Distinctive Features of Fuzzy Logic Control

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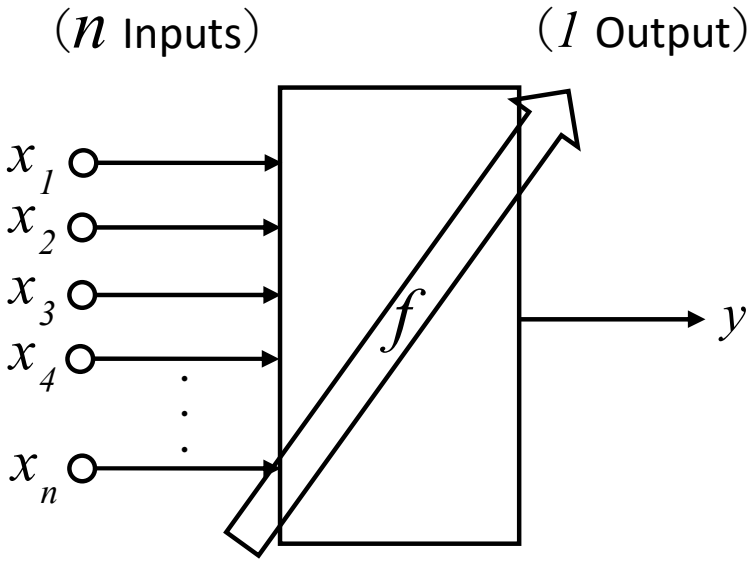
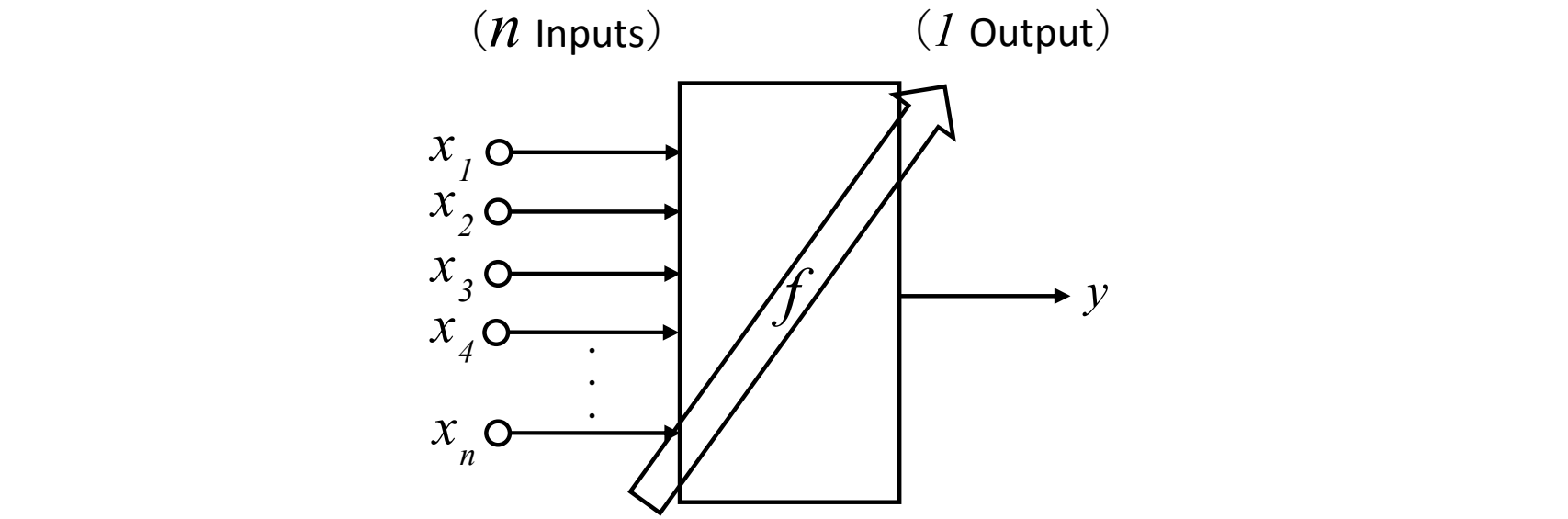


n-Input 1-Output System

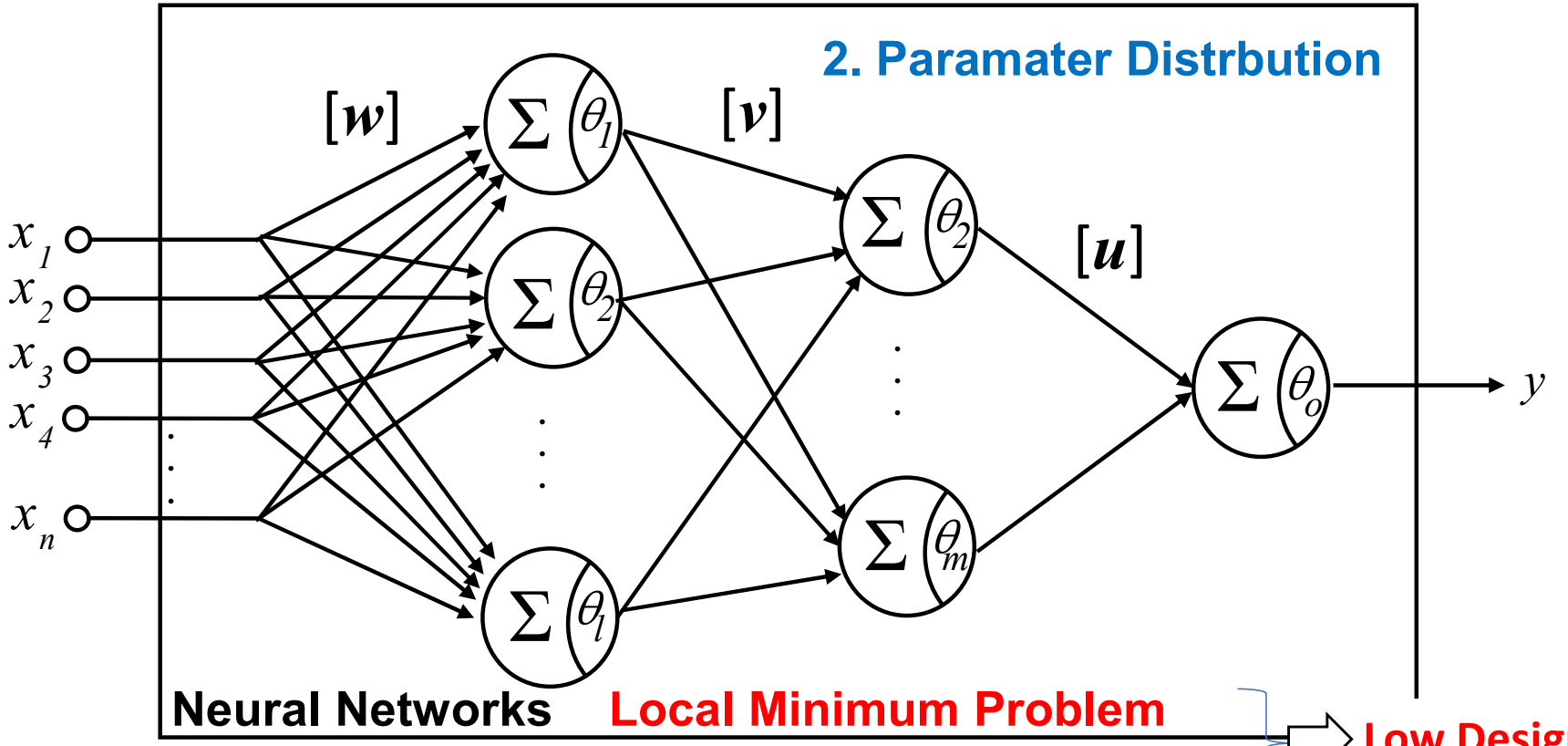
$$y = f(x_1, x_2, x_3, \cdots, x_n)$$

1. Mathematical Equation

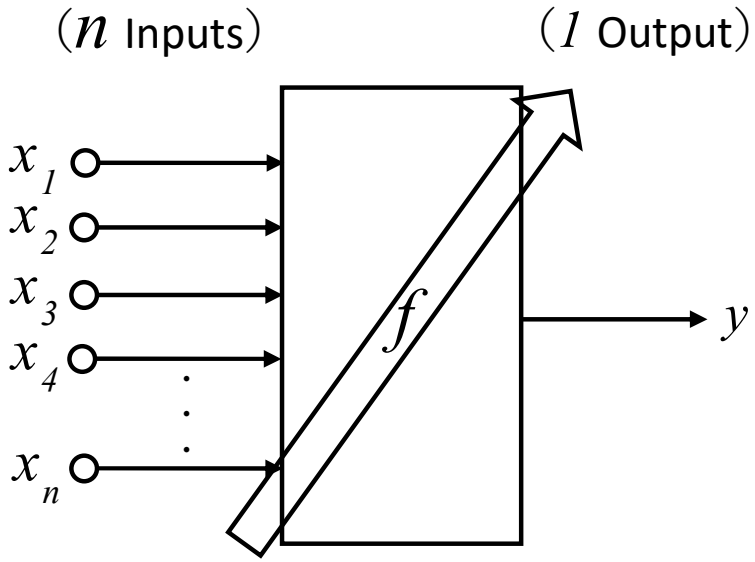
Difficult to remodel



n-Input 1-Output System



Neural Networks **Local Minimum Problem** **How Many Layers Needed?** **Low Designability**



***n*-Input *1*-Output System**

Rule NO.1 If x_1 is A_{11} and x_2 is A_{12} and x_3 is A_{13} · · · , then y is B_1.

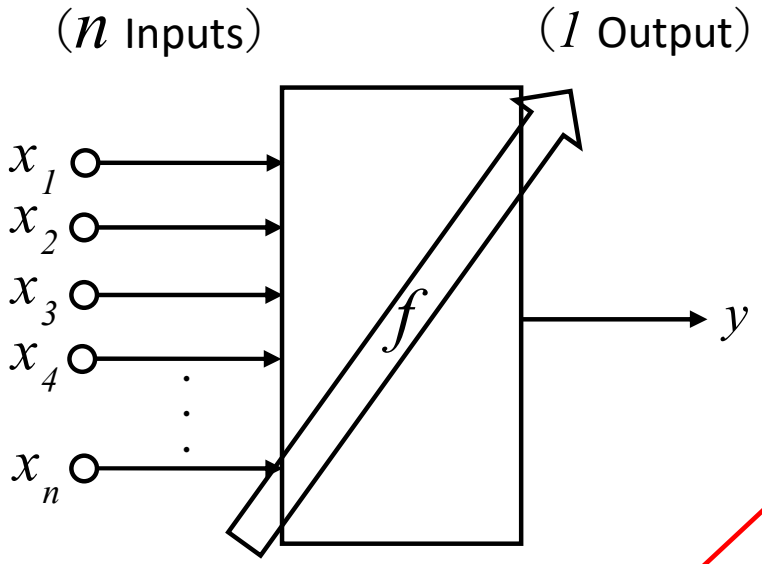
Rule NO.2 If x_1 is A_{21} and x_2 is A_{22} and x_3 is A_{23} · · · , then y is B_2.

Rule NO.3 If x_1 is A_{31} and x_2 is A_{32} and x_3 is A_{33} · · · , then y is B_3.

. . . . . .

Rule NO.r If x_1 is A_{r1} and x_2 is A_{r2} and x_3 is A_{r3} · · · , then y is B_r.

