

Modal Logic S4 (K+T+4)

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1 Height preserving admissibility of weakening on the left

- Case(s) rule \rightarrow_R

$$\frac{h_1 : F_4, \Delta_2 \vdash F_5, \Delta_3}{\bullet h_1 : \Delta_2 \vdash \Delta_3, F_4 \rightarrow F_5} \rightarrow_R \rightsquigarrow \frac{\frac{h_1 : \Delta_2, F_4 \vdash \Delta_3, F_5}{h_1 : \Delta_2, F_4, F_W \vdash \Delta_3, F_5} \text{IH} \quad \frac{}{h_1 : \Delta_2, F_4 \vdash \Delta_3, F_5} \text{ax}}{\bullet h_1 : \Delta_2, F_W \vdash \Delta_3, F_4 \rightarrow F_5} \rightarrow_R$$

- Case(s) rule \wedge_R

$$\frac{h_1 : \Delta_2 \vdash F_4, \Delta_3 \quad h_1 : \Delta_2 \vdash F_5, \Delta_3}{\bullet h_1 : \Delta_2 \vdash \Delta_3, F_4 \wedge F_5} \wedge_R \rightsquigarrow \frac{\frac{h_1 : \Delta_2 \vdash \Delta_3, F_4}{h_1 : \Delta_2, F_W \vdash \Delta_3, F_4} \text{IH} \quad \frac{h_1 : \Delta_2 \vdash \Delta_3, F_5}{h_1 : \Delta_2, F_W \vdash \Delta_3, F_5} \text{IH}}{\bullet h_1 : \Delta_2, F_W \vdash \Delta_3, F_4 \wedge F_5} \wedge_R$$

- Case(s) rule \vee_R

$$\frac{h_1 : \Delta_2 \vdash F_4, F_5, \Delta_3}{\bullet h_1 : \Delta_2 \vdash \Delta_3, F_4 \vee F_5} \vee_R \rightsquigarrow \frac{\frac{h_1 : \Delta_2 \vdash \Delta_3, F_4, F_5}{h_1 : \Delta_2, F_W \vdash \Delta_3, F_4, F_5} \text{IH} \quad \frac{}{h_1 : \Delta_2 \vdash \Delta_3, F_4, F_5} \text{ax}}{\bullet h_1 : \Delta_2, F_W \vdash \Delta_3, F_4 \vee F_5} \vee_R$$

- Case(s) rule \perp_R

$$\frac{h_1 : \Delta_2 \vdash \Delta_3}{\bullet h_1 : \Delta_2 \vdash \perp, \Delta_3} \perp_R \rightsquigarrow \frac{\frac{h_1 : \Delta_2 \vdash \Delta_3}{h_1 : \Delta_2, F_W \vdash \Delta_3} \text{IH} \quad \frac{}{h_1 : \Delta_2 \vdash \Delta_3} \text{ax}}{\bullet h_1 : \Delta_2, F_W \vdash \perp, \Delta_3} \perp_R$$

- Case(s) rule \top_R

$$\frac{}{\bullet h_1 : \Delta_2 \vdash \top, \Delta_3} \top_R \rightsquigarrow \frac{}{\bullet h_1 : \Delta_2, F_W \vdash \top, \Delta_3} \top_R$$

- Case(s) rule $A4$

$$\frac{h_1 : \Box \Gamma_2 \vdash F_5}{\bullet h_1 : \Box \Gamma_2, \Delta_3 \vdash \Delta_4, [\Box] F_5} A4 \rightsquigarrow \frac{\frac{h_1 : \Box \Gamma_2 \vdash F_5}{h_1 : \Delta_3, F_W, \Box \Gamma_2 \vdash \Delta_4, [\Box] F_5} \text{ax}}{\bullet h_1 : \Delta_3, F_W, \Box \Gamma_2 \vdash \Delta_4, [\Box] F_5} A4$$

- Case(s) rule \rightarrow_L

$$\frac{h_1 : \Delta_2 \vdash F_3, \Delta_5 \quad h_1 : F_4, \Delta_2 \vdash \Delta_5}{\bullet h_1 : \Delta_2, F_3 \rightarrow F_4 \vdash \Delta_5} \rightarrow_L \rightsquigarrow \frac{\frac{h_1 : \Delta_2 \vdash \Delta_5, F_3}{h_1 : \Delta_2, F_W \vdash \Delta_5, F_3} \text{IH} \quad \frac{h_1 : \Delta_2, F_4 \vdash \Delta_5}{h_1 : \Delta_2, F_4, F_W \vdash \Delta_5} \text{IH}}{\bullet h_1 : \Delta_2, F_W, F_3 \rightarrow F_4 \vdash \Delta_5} \rightarrow_L$$

- Case(s) rule \wedge_L

$$\frac{h_1 : F_3, F_4, \Delta_2 \vdash \Delta_5}{\bullet h_1 : \Delta_2, F_3 \wedge F_4 \vdash \Delta_5} \wedge_L \rightsquigarrow \frac{\frac{h_1 : \Delta_2, F_3, F_4 \vdash \Delta_5}{h_1 : \Delta_2, F_3, F_4, F_W \vdash \Delta_5} \text{IH} \quad \frac{}{h_1 : \Delta_2, F_3, F_4 \vdash \Delta_5} \text{ax}}{\bullet h_1 : \Delta_2, F_W, F_3 \wedge F_4 \vdash \Delta_5} \wedge_L$$

- Case(s) rule \vee_L

$$\frac{h_1 : F_3, \Delta_2 \vdash \Delta_5 \quad h_1 : F_4, \Delta_2 \vdash \Delta_5}{\bullet h_1 : \Delta_2, F_3 \vee F_4 \vdash \Delta_5} \vee_L \rightsquigarrow \frac{\frac{h_1 : \Delta_2, F_3 \vdash \Delta_5}{h_1 : \Delta_2, F_3, F_W \vdash \Delta_5} \text{IH} \quad \frac{h_1 : \Delta_2, F_4 \vdash \Delta_5}{h_1 : \Delta_2, F_4, F_W \vdash \Delta_5} \text{IH}}{\bullet h_1 : \Delta_2, F_W, F_3 \vee F_4 \vdash \Delta_5} \vee_L$$

- Case(s) rule AT

$$\frac{h_1 : F_3, \Delta_2, []F_3 \vdash \Delta_4}{\bullet h_1 : \Delta_2, []F_3 \vdash \Delta_4} AT \quad \rightsquigarrow \quad \frac{\frac{h_1 : \Delta_2, F_3, []F_3 \vdash \Delta_4}{h_1 : \Delta_2, F_3, F_W, []F_3 \vdash \Delta_4} IH}{\bullet h_1 : \Delta_2, F_W, []F_3 \vdash \Delta_4} AT$$

- Case(s) rule \perp_L

$$\frac{}{\bullet h_1 : \perp, \Delta_2 \vdash \Delta_3} \perp_L \quad \rightsquigarrow \quad \frac{}{\bullet h_1 : \perp, \Delta_2, F_W \vdash \Delta_3} \perp_L$$

- Case(s) rule I

$$\frac{}{\bullet h_1 : \Delta_2, p_3 \vdash \Delta_4, p_3} I \quad \rightsquigarrow \quad \frac{}{\bullet h_1 : \Delta_2, F_W, p_3 \vdash \Delta_4, p_3} I$$

- Case(s) rule \top_L

$$\frac{h_1 : \Delta_2 \vdash \Delta_3}{\bullet h_1 : \top, \Delta_2 \vdash \Delta_3} \top_L \quad \rightsquigarrow \quad \frac{\frac{h_1 : \Delta_2 \vdash \Delta_3}{h_1 : \Delta_2, F_W \vdash \Delta_3} IH}{\bullet h_1 : \top, \Delta_2, F_W \vdash \Delta_3} \top_L$$

2 Height preserving admissibility of weakening on the right

- Case(s) rule \rightarrow_R

$$\frac{h_1 : F_4, \Delta_2 \vdash F_5, \Delta_3}{\bullet h_1 : \Delta_2 \vdash \Delta_3, F_4 \rightarrow F_5} \rightarrow_R \rightsquigarrow \frac{\frac{h_1 : \Delta_2, F_4 \vdash \Delta_3, F_5}{\bullet h_1 : \Delta_2 \vdash \Delta_3, F_4 \rightarrow F_5} \text{ax} \quad \frac{h_1 : \Delta_2, F_4 \vdash \Delta_3, F_5, F_W}{\bullet h_1 : \Delta_2 \vdash \Delta_3, F_W, F_4 \rightarrow F_5} \text{IH}}{\bullet h_1 : \Delta_2 \vdash \Delta_3, F_W, F_4 \rightarrow F_5} \rightarrow_R$$

- Case(s) rule \wedge_R

$$\frac{h_1 : \Delta_2 \vdash F_4, \Delta_3 \quad h_1 : \Delta_2 \vdash F_5, \Delta_3}{\bullet h_1 : \Delta_2 \vdash \Delta_3, F_4 \wedge F_5} \wedge_R \rightsquigarrow \frac{\frac{h_1 : \Delta_2 \vdash \Delta_3, F_4}{\bullet h_1 : \Delta_2 \vdash \Delta_3, F_4, F_W} \text{ax} \quad \frac{h_1 : \Delta_2 \vdash \Delta_3, F_5}{\bullet h_1 : \Delta_2 \vdash \Delta_3, F_5, F_W} \text{ax}}{\frac{h_1 : \Delta_2 \vdash \Delta_3, F_4, F_W}{\bullet h_1 : \Delta_2 \vdash \Delta_3, F_W, F_4 \wedge F_5} \text{IH} \quad \frac{h_1 : \Delta_2 \vdash \Delta_3, F_5, F_W}{\bullet h_1 : \Delta_2 \vdash \Delta_3, F_W, F_4 \wedge F_5} \text{IH}}{\bullet h_1 : \Delta_2 \vdash \Delta_3, F_W, F_4 \wedge F_5} \wedge_R$$

