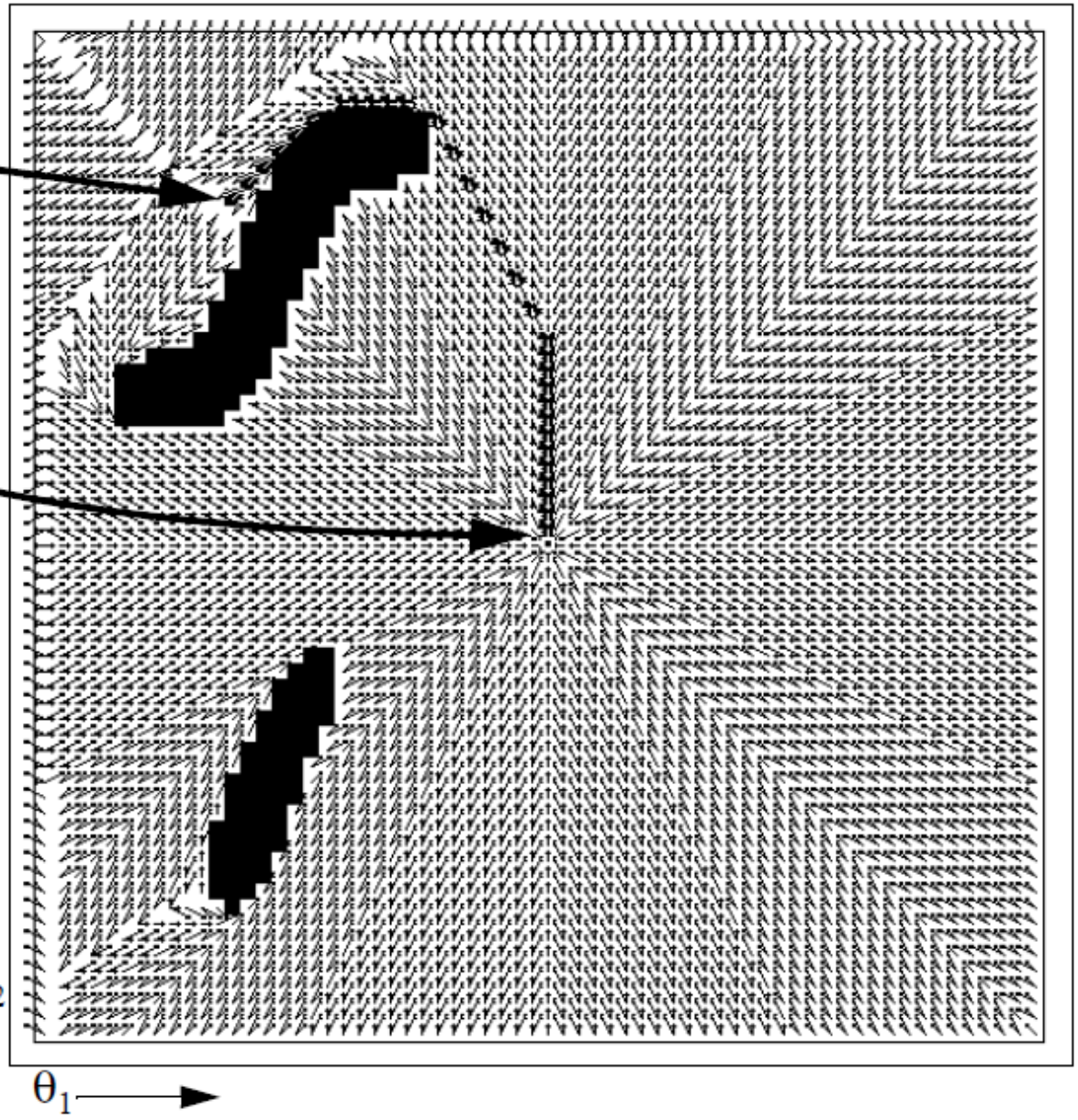


path planning issue	graph search concept	$\mathcal{C}$-space term
possible states	graph	configuration space
state, configuration, pose	node	point
basic possible motion	edge, transition	connectivity
effort, criterion	transition cost	metric
navigation function	explicated graph	distance function
obstacle	missing node	forbidden region
goal states	start nodes of search	region with distance $= 0$
start state	termination node	current state
—	heuristic	opt. est. remn. distance
—	`OPEN` or fringe nodes	'wave front'
path planning	A^*-search	'wave propagation'
optimal motion	explicated transition	gradient step
optimal path	solution path	geodesic (shortest arc)
moving obstacle	nonstandard: ∂A^*	displaced forbidden set

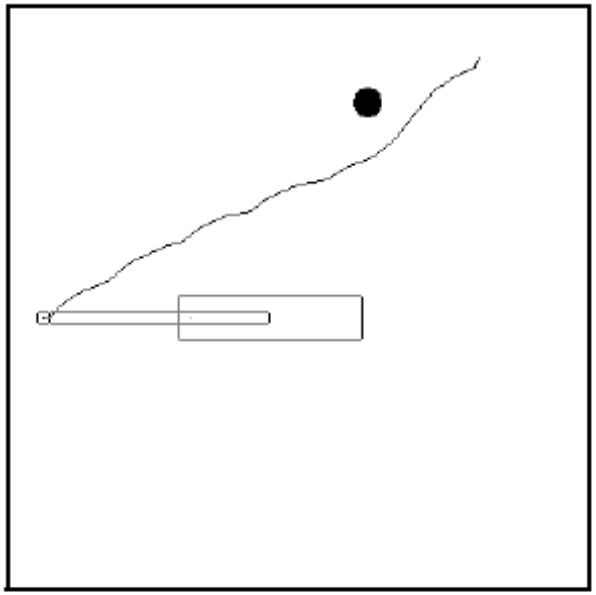


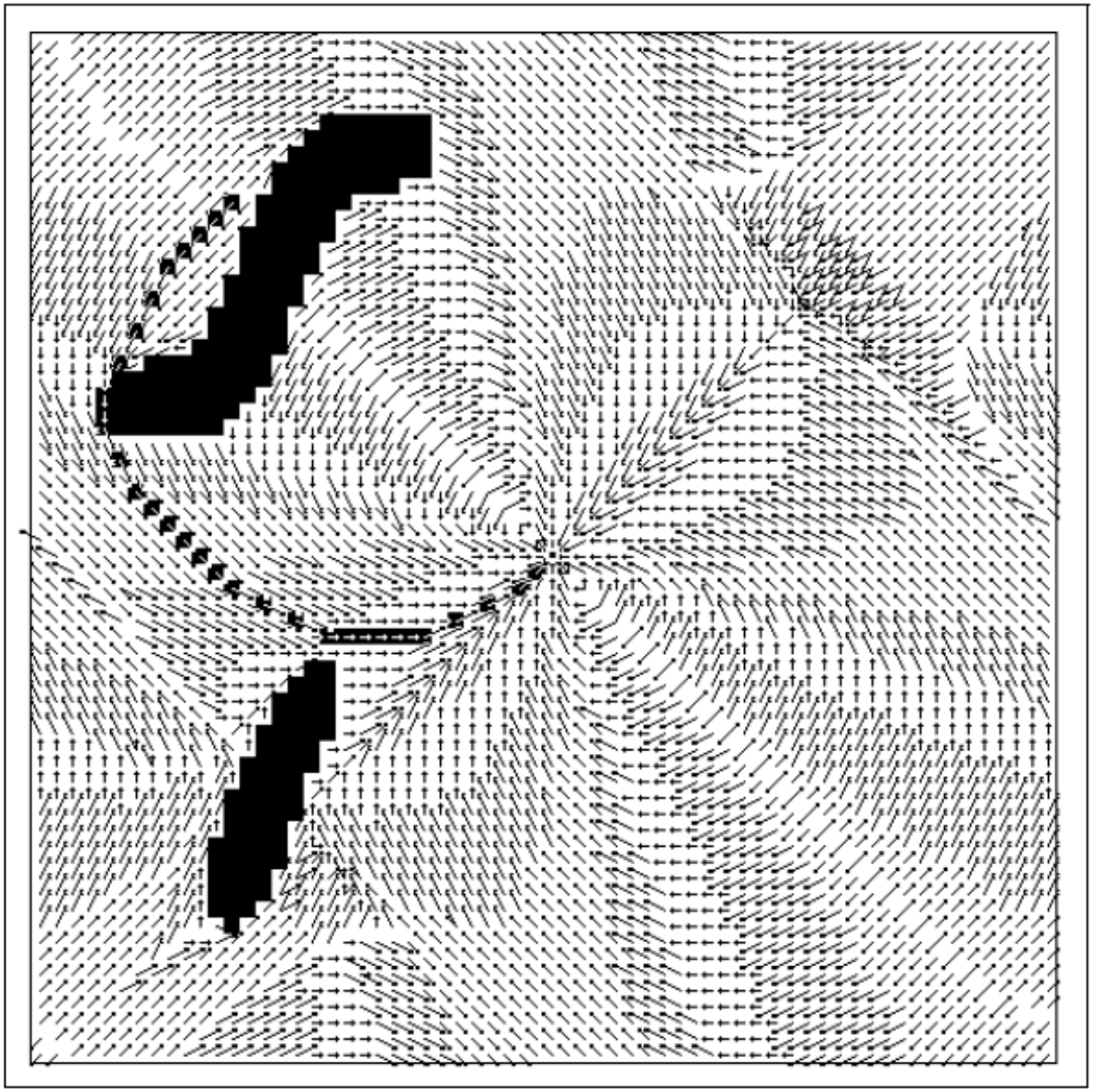
Above: Task Space with robot, obstacle and trace of end-effector.

