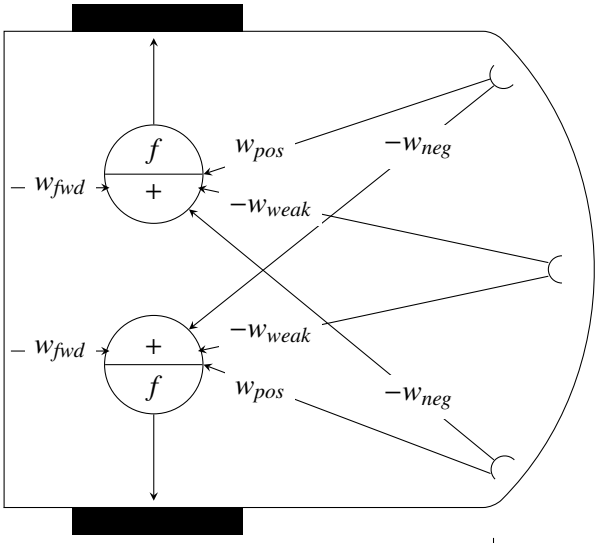
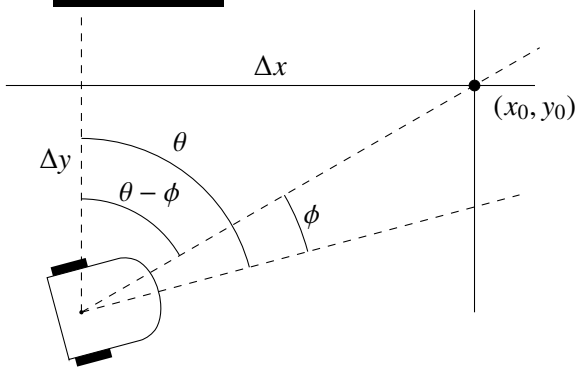
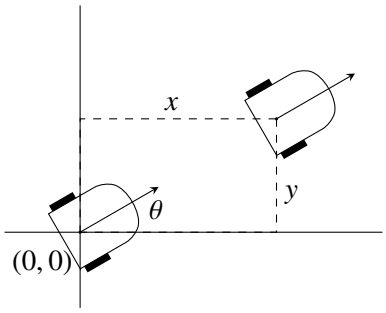
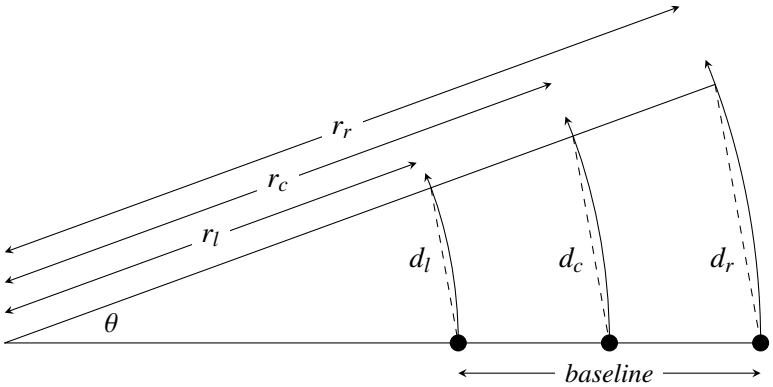
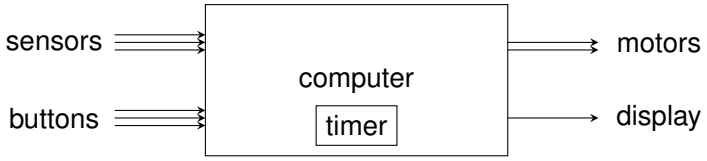
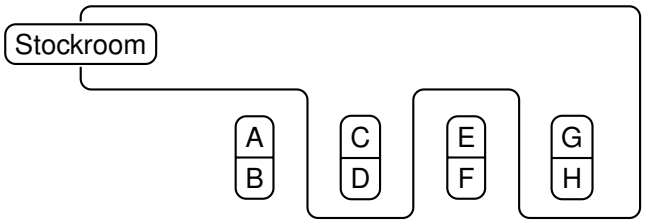

f
+
w_{pos}
$-w_{neg}$
$-w_{fwd}$
$-w_{weak}$
$-w_{weak}$
$-w_{fwd}$
+
f
w_{pos}
$-w_{neg}$

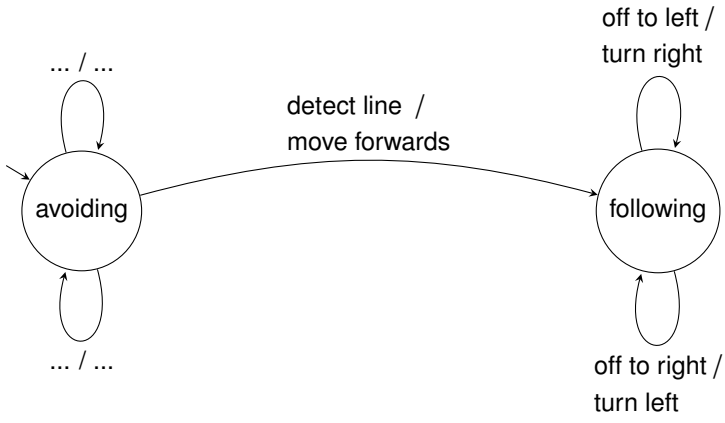

Δx
(x_0, y_0)
Δy
θ
$\theta - \phi$
ϕ

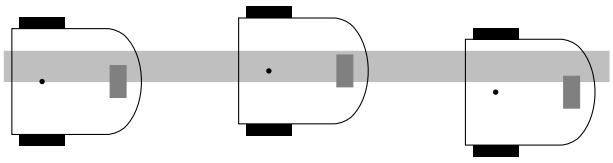

x
y
θ
$(0, 0)$

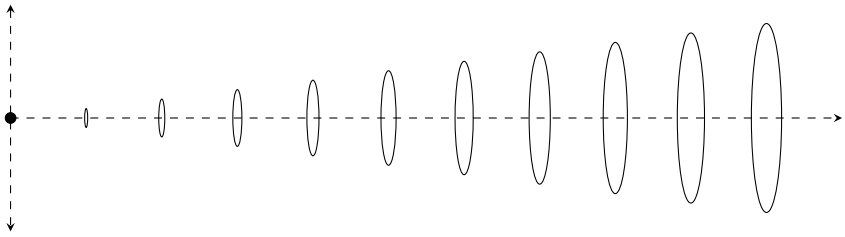

r_r
r_c
r_l
d_l
d_c
d_r
θ
baseline

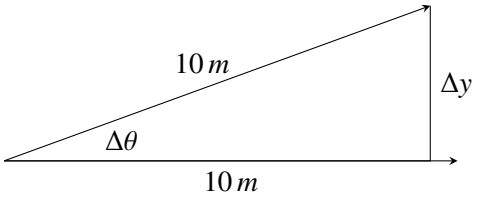

sensors
buttons
computer
timer
motors
display

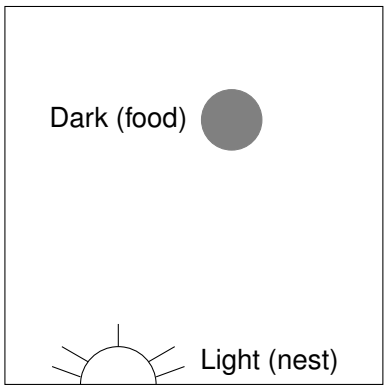

Stockroom
A
B
C
D
E
F
G
H

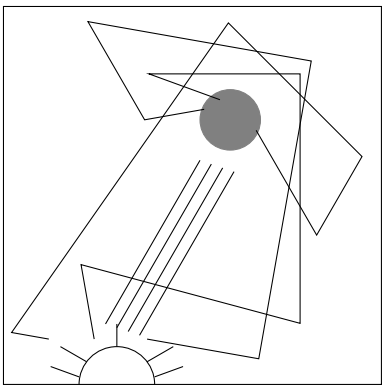

... / ...
detect line /
move forwards
off to left /
turn right
avoiding
following
... / ...
off to right /
turn left

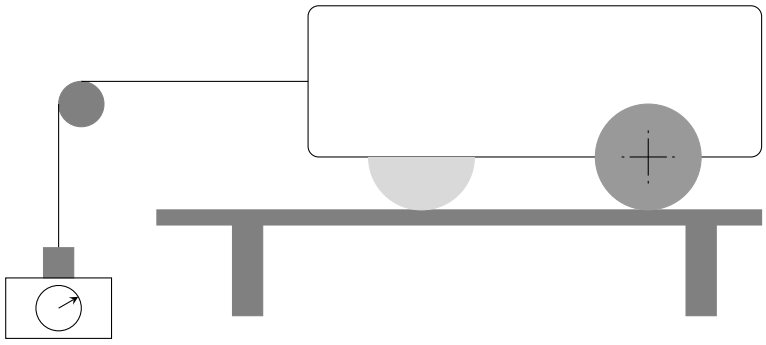


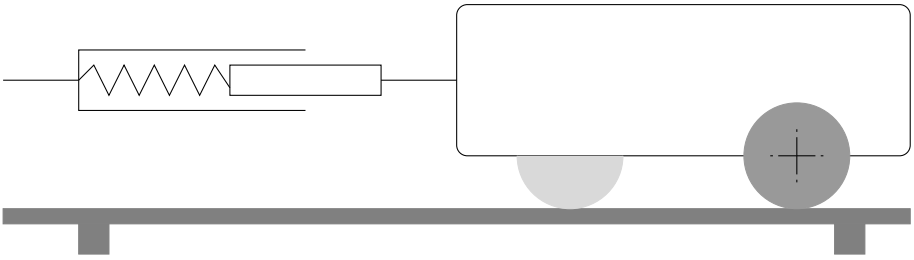


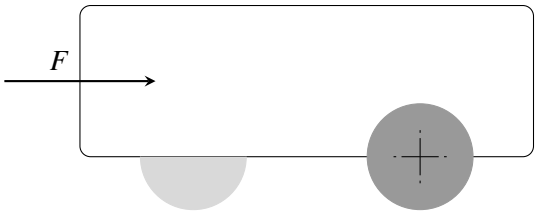

10 m
Δy
Δθ
10 m

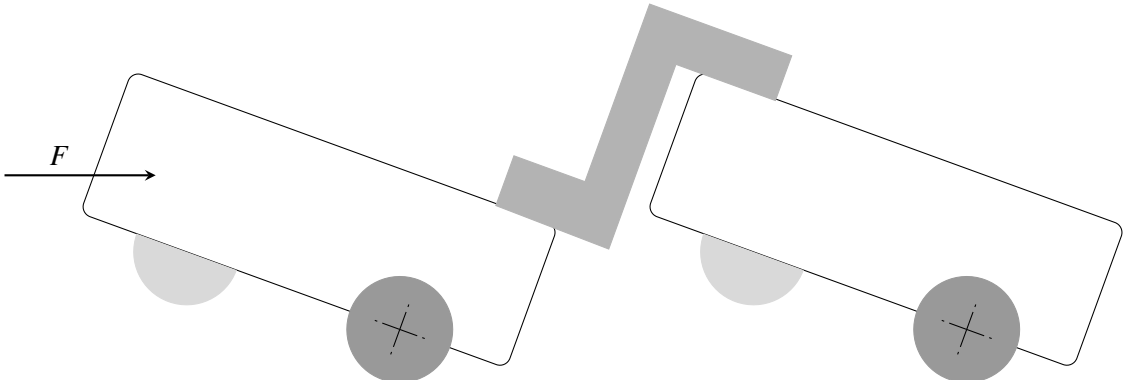

Dark (food)
Light (nest)

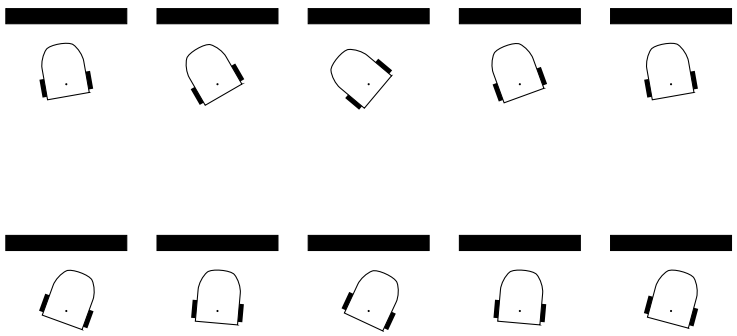


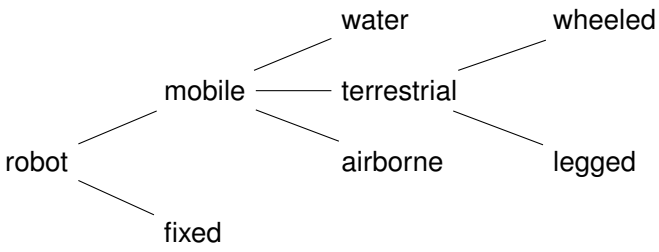


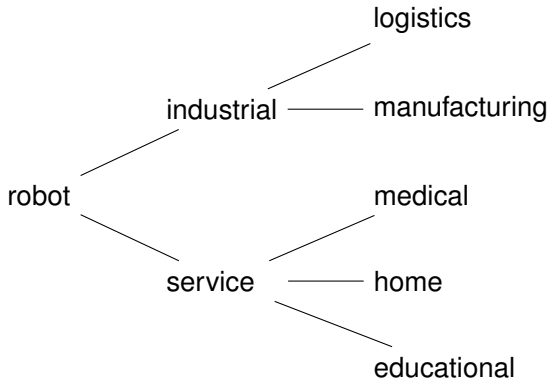


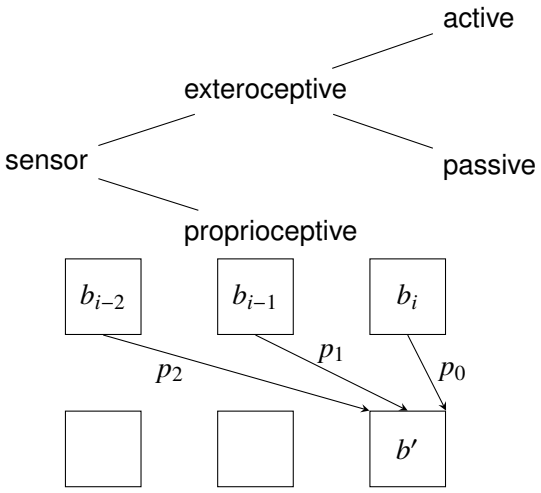

F

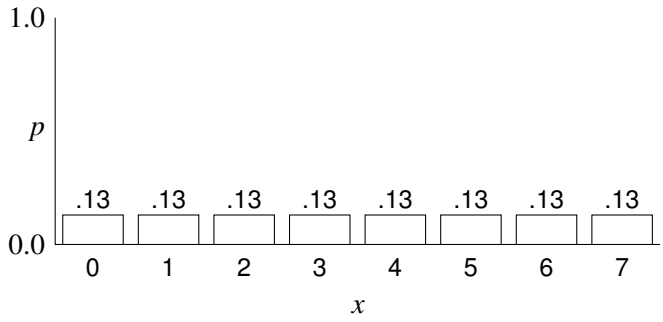

F

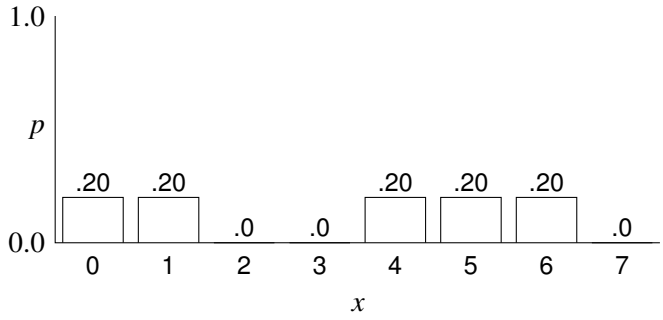


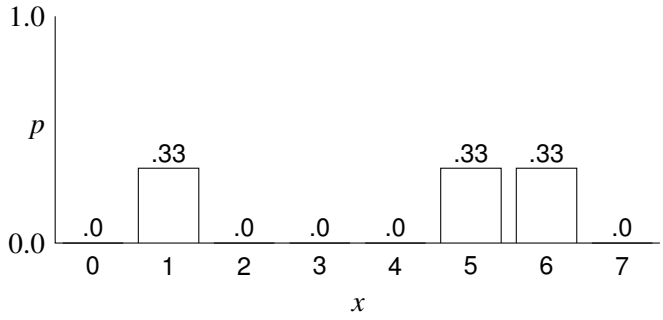

water
wheeled
mobile
terrestrial
robot
airborne
legged
fixed

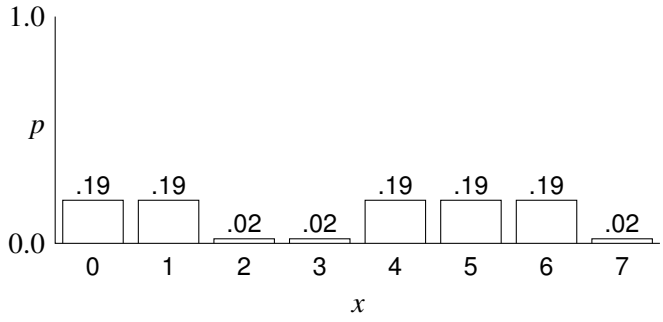

logistics
industrial
manufacturing
robot
medical
service
home
educational

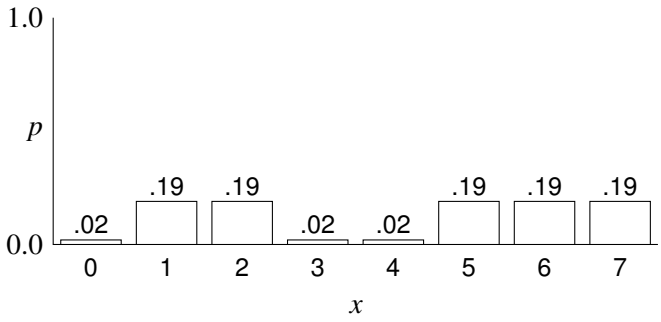

active
exteroceptive
sensor
passive
proprioceptive
b_{i-2}
b_{i-1}
b_i
p_1
p_2
p_0
b'

