

# How Logic Works: Solutions to Problems

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## Chapter 3

### Exercise 3.1

1.  $P \vdash Q \rightarrow (P \wedge Q)$

1	(1)	$P$	A
2	(2)	$Q$	A
1,2	(3)	$P \wedge Q$	1,2 $\wedge I$
1	(4)	$Q \rightarrow (P \wedge Q)$	2,3 CP

2.  $(P \rightarrow Q) \wedge (P \rightarrow R) \vdash P \rightarrow (Q \wedge R)$

1	(1)	$(P \rightarrow Q) \wedge (P \rightarrow R)$	A
2	(2)	$P$	A
1	(3)	$P \rightarrow Q$	1 $\wedge E$
1	(4)	$P \rightarrow R$	1 $\wedge E$
1,2	(5)	$Q$	3,2 MP
1,2	(6)	$R$	4,2 MP
1,2	(7)	$Q \wedge R$	5,6 $\wedge I$
1	(8)	$P \rightarrow (Q \wedge R)$	2,7 CP

3.  $P \rightarrow (Q \rightarrow R) \vdash Q \rightarrow (P \rightarrow R)$

1	(1)	$P \rightarrow (Q \rightarrow R)$	A
2	(2)	$Q$	A
3	(3)	$P$	A
1,3	(4)	$Q \rightarrow R$	3,1 MP
1,2,3	(5)	$R$	4,2 MP
1,2	(6)	$P \rightarrow R$	3,5 CP
1	(7)	$Q \rightarrow (P \rightarrow R)$	2,6 CP

4.  $P \rightarrow Q \vdash (Q \rightarrow R) \rightarrow (P \rightarrow R)$

1	(1)	$P \rightarrow Q$	A
2	(2)	$Q \rightarrow R$	A
3	(3)	$P$	A
1,3	(4)	$Q$	1,3 MP
1,2,3	(5)	$R$	2,4 MP
1,2	(6)	$P \rightarrow R$	3,5 CP
1	(7)	$(Q \rightarrow R) \rightarrow (P \rightarrow R)$	2,6 CP

5.  $P \rightarrow (P \rightarrow Q) \vdash P \rightarrow Q$

1	(1)	$P \rightarrow (P \rightarrow Q)$	A
2	(2)	$P$	A
1,2	(3)	$P \rightarrow Q$	1,2 MP
1,2	(4)	$Q$	3,2 MP
1	(5)	$P \rightarrow Q$	2,4 CP

6.  $P \rightarrow (Q \rightarrow R) \vdash (P \wedge Q) \rightarrow R$

1	(1)	$P \rightarrow (Q \rightarrow R)$	A
2	(2)	$P \wedge Q$	A
2	(3)	$P$	2 $\wedge$ E
2	(4)	$Q$	2 $\wedge$ E
1,2	(5)	$Q \rightarrow R$	1,3 MP
1,2	(6)	$R$	5,4 MP
1	(7)	$(P \wedge Q) \rightarrow R$	2,6 CP

7.  $(P \vee Q) \rightarrow R \vdash P \rightarrow R$

1	(1)	$(P \vee Q) \rightarrow R$	A
2	(2)	$P$	A
2	(3)	$P \vee Q$	2 $\vee$ I
1,2	(4)	$R$	1,3 MP
1	(5)	$P \rightarrow R$	2,4 CP

8.  $\neg P \vdash \neg(P \wedge Q)$

1	(1)	$\neg P$	A
2	(2)	$P \wedge Q$	A
2	(3)	$P$	2 $\wedge$ E
	(4)	$(P \wedge Q) \rightarrow P$	2,3 CP
1	(5)	$\neg(P \wedge Q)$	4,1 MT

9.  $\neg(P \vee Q) \vdash \neg P \wedge \neg Q$

1	(1)	$\neg(P \vee Q)$	A
2	(2)	$P$	A
2	(3)	$P \vee Q$	2 $\vee$ I
	(4)	$P \rightarrow (P \vee Q)$	2,3 CP
1	(5)	$\neg P$	4,1 MT
6	(6)	$Q$	A
6	(7)	$P \vee Q$	6 $\vee$ I
	(8)	$Q \rightarrow (P \vee Q)$	6,7 CP
1	(9)	$\neg Q$	8,1 MT
1	(10)	$\neg P \wedge \neg Q$	5,9 $\wedge$ I

10.  $P \rightarrow \neg P \vdash \neg P$

1	(1)	$P$	A
2	(2)	$P \rightarrow \neg P$	A
1,2	(3)	$\neg P$	2,1 MP
1	(4)	$(P \rightarrow \neg P) \rightarrow \neg P$	2,3 CP
1	(5)	$\neg \neg P$	1 DN
1	(6)	$\neg(P \rightarrow \neg P)$	4,5 MT
	(7)	$P \rightarrow \neg(P \rightarrow \neg P)$	1,6 CP
2	(8)	$\neg \neg(P \rightarrow \neg P)$	2 DN
2	(9)	$\neg P$	7,8 MT

### Exercise 3.4

1.  $P \rightarrow Q \vdash \neg(P \wedge \neg Q)$

1	(1)	$P \rightarrow Q$	A
2	(2)	$P \wedge \neg Q$	A
2	(3)	$P$	2 $\wedge$ E
1,2	(4)	$Q$	1,3 MP
2	(5)	$\neg Q$	2 $\wedge$ E
1,2	(6)	$Q \wedge \neg Q$	4,5 $\wedge$ I
1	(7)	$\neg(P \wedge \neg Q)$	2,6 RA