Right: Configuration Space with transformed obstacles, direction arrows and path using min. CS distance.



$$C(\alpha_{\theta 1},\alpha_{\theta 2},\beta_{\theta 1},\beta_{\theta 2}) = \sqrt{(\delta\theta_1)^2 + (\delta\theta_2)^2}$$

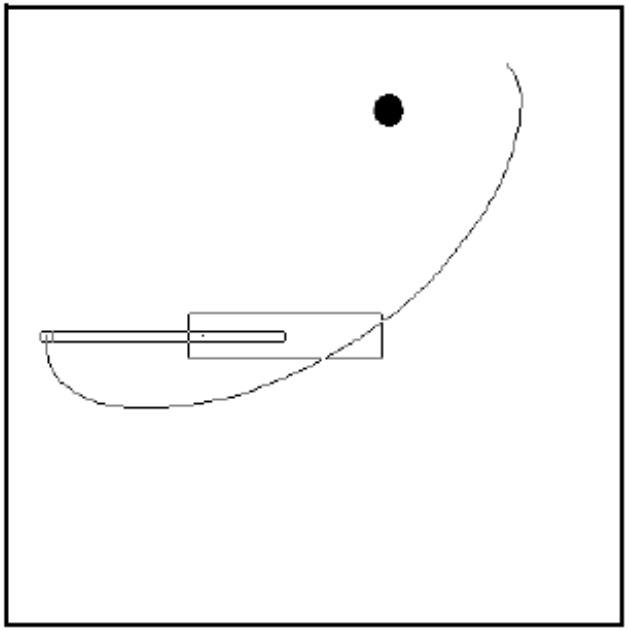


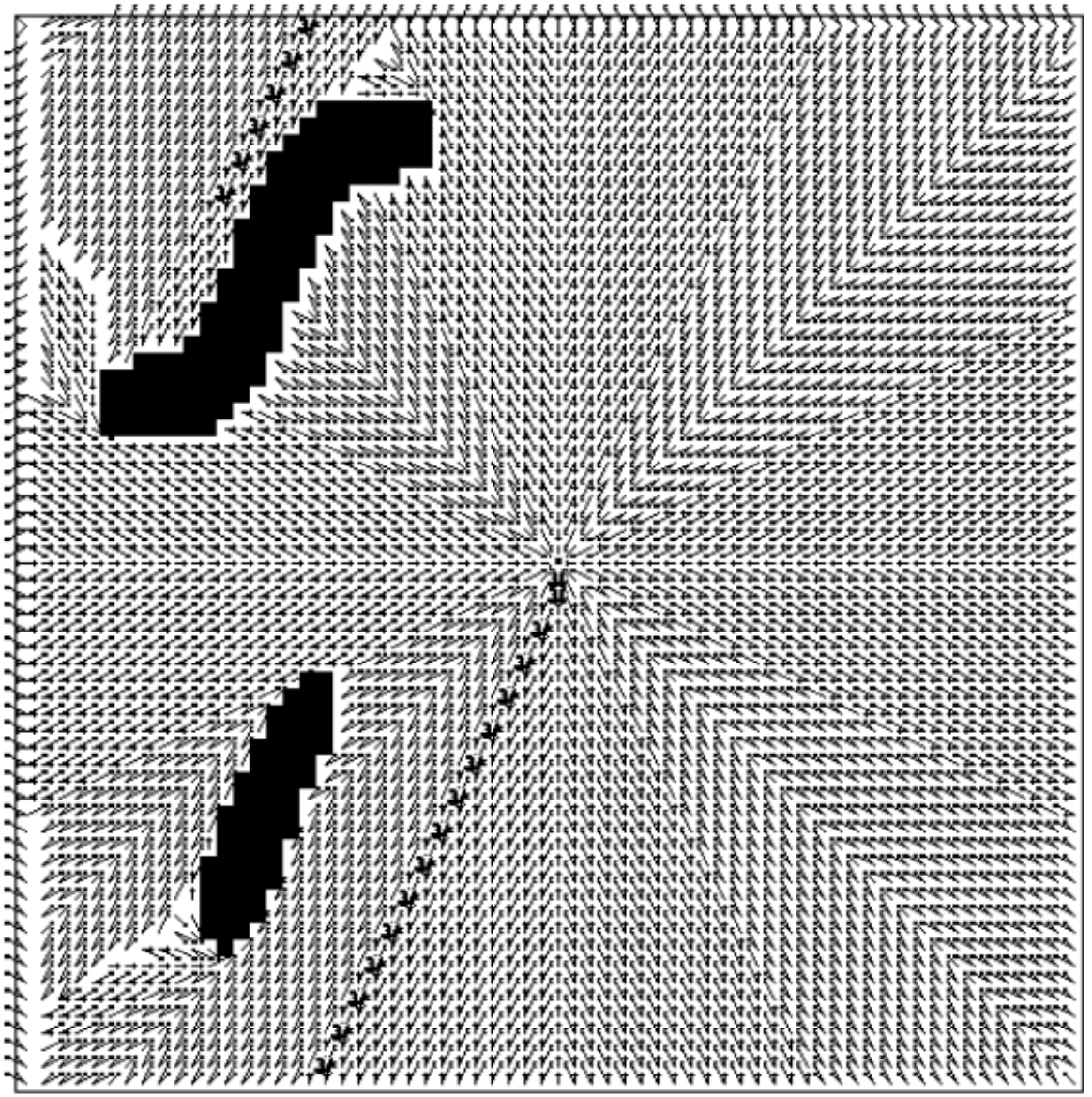


Above: Task Space path corresponding to Config. Space solution.

Right: Resulting field of arrows from A* in Config. Space using minimum distance (straightest end effector path) criterion.

$$C(\theta_1,\theta_2,\delta\theta_1,\delta\theta_2) = \sqrt{(L_1\delta\theta_1)^2 + (L_2\delta\theta_2)^2 + 2L_1\delta\theta_1 L_2\delta\theta_2\cos(\theta_1-\theta_2)}$$



