Figures of Chapter 3

Fuzzy Logic Control

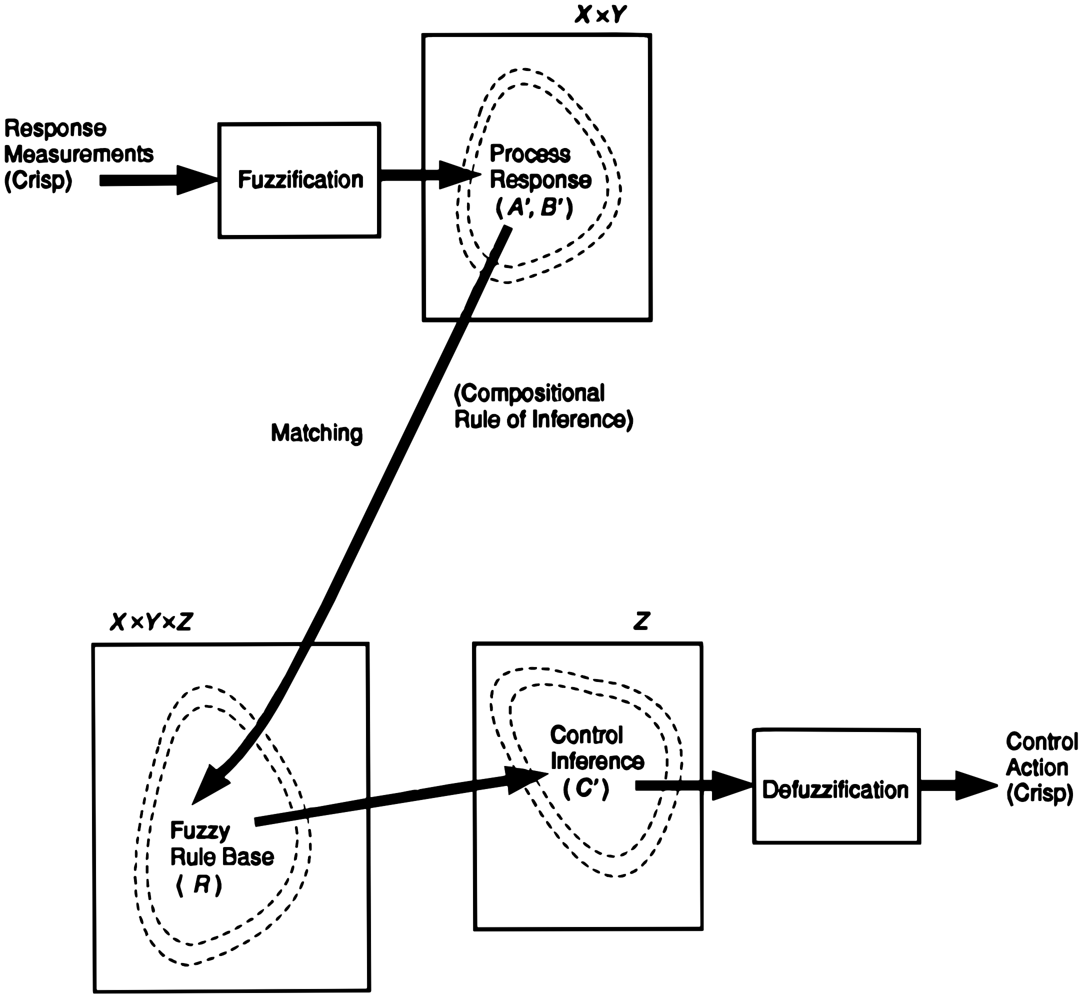

Figure 3.1. A fuzzy logic controller (FLC).

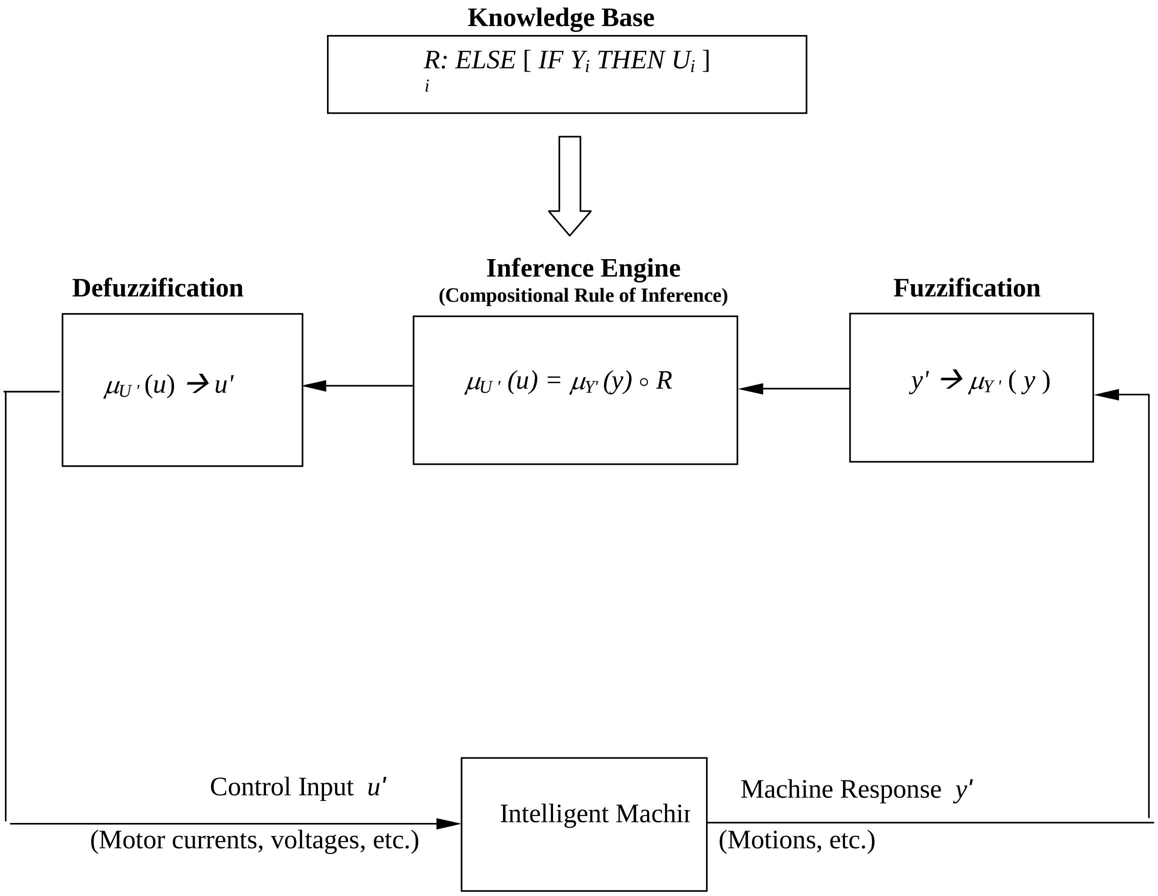

Figure 3.2.Structure of a direct fuzzy controller.

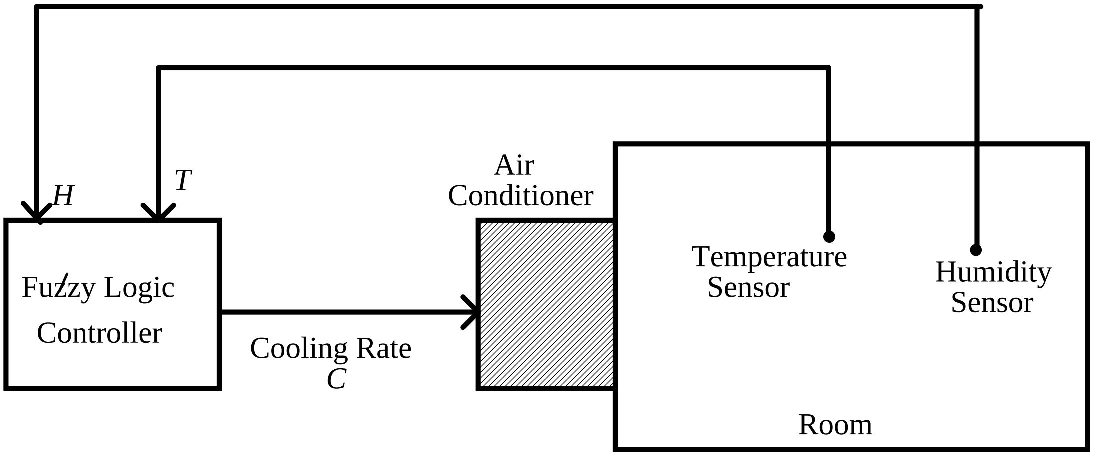

Figure 3.3. Comfort control system of a room.