2.  $\neg(P \wedge Q) \vdash \neg P \vee \neg Q$

1	(1)	$\neg(P \wedge Q)$	A
2	(2)	$\neg(\neg P \vee \neg Q)$	A
3	(3)	$\neg P$	A
3	(4)	$\neg P \vee \neg Q$	3 $\vee$ I
2,3	(5)	$(\neg P \vee \neg Q) \wedge \neg(\neg P \vee \neg Q)$	4,2 $\wedge$ I
2	(6)	$\neg\neg P$	3,5 RA
2	(7)	$P$	6 DN
8	(8)	$\neg Q$	A
8	(9)	$\neg P \vee \neg Q$	8 $\vee$ I
2,8	(10)	$(\neg P \vee \neg Q) \wedge \neg(\neg P \vee \neg Q)$	9,2 $\wedge$ I
2	(11)	$\neg\neg Q$	8,10 RA
2	(12)	$Q$	11 DN
2	(13)	$P \wedge Q$	7,12 $\wedge$ I
1,2	(14)	$(P \wedge Q) \wedge \neg(P \wedge Q)$	13,1 $\wedge$ I
1	(15)	$\neg\neg(\neg P \vee \neg Q)$	2,14 RA
1	(16)	$\neg P \vee \neg Q$	15 DN

3.  $\neg(P \rightarrow Q) \vdash P \wedge \neg Q$

1	(1)	$\neg(P \rightarrow Q)$	A
2	(2)	$\neg P$	A
3	(3)	$\neg Q$	A
4	(4)	$P$	A
2,4	(5)	$P \wedge \neg P$	2,4 $\wedge$ I
2,4	(6)	$\neg\neg Q$	3,5 RA
2,4	(7)	$Q$	6 DN
2	(8)	$P \rightarrow Q$	4,7 CP
1,2	(9)	$(P \rightarrow Q) \wedge \neg(P \rightarrow Q)$	8,1 $\wedge$ I
1	(10)	$\neg\neg P$	2,9 RA
1	(11)	$P$	10 DN
12	(12)	$Q$	A
12	(13)	$P \rightarrow Q$	4,12 CP
1,12	(14)	$(P \rightarrow Q) \wedge \neg(P \rightarrow Q)$	13,1 $\wedge$ I
1	(15)	$\neg Q$	12,14 RA
1	(16)	$P \wedge \neg Q$	11,15 $\wedge$ I

4.  $\vdash (P \rightarrow Q) \vee (Q \rightarrow P)$

1	(1)	$\neg((P \rightarrow Q) \vee (Q \rightarrow P))$	A
2	(2)	$P$	A
3	(3)	$Q$	A
2	(4)	$Q \rightarrow P$	3,2 CP
2	(5)	$(P \rightarrow Q) \vee (Q \rightarrow P)$	4 $\vee$ I
1,2	(6)	$((P \rightarrow Q) \vee (Q \rightarrow P)) \wedge \neg((P \rightarrow Q) \vee (Q \rightarrow P))$	5,1 $\wedge$ I
1	(7)	$\neg P$	2,6 RA
8	(8)	$\neg Q$	A
1,2	(9)	$P \wedge \neg P$	2,7 $\wedge$ I
1,2	(10)	$\neg\neg Q$	8,9 RA
1,2	(11)	$Q$	10 DN
1	(12)	$P \rightarrow Q$	2,11 CP
1	(13)	$(P \rightarrow Q) \vee (Q \rightarrow P)$	12 $\vee$ I
1	(14)	$((P \rightarrow Q) \vee (Q \rightarrow P)) \wedge \neg((P \rightarrow Q) \vee (Q \rightarrow P))$	13,1 $\wedge$ I
$\emptyset$	(15)	$\neg\neg((P \rightarrow Q) \vee (Q \rightarrow P))$	1,14 RA
$\emptyset$	(16)	$(P \rightarrow Q) \vee (Q \rightarrow P)$	15 DN

5.  $P \rightarrow (Q \vee R) \vdash (P \rightarrow Q) \vee (P \rightarrow R)$

1	(1)	$P \rightarrow (Q \vee R)$	A
2	(2)	$\neg((P \rightarrow Q) \vee (P \rightarrow R))$	A
3	(3)	$\neg P$	A
4	(4)	$P$	A
5	(5)	$\neg Q$	A
3,4	(6)	$P \wedge \neg P$	4,3 $\wedge$ I
3,4	(7)	$\neg\neg Q$	5,6 RA
3,4	(8)	$Q$	7 DN
3	(9)	$P \rightarrow Q$	4,8 CP
3	(10)	$(P \rightarrow Q) \vee (P \rightarrow R)$	9 $\vee$ I
2,3	(11)	$((P \rightarrow Q) \vee (P \rightarrow R)) \wedge \neg((P \rightarrow Q) \vee (P \rightarrow R))$	10,2 $\wedge$ I
2	(12)	$\neg\neg P$	3,11 RA
2	(13)	$P$	12 DN
1,2	(14)	$Q \vee R$	1,13 MP
15	(15)	$Q$	A
15	(16)	$P \rightarrow Q$	4,15 CP
15	(17)	$(P \rightarrow Q) \vee (P \rightarrow R)$	16 $\vee$ I
18	(18)	$R$	A
18	(19)	$P \rightarrow R$	4,18 CP
18	(20)	$(P \rightarrow Q) \vee (P \rightarrow R)$	19 $\vee$ I
1,2	(21)	$(P \rightarrow Q) \vee (P \rightarrow R)$	14,15,17,18,20 $\vee$ E
1,2	(22)	$((P \rightarrow Q) \vee (P \rightarrow R)) \wedge \neg((P \rightarrow Q) \vee (P \rightarrow R))$	21,2 $\wedge$ I
1	(23)	$\neg\neg((P \rightarrow Q) \vee (P \rightarrow R))$	2,22 RA
1	(24)	$(P \rightarrow Q) \vee (P \rightarrow R)$	23 DN