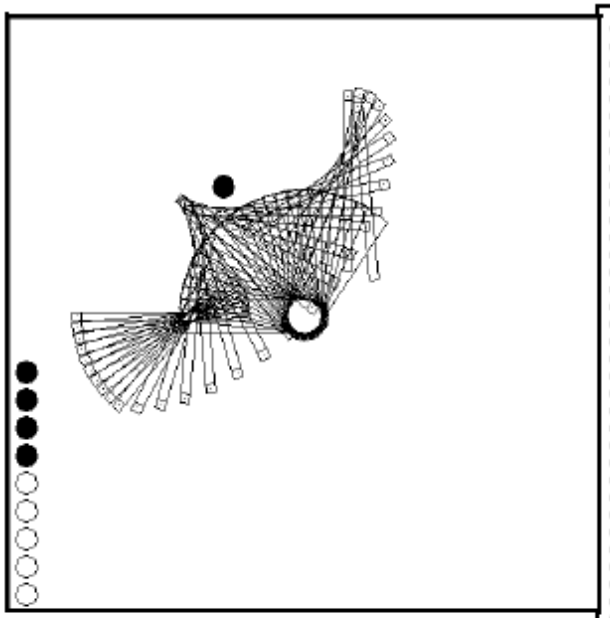


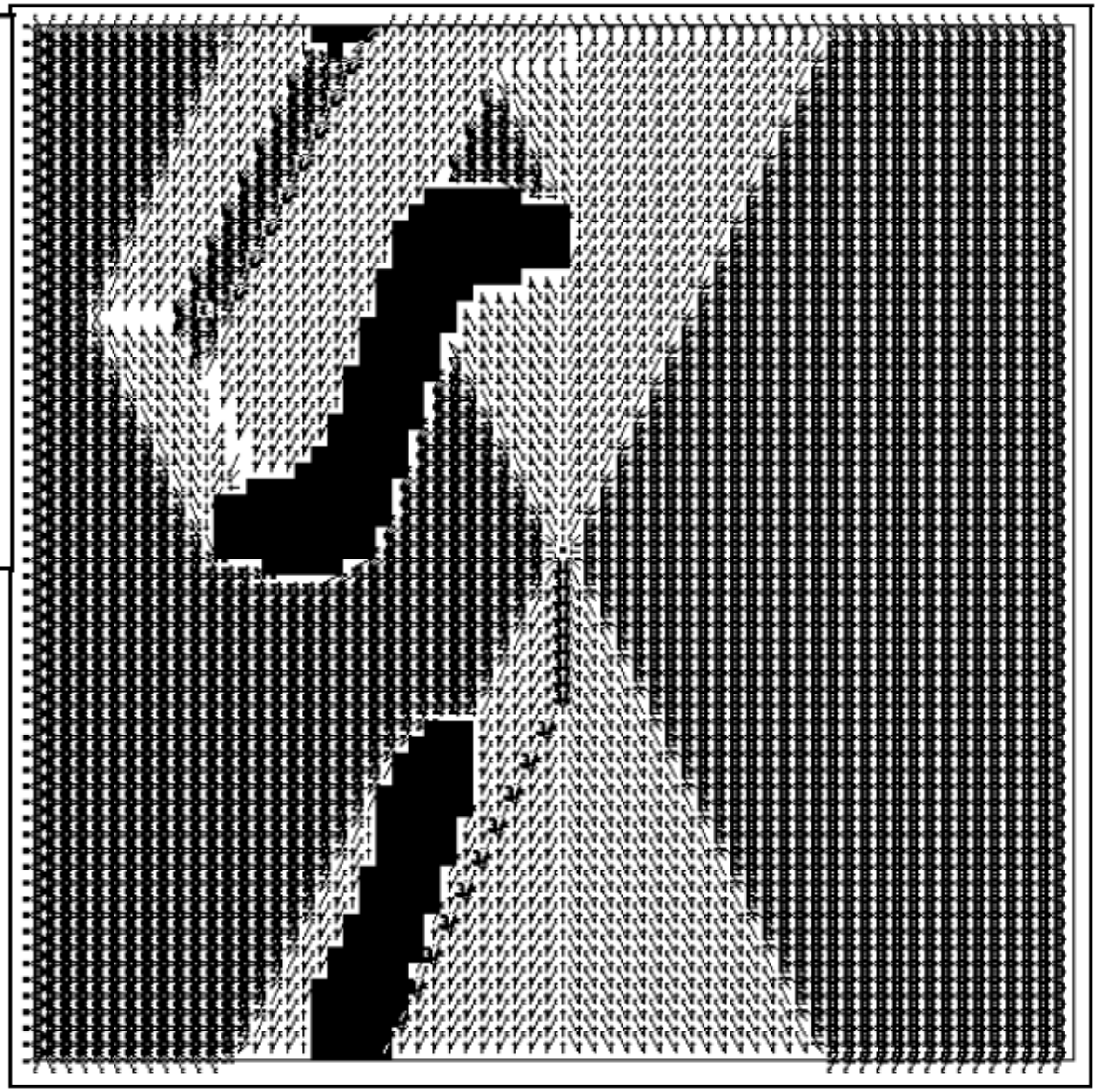
Above: Task Space min path corresponding to Config. Space.

Right: Configuration Space. 'Effort' cost measured as a function of change in joint angles where m_1 and m_2 are

the mass of link 1 and link 2.

$$C(\delta\theta_1, \delta\theta_2) = \sqrt{(m_1\delta\theta_1)^2 + (m_2\delta\theta_2)^2}$$

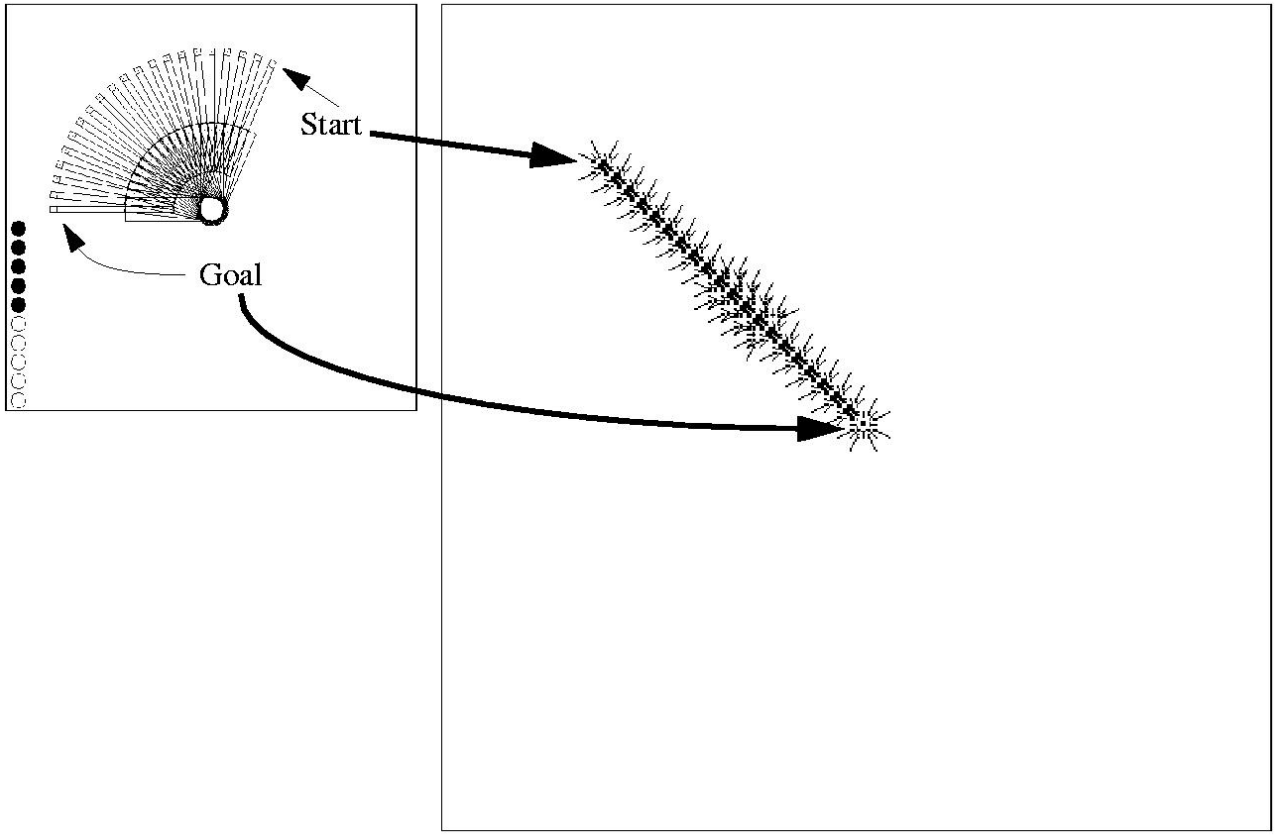


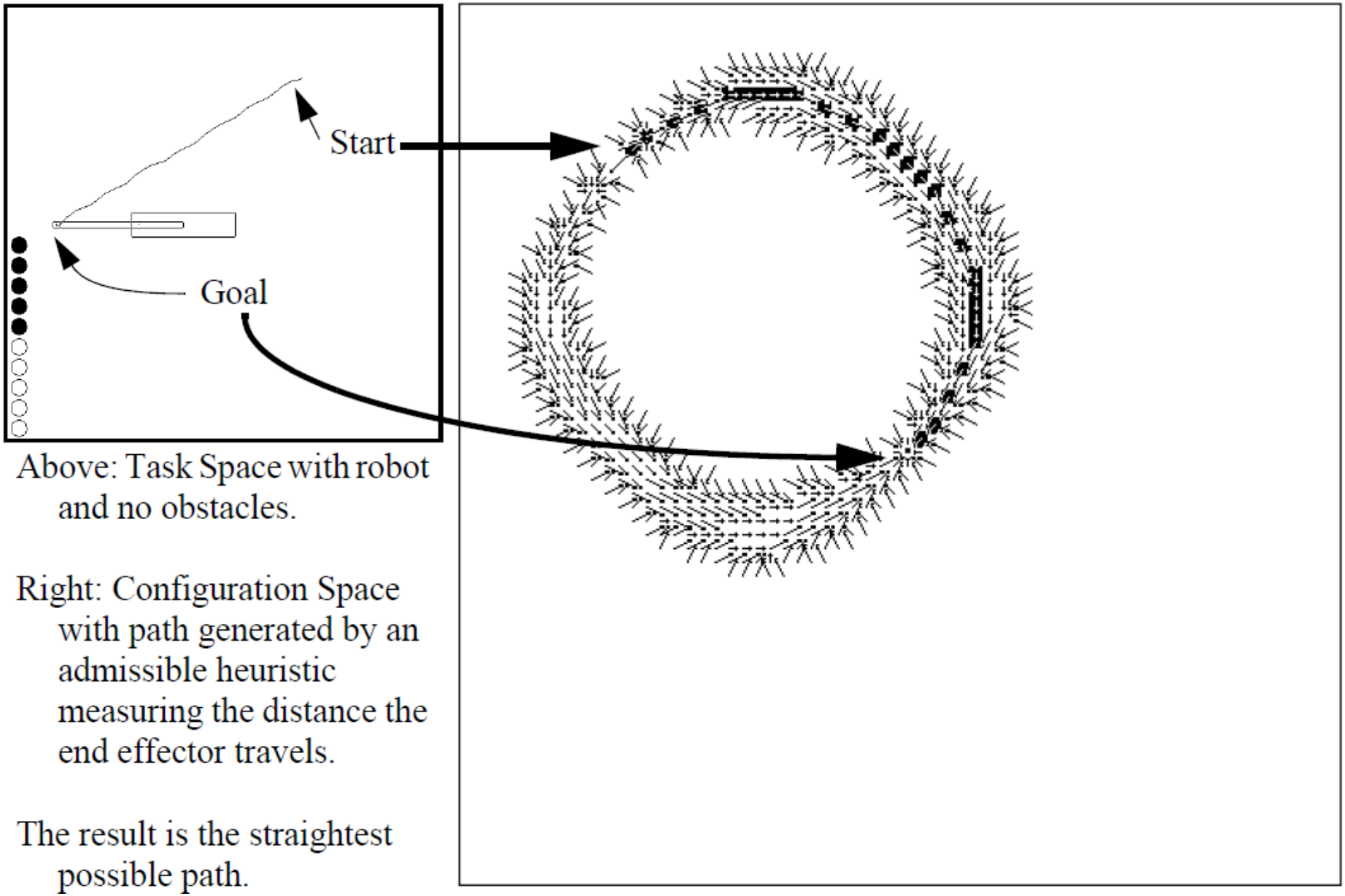


Above: Minimum Time motion. Second link moves twice the rate of the first link.