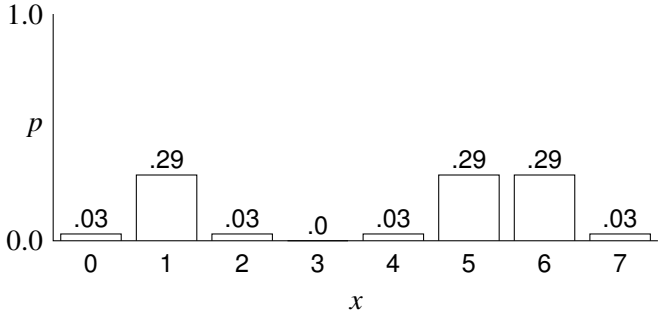

1.0
p
0.0
.13 .13 .13 .13 .13 .13 .13 .13
0 1 2 3 4 5 6 7
x

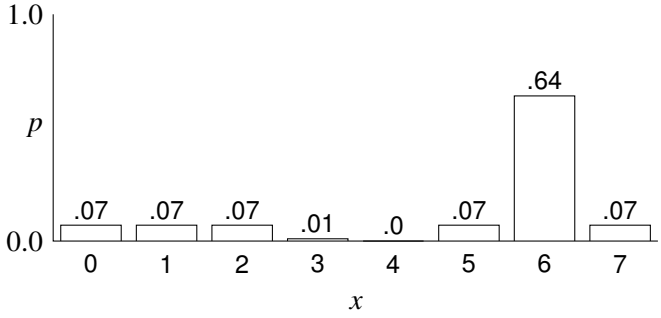

1.0
p
0.0
.20 .20 .0 .0 .20 .20 .20 .0
0 1 2 3 4 5 6 7
x

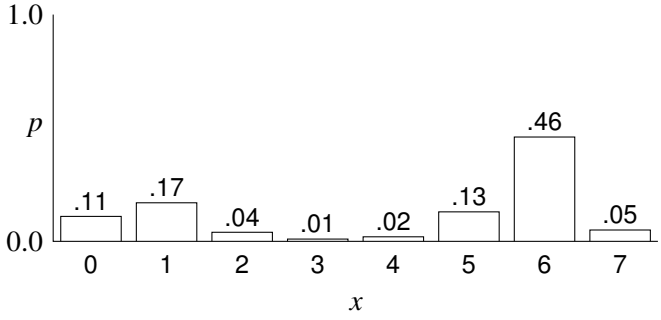

1.0
p
0.0
.0 .33 .0 .0 .0 .33 .33 .0
0 1 2 3 4 5 6 7
x

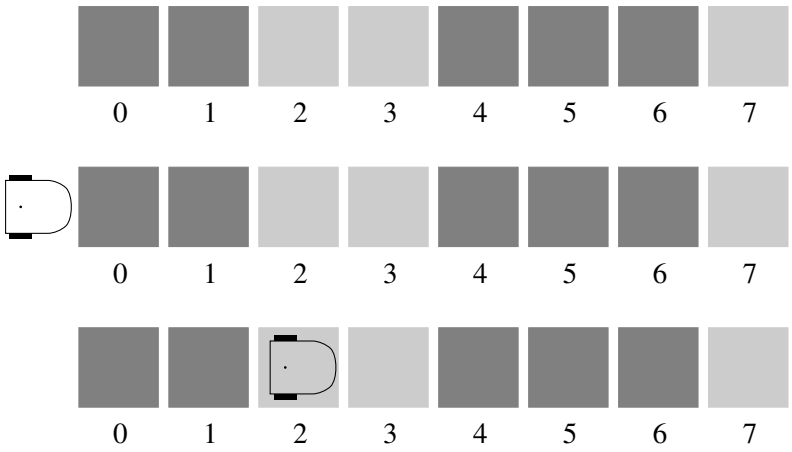

1.0
p
0.0
.19 .19 .02 .02 .19 .19 .19 .02
0 1 2 3 4 5 6 7
x

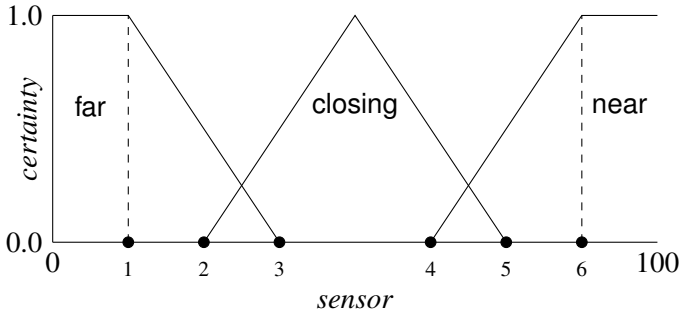

1.0
p
0.0
.02
.19
.19
.02
.02
.19
.19
.19
0
1
2
3
4
5
6
7
x

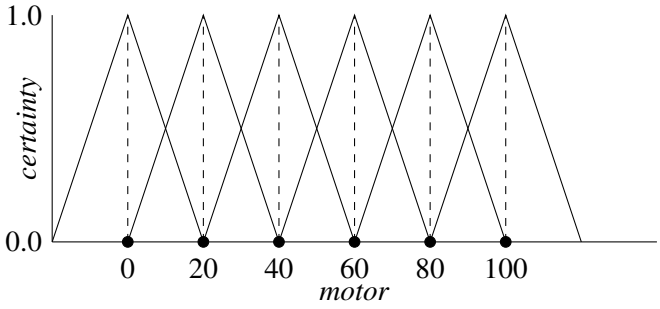

1.0
p
0.0
.03
.29
.03
.0
.03
.29
.29
.03
0
1
2
3
4
5
6
7
x

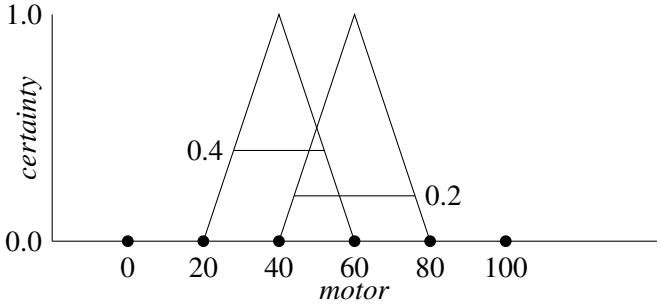

1.0
p
0.0
.07
.07
.07
.01
.0
.07
.64
.07
0
1
2
3
4
5
6
7
x

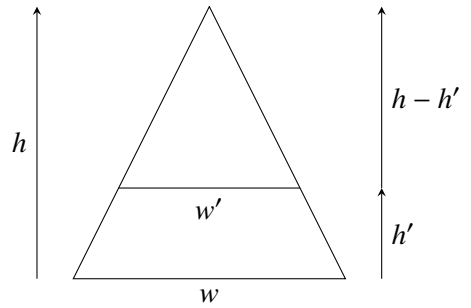

1.0
p
0.0
.11
.17
.04
.01
.02
.13
.46
.05
0
1
2
3
4
5
6
7
x

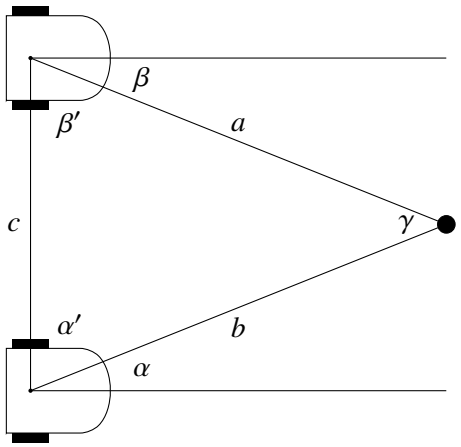

0 1 2 3 4 5 6 7
0 1 2 3 4 5 6 7
0 1 2 3 4 5 6 7

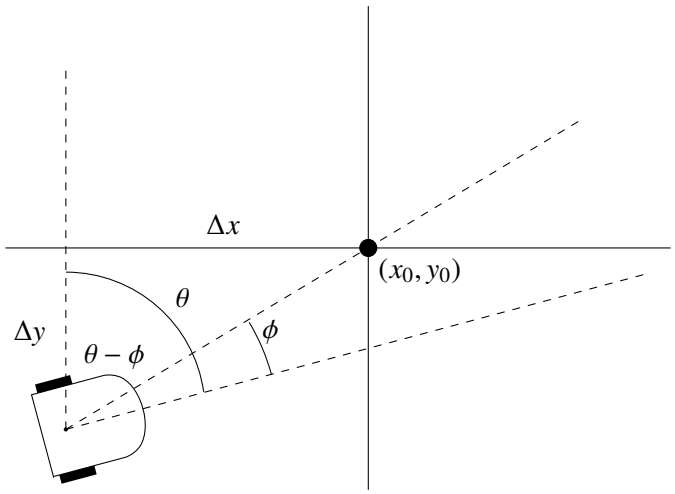

1.0
certainty
0.0
far
closing
near
0
1
2
3
4
5
6
100
sensor

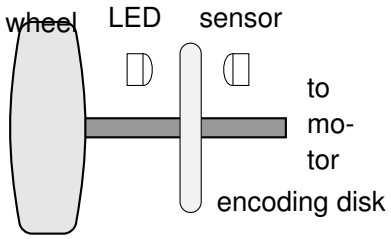

1.0
certainty
0.0
0
20
40
60
80
100
motor

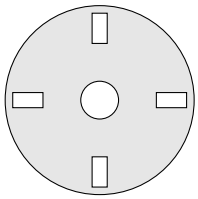

1.0
certainty
0.4
0.2
0.0
0
20
40
60
80
100
motor

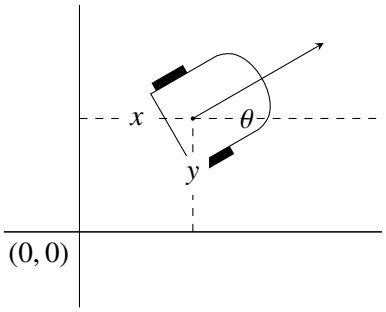

h
h − h′
w′
h′
w

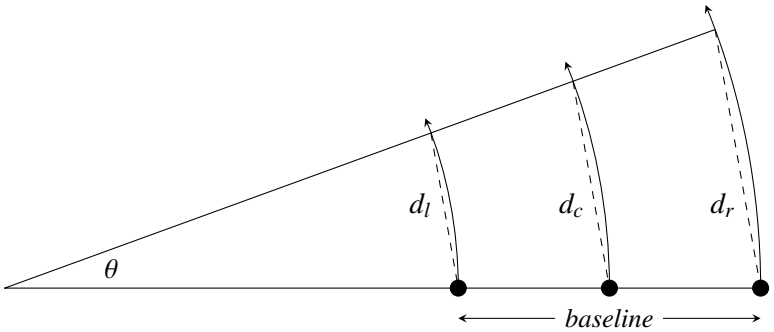

β
β′
a
c
γ
α′
b
α

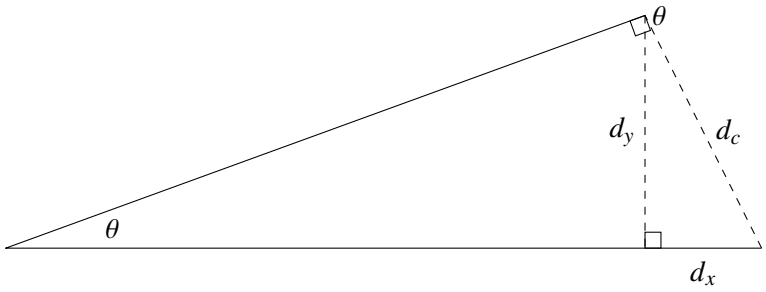

Δx
(x0, y0)
θ
Δy
θ − ϕ
ϕ

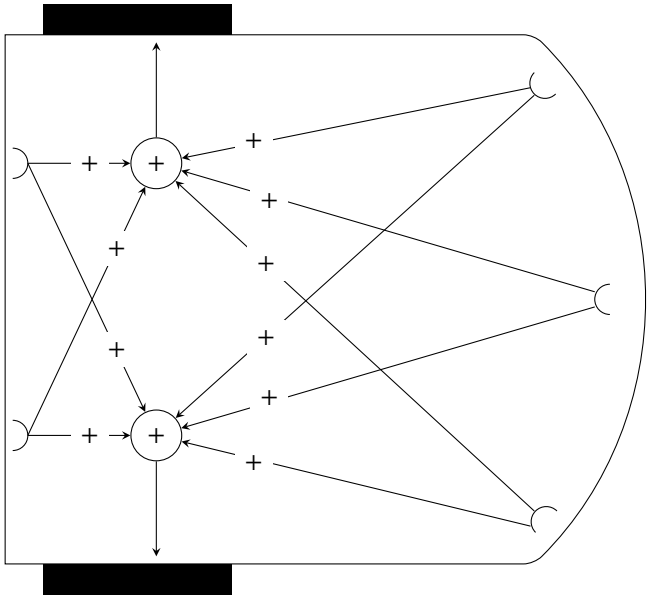

wheel
LED
sensor
to
mo-
tor
encoding disk

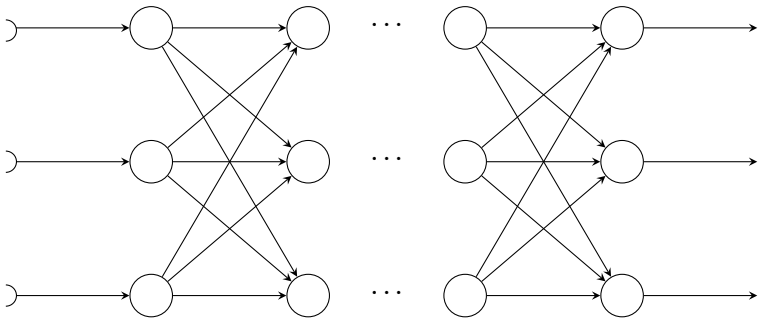


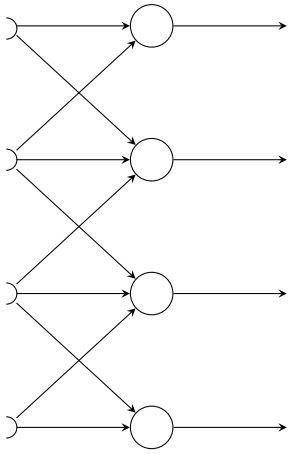

x
θ
y
(0, 0)