- Case(s) rule \vee_R

$$\frac{h_1 : \Delta_2 \vdash F_4, F_5, \Delta_3}{\bullet h_1 : \Delta_2 \vdash \Delta_3, F_4 \vee F_5} \vee_R \rightsquigarrow \frac{\frac{h_1 : \Delta_2 \vdash \Delta_3, F_4, F_5}{\bullet h_1 : \Delta_2 \vdash \Delta_3, F_4, F_5, F_W} \text{ax} \quad \frac{h_1 : \Delta_2 \vdash \Delta_3, F_4, F_5, F_W}{\bullet h_1 : \Delta_2 \vdash \Delta_3, F_W, F_4 \vee F_5} \text{IH}}{\bullet h_1 : \Delta_2 \vdash \Delta_3, F_W, F_4 \vee F_5} \vee_R$$

- Case(s) rule \perp_R

$$\frac{h_1 : \Delta_2 \vdash \Delta_3}{\bullet h_1 : \Delta_2 \vdash \perp, \Delta_3} \perp_R \rightsquigarrow \frac{\frac{h_1 : \Delta_2 \vdash \Delta_3}{\bullet h_1 : \Delta_2 \vdash \Delta_3, F_W} \text{ax} \quad \frac{h_1 : \Delta_2 \vdash \Delta_3, F_W}{\bullet h_1 : \Delta_2 \vdash \perp, \Delta_3, F_W} \text{IH}}{\bullet h_1 : \Delta_2 \vdash \perp, \Delta_3, F_W} \perp_R$$

- Case(s) rule \top_R

$$\frac{}{\bullet h_1 : \Delta_2 \vdash \top, \Delta_3} \top_R \rightsquigarrow \frac{}{\bullet h_1 : \Delta_2 \vdash \top, \Delta_3, F_W} \top_R$$

- Case(s) rule $A4$

$$\frac{h_1 : \Box \Gamma_2 \vdash F_5}{\bullet h_1 : \Box \Gamma_2, \Delta_3 \vdash \Delta_4, [\Box F_5]} A4 \rightsquigarrow \frac{\frac{h_1 : \Box \Gamma_2 \vdash F_5}{\bullet h_1 : \Delta_3, \Box \Gamma_2 \vdash \Delta_4, F_W, [\Box F_5]} \text{ax}}{\bullet h_1 : \Delta_3, \Box \Gamma_2 \vdash \Delta_4, F_W, [\Box F_5]} A4$$

- Case(s) rule \rightarrow_L

$$\frac{h_1 : \Delta_2 \vdash F_3, \Delta_5 \quad h_1 : F_4, \Delta_2 \vdash \Delta_5}{\bullet h_1 : \Delta_2, F_3 \rightarrow F_4 \vdash \Delta_5} \rightarrow_L \rightsquigarrow \frac{\frac{h_1 : \Delta_2 \vdash \Delta_5, F_3}{\bullet h_1 : \Delta_2 \vdash \Delta_5, F_3, F_W} \text{ax} \quad \frac{h_1 : \Delta_2, F_4 \vdash \Delta_5}{\bullet h_1 : \Delta_2, F_3 \rightarrow F_4 \vdash \Delta_5, F_W} \text{ax}}{\bullet h_1 : \Delta_2, F_3 \rightarrow F_4 \vdash \Delta_5, F_W} \rightarrow_L$$

- Case(s) rule \wedge_L

$$\frac{h_1 : F_3, F_4, \Delta_2 \vdash \Delta_5}{\bullet h_1 : \Delta_2, F_3 \wedge F_4 \vdash \Delta_5} \wedge_L \rightsquigarrow \frac{\frac{h_1 : \Delta_2, F_3, F_4 \vdash \Delta_5}{\bullet h_1 : \Delta_2, F_3, F_4 \vdash \Delta_5, F_W} \text{ax} \quad \frac{h_1 : \Delta_2, F_3, F_4 \vdash \Delta_5, F_W}{\bullet h_1 : \Delta_2, F_3 \wedge F_4 \vdash \Delta_5, F_W} \text{IH}}{\bullet h_1 : \Delta_2, F_3 \wedge F_4 \vdash \Delta_5, F_W} \wedge_L$$

- Case(s) rule \vee_L

$$\frac{h_1 : F_3, \Delta_2 \vdash \Delta_5 \quad h_1 : F_4, \Delta_2 \vdash \Delta_5}{\bullet h_1 : \Delta_2, F_3 \vee F_4 \vdash \Delta_5} \vee_L \rightsquigarrow \frac{\frac{h_1 : \Delta_2, F_3 \vdash \Delta_5}{\bullet h_1 : \Delta_2, F_3 \vdash \Delta_5, F_W} \text{ax} \quad \frac{h_1 : \Delta_2, F_4 \vdash \Delta_5}{\bullet h_1 : \Delta_2, F_4 \vdash \Delta_5, F_W} \text{ax}}{\frac{h_1 : \Delta_2, F_3 \vdash \Delta_5, F_W}{\bullet h_1 : \Delta_2, F_3 \vee F_4 \vdash \Delta_5, F_W} \text{IH} \quad \frac{h_1 : \Delta_2, F_4 \vdash \Delta_5, F_W}{\bullet h_1 : \Delta_2, F_3 \vee F_4 \vdash \Delta_5, F_W} \text{IH}}{\bullet h_1 : \Delta_2, F_3 \vee F_4 \vdash \Delta_5, F_W} \vee_L$$

- Case(s) rule AT

$$\frac{h_1 : F_3, \Delta_2, [\Box F_3] \vdash \Delta_4}{\bullet h_1 : \Delta_2, [\Box F_3] \vdash \Delta_4} AT \rightsquigarrow \frac{\frac{h_1 : \Delta_2, F_3, [\Box F_3] \vdash \Delta_4}{\bullet h_1 : \Delta_2, F_3, [\Box F_3] \vdash \Delta_4, F_W} \text{ax} \quad \frac{h_1 : \Delta_2, F_3, [\Box F_3] \vdash \Delta_4, F_W}{\bullet h_1 : \Delta_2, [\Box F_3] \vdash \Delta_4, F_W} \text{IH}}{\bullet h_1 : \Delta_2, [\Box F_3] \vdash \Delta_4, F_W} AT$$

- Case(s) rule \perp_L

$$\frac{}{\bullet h_1 : \perp, \Delta_2 \vdash \Delta_3} \perp_L \quad \rightsquigarrow \quad \frac{}{\bullet h_1 : \perp, \Delta_2 \vdash \Delta_3, F_W} \perp_L$$

- Case(s) rule I

$$\frac{}{\bullet h_1 : \Delta_2, p_3 \vdash \Delta_4, p_3} I \quad \rightsquigarrow \quad \frac{}{\bullet h_1 : \Delta_2, p_3 \vdash \Delta_4, F_W, p_3} I$$

- Case(s) rule \top_L

$$\frac{h_1 : \Delta_2 \vdash \Delta_3}{\bullet h_1 : \top, \Delta_2 \vdash \Delta_3} \top_L \quad \rightsquigarrow \quad \frac{\frac{h_1 : \Delta_2 \vdash \Delta_3}{\bullet h_1 : \Delta_2 \vdash \Delta_3} \text{ax}}{\frac{h_1 : \Delta_2 \vdash \Delta_3, F_W}{\bullet h_1 : \top, \Delta_2 \vdash \Delta_3, F_W} \text{IH}} \top_L$$

3 Measure of derivations

- Case(s) rule \rightarrow_R

$$\frac{h_1 : F_4, \Delta_2 \vdash F_5, \Delta_3}{\bullet h_1 : \Delta_2 \vdash \Delta_3, F_4 \rightarrow F_5} \rightarrow_R \rightsquigarrow \frac{\frac{h_1 : \Delta_2, F_4 \vdash \Delta_3, F_5}{\bullet h_1 : \Delta_2, F_4 \vdash \Delta_3, F_5} \text{ ax}}{\bullet \bullet h_1 : \Delta_2 \vdash \Delta_3, F_4 \rightarrow F_5} \text{ IH} \rightarrow_R$$

- Case(s) rule \wedge_R

$$\frac{h_1 : \Delta_2 \vdash F_4, \Delta_3 \quad h_1 : \Delta_2 \vdash F_5, \Delta_3}{\bullet h_1 : \Delta_2 \vdash \Delta_3, F_4 \wedge F_5} \wedge_R \rightsquigarrow \frac{\frac{h_1 : \Delta_2 \vdash \Delta_3, F_4}{\bullet h_1 : \Delta_2 \vdash \Delta_3, F_4} \text{ ax} \quad \frac{h_1 : \Delta_2 \vdash \Delta_3, F_5}{\bullet h_1 : \Delta_2 \vdash \Delta_3, F_5} \text{ ax}}{\bullet \bullet h_1 : \Delta_2 \vdash \Delta_3, F_4 \wedge F_5} \text{ IH} \wedge_R$$

- Case(s) rule \vee_R

$$\frac{h_1 : \Delta_2 \vdash F_4, F_5, \Delta_3}{\bullet h_1 : \Delta_2 \vdash \Delta_3, F_4 \vee F_5} \vee_R \rightsquigarrow \frac{\frac{h_1 : \Delta_2 \vdash \Delta_3, F_4, F_5}{\bullet h_1 : \Delta_2 \vdash \Delta_3, F_4, F_5} \text{ ax}}{\bullet \bullet h_1 : \Delta_2 \vdash \Delta_3, F_4 \vee F_5} \text{ IH} \vee_R$$

- Case(s) rule \perp_R

$$\frac{h_1 : \Delta_2 \vdash \Delta_3}{\bullet h_1 : \Delta_2 \vdash \perp, \Delta_3} \perp_R \rightsquigarrow \frac{\frac{h_1 : \Delta_2 \vdash \Delta_3}{\bullet h_1 : \Delta_2 \vdash \Delta_3} \text{ ax}}{\bullet \bullet h_1 : \Delta_2 \vdash \perp, \Delta_3} \text{ IH} \perp_R$$

- Case(s) rule \top_R

$$\frac{}{\bullet h_1 : \Delta_2 \vdash \top, \Delta_3} \top_R \rightsquigarrow \frac{}{\bullet \bullet h_1 : \Delta_2 \vdash \top, \Delta_3} \top_R$$

- Case(s) rule $A4$

$$\frac{h_1 : \Box \Gamma_2 \vdash F_5}{\bullet h_1 : \Box \Gamma_2, \Delta_3 \vdash \Delta_4, [\Box F_5]} A4 \rightsquigarrow \frac{\frac{h_1 : \Box \Gamma_2 \vdash F_5}{\bullet h_1 : \Box \Gamma_2 \vdash F_5} \text{ ax}}{\bullet \bullet h_1 : \Delta_3, \Box \Gamma_2 \vdash \Delta_4, [\Box F_5]} \text{ IH} A4$$