Right: Configuration Space. Dark areas represent areas where there are multiple paths for the fast link.

$$C(\delta\theta_1, \delta\theta_2) = max \left\{ \left| \frac{\delta\theta_1}{v_1} \right|, \left| \frac{\delta\theta_2}{v_2} \right| \right\}$$

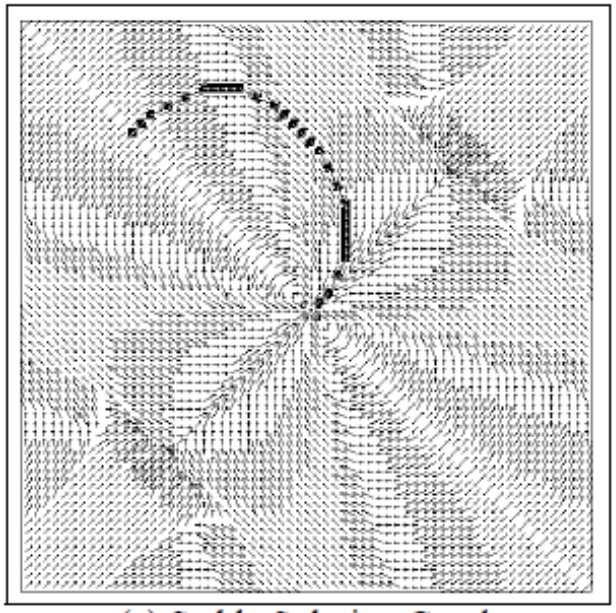

Start
Goal



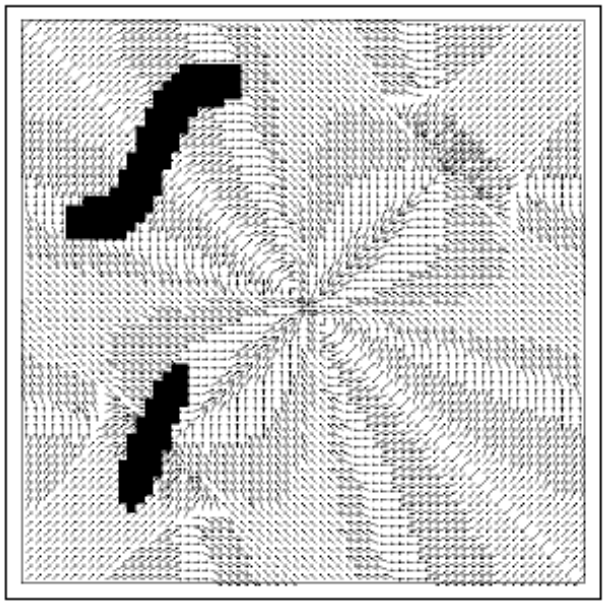
Above: Task Space with robot and no obstacles.

Right: Configuration Space with path generated by an admissible heuristic measuring the distance the end effector travels.

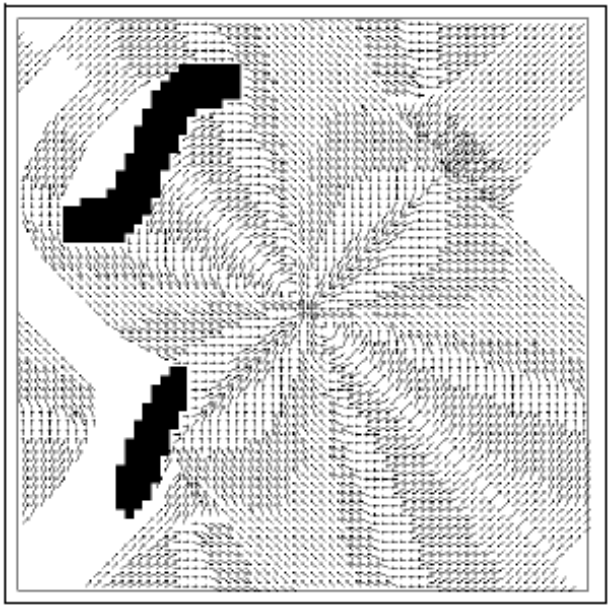
The result is the straightest possible path.



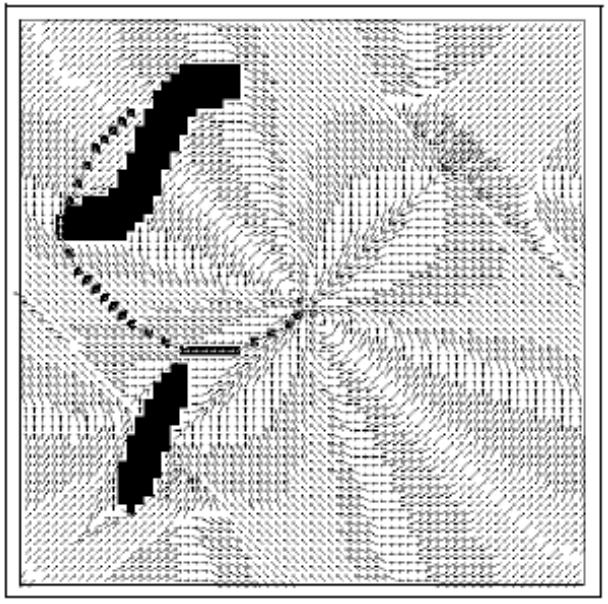
(a) Stable Solution Graph



(b) New Obstacles (many states)



