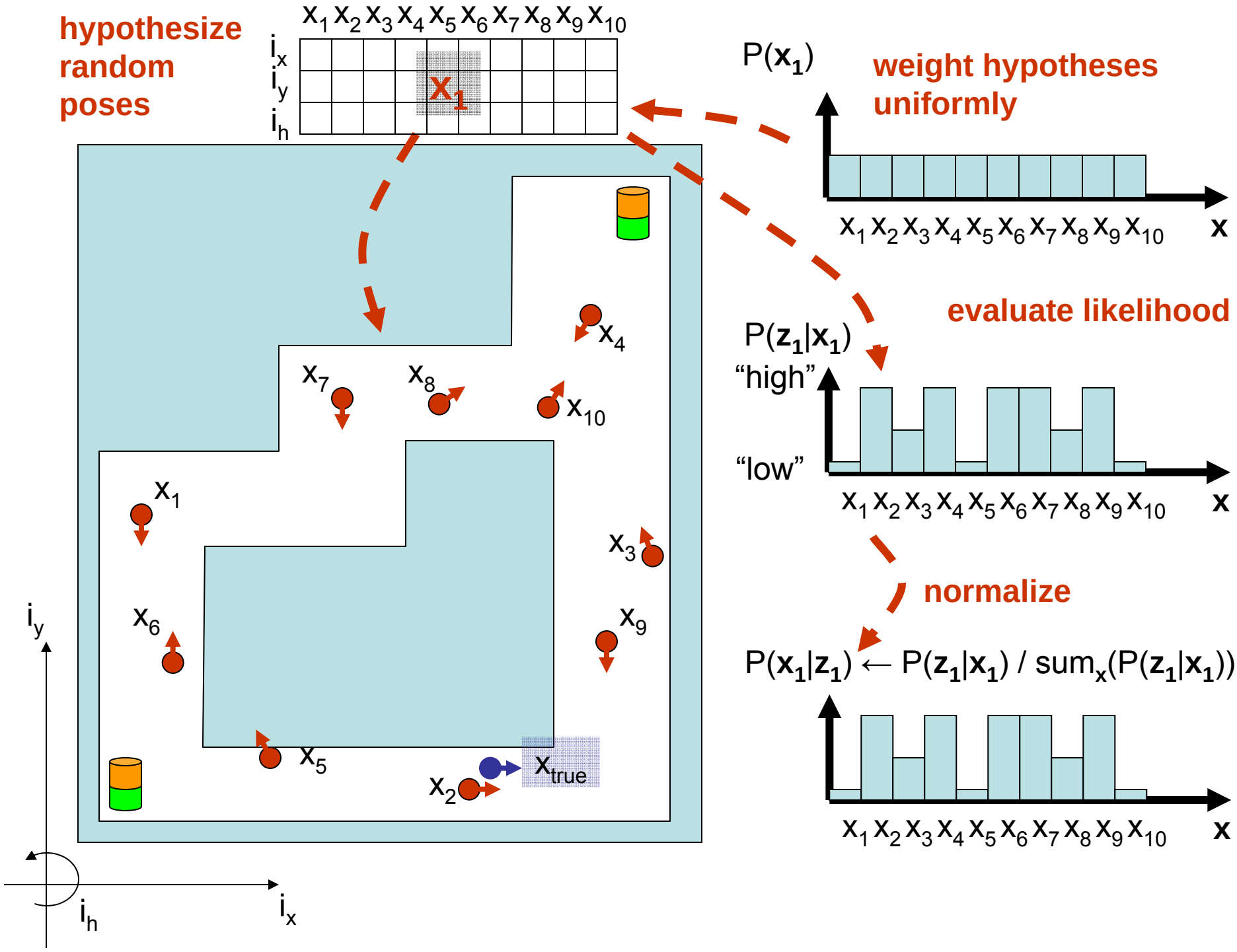
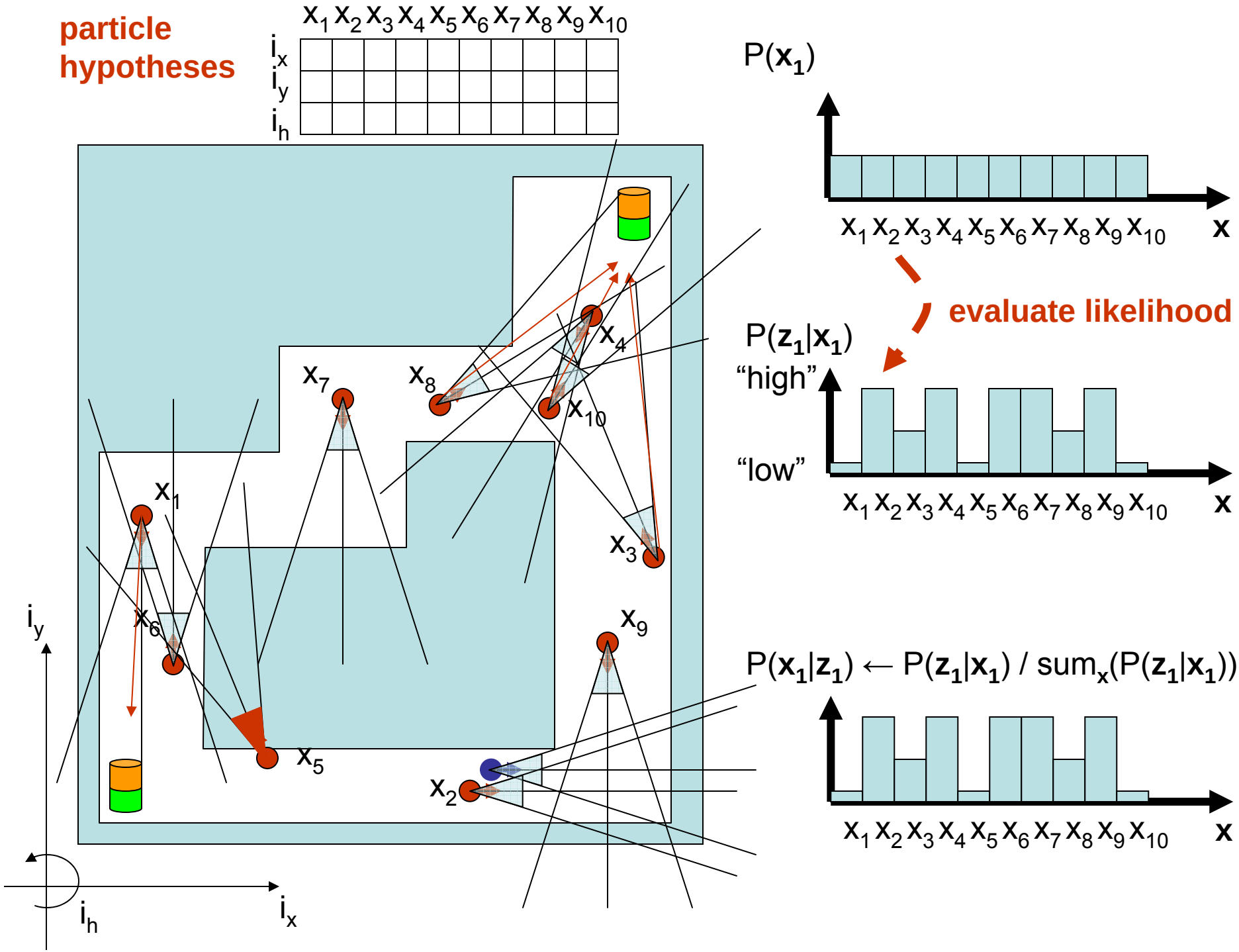
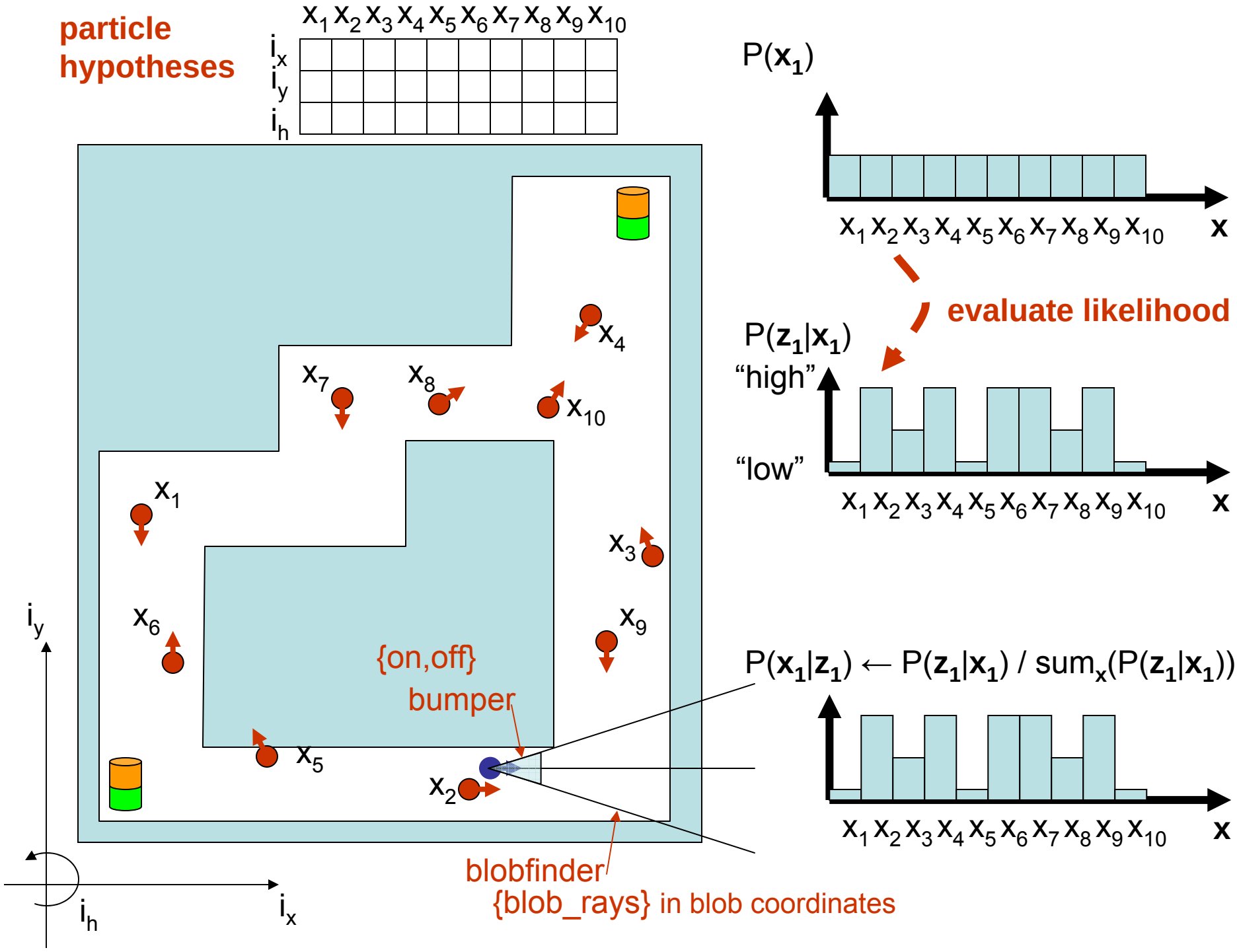
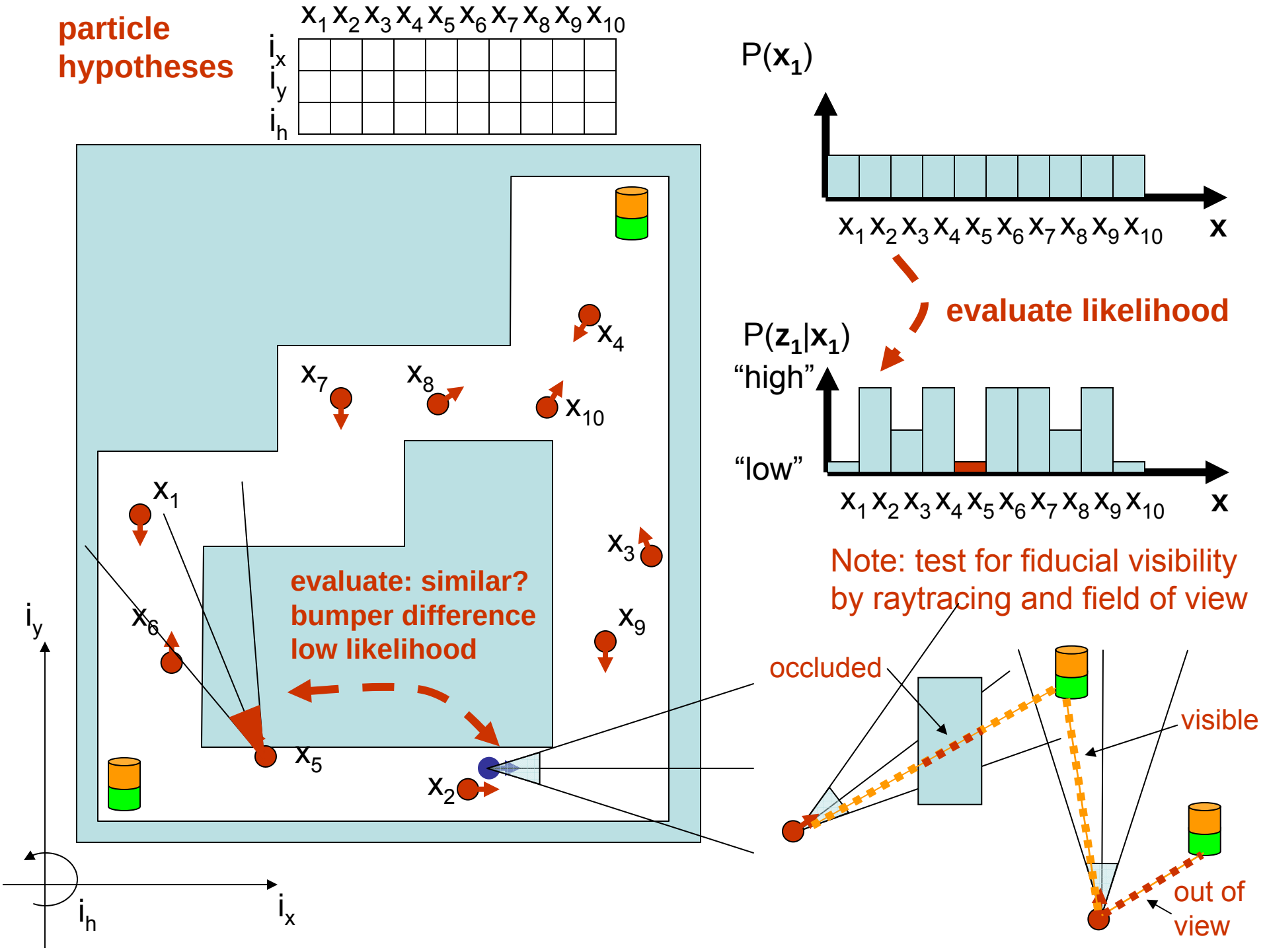
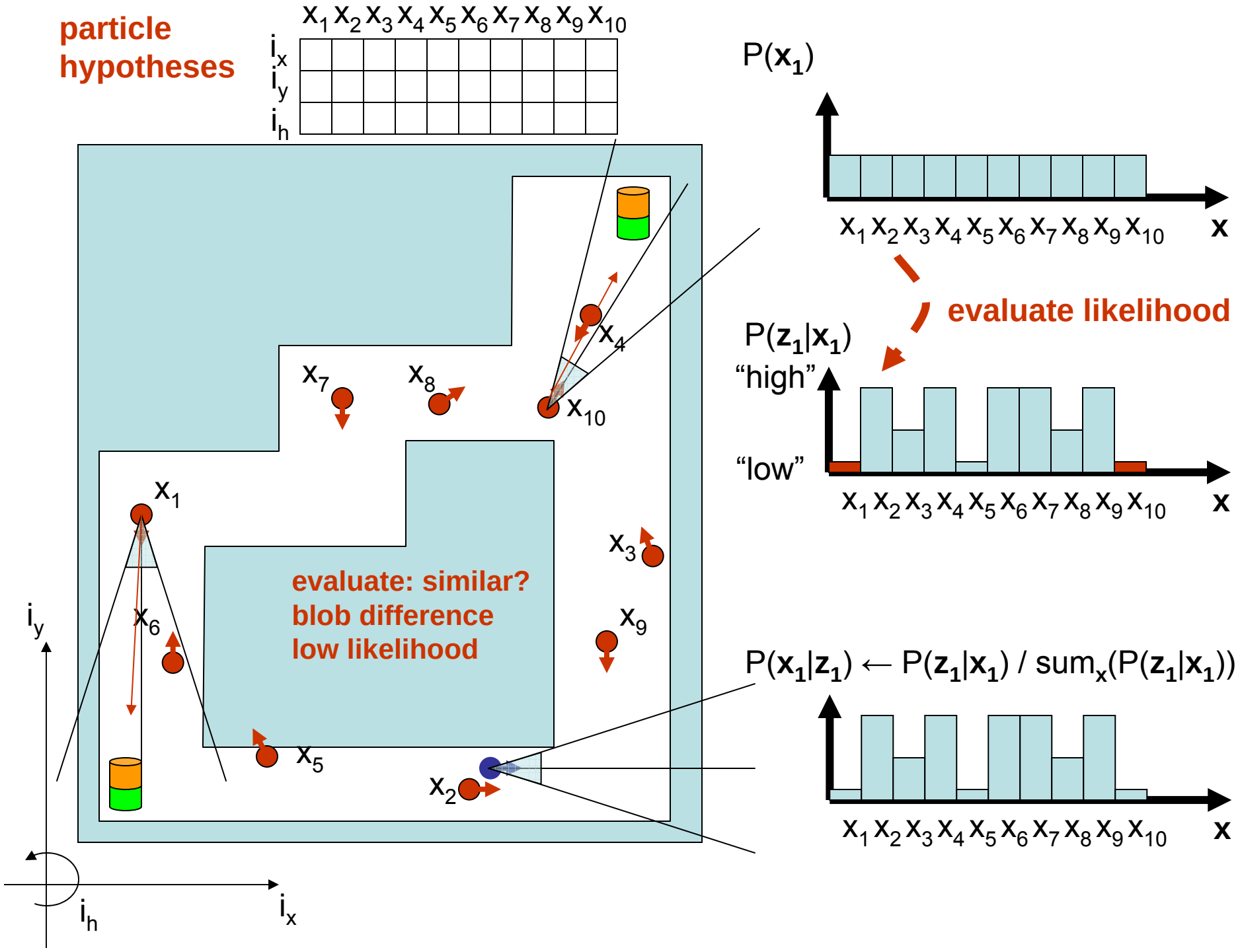