- Case(s) rule \rightarrow_L

$$\frac{h_1 : \Delta_2 \vdash F_3, \Delta_5 \quad h_1 : F_4, \Delta_2 \vdash \Delta_5}{\bullet h_1 : \Delta_2, F_3 \rightarrow F_4 \vdash \Delta_5} \rightarrow_L \rightsquigarrow \frac{\frac{h_1 : \Delta_2 \vdash \Delta_5, F_3}{\bullet h_1 : \Delta_2 \vdash \Delta_5, F_3} \text{ ax} \quad \frac{h_1 : \Delta_2, F_4 \vdash \Delta_5}{\bullet h_1 : \Delta_2, F_4 \vdash \Delta_5} \text{ ax}}{\bullet \bullet h_1 : \Delta_2, F_3 \rightarrow F_4 \vdash \Delta_5} \text{ IH} \rightarrow_L$$

- Case(s) rule \wedge_L

$$\frac{h_1 : F_3, F_4, \Delta_2 \vdash \Delta_5}{\bullet h_1 : \Delta_2, F_3 \wedge F_4 \vdash \Delta_5} \wedge_L \rightsquigarrow \frac{\frac{h_1 : \Delta_2, F_3, F_4 \vdash \Delta_5}{\bullet h_1 : \Delta_2, F_3, F_4 \vdash \Delta_5} \text{ ax}}{\bullet \bullet h_1 : \Delta_2, F_3 \wedge F_4 \vdash \Delta_5} \text{ IH} \wedge_L$$

- Case(s) rule \vee_L

$$\frac{h_1 : F_3, \Delta_2 \vdash \Delta_5 \quad h_1 : F_4, \Delta_2 \vdash \Delta_5}{\bullet h_1 : \Delta_2, F_3 \vee F_4 \vdash \Delta_5} \vee_L \rightsquigarrow \frac{\frac{h_1 : \Delta_2, F_3 \vdash \Delta_5}{\bullet h_1 : \Delta_2, F_3 \vdash \Delta_5} \text{ ax} \quad \frac{h_1 : \Delta_2, F_4 \vdash \Delta_5}{\bullet h_1 : \Delta_2, F_4 \vdash \Delta_5} \text{ ax}}{\bullet \bullet h_1 : \Delta_2, F_3 \vee F_4 \vdash \Delta_5} \text{ IH} \vee_L$$

- Case(s) rule AT

$$\frac{h_1 : F_3, \Delta_2, [\Box F_3] \vdash \Delta_4}{\bullet h_1 : \Delta_2, [\Box F_3] \vdash \Delta_4} AT \rightsquigarrow \frac{\frac{h_1 : \Delta_2, F_3, [\Box F_3] \vdash \Delta_4}{\bullet h_1 : \Delta_2, F_3, [\Box F_3] \vdash \Delta_4} \text{ ax}}{\bullet \bullet h_1 : \Delta_2, [\Box F_3] \vdash \Delta_4} \text{ IH} AT$$

- Case(s) rule \perp_L

$$\frac{}{\bullet h_1 : \perp, \Delta_2 \vdash \Delta_3} \perp_L \quad \rightsquigarrow \quad \frac{}{\bullet \bullet h_1 : \perp, \Delta_2 \vdash \Delta_3} \perp_L$$

- Case(s) rule I

$$\frac{}{\bullet h_1 : \Delta_2, p_3 \vdash \Delta_4, p_3} I \quad \rightsquigarrow \quad \frac{}{\bullet \bullet h_1 : \Delta_2, p_3 \vdash \Delta_4, p_3} I$$

- Case(s) rule \top_L

$$\frac{h_1 : \Delta_2 \vdash \Delta_3}{\bullet h_1 : \top, \Delta_2 \vdash \Delta_3} \top_L \quad \rightsquigarrow \quad \frac{\frac{h_1 : \Delta_2 \vdash \Delta_3}{\bullet h_1 : \Delta_2 \vdash \Delta_3} \text{IH}}{\bullet \bullet h_1 : \top, \Delta_2 \vdash \Delta_3} \top_L$$

4 Invertibility of Rules

4.1 Status of \rightarrow_R : : Invertible

- Case rule \rightarrow_R

$$\frac{h_3 : F_5, \Delta_4 \vdash F_6, \Delta_7, F_1 \rightarrow F_2}{\bullet h_3 : \Delta_4 \vdash (\Delta_7, F_1 \rightarrow F_2), F_5 \rightarrow F_6} \rightarrow_R \rightsquigarrow \frac{\overline{h_3 : \Delta_4, F_1, F_5 \vdash \Delta_7, F_2, F_6}}{\bullet h_3 : \Delta_4, F_1 \vdash \Delta_7, F_2, F_5 \rightarrow F_6} \text{ax/ind} \rightarrow_R$$

$$\frac{h_1 : F_4, \Delta_2 \vdash F_5, \Delta_3}{\bullet h_1 : \Delta_2 \vdash \Delta_3, F_4 \rightarrow F_5} \rightarrow_R \rightsquigarrow \frac{\overline{h_1 : \Delta_2, F_4 \vdash \Delta_3, F_5}}{\bullet h_1 : \Delta_2, F_4 \vdash \Delta_3, F_5} \text{ax} \text{H}$$

- Case rule \wedge_R

$$\frac{h_3 : \Delta_4 \vdash F_5, \Delta_7, F_1 \rightarrow F_2 \quad h_3 : \Delta_4 \vdash F_6, \Delta_7, F_1 \rightarrow F_2}{\bullet h_3 : \Delta_4 \vdash (\Delta_7, F_1 \rightarrow F_2), F_5 \wedge F_6} \wedge_R \rightsquigarrow \frac{\overline{h_3 : \Delta_4, F_1 \vdash \Delta_7, F_2, F_5} \text{ax/ind} \quad \overline{h_3 : \Delta_4, F_1 \vdash \Delta_7, F_2, F_6} \text{ax/ind}}{\bullet h_3 : \Delta_4, F_1 \vdash \Delta_7, F_2, F_5 \wedge F_6} \wedge_R$$

- Case rule \vee_R

$$\frac{h_3 : \Delta_4 \vdash F_5, F_6, \Delta_7, F_1 \rightarrow F_2}{\bullet h_3 : \Delta_4 \vdash (\Delta_7, F_1 \rightarrow F_2), F_5 \vee F_6} \vee_R \rightsquigarrow \frac{\overline{h_3 : \Delta_4, F_1 \vdash \Delta_7, F_2, F_5, F_6} \text{ax/ind}}{\bullet h_3 : \Delta_4, F_1 \vdash \Delta_7, F_2, F_5 \vee F_6} \vee_R$$

- Case rule \perp_R

$$\frac{h_3 : \Delta_4 \vdash \Delta_5, F_1 \rightarrow F_2}{\bullet h_3 : \Delta_4 \vdash \perp, \Delta_5, F_1 \rightarrow F_2} \perp_R \rightsquigarrow \frac{\overline{h_3 : \Delta_4, F_1 \vdash \Delta_5, F_2} \text{ax/ind}}{\bullet h_3 : \Delta_4, F_1 \vdash \perp, \Delta_5, F_2} \perp_R$$

- Case rule \top_R

$$\frac{}{\bullet h_3 : \Delta_4 \vdash \top, \Delta_5, F_1 \rightarrow F_2} \top_R \rightsquigarrow \frac{}{\bullet h_3 : \Delta_4, F_1 \vdash \top, \Delta_5, F_2} \top_R$$

- Case rule $A4$

$$\frac{h_3 : \Box \Gamma_4 \vdash F_6}{\bullet h_3 : \Box \Gamma_4, \Delta_5 \vdash (\Delta_7, F_1 \rightarrow F_2), \Box F_6} A4 \rightsquigarrow \frac{\overline{h_3 : \Box \Gamma_4 \vdash F_6} \text{ax}}{\bullet h_3 : \Delta_5, F_1, \Box \Gamma_4 \vdash \Delta_7, F_2, \Box F_6} A4$$

- Case rule \rightarrow_L

$$\frac{h_4 : \Delta_5 \vdash F_6, \Delta_1, F_2 \rightarrow F_3 \quad h_4 : F_7, \Delta_5 \vdash \Delta_1, F_2 \rightarrow F_3}{\bullet h_4 : \Delta_5, F_6 \rightarrow F_7 \vdash \Delta_1, F_2 \rightarrow F_3} \rightarrow_L \rightsquigarrow \frac{\overline{h_4 : \Delta_5, F_2 \vdash \Delta_1, F_3, F_6} \text{ax/ind} \quad \overline{h_4 : \Delta_5, F_2, F_7 \vdash \Delta_1, F_3} \text{ax/ind}}{\bullet h_4 : \Delta_5, F_2, F_6 \rightarrow F_7 \vdash \Delta_1, F_3} \rightarrow_L$$

- Case rule \wedge_L

$$\frac{h_4 : F_6, F_7, \Delta_5 \vdash \Delta_1, F_2 \rightarrow F_3}{\bullet h_4 : \Delta_5, F_6 \wedge F_7 \vdash \Delta_1, F_2 \rightarrow F_3} \wedge_L \rightsquigarrow \frac{\overline{h_4 : \Delta_5, F_2, F_6, F_7 \vdash \Delta_1, F_3} \text{ax/ind}}{\bullet h_4 : \Delta_5, F_2, F_6 \wedge F_7 \vdash \Delta_1, F_3} \wedge_L$$

- Case rule \vee_L

$$\frac{h_4 : F_6, \Delta_5 \vdash \Delta_1, F_2 \rightarrow F_3 \quad h_4 : F_7, \Delta_5 \vdash \Delta_1, F_2 \rightarrow F_3}{\bullet h_4 : \Delta_5, F_6 \vee F_7 \vdash \Delta_1, F_2 \rightarrow F_3} \vee_L \quad \rightsquigarrow \quad \frac{\overline{h_4 : \Delta_5, F_2, F_6 \vdash \Delta_1, F_3} \text{ ax/ind} \quad \overline{h_4 : \Delta_5, F_2, F_7 \vdash \Delta_1, F_3} \text{ ax/ind}}{\bullet h_4 : \Delta_5, F_2, F_6 \vee F_7 \vdash \Delta_1, F_3} \vee_L$$