(c) χ (Obstacles) Produce Affected Area



(d) Arrow Pattern Adjusted

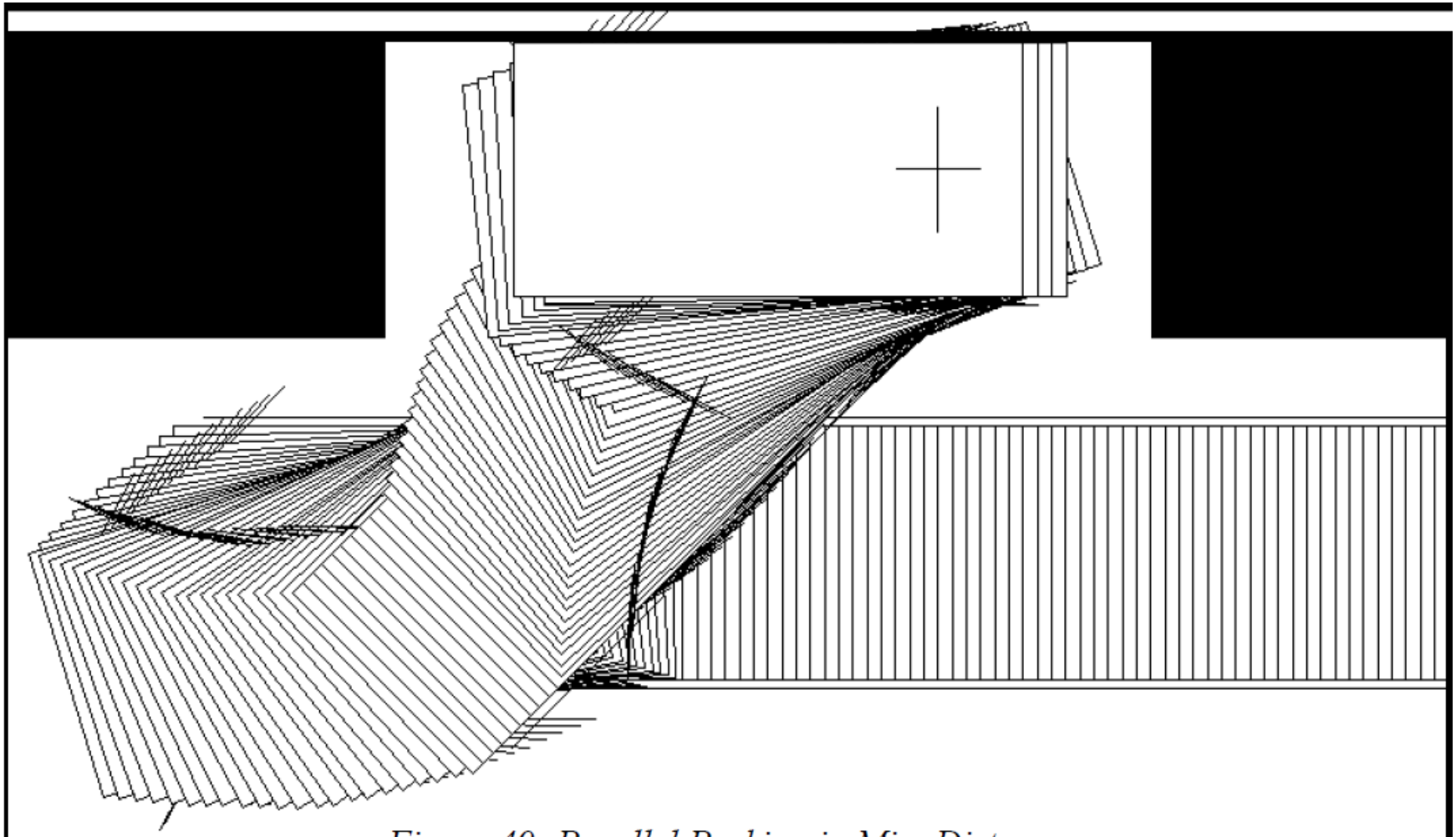
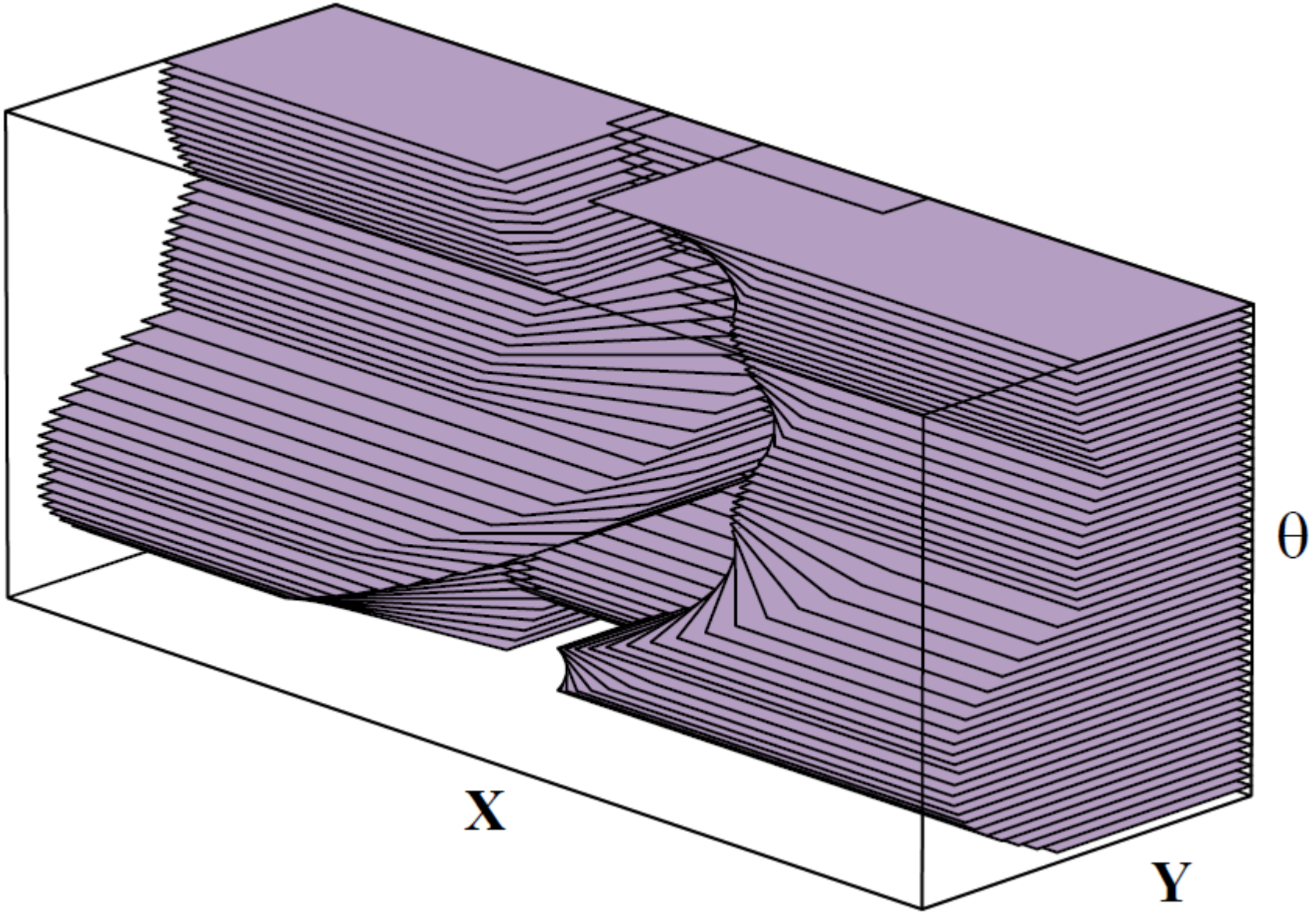