6.	$(P \wedge Q) \rightarrow \neg Q \vdash P \rightarrow \neg Q$		
1	(1)	$(P \wedge Q) \rightarrow \neg Q$	A
2	(2)	$P$	A
3	(3)	$Q$	A
2,3	(4)	$P \wedge Q$	2,3 $\wedge$ I
1,2,3	(5)	$\neg Q$	1,4 MP
1,2,3	(6)	$Q \wedge \neg Q$	3,5 $\wedge$ I
1,2	(7)	$\neg Q$	3,6 RA
1	(8)	$P \rightarrow \neg Q$	2,7 CP

## Chapter 6

### Exercise 6.1

1. No logicians are celebrities.  $(Lx, Cx)$

$$\forall x (Lx \rightarrow \neg Cx)$$

Equivalently:  $\neg \exists x (Lx \wedge Cx)$

2. Some celebrities are not logicians.  $(Lx, Cx)$

$$\exists x (Cx \wedge \neg Lx)$$

3. Only students who do the homework will learn logic.  $(Sx, Hx, Lx)$

Either

$$\forall x (Lx \rightarrow (Sx \wedge Hx))$$

or (inequivalently)

$$\forall x ((Sx \wedge Lx) \rightarrow Hx)$$

depending on whether one intends to restrict the claim to students.

4. All rich logicians are computer scientists.  $(Rx, Lx, Cx)$

$$\forall x ((Rx \wedge Lx) \rightarrow Cx)$$

5. All students and professors get a discount.  $(Sx, Px, Dx)$

$$\forall x ((Sx \vee Px) \rightarrow Dx)$$

6. No logician is rich, unless she is a computer scientist.  $(Lx, Rx, Cx)$

$$\forall x ((Lx \wedge Rx) \rightarrow Cx)$$

Equivalent form:  $\forall x ((Lx \wedge \neg Cx) \rightarrow \neg Rx)$

7. Not all logicians are computer scientists.  $(Lx, Cx)$

$$\neg \forall x (Lx \rightarrow Cx)$$

Often put as:  $\exists x (Lx \wedge \neg Cx)$ .

8. Some logicians are rich computer scientists.  $(Lx, Rx, Cx)$

$$\exists x (Lx \wedge (Rx \wedge Cx))$$

9. If there are rich logicians, then some logicians are computer scientists.  $(Rx, Lx, Cx)$

$$\exists x (Rx \wedge Lx) \rightarrow \exists y (Ly \wedge Cy)$$

10. No pets except service animals are permitted in dorms.  $(Px, Sx, Dx)$

Can be read in a minimal way as:

$$\forall x ((Px \wedge Dx) \rightarrow Sx),$$

which says only that no non-service pets are allowed in dorms. However, ordinary policy language is typically understood more strongly: among pets, *being permitted in the dorms* and *being a service animal* coincide. That reading is captured by:

$$\forall x (Px \rightarrow (Dx \leftrightarrow Sx)).$$

This biconditional formalization is therefore closer to the intended rule.

11. If anyone is rich, then Mary is.  $(Rx, m)$

$$(\exists x Rx) \rightarrow Rm$$

## Exercise 6.2

1. Mary loves everyone who loves her.  $(m, Lxy)$

$$\forall x (Lxm \rightarrow Lmx)$$

2. Mary loves all and only those people who don't love themselves.  $(Lxy, m)$

$$\forall x (Lmx \leftrightarrow \neg Lxx)$$

3. Everyone loves their mother.  $(Lxy, Mxy)$

$$\forall x \forall y (Myx \rightarrow Lxy)$$

4. Some people love only those people who love their mother.  $(Lxy, Mxy)$

$$\exists x \forall y (Lxy \rightarrow \forall z (Mzy \rightarrow Lyz))$$

5. Snape killed someone.  $(Kxy, s)$

$$\exists x Ksx$$

6. Snape is a killer.  $(Kxy, s)$

$$\exists x Ksx$$

7. Someone was killed by Snape.  $(Kxy, s)$

$$\exists x Ksx$$

8. Some wizards only marry other wizards.  $(Wx, Mxy)$

$$\exists x (Wx \wedge \forall y (Mxy \rightarrow Wy))$$

9. There is no greatest number.  $(Nx, x < y)$

$$\forall x (Nx \rightarrow \exists y (Ny \wedge x < y))$$

10.  $c$  is the least upper bound of  $a$  and  $b$ .  $(a, b, c, x \leq y)$

$$(a \leq c \wedge b \leq c) \wedge \forall x ((a \leq x \wedge b \leq x) \rightarrow c \leq x)$$