- Case rule AT

$$\frac{h_4 : F_6, \Delta_5, []F_6 \vdash \Delta_1, F_2 \rightarrow F_3}{\bullet h_4 : \Delta_5, []F_6 \vdash \Delta_1, F_2 \rightarrow F_3} AT \quad \rightsquigarrow \quad \frac{\overline{h_4 : \Delta_5, F_2, F_6, []F_6 \vdash \Delta_1, F_3} \text{ ax/ind}}{\bullet h_4 : \Delta_5, F_2, []F_6 \vdash \Delta_1, F_3} AT$$

- Case rule \perp_L

$$\overline{\bullet h_4 : \perp, \Delta_5 \vdash \Delta_1, F_2 \rightarrow F_3} \perp_L \quad \rightsquigarrow \quad \overline{\bullet h_4 : \perp, \Delta_5, F_2 \vdash \Delta_1, F_3} \perp_L$$

- Case rule I

$$\overline{\bullet h_3 : p_5, \Delta_4 \vdash p_5, \Delta_6, F_1 \rightarrow F_2} I \quad \rightsquigarrow \quad \overline{\bullet h_3 : \Delta_4, F_1, p_5 \vdash \Delta_6, F_2, p_5} I$$

- Case rule \top_L

$$\frac{h_4 : \Delta_5 \vdash \Delta_1, F_2 \rightarrow F_3}{\bullet h_4 : \top, \Delta_5 \vdash \Delta_1, F_2 \rightarrow F_3} \top_L \quad \rightsquigarrow \quad \frac{\overline{h_4 : \Delta_5, F_2 \vdash \Delta_1, F_3} \text{ ax/ind}}{\bullet h_4 : \top, \Delta_5, F_2 \vdash \Delta_1, F_3} \top_L$$

4.2 Status of \wedge_R : (Left Premise): Invertible

- Case rule \rightarrow_R

$$\frac{h_3 : F_5, \Delta_4 \vdash F_6, \Delta_7, F_1 \wedge F_2}{\bullet h_3 : \Delta_4 \vdash (\Delta_7, F_1 \wedge F_2), F_5 \rightarrow F_6} \rightarrow_R \quad \rightsquigarrow \quad \frac{\overline{h_3 : \Delta_4, F_5 \vdash \Delta_7, F_1, F_6} \text{ ax/ind}}{\bullet h_3 : \Delta_4 \vdash \Delta_7, F_1, F_5 \rightarrow F_6} \rightarrow_R$$

- Case rule \wedge_R

$$\frac{h_3 : \Delta_4 \vdash F_5, \Delta_7, F_1 \wedge F_2 \quad h_3 : \Delta_4 \vdash F_6, \Delta_7, F_1 \wedge F_2}{\bullet h_3 : \Delta_4 \vdash (\Delta_7, F_1 \wedge F_2), F_5 \wedge F_6} \wedge_R \quad \rightsquigarrow \quad \frac{\overline{h_3 : \Delta_4 \vdash \Delta_7, F_1, F_5} \text{ ax/ind} \quad \overline{h_3 : \Delta_4 \vdash \Delta_7, F_1, F_6} \text{ ax/ind}}{\bullet h_3 : \Delta_4 \vdash \Delta_7, F_1, F_5 \wedge F_6} \wedge_R$$

$$\frac{h_1 : \Delta_2 \vdash F_4, \Delta_3 \quad h_1 : \Delta_2 \vdash F_5, \Delta_3}{\bullet h_1 : \Delta_2 \vdash \Delta_3, F_4 \wedge F_5} \wedge_R \quad \rightsquigarrow \quad \frac{\overline{h_1 : \Delta_2 \vdash \Delta_3, F_4} \text{ ax}}{\bullet h_1 : \Delta_2 \vdash \Delta_3, F_4} \wedge_R$$

- Case rule \vee_R

$$\frac{h_3 : \Delta_4 \vdash F_5, F_6, \Delta_7, F_1 \wedge F_2}{\bullet h_3 : \Delta_4 \vdash (\Delta_7, F_1 \wedge F_2), F_5 \vee F_6} \vee_R \quad \rightsquigarrow \quad \frac{\overline{h_3 : \Delta_4 \vdash \Delta_7, F_1, F_5, F_6} \text{ ax/ind}}{\bullet h_3 : \Delta_4 \vdash \Delta_7, F_1, F_5 \vee F_6} \vee_R$$

- Case rule \perp_R

$$\frac{h_3 : \Delta_4 \vdash \Delta_5, F_1 \wedge F_2}{\bullet h_3 : \Delta_4 \vdash \perp, \Delta_5, F_1 \wedge F_2} \perp_R \quad \rightsquigarrow \quad \frac{\overline{h_3 : \Delta_4 \vdash \Delta_5, F_1} \text{ ax/ind}}{\bullet h_3 : \Delta_4 \vdash \perp, \Delta_5, F_1} \perp_R$$

- Case rule \top_R

$$\frac{}{\bullet h_3 : \Delta_4 \vdash \top, \Delta_5, F_1 \wedge F_2} \top_R \rightsquigarrow \frac{}{\bullet h_3 : \Delta_4 \vdash \top, \Delta_5, F_1} \top_R$$

- Case rule $A4$

$$\frac{h_3 : \Box \Gamma_4 \vdash F_6}{\bullet h_3 : \Box \Gamma_4, \Delta_5 \vdash (\Delta_7, F_1 \wedge F_2), [] F_6} A4 \rightsquigarrow \frac{\frac{}{h_3 : \Box \Gamma_4 \vdash F_6} ax}{\bullet h_3 : \Delta_5, \Box \Gamma_4 \vdash \Delta_7, F_1, [] F_6} A4$$

- Case rule \rightarrow_L

$$\frac{h_4 : \Delta_5 \vdash F_6, \Delta_1, F_2 \wedge F_3 \quad h_4 : F_7, \Delta_5 \vdash \Delta_1, F_2 \wedge F_3}{\bullet h_4 : \Delta_5, F_6 \rightarrow F_7 \vdash \Delta_1, F_2 \wedge F_3} \rightarrow_L \rightsquigarrow \frac{\frac{}{h_4 : \Delta_5 \vdash \Delta_1, F_2, F_6} ax/ind \quad \frac{}{h_4 : \Delta_5, F_7 \vdash \Delta_1, F_2} ax/ind}{\bullet h_4 : \Delta_5, F_6 \rightarrow F_7 \vdash \Delta_1, F_2} \rightarrow_L$$

- Case rule \wedge_L

$$\frac{h_4 : F_6, F_7, \Delta_5 \vdash \Delta_1, F_2 \wedge F_3}{\bullet h_4 : \Delta_5, F_6 \wedge F_7 \vdash \Delta_1, F_2 \wedge F_3} \wedge_L \rightsquigarrow \frac{\frac{}{h_4 : \Delta_5, F_6, F_7 \vdash \Delta_1, F_2} ax/ind}{\bullet h_4 : \Delta_5, F_6 \wedge F_7 \vdash \Delta_1, F_2} \wedge_L$$

- Case rule \vee_L

$$\frac{h_4 : F_6, \Delta_5 \vdash \Delta_1, F_2 \wedge F_3 \quad h_4 : F_7, \Delta_5 \vdash \Delta_1, F_2 \wedge F_3}{\bullet h_4 : \Delta_5, F_6 \vee F_7 \vdash \Delta_1, F_2 \wedge F_3} \vee_L \rightsquigarrow \frac{\frac{}{h_4 : \Delta_5, F_6 \vdash \Delta_1, F_2} ax/ind \quad \frac{}{h_4 : \Delta_5, F_7 \vdash \Delta_1, F_2} ax/ind}{\bullet h_4 : \Delta_5, F_6 \vee F_7 \vdash \Delta_1, F_2} \vee_L$$

- Case rule AT

$$\frac{h_4 : F_6, \Delta_5, [] F_6 \vdash \Delta_1, F_2 \wedge F_3}{\bullet h_4 : \Delta_5, [] F_6 \vdash \Delta_1, F_2 \wedge F_3} AT \rightsquigarrow \frac{\frac{}{h_4 : \Delta_5, F_6, [] F_6 \vdash \Delta_1, F_2} ax/ind}{\bullet h_4 : \Delta_5, [] F_6 \vdash \Delta_1, F_2} AT$$

- Case rule \perp_L

$$\frac{}{\bullet h_4 : \perp, \Delta_5 \vdash \Delta_1, F_2 \wedge F_3} \perp_L \rightsquigarrow \frac{}{\bullet h_4 : \perp, \Delta_5 \vdash \Delta_1, F_2} \perp_L$$

- Case rule I

$$\frac{}{\bullet h_3 : p_5, \Delta_4 \vdash p_5, \Delta_6, F_1 \wedge F_2} I \rightsquigarrow \frac{}{\bullet h_3 : \Delta_4, p_5 \vdash \Delta_6, F_1, p_5} I$$

- Case rule \top_L

$$\frac{h_4 : \Delta_5 \vdash \Delta_1, F_2 \wedge F_3}{\bullet h_4 : \top, \Delta_5 \vdash \Delta_1, F_2 \wedge F_3} \top_L \rightsquigarrow \frac{\frac{}{h_4 : \Delta_5 \vdash \Delta_1, F_2} ax/ind}{\bullet h_4 : \top, \Delta_5 \vdash \Delta_1, F_2} \top_L$$

4.3 Status of \wedge_R (Right Premise): : Invertible

- Case rule \rightarrow_R

$$\frac{h_3 : F_5, \Delta_4 \vdash F_6, \Delta_7, F_1 \wedge F_2}{\bullet h_3 : \Delta_4 \vdash (\Delta_7, F_1 \wedge F_2), F_5 \rightarrow F_6} \rightarrow_R \rightsquigarrow \frac{\overline{h_3 : \Delta_4, F_5 \vdash \Delta_7, F_2, F_6} \text{ ax/ind}}{\bullet h_3 : \Delta_4 \vdash \Delta_7, F_2, F_5 \rightarrow F_6} \rightarrow_R$$