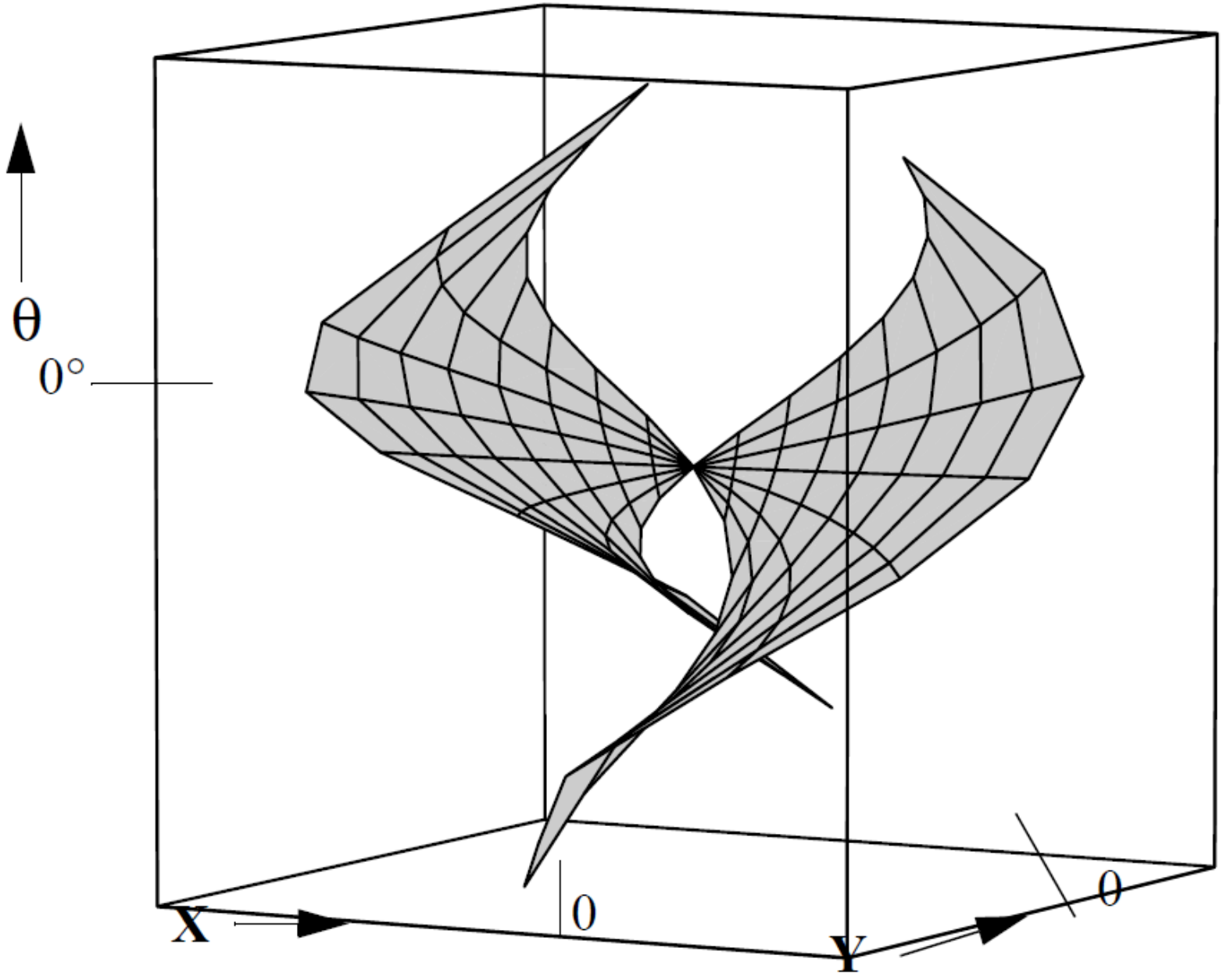
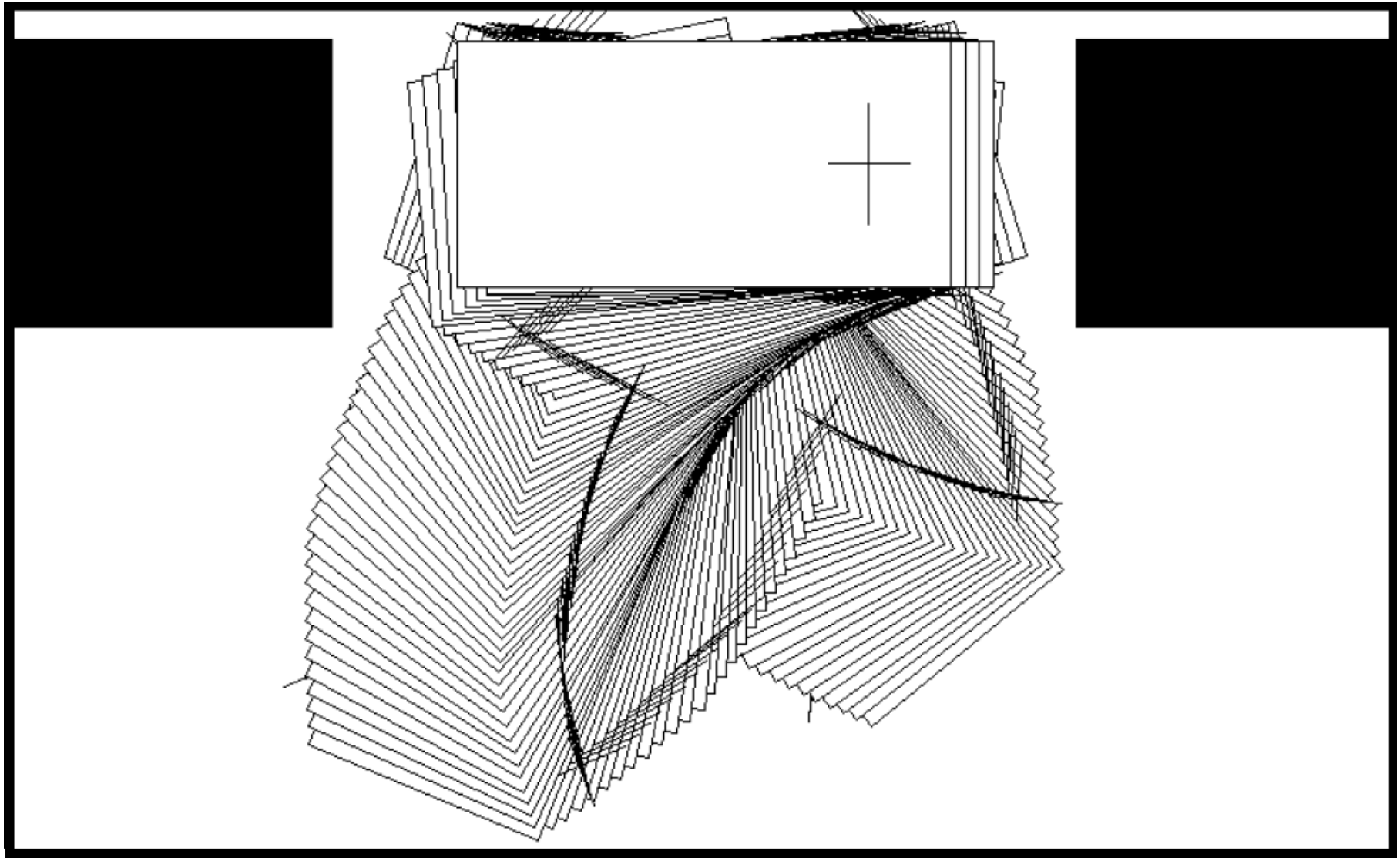
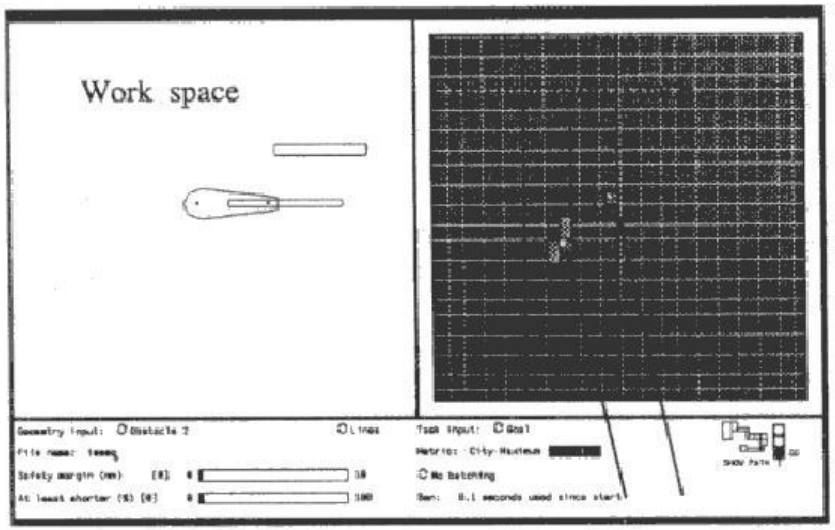