11.  $c$  is the greatest common divisor of  $a$  and  $b$ .  $(a, b, c, Dxy, x \leq y)$

$$(Dca \wedge Dcb) \wedge \forall x ((Dxa \wedge Dxb) \rightarrow x \leq c)$$

## Exercise 6.8

1.  $\neg \exists x (Fx \wedge Gx) \vdash \forall x (Fx \rightarrow \neg Gx)$

1	(1)	$\neg \exists x (Fx \wedge Gx)$	A
2	(2)	$Fa$	A
3	(3)	$Ga$	A
2,3	(4)	$Fa \wedge Ga$	2,3 $\wedge I$
2,3	(5)	$\exists x (Fx \wedge Gx)$	4 EI
1,2,3	(6)	$\exists x (Fx \wedge Gx) \wedge \neg \exists x (Fx \wedge Gx)$	5,1 $\wedge I$
1,2	(7)	$\neg Ga$	3,6 RA
1	(8)	$Fa \rightarrow \neg Ga$	2,7 CP
1	(9)	$\forall x (Fx \rightarrow \neg Gx)$	8 UI



2.  $\forall xFx \vdash \exists xFx$

1	(1)	$\forall xFx$	A
1	(2)	$Fa$	1 UE
1	(3)	$\exists xFx$	2 EI

3.  $\forall x(Fx \rightarrow Gx), Fa \vdash \exists xGx$

1	(1)	$\forall x(Fx \rightarrow Gx)$	A
2	(2)	$Fa$	A
1	(3)	$Fa \rightarrow Ga$	1 UE
1,2	(4)	$Ga$	3,2 MP
1,2	(5)	$\exists xGx$	4 EI

4.  $\neg Fa \vdash \exists x(Fx \rightarrow P)$

1	(1)	$\neg Fa$	A
1	(2)	$Fa \rightarrow P$	1 negative paradox
1	(3)	$\exists x(Fx \rightarrow P)$	2 EI

5.  $\neg \forall xFx \vdash \exists x(Fx \rightarrow P)$

1	(1)	$\neg \forall xFx$	A
2	(2)	$\neg \exists x(Fx \rightarrow P)$	A
3	(3)	$Fa \rightarrow P$	A
3	(4)	$\exists x(Fx \rightarrow P)$	3 EI
2,3	(5)	$\exists x(Fx \rightarrow P) \wedge \neg \exists x(Fx \rightarrow P)$	4,2 $\wedge$ I
2	(6)	$\neg(Fa \rightarrow P)$	3,5 RA
2	(7)	$Fa$	6 material conditional
2	(8)	$\forall xFx$	7 UI
1,2	(9)	$\forall xFx \wedge \neg \forall xFx$	8,1 $\wedge$ I
1	(10)	$\neg \neg \exists x(Fx \rightarrow P)$	2,9 RA
1	(11)	$\exists x(Fx \rightarrow P)$	10 DN

6.  $\neg \exists xFx \vdash \forall x(Fx \rightarrow Gx)$

1	(1)	$\neg \exists xFx$	A
2	(2)	$Fa$	A
3	(3)	$\neg Ga$	A
2	(4)	$\exists xFx$	2 EI
1,2	(5)	$\exists xFx \wedge \neg \exists xFx$	4,1 $\wedge$ I
1,2	(6)	$\neg \neg Ga$	3,5 RA
1,2	(7)	$Ga$	6 DN
1	(8)	$Fa \rightarrow Ga$	2,7 CP
1	(9)	$\forall x(Fx \rightarrow Gx)$	8 UI

7.  $\forall x \forall y Rxy \vdash \exists x Rxx$

1	(1)	$\forall x\forall yRxy$	A
1	(2)	$\forall yRay$	1 UE
1	(3)	$Raa$	2 UE
1	(4)	$\exists xRxx$	3 EI

8.  $P \rightarrow Fa \vdash P \rightarrow \exists xFx$

1	(1)	$P \rightarrow Fa$	A
2	(2)	$P$	A
1,2	(3)	$Fa$	1,2 MP
1,2	(4)	$\exists xFx$	3 EI
1	(5)	$P \rightarrow \exists xFx$	2,4 CP

9.  $\exists xFx \rightarrow P \vdash \forall x(Fx \rightarrow P)$

1	(1)	$\exists xFx \rightarrow P$	A
2	(2)	$Fa$	A
2	(3)	$\exists xFx$	2 EI
1,2	(4)	$P$	1,3 MP
1	(5)	$Fa \rightarrow P$	2,4 CP
1	(6)	$\forall x(Fx \rightarrow P)$	5 UI

There is a typo here in the book: the direction  $\forall x(Fx \rightarrow P) \vdash \exists xFx \rightarrow P$  cannot be proven without EE, which is only introduced in the next section.