- Case rule \wedge_R

$$\frac{h_3 : \Delta_4 \vdash F_5, \Delta_7, F_1 \wedge F_2 \quad h_3 : \Delta_4 \vdash F_6, \Delta_7, F_1 \wedge F_2}{\bullet h_3 : \Delta_4 \vdash (\Delta_7, F_1 \wedge F_2), F_5 \wedge F_6} \wedge_R \rightsquigarrow \frac{\overline{h_3 : \Delta_4 \vdash \Delta_7, F_2, F_5} \text{ ax/ind} \quad \overline{h_3 : \Delta_4 \vdash \Delta_7, F_2, F_6} \text{ ax/ind}}{\bullet h_3 : \Delta_4 \vdash \Delta_7, F_2, F_5 \wedge F_6} \wedge_R$$

$$\frac{h_1 : \Delta_2 \vdash F_4, \Delta_3 \quad h_1 : \Delta_2 \vdash F_5, \Delta_3}{\bullet h_1 : \Delta_2 \vdash \Delta_3, F_4 \wedge F_5} \wedge_R \rightsquigarrow \frac{\overline{h_1 : \Delta_2 \vdash \Delta_3, F_5} \text{ ax}}{\bullet h_1 : \Delta_2 \vdash \Delta_3, F_5} \text{ H}$$

- Case rule \vee_R

$$\frac{h_3 : \Delta_4 \vdash F_5, F_6, \Delta_7, F_1 \wedge F_2}{\bullet h_3 : \Delta_4 \vdash (\Delta_7, F_1 \wedge F_2), F_5 \vee F_6} \vee_R \rightsquigarrow \frac{\overline{h_3 : \Delta_4 \vdash \Delta_7, F_2, F_5, F_6} \text{ ax/ind}}{\bullet h_3 : \Delta_4 \vdash \Delta_7, F_2, F_5 \vee F_6} \vee_R$$

- Case rule \perp_R

$$\frac{h_3 : \Delta_4 \vdash \Delta_5, F_1 \wedge F_2}{\bullet h_3 : \Delta_4 \vdash \perp, \Delta_5, F_1 \wedge F_2} \perp_R \rightsquigarrow \frac{\overline{h_3 : \Delta_4 \vdash \Delta_5, F_2} \text{ ax/ind}}{\bullet h_3 : \Delta_4 \vdash \perp, \Delta_5, F_2} \perp_R$$

- Case rule \top_R

$$\frac{}{\bullet h_3 : \Delta_4 \vdash \top, \Delta_5, F_1 \wedge F_2} \top_R \rightsquigarrow \frac{}{\bullet h_3 : \Delta_4 \vdash \top, \Delta_5, F_2} \top_R$$

- Case rule $A4$

$$\frac{h_3 : \Box \Gamma_4 \vdash F_6}{\bullet h_3 : \Box \Gamma_4, \Delta_5 \vdash (\Delta_7, F_1 \wedge F_2), [\Box F_6]} A4 \rightsquigarrow \frac{\overline{h_3 : \Box \Gamma_4 \vdash F_6} \text{ ax}}{\bullet h_3 : \Delta_5, \Box \Gamma_4 \vdash \Delta_7, F_2, [\Box F_6]} A4$$

- Case rule \rightarrow_L

$$\frac{h_4 : \Delta_5 \vdash F_6, \Delta_1, F_2 \wedge F_3 \quad h_4 : F_7, \Delta_5 \vdash \Delta_1, F_2 \wedge F_3}{\bullet h_4 : \Delta_5, F_6 \rightarrow F_7 \vdash \Delta_1, F_2 \wedge F_3} \rightarrow_L \rightsquigarrow \frac{\overline{h_4 : \Delta_5 \vdash \Delta_1, F_3, F_6} \text{ ax/ind} \quad \overline{h_4 : \Delta_5, F_7 \vdash \Delta_1, F_3} \text{ ax/ind}}{\bullet h_4 : \Delta_5, F_6 \rightarrow F_7 \vdash \Delta_1, F_3} \rightarrow_L$$

- Case rule \wedge_L

$$\frac{h_4 : F_6, F_7, \Delta_5 \vdash \Delta_1, F_2 \wedge F_3}{\bullet h_4 : \Delta_5, F_6 \wedge F_7 \vdash \Delta_1, F_2 \wedge F_3} \wedge_L \rightsquigarrow \frac{\overline{h_4 : \Delta_5, F_6, F_7 \vdash \Delta_1, F_3} \text{ ax/ind}}{\bullet h_4 : \Delta_5, F_6 \wedge F_7 \vdash \Delta_1, F_3} \wedge_L$$

- Case rule \vee_L

$$\frac{h_4 : F_6, \Delta_5 \vdash \Delta_1, F_2 \wedge F_3 \quad h_4 : F_7, \Delta_5 \vdash \Delta_1, F_2 \wedge F_3}{\bullet h_4 : \Delta_5, F_6 \vee F_7 \vdash \Delta_1, F_2 \wedge F_3} \vee_L \rightsquigarrow \frac{\overline{h_4 : \Delta_5, F_6 \vdash \Delta_1, F_3} \text{ ax/ind} \quad \overline{h_4 : \Delta_5, F_7 \vdash \Delta_1, F_3} \text{ ax/ind}}{\bullet h_4 : \Delta_5, F_6 \vee F_7 \vdash \Delta_1, F_3} \vee_L$$

- Case rule AT

$$\frac{h_4 : F_6, \Delta_5, []F_6 \vdash \Delta_1, F_2 \wedge F_3}{\bullet h_4 : \Delta_5, []F_6 \vdash \Delta_1, F_2 \wedge F_3} AT \quad \rightsquigarrow \quad \frac{\overline{h_4 : \Delta_5, F_6, []F_6 \vdash \Delta_1, F_3}}{\bullet h_4 : \Delta_5, []F_6 \vdash \Delta_1, F_3} \frac{ax/ind}{AT}$$

- Case rule \perp_L

$$\frac{}{\bullet h_4 : \perp, \Delta_5 \vdash \Delta_1, F_2 \wedge F_3} \perp_L \quad \rightsquigarrow \quad \frac{}{\bullet h_4 : \perp, \Delta_5 \vdash \Delta_1, F_3} \perp_L$$

- Case rule I

$$\frac{}{\bullet h_3 : p_5, \Delta_4 \vdash p_5, \Delta_6, F_1 \wedge F_2} I \quad \rightsquigarrow \quad \frac{}{\bullet h_3 : \Delta_4, p_5 \vdash \Delta_6, F_2, p_5} I$$

- Case rule \top_L

$$\frac{h_4 : \Delta_5 \vdash \Delta_1, F_2 \wedge F_3}{\bullet h_4 : \top, \Delta_5 \vdash \Delta_1, F_2 \wedge F_3} \top_L \quad \rightsquigarrow \quad \frac{\overline{h_4 : \Delta_5 \vdash \Delta_1, F_3}}{\bullet h_4 : \top, \Delta_5 \vdash \Delta_1, F_3} \frac{ax/ind}{\top_L}$$

4.4 Status of \vee_R : : Invertible

- Case rule \rightarrow_R

$$\frac{h_3 : F_5, \Delta_4 \vdash F_6, \Delta_7, F_1 \vee F_2}{\bullet h_3 : \Delta_4 \vdash (\Delta_7, F_1 \vee F_2), F_5 \rightarrow F_6} \rightarrow_R \quad \rightsquigarrow \quad \frac{\overline{h_3 : \Delta_4, F_5 \vdash \Delta_7, F_1, F_2, F_6}}{\bullet h_3 : \Delta_4 \vdash \Delta_7, F_1, F_2, F_5 \rightarrow F_6} \frac{ax/ind}{\rightarrow_R}$$

- Case rule \wedge_R

$$\frac{h_3 : \Delta_4 \vdash F_5, \Delta_7, F_1 \vee F_2 \quad h_3 : \Delta_4 \vdash F_6, \Delta_7, F_1 \vee F_2}{\bullet h_3 : \Delta_4 \vdash (\Delta_7, F_1 \vee F_2), F_5 \wedge F_6} \wedge_R \quad \rightsquigarrow \quad \frac{\overline{h_3 : \Delta_4 \vdash \Delta_7, F_1, F_2, F_5} \quad \overline{h_3 : \Delta_4 \vdash \Delta_7, F_1, F_2, F_6}}{\bullet h_3 : \Delta_4 \vdash \Delta_7, F_1, F_2, F_5 \wedge F_6} \frac{ax/ind}{\wedge_R}$$

- Case rule \vee_R

$$\frac{h_3 : \Delta_4 \vdash F_5, F_6, \Delta_7, F_1 \vee F_2}{\bullet h_3 : \Delta_4 \vdash (\Delta_7, F_1 \vee F_2), F_5 \vee F_6} \vee_R \quad \rightsquigarrow \quad \frac{\overline{h_3 : \Delta_4 \vdash \Delta_7, F_1, F_2, F_5, F_6}}{\bullet h_3 : \Delta_4 \vdash \Delta_7, F_1, F_2, F_5 \vee F_6} \frac{ax/ind}{\vee_R}$$

$$\frac{h_1 : \Delta_2 \vdash F_4, F_5, \Delta_3}{\bullet h_1 : \Delta_2 \vdash \Delta_3, F_4 \vee F_5} \vee_R \quad \rightsquigarrow \quad \frac{\overline{h_1 : \Delta_2 \vdash \Delta_3, F_4, F_5}}{\bullet h_1 : \Delta_2 \vdash \Delta_3, F_4, F_5} \frac{ax}{H}$$

- Case rule \perp_R

$$\frac{h_3 : \Delta_4 \vdash \Delta_5, F_1 \vee F_2}{\bullet h_3 : \Delta_4 \vdash \perp, \Delta_5, F_1 \vee F_2} \perp_R \quad \rightsquigarrow \quad \frac{\overline{h_3 : \Delta_4 \vdash \Delta_5, F_1, F_2}}{\bullet h_3 : \Delta_4 \vdash \perp, \Delta_5, F_1, F_2} \frac{ax/ind}{\perp_R}$$

- Case rule \top_R

$$\frac{}{\bullet h_3 : \Delta_4 \vdash \top, \Delta_5, F_1 \vee F_2} \top_R \quad \rightsquigarrow \quad \frac{}{\bullet h_3 : \Delta_4 \vdash \top, \Delta_5, F_1, F_2} \top_R$$

- Case rule $A4$

$$\frac{h_3 : \Box \Gamma_4 \vdash F_6}{\bullet h_3 : \Box \Gamma_4, \Delta_5 \vdash (\Delta_7, F_1 \vee F_2), []F_6} A4 \rightsquigarrow \frac{\overline{h_3 : \Box \Gamma_4 \vdash F_6}^{ax}}{\bullet h_3 : \Delta_5, \Box \Gamma_4 \vdash \Delta_7, F_1, F_2, []F_6} A4$$