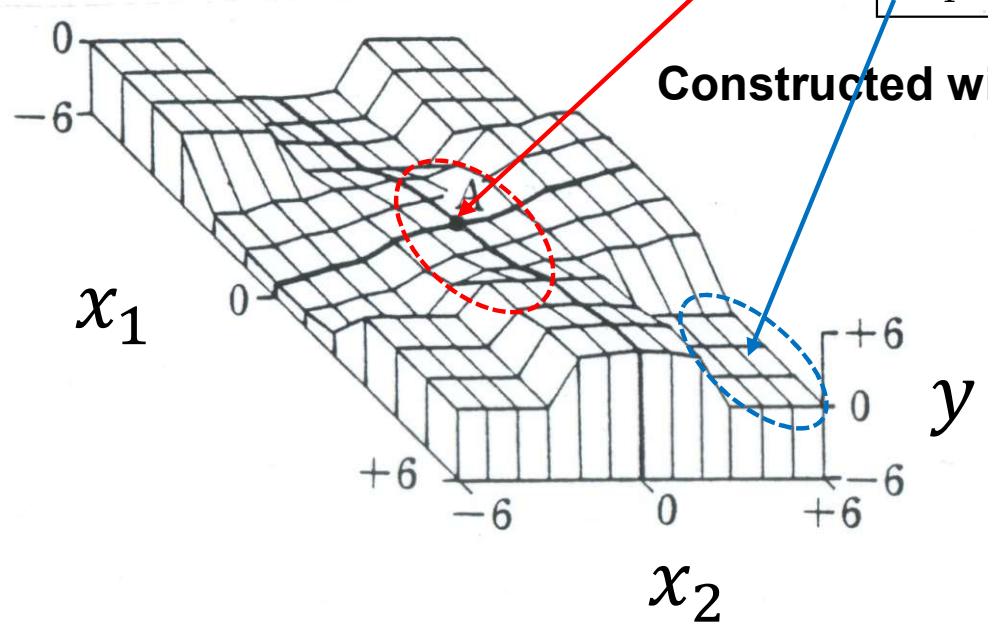
3. A Set of Fuzzy IF-THEN Rules + a Fuzzy Inference Engine + a Defuzzifier



n-Input *1*-Output System

If $x_1 \approx -6$ and $x_2 \approx -6$, then $y \approx 0$
If $x_1 \approx -6$ and $x_2 \approx 0$, then $y \approx -6$
If $x_1 \approx -6$ and $x_2 \approx +6$, then $y \approx 0$
If $x_1 \approx 0$ and $x_2 \approx -6$, then $y \approx -6$
If $x_1 \approx 0$ and $x_2 \approx 0$, then $y \approx 0$
If $x_1 \approx 0$ and $x_2 \approx +6$, then $y \approx +6$
If $x_1 \approx +6$ and $x_2 \approx -6$, then $y \approx 0$
If $x_1 \approx +6$ and $x_2 \approx 0$, then $y \approx +6$
If $x_1 \approx +6$ and $x_2 \approx +6$, then $y \approx 0$

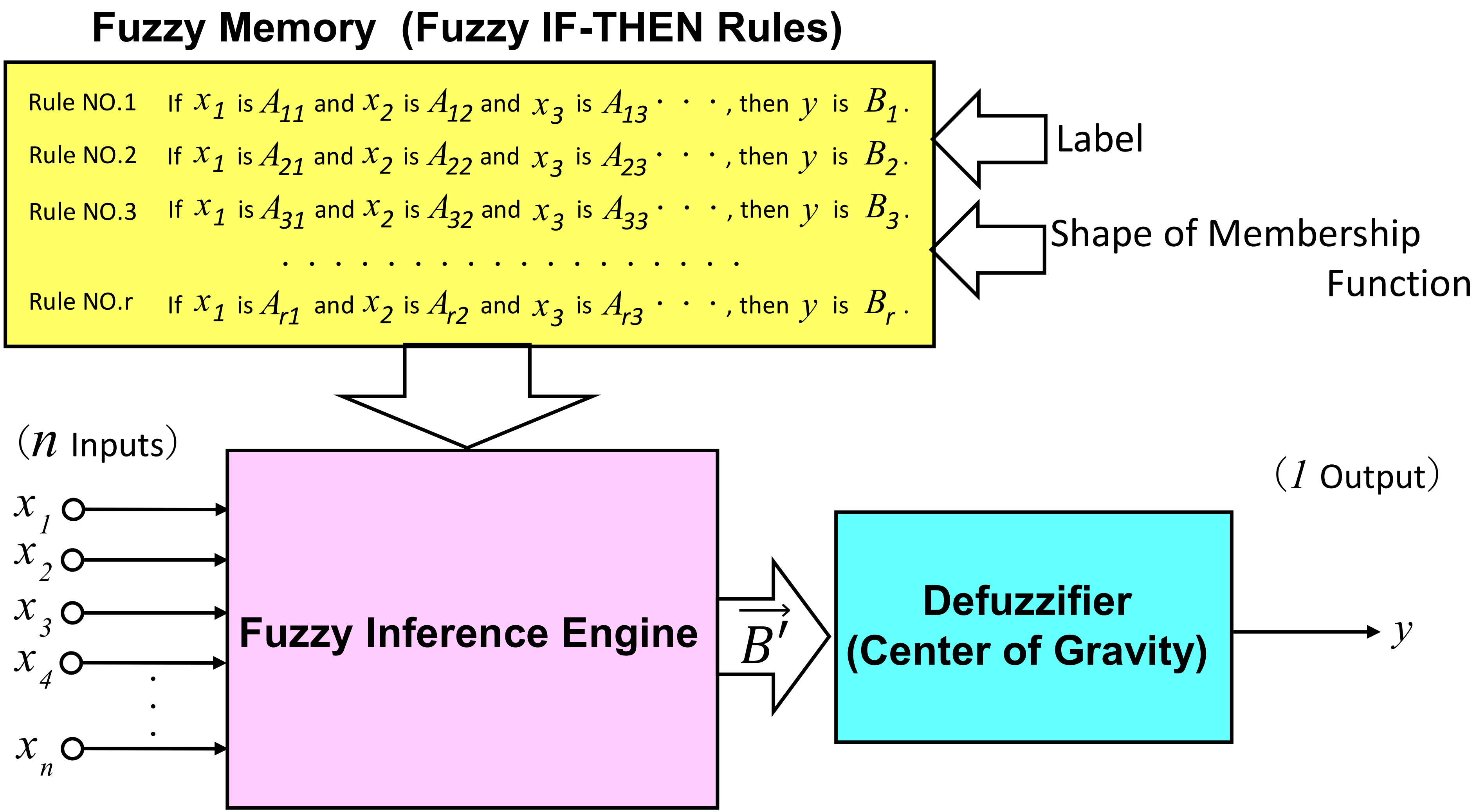
Constructed with 9 Independent Rules



High Describability (Flexible)

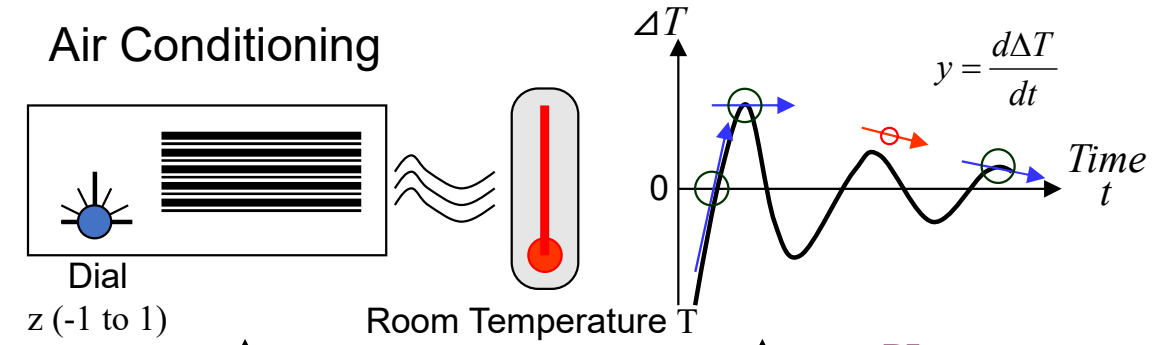
Input-Output Characteristics of 2 Input-1 Output System