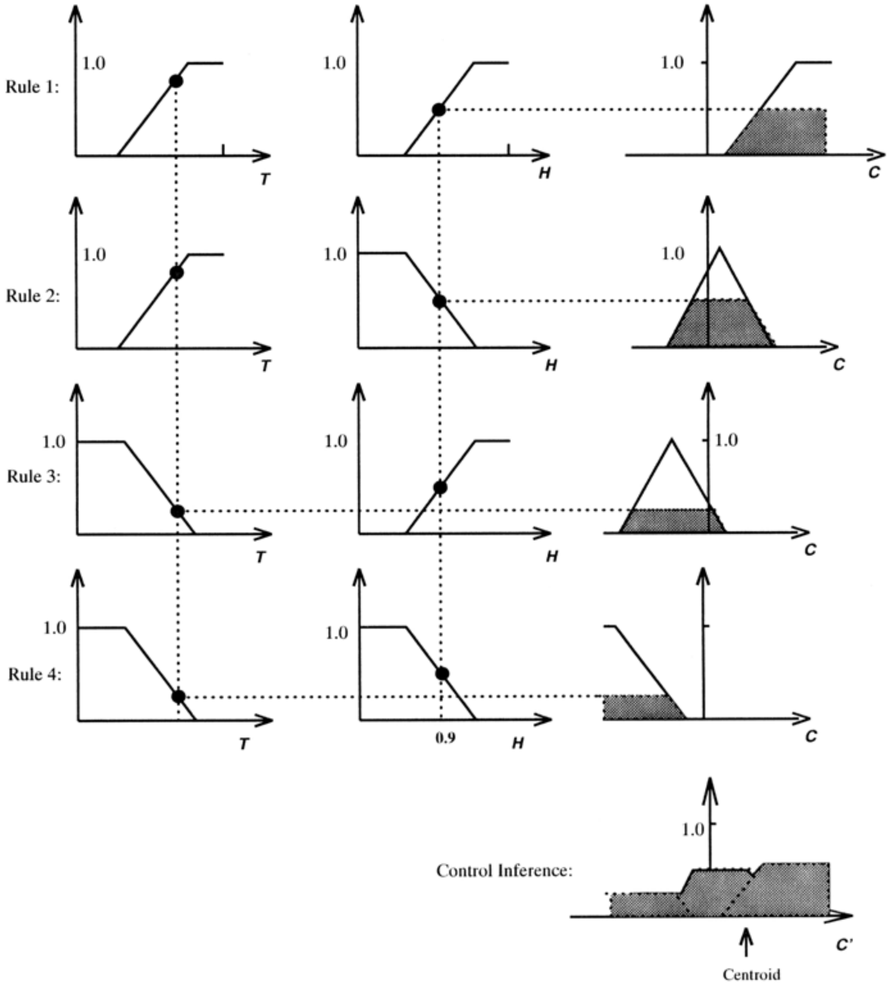

Figure 3.4. The fuzzy knowledge base of the comfort controller.

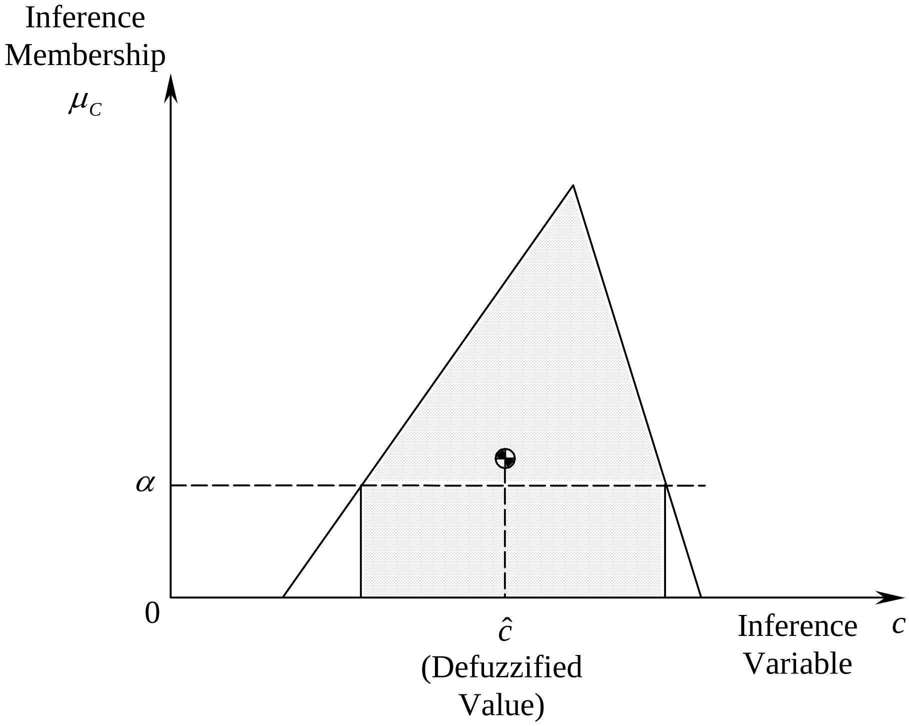

Figure 3.5. Thresholded defuzzification

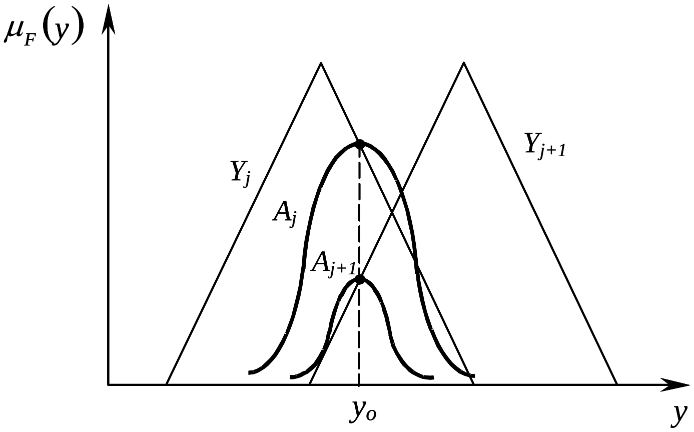

Figure 3.6. Fuzzification using a Gaussian shape function.

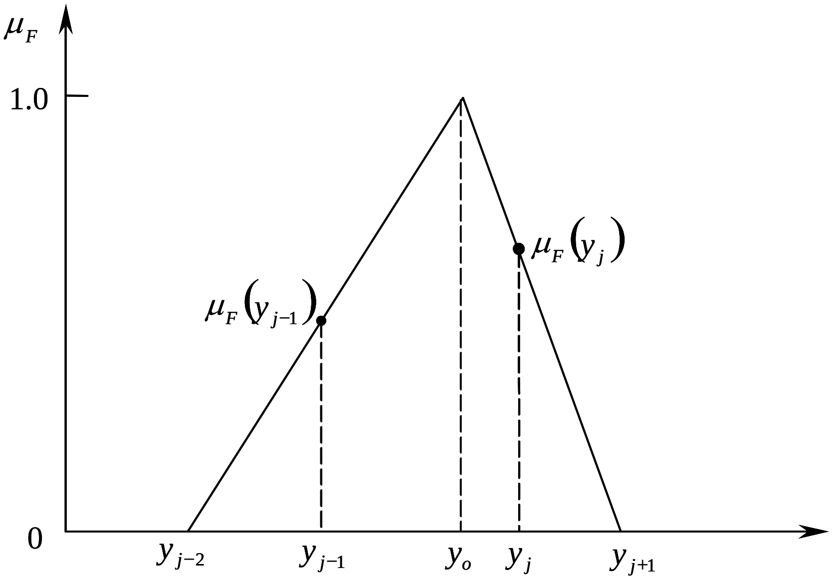

Figure 3.7. Fuzzification using a discrete membership function.