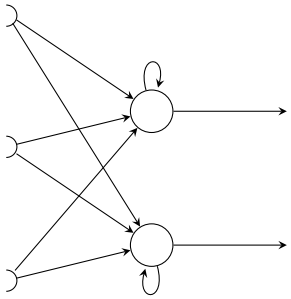

θ
d_l
d_c
d_r
baseline

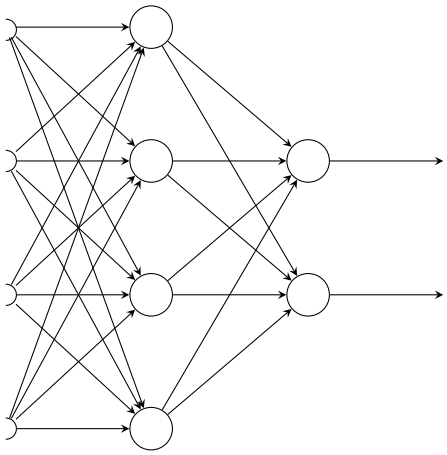

θ
d_y
d_c
θ
d_x

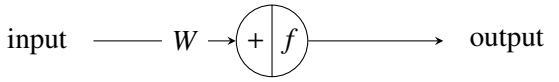


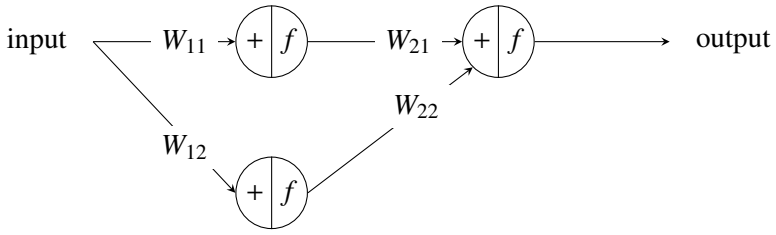


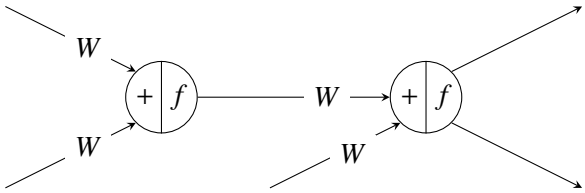




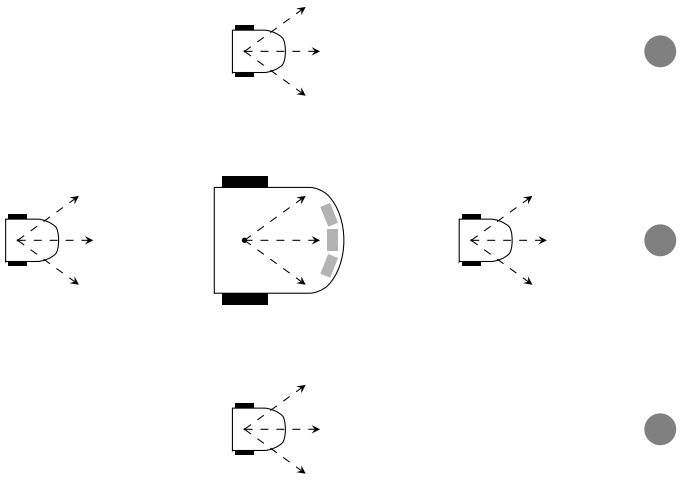


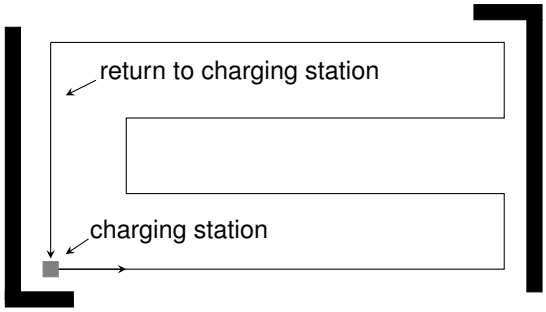


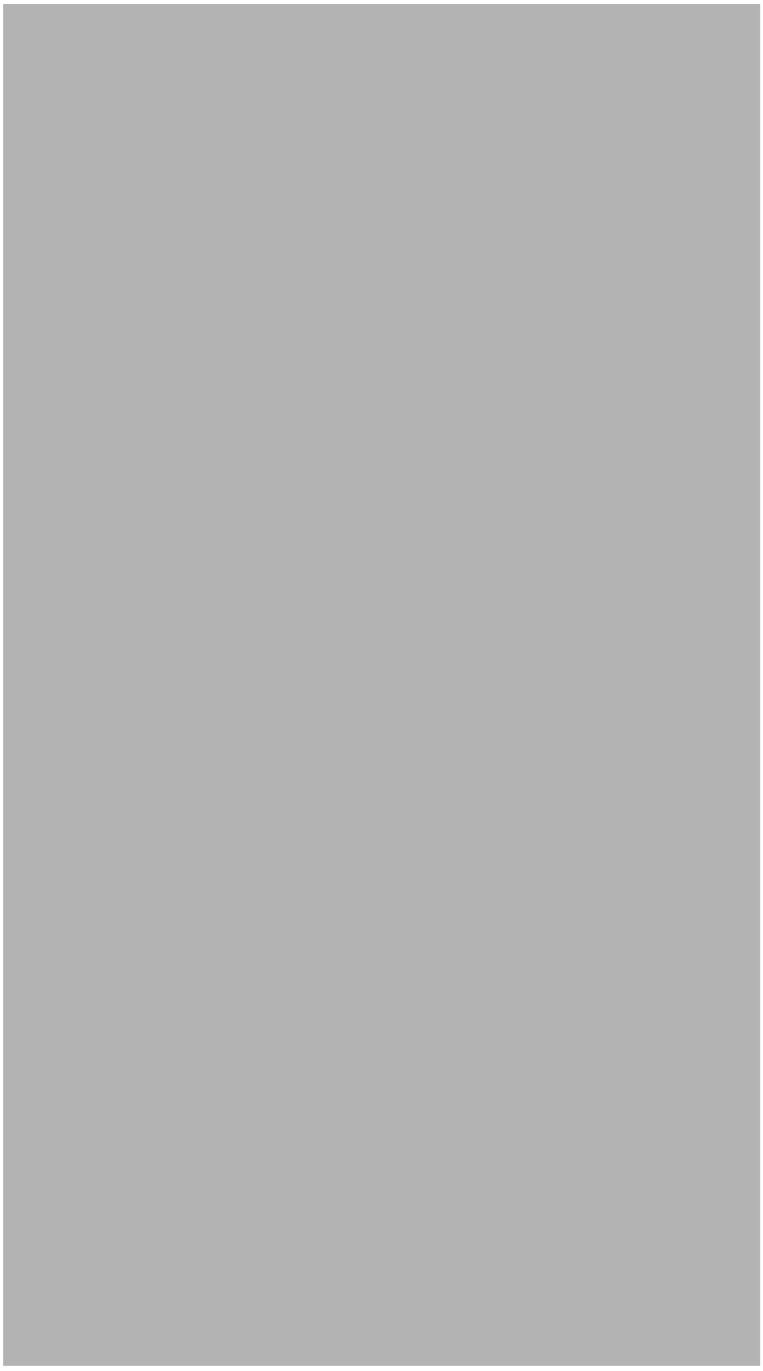


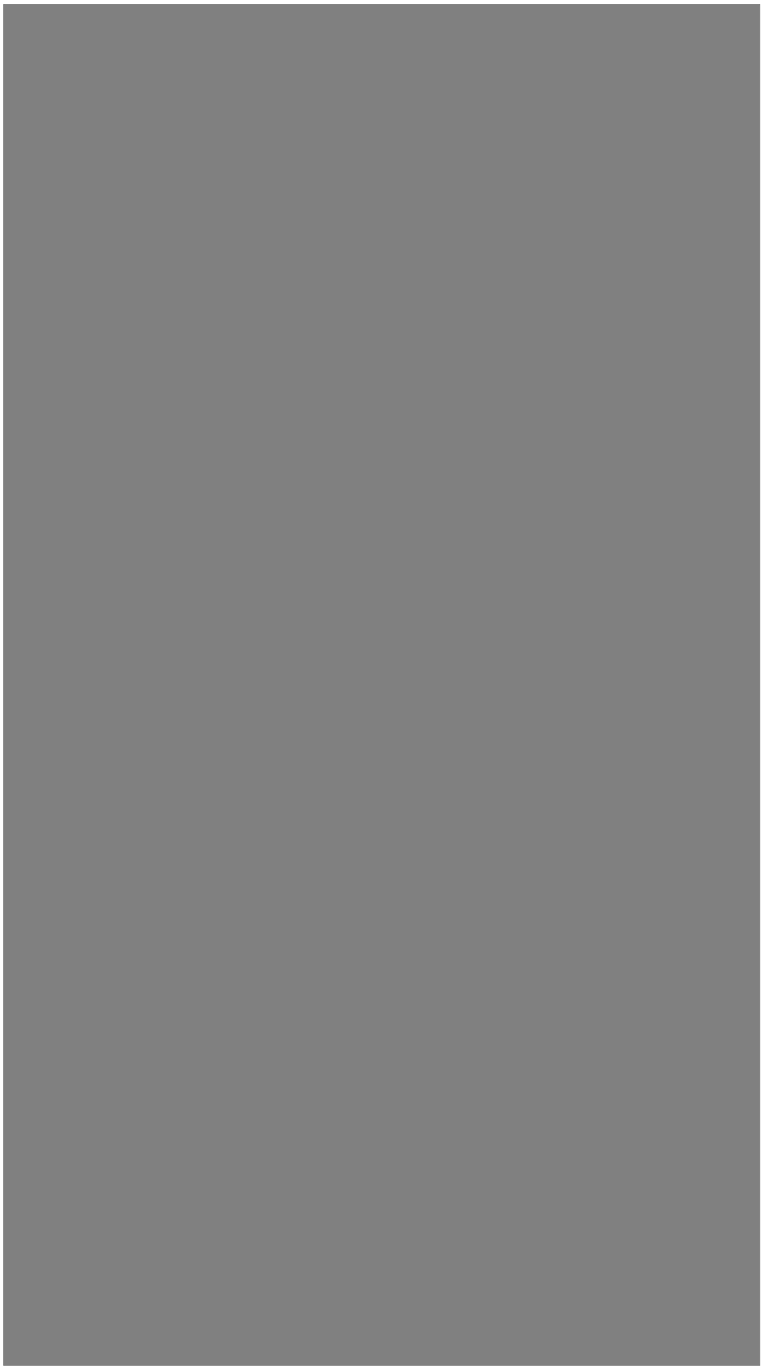


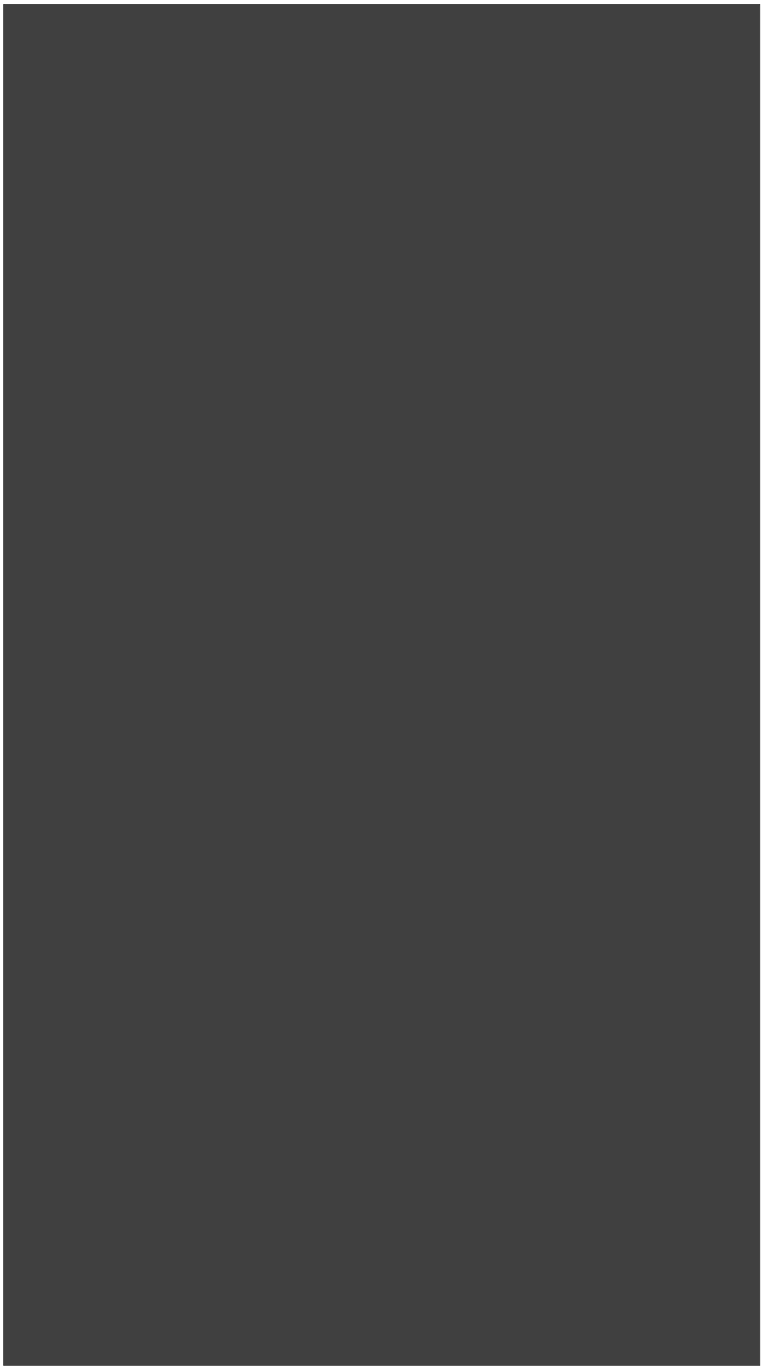
W = connection weight
$+$ = sum of inputs
f = output function