10.  $\neg\exists xFx \vdash \forall x(Fx \rightarrow P)$

1	(1)	$\neg\exists xFx$	A
2	(2)	$Fa$	A
2	(3)	$\exists xFx$	2 EI
1,2	(4)	$\exists xFx \wedge \neg\exists xFx$	3,1 $\wedge$ I
1	(5)	$\neg Fa$	2,4 RA
1	(6)	$Fa \rightarrow P$	5 neg paradox
1	(7)	$\forall x(Fx \rightarrow P)$	6 UI

11.  $\neg\exists x(Fx \rightarrow P) \vdash \forall xFx \wedge \neg P$

1	(1)	$\neg\exists x(Fx \rightarrow P)$	A
2	(2)	$Fa \rightarrow P$	A
2	(3)	$\exists x(Fx \rightarrow P)$	2 EI
1,2	(4)	$\exists x(Fx \rightarrow P) \wedge \neg\exists x(Fx \rightarrow P)$	3,1 $\wedge$ I
1	(5)	$\neg(Fa \rightarrow P)$	2,4 RA
1	(6)	$Fa \wedge \neg P$	5 material conditional
1	(7)	$\neg P$	6 $\wedge$ E
1	(8)	$Fa$	6 $\wedge$ E
1	(9)	$\forall xFx$	8 UI
1	(10)	$\forall xFx \wedge \neg P$	9,7 $\wedge$ I

12.  $\forall xFx \rightarrow P \vdash \exists x(Fx \rightarrow P)$

1	(1)	$\forall xFx \rightarrow P$	A
2	(2)	$\neg \exists x(Fx \rightarrow P)$	A
3	(3)	$\neg Fa$	A
3	(4)	$Fa \rightarrow P$	3 neg paradox
3	(5)	$\exists x(Fx \rightarrow P)$	4 EI
2,3	(6)	$\exists x(Fx \rightarrow P) \wedge \neg \exists x(Fx \rightarrow P)$	5,2 $\wedge$ I
2	(7)	$\neg \neg Fa$	3,6 RA
2	(8)	$Fa$	7 DN
2	(9)	$\forall xFx$	8 UI
1,2	(10)	$P$	1,9 MP
1,2	(11)	$Fb \rightarrow P$	10 pos paradox
1,2	(12)	$\exists x(Fx \rightarrow P)$	11 EI
1,2	(13)	$\exists x(Fx \rightarrow P) \wedge \neg \exists x(Fx \rightarrow P)$	12,2 $\wedge$ I
1	(14)	$\neg \neg \exists x(Fx \rightarrow P)$	2,13 RA
1	(15)	$\exists x(Fx \rightarrow P)$	14 DN

### Exercise 6.11

1.  $\exists xFx \vee \exists xGx \vdash \exists x(Fx \vee Gx)$

1	(1)	$\exists xFx \vee \exists xGx$	A
2	(2)	$\exists xFx$	A
3	(3)	$Fa$	A
3	(4)	$Fa \vee Ga$	3 $\vee$ I
3	(5)	$\exists x(Fx \vee Gx)$	4 EI
2	(6)	$\exists x(Fx \vee Gx)$	2,3,5 EE
7	(7)	$\exists xGx$	A
8	(8)	$Ga$	A
8	(9)	$Fa \vee Ga$	8 $\vee$ I
8	(10)	$\exists x(Fx \vee Gx)$	9 EI
7	(11)	$\exists x(Fx \vee Gx)$	7,8,10 EE
1	(12)	$\exists x(Fx \vee Gx)$	1,2,6,7,11 $\vee$ E

2.  $\forall x(Fx \rightarrow Gx), \neg \exists xGx \vdash \neg \exists xFx$

1	(1)	$\forall x(Fx \rightarrow Gx)$	A
2	(2)	$\neg \exists xGx$	A
3	(3)	$\exists xFx$	A
4	(4)	$Fa$	A
1	(5)	$Fa \rightarrow Ga$	1 UE
1,4	(6)	$Ga$	5,4 MP
1,4	(7)	$\exists xGx$	6 EI
1,3	(8)	$\exists xGx$	3,4,7 EE
1,2,3	(9)	$\exists xGx \wedge \neg \exists xGx$	8,2 $\wedge$ I
1,2	(10)	$\neg \exists xFx$	3,9 RA
3. $\forall x(Fx \rightarrow Gx) \vdash \exists x\neg Gx \rightarrow \exists x\neg Fx$			
1	(1)	$\forall x(Fx \rightarrow Gx)$	A
2	(2)	$\exists x\neg Gx$	A
3	(3)	$\neg Ga$	A
1	(4)	$Fa \rightarrow Ga$	1 UE
1,3	(5)	$\neg Fa$	4,3 MT
1,3	(6)	$\exists x\neg Fx$	5 EI
1,2	(7)	$\exists x\neg Fx$	2,3,6 EE
1	(8)	$\exists x\neg Gx \rightarrow \exists x\neg Fx$	2,7 CP
4. $\forall x(Fx \rightarrow P) \vdash \exists xFx \rightarrow P$			
1	(1)	$\forall x(Fx \rightarrow P)$	A
2	(2)	$\exists xFx$	A
3	(3)	$Fa$	A
1	(4)	$Fa \rightarrow P$	1 UE
1,3	(5)	$P$	4,3 MP
1,2	(6)	$P$	2,3,5 EE
1	(7)	$\exists xFx \rightarrow P$	2,6 CP
5. $P \wedge \exists xFx \vdash \exists x(P \wedge Fx)$			
1	(1)	$P \wedge \exists xFx$	A
1	(2)	$P$	1 $\wedge$ E
1	(3)	$\exists xFx$	1 $\wedge$ E
4	(4)	$Fa$	A
1,4	(5)	$P \wedge Fa$	2,4 $\wedge$ I
1,4	(6)	$\exists x(P \wedge Fx)$	5 EI
1	(7)	$\exists x(P \wedge Fx)$	3,4,6 EE
6. $\exists x(Fx \rightarrow P) \vdash \forall xFx \rightarrow P$			