3. A Set of Fuzzy IF-THEN Rules + a Fuzzy Inference Engine + a Defuzzifier



***n*-Input *1*-Output Fuzzy System**

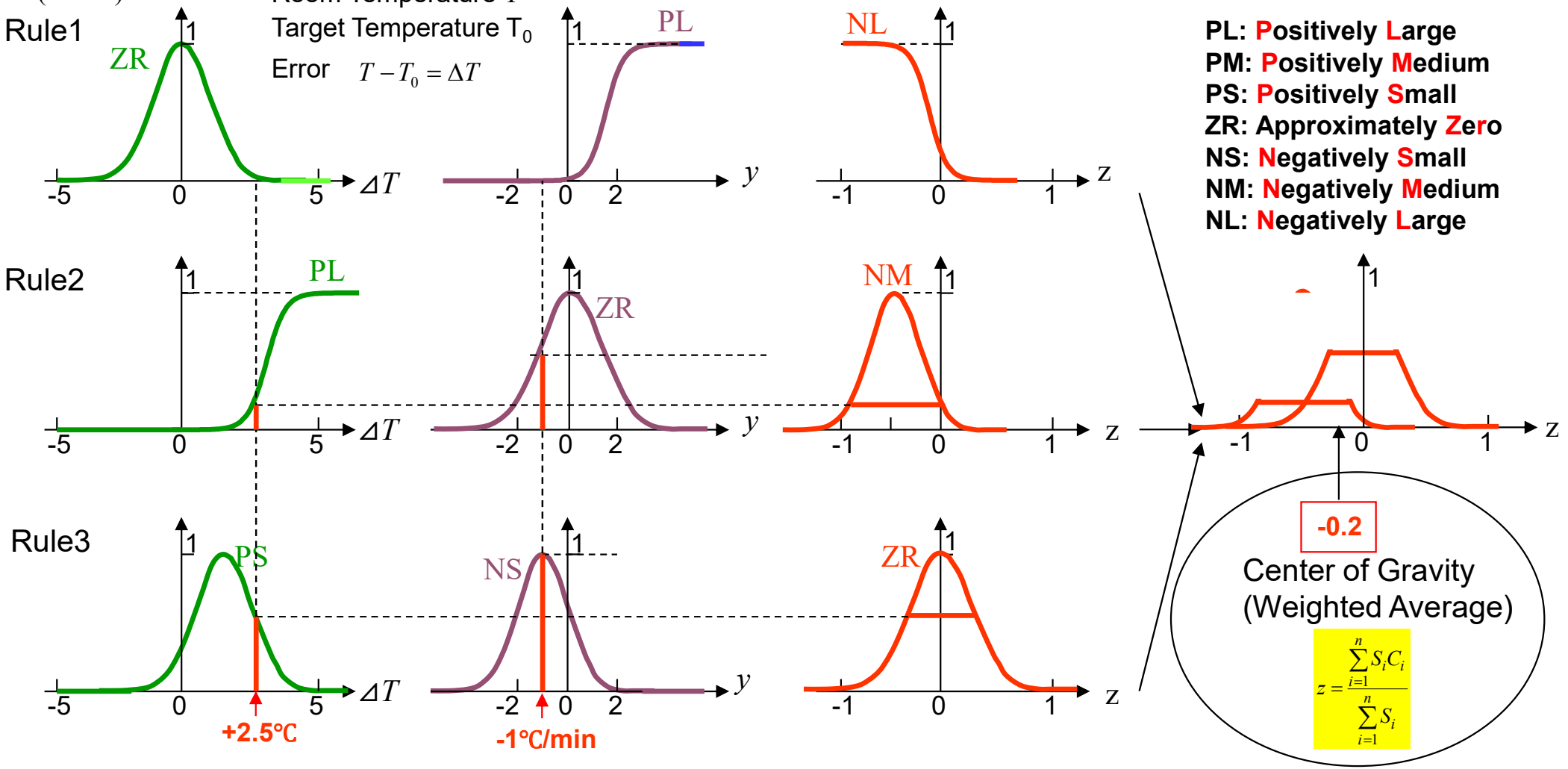
Fuzzy Inference



Fuzzy IF-THEN Rules

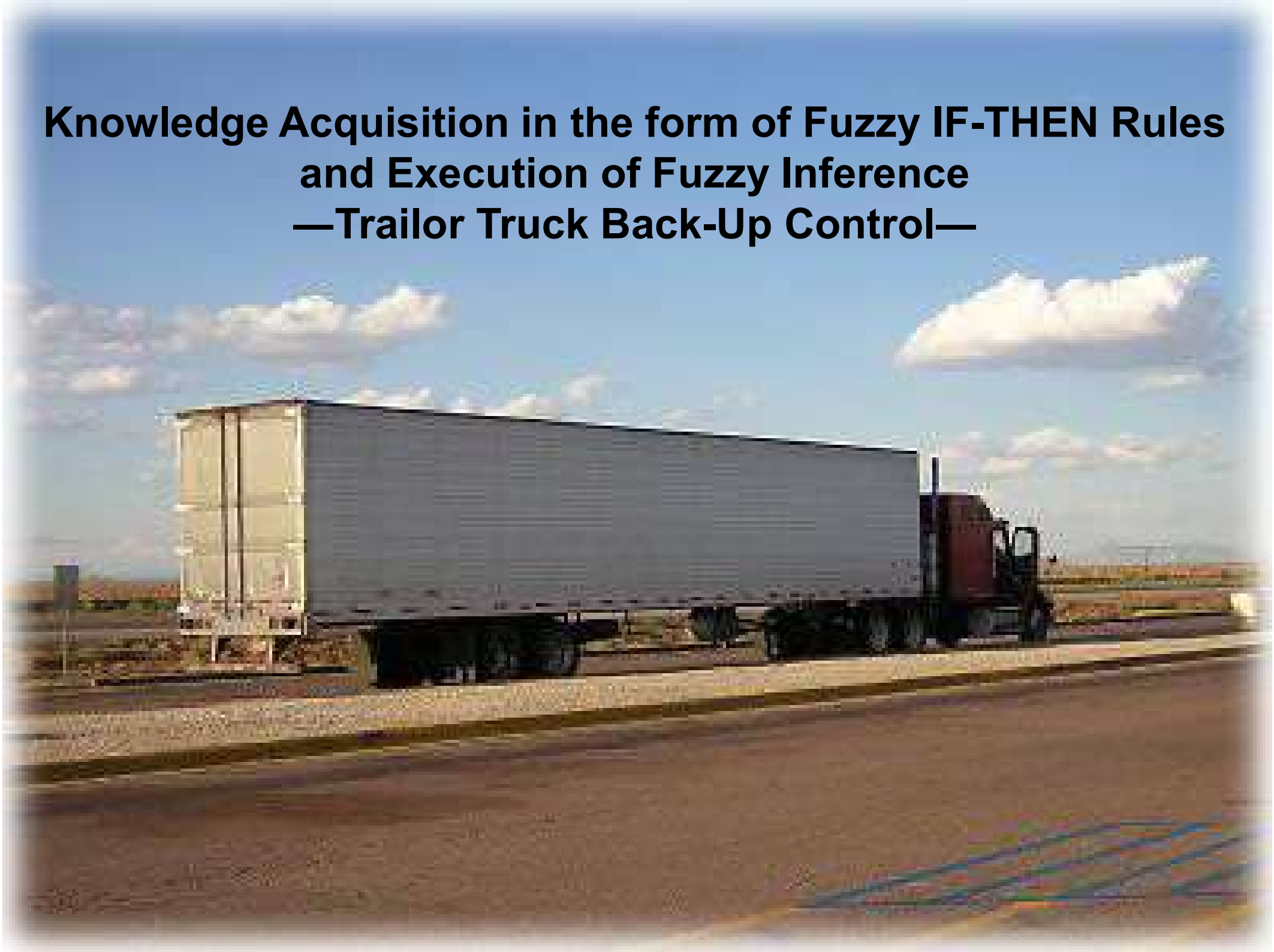
Rule1: If ΔT is ZR and y is PL, then z is NL.
Rule2: If ΔT is PL and y is ZR, then z is NM.
Rule3: If ΔT is PS and y is NS, then z is ZR.
⋮ ⋮
Fact : ΔT is +2.5℃ and y is -1℃/min

Conclusion : z is ??



PL: Positively Large
PM: Positively Medium
PS: Positively Small
ZR: Approximately Zero
NS: Negatively Small
NM: Negatively Medium
NL: Negatively Large

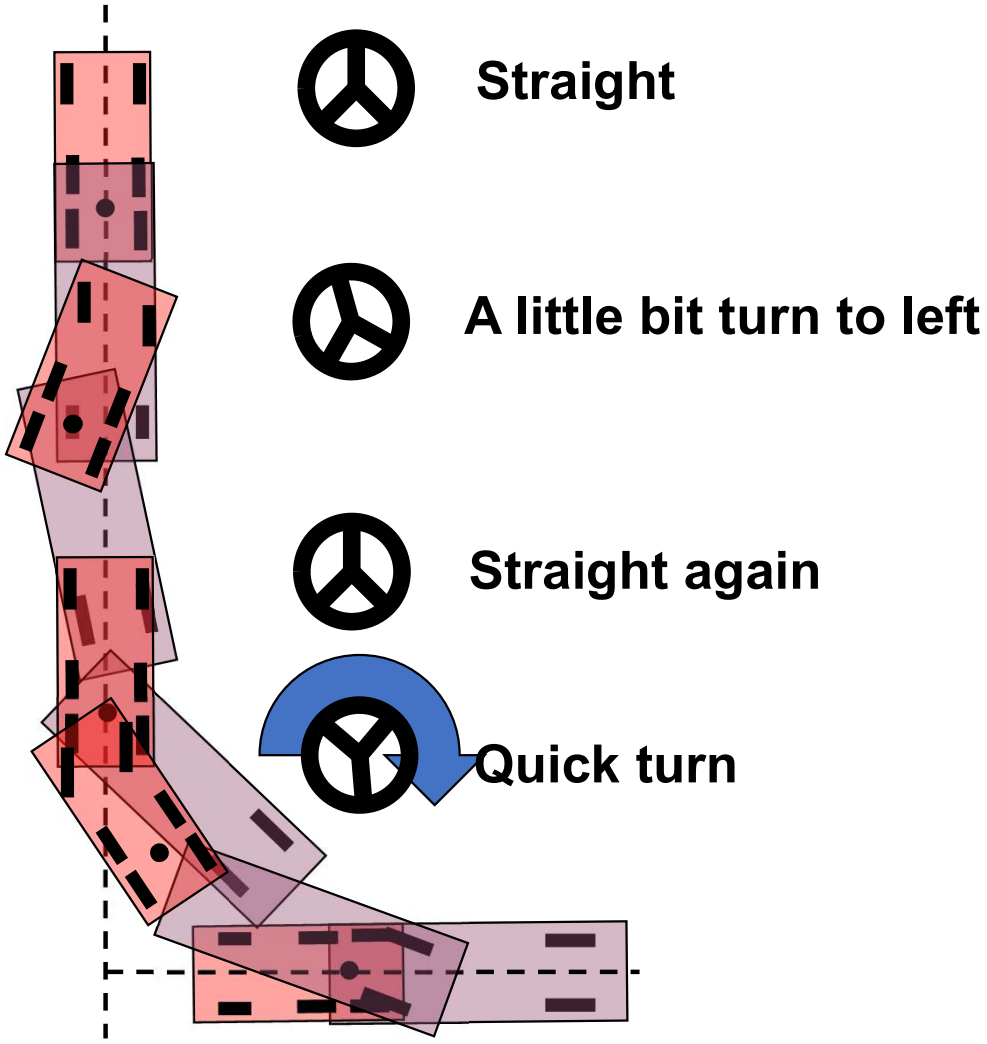
Knowledge Acquisition in the form of Fuzzy IF-THEN Rules and Execution of Fuzzy Inference —Trailor Truck Back-Up Control—



Trailer-Truck Back-Up Control

Difficulty in Trailer-Truck Back-Up

★ **Steering Wheel Control ; opposite direction to ordinary cars**



Trailer-Truck Back-Up Control

Difficulty in Trailer-Truck Back-Up

★ **Steering Wheel Control** ; opposite direction to ordinary cars

★ **Response of Trailer to Truck Movement** ; significant delay

Low speed → easy turning of steering wheel

↕

difficult detection of timing for quick turn

High speed → easy detection of timing fo

↕

difficult turning of steering wheel

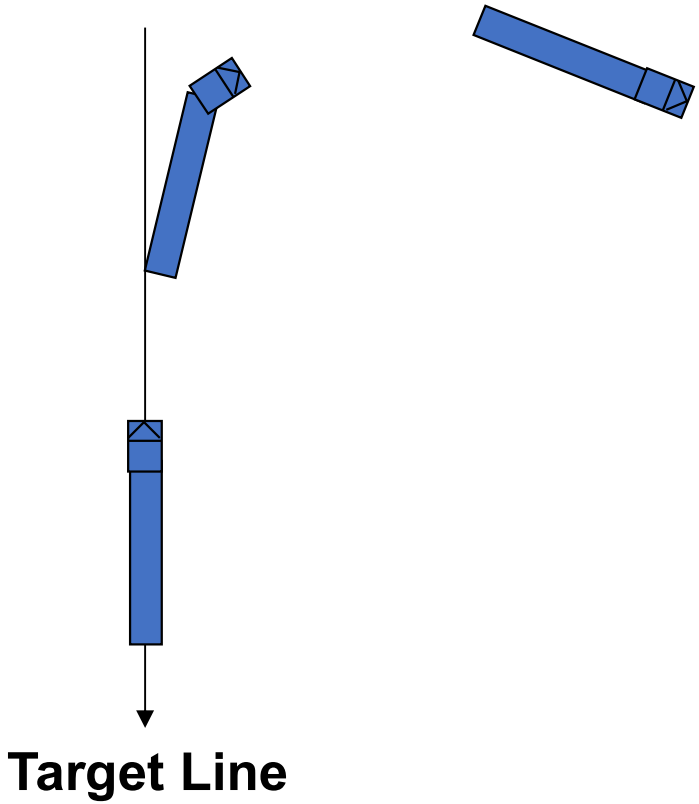
Semi-Trailer

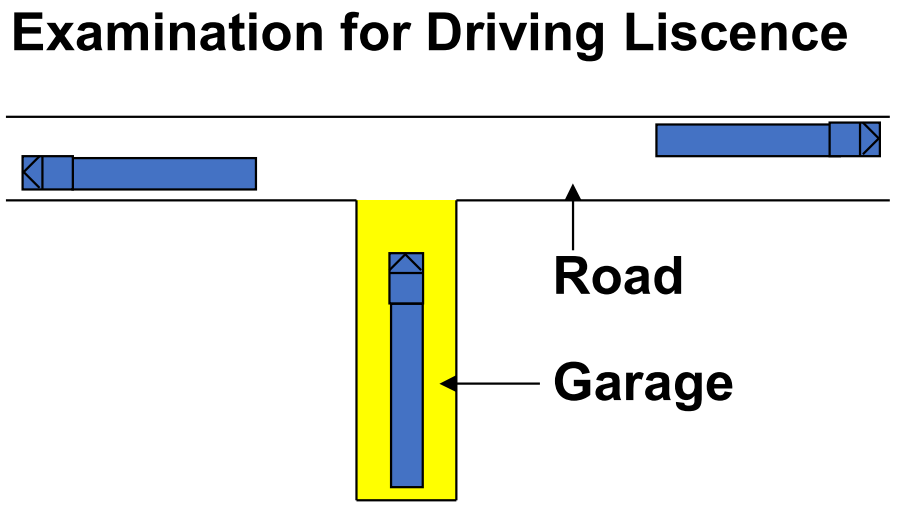
★ **Clutch/Accelerator/Brake** ;
nonlinear action-effect

★ **Driving View** ; unsymmetrical

The uncontrollable state, **"Jackknife state"**, must be avoided.