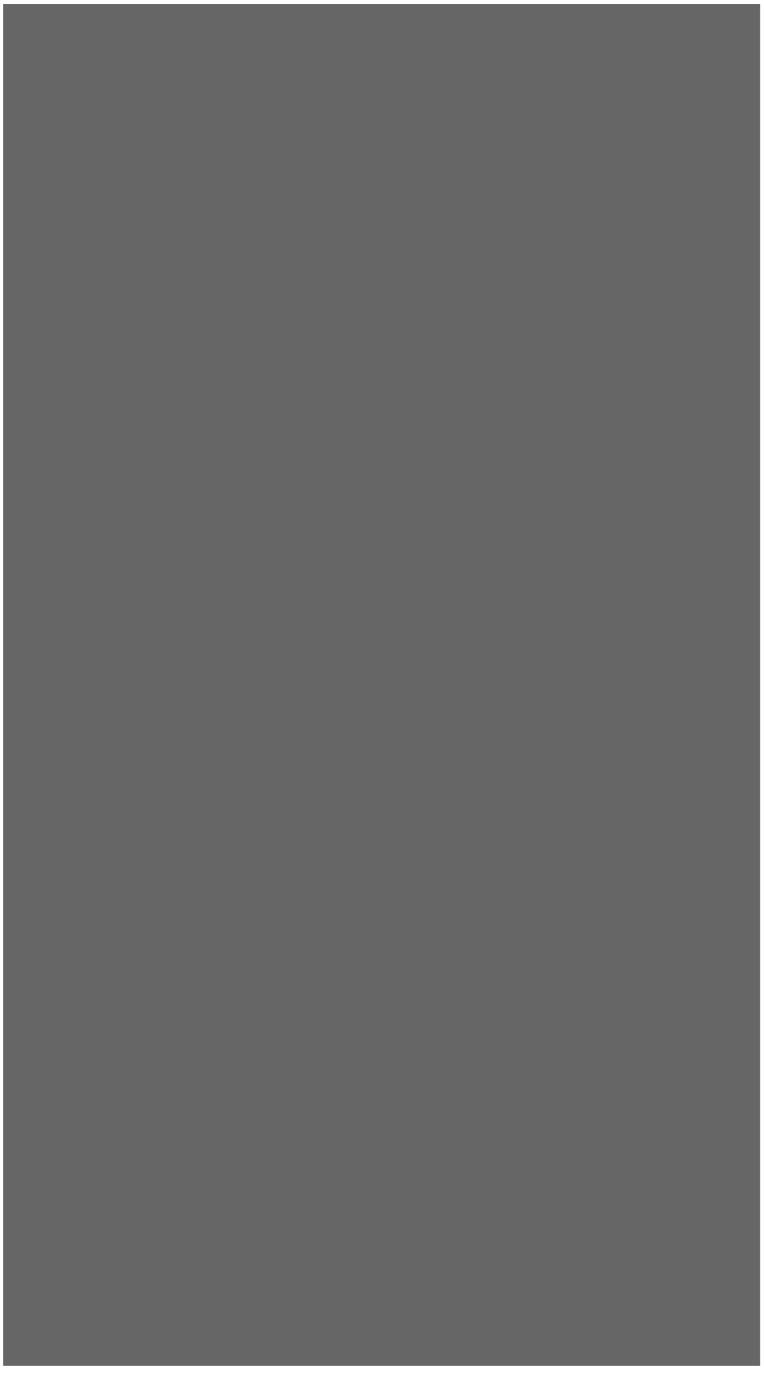


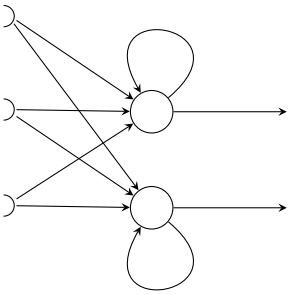

return to charging station
charging station

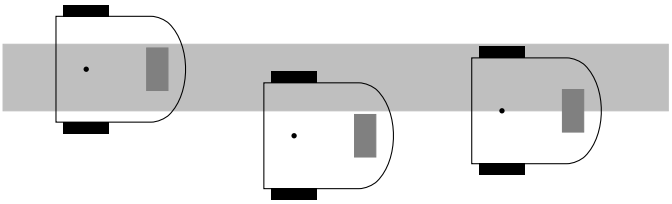


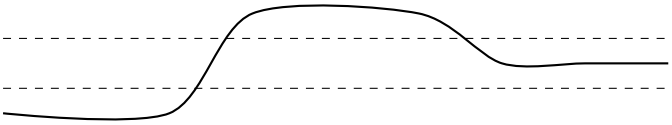


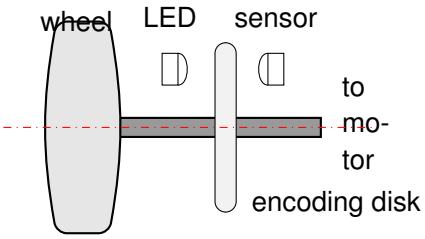


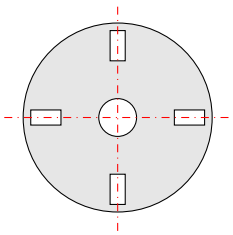


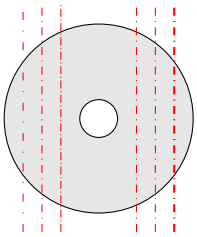


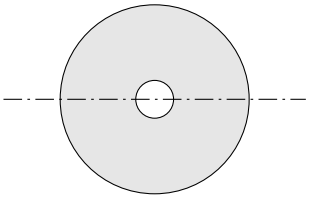


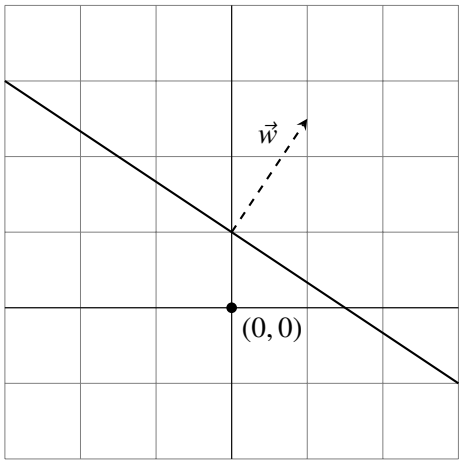


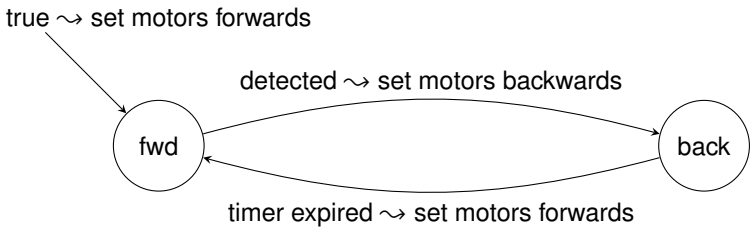

wheel
LED
sensor
to
mo-
tor
encoding disk



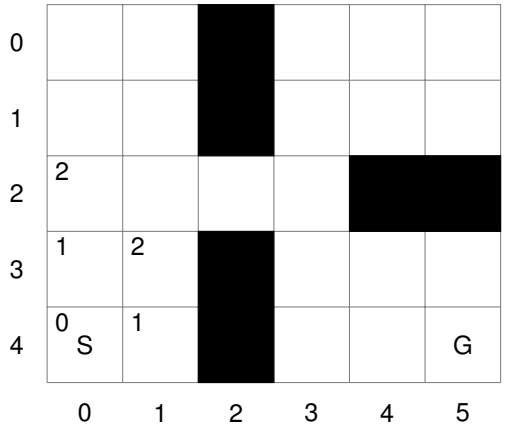


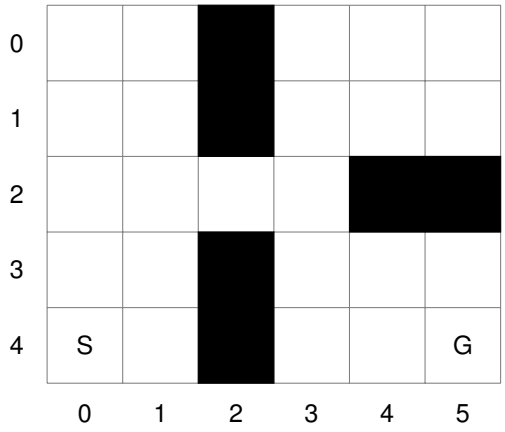


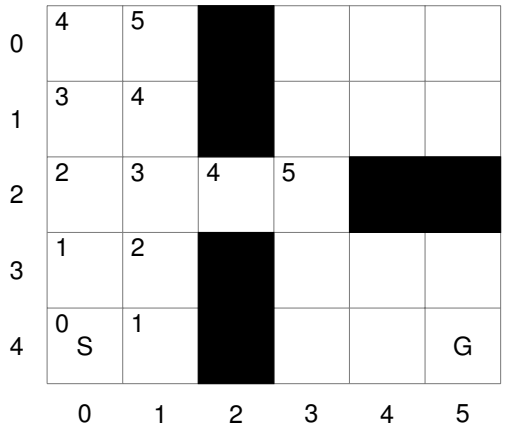


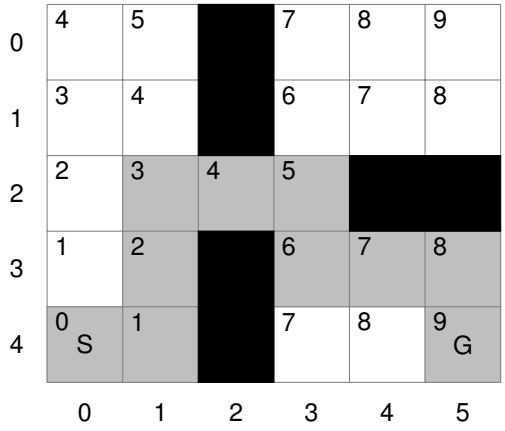


fwd = robot is moving forwards
back=robot is moving backwards

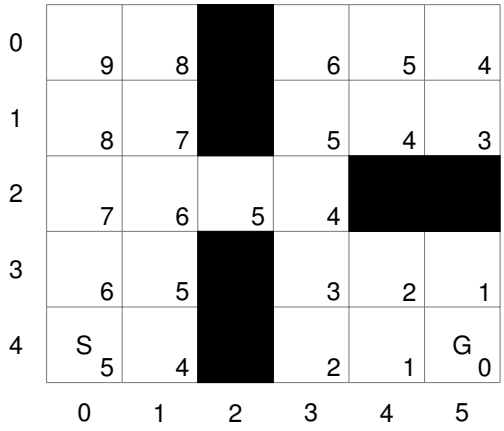

0
1
2
3
4
2
1
2
0
S
1
G
0
1
2
3
4
5

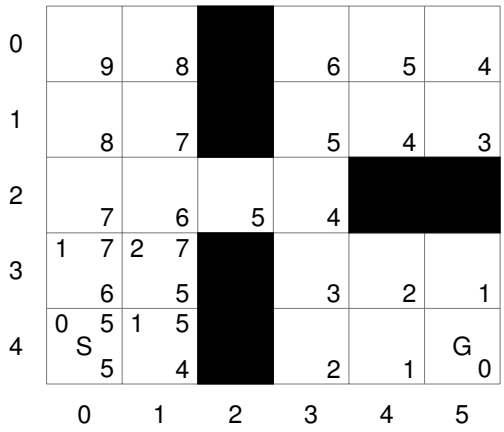

0
1
2
3
4
S
G
0
1
2
3
4
5

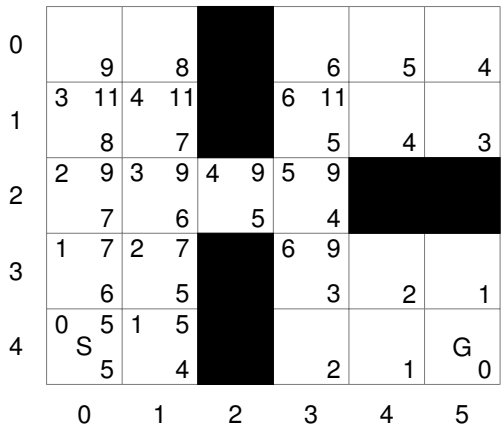

0
1
2
3
4
4 5
3 4
2 3 4 5
1 2
0 S 1
G
0 1 2 3 4 5

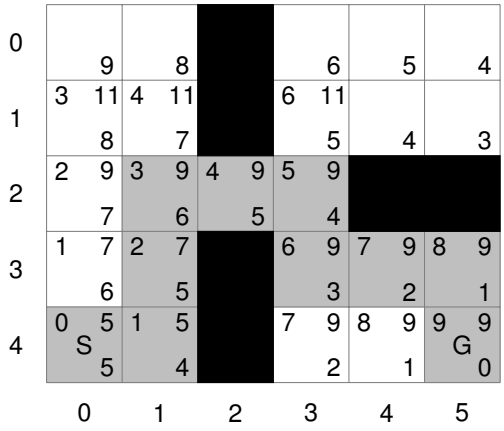

0
1
2
3
4
4 5 7 8 9
3 4 6 7 8
2 3 4 5
1 2 6 7 8
0 S 1 7 8 9 G
0 1 2 3 4 5

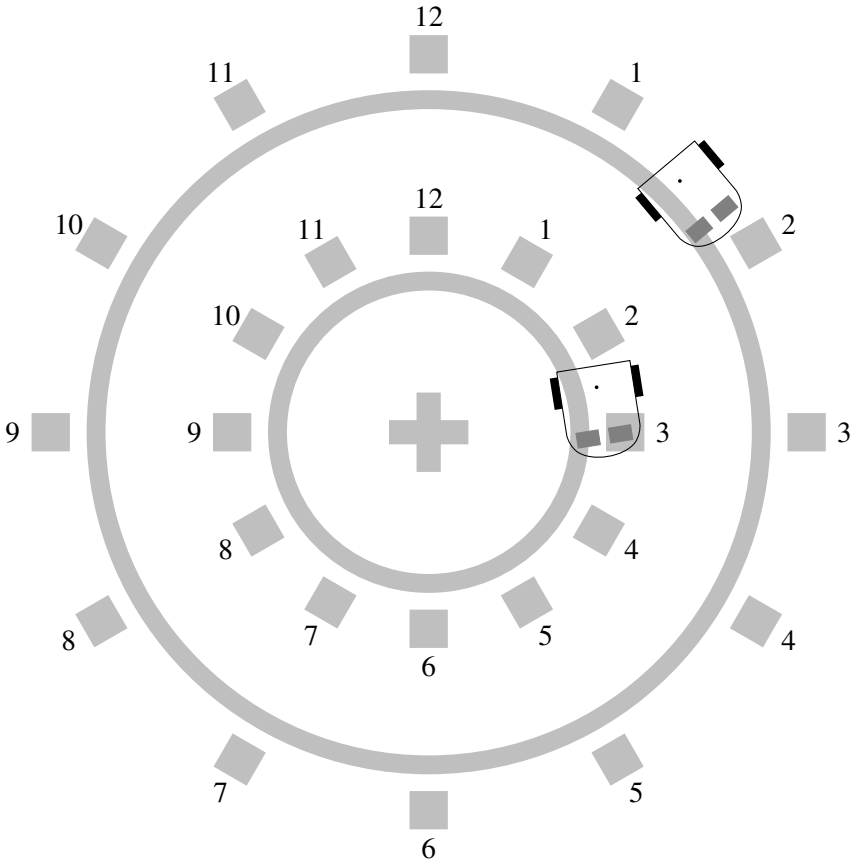
g	f
	h

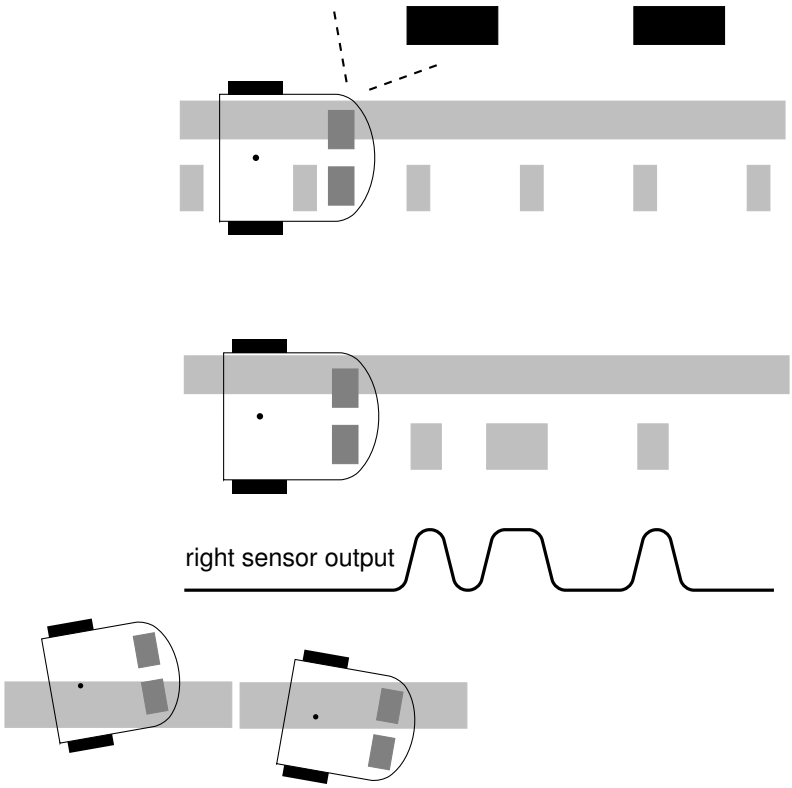

0
1
2
3
4
9 8 6 5 4
8 7 5 4 3
7 6 5 4
6 5 3 2 1
S 5 4 2 1 G 0
0 1 2 3 4 5

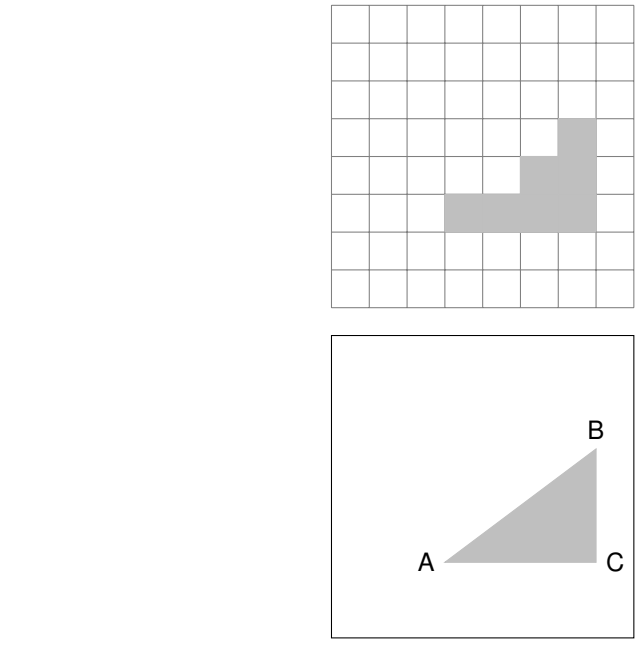

0
1
2
3
4
9 8 6 5 4
8 7 5 4 3
7 6 5 4
1 7 6 2 7 5 3 2 1
0 S 5 5 1 5 4 2 1 G 0
0 1 2 3 4 5

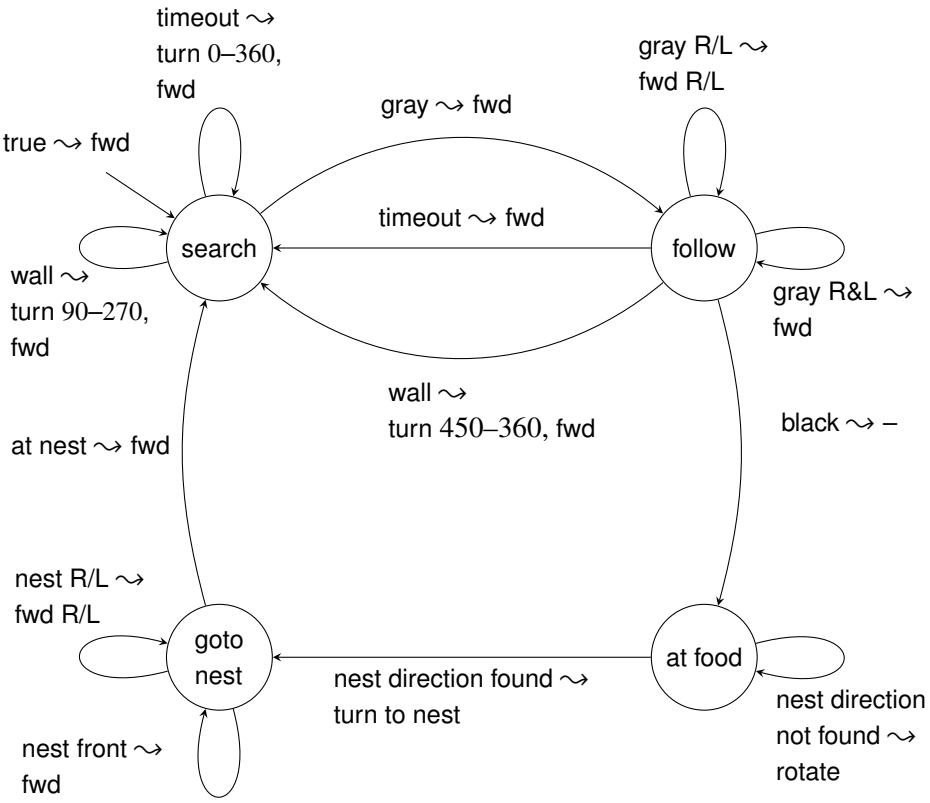

0
1
2
3
4
9 8 6 5 4
3 11 8 4 11 7 6 11 5 4 3
2 9 7 3 9 6 4 9 5 5 9 4
1 7 6 2 7 5 6 9 3 2 1
0 S 5 5 1 5 4 2 1 G 0
0 1 2 3 4 5