hypothesize random poses
$x_1 x_2 x_3 x_4 x_5 x_6 x_7 x_8 x_9 x_{10}$
i_x
i_y
i_h
x_1
$P(x_1)$
weight hypotheses uniformly
$x_1 x_2 x_3 x_4 x_5 x_6 x_7 x_8 x_9 x_{10}$ x
evaluate likelihood
$P(z_1|x_1)$
"high"
"low"
$x_1 x_2 x_3 x_4 x_5 x_6 x_7 x_8 x_9 x_{10}$ x
normalize
$P(x_1|z_1) \leftarrow P(z_1|x_1) / \text{sum}_x(P(z_1|x_1))$
$x_1 x_2 x_3 x_4 x_5 x_6 x_7 x_8 x_9 x_{10}$ x
x_4
x_7
x_8
x_{10}
x_1
x_3
x_6
x_9
x_5
x_2
x_{true}
i_y
i_h
i_x

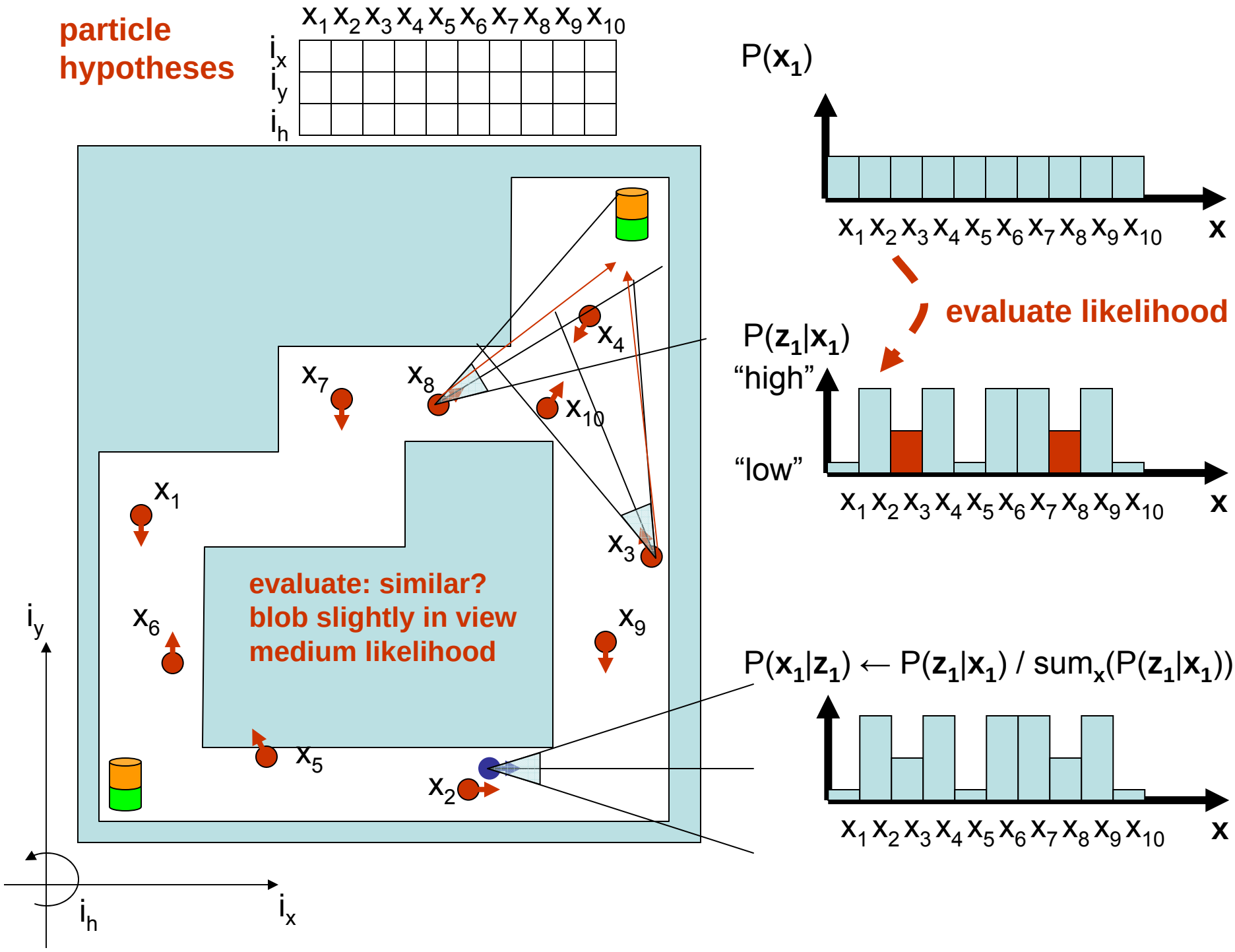

particle hypotheses
x1 x2 x3 x4 x5 x6 x7 x8 x9 x10
ix
iy
ih
P(x1)
x1 x2 x3 x4 x5 x6 x7 x8 x9 x10
x
evaluate likelihood
P(z1|x1)
“high”
“low”
x1 x2 x3 x4 x5 x6 x7 x8 x9 x10
x
P(x1|z1) ← P(z1|x1) / sumx(P(z1|x1))
x1 x2 x3 x4 x5 x6 x7 x8 x9 x10
x
x1
x2
x3
x4
x5
x6
x7
x8
x9
x10
iy
ih
ix