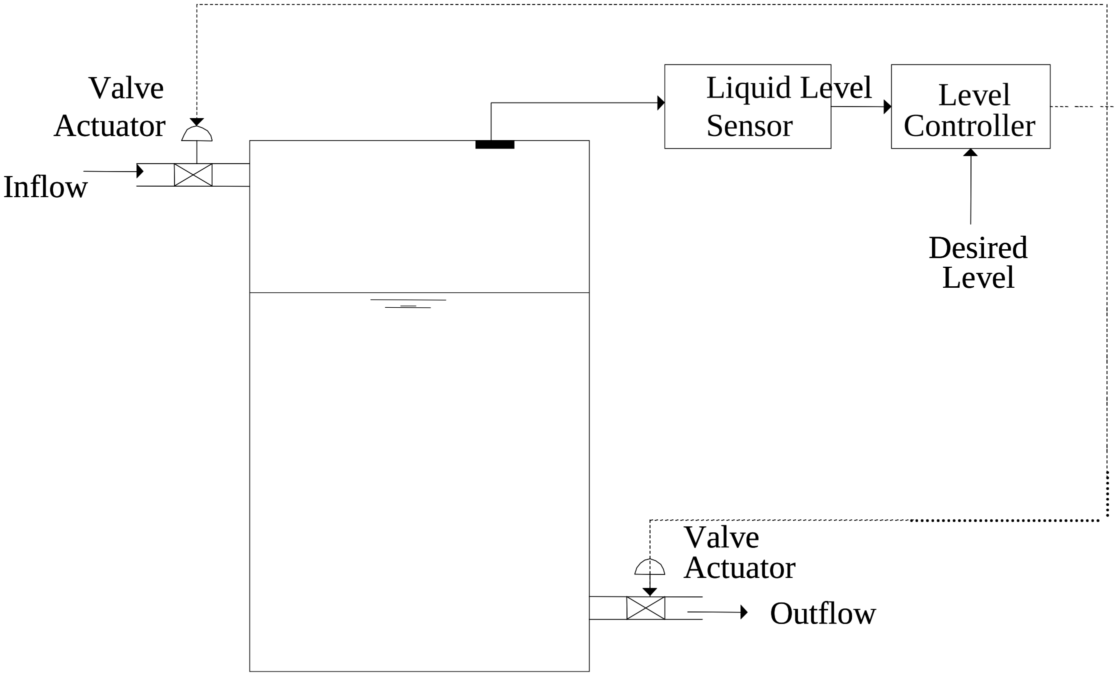

Figure 3.8(a). Liquid level control system.

ΔE E	NL	NS	ZO	PS	PL
NL	NL	NL	NM	NS	ZO
NS	NL	NM	NS	ZO	PS
ZO	NM	NS	ZO	PS	PM
PS	NS	ZO	PS	PM	PL
PL	ZO	PS	PM	PL	PL

Figure 3.8(b). The control rule-base.

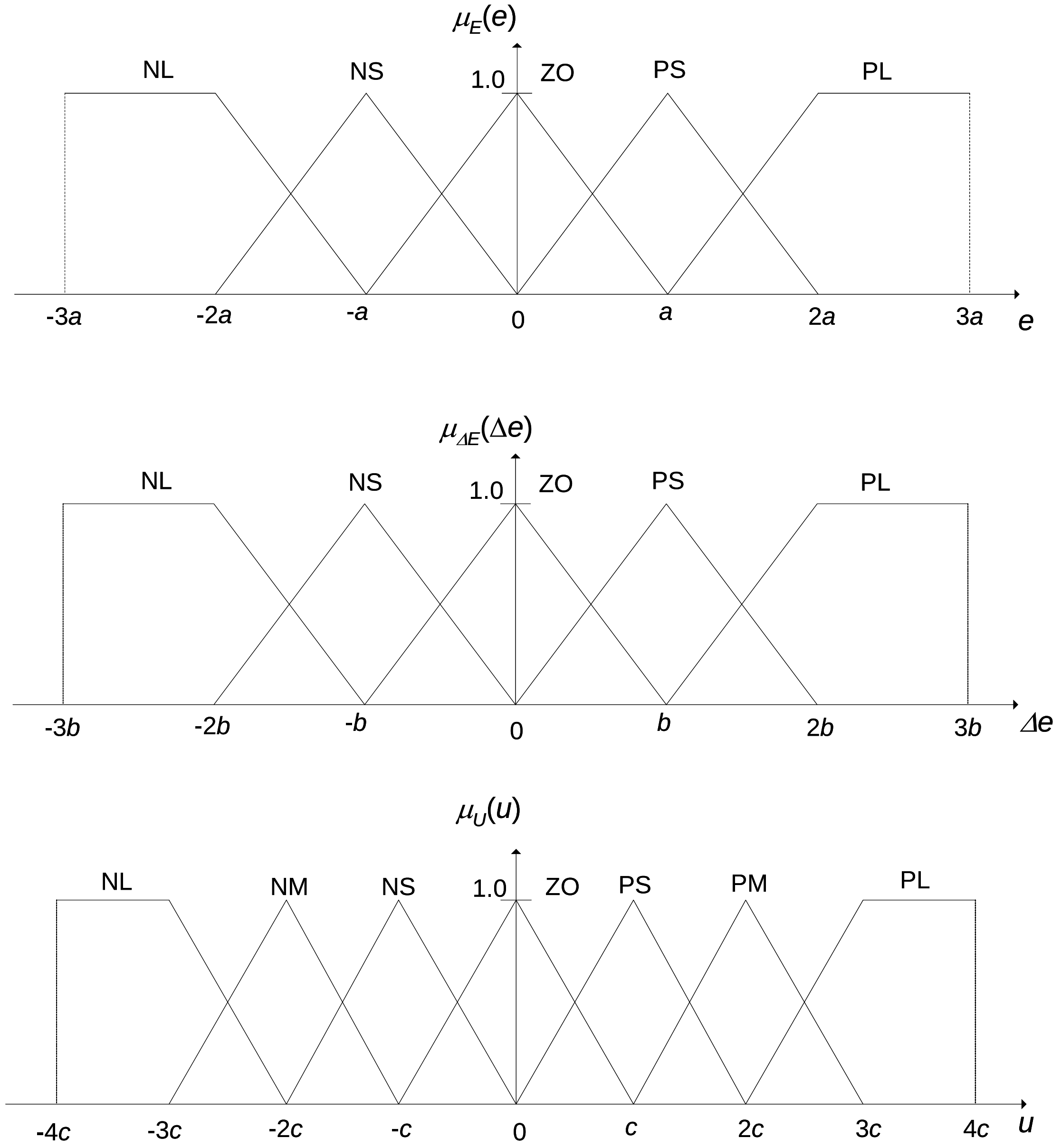

Figure 3.8(c). The membership functions of Error, Change in Error, and Control Action.