- Case rule \rightarrow_L

$$\frac{h_4 : \Delta_5 \vdash F_6, \Delta_1, F_2 \vee F_3 \quad h_4 : F_7, \Delta_5 \vdash \Delta_1, F_2 \vee F_3}{\bullet h_4 : \Delta_5, F_6 \rightarrow F_7 \vdash \Delta_1, F_2 \vee F_3} \rightarrow_L \rightsquigarrow \frac{\overline{h_4 : \Delta_5 \vdash \Delta_1, F_2, F_3, F_6}^{ax/ind} \quad \overline{h_4 : \Delta_5, F_7 \vdash \Delta_1, F_2, F_3}^{ax/ind}}{\bullet h_4 : \Delta_5, F_6 \rightarrow F_7 \vdash \Delta_1, F_2, F_3} \rightarrow_L$$

- Case rule \wedge_L

$$\frac{h_4 : F_6, F_7, \Delta_5 \vdash \Delta_1, F_2 \vee F_3}{\bullet h_4 : \Delta_5, F_6 \wedge F_7 \vdash \Delta_1, F_2 \vee F_3} \wedge_L \rightsquigarrow \frac{\overline{h_4 : \Delta_5, F_6, F_7 \vdash \Delta_1, F_2, F_3}^{ax/ind}}{\bullet h_4 : \Delta_5, F_6 \wedge F_7 \vdash \Delta_1, F_2, F_3} \wedge_L$$

- Case rule \vee_L

$$\frac{h_4 : F_6, \Delta_5 \vdash \Delta_1, F_2 \vee F_3 \quad h_4 : F_7, \Delta_5 \vdash \Delta_1, F_2 \vee F_3}{\bullet h_4 : \Delta_5, F_6 \vee F_7 \vdash \Delta_1, F_2 \vee F_3} \vee_L \rightsquigarrow \frac{\overline{h_4 : \Delta_5, F_6 \vdash \Delta_1, F_2, F_3}^{ax/ind} \quad \overline{h_4 : \Delta_5, F_7 \vdash \Delta_1, F_2, F_3}^{ax/ind}}{\bullet h_4 : \Delta_5, F_6 \vee F_7 \vdash \Delta_1, F_2, F_3} \vee_L$$

- Case rule AT

$$\frac{h_4 : F_6, \Delta_5, []F_6 \vdash \Delta_1, F_2 \vee F_3}{\bullet h_4 : \Delta_5, []F_6 \vdash \Delta_1, F_2 \vee F_3} AT \rightsquigarrow \frac{\overline{h_4 : \Delta_5, F_6, []F_6 \vdash \Delta_1, F_2, F_3}^{ax/ind}}{\bullet h_4 : \Delta_5, []F_6 \vdash \Delta_1, F_2, F_3} AT$$

- Case rule \perp_L

$$\frac{}{\bullet h_4 : \perp, \Delta_5 \vdash \Delta_1, F_2 \vee F_3} \perp_L \rightsquigarrow \frac{}{\bullet h_4 : \perp, \Delta_5 \vdash \Delta_1, F_2, F_3} \perp_L$$

- Case rule I

$$\frac{}{\bullet h_3 : p_5, \Delta_4 \vdash p_5, \Delta_6, F_1 \vee F_2} I \rightsquigarrow \frac{}{\bullet h_3 : \Delta_4, p_5 \vdash \Delta_6, F_1, F_2, p_5} I$$

- Case rule \top_L

$$\frac{h_4 : \Delta_5 \vdash \Delta_1, F_2 \vee F_3}{\bullet h_4 : \top, \Delta_5 \vdash \Delta_1, F_2 \vee F_3} \top_L \rightsquigarrow \frac{\overline{h_4 : \Delta_5 \vdash \Delta_1, F_2, F_3}^{ax/ind}}{\bullet h_4 : \top, \Delta_5 \vdash \Delta_1, F_2, F_3} \top_L$$

4.5 Status of \perp_R : : Invertible

- Case rule \rightarrow_R

$$\frac{h_1 : F_3, \Delta_2 \vdash \perp, F_4, \Delta_5}{\bullet h_1 : \Delta_2 \vdash (\perp, \Delta_5), F_3 \rightarrow F_4} \rightarrow_R \rightsquigarrow \frac{\overline{h_1 : \Delta_2, F_3 \vdash \Delta_5, F_4}^{ax/ind}}{\bullet h_1 : \Delta_2 \vdash \Delta_5, F_3 \rightarrow F_4} \rightarrow_R$$

- Case rule \wedge_R

$$\frac{\frac{h_1 : \Delta_2 \vdash \perp, F_3, \Delta_5 \quad h_1 : \Delta_2 \vdash \perp, F_4, \Delta_5}{\bullet h_1 : \Delta_2 \vdash (\perp, \Delta_5), F_3 \wedge F_4}}{\wedge_R} \rightsquigarrow \frac{\frac{\frac{h_1 : \Delta_2 \vdash \Delta_5, F_3}{\text{ax/ind}} \quad \frac{h_1 : \Delta_2 \vdash \Delta_5, F_4}{\text{ax/ind}}}{\bullet h_1 : \Delta_2 \vdash \Delta_5, F_3 \wedge F_4}}{\wedge_R}$$

- Case rule \vee_R

$$\frac{h_1 : \Delta_2 \vdash \perp, F_3, F_4, \Delta_5}{\bullet h_1 : \Delta_2 \vdash (\perp, \Delta_5), F_3 \vee F_4} \vee_R \rightsquigarrow \frac{\frac{h_1 : \Delta_2 \vdash \Delta_5, F_3, F_4}{\text{ax/ind}}}{\bullet h_1 : \Delta_2 \vdash \Delta_5, F_3 \vee F_4} \vee_R$$

- Case rule \perp_R

$$\frac{h_1 : \Delta_2 \vdash \Delta_3}{\bullet h_1 : \Delta_2 \vdash \perp, \Delta_3} \perp_R \rightsquigarrow \frac{\frac{h_1 : \Delta_2 \vdash \Delta_3}{\text{ax}}}{\bullet h_1 : \Delta_2 \vdash \Delta_3} \text{H}$$

- Case rule \top_R

$$\frac{}{\bullet h_1 : \Delta_2 \vdash \top, \perp, \Delta_3} \top_R \rightsquigarrow \frac{}{\bullet h_1 : \Delta_2 \vdash \top, \Delta_3} \top_R$$

- Case rule $A4$

$$\frac{h_1 : \Box \Gamma_2 \vdash F_4}{\bullet h_1 : \Box \Gamma_2, \Delta_3 \vdash (\perp, \Delta_5), [\Box F_4]} A4 \rightsquigarrow \frac{\frac{h_1 : \Box \Gamma_2 \vdash F_4}{\text{ax}}}{\bullet h_1 : \Delta_3, \Box \Gamma_2 \vdash \Delta_5, [\Box F_4]} A4$$

- Case rule \rightarrow_L

$$\frac{h_2 : \Delta_3 \vdash \perp, F_4, \Delta_1 \quad h_2 : F_5, \Delta_3 \vdash \perp, \Delta_1}{\bullet h_2 : \Delta_3, F_4 \rightarrow F_5 \vdash \perp, \Delta_1} \rightarrow_L \rightsquigarrow \frac{\frac{h_2 : \Delta_3 \vdash \Delta_1, F_4}{\text{ax/ind}} \quad \frac{h_2 : \Delta_3, F_5 \vdash \Delta_1}{\text{ax/ind}}}{\bullet h_2 : \Delta_3, F_4 \rightarrow F_5 \vdash \Delta_1} \rightarrow_L$$

- Case rule \wedge_L

$$\frac{h_2 : F_4, F_5, \Delta_3 \vdash \perp, \Delta_1}{\bullet h_2 : \Delta_3, F_4 \wedge F_5 \vdash \perp, \Delta_1} \wedge_L \rightsquigarrow \frac{\frac{h_2 : \Delta_3, F_4, F_5 \vdash \Delta_1}{\text{ax/ind}}}{\bullet h_2 : \Delta_3, F_4 \wedge F_5 \vdash \Delta_1} \wedge_L$$

- Case rule \vee_L

$$\frac{h_2 : F_4, \Delta_3 \vdash \perp, \Delta_1 \quad h_2 : F_5, \Delta_3 \vdash \perp, \Delta_1}{\bullet h_2 : \Delta_3, F_4 \vee F_5 \vdash \perp, \Delta_1} \vee_L \rightsquigarrow \frac{\frac{h_2 : \Delta_3, F_4 \vdash \Delta_1}{\text{ax/ind}} \quad \frac{h_2 : \Delta_3, F_5 \vdash \Delta_1}{\text{ax/ind}}}{\bullet h_2 : \Delta_3, F_4 \vee F_5 \vdash \Delta_1} \vee_L$$

- Case rule AT

$$\frac{h_2 : F_4, \Delta_3, [\Box F_4 \vdash \perp, \Delta_1]}{\bullet h_2 : \Delta_3, [\Box F_4 \vdash \perp, \Delta_1]} AT \rightsquigarrow \frac{\frac{h_2 : \Delta_3, F_4, [\Box F_4 \vdash \Delta_1]}{\text{ax/ind}}}{\bullet h_2 : \Delta_3, [\Box F_4 \vdash \Delta_1]} AT$$

- Case rule \perp_L

$$\frac{}{\bullet h_2 : \perp, \Delta_3 \vdash \perp, \Delta_1} \perp_L \rightsquigarrow \frac{}{\bullet h_2 : \perp, \Delta_3 \vdash \Delta_1} \perp_L$$

- Case rule I

$$\frac{}{\bullet h_1 : p_3, \Delta_2 \vdash p_3, \perp, \Delta_4} I \quad \rightsquigarrow \quad \frac{}{\bullet h_1 : \Delta_2, p_3 \vdash \Delta_4, p_3} I$$

- Case rule \top_L

$$\frac{h_2 : \Delta_3 \vdash \perp, \Delta_1}{\bullet h_2 : \top, \Delta_3 \vdash \perp, \Delta_1} \top_L \quad \rightsquigarrow \quad \frac{\frac{}{h_2 : \Delta_3 \vdash \Delta_1} \text{ax/ind}}{\bullet h_2 : \top, \Delta_3 \vdash \Delta_1} \top_L$$