Trailer-Truck Back-Up Control





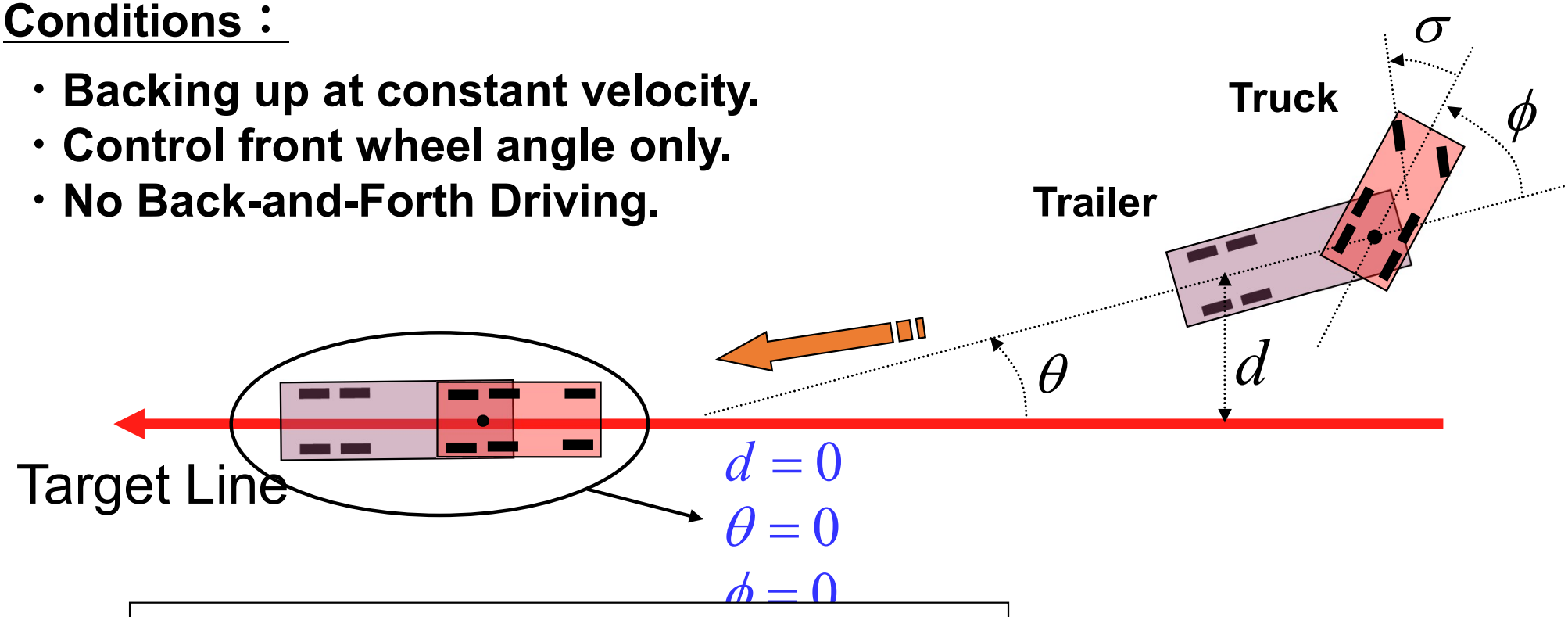
Trailer-Truck Back-Up Control

Control Objective：

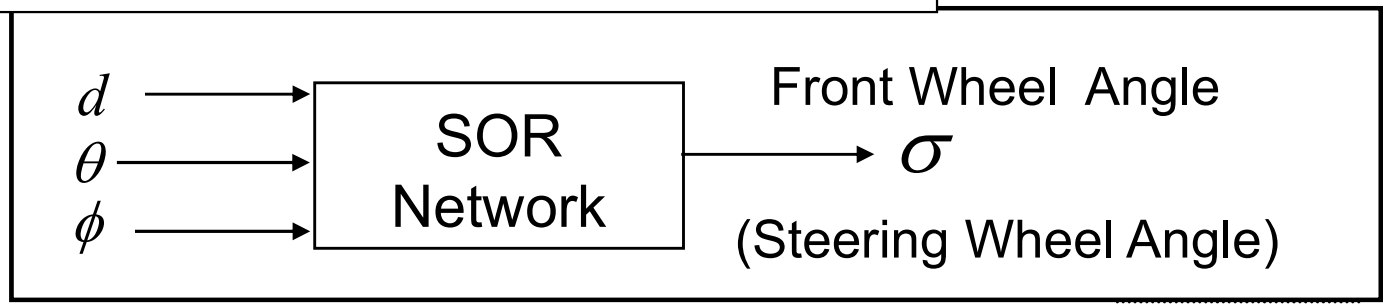
- **Follow the target line from various initial state.**

Conditions：

- **Backing up at constant velocity.**
- **Control front wheel angle only.**
- **No Back-and-Forth Driving.**



Design of 3-input 1-output controller



Design and Operation of a Controller for Trailer-Truck Back-Up

1. Generating learning vectors and evaluation

Difficult for Human Beings

Sampling of learning vectors (at random)

Evaluation of learning vectors

Proposed Method

Fuzzy Inference based Evaluation

2. Learning mode of SOR network

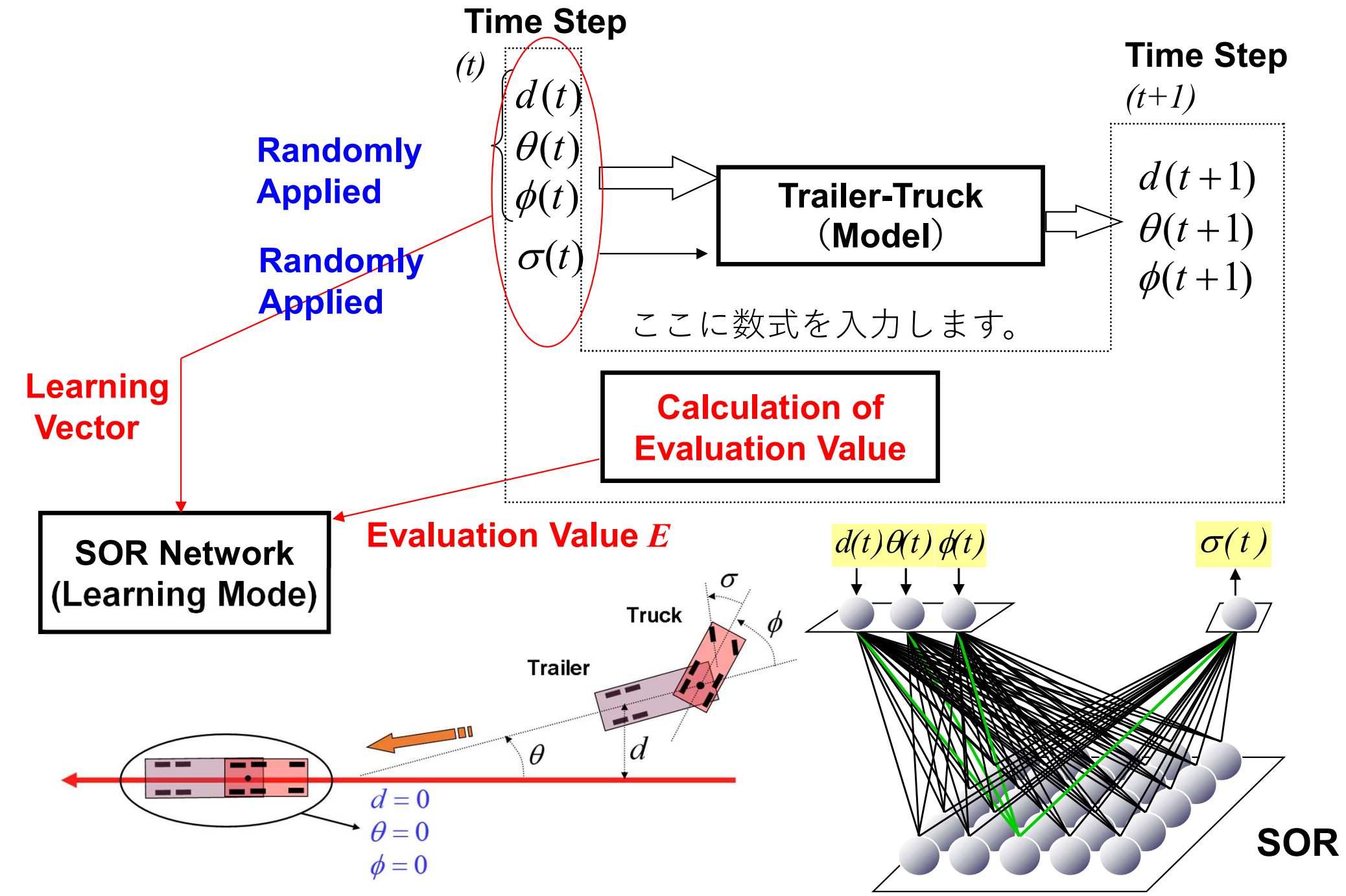
(The controller is automatically established by unsupervised learning)

3. Execution mode of SOR network

(The controller produces the adequate output in accordance with the input signals)

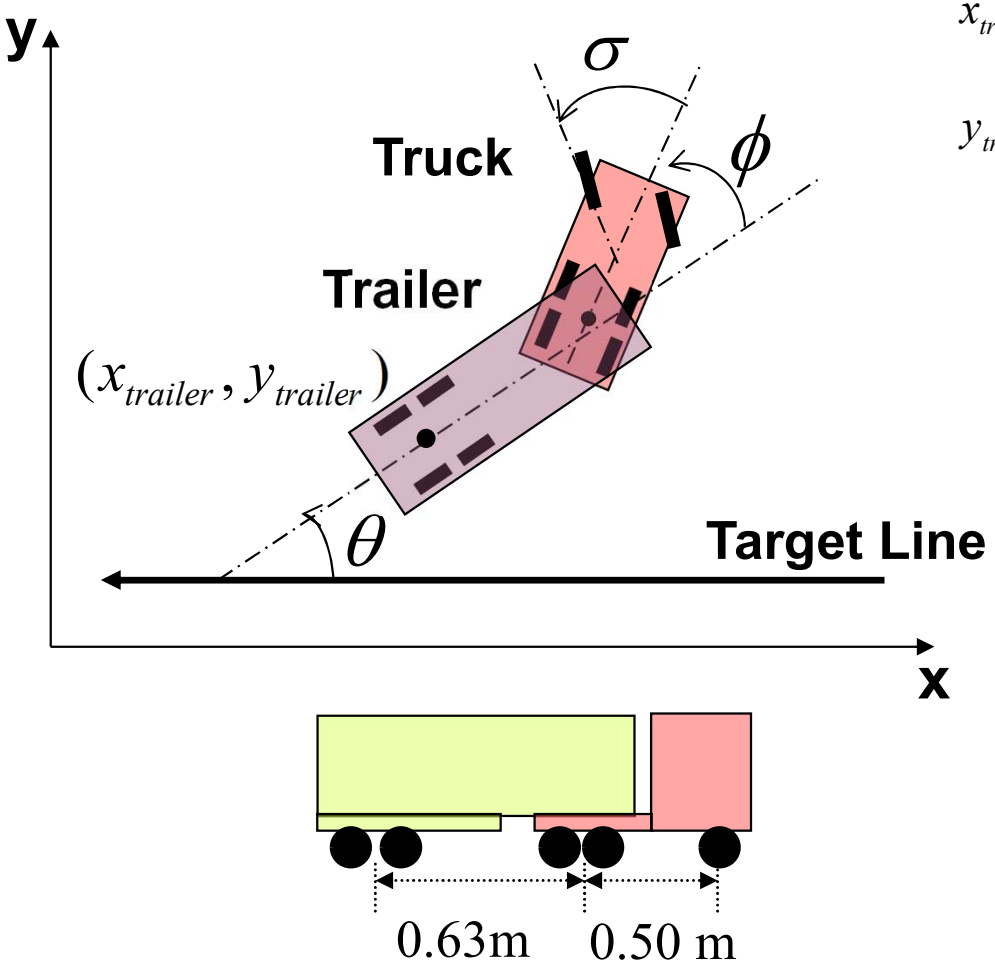
Learning Data Acquisition and Evaluation