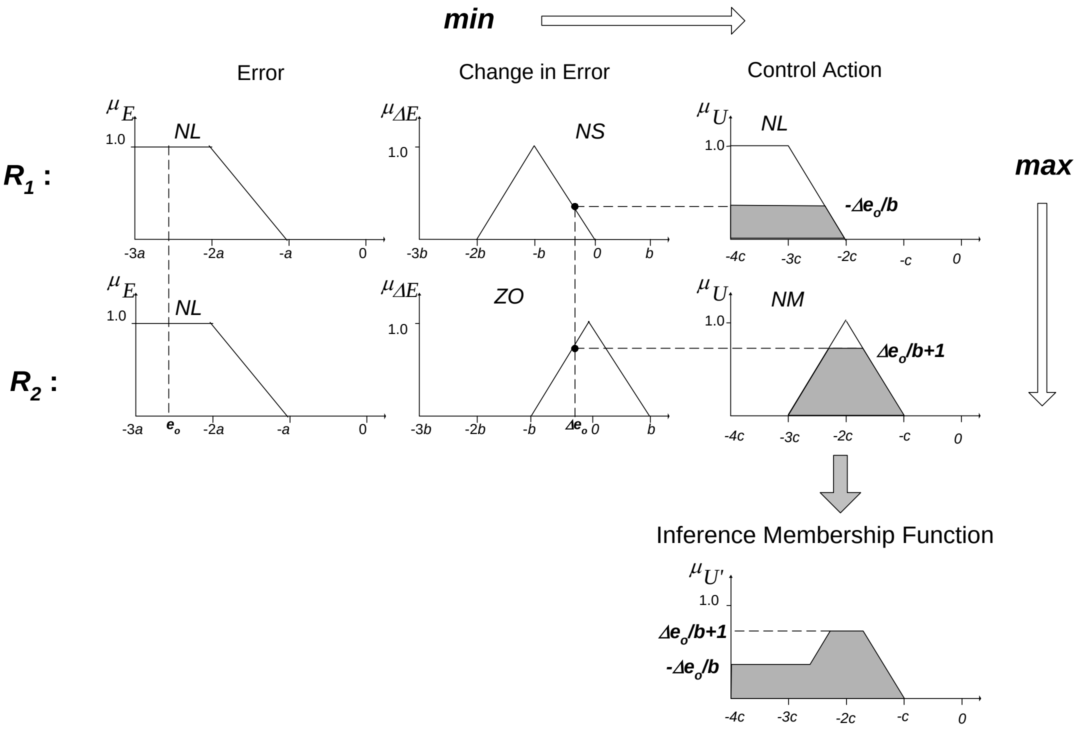

Figure 3.9. Individual rule-based inference for e_o[-3a,-2a] and Δe_o[-b/2,0].

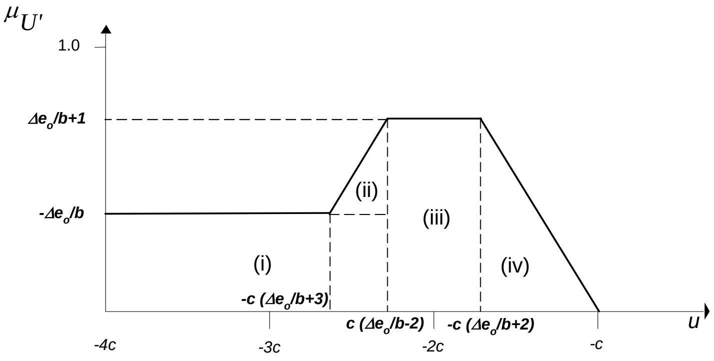

Figure 3.10. Sub-regions and critical points for calculation of the centroid.

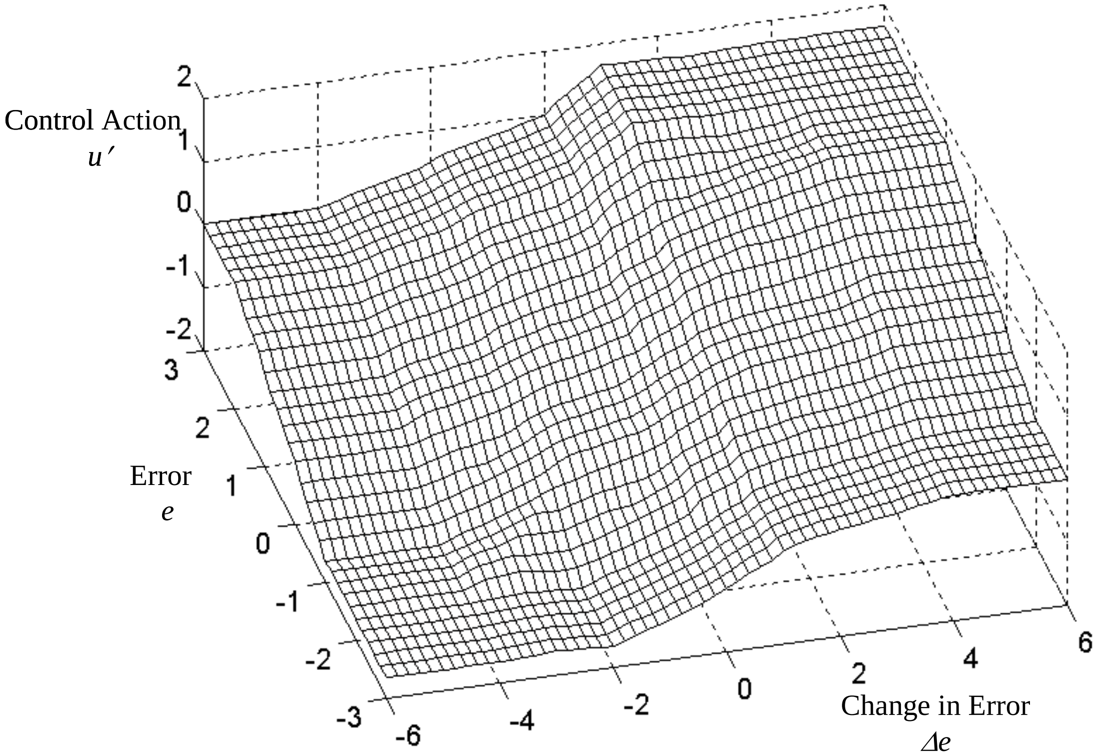

Figure 3.11. Control surface with *a* = 1, *b* =2, and *c* = 0.5.

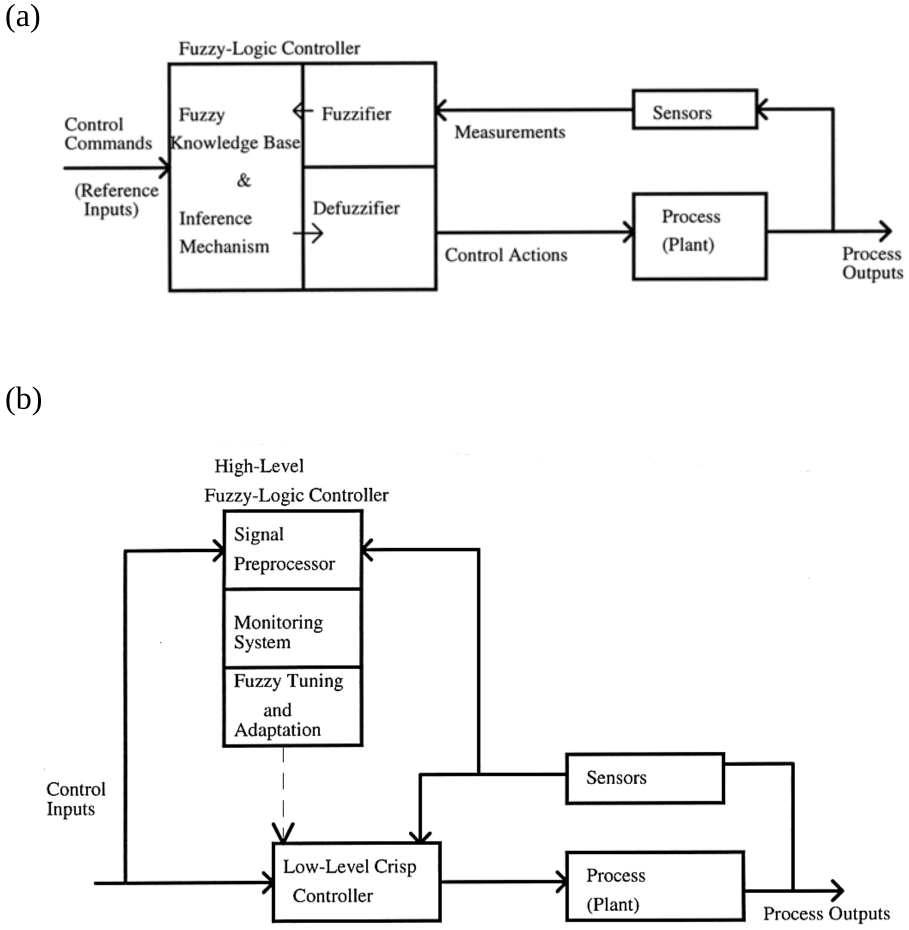

Figure 3.12 Architectures of fuzzy control
(a) Low-level direct control
(b) High-level supervisory control.