4.6 Status of \top_R : : Invertible

- Case rule \rightarrow_R

$$\frac{h_1 : F_3, \Delta_2 \vdash \top, F_4, \Delta_5}{\bullet h_1 : \Delta_2 \vdash (\top, \Delta_5), F_3 \rightarrow F_4} \rightarrow_R \quad \rightsquigarrow \quad \text{trivial}$$

- Case rule \wedge_R

$$\frac{h_1 : \Delta_2 \vdash \top, F_3, \Delta_5 \quad h_1 : \Delta_2 \vdash \top, F_4, \Delta_5}{\bullet h_1 : \Delta_2 \vdash (\top, \Delta_5), F_3 \wedge F_4} \wedge_R \quad \rightsquigarrow \quad \text{trivial}$$

- Case rule \vee_R

$$\frac{h_1 : \Delta_2 \vdash \top, F_3, F_4, \Delta_5}{\bullet h_1 : \Delta_2 \vdash (\top, \Delta_5), F_3 \vee F_4} \vee_R \quad \rightsquigarrow \quad \text{trivial}$$

- Case rule \perp_R

$$\frac{h_1 : \Delta_2 \vdash \top, \Delta_3}{\bullet h_1 : \Delta_2 \vdash \perp, \top, \Delta_3} \perp_R \quad \rightsquigarrow \quad \text{trivial}$$

- Case rule \top_R

$$\frac{}{\bullet h_1 : \Delta_2 \vdash \top, \Delta_3} \top_R \quad \rightsquigarrow \quad \text{trivial}$$

- Case rule $A4$

$$\frac{h_1 : \Box \Gamma_2 \vdash F_4}{\bullet h_1 : \Box \Gamma_2, \Delta_3 \vdash (\top, \Delta_5), [\top] F_4} A4 \quad \rightsquigarrow \quad \text{trivial}$$

- Case rule \rightarrow_L

$$\frac{h_2 : \Delta_3 \vdash \top, F_4, \Delta_1 \quad h_2 : F_5, \Delta_3 \vdash \top, \Delta_1}{\bullet h_2 : \Delta_3, F_4 \rightarrow F_5 \vdash \top, \Delta_1} \rightarrow_L \quad \rightsquigarrow \quad \text{trivial}$$

- Case rule \wedge_L

$$\frac{h_2 : F_4, F_5, \Delta_3 \vdash \top, \Delta_1}{\bullet h_2 : \Delta_3, F_4 \wedge F_5 \vdash \top, \Delta_1} \wedge_L \quad \rightsquigarrow \quad \text{trivial}$$

- Case rule \vee_L

$$\frac{h_2 : F_4, \Delta_3 \vdash \top, \Delta_1 \quad h_2 : F_5, \Delta_3 \vdash \top, \Delta_1}{\bullet h_2 : \Delta_3, F_4 \vee F_5 \vdash \top, \Delta_1} \vee_L \rightsquigarrow \text{trivial}$$

- Case rule AT

$$\frac{h_2 : F_4, \Delta_3, [\Box F_4 \vdash \top, \Delta_1]}{\bullet h_2 : \Delta_3, [\Box F_4 \vdash \top, \Delta_1]} AT \rightsquigarrow \text{trivial}$$

- Case rule \perp_L

$$\frac{}{\bullet h_2 : \perp, \Delta_3 \vdash \top, \Delta_1} \perp_L \rightsquigarrow \text{trivial}$$

- Case rule I

$$\frac{}{\bullet h_1 : p_3, \Delta_2 \vdash p_3, \top, \Delta_4} I \rightsquigarrow \text{trivial}$$

- Case rule \top_L

$$\frac{h_2 : \Delta_3 \vdash \top, \Delta_1}{\bullet h_2 : \top, \Delta_3 \vdash \top, \Delta_1} \top_L \rightsquigarrow \text{trivial}$$

4.7 Status of A4: : Non invertible

- Case rule \rightarrow_R

$$\frac{h_4 : \Box \Gamma_1, F_5, \Delta_2 \vdash F_6, \Delta_7, [\Box F_3]}{\bullet h_4 : \Box \Gamma_1, \Delta_2 \vdash (\Delta_7, [\Box F_3]), F_5 \rightarrow F_6} \rightarrow_R \rightsquigarrow \frac{\frac{}{h_4 : \Box \Gamma_1 \vdash F_3} \text{ax/ind}}{\bullet h_4 : \Box \Gamma_1 \vdash F_3} H$$

- Case rule \wedge_R

$$\frac{h_4 : \Box \Gamma_1, \Delta_2 \vdash F_5, \Delta_7, [\Box F_3] \quad h_4 : \Box \Gamma_1, \Delta_2 \vdash F_6, \Delta_7, [\Box F_3]}{\bullet h_4 : \Box \Gamma_1, \Delta_2 \vdash (\Delta_7, [\Box F_3]), F_5 \wedge F_6} \wedge_R \rightsquigarrow \frac{\frac{}{h_4 : \Box \Gamma_1 \vdash F_3} \text{ax/ind}}{\bullet h_4 : \Box \Gamma_1 \vdash F_3} H$$

- Case rule \vee_R

$$\frac{h_4 : \Box \Gamma_1, \Delta_2 \vdash F_5, F_6, \Delta_7, [\Box F_3]}{\bullet h_4 : \Box \Gamma_1, \Delta_2 \vdash (\Delta_7, [\Box F_3]), F_5 \vee F_6} \vee_R \rightsquigarrow \frac{\frac{}{h_4 : \Box \Gamma_1 \vdash F_3} \text{ax/ind}}{\bullet h_4 : \Box \Gamma_1 \vdash F_3} H$$

- Case rule \perp_R

$$\frac{h_4 : \Box \Gamma_1, \Delta_2 \vdash \Delta_5, [\Box F_3]}{\bullet h_4 : \Box \Gamma_1, \Delta_2 \vdash \perp, \Delta_5, [\Box F_3]} \perp_R \rightsquigarrow \frac{\frac{}{h_4 : \Box \Gamma_1 \vdash F_3} \text{ax/ind}}{\bullet h_4 : \Box \Gamma_1 \vdash F_3} H$$

- Case rule \top_R

$$\frac{}{\bullet h_4 : \Box \Gamma_1, \Delta_2 \vdash \top, \Delta_5, [] F_3} \top_R \rightsquigarrow \frac{}{\bullet h_4 : \Box \Gamma_1 \vdash F_3} \text{fail}$$

- Case rule $A4$

$$\frac{h_2 : \Box \Gamma_5, \Box \Gamma_6 \vdash F_3}{\bullet h_2 : (\Box \Gamma_5, \Box \Gamma_6), \Box \Gamma_7, \Delta_8 \vdash (\Delta_4, [] F_1), [] F_3} A4 \rightsquigarrow \frac{}{\bullet h_2 : \Box \Gamma_5, \Box \Gamma_7 \vdash F_1} \text{fail}$$

$$\frac{h_1 : \Box \Gamma_4, \Box \Gamma_5 \vdash F_3}{\bullet h_1 : (\Box \Gamma_4, \Box \Gamma_5), \Box \Gamma_6, \Delta_7 \vdash \Delta_2, [] F_3} A4 \rightsquigarrow \frac{}{\bullet h_1 : \Box \Gamma_4, \Box \Gamma_6 \vdash F_3} \text{fail}$$

- Case rule \rightarrow_L

$$\frac{h_4 : \Box \Gamma_1, \Delta_7 \vdash F_5, \Delta_2, [] F_3 \quad h_4 : \Box \Gamma_1, F_6, \Delta_7 \vdash \Delta_2, [] F_3}{\bullet h_4 : (\Box \Gamma_1, \Delta_7), F_5 \rightarrow F_6 \vdash \Delta_2, [] F_3} \rightarrow_L \rightsquigarrow \frac{}{h_4 : \Box \Gamma_1 \vdash F_3} \text{ax/ind} \quad \frac{}{\bullet h_4 : \Box \Gamma_1 \vdash F_3} H$$

- Case rule \wedge_L

$$\frac{h_4 : \Box \Gamma_1, F_5, F_6, \Delta_7 \vdash \Delta_2, [] F_3}{\bullet h_4 : (\Box \Gamma_1, \Delta_7), F_5 \wedge F_6 \vdash \Delta_2, [] F_3} \wedge_L \rightsquigarrow \frac{}{h_4 : \Box \Gamma_1 \vdash F_3} \text{ax/ind} \quad \frac{}{\bullet h_4 : \Box \Gamma_1 \vdash F_3} H$$

- Case rule \vee_L

$$\frac{h_4 : \Box \Gamma_1, F_5, \Delta_7 \vdash \Delta_2, [] F_3 \quad h_4 : \Box \Gamma_1, F_6, \Delta_7 \vdash \Delta_2, [] F_3}{\bullet h_4 : (\Box \Gamma_1, \Delta_7), F_5 \vee F_6 \vdash \Delta_2, [] F_3} \vee_L \rightsquigarrow \frac{}{h_4 : \Box \Gamma_1 \vdash F_3} \text{ax/ind} \quad \frac{}{\bullet h_4 : \Box \Gamma_1 \vdash F_3} H$$

- Case rule AT

$$\frac{h_4 : \Box \Gamma_6, F_5, \Delta_1, [] F_5 \vdash \Delta_2, [] F_3}{\bullet h_4 : (\Box \Gamma_6, \Delta_1), [] F_5 \vdash \Delta_2, [] F_3} AT \rightsquigarrow \frac{}{h_4 : \Box \Gamma_6, [] F_5 \vdash F_3} \text{ax/ind} \quad \frac{}{\bullet h_4 : \Box \Gamma_6, [] F_5 \vdash F_3} H$$

$$\frac{h_4 : \Box \Gamma_1, F_5, \Delta_6, [] F_5 \vdash \Delta_2, [] F_3}{\bullet h_4 : (\Box \Gamma_1, \Delta_6), [] F_5 \vdash \Delta_2, [] F_3} AT \rightsquigarrow \frac{}{h_4 : \Box \Gamma_1 \vdash F_3} \text{ax/ind} \quad \frac{}{\bullet h_4 : \Box \Gamma_1 \vdash F_3} H$$