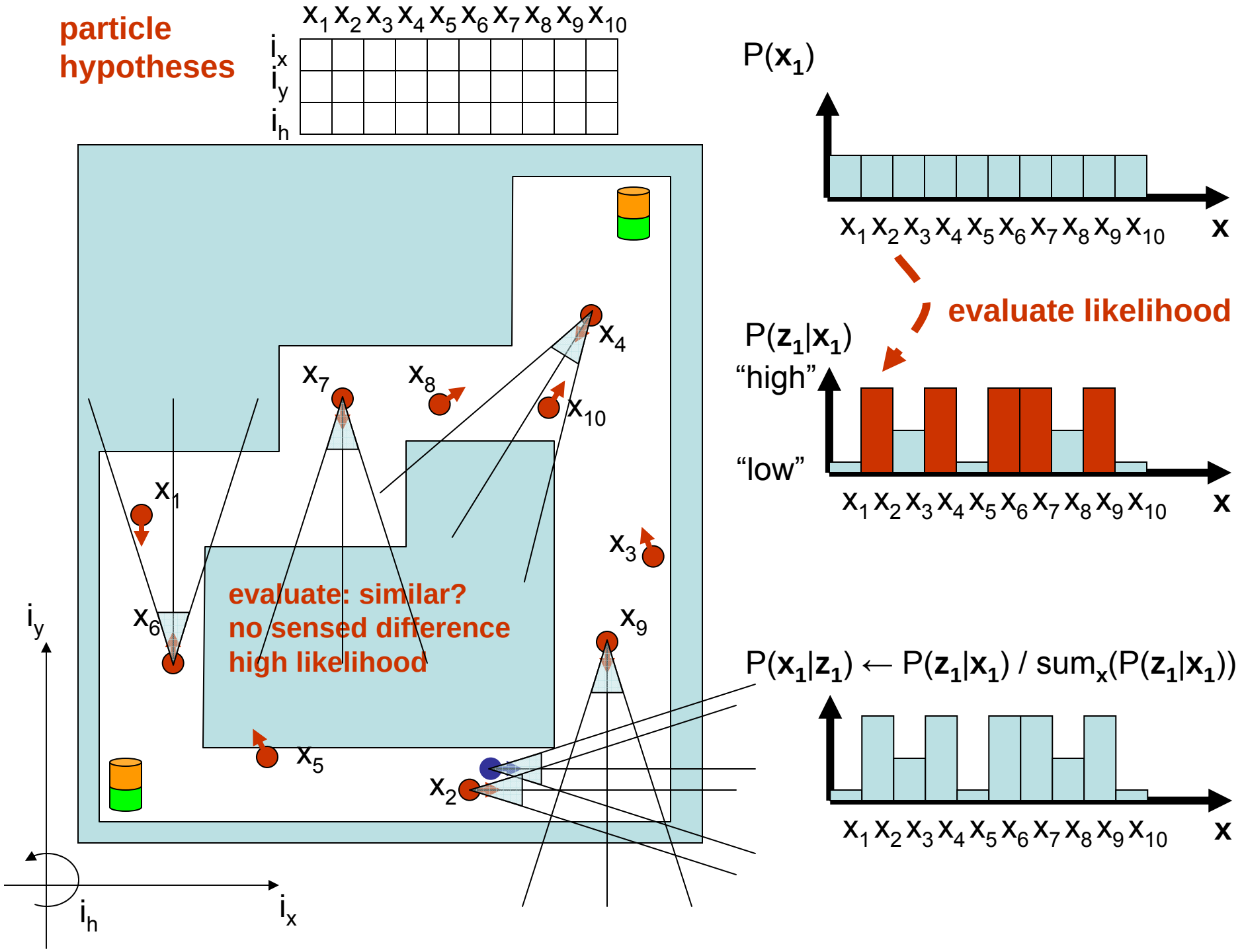

particle hypotheses
x1 x2 x3 x4 x5 x6 x7 x8 x9 x10
ix
iy
ih
P(x1)
x1 x2 x3 x4 x5 x6 x7 x8 x9 x10 x
evaluate likelihood
P(z1|x1)
"high"
"low"
x1 x2 x3 x4 x5 x6 x7 x8 x9 x10 x
x4
x7
x8
x10
x1
x3
x6
x9
{on,off}
bumper
x5
x2
iy
ih
ix
P(x1|z1) ← P(z1|x1) / sumx(P(z1|x1))
x1 x2 x3 x4 x5 x6 x7 x8 x9 x10 x
blobfinder
{blob_rays} in blob coordinates