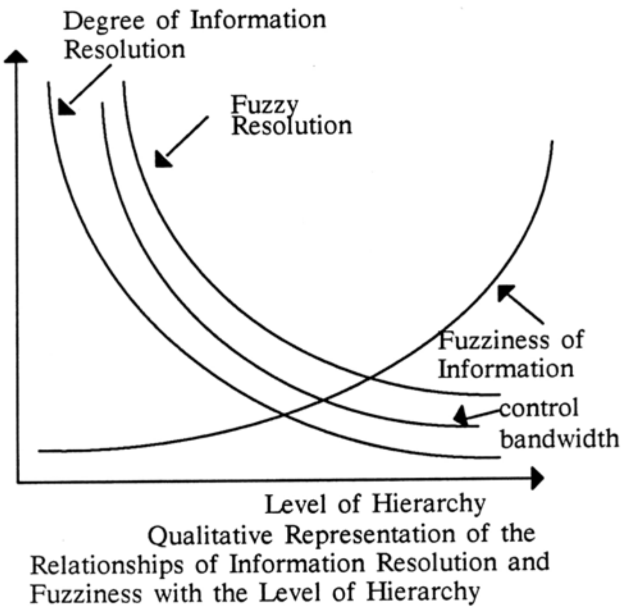

Figure 3.13. Relationships of information resolution and fuzziness with respect to hierarchical level.

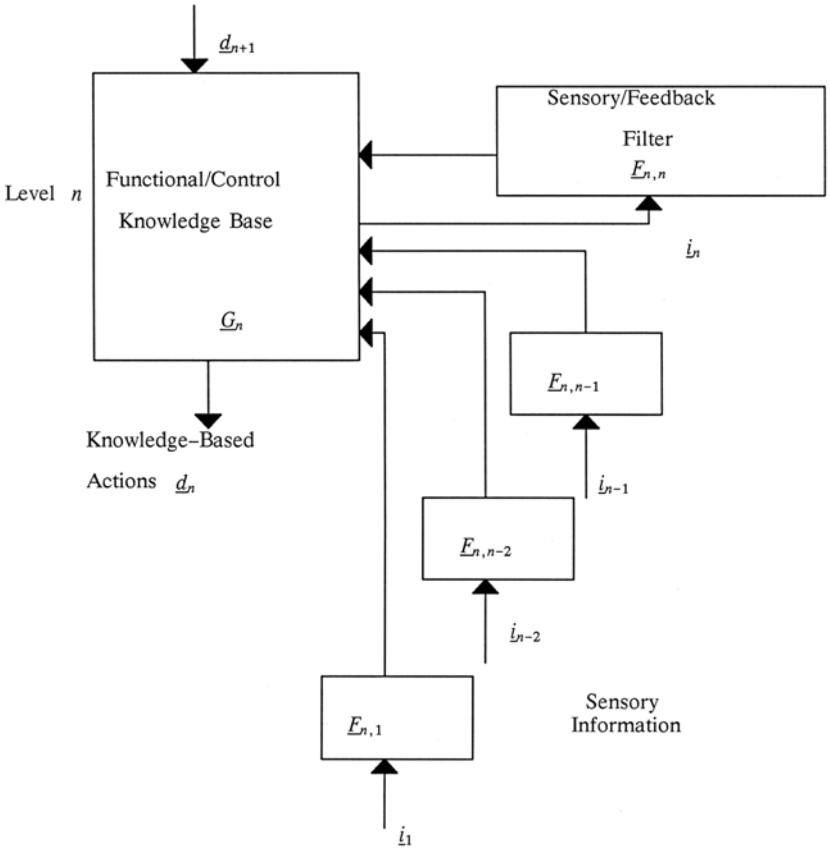

Figure 3.14. Schematic representation of a hierarchical model.

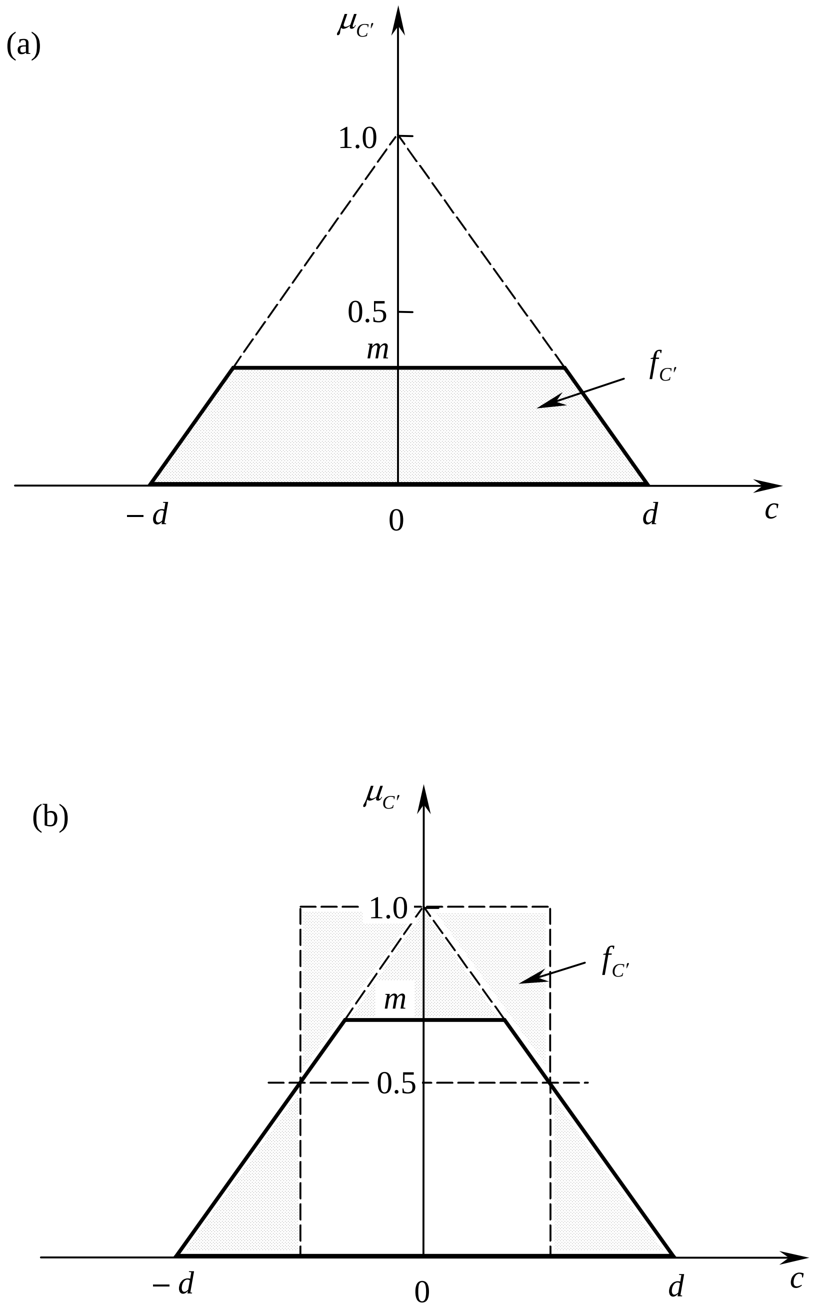

Figure 3.15. Control inference and its 1/2-cut when
(a) the context membership is < 0.5
(b) the context membership is ≥ 0.5.