SOR (Self-Organizing Relationship) Network



Kinematic Model of Semi-Trailer

- **Mass, inertia, and friction, etc. are neglected.**
- **No sideslip of tires is assumed.**



$$\theta_{truck}[i+1] = \theta_{truck}[i] + \frac{v \cdot \Delta t \cdot \tan\sigma[i]}{L_{truck}}$$

$$\theta_{trailer}[i+1] = \theta_{trailer}[i] + \frac{v \cdot \Delta t \cdot \sin\phi[i]}{L_{trailer}}$$

$$\phi[i] = \theta_{truck}[i] - \theta_{trailer}[i]$$

$$x_{trailer}[i+1] = x_{trailer}[i] + v \cdot \Delta t \cdot \cos\phi[i] \cdot \cos\frac{\theta_{trailer}[i+1] + \theta_{trailer}[i]}{2}$$

$$y_{trailer}[i+1] = y_{trailer}[i] + v \cdot \Delta t \cdot \cos\phi[i] \cdot \sin\frac{\theta_{trailer}[i+1] + \theta_{trailer}[i]}{2}$$

σ： Front wheel angle of truck (rad)

$\theta_{trailer}$： Trailer angle against target line(rad)

θ_{truck}： Truck angle against target line (rad)

ϕ： Angle between truck and trailer (rad)

$x_{trailer}$： x direction coordinate of trailer (m)

$y_{trailer}$： y direction coordinate of trailer (m)

L_{truck}： Wheel base of truck (m)

$L_{trailer}$： Wheel base of trailer (m)

⊿t: Sampling interval (sec)

v: Backing up velocity (m/sec)

Evaluation by Fuzzy Inference

Antecedent Part of Fuzzy If-Then Rules

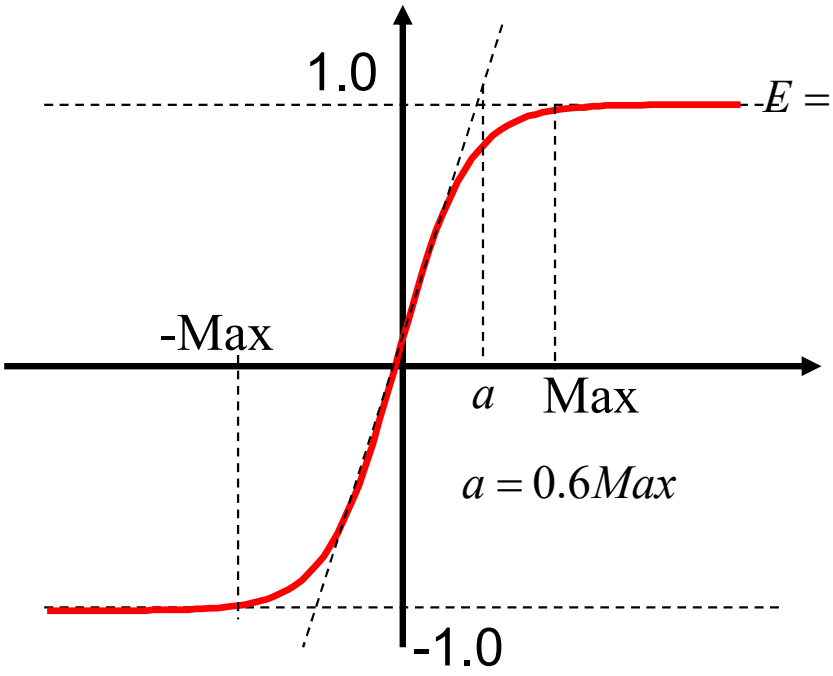
State of Trailer-Truck at *t* $(\phi(t), \theta(t), d(t))$.

Consequent Part of Fuzzy If-Then Rules.

Evaluation Value for I/O relationship of target system.

(Evaluation value is calculated based on decrease of error between *t* and *t+1*)

Evaluation Value $E\ \{E_\phi, E_\theta, E_d\}$



$$E = \frac{\tanh(\Delta\phi, \Delta\theta, \Delta d)}{a}$$

$$\Delta\phi = |\phi(t)| - |\phi(t+1)|$$

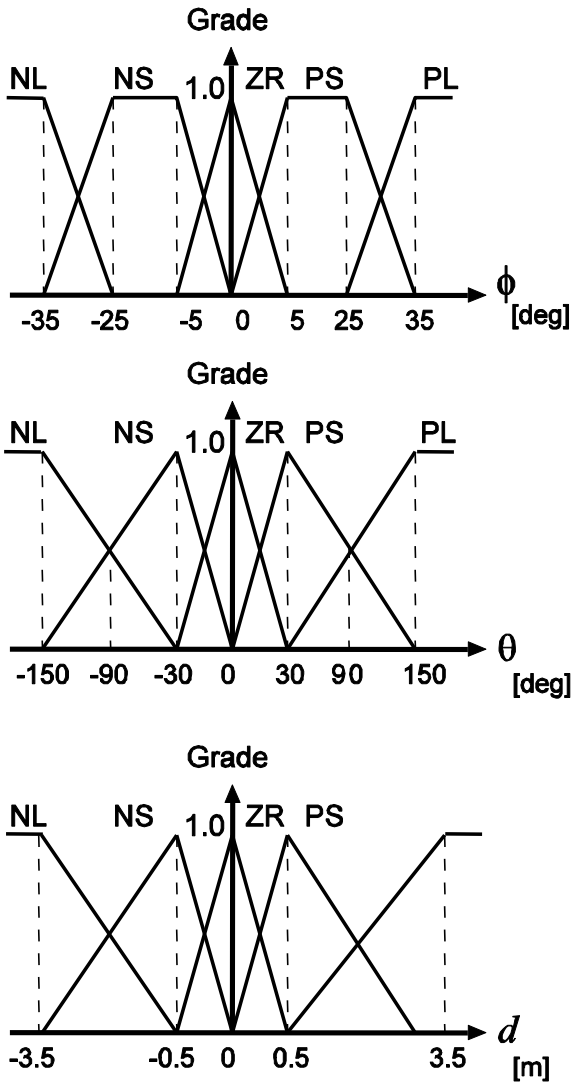
$$\Delta\theta = |\theta(t)| - |\theta(t+1)|$$

$$\Delta d = |d(t)| - |d(t+1)|$$

Evaluation by Fuzzy Inference

If φis PS, θis ZR and *d* is PL , then Evaluation is calculated by E_ϕ

φ		*d*		θ: NL	θ: NS	θ: ZR	θ: PS	θ: PL
φ	PL	*d*	PL	$E\phi$				
			PS					
			ZR					
			NS					
			NL					
	PS	*d*	PL	$E\phi$			Ed	$E\theta$
			PS				$E\theta$	
			ZR				$E\theta$	
			NS	$E\phi$	$E\phi$		$E\theta$	
			NL		Ed			
	ZR	*d*	PL	$E\theta$		Ed	Ed	$E\theta$
			PS				$E\theta$	
			ZR			$E\phi$	$E\theta$	
			NS	$E\theta$	$E\theta$	Ed	$E\theta$	
			NL		Ed			
	NS	*d*	PL	$E\theta$		Ed	$E\phi$	
			PS			$E\phi$		
			ZR			$E\phi$		
			NS	$E\theta$	$E\theta$	$E\phi$		
			NL		Ed			
	NL	*d*	PL	$E\phi$				
			PS					
			ZR					
			NS					
			NL					



If-Then Rule Table and Membership Function

Number of Rules: 5X5X5=125

The rule table means that which variable should be decreased in each situation.

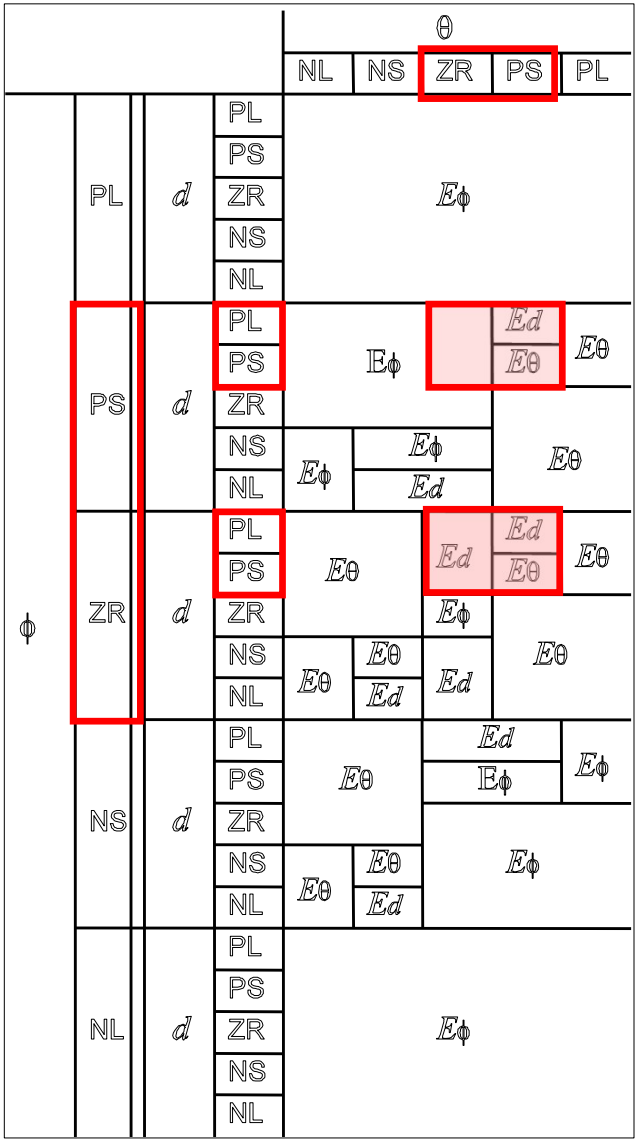
The rules can be merged according to the situation as shown.

The rule table is symmetrical about a point.

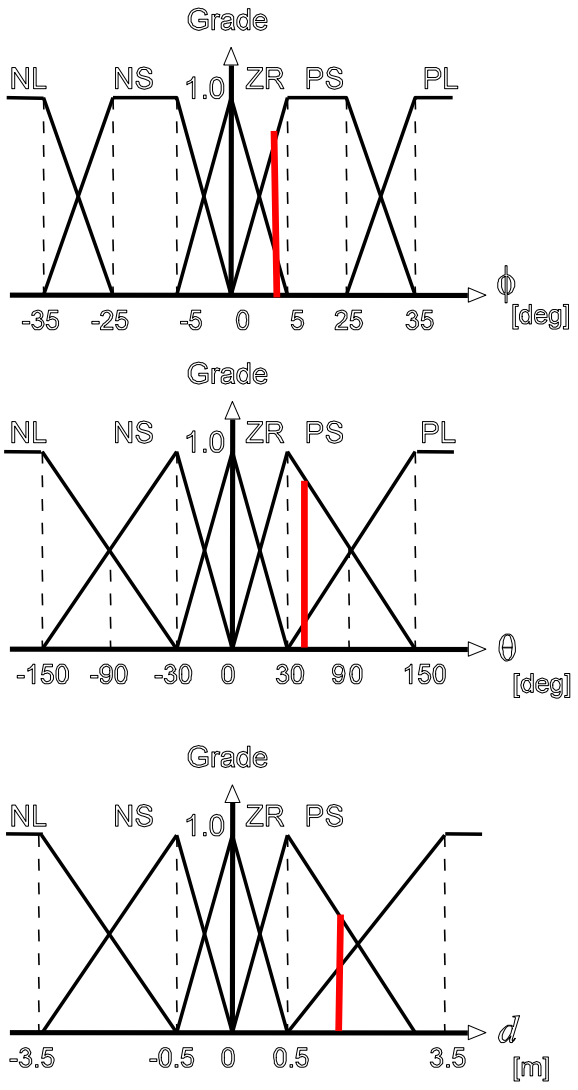
Practically, about 16 rules should be considered.