1	(1)	$\exists x(Fx \rightarrow P)$	A
2	(2)	$\forall xFx$	A
3	(3)	$Fa \rightarrow P$	A
2	(4)	$Fa$	2 UE
2,3	(5)	$P$	3,4 MP
3	(6)	$\forall xFx \rightarrow P$	2,5 CP
1	(7)	$\forall xFx \rightarrow P$	1,3,6 EE

### Exercise 6.13

1.  $P \rightarrow \exists xFx \vdash \exists x(P \rightarrow Fx)$

1	(1)	$P \rightarrow \exists xFx$	A
$\emptyset$	(2)	$\exists xFx \vee \neg \exists xFx$	prop taut
3	(3)	$\exists xFx$	A
4	(4)	$Fa$	A
4	(5)	$P \rightarrow Fa$	4 prop taut
4	(6)	$\exists x(P \rightarrow Fx)$	5 EI
3	(7)	$\exists x(P \rightarrow Fx)$	3,4,6 EE
8	(8)	$\neg \exists xFx$	A
1,8	(9)	$\neg P$	1,8 MT
1,8	(10)	$P \rightarrow Fb$	9 prop taut
1,8	(11)	$\exists x(P \rightarrow Fx)$	10 EI
1	(12)	$\exists x(P \rightarrow Fx)$	2,3,7,8,11 $\vee$ E

2.  $\exists x(Fx \rightarrow P) \vdash \forall xFx \rightarrow P$

1	(1)	$\exists x(Fx \rightarrow P)$	A
2	(2)	$\forall xFx$	A
3	(3)	$Fa \rightarrow P$	A
2	(4)	$Fa$	2 UE
2,3	(5)	$P$	3,4 MP
1,2	(6)	$P$	1,3,5 EE
1	(7)	$\forall xFx \rightarrow P$	2,6 CP

### Exercise 6.14

1.  $\vdash \forall x(Fx \rightarrow Fx)$

1	(1)	$Fa$	A
$\emptyset$	(2)	$Fa \rightarrow Fa$	1,1 CP
$\emptyset$	(3)	$\forall x(Fx \rightarrow Fx)$	2 UI

2.  $\vdash \forall xFx \vee \exists x\neg Fx$

$\emptyset$	(1)	$\neg\exists x\neg Fx \vee \exists x\neg Fx$	prop taut
2	(2)	$\neg\exists x\neg Fx$	A
3	(3)	$\neg Fa$	A
3	(4)	$\exists x\neg Fx$	3 EI
2,3	(5)	$\exists x\neg Fx \wedge \neg\exists x\neg Fx$	4,2 $\wedge$ I
2	(6)	$\neg\neg Fa$	3,5 RA
2	(7)	$Fa$	6 DN
2	(8)	$\forall xFx$	7 UI
2	(9)	$\forall xFx \vee \exists x\neg Fx$	8 $\vee$ I
10	(10)	$\exists x\neg Fx$	A
10	(11)	$\forall xFx \vee \exists x\neg Fx$	10 $\vee$ I
$\emptyset$	(12)	$\forall xFx \vee \exists x\neg Fx$	1,2,9,10,11 $\vee$ E

3.  $\vdash \forall x\neg(Fx \wedge \neg Fx)$

1	(1)	$Fa \wedge \neg Fa$	A
$\emptyset$	(2)	$\neg(Fa \wedge \neg Fa)$	1,1 RA
$\emptyset$	(3)	$\forall x\neg(Fx \wedge \neg Fx)$	2 UI

4.  $\vdash \neg\exists x(Fx \wedge \neg Fx)$

1	(1)	$\exists x(Fx \wedge \neg Fx)$	A
2	(2)	$Fa \wedge \neg Fa$	A
2	(3)	$\neg\exists x(Fx \wedge \neg Fx)$	1,2 RA
1	(4)	$\neg\exists x(Fx \wedge \neg Fx)$	1,2,3 EE
1	(5)	$\exists x(Fx \wedge \neg Fx) \wedge \neg\exists x(Fx \wedge \neg Fx)$	1,3 $\wedge$ I
$\emptyset$	(6)	$\neg\exists x(Fx \wedge \neg Fx)$	1,5 RA

5.  $\vdash \forall x\exists y(Rxy \rightarrow Rxx)$

1	(1)	$Raa$	A
$\emptyset$	(2)	$Raa \rightarrow Raa$	1,1 CP
$\emptyset$	(3)	$\exists y(Ray \rightarrow Raa)$	2 EI
$\emptyset$	(4)	$\forall x\exists y(Rxy \rightarrow Rxx)$	3 UI