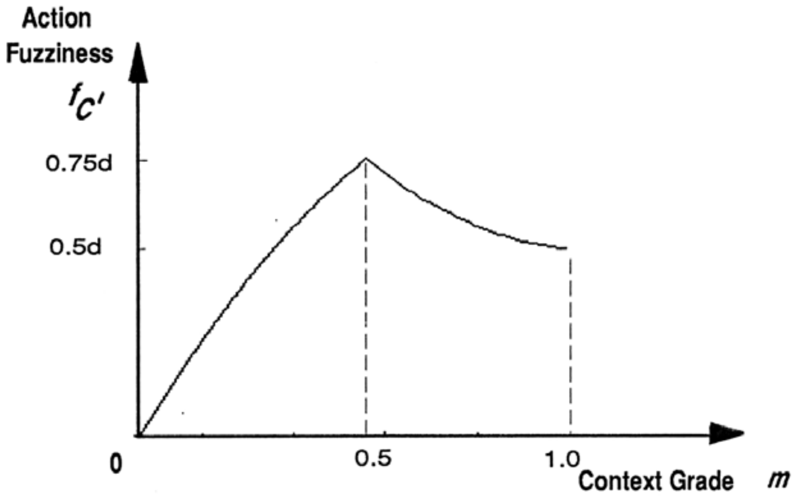

Figure 3.16. Variation of the fuzziness of a control inference with the membership grade of the rule-base context.

If the response oscillations are low then slightly decrease the proportional gain and slightly increase the derivative time constant; or if the response is moderately oscillatory, then moderately decrease the proportional gain and moderately increase the derivative time constant; or if the response is highly oscillatory, then make a large decrease in the proportional gain and a large increase in the derivative time constant; or if the response is extremely oscillatory, then make a large decrease in the proportional gain and a large increase in the derivative time constant and a slight decrease in the integral rate.

If the response is slow then increase the derivative time constant slightly and increase the proportional gain moderately; or if the speed of response is moderate then increase the derivative time constant slightly and increase the proportional gain slightly; or if the speed of response is high increase the derivative time constant slightly and decrease the proportional gain slightly; or if the speed of response is very high decrease the proportional gain moderately.

If the response diverges slowly then slightly decrease the proportional gain and slightly increase the derivative time constant; or if the response diverges moderately then slightly decrease the proportional gain and moderately increase the derivative time constant; or if the response diverges rapidly then slightly decrease the proportional gain and increase the derivative time constant by a large amount and slightly decrease the integral rate; or if the response diverges very rapidly then moderately decrease the proportional gain and increase the derivative time constant by a large amount and moderately decrease the integral rate.

If the offset is low then slightly increase the proportional gain, and slightly increase the integral rate; or if the offset is moderate then moderately increase the integral rate; or if the offset is high then increase the proportional gain slightly and increase the integral rate by a large value; or if the offset is very high then moderately increase the proportional gain and increase the integral rate by a large value.

Figure 3.17. A typical set of linguistic protocols for tuning a PID servo.

	if	OSC=LOW	then	DP=NL
			and	DD=PL
or	if	OSC=MOD	then	DP=NM
			and	DD=PM
or	if	OSC=HIG	then	DP=NH
			and	DD=PH
or	if	OSC=VHI	then	DP=NH
			and	DI=NL
			and	DD=PH

	if	RSP=LOW	then	DP=PM
			and	DD=PL
or	if	RSP=MOD	then	DP=PL
			and	DD=PL
or	if	RSP=HIG	then	DP=NL
			and	DD=PL
or	if	RSP=VHI	then	DP=NM

	if	DIV=LOW	then	DP=NL
			and	DD=PL
or	if	DIV=MOD	then	DP=NL
			and	DD=PM
or	if	DIV=HIG	then	DP=NL
			and	DI=NL
			and	DD=PH
or	if	DIV=VHI	then	DP=NM
			and	DI=NM
			and	DD=PH

	if	OFS=LOW	then	DP=PL
			and	DI=PL
or	if	OFS=MOD	then	DI=PM
or	if	OFS=HIG	then	DP=PL
			and	DI=PH
or	if	OFS=VHI	then	DP=PM
			and	DI=PH

Figure 3.18. Condensed form of tuning protocols.

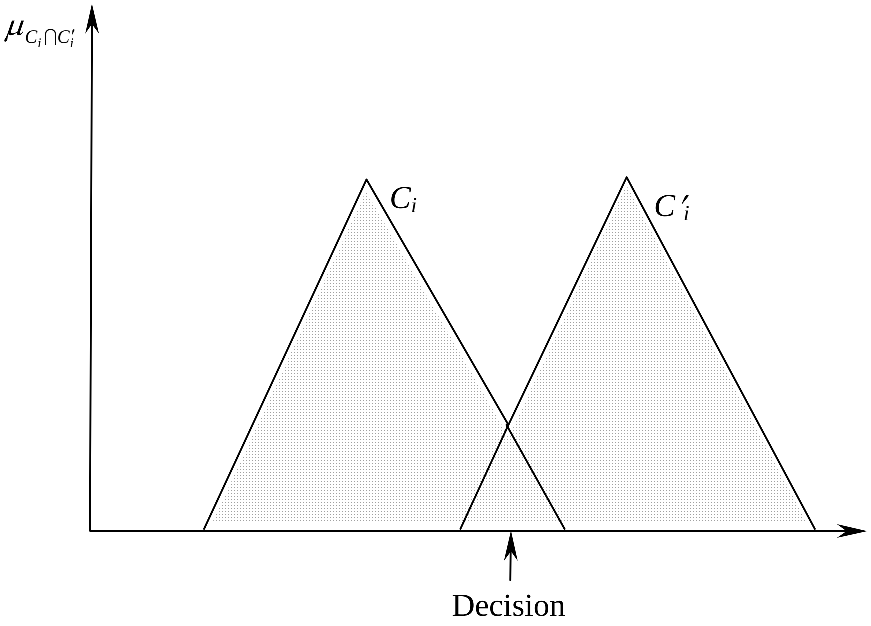

Figure 3.19. Consistency of two rules connected by OR.

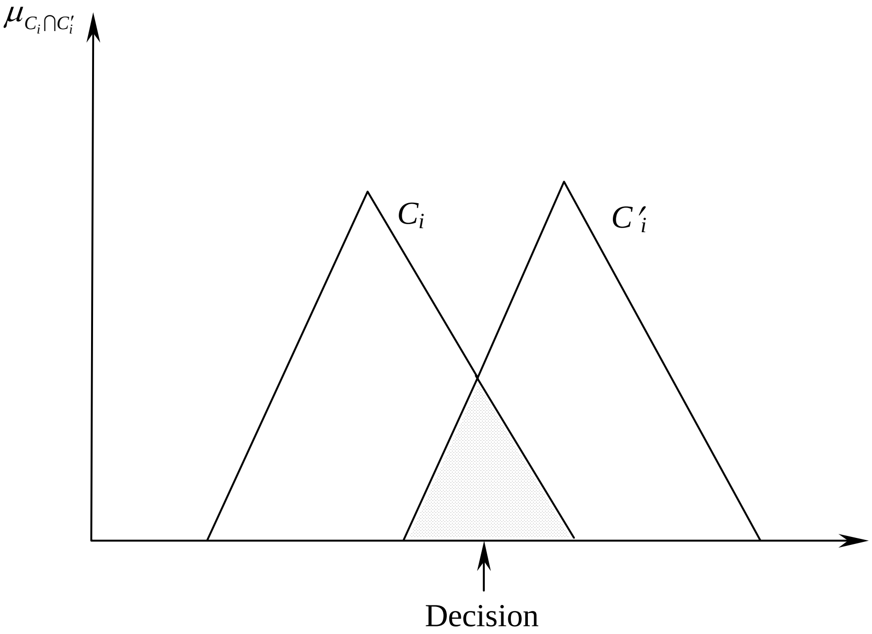

Figure 3.20. Consistency of two rules connected by AND.