Evaluation by Fuzzy Inference

Complementary Membership Function ⟶ 2X2X2=8 rules activated



If-Then Rule Table and Membership Function



Example of Inference Process：

Fact :

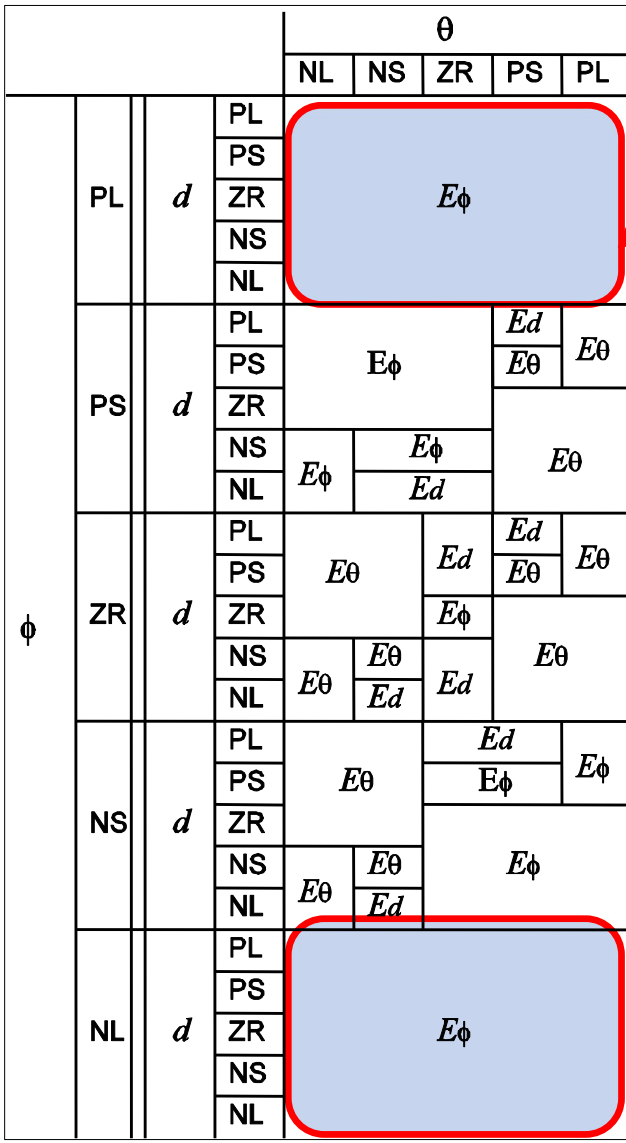
ϕis 4.0, θis 45.0 and *d* is 1.0

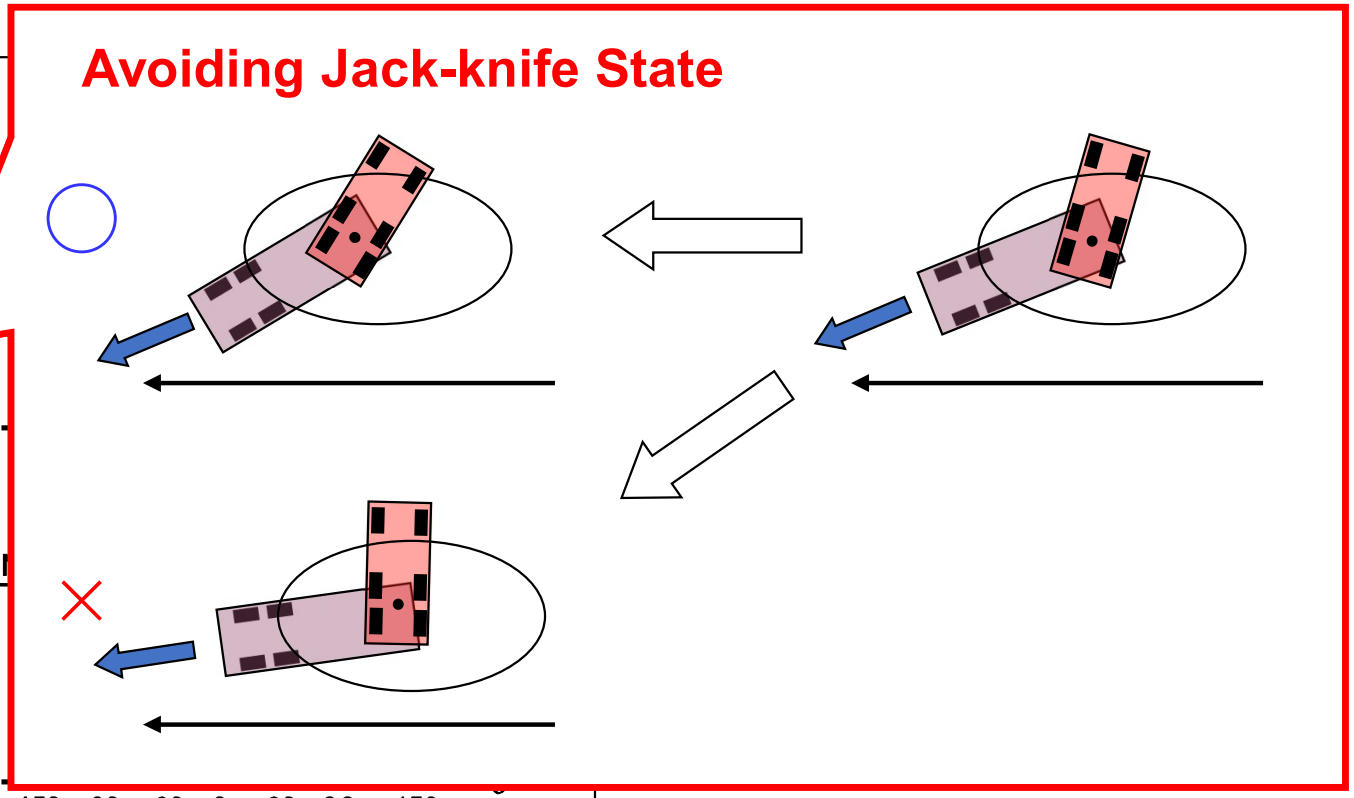
Conclusion:

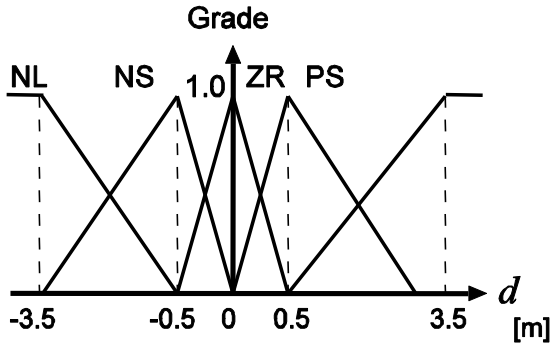
$$E = \frac{(\mu_1 + \mu_2)E_\phi + (\mu_3 + \mu_4)E_\theta + (\mu_5 + \mu_6 + \mu_7 + \mu_8)E_d}{\sum_{i=1}^{8} \mu_i}$$

The Evaluation Value is a weighted average of the activated rules.