Figure 49: Parallel Parking in Min. Distance.


θ
X
Y

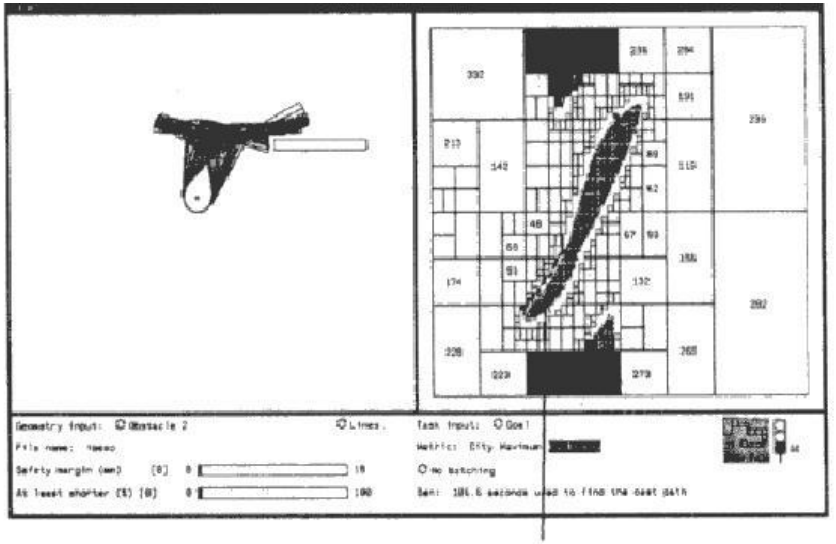

θ
0°
X
0
Y
θ





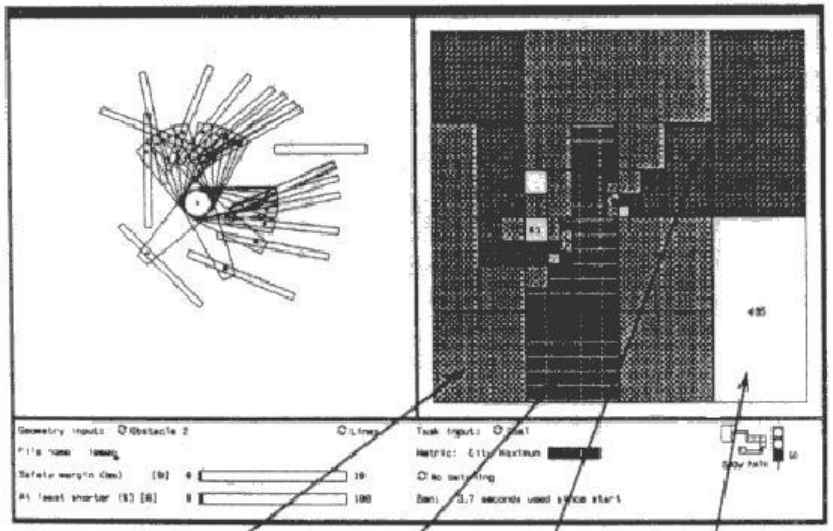
a

Start Goal

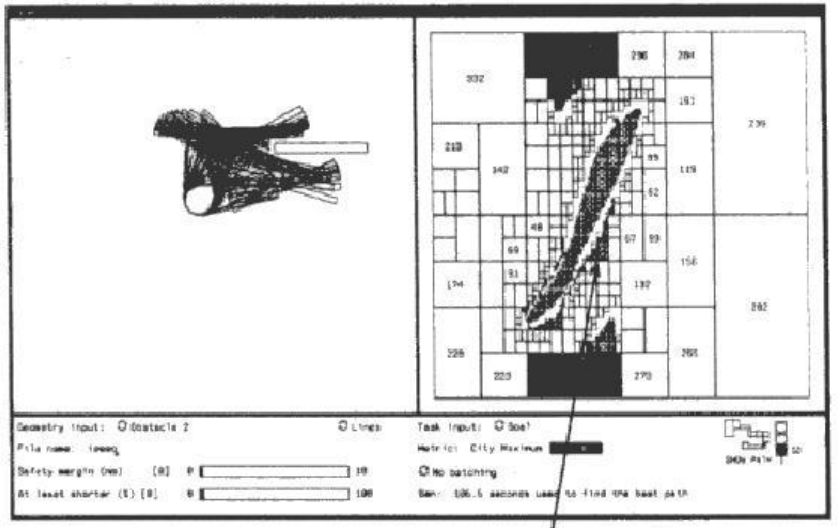


a

Prohibited region in finest resolution

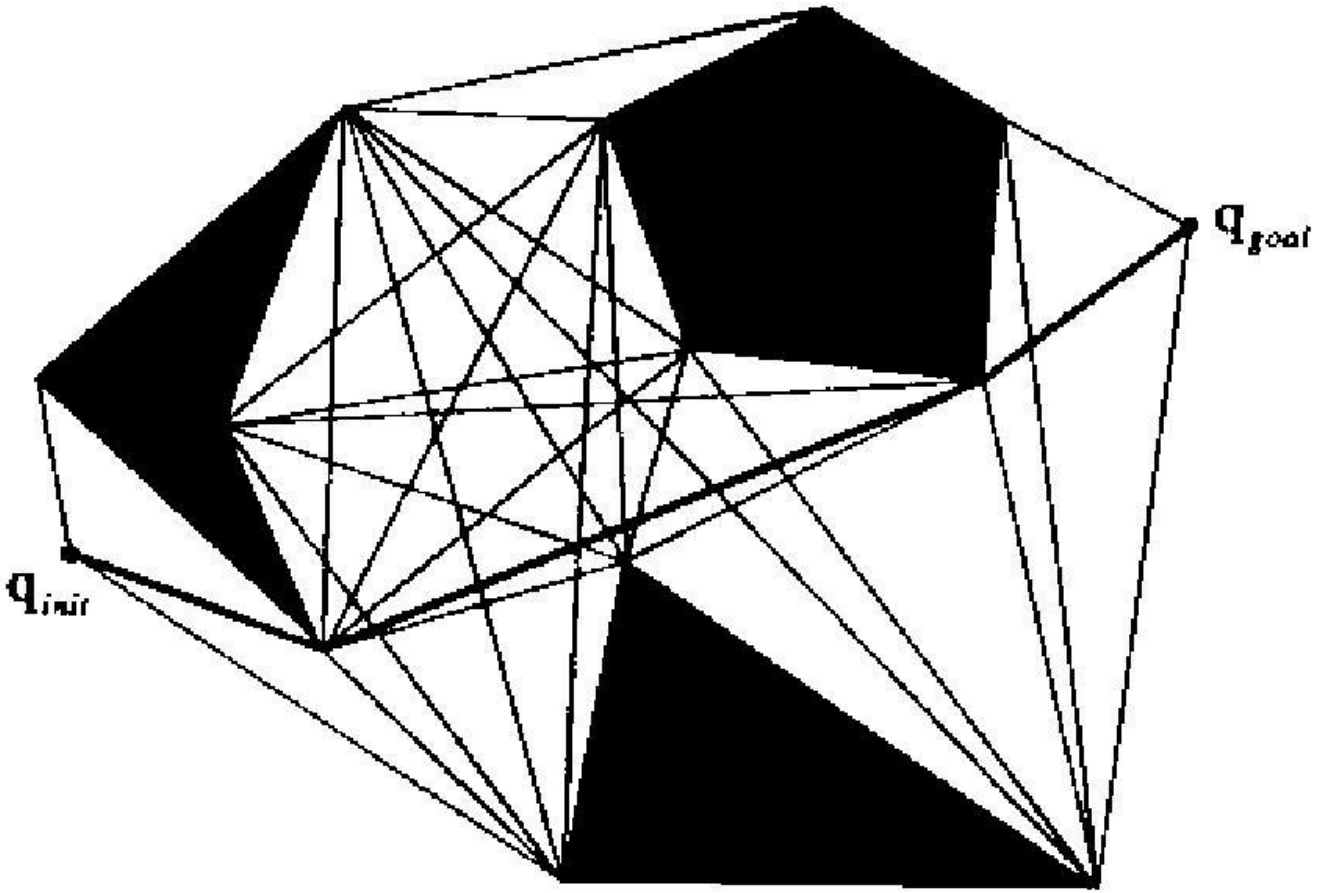


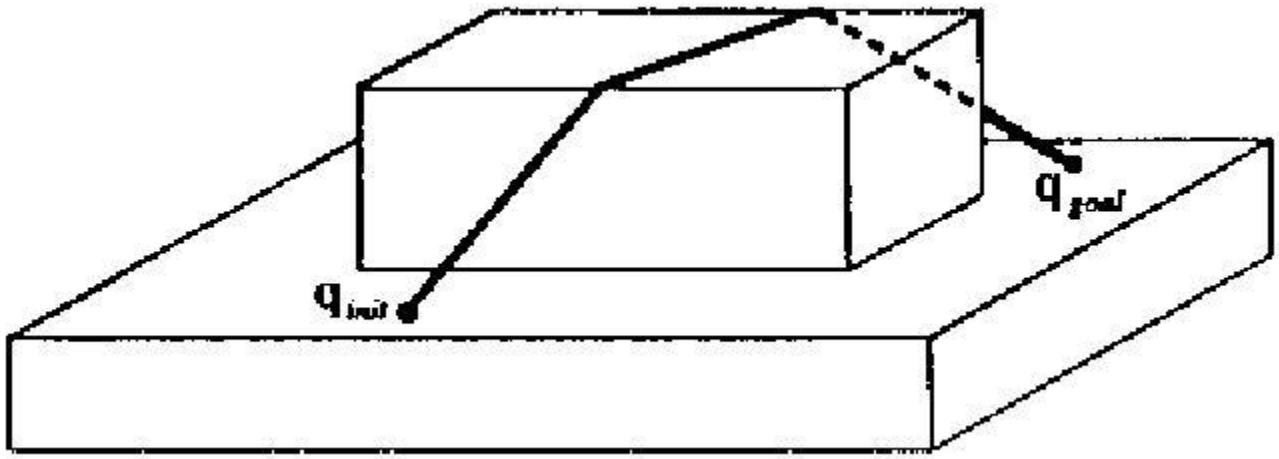
b interesting not-interesting path free block