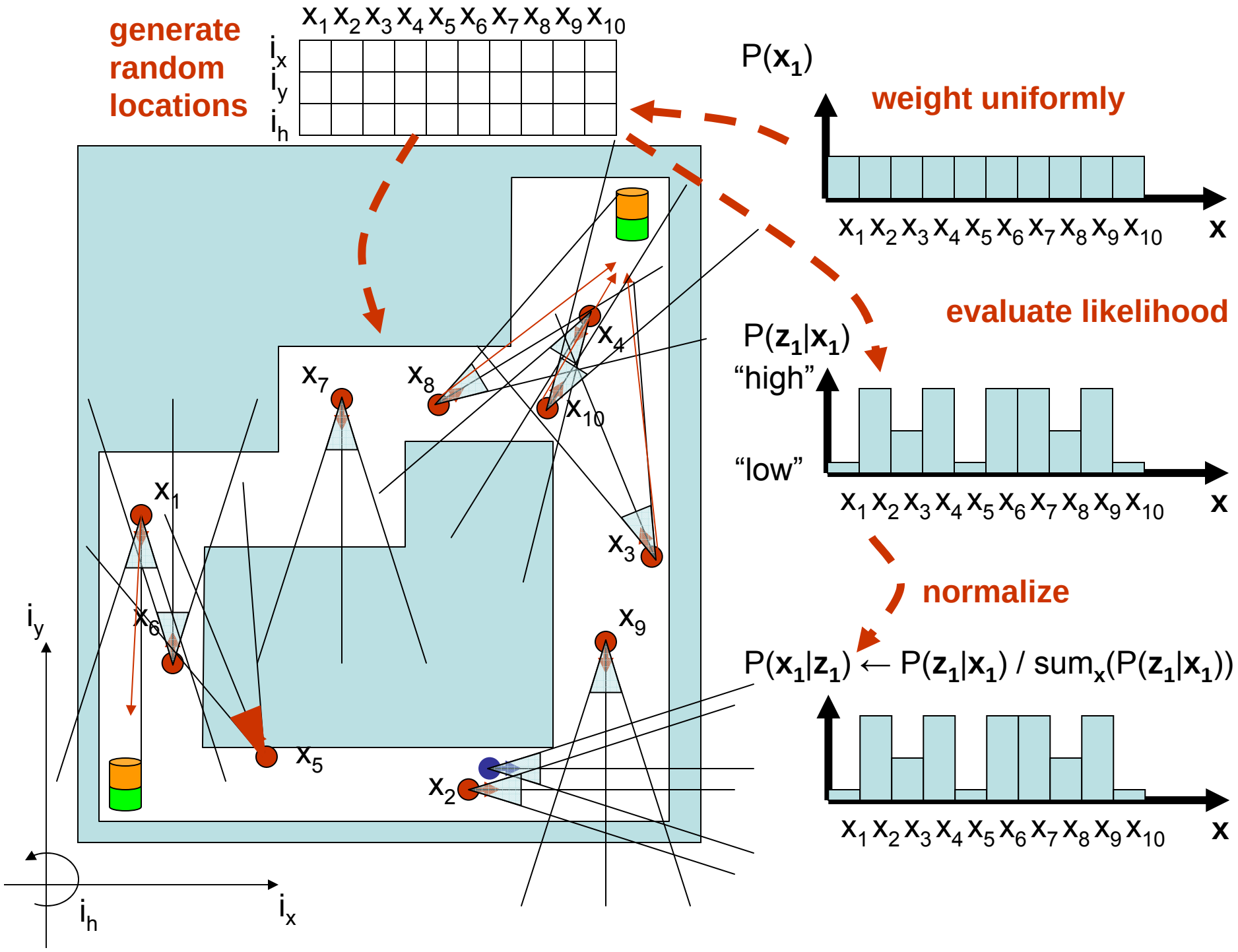
particle hypotheses

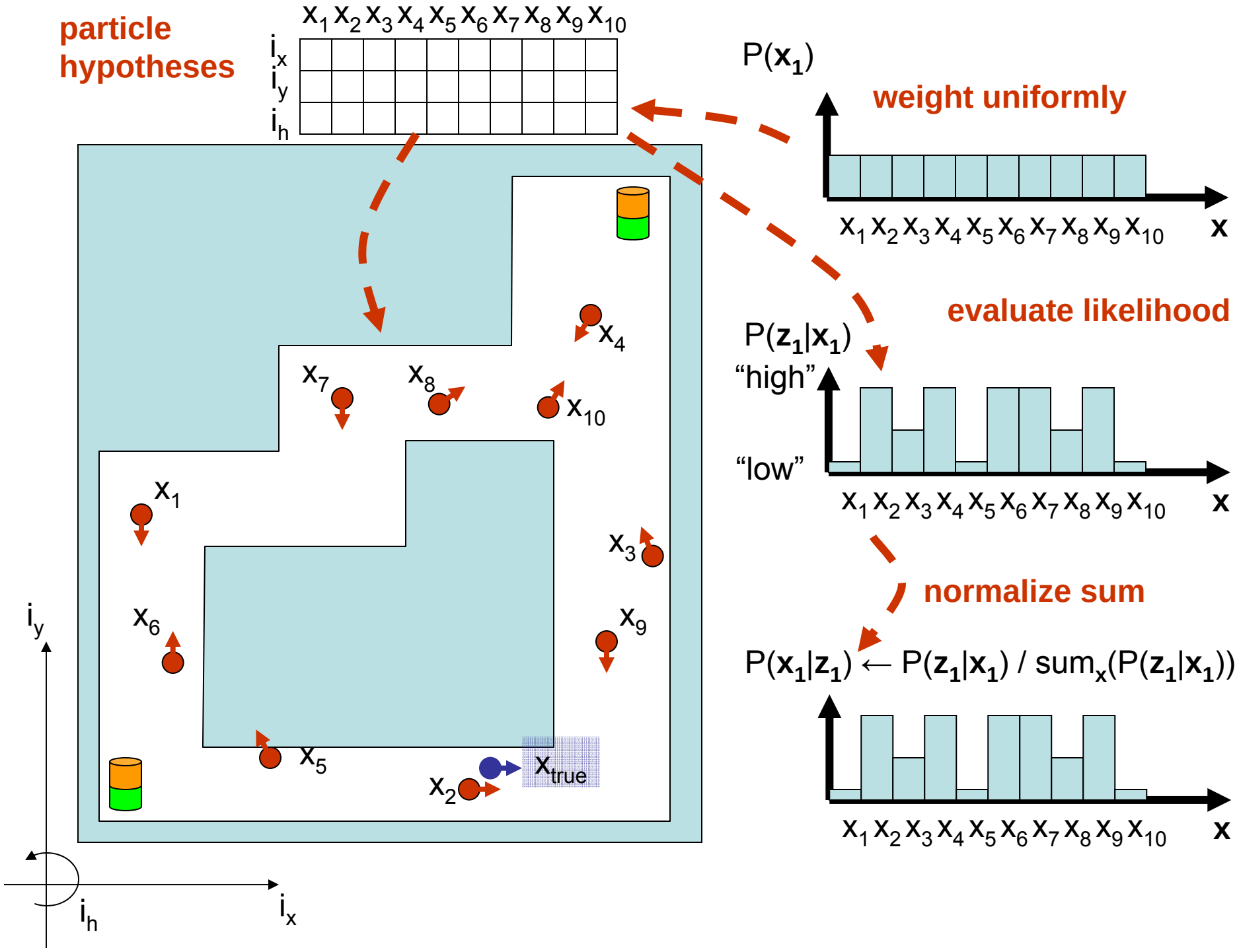


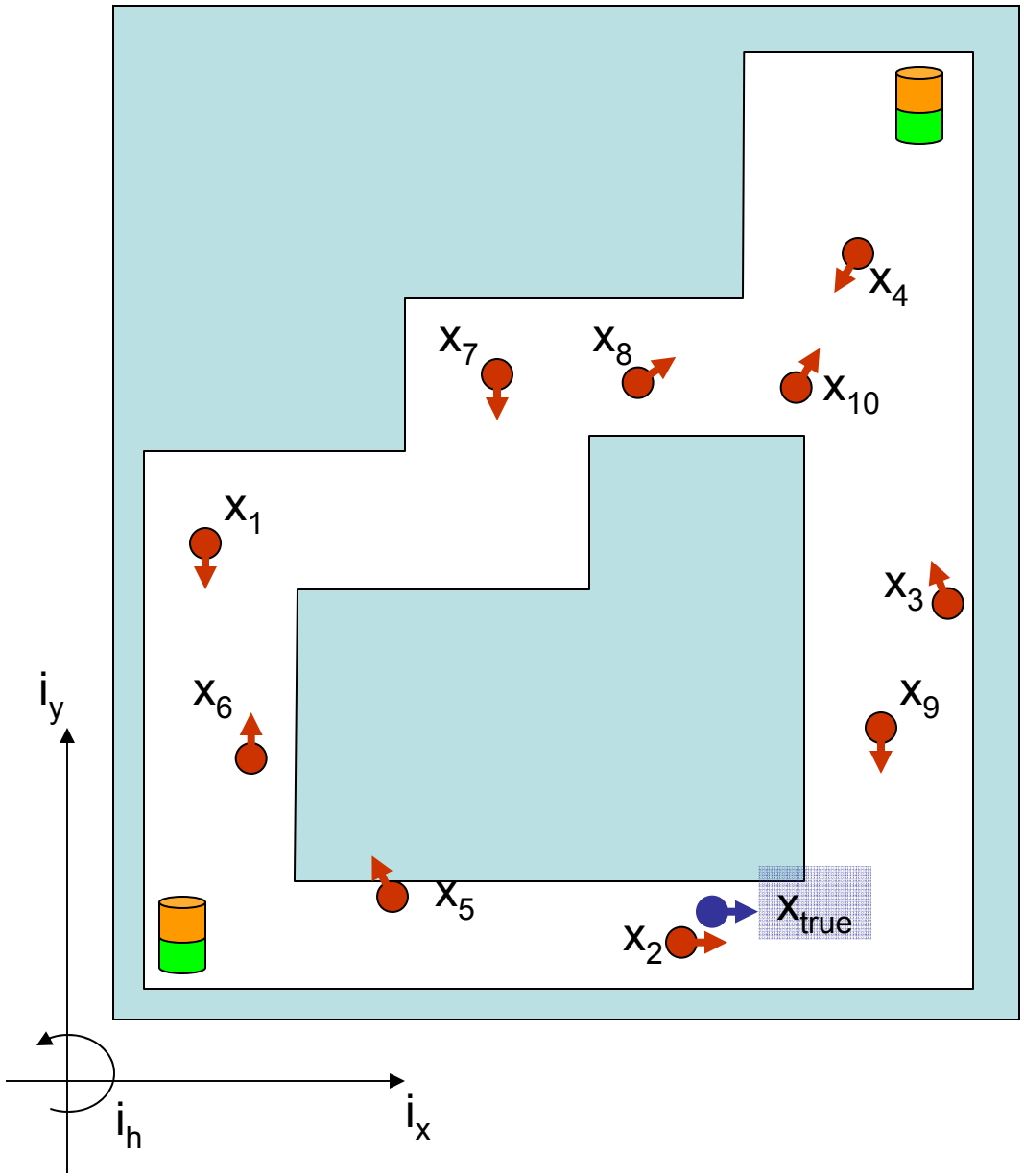

particle hypotheses
x1 x2 x3 x4 x5 x6 x7 x8 x9 x10
ix
iy
ih
x1
x2
x3
x4
x5
x6
x7
x8
x9
x10
evaluate: similar?
blob difference
low likelihood
iy
ih
ix
P(x1)
x1 x2 x3 x4 x5 x6 x7 x8 x9 x10
x
evaluate likelihood
P(z1|x1)
“high”
“low”
x1 x2 x3 x4 x5 x6 x7 x8 x9 x10
x
P(x1|z1) ← P(z1|x1) / sumx(P(z1|x1))
x1 x2 x3 x4 x5 x6 x7 x8 x9 x10
x


particle hypotheses
x1 x2 x3 x4 x5 x6 x7 x8 x9 x10
ix
iy
ih
x7
x8
x4
x10
x1
x3
x6
x9
x5
x2
evaluate: similar?
blob slightly in view
medium likelihood
iy
ih
ix
P(x1)
x1 x2 x3 x4 x5 x6 x7 x8 x9 x10
x
evaluate likelihood
P(z1|x1)
“high”
“low”
x1 x2 x3 x4 x5 x6 x7 x8 x9 x10
x
P(x1|z1) ← P(z1|x1) / sumx(P(z1|x1))
x1 x2 x3 x4 x5 x6 x7 x8 x9 x10
x

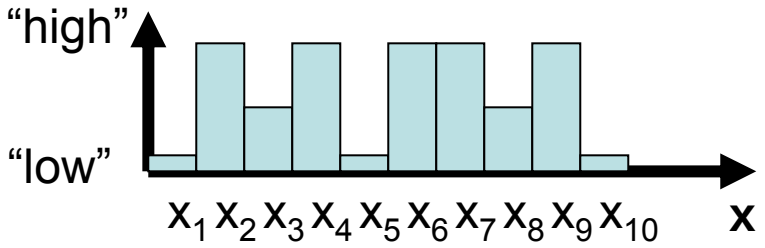

particle hypotheses
x1 x2 x3 x4 x5 x6 x7 x8 x9 x10
ix
iy
ih
P(x1)
x1 x2 x3 x4 x5 x6 x7 x8 x9 x10 x
evaluate likelihood
P(z1|x1)
"high"
"low"
x1 x2 x3 x4 x5 x6 x7 x8 x9 x10 x
x4
x7
x8
x10
x1
x3
x6
x9
evaluate: similar?
no sensed difference
high likelihood
x5
x2
iy
ih
ix
P(x1|z1) ← P(z1|x1) / sumx(P(z1|x1))
x1 x2 x3 x4 x5 x6 x7 x8 x9 x10 x


generate random locations
$x_1 x_2 x_3 x_4 x_5 x_6 x_7 x_8 x_9 x_{10}$
i_x
i_y
i_h
$P(x_1)$
weight uniformly
$x_1 x_2 x_3 x_4 x_5 x_6 x_7 x_8 x_9 x_{10}$ x
evaluate likelihood
$P(z_1|x_1)$
"high"
"low"
$x_1 x_2 x_3 x_4 x_5 x_6 x_7 x_8 x_9 x_{10}$ x
normalize
$P(x_1|z_1) \leftarrow P(z_1|x_1) / \text{sum}_x(P(z_1|x_1))$
$x_1 x_2 x_3 x_4 x_5 x_6 x_7 x_8 x_9 x_{10}$ x
x_1 x_2 x_3 x_4 x_5 x_6 x_7 x_8 x_9 x_{10}
i_y
i_h
i_x


particle hypotheses
$x_1\ x_2\ x_3\ x_4\ x_5\ x_6\ x_7\ x_8\ x_9\ x_{10}$
i_x
i_y
i_h
$P(x_1)$
weight uniformly
$x_1\ x_2\ x_3\ x_4\ x_5\ x_6\ x_7\ x_8\ x_9\ x_{10}$ x
evaluate likelihood
$P(z_1|x_1)$
"high"
"low"
$x_1\ x_2\ x_3\ x_4\ x_5\ x_6\ x_7\ x_8\ x_9\ x_{10}$ x
normalize sum
$P(x_1|z_1) \leftarrow P(z_1|x_1) / \text{sum}_x(P(z_1|x_1))$
$x_1\ x_2\ x_3\ x_4\ x_5\ x_6\ x_7\ x_8\ x_9\ x_{10}$ x
x_1
x_2
x_3
x_4
x_5
x_6
x_7
x_8
x_9
x_{10}
x_{true}
i_y
i_h
i_x

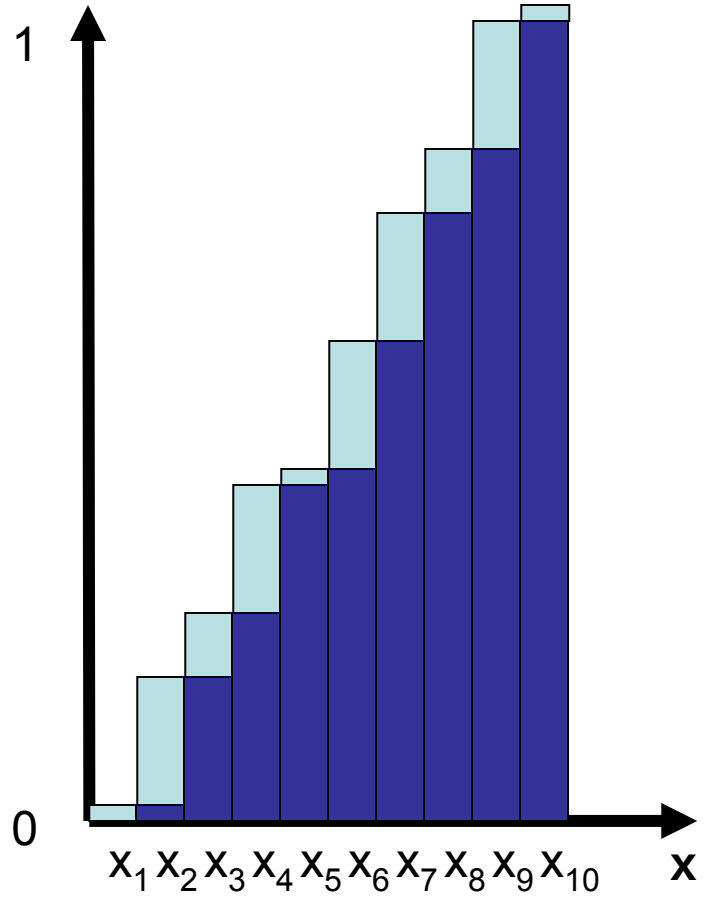


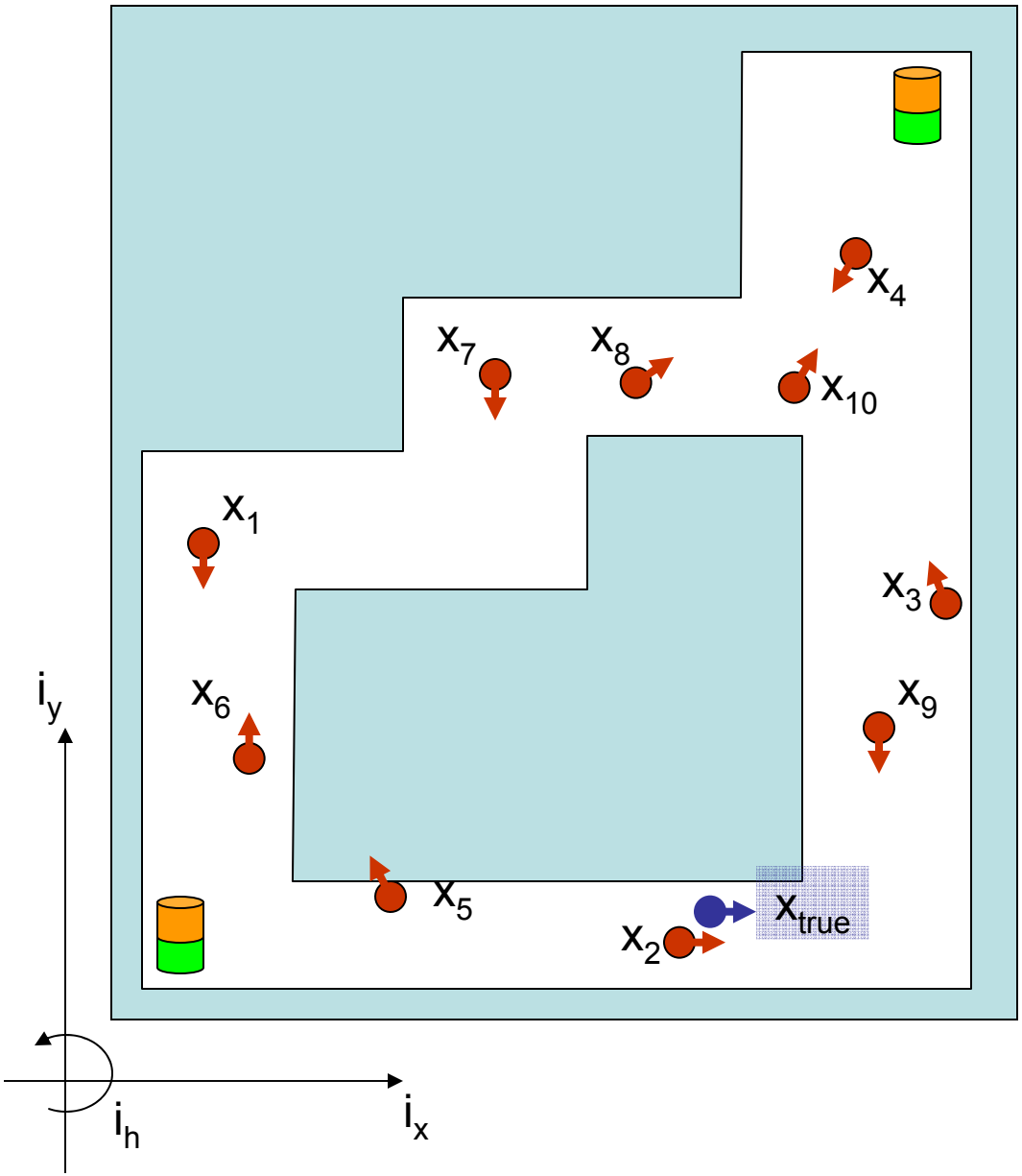
$P(\mathbf{x}_1|\mathbf{z}_1) \leftarrow P(\mathbf{z}_1|\mathbf{x}_1) / \text{sum}_x(P(\mathbf{z}_1|\mathbf{x}_1))$