Evaluation by Fuzzy Inference

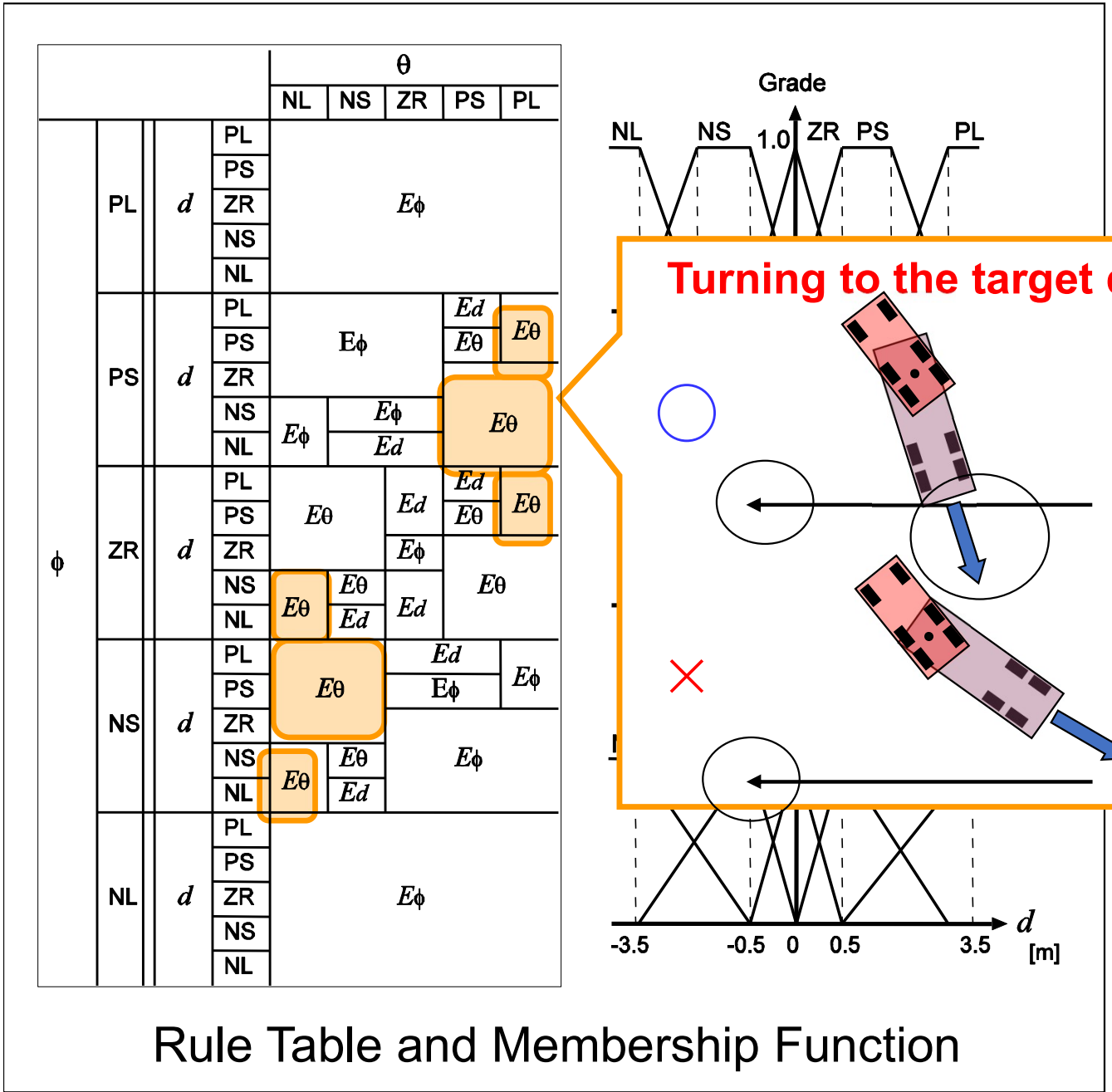






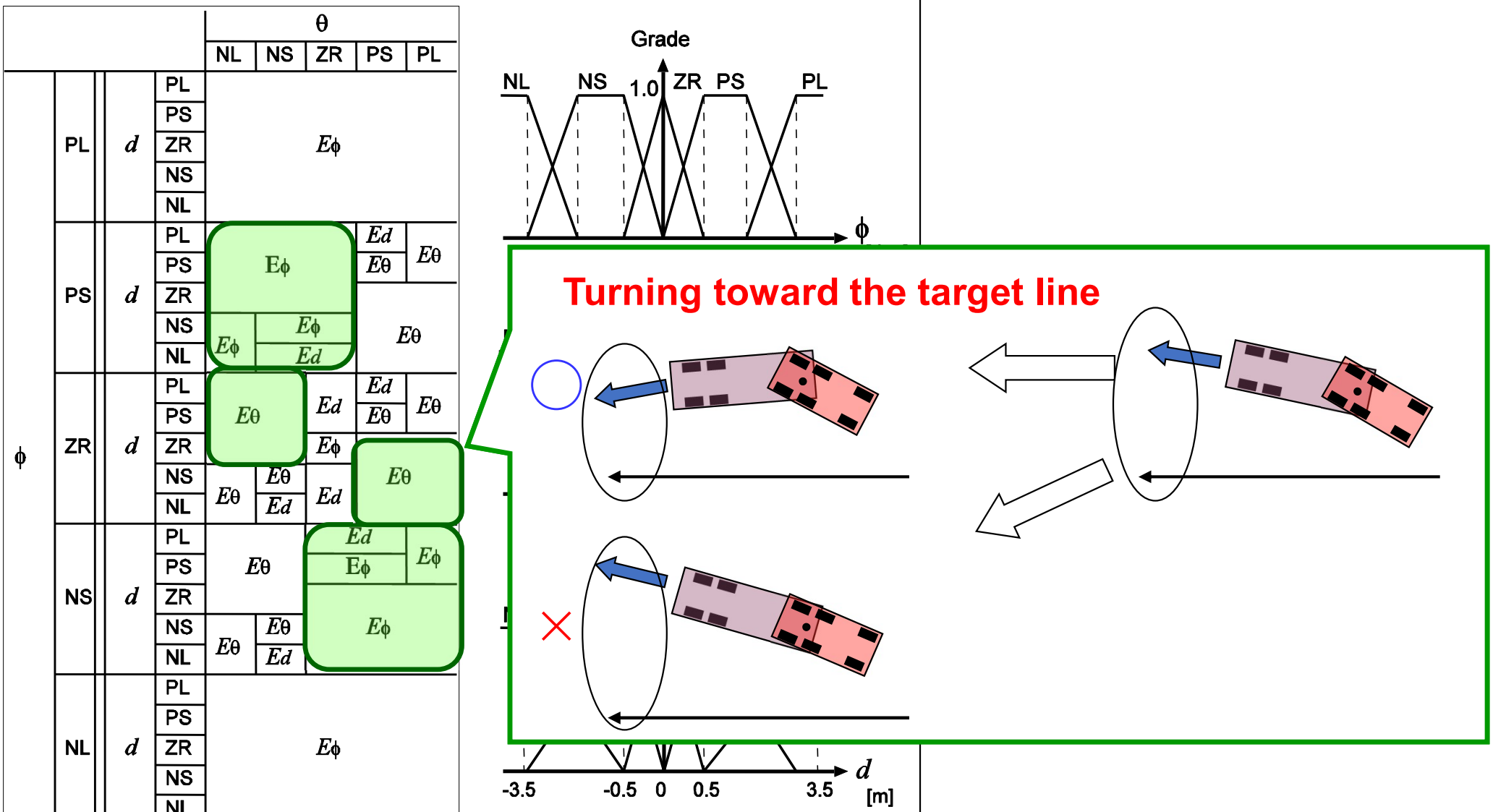
Rule Table and Membership Function

Evaluation by Fuzzy Inference



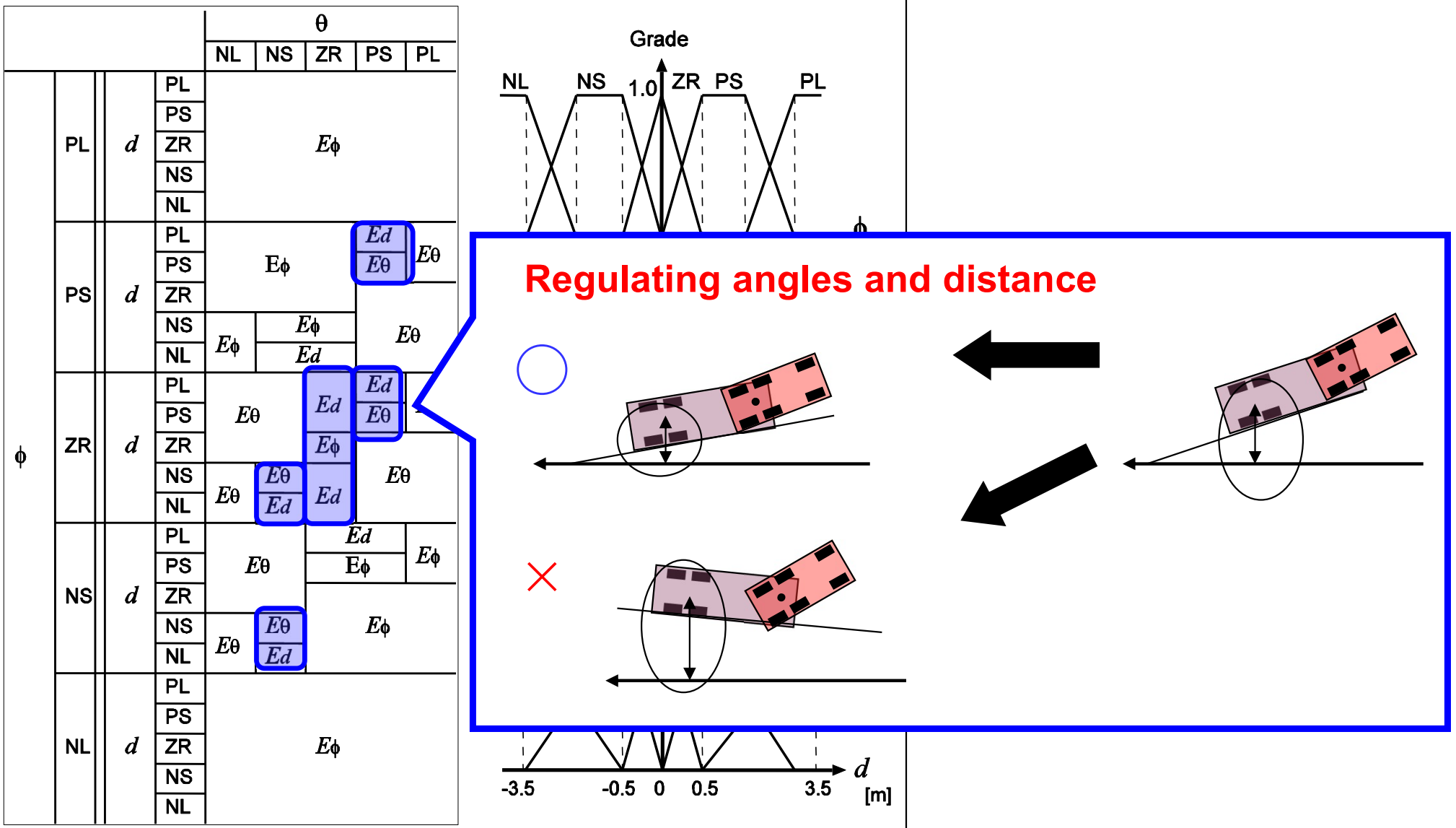
Rule Table and Membership Function

Evaluation by Fuzzy Inference



Rule Table and Membership Function

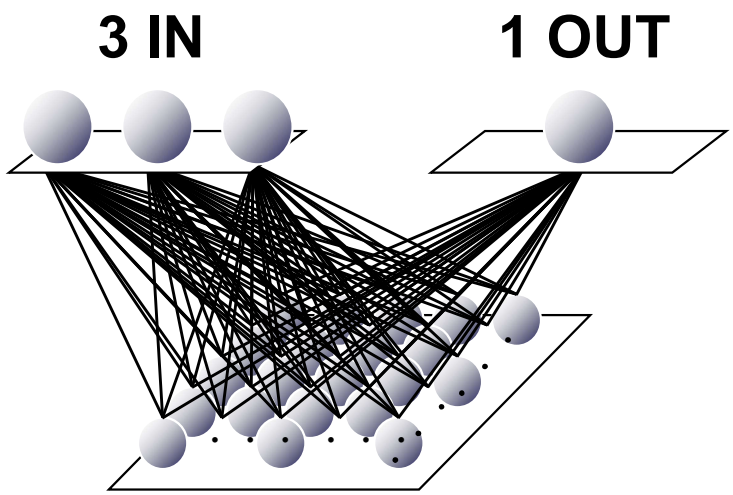
Evaluation by Fuzzy Inference



Rule Table and Membership Function

Condition of Computer Simulation

SOR Network (Batch Learning)



Number of Learning Vector: 9^4=6,561

Number of units: 25 × 25=625

Parameter of Neighborhood Function : r 25 → 0.25

Value of Attractive Learning Rate : α 1.0→0.01

Value of Repulsive Learning Rate : β 0.1→0.005

Radius of Repulsive Field: r_r 0.1

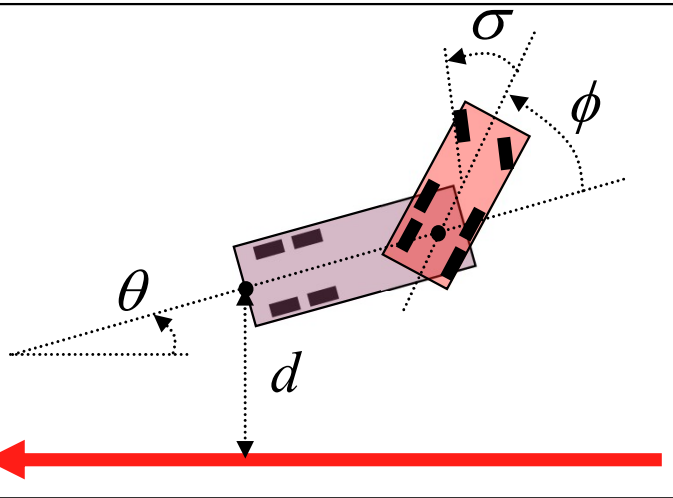
Learning Iteration: 200

Decay Rate: 30.0

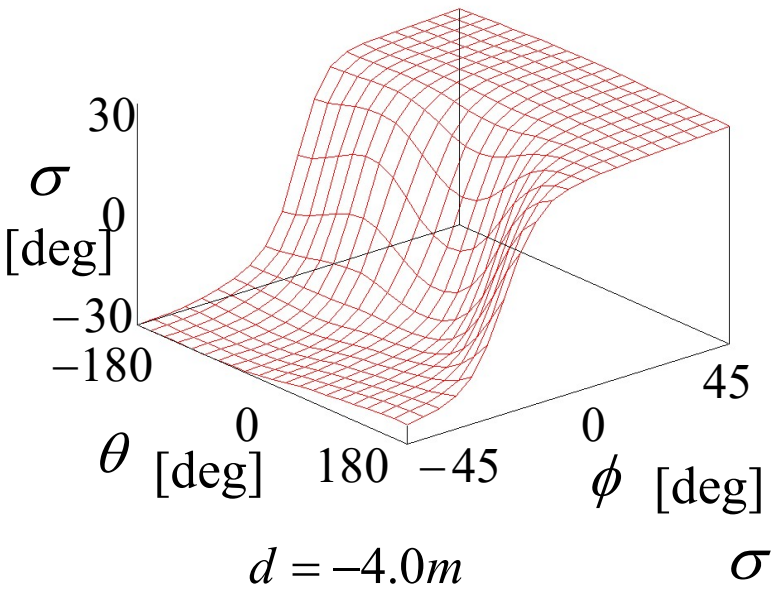
$$\left.\begin{aligned} a_\phi &= 1.5^\circ \\ a_\theta &= 1.9^\circ \\ a_d &= 0.03m \end{aligned}\right\} = 0.6 \times \left(\phi_{\max}, \theta_{\max}, d_{\max}\right)$$