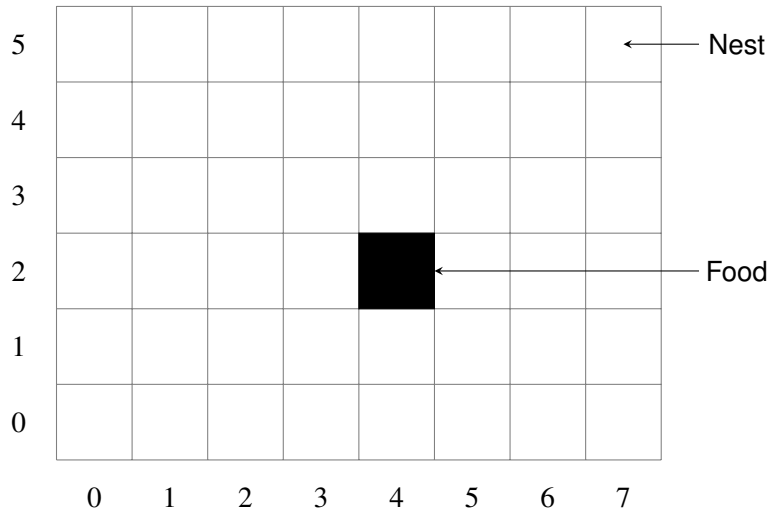

0
1
2
3
4
0 1 2 3 4 5
S
G

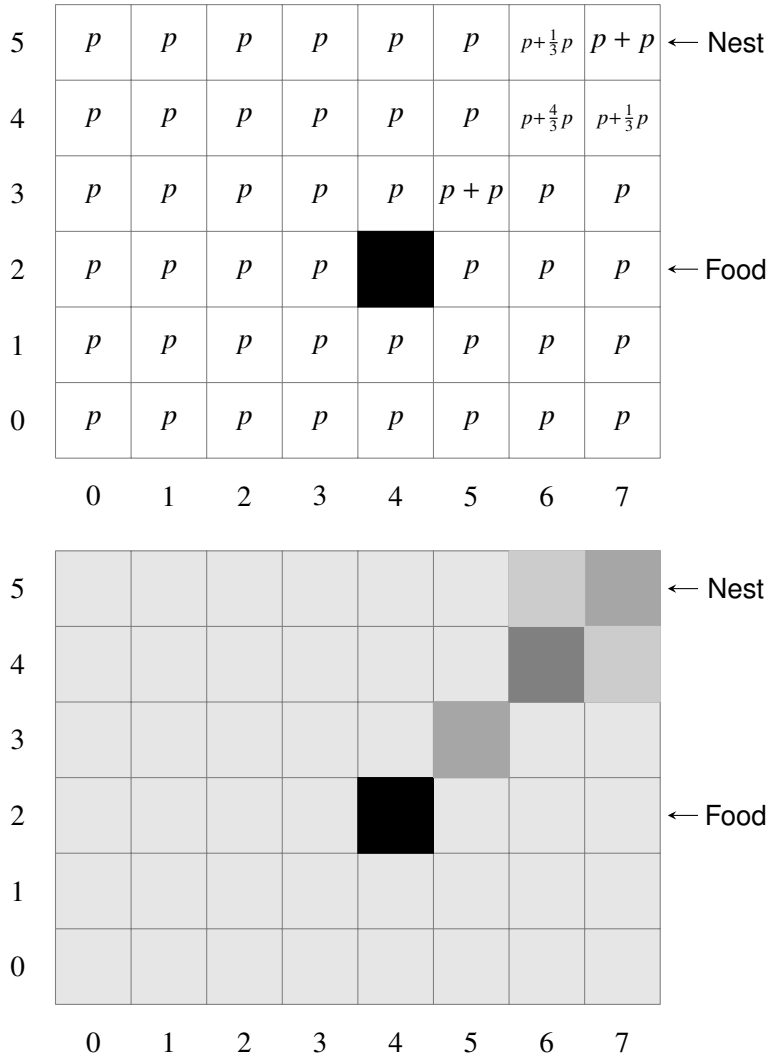

12
1
2
3
4
5
6
7
8
9
10
11

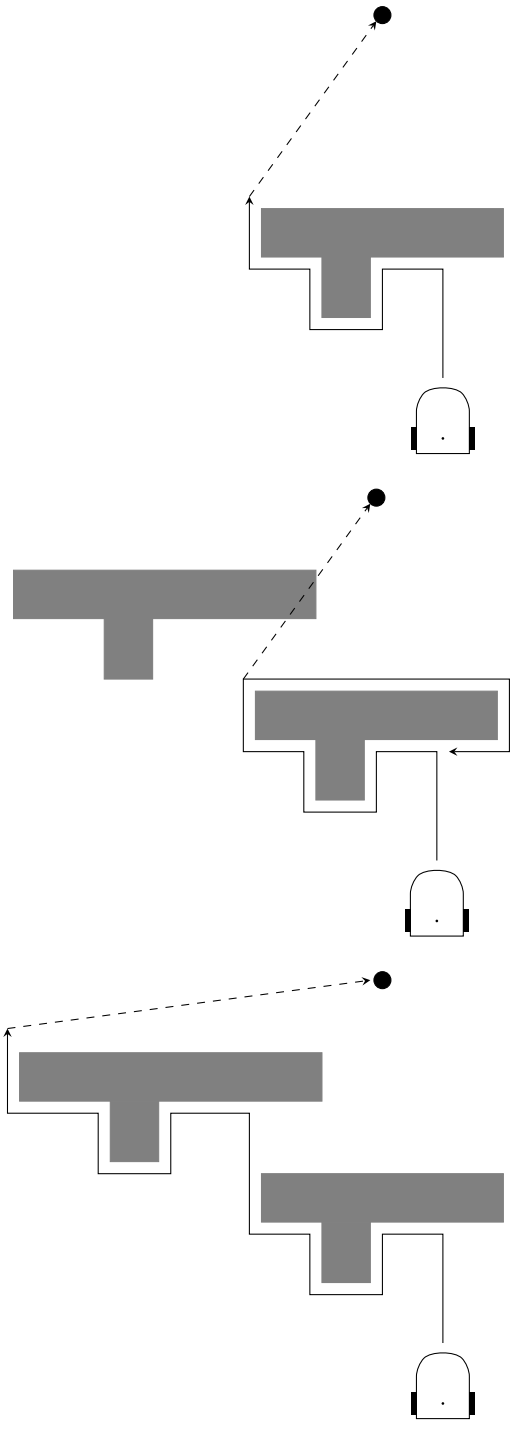

right sensor output

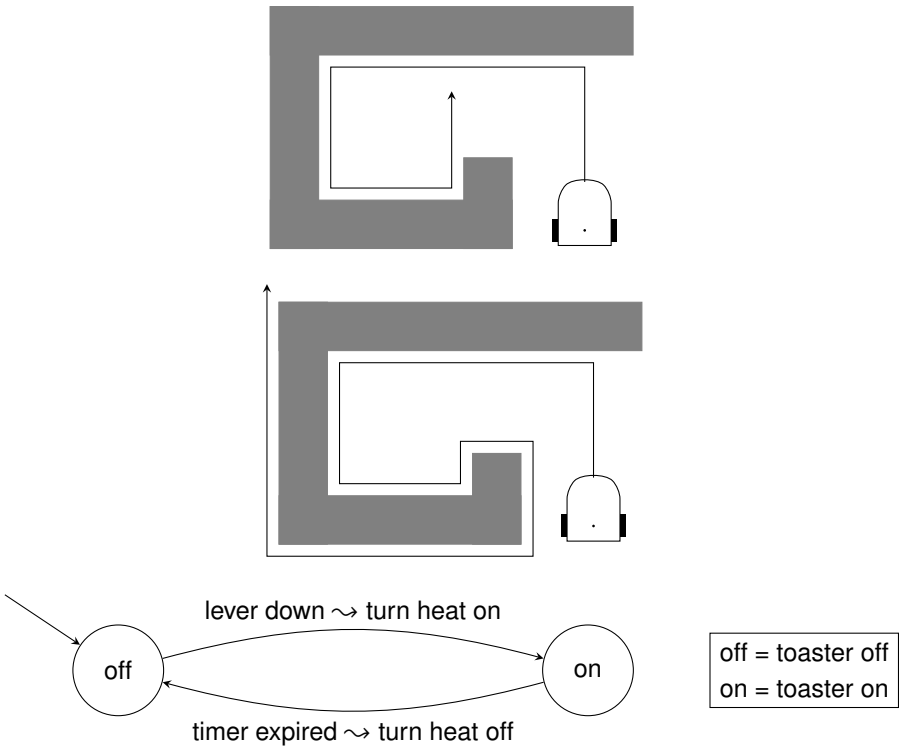

B
A
C

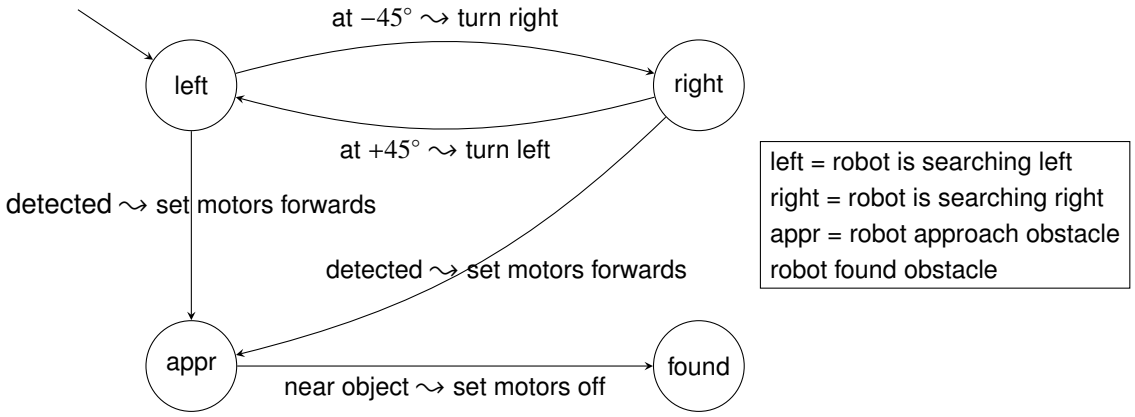

timeout ⇝
turn 0–360,
fwd
gray R/L ⇝
fwd R/L
gray ⇝ fwd
true ⇝ fwd
timeout ⇝ fwd
search
follow
wall ⇝
turn 90–270,
fwd
gray R&L ⇝
fwd
wall ⇝
turn 450–360, fwd
black ⇝ –
at nest ⇝ fwd
nest R/L ⇝
fwd R/L
goto
nest
at food
nest direction found ⇝
turn to nest
nest direction
not found ⇝
rotate
nest front ⇝
fwd

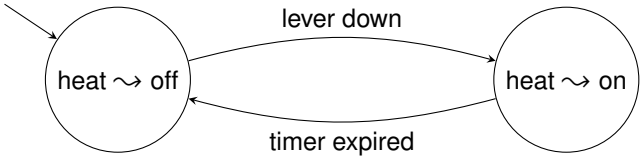

5
4
3
2
1
0
Nest
Food
0
1
2
3
4
5
6
7

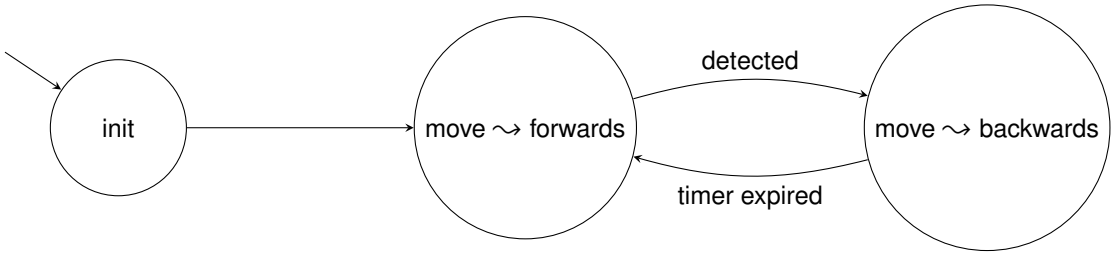

5 p p p p p p p+1/3 p p + p ← Nest
4 p p p p p p p+4/3 p p+1/3 p
3 p p p p p p + p p p
2 p p p p p p p ← Food
1 p p p p p p p p
0 p p p p p p p p
0 1 2 3 4 5 6 7
5 ← Nest
4
3
2 ← Food
1
0
0 1 2 3 4 5 6 7

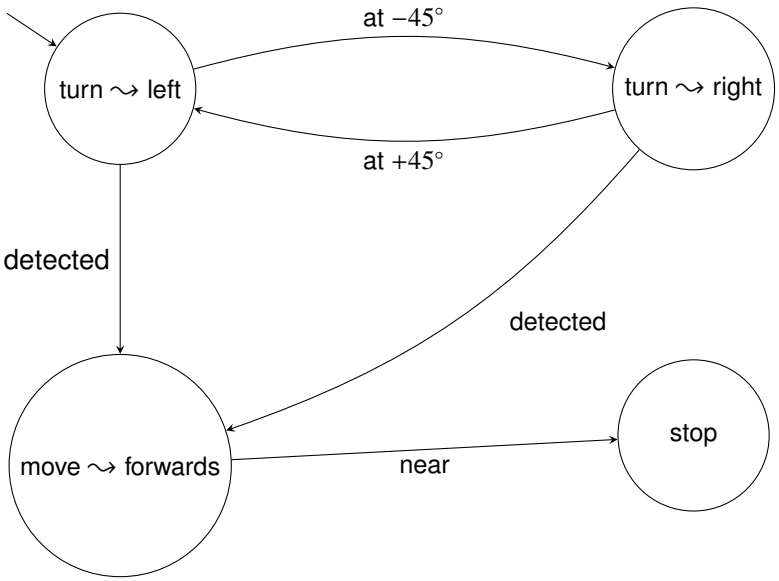


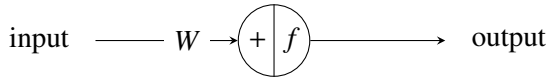

lever down ⇝ turn heat on
off
on
timer expired ⇝ turn heat off
off = toaster off
on = toaster on
init
true ⇝ set motors forwards
detected ⇝ set motors backwards
fwd
back
timer expired ⇝ set motors forwards
init = initial state
fwd = robot is moving forwards
back=robot is moving backwards

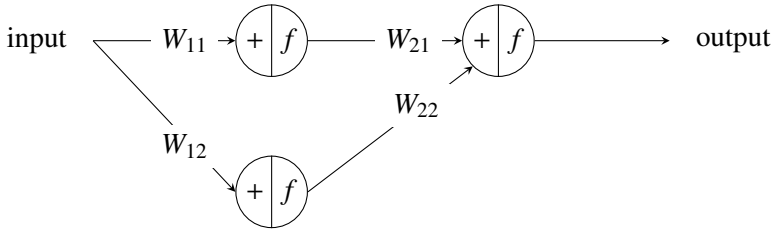

at −45° ⇝ turn right
left
right
at +45° ⇝ turn left
detected ⇝ set motors forwards
detected ⇝ set motors forwards
appr
found
near object ⇝ set motors off
left = robot is searching left
right = robot is searching right
appr = robot approach obstacle
robot found obstacle

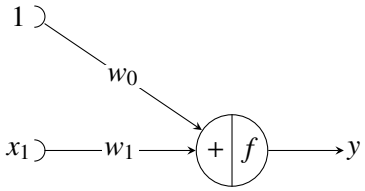

lever down
heat ⇝ off
heat ⇝ on
timer expired

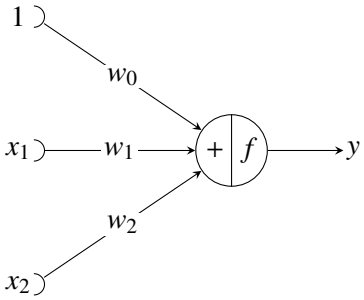

detected
init
move ⇝ forwards
move ⇝ backwards
timer expired

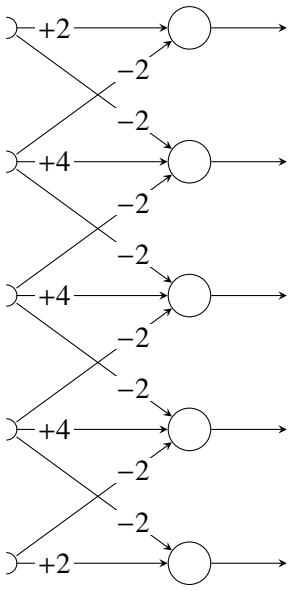

turn ⇝ left
at −45°
turn ⇝ right
at +45°
detected
detected
move ⇝ forwards
near
stop