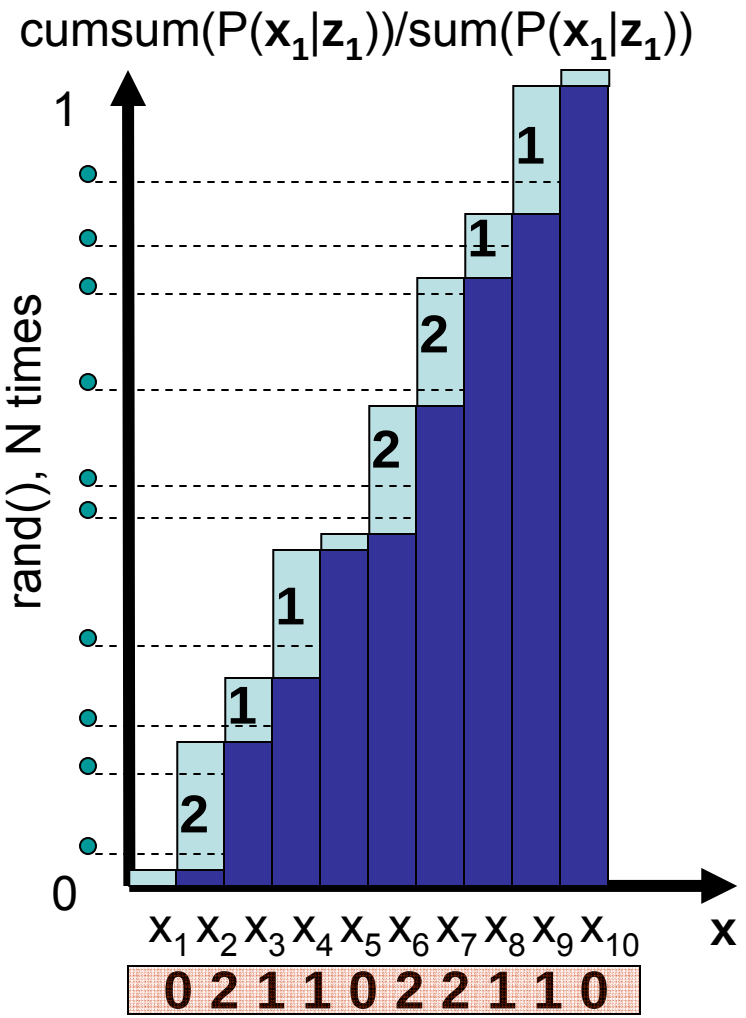


weight by importance:
normalized running sum

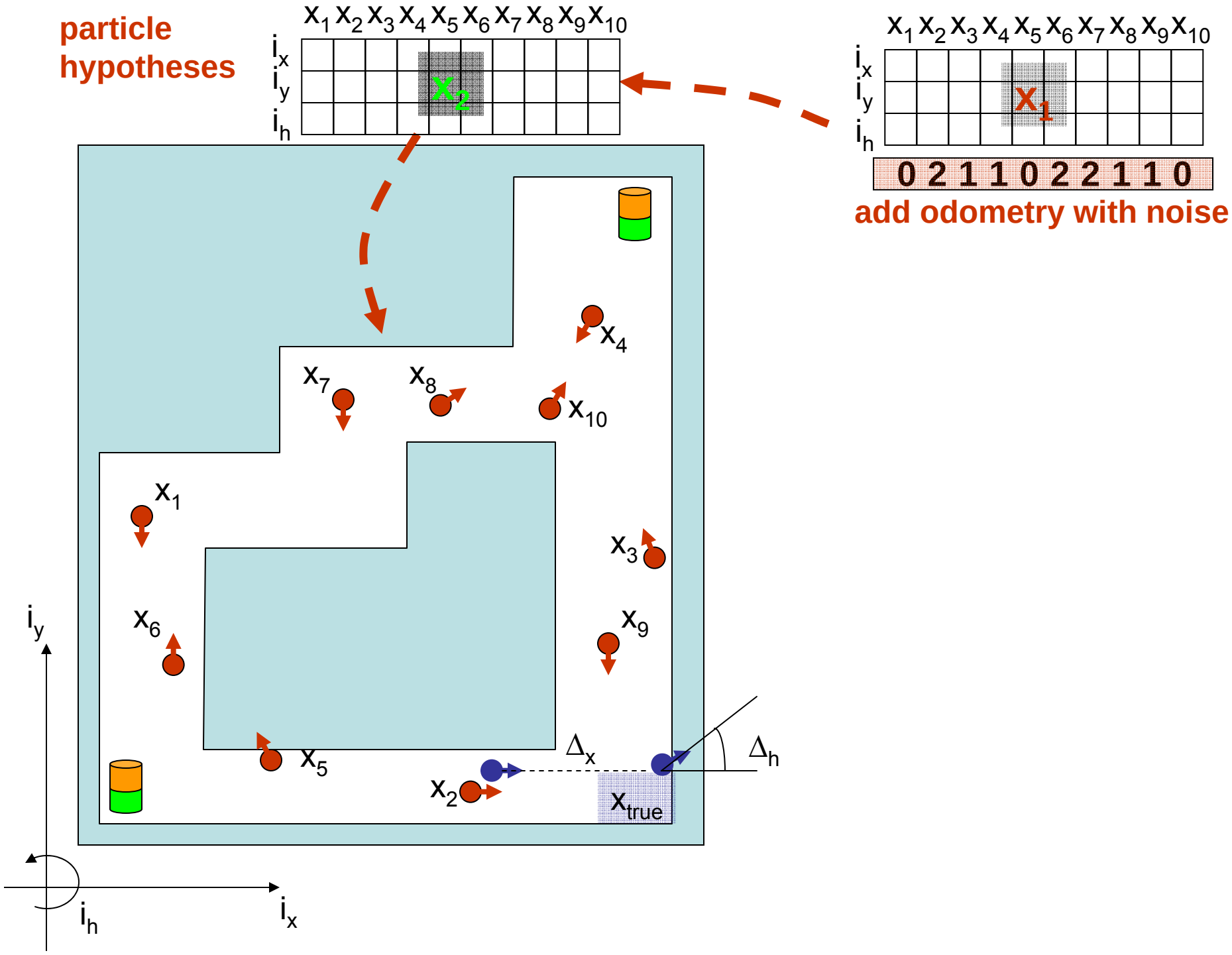
cumsum($P(\mathbf{x}_1|\mathbf{z}_1)$)/sum($P(\mathbf{x}_1|\mathbf{z}_1)$)



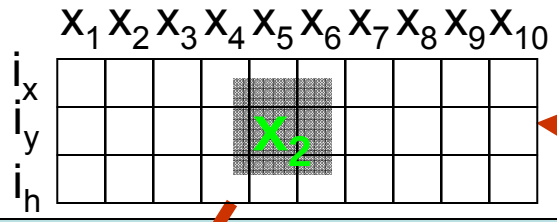


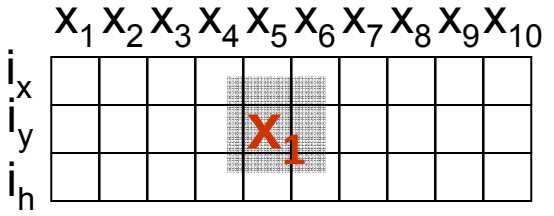


 # resamples per hypothesis (i.e., particle importance)


particle hypotheses
x1 x2 x3 x4 x5 x6 x7 x8 x9 x10
ix
iy
ih
x2
x1 x2 x3 x4 x5 x6 x7 x8 x9 x10
ix
iy
ih
x1
0 2 1 1 0 2 2 1 1 0
add odometry with noise
x4
x7
x8
x10
x1
x3
x6
x9
x5
x2
xtrue
Δx
Δh
iy
ih
ix