6.  $\vdash \forall x\exists y(Rxy \rightarrow Ryx)$

1	(1)	$Raa$	A
$\emptyset$	(2)	$Raa \rightarrow Raa$	1,1 CP
$\emptyset$	(3)	$\exists y(Ray \rightarrow Ryx)$	2 EI
$\emptyset$	(4)	$\forall x\exists y(Rxy \rightarrow Ryx)$	3 UI

7.  $\vdash \exists x(Fx \rightarrow \forall yFy)$

1	(1)	$\neg\exists x(Fx \rightarrow \forall yFy)$	A
2	(2)	$\neg Fa$	A
2	(3)	$Fa \rightarrow \forall yFy$	2 prop taut
2	(4)	$\exists x(Fx \rightarrow \forall yFy)$	3 EI
1,2	(5)	$\exists x(Fx \rightarrow \forall yFy) \wedge \neg\exists x(Fx \rightarrow \forall yFy)$	4,1 $\wedge$ I
1	(6)	$\neg\neg Fa$	2,5 RA
1	(7)	$Fa$	6 DN
1	(8)	$\forall yFy$	7 UI
1	(9)	$Fa \rightarrow \forall yFy$	8 prop taut
1	(10)	$\exists x(Fx \rightarrow \forall yFy)$	9 EI
1	(11)	$\exists x(Fx \rightarrow \forall yFy) \wedge \neg\exists x(Fx \rightarrow \forall yFy)$	10,1 $\wedge$ I
$\emptyset$	(12)	$\neg\neg\exists x(Fx \rightarrow \forall yFy)$	1,11 RA
$\emptyset$	(13)	$\exists x(Fx \rightarrow \forall yFy)$	12 DN

8.  $\vdash \exists x\forall y(Fx \rightarrow Fy)$

1	(1)	$\neg\exists x\forall y(Fx \rightarrow Fy)$	A
2	(2)	$\neg Fa$	A
2	(3)	$Fa \rightarrow Fb$	2 prop taut
2	(4)	$\forall y(Fa \rightarrow Fy)$	3 UI
2	(5)	$\exists x\forall y(Fx \rightarrow Fy)$	4 EI
1,2	(6)	$\exists x\forall y(Fx \rightarrow Fy) \wedge \neg\exists x\forall y(Fx \rightarrow Fy)$	5,1 $\wedge$ I
1	(7)	$\neg\neg Fa$	2,6 RA
1	(8)	$Fa$	7 DN
1	(9)	$Fc \rightarrow Fa$	8 prop taut
1	(10)	$\forall y(Fc \rightarrow Fy)$	9 UI
1	(11)	$\exists x\forall y(Fx \rightarrow Fy)$	10 EI
1	(12)	$\exists x\forall y(Fx \rightarrow Fy) \wedge \neg\exists x\forall y(Fx \rightarrow Fy)$	11,1 $\wedge$ I
$\emptyset$	(13)	$\neg\neg\exists x\forall y(Fx \rightarrow Fy)$	1,12 RA
$\emptyset$	(14)	$\exists x\forall y(Fx \rightarrow Fy)$	13 DN

9.  $\forall x\exists y(Fx \rightarrow Gy) \vdash \exists y\forall x(Fx \rightarrow Gy)$

1	(1)	$\forall x \exists y (Fx \rightarrow Gy)$	A
$\emptyset$	(2)	$\exists y Gy \vee \neg \exists y Gy$	prop taut
3	(3)	$\exists y Gy$	A
4	(4)	$Ga$	A
4	(5)	$Fb \rightarrow Ga$	4 prop taut
4	(6)	$\forall x (Fx \rightarrow Ga)$	5 UI
4	(7)	$\exists y \forall x (Fx \rightarrow Gy)$	6 EI
3	(8)	$\exists y \forall x (Fx \rightarrow Gy)$	3,4,7 EE
9	(9)	$\neg \exists y Gy$	A
10	(10)	$Fc$	A
1	(11)	$\exists y (Fc \rightarrow Gy)$	1 UE
12	(12)	$Fc \rightarrow Gd$	A
10,12	(13)	$Gd$	12,10 MP
10,12	(14)	$\exists y Gy$	13 EI
9,10,12	(15)	$\exists y Gy \wedge \neg \exists y Gy$	14,9 $\wedge$ I
9,12	(16)	$\neg Fc$	10,15 RA
9,12	(17)	$Fc \rightarrow Ge$	16 prop taut
1,9	(18)	$Fc \rightarrow Ge$	11,12,17 EE
1,9	(19)	$\forall x (Fx \rightarrow Ge)$	18 UI
1,9	(20)	$\exists y \forall x (Fx \rightarrow Gy)$	19 EI
1	(21)	$\exists y \forall x (Fx \rightarrow Gy)$	2,3,8,9,20 $\vee$ E