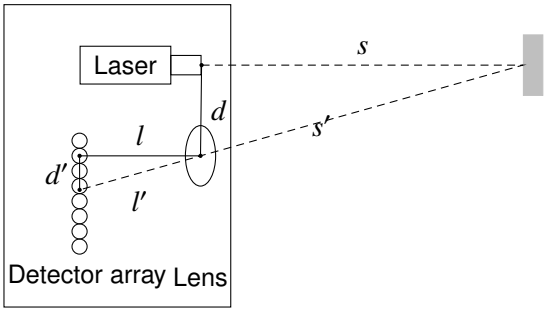

input
W
+
f
output

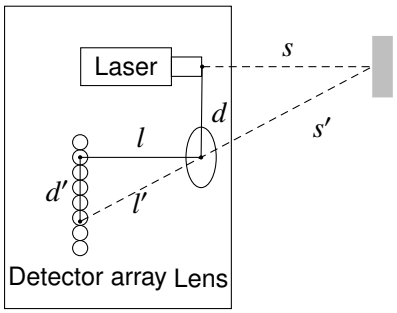

input
W11
W21
W22
W12
output

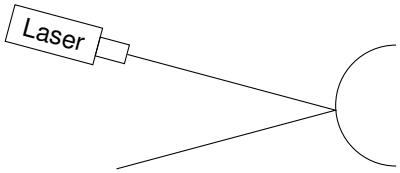

1
w0
x1
w1
y

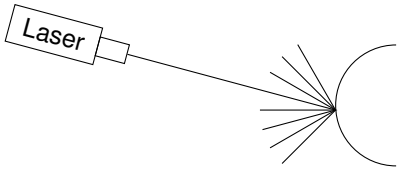

1
w0
x1
w1
y
w2
x2

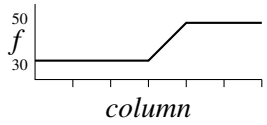

+2
−2
−2
+4
−2
−2
+4
−2
−2
+4
−2
−2
+2

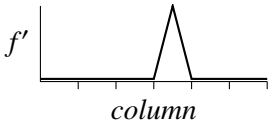

Laser
s
d
s′
l
d′
l′
Detector array
Lens

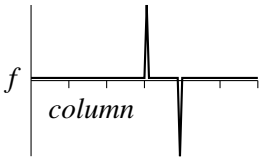

Laser
s
d
s′
l
d′
l′
Detector array
Lens

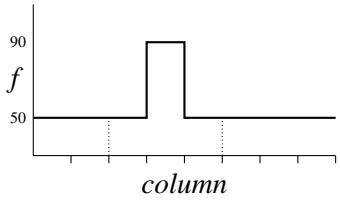

Laser

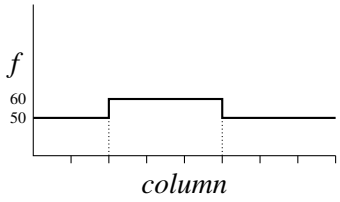

Laser

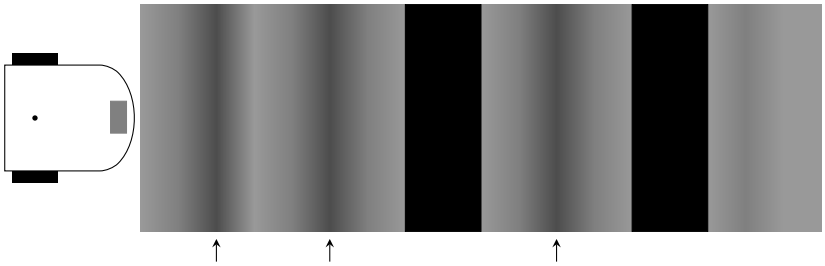

50
f
30
column

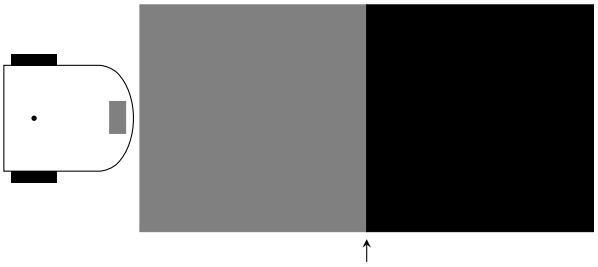

f′
column

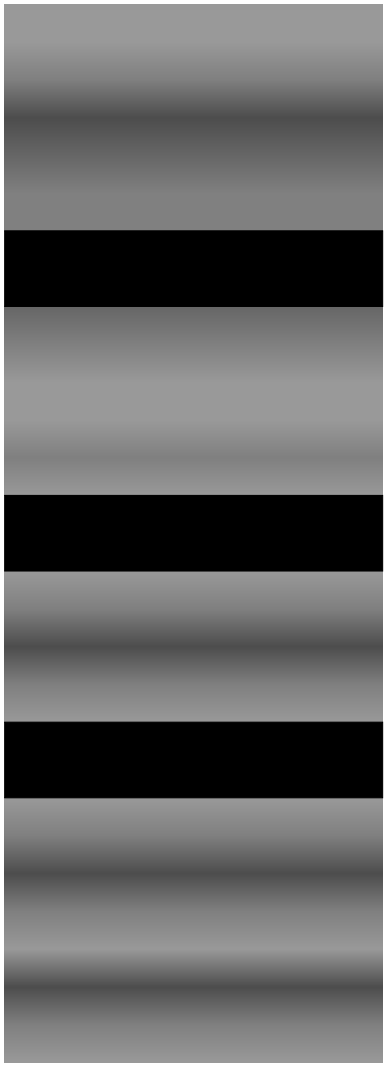

f
column

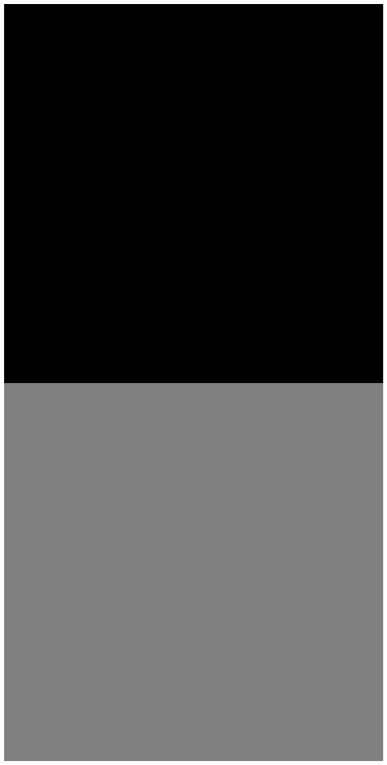

90
f
50
column

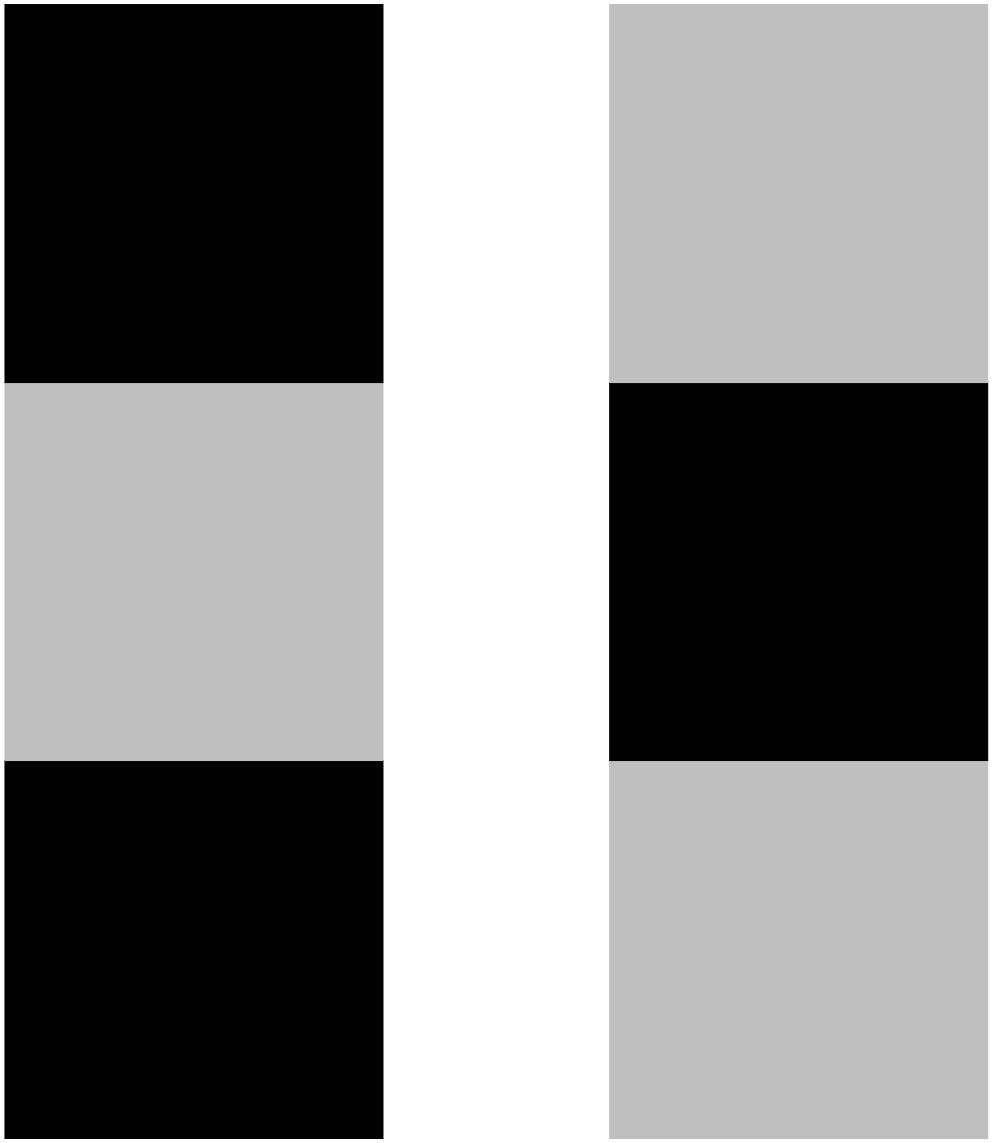

f
60
50
column

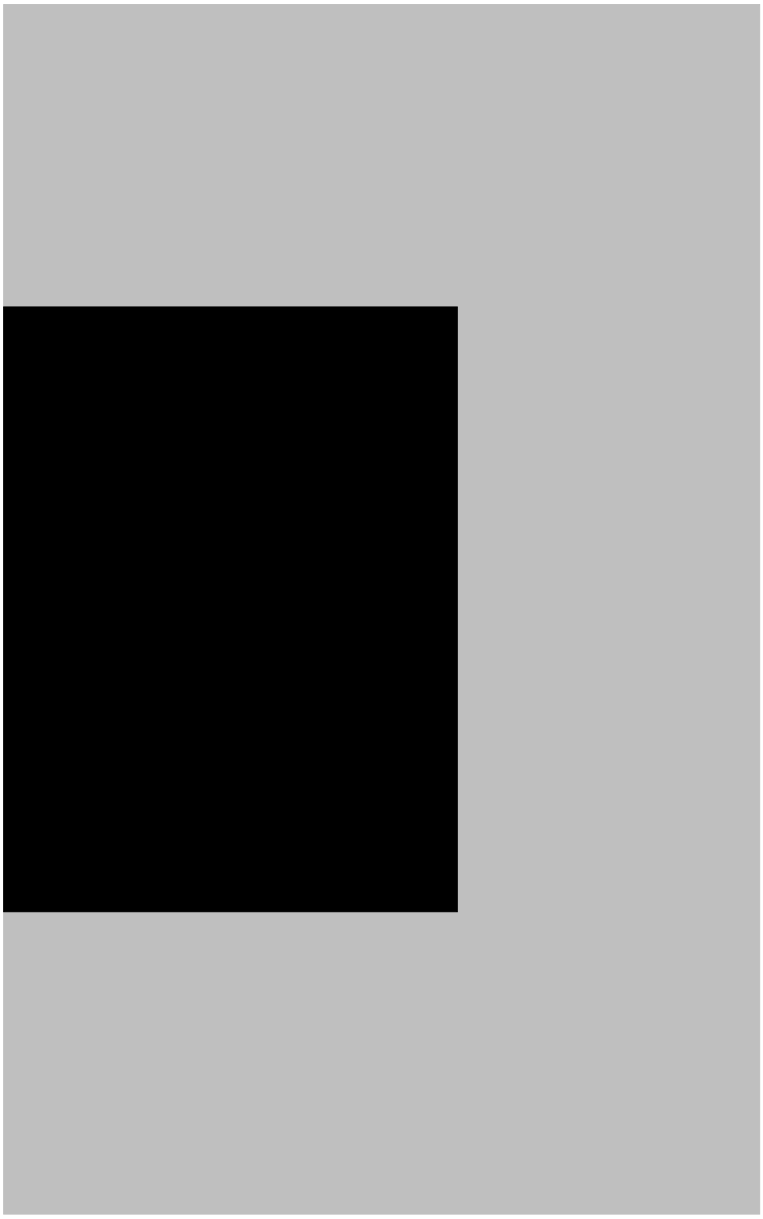


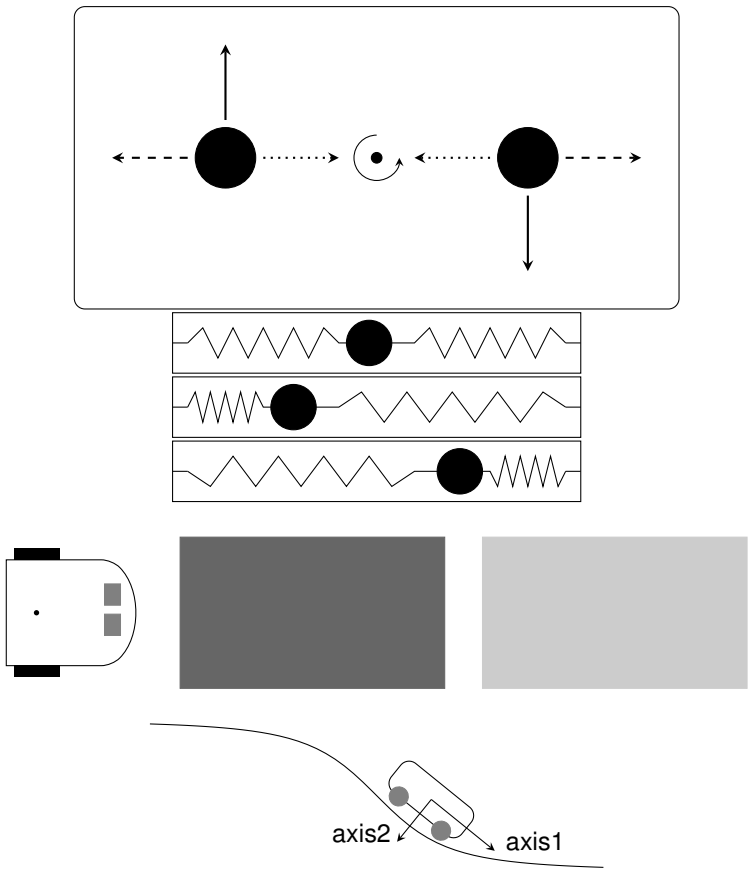


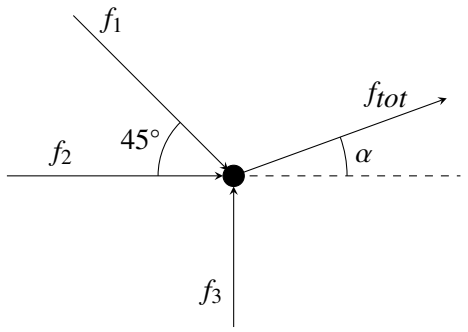


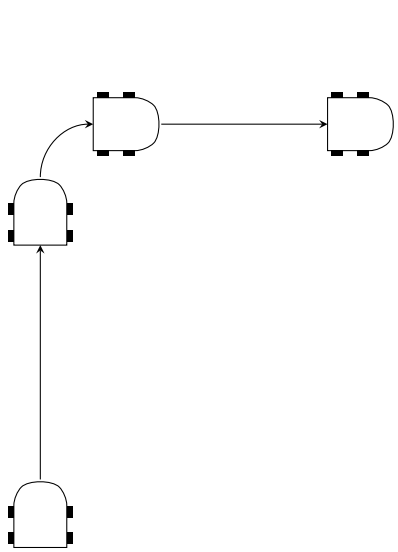


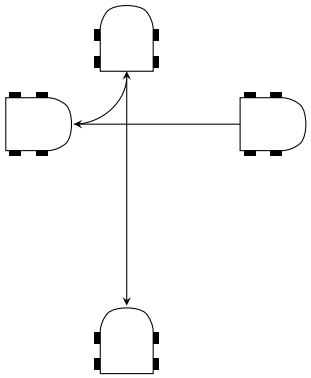


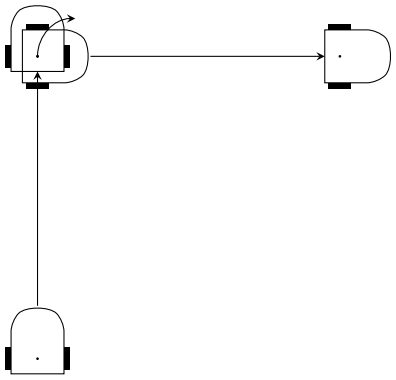


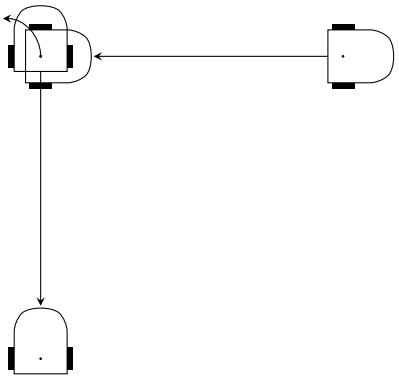

axis2
axis1
1
x_1
x_2
x_n
w_0
w_1
w_2
w_2
+
f
y

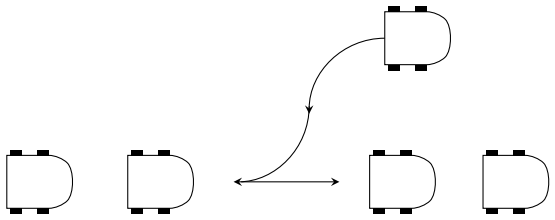

f_1
f_{tot}
45°
f_2
α
f_3

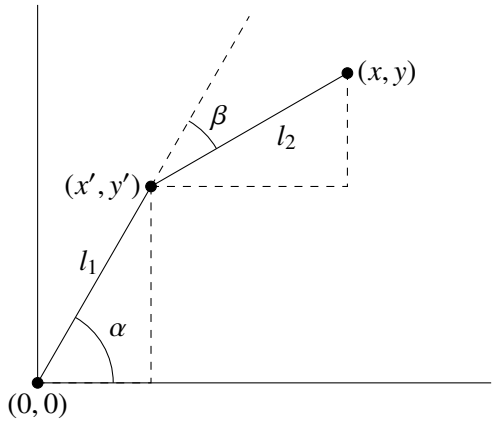


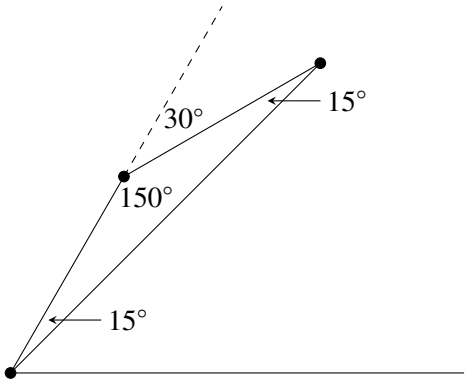


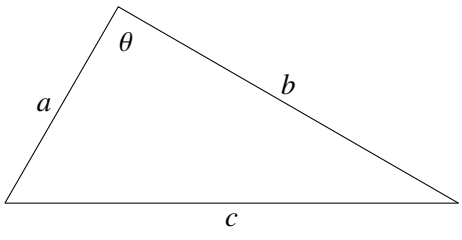


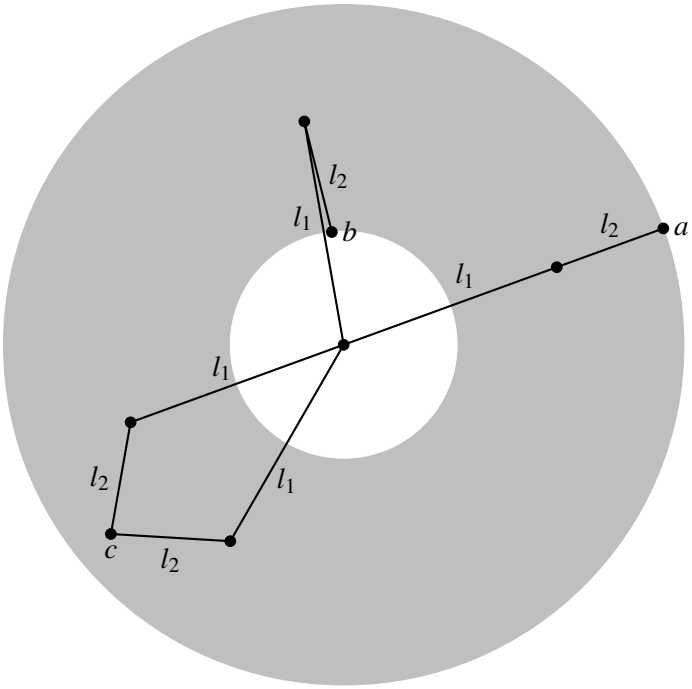


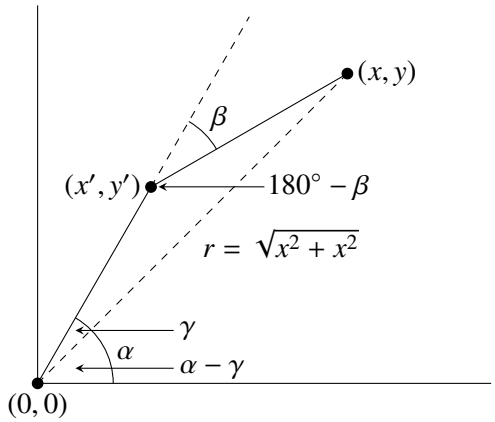


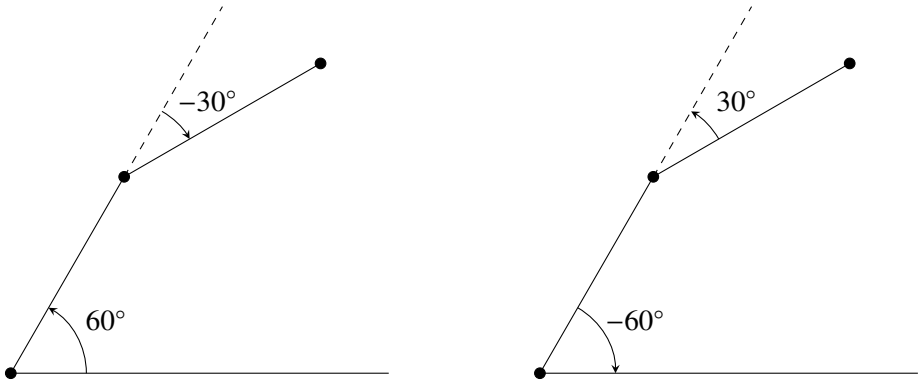

(x, y)
β
l2
(x′, y′)
l1
α
(0, 0)

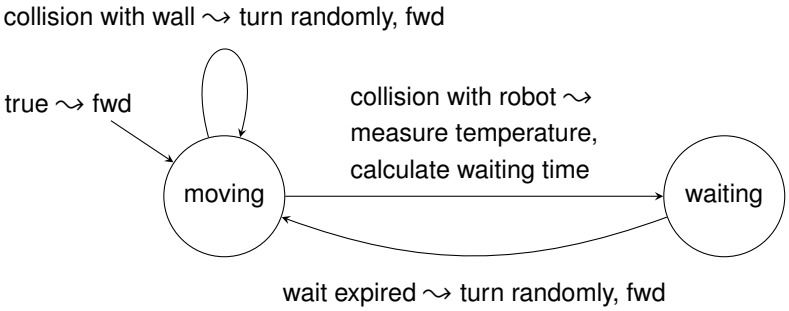

30°
15°
150°
15°

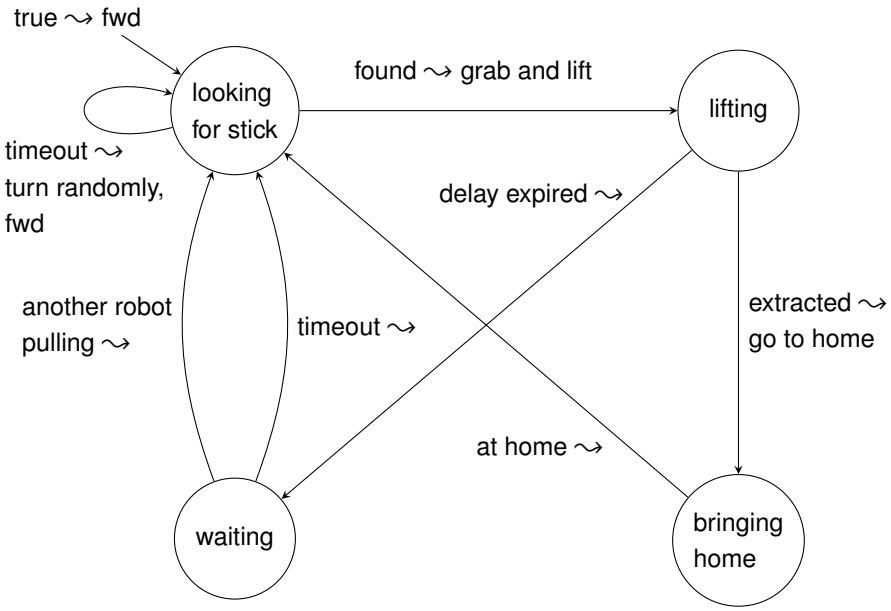

θ
a
b
c

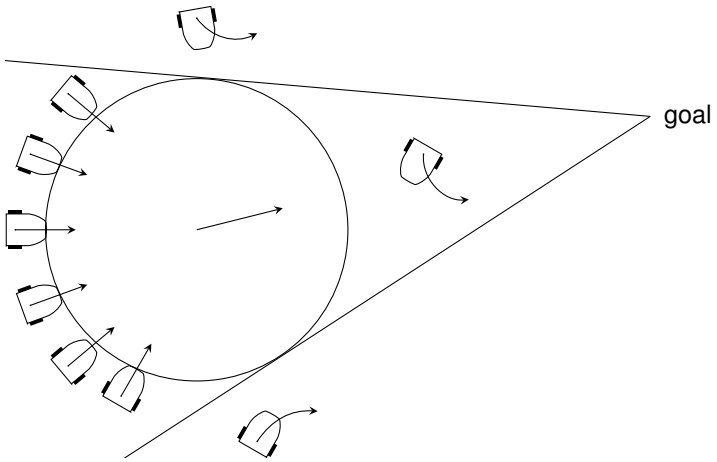

l_2
l_1
b
l_2
a
l_1
l_1
l_2
l_1
c
l_2

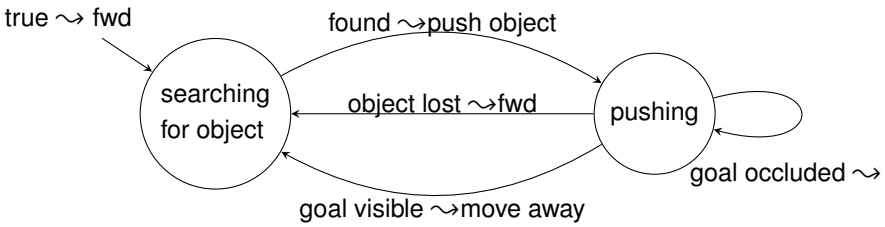

(x, y)
β
(x', y')
$180° - \beta$
$r = \sqrt{x^2 + x^2}$
γ
α
$\alpha - \gamma$
$(0, 0)$