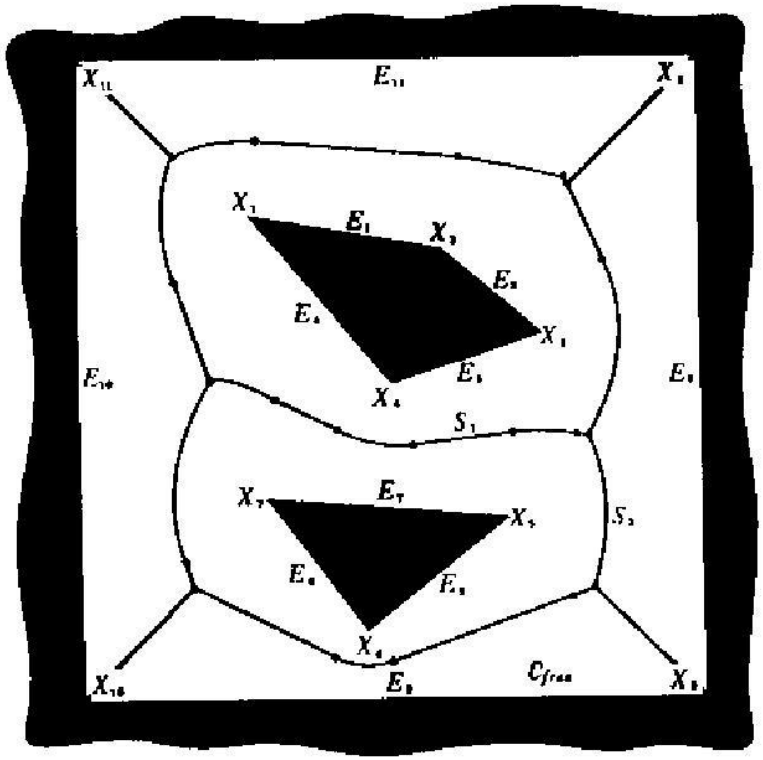


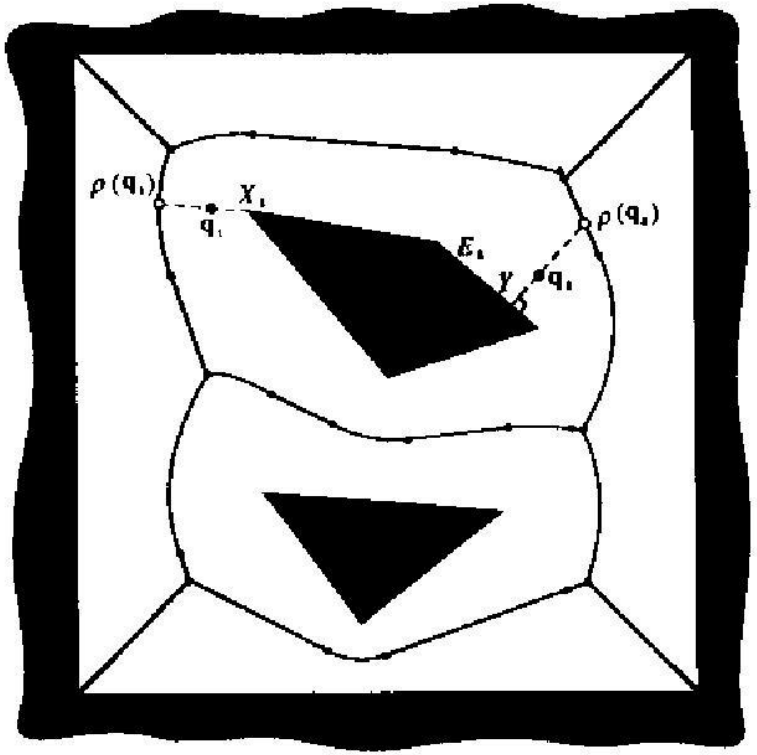
b

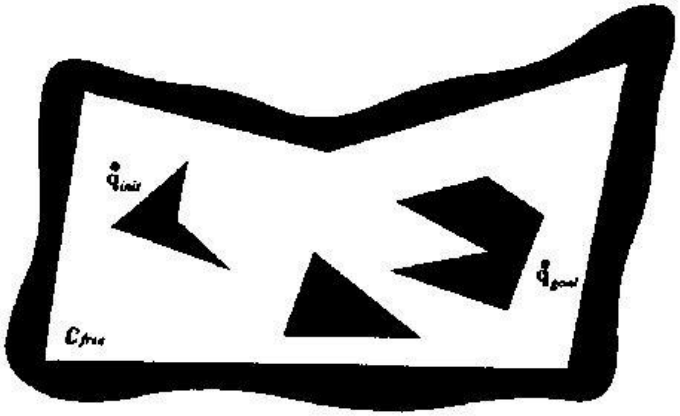
Path in configuration space


q_{goal}
q_{init}

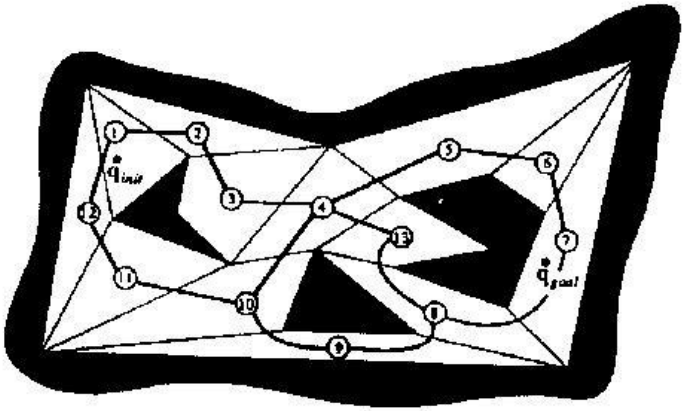

q_{goal}
q_{init}


X_{11}
E_{11}
X_1
X_2
E_1
X_3
E_2
E_3
X_4
E_4
X_5
E_{10}
E_5
S_1
X_7
E_7
X_6
S_2
E_6
E_8
X_8
X_{10}
E_9
C_{free}
X_9

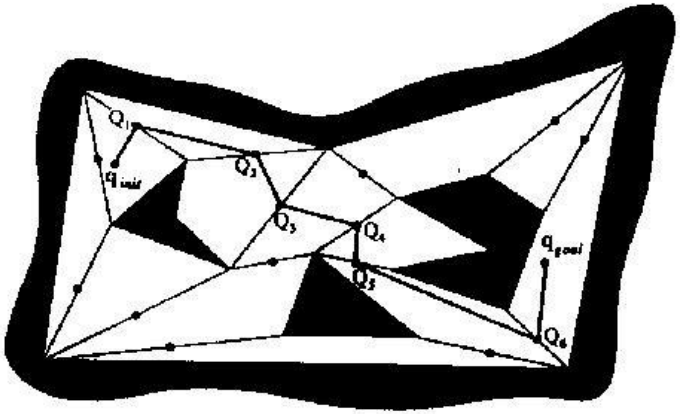

$\rho(q_1)$
q_1
X_1
E_1
$\rho(q_2)$
γ
β
q_2


q_{init}
q_{goal}
C_{free}

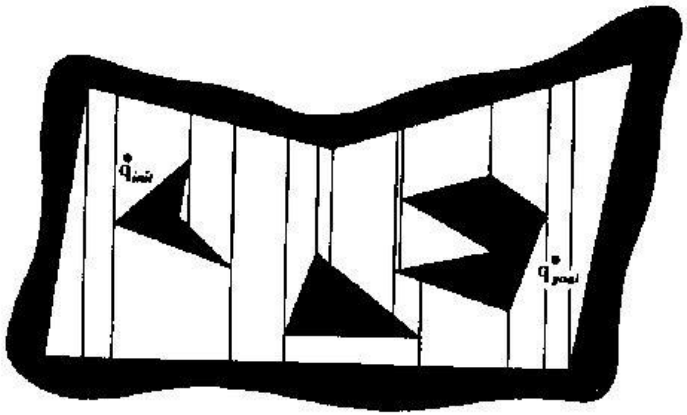
(a)


1
2
3
4
5
6
7
8
9
10
11
12
13
q_{init}
q_{goal}

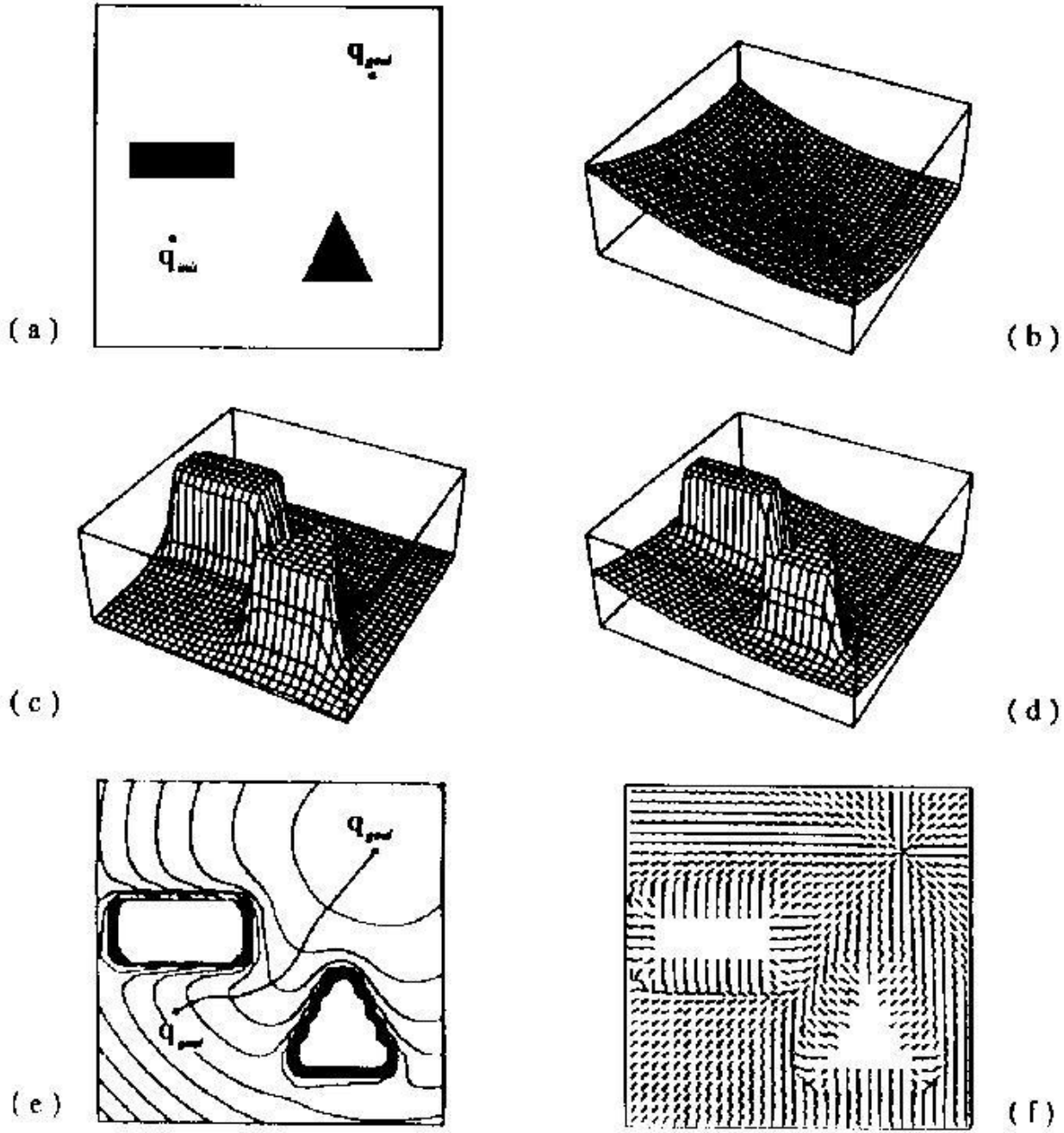
(b)


Q_1
Q_2
Q_3
Q_4
Q_5
Q_6
q_{init}
q_{goal}

(c)


q_{init}
q_{goal}

(d)


(a)
(b)
(c)
(d)
(e)
(f)