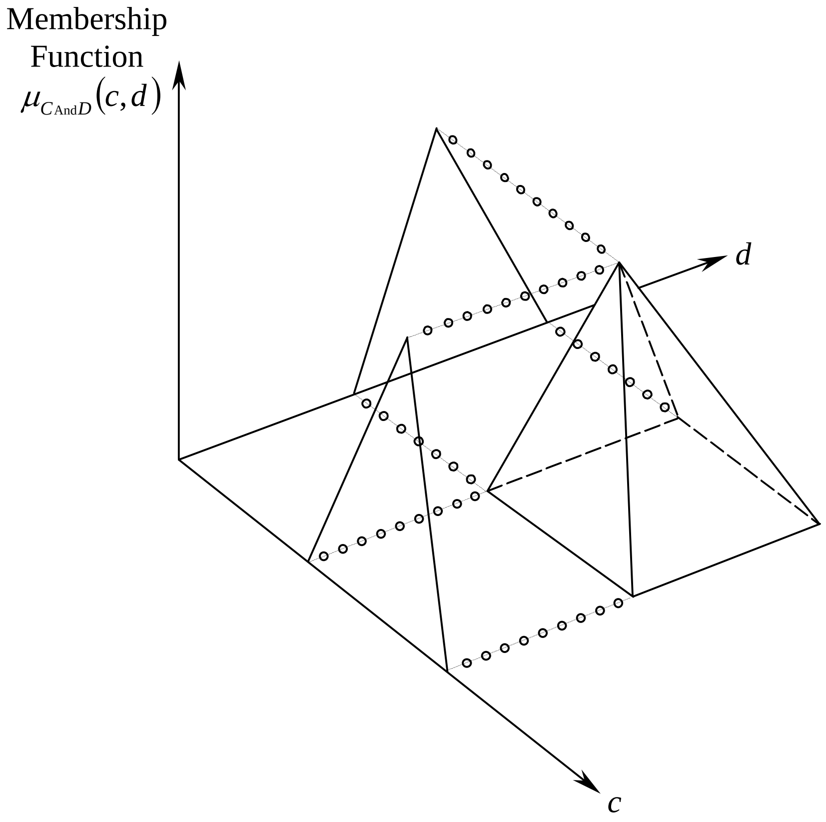

Figure 3.21. Rule consistency when the two consequents are in different universes.

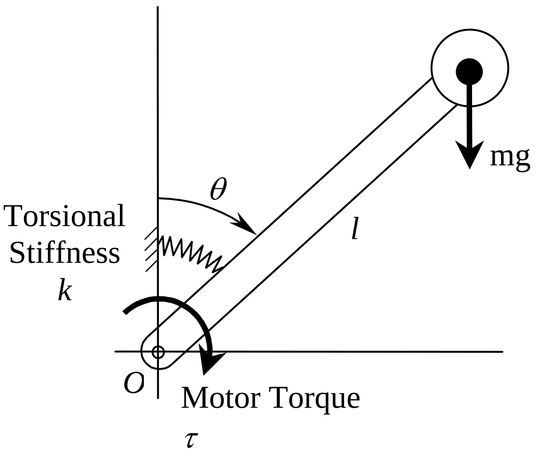

Figure 3.22. A single-link manipulator.

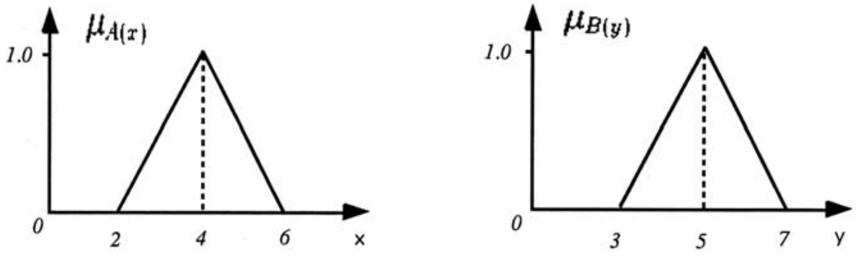

Figure P3.2. Membership functions of two fuzzy sets.

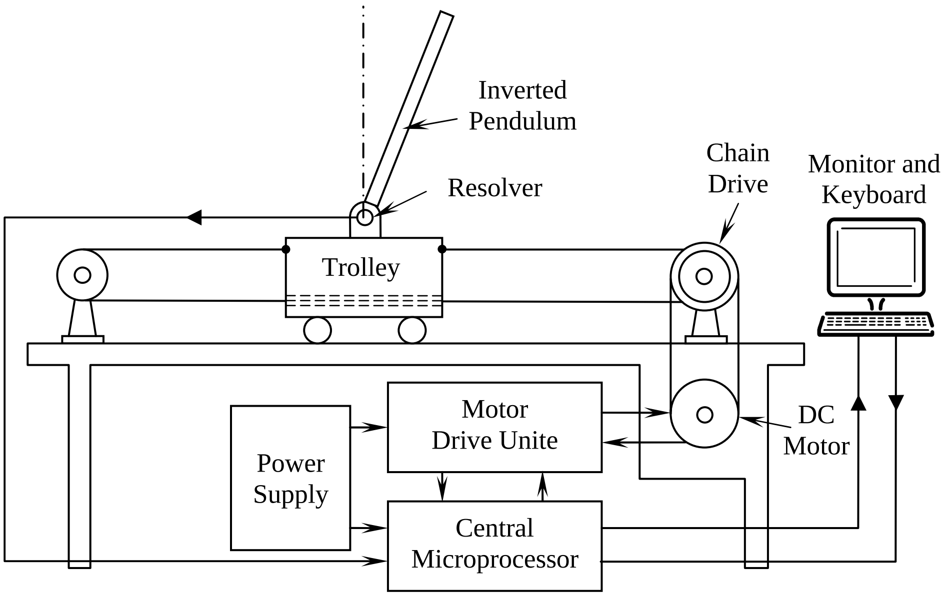

Figure P3.3. A computer-controlled inverted pendulum.

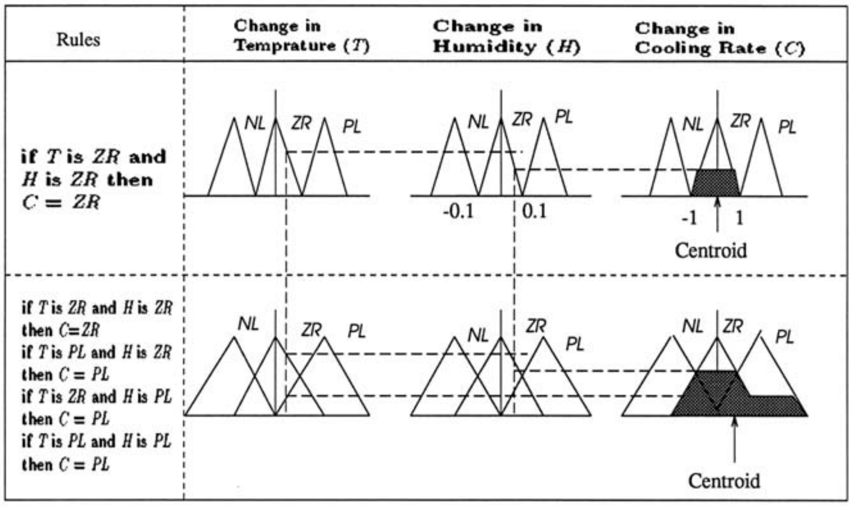

Figure P3.4. The effect of membership overlap on the validity of control inference.