10.  $\vdash \forall x \exists y (Rxy \rightarrow \forall z Rxz)$

$\emptyset$	(1)	$\exists y \neg Ray \vee \neg \exists y \neg Ray$	prop taut
2	(2)	$\exists y \neg Ray$	A
3	(3)	$\neg Rab$	A
3	(4)	$Rab \rightarrow \forall z Raz$	3 prop taut
3	(5)	$\exists y (Ray \rightarrow \forall z Raz)$	4 EI
2	(6)	$\exists y (Ray \rightarrow \forall z Raz)$	2,3,5 EE
7	(7)	$\neg \exists y \neg Ray$	A
8	(8)	$\neg Rac$	A
8	(9)	$\exists y \neg Ray$	8 EI
7,8	(10)	$\exists y \neg Ray \wedge \neg \exists y \neg Ray$	9,7 $\wedge$ I
7	(11)	$\neg \neg Rac$	8,10 RA
7	(12)	$Rac$	11 DN
7	(13)	$\forall z Raz$	12 UI
7	(14)	$Rab \rightarrow \forall z Raz$	13 prop taut
7	(15)	$\exists y (Ray \rightarrow \forall z Raz)$	14 EI
$\emptyset$	(16)	$\exists y (Ray \rightarrow \forall z Raz)$	1,2,6,7,15 $\vee$ E
$\emptyset$	(17)	$\forall x \exists y (Rxy \rightarrow \forall z Rxz)$	16 UI



## Exercise 6.17

$$\forall x(\exists zRxx \rightarrow \forall yRxy), \exists x\exists y \vdash \exists x\forall yRxy$$

1	(1)	$\forall x(\exists zRxx \rightarrow \forall yRxy)$	A
2	(2)	$\exists x\exists yRxy$	A
3	(3)	$\exists yRay$	A
4	(4)	$Rab$	A
4	(5)	$\exists zRaz$	4 EI
1	(6)	$\exists zRaz \rightarrow \forall yRay$	1 UE
1,4	(7)	$\forall yRay$	6,5 MP
1,4	(8)	$\exists x\forall yRxy$	7 EI
1,3	(9)	$\exists x\forall yRxy$	3,4,8 EE
1,2	(10)	$\exists x\forall yRxy$	2,3,9 EE

Question: Does it follow from these premises that  $\forall x\forall yRxy$ ?

Answer: No.  $\bigcirc a \longrightarrow b$

## Chapter 7

### Exercise 7.1

Here the proof is lengthened because of the strictness of the  $=$  rules. From  $a = c$  and  $b = c$ , we cannot immediately apply  $=E$  to get  $a = b$ .

1	(1)	$\exists x\forall y(Py \rightarrow y = x)$	A
2	(2)	$Pa \wedge Pb$	A
3	(3)	$\forall y(Py \rightarrow y = c)$	A
3	(4)	$Pa \rightarrow a = c$	3 UE
3	(5)	$Pb \rightarrow b = c$	3 UE
2	(6)	$Pa$	2 $\wedge E$
2	(7)	$Pb$	2 $\wedge E$
2,3	(8)	$a = c$	4,6 MP
2,3	(9)	$b = c$	5,7 MP
$\emptyset$	(10)	$b = b$	$=I$
2,3	(11)	$c = b$	10,9 $=E$
2,3	(12)	$a = b$	8,11 $=E$
1,2	(13)	$a = b$	1,3,12 EE
1	(14)	$(Pa \wedge Pb) \rightarrow a = b$	2,13 CP
1	(15)	$\forall y((Pa \wedge Py) \rightarrow a = y)$	14 UI
1	(16)	$\forall x\forall y((Px \wedge Py) \rightarrow x = y)$	15 UI

## Exercise 7.2

1	(1)	$Fa \wedge \forall x(Fx \rightarrow x = a)$	A
2	(2)	$Fb$	A
1	(3)	$\forall x(Fx \rightarrow x = a)$	1 $\wedge$ E
1	(4)	$Fb \rightarrow b = a$	3 UE
1,2	(5)	$b = a$	4,2 MP
6	(6)	$b = a$	A
1	(7)	$Fa$	1 $\wedge$ E
$\emptyset$	(8)	$b = b$	=I
6	(9)	$a = b$	8,6 =E
1,6	(10)	$Fb$	7,9 =E
1	(11)	$Fb \leftrightarrow b = a$	2,5,6,10 CP $\times$ 2
1	(12)	$\forall x(Fx \leftrightarrow x = a)$	11 UI
1	(1)	$\forall x(Fx \leftrightarrow x = a)$	A
1	(2)	$Fa \leftrightarrow a = a$	1 UE
$\emptyset$	(3)	$a = a$	=I
1	(4)	$Fa$	2,3 MP
1	(5)	$Fb \leftrightarrow b = a$	1 UE
1	(6)	$Fb \rightarrow b = a$	5 $\wedge$ E
1	(7)	$\forall x(Fx \rightarrow x = a)$	6 UI
1	(8)	$Fa \wedge \forall x(Fx \rightarrow x = a)$	4,7 $\wedge$ I

## Chapter 9

### Exercise 9.14

- Hint: Define a map  $F$  from sentences to sentences to be the identity on atomic sentences, to commute with conjunction and negation, and such that  $F(\varphi \vee \psi) = \neg(\neg F(\varphi) \wedge \neg F(\psi))$  and  $F(\varphi \rightarrow \psi) = \neg(F(\varphi) \wedge \neg F(\psi))$ . Thus,  $F(\varphi)$  is always conjunctive, and if  $\varphi$  is conjunctive, then  $F(\varphi) = \varphi$ . Use induction on the construction of sequents to show that if  $\Gamma \vdash \varphi$  then  $F(\Gamma) \succ F(\varphi)$ . For example, the inductive step for MP requires us to show that  $\neg(\varphi \wedge \neg\psi), \varphi \succ \psi$ .