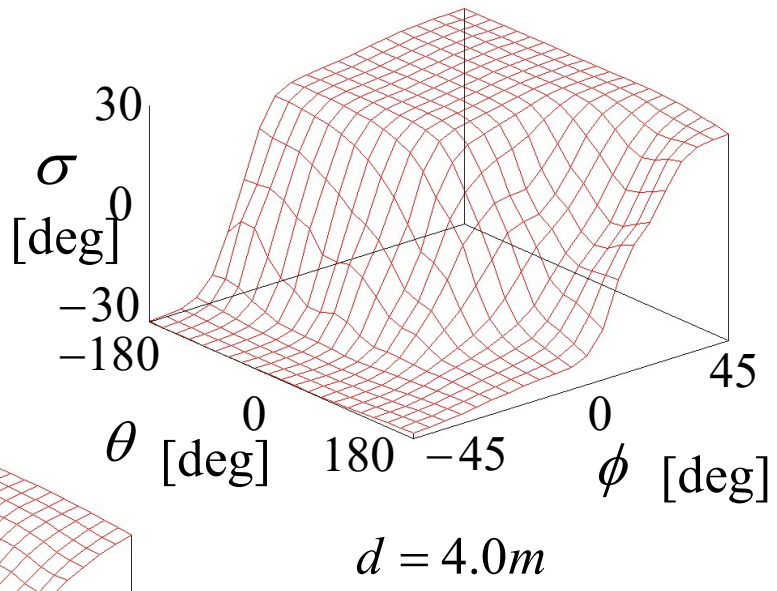
Range of Variables

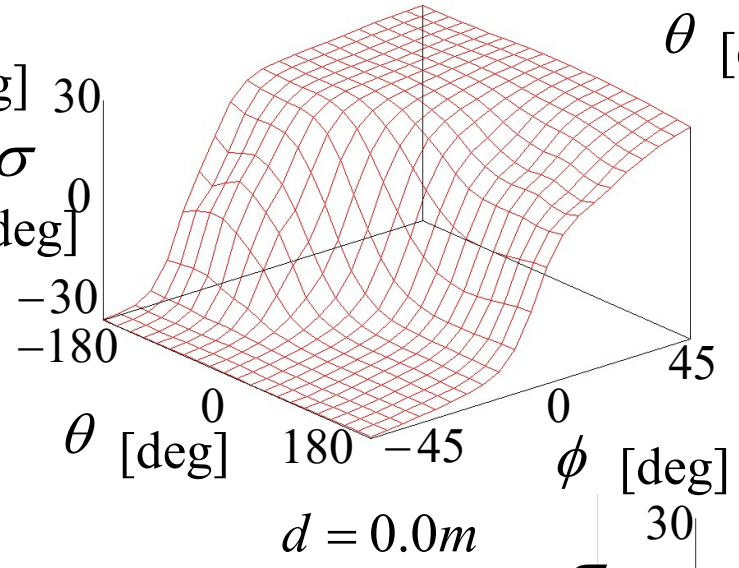
$$-180^\circ \le \theta \le 180^\circ$$
$$-45^\circ \le \phi \le 45^\circ$$
$$-4.0m \le d \le 4.0m$$
$$-30^\circ \le \sigma \le 30^\circ$$

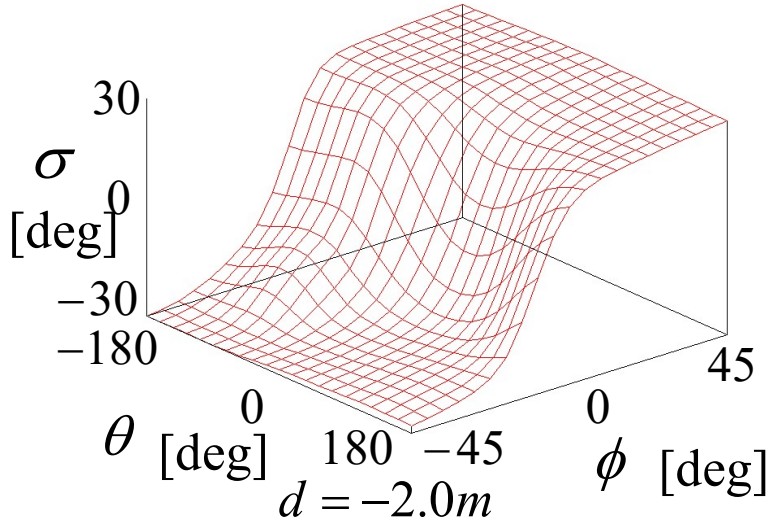


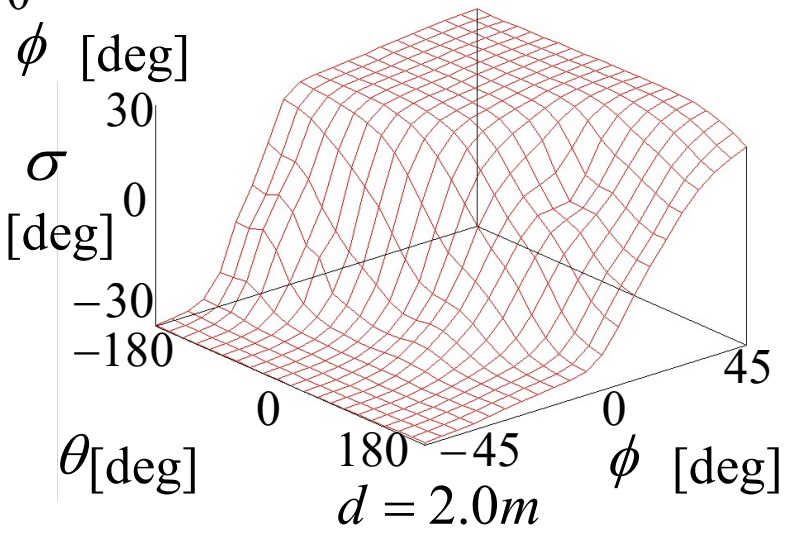
Desirable I/O Relationship Obtained by Learning of SOR Network





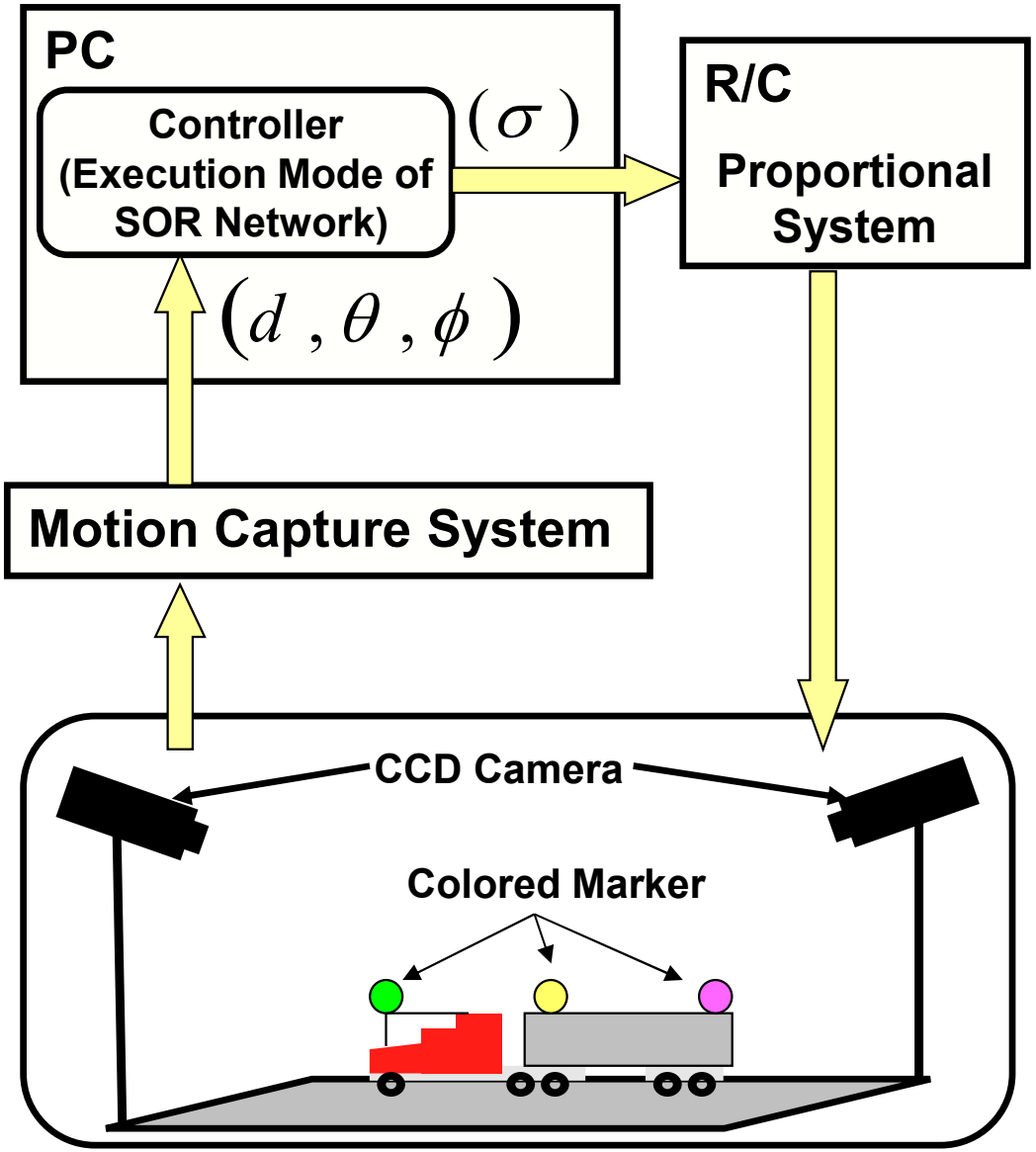




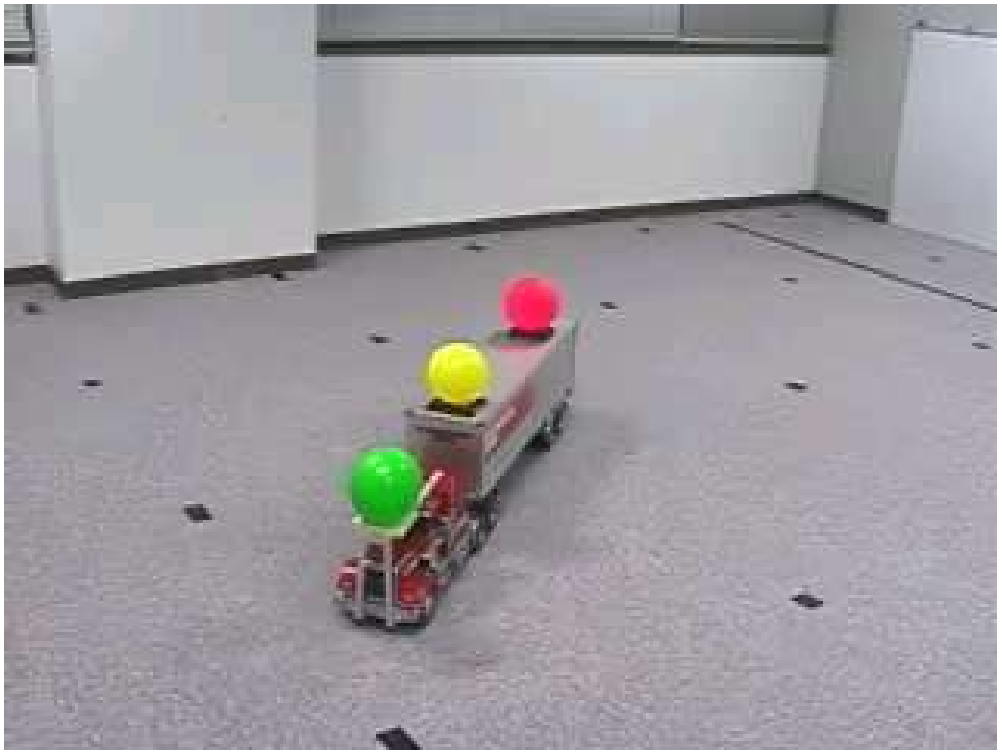


Practical Experiment

Overview of the Experiment System



An Example of the Practical Experiment



Initial State of the Trailer-Truck

$$\theta = 135° \quad \phi = 0° \quad d = 2.5m$$


Thank You Very Much
For Your Kind Attentions
2019/05/29
Questions are welcome