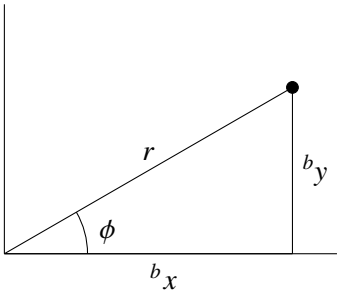

−30°
60°
30°
−60°

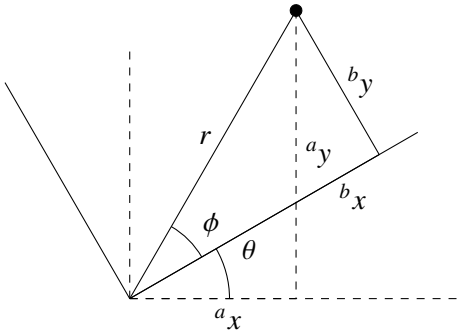

collision with wall ⇝ turn randomly, fwd
true ⇝ fwd
collision with robot ⇝
measure temperature,
calculate waiting time
moving
waiting
wait expired ⇝ turn randomly, fwd

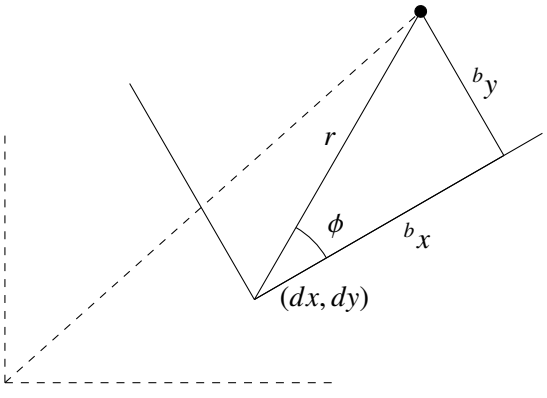

true ⇝ fwd
looking for stick
found ⇝ grab and lift
lifting
timeout ⇝ turn randomly, fwd
delay expired ⇝
another robot pulling ⇝
timeout ⇝
extracted ⇝ go to home
at home ⇝
waiting
bringing home

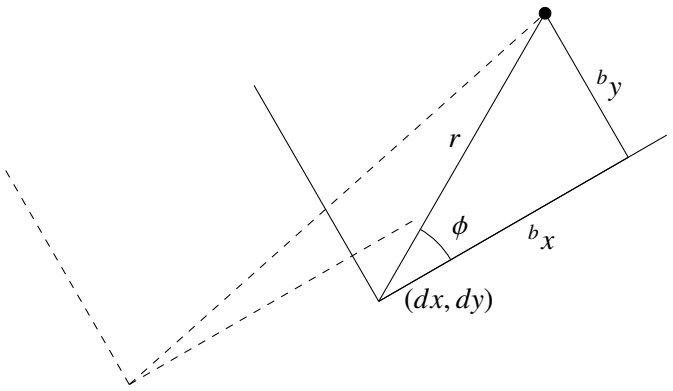

goal


true ⇝ fwd
found ⇝push object
searching
for object
object lost ⇝fwd
pushing
goal occluded ⇝
goal visible ⇝move away


r
^{b}y
ϕ
^{b}x


^{b}y
r
^{a}y
^{b}x
ϕ
θ
^{a}x

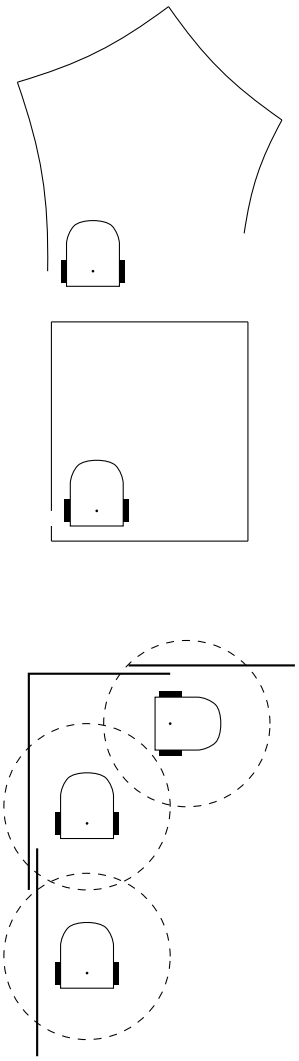

^{b}y
r
ϕ
^{b}x
(dx, dy)

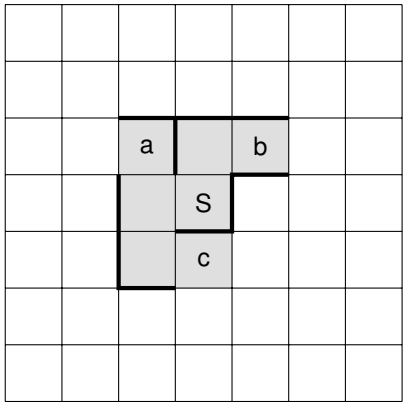


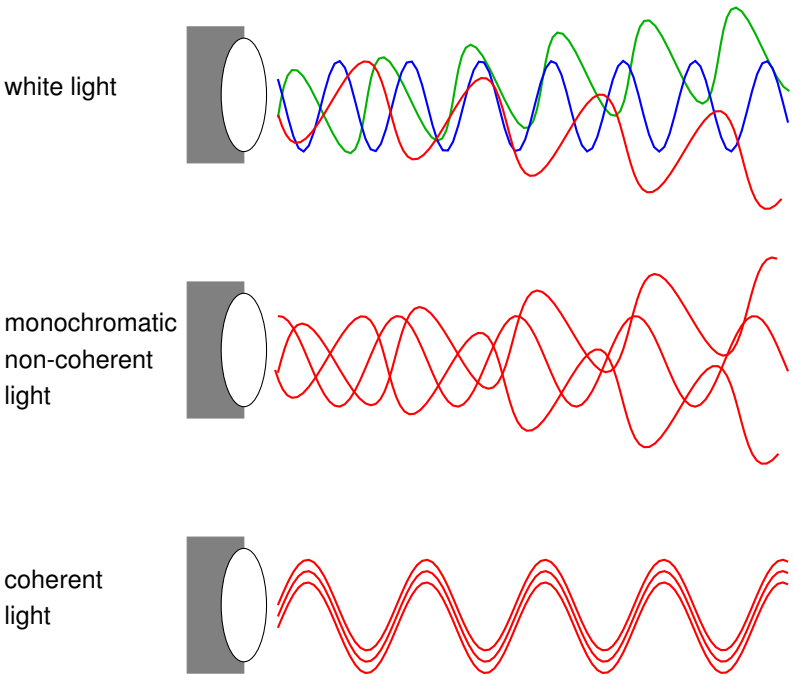
$$\begin{bmatrix} {}^{a}x \\ {}^{a}y \\ 1 \end{bmatrix} = \begin{bmatrix} \frac{\sqrt{3}}{2} & -\frac{1}{2} & 3 \\ \frac{1}{2} & \frac{\sqrt{3}}{2} & 1 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \frac{\sqrt{3}}{2} \\ \frac{1}{2} \\ 1 \end{bmatrix} = \begin{bmatrix} \frac{1}{2} + 3 \\ \frac{\sqrt{3}}{2} + 1 \\ 1 \end{bmatrix}$$

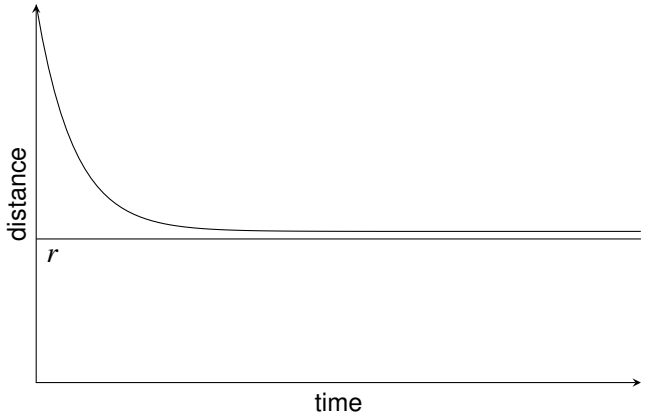
$$\begin{bmatrix} 1 & 0 & 3 \\ 0 & 1 & 1 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \frac{\sqrt{3}}{2} & -\frac{1}{2} & 0 \\ \frac{1}{2} & \frac{\sqrt{3}}{2} & 0 \\ 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} \frac{\sqrt{3}}{2} & -\frac{1}{2} & 3 \\ \frac{1}{2} & \frac{\sqrt{3}}{2} & 1 \\ 0 & 0 & 1 \end{bmatrix}$$

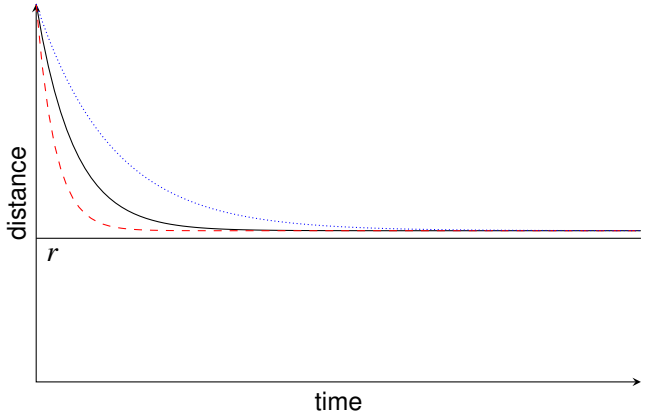
	0	1	2	3	4	5	6
0	?	?	?	?	?	?	?
1	?	?	?	.1	?	?	?
2	?	?	.1	.1	1	?	?
3	?	?	.1	.1	1	?	?
4	?	1	1	1	1	?	?
5	?	?	?	?	?	?	?
6	?	?	?	?	?	?	?

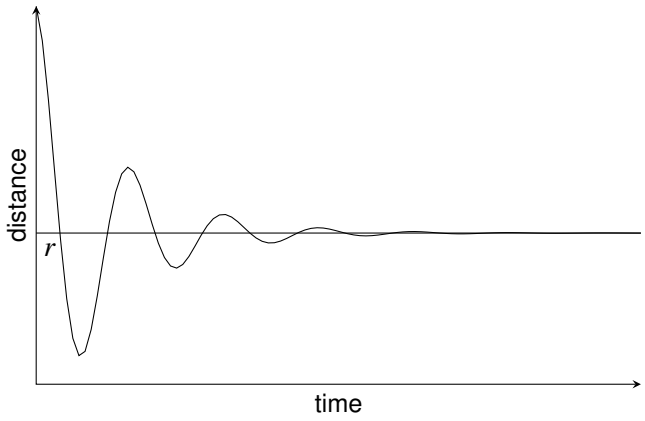


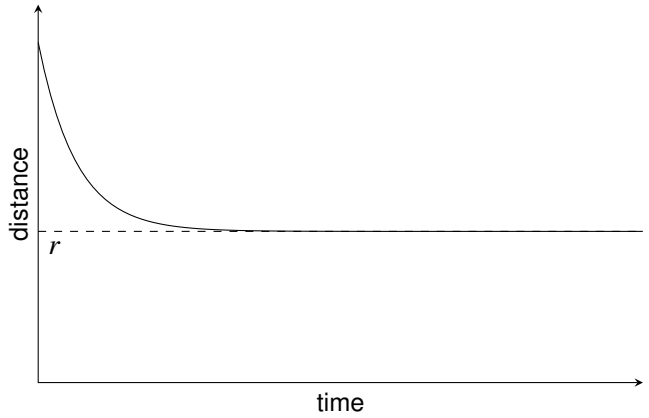

a
b
S
c


white light
monochromatic
non-coherent
light
coherent
light

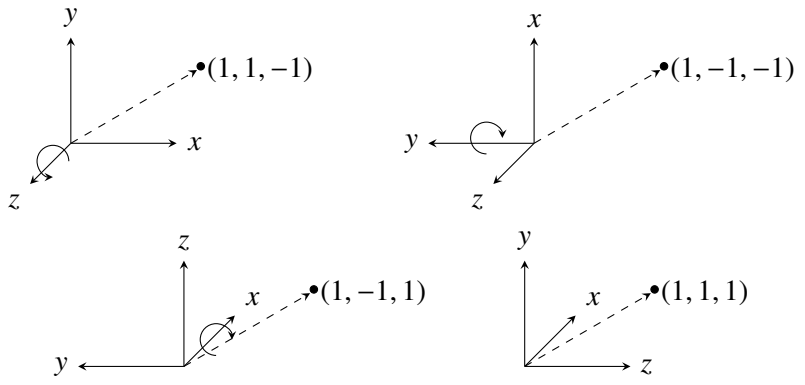

distance
r
time

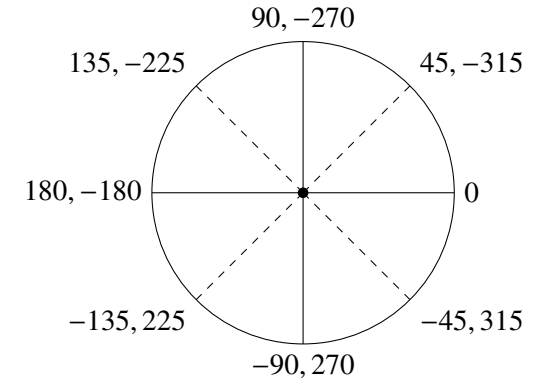

distance
r
time

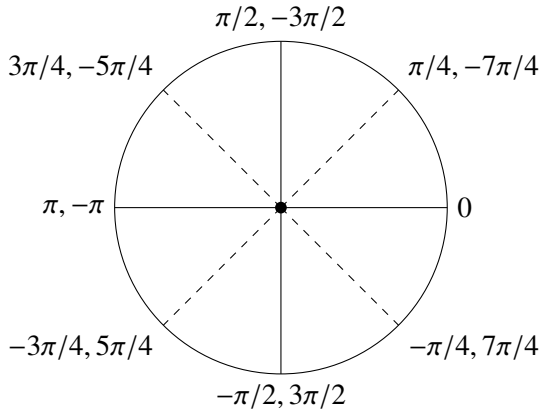

distance
r
time

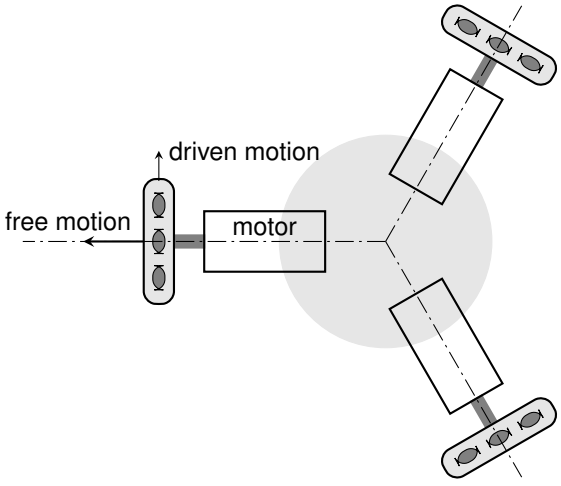


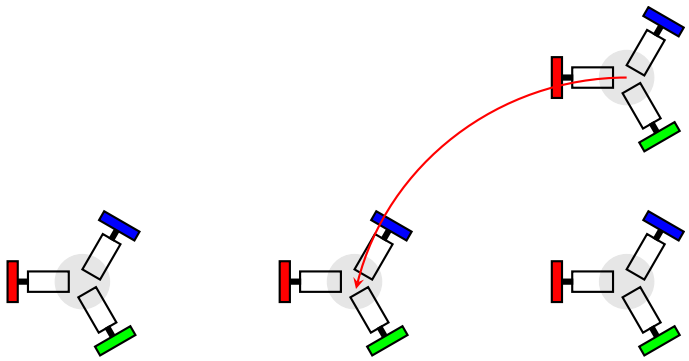
?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
?	?	?	?	?	?	0.1	0.1	?	?	?	?	?	?	?	?
?	?	?	?	?	?	0.1	0.1	0.1	0.1	0.1	0.1	?	?	?	?
?	?	?	?	?	?	0.1	0.1	0.1	0.1	0.1	0.1	?	?	?	?
?	?	?	?	?	0.1	0.1	0.1	0.1	0.1	0.1	0.1	?	?	?	?
?	?	?	?	?	0.1	0.1	0.1	0.1	0.1	0.1	0.1	?	?	?	?
?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?