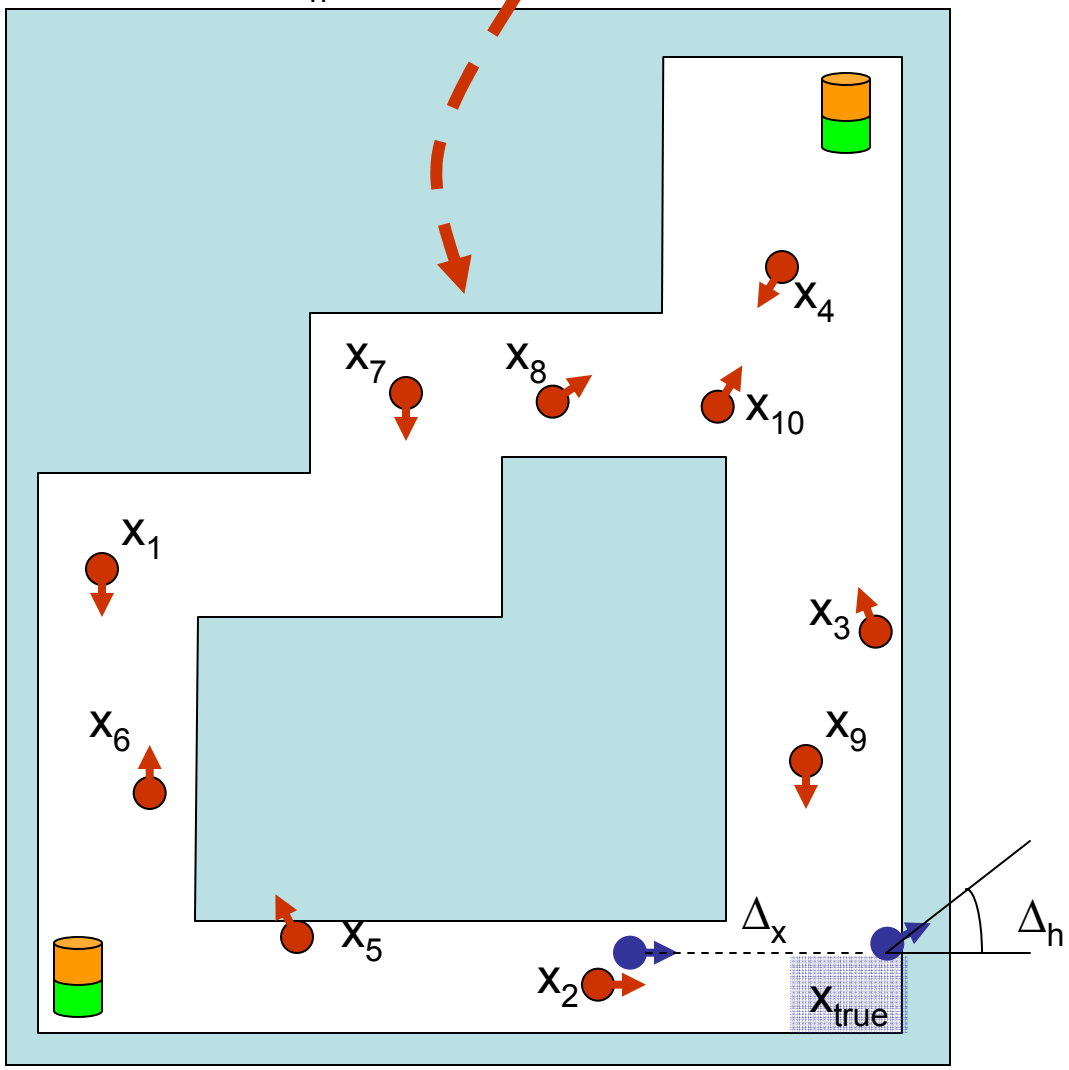
particle hypotheses



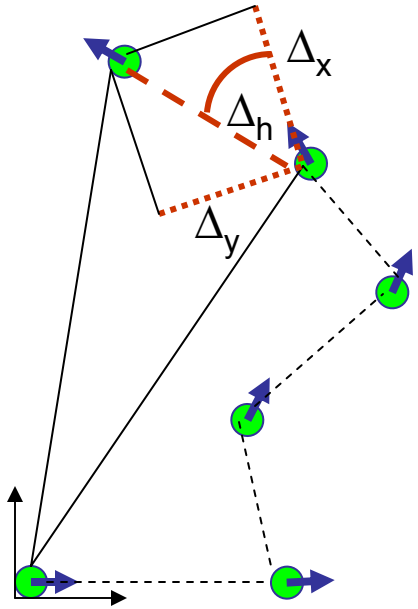


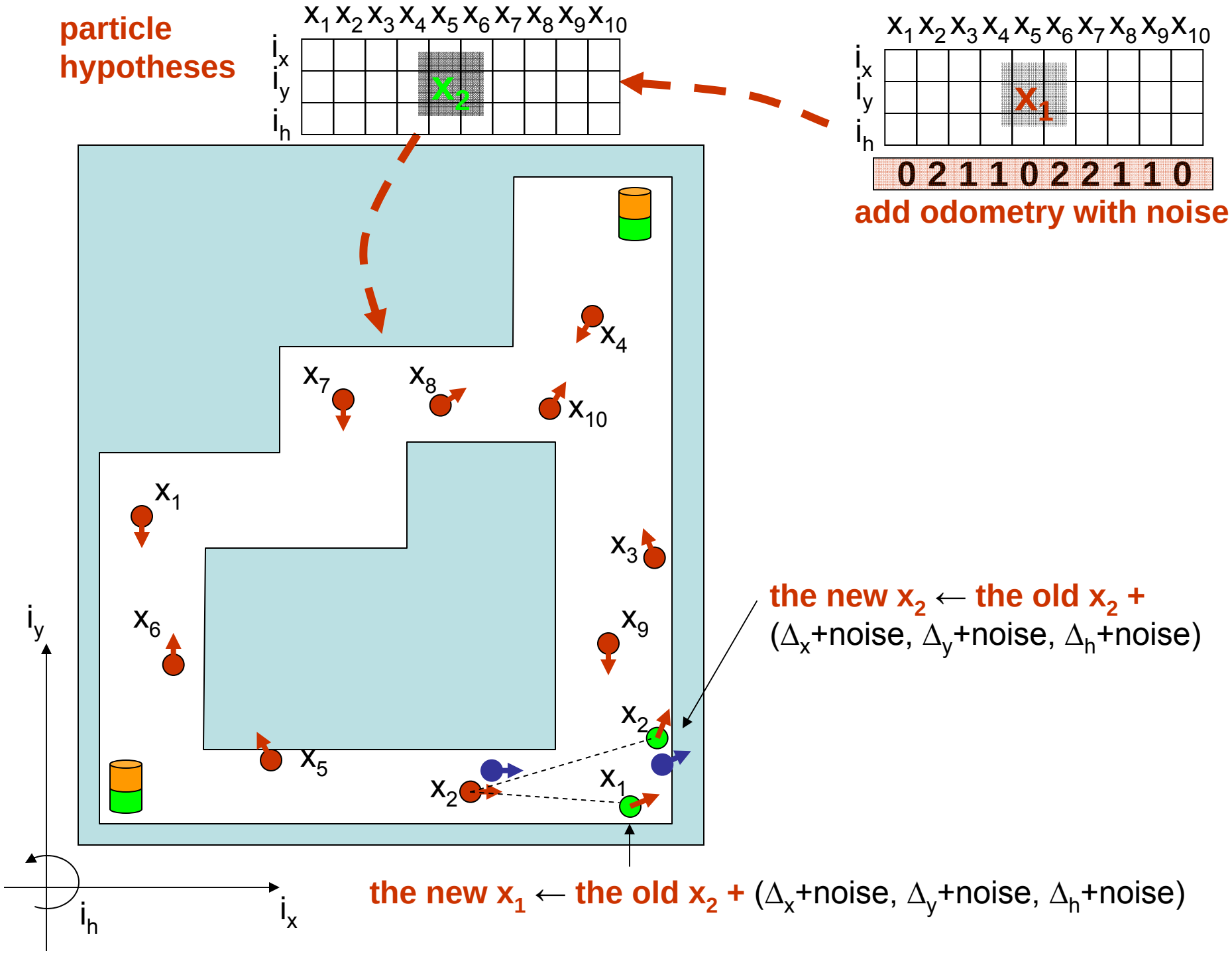
0 2 1 1 0 2 2 1 1 0

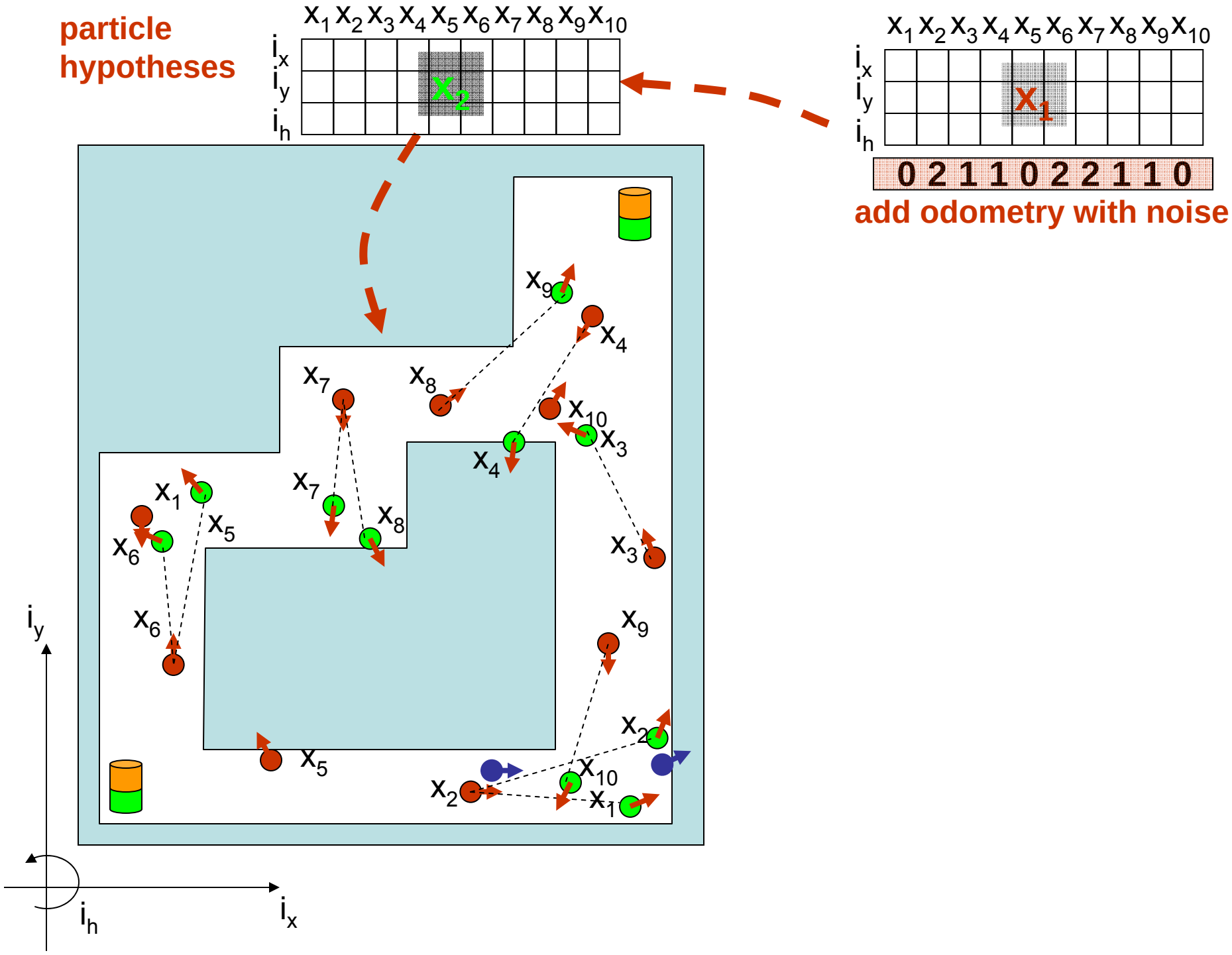
add odometry with noise

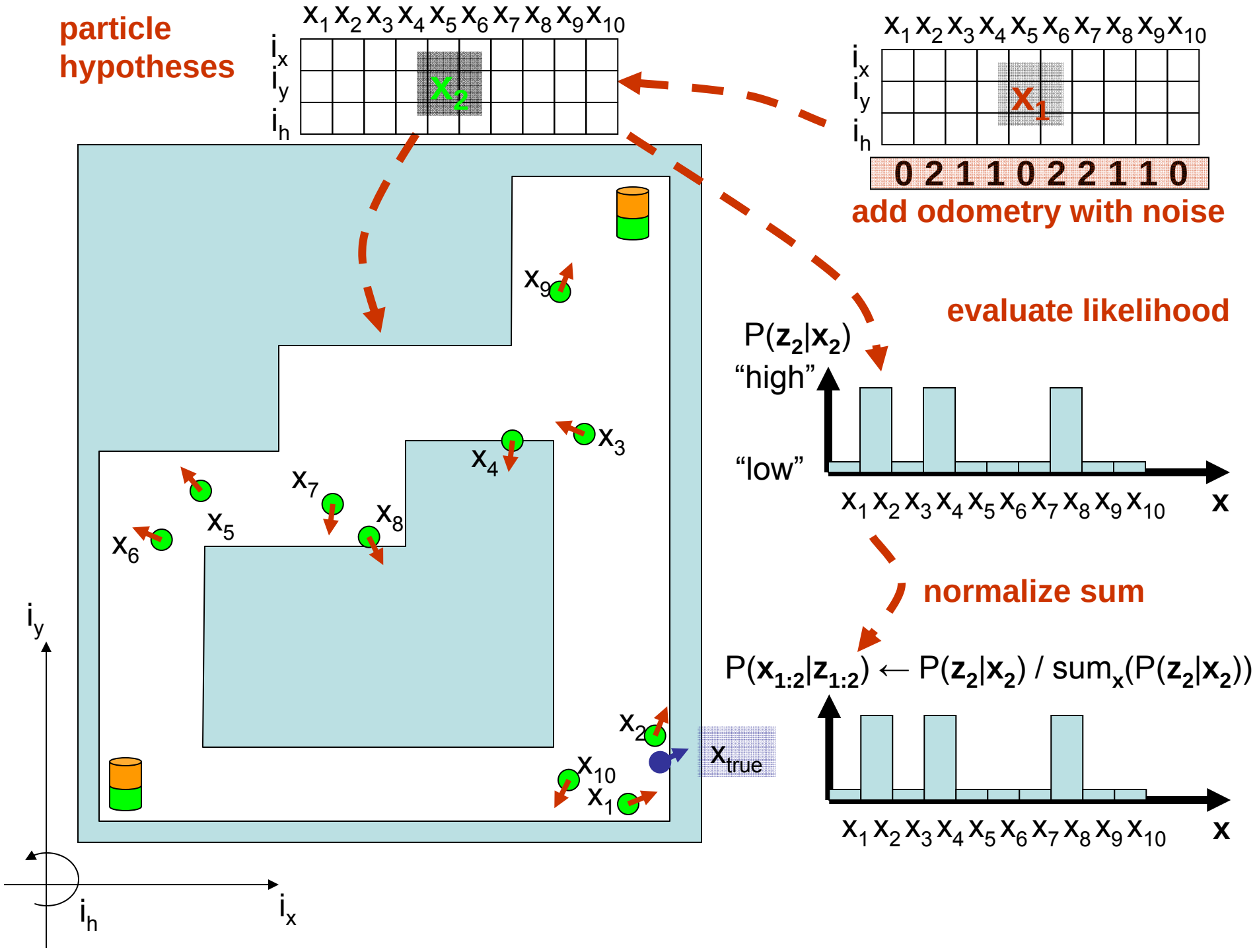


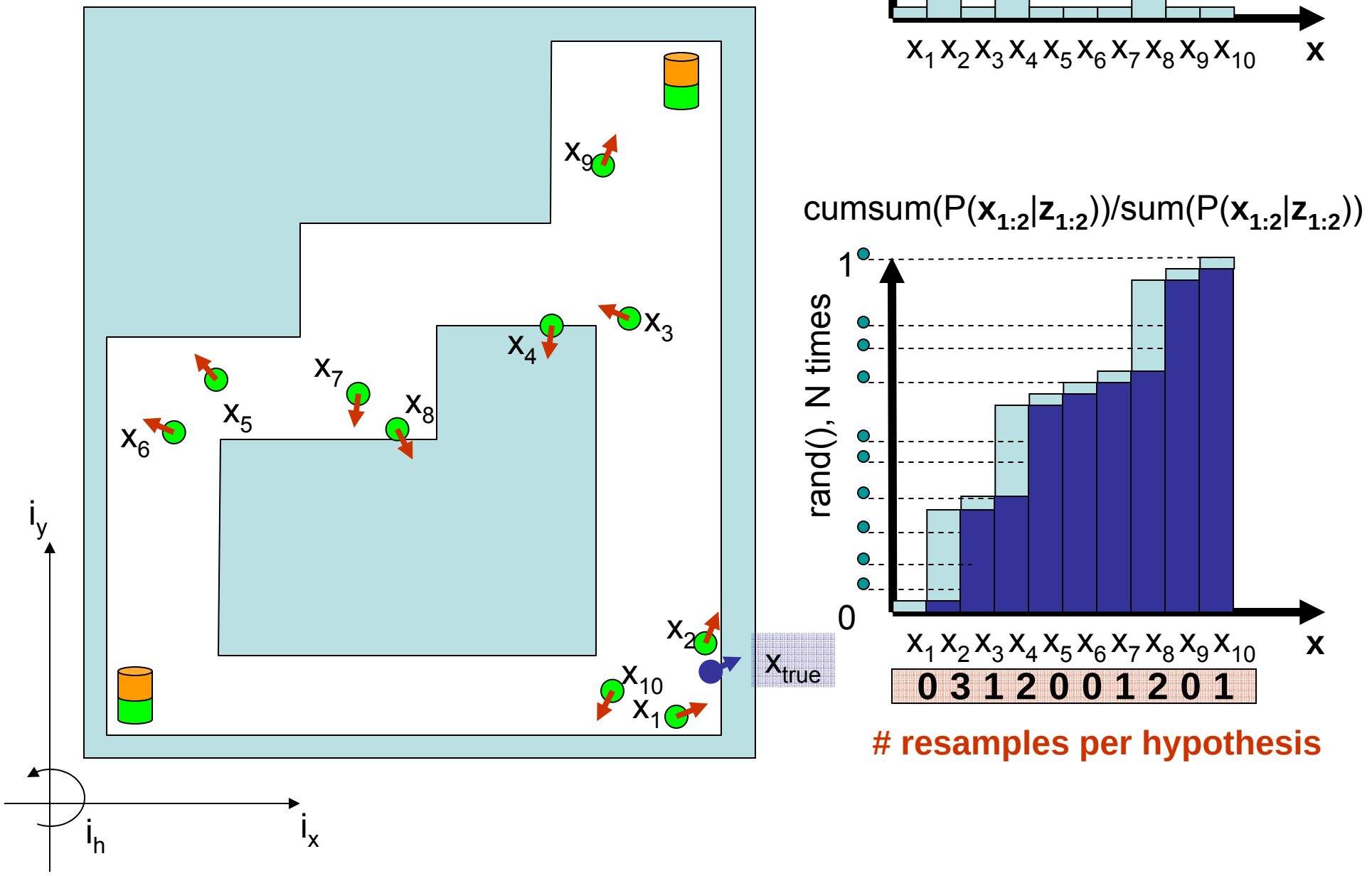
Note: odometry exists in “initial” coordinates, extract delta in “previous” coordinates

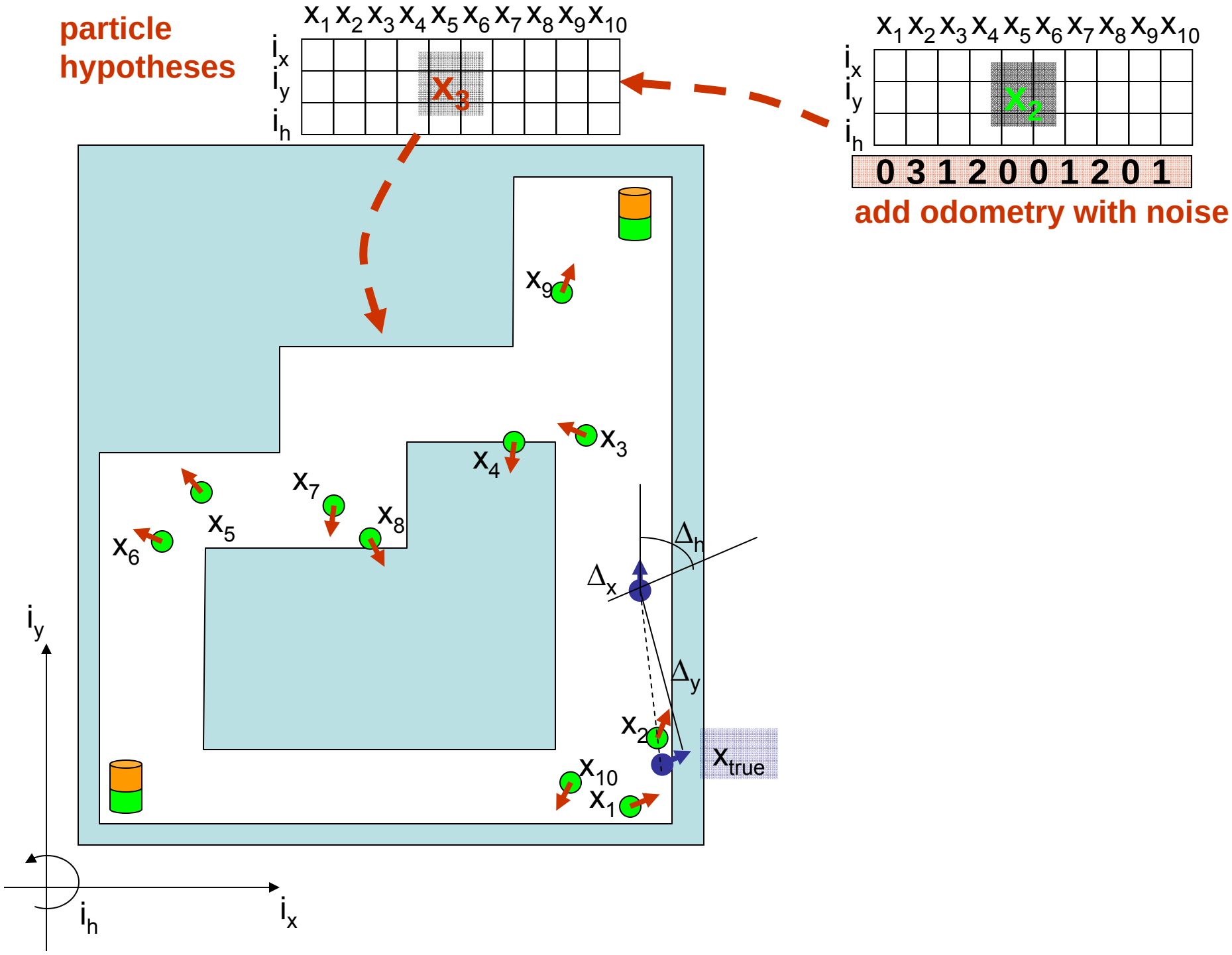