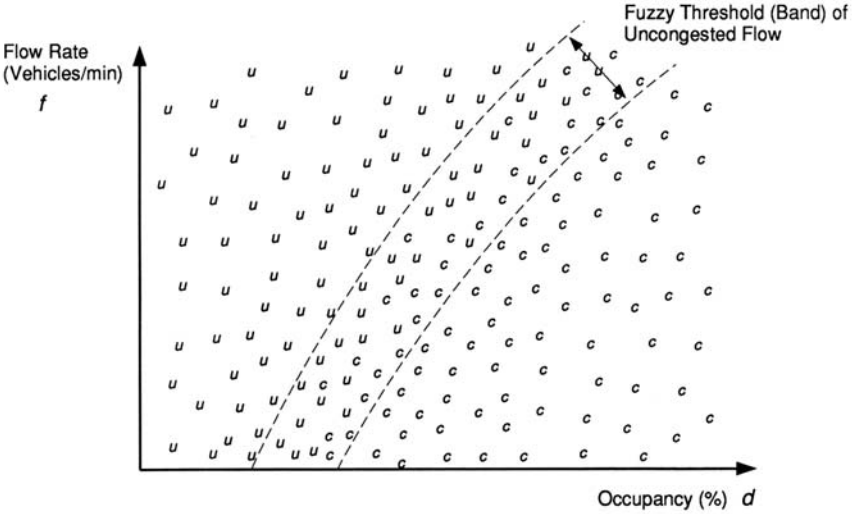

Figure P3.8. Occupancy-flow information for a freeway lane segment

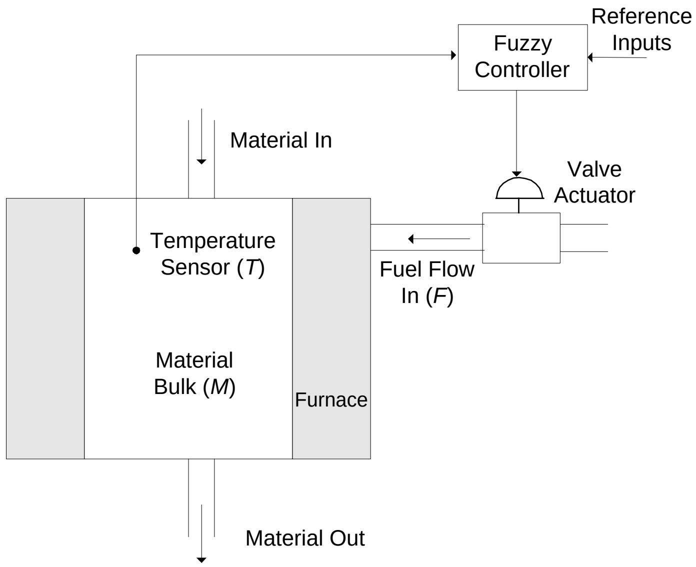

Figure P3.12(a). A metallurgical heat treatment process.

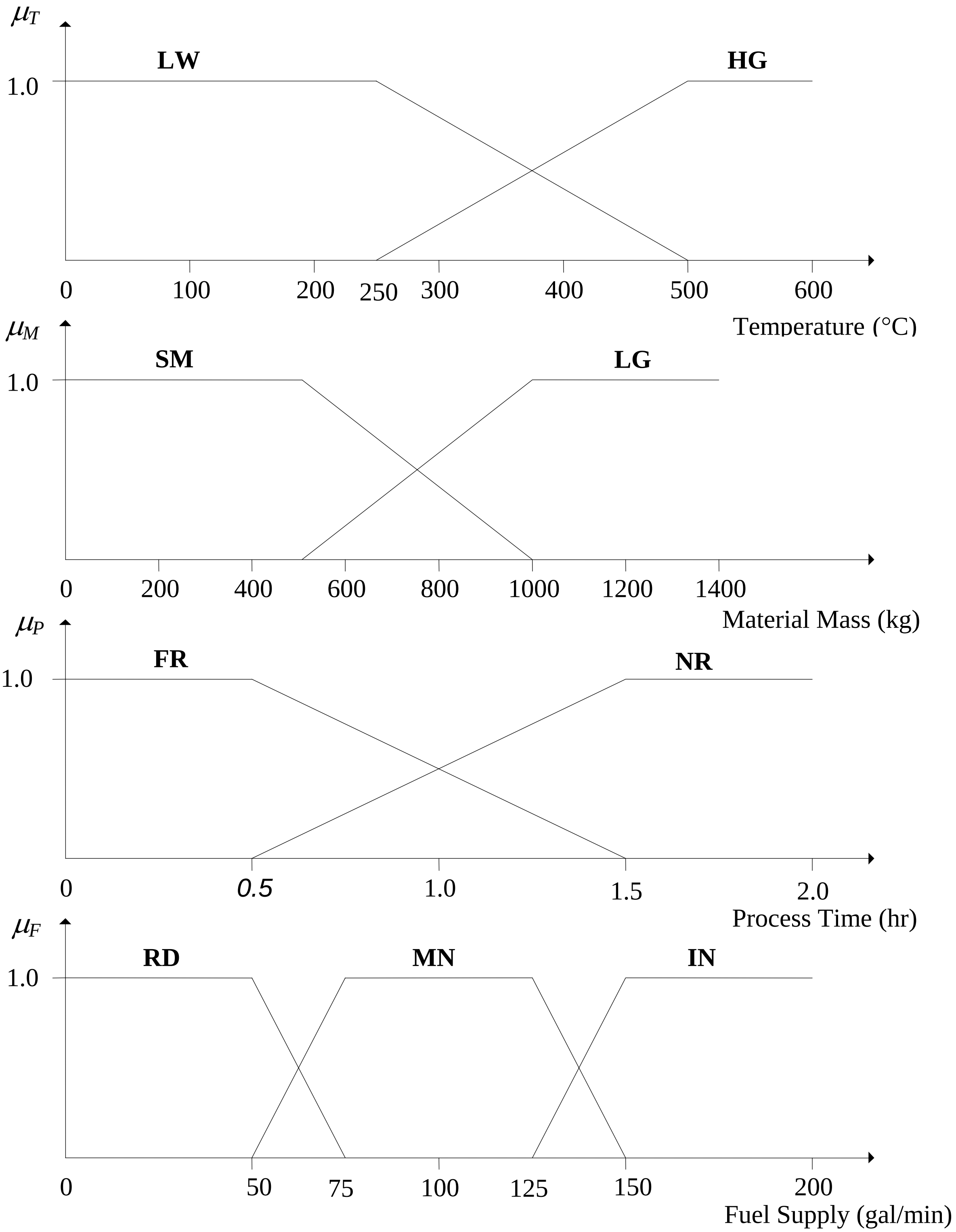

Figure P3.12(b). Membership functions.

If the error response is not oscillatory *then* do not change the proportional *and* derivative control parameters;
or if the error response is moderately oscillatory *then* make a small decrease in the proportional gain *and* a small increase in the derivative time constant;
or if the error response is highly oscillatory *then* make a large decrease in the proportional gain *and* a large increase in the derivative time constant

If the error response is fast enough *then* do not change the proportional *and* derivative control parameters;
or *if* the error response is not fast enough *then* make a small increase in the proportional gain *and* a small increase in the derivative time constant.

If the error response does not steadily diverge *then* do not change the proportional *and integral and* derivative control parameters; *or if* the error response steadily diverges *then* slightly decrease the proportional gain *and* slightly decrease the integral rate *and* make a large increase in the derivative time constant.

If the error response does not have an offset *then* do not change the proportional *and* integral control parameters;
or if the error response has an offset *then* slightly increase the proportional gain *and* make a large increase in the integral rate.

Figure P3.15(a). Linguistic fuzzy rules for tuning a PID controller.

If OSC = OKY then DP = NC
and DD = NC

or If OSC = MOD then DP = NL
and DD = PL

or If OSC = HIG then DP = NH
and DD = PH

If RSP = OKY then DP = NC
and DD = PL

If DIV = OKY then DP = NC
and DI = NC
and DD = NC

or If DIV = NOK then DP = NL
and DI = NL
and DD = PH

If OFF = OKY then DP = NC
and DI = NC

or If OFF = NOK then DP = PL
and DI = PH

Figure P3.15(b). Condensed form of the fuzzy protocols.

OSC = Oscillations in the error response
RSP = Speed of response (decay) of the error
DIV = Divergence of the error response
OFF = Offset in the error response

OKY = Satisfactory
MOD = Moderately unsatisfactory
HIG = Highly unsatisfactory
NOK = Unsatisfactory

DP = Change (relative) of the proportional gain
DI = Change (relative) of the integral rate
DD = Change (relative) of the derivative time constant

NH = Negative high (magnitude)
NL = Negative low (magnitude)
NC = No change
PL = Positive low
PH = Positive high

Figure P15(c). The notation used for the fuzzy quantities.