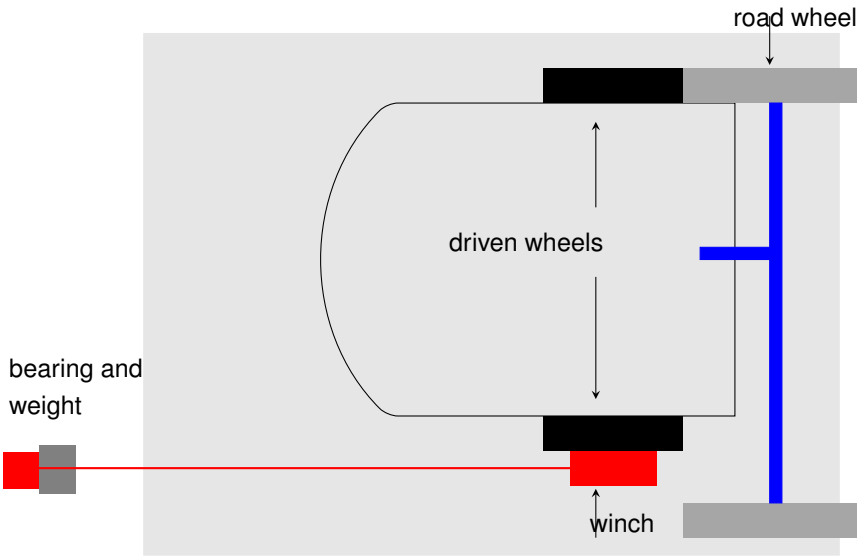


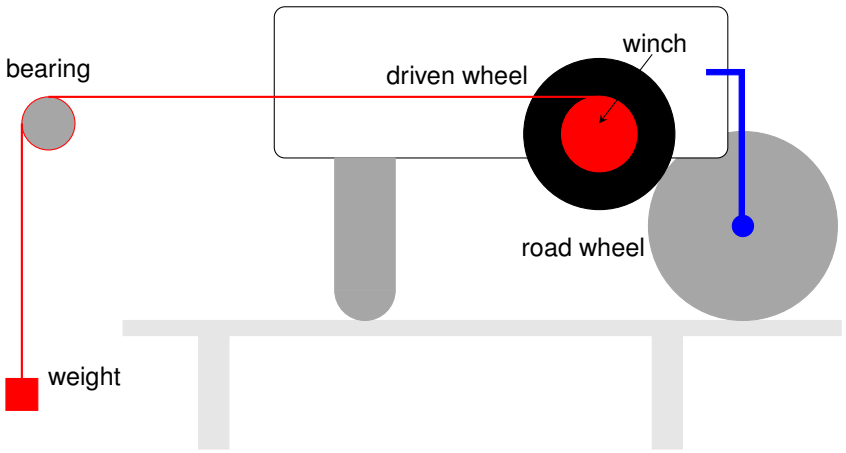

90, −270
135, −225
45, −315
180, −180
0
−135, 225
−45, 315
−90, 270

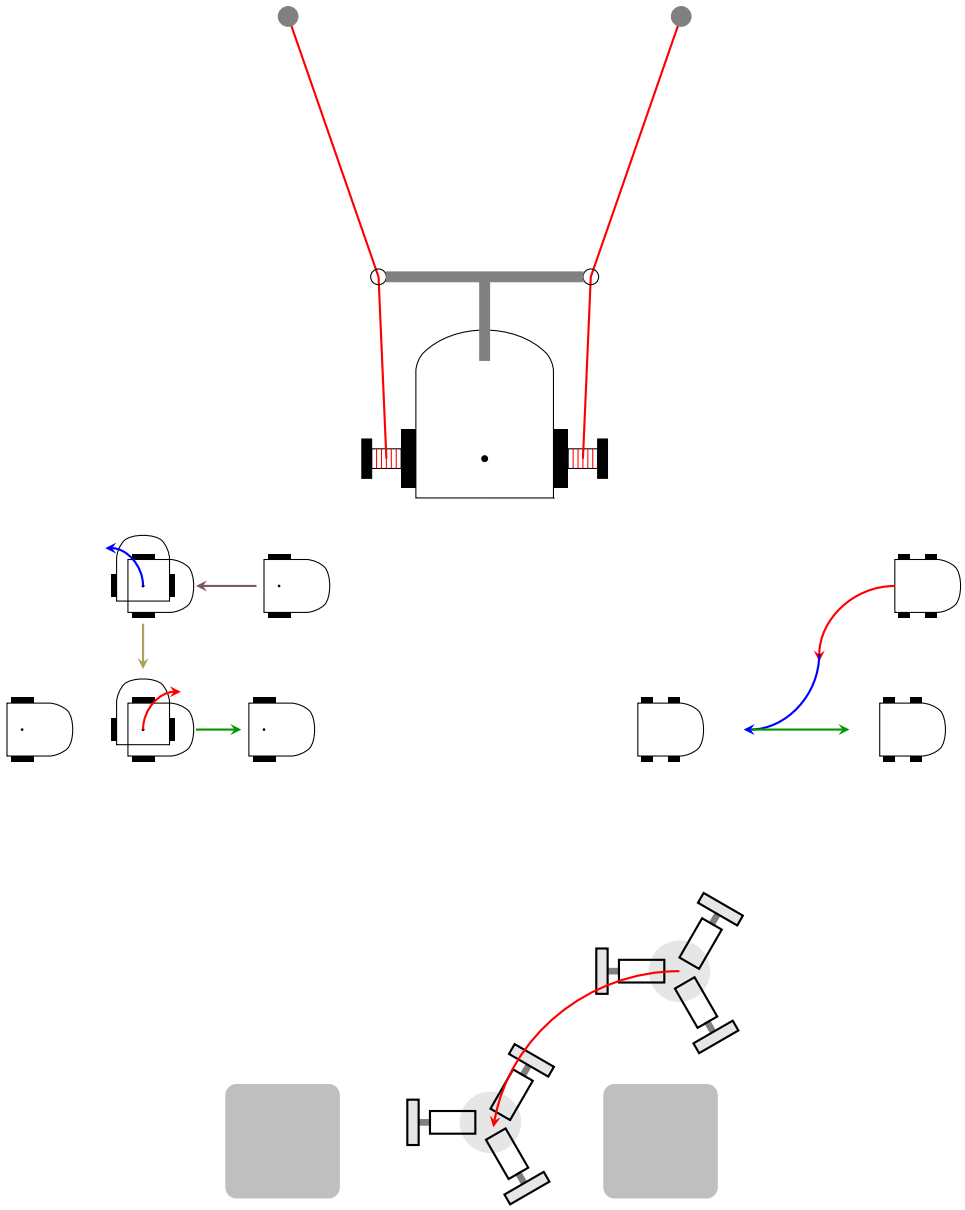

π/2, −3π/2
3π/4, −5π/4
π/4, −7π/4
π, −π
0
−3π/4, 5π/4
−π/4, 7π/4
−π/2, 3π/2

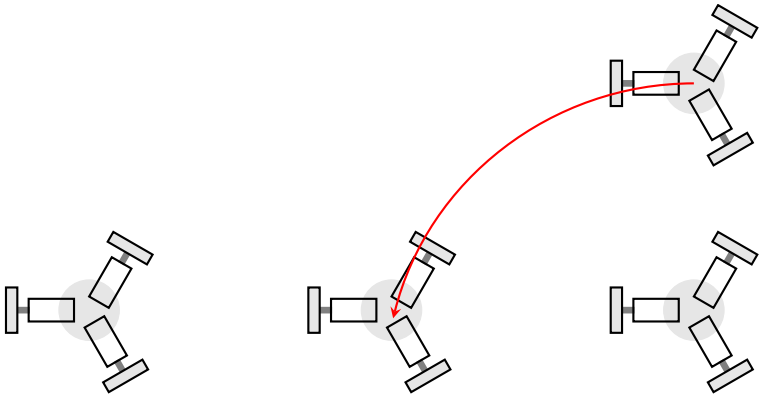

driven motion
free motion
motor

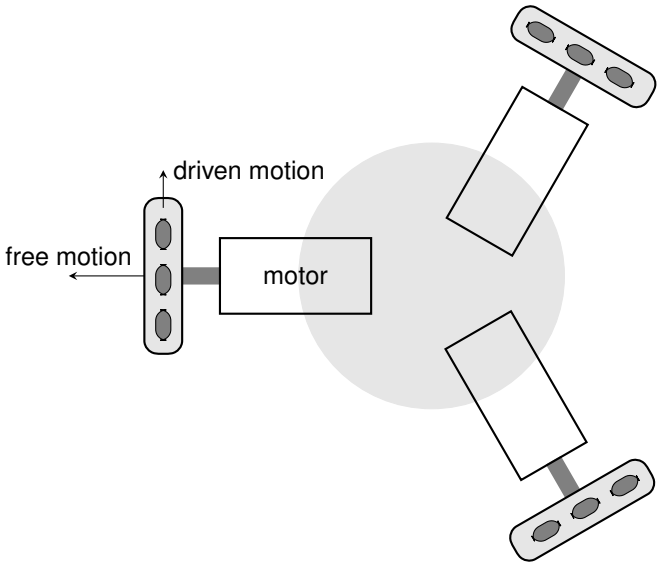


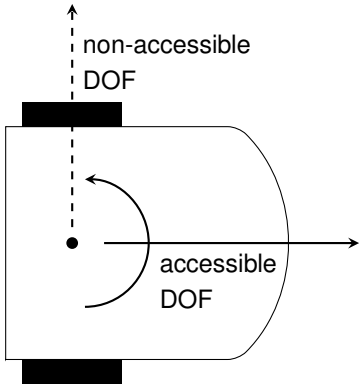

road wheel
driven wheels
bearing and
weight
winch

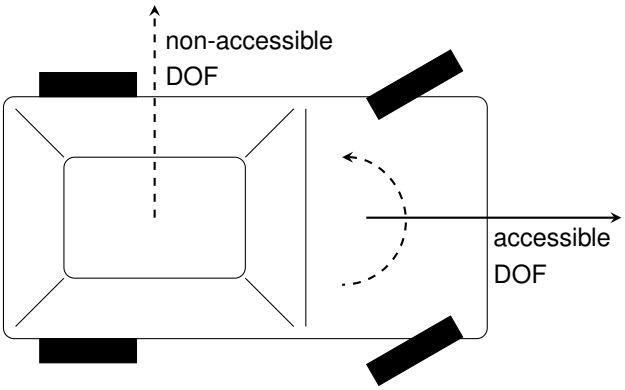

bearing
driven wheel
winch
road wheel
weight

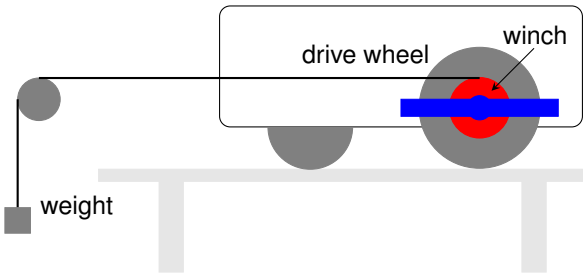


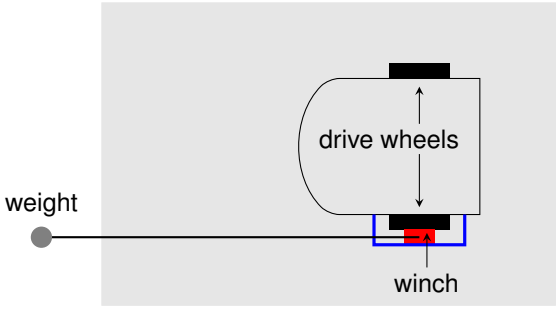


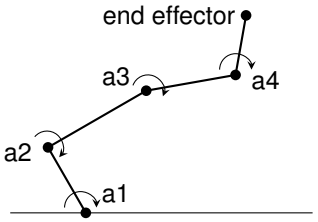

driven motion
free motion
motor

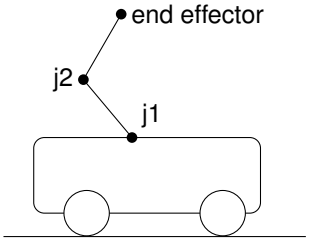

non-accessible
DOF
accessible
DOF

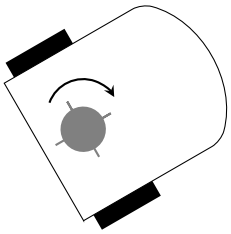

non-accessible
DOF
accessible
DOF

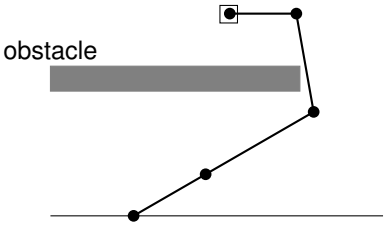

drive wheel
winch
weight

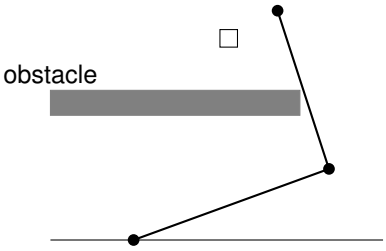

drive wheels
weight
winch

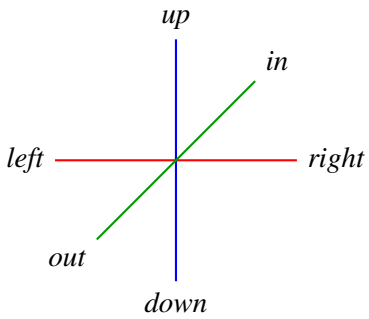

end effector
a3
a4
a2
a1

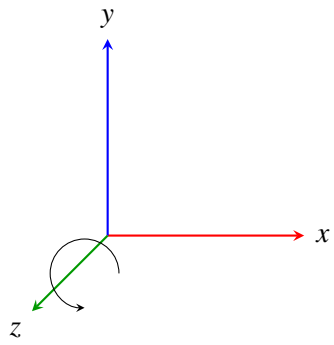

end effector
j2
j1

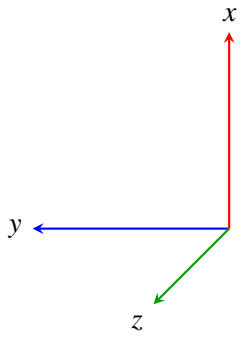


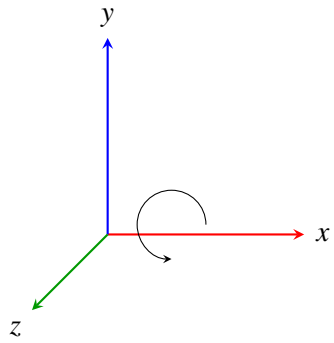

obstacle

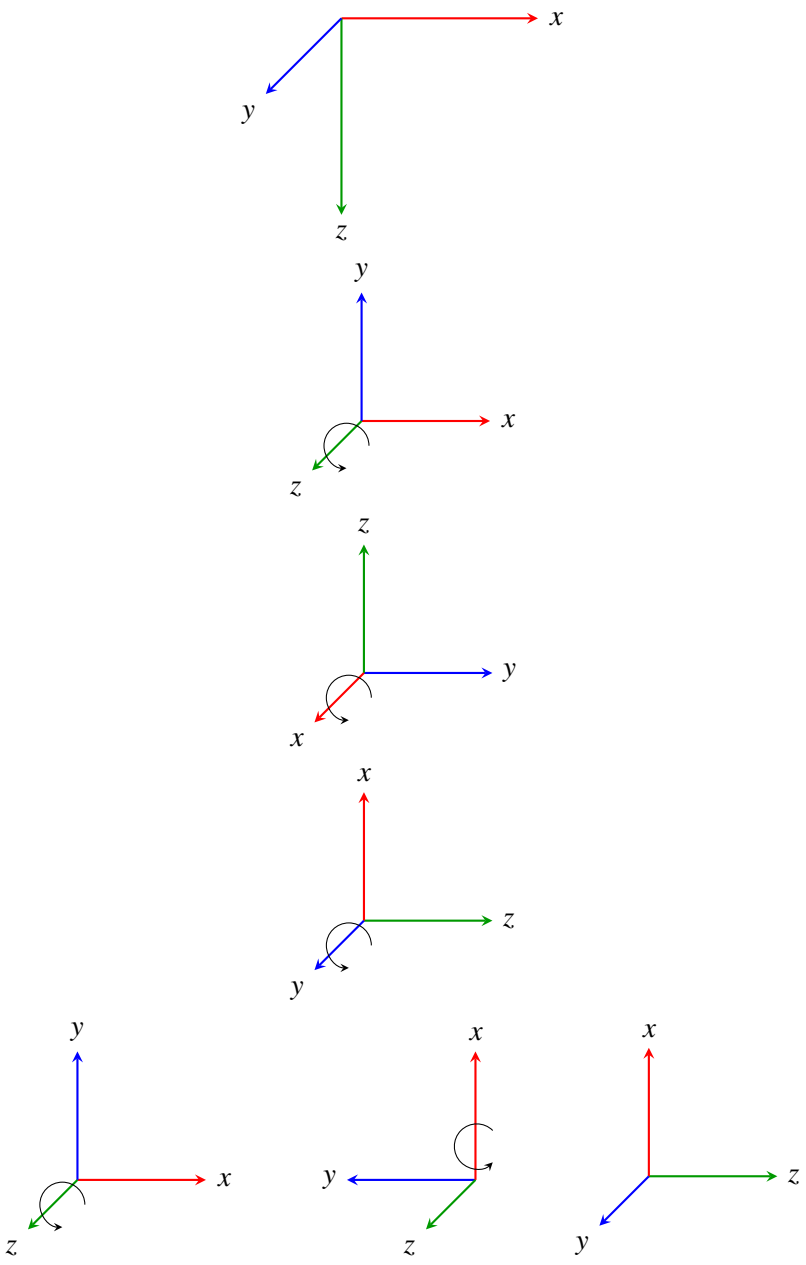

obstacle

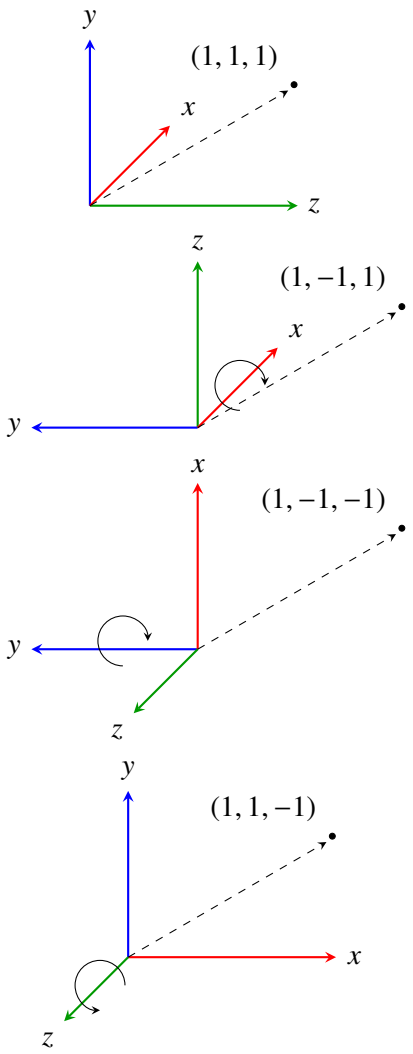

up
in
left
right
out
down


y
x
z


x
y
z


y
x
z


x
y
z
y
x
z
z
y
x
x
z
y
y
x
z
x
y
z
x
z
y


y
(1, 1, 1)
x
z
z
(1, −1, 1)
x
y
x
(1, −1, −1)
y
z
y
(1, 1, −1)
x
z