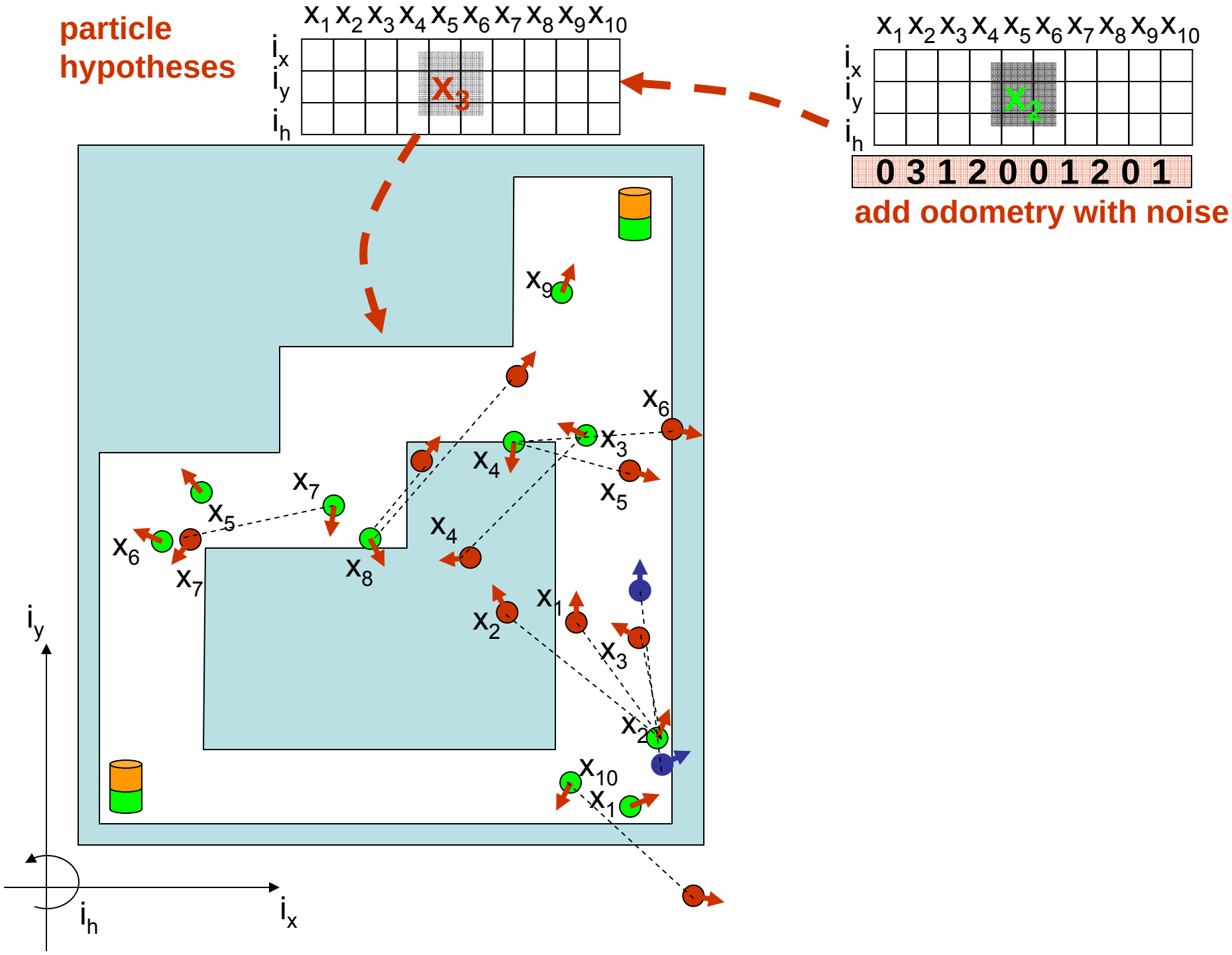

particle hypotheses
$x_1 x_2 x_3 x_4 x_5 x_6 x_7 x_8 x_9 x_{10}$
i_x
i_y
i_h
x_2
$x_1 x_2 x_3 x_4 x_5 x_6 x_7 x_8 x_9 x_{10}$
i_x
i_y
i_h
x_1
0 2 1 1 0 2 2 1 1 0
add odometry with noise
x_4
x_7
x_8
x_{10}
x_1
x_3
x_6
x_9
x_2
x_5
x_2
x_1
i_y
i_h
i_x
the new x_2 ← the old x_2 + (Δ_x+noise, Δ_y+noise, Δ_h+noise)
the new x_1 ← the old x_2 + (Δ_x+noise, Δ_y+noise, Δ_h+noise)

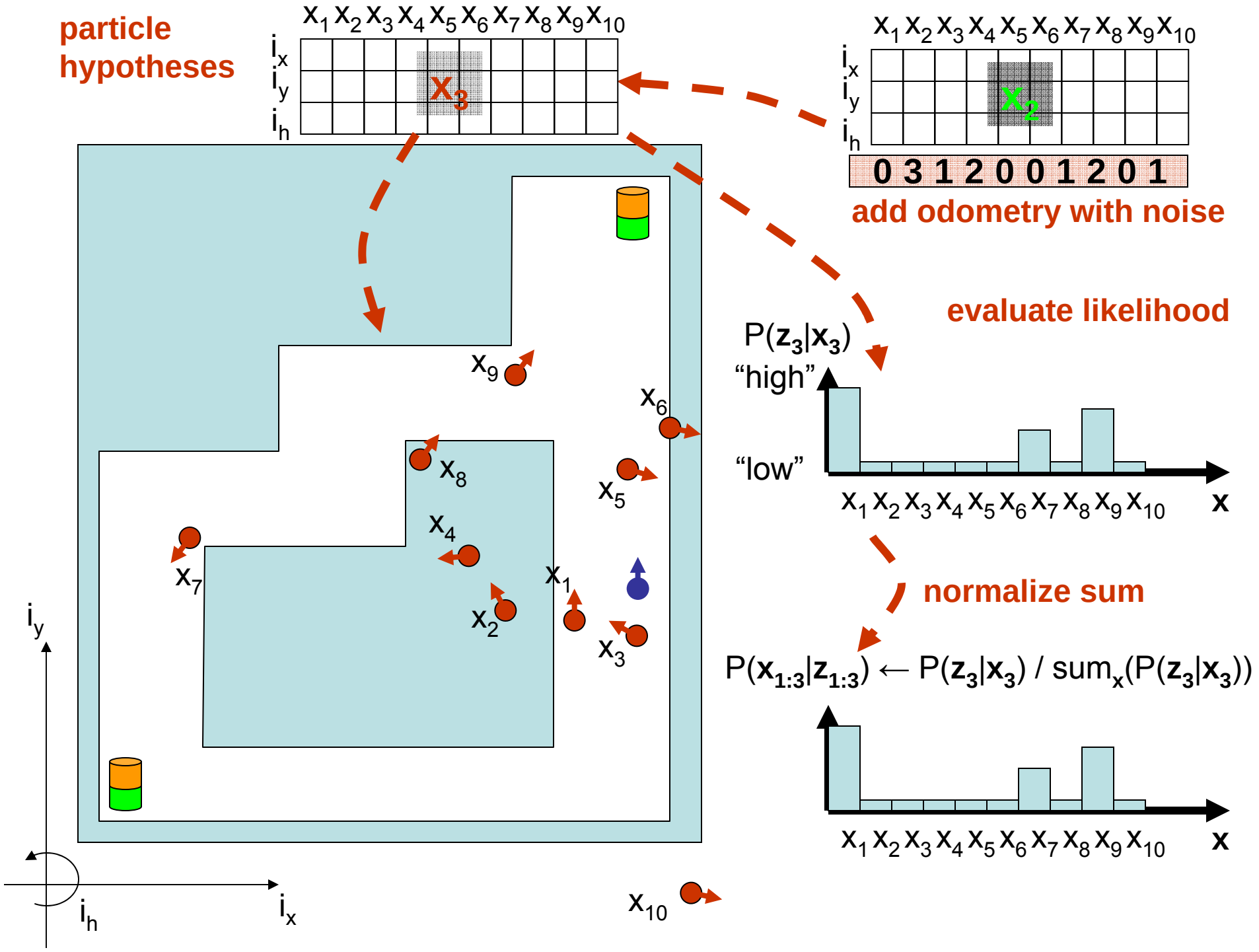

particle hypotheses
x1 x2 x3 x4 x5 x6 x7 x8 x9 x10
ix
iy
ih
x2
x1
0 2 1 1 0 2 2 1 1 0
add odometry with noise
x9
x4
x7
x8
x10
x3
x1
x5
x6
x7
x8
x4
x3
x6
x9
x2
x5
x10
x2
x1
iy
ih
ix

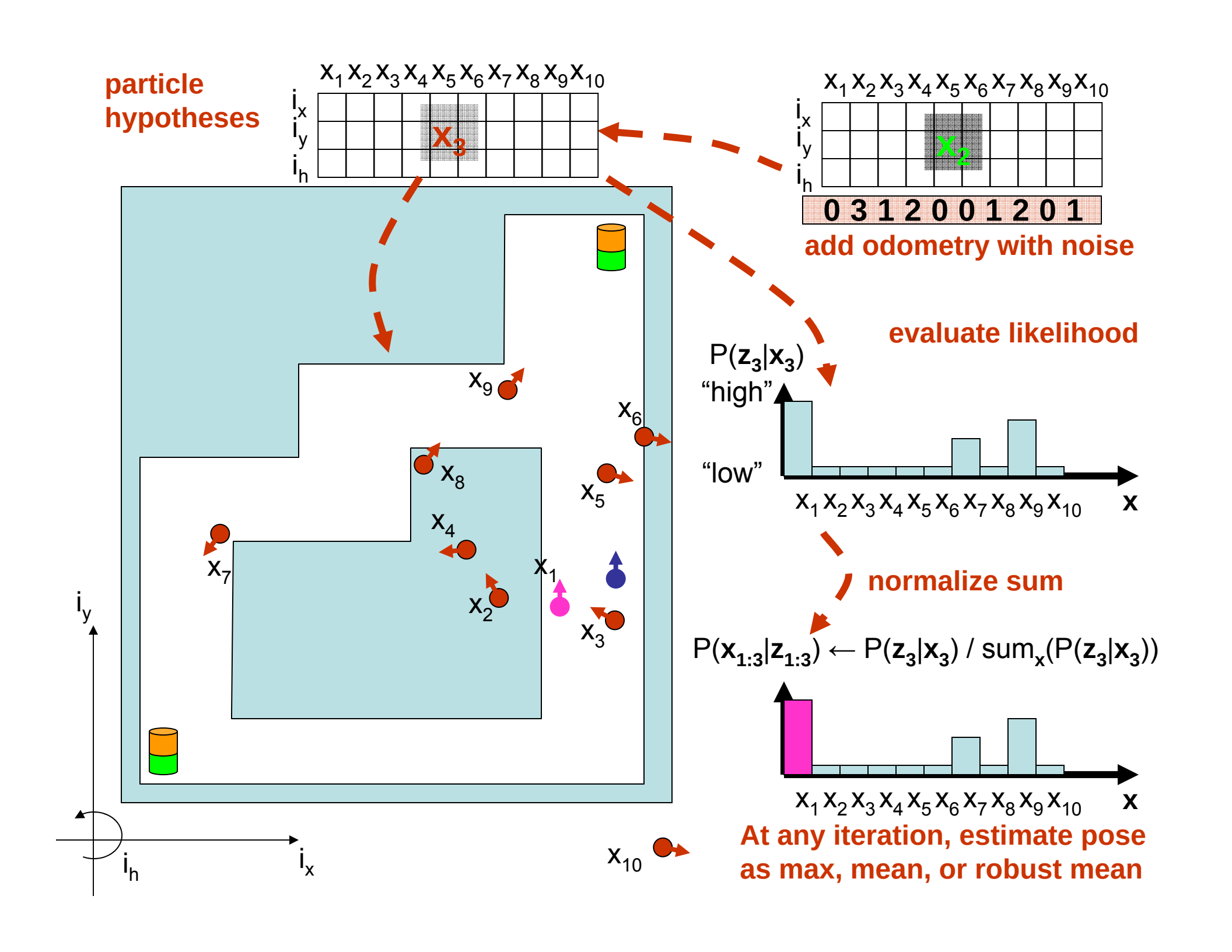

particle hypotheses
$x_1 x_2 x_3 x_4 x_5 x_6 x_7 x_8 x_9 x_{10}$
i_x
i_y
i_h
x_2
x_1
0 2 1 1 0 2 2 1 1 0
add odometry with noise
evaluate likelihood
$P(z_2|x_2)$
"high"
"low"
$x_1 x_2 x_3 x_4 x_5 x_6 x_7 x_8 x_9 x_{10}$
x
normalize sum
$P(x_{1:2}|z_{1:2}) \leftarrow P(z_2|x_2) / \text{sum}_x(P(z_2|x_2))$
x_9
x_3
x_4
x_7
x_5
x_8
x_6
x_2
x_{true}
x_{10}
x_1
i_y
i_h
i_x


$P(x_{1:2}|z_{1:2}) \leftarrow P(z_2|x_2) / sum_x(P(z_2|x_2))$
x_1 x_2 x_3 x_4 x_5 x_6 x_7 x_8 x_9 x_{10}
x
cumsum(P(x1:2|z1:2))/sum(P(x1:2|z1:2))
rand(), N times
1
0
0 3 1 2 0 0 1 2 0 1
resamples per hypothesis
x_{true}
i_y
i_h
i_x


particle hypotheses
x1 x2 x3 x4 x5 x6 x7 x8 x9 x10
ix
iy
ih
x3
x1 x2 x3 x4 x5 x6 x7 x8 x9 x10
ix
iy
ih
x2
0 3 1 2 0 0 1 2 0 1
add odometry with noise
x9
x3
x4
x7
x5
x8
x6
Δh
Δx
Δy
x2
xtrue
x10
x1
iy
ih
ix


particle hypotheses
x1 x2 x3 x4 x5 x6 x7 x8 x9 x10
ix
iy
ih
x3
x1 x2 x3 x4 x5 x6 x7 x8 x9 x10
ix
iy
ih
x2
0 3 1 2 0 0 1 2 0 1
add odometry with noise
x9
x6
x3
x4
x5
x7
x5
x6
x7
x8
x4
x2
x1
x3
x2
x10
x1
iy
ih
ix


particle hypotheses
$x_1 x_2 x_3 x_4 x_5 x_6 x_7 x_8 x_9 x_{10}$
i_x
i_y
i_h
x_3
$x_1 x_2 x_3 x_4 x_5 x_6 x_7 x_8 x_9 x_{10}$
i_x
i_y
i_h
x_2
0 3 1 2 0 0 1 2 0 1
add odometry with noise
evaluate likelihood
$P(z_3|x_3)$
"high"
"low"
$x_1 x_2 x_3 x_4 x_5 x_6 x_7 x_8 x_9 x_{10}$
x
normalize sum
$P(x_{1:3}|z_{1:3}) \leftarrow P(z_3|x_3) / \text{sum}_x(P(z_3|x_3))$
$x_1 x_2 x_3 x_4 x_5 x_6 x_7 x_8 x_9 x_{10}$
x
x_9
x_6
x_8
x_5
x_4
x_7
x_1
x_2
x_3
x_{10}
i_y
i_h
i_x


particle hypotheses
$x_1 x_2 x_3 x_4 x_5 x_6 x_7 x_8 x_9 x_{10}$
i_x
i_y
i_h
x_3
$x_1 x_2 x_3 x_4 x_5 x_6 x_7 x_8 x_9 x_{10}$
i_x
i_y
i_h
x_2
0 3 1 2 0 0 1 2 0 1
add odometry with noise
evaluate likelihood
$P(z_3|x_3)$
"high"
"low"
$x_1 x_2 x_3 x_4 x_5 x_6 x_7 x_8 x_9 x_{10}$
x
normalize sum
$P(x_{1:3}|z_{1:3}) \leftarrow P(z_3|x_3) / \text{sum}_x(P(z_3|x_3))$
$x_1 x_2 x_3 x_4 x_5 x_6 x_7 x_8 x_9 x_{10}$
x
At any iteration, estimate pose as max, mean, or robust mean
x_9
x_6
x_8
x_5
x_4
x_7
x_1
x_2
x_3
x_{10}
i_y
i_h
i_x