- Case rule \perp_L

$$\frac{}{\bullet h_4 : \perp, \Box \Gamma_1, \Delta_5 \vdash \Delta_2, [] F_3} \perp_L \rightsquigarrow \frac{}{\bullet h_4 : \Box \Gamma_1 \vdash F_3} \text{fail}$$

- Case rule I

$$\frac{}{\bullet h_3 : p_4, \Box \Gamma_1, \Delta_6 \vdash p_4, \Delta_5, [] F_2} I \rightsquigarrow \frac{}{\bullet h_3 : \Box \Gamma_1 \vdash F_2} \text{fail}$$

- Case rule \top_L

$$\frac{h_4 : \Box \Gamma_1, \Delta_5 \vdash \Delta_2, [] F_3}{\bullet h_4 : \top, \Box \Gamma_1, \Delta_5 \vdash \Delta_2, [] F_3} \top_L \rightsquigarrow \frac{}{h_4 : \Box \Gamma_1 \vdash F_3} \text{ax/ind} \quad \frac{}{\bullet h_4 : \Box \Gamma_1 \vdash F_3} H$$

4.8 Status of \rightarrow_L : (Left Premise): Invertible

- Case rule \rightarrow_R

$$\frac{h_4 : F_6, \Delta_1, F_2 \rightarrow F_3 \vdash F_7, \Delta_5}{\bullet h_4 : \Delta_1, F_2 \rightarrow F_3 \vdash \Delta_5, F_6 \rightarrow F_7} \rightarrow_R \rightsquigarrow \frac{\overline{h_4 : \Delta_1, F_6 \vdash \Delta_5, F_2, F_7}}{\bullet h_4 : \Delta_1 \vdash \Delta_5, F_2, F_6 \rightarrow F_7} \text{ax/ind} \rightarrow_R$$

- Case rule \wedge_R

$$\frac{h_4 : \Delta_1, F_2 \rightarrow F_3 \vdash F_6, \Delta_5 \quad h_4 : \Delta_1, F_2 \rightarrow F_3 \vdash F_7, \Delta_5}{\bullet h_4 : \Delta_1, F_2 \rightarrow F_3 \vdash \Delta_5, F_6 \wedge F_7} \wedge_R \rightsquigarrow \frac{\overline{h_4 : \Delta_1 \vdash \Delta_5, F_2, F_6} \text{ax/ind} \quad \overline{h_4 : \Delta_1 \vdash \Delta_5, F_2, F_7} \text{ax/ind}}{\bullet h_4 : \Delta_1 \vdash \Delta_5, F_2, F_6 \wedge F_7} \wedge_R$$

- Case rule \vee_R

$$\frac{h_4 : \Delta_1, F_2 \rightarrow F_3 \vdash F_6, F_7, \Delta_5}{\bullet h_4 : \Delta_1, F_2 \rightarrow F_3 \vdash \Delta_5, F_6 \vee F_7} \vee_R \rightsquigarrow \frac{\overline{h_4 : \Delta_1 \vdash \Delta_5, F_2, F_6, F_7} \text{ax/ind}}{\bullet h_4 : \Delta_1 \vdash \Delta_5, F_2, F_6 \vee F_7} \vee_R$$

- Case rule \perp_R

$$\frac{h_4 : \Delta_1, F_2 \rightarrow F_3 \vdash \Delta_5}{\bullet h_4 : \Delta_1, F_2 \rightarrow F_3 \vdash \perp, \Delta_5} \perp_R \rightsquigarrow \frac{\overline{h_4 : \Delta_1 \vdash \Delta_5, F_2} \text{ax/ind}}{\bullet h_4 : \Delta_1 \vdash \perp, \Delta_5, F_2} \perp_R$$

- Case rule \top_R

$$\frac{}{\bullet h_4 : \Delta_1, F_2 \rightarrow F_3 \vdash \top, \Delta_5} \top_R \rightsquigarrow \frac{}{\bullet h_4 : \Delta_1 \vdash \top, \Delta_5, F_2} \top_R$$

- Case rule $A4$

$$\frac{h_3 : \Box \Gamma_4 \vdash F_6}{\bullet h_3 : \Box \Gamma_4, \Delta_7, F_1 \rightarrow F_2 \vdash \Delta_5, \Box F_6} A4 \rightsquigarrow \frac{\overline{h_3 : \Box \Gamma_4 \vdash F_6} \text{ax}}{\bullet h_3 : \Delta_7, \Box \Gamma_4 \vdash \Delta_5, F_1, \Box F_6} A4$$

- Case rule \rightarrow_L

$$\frac{h_3 : \Delta_7, F_1 \rightarrow F_2 \vdash F_4, \Delta_6 \quad h_3 : F_5, \Delta_7, F_1 \rightarrow F_2 \vdash \Delta_6}{\bullet h_3 : (\Delta_7, F_1 \rightarrow F_2), F_4 \rightarrow F_5 \vdash \Delta_6} \rightarrow_L \rightsquigarrow \frac{\overline{h_3 : \Delta_7 \vdash \Delta_6, F_1, F_4} \text{ax/ind} \quad \overline{h_3 : \Delta_7, F_5 \vdash \Delta_6, F_1} \text{ax/ind}}{\bullet h_3 : \Delta_7, F_4 \rightarrow F_5 \vdash \Delta_6, F_1} \rightarrow_L$$

$$\frac{h_1 : \Delta_2 \vdash F_3, \Delta_5 \quad h_1 : F_4, \Delta_2 \vdash \Delta_5}{\bullet h_1 : \Delta_2, F_3 \rightarrow F_4 \vdash \Delta_5} \rightarrow_L \rightsquigarrow \frac{\overline{h_1 : \Delta_2 \vdash \Delta_5, F_3} \text{ax}}{\bullet h_1 : \Delta_2 \vdash \Delta_5, F_3} H$$

- Case rule \wedge_L

$$\frac{h_3 : F_4, F_5, \Delta_7, F_1 \rightarrow F_2 \vdash \Delta_6}{\bullet h_3 : (\Delta_7, F_1 \rightarrow F_2), F_4 \wedge F_5 \vdash \Delta_6} \wedge_L \rightsquigarrow \frac{\overline{h_3 : \Delta_7, F_4, F_5 \vdash \Delta_6, F_1} \text{ax/ind}}{\bullet h_3 : \Delta_7, F_4 \wedge F_5 \vdash \Delta_6, F_1} \wedge_L$$

- Case rule \vee_L

$$\frac{h_3 : F_4, \Delta_7, F_1 \rightarrow F_2 \vdash \Delta_6 \quad h_3 : F_5, \Delta_7, F_1 \rightarrow F_2 \vdash \Delta_6}{\bullet h_3 : (\Delta_7, F_1 \rightarrow F_2), F_4 \vee F_5 \vdash \Delta_6} \vee_L \rightsquigarrow \frac{\overline{h_3 : \Delta_7, F_4 \vdash \Delta_6, F_1} \text{ax/ind} \quad \overline{h_3 : \Delta_7, F_5 \vdash \Delta_6, F_1} \text{ax/ind}}{\bullet h_3 : \Delta_7, F_4 \vee F_5 \vdash \Delta_6, F_1} \vee_L$$

- Case rule AT

$$\frac{h_3 : F_4, \Delta_6, []F_4, F_1 \rightarrow F_2 \vdash \Delta_5}{\bullet h_3 : (\Delta_6, F_1 \rightarrow F_2), []F_4 \vdash \Delta_5} AT \quad \rightsquigarrow \quad \frac{\overline{h_3 : \Delta_6, F_4, []F_4 \vdash \Delta_5, F_1}}{\bullet h_3 : \Delta_6, []F_4 \vdash \Delta_5, F_1} \frac{ax/ind}{AT}$$

- Case rule \perp_L

$$\frac{}{\bullet h_3 : \perp, \Delta_5, F_1 \rightarrow F_2 \vdash \Delta_4} \perp_L \quad \rightsquigarrow \quad \frac{}{\bullet h_3 : \perp, \Delta_5 \vdash \Delta_4, F_1} \perp_L$$

- Case rule I

$$\frac{}{\bullet h_3 : p_4, \Delta_6, F_1 \rightarrow F_2 \vdash p_4, \Delta_5} I \quad \rightsquigarrow \quad \frac{}{\bullet h_3 : \Delta_6, p_4 \vdash \Delta_5, F_1, p_4} I$$

- Case rule \top_L

$$\frac{h_3 : \Delta_5, F_1 \rightarrow F_2 \vdash \Delta_4}{\bullet h_3 : \top, \Delta_5, F_1 \rightarrow F_2 \vdash \Delta_4} \top_L \quad \rightsquigarrow \quad \frac{\overline{h_3 : \Delta_5 \vdash \Delta_4, F_1}}{\bullet h_3 : \top, \Delta_5 \vdash \Delta_4, F_1} \frac{ax/ind}{\top_L}$$

4.9 Status of \rightarrow_L (Right Premise): : Invertible

- Case rule \rightarrow_R

$$\frac{h_4 : F_6, \Delta_1, F_2 \rightarrow F_3 \vdash F_7, \Delta_5}{\bullet h_4 : \Delta_1, F_2 \rightarrow F_3 \vdash \Delta_5, F_6 \rightarrow F_7} \rightarrow_R \quad \rightsquigarrow \quad \frac{\overline{h_4 : \Delta_1, F_3, F_6 \vdash \Delta_5, F_7}}{\bullet h_4 : \Delta_1, F_3 \vdash \Delta_5, F_6 \rightarrow F_7} \frac{ax/ind}{\rightarrow_R}$$

- Case rule \wedge_R

$$\frac{h_4 : \Delta_1, F_2 \rightarrow F_3 \vdash F_6, \Delta_5 \quad h_4 : \Delta_1, F_2 \rightarrow F_3 \vdash F_7, \Delta_5}{\bullet h_4 : \Delta_1, F_2 \rightarrow F_3 \vdash \Delta_5, F_6 \wedge F_7} \wedge_R \quad \rightsquigarrow \quad \frac{\overline{h_4 : \Delta_1, F_3 \vdash \Delta_5, F_6} \quad \overline{h_4 : \Delta_1, F_3 \vdash \Delta_5, F_7}}{\bullet h_4 : \Delta_1, F_3 \vdash \Delta_5, F_6 \wedge F_7} \frac{ax/ind}{\wedge_R}$$

- Case rule \vee_R

$$\frac{h_4 : \Delta_1, F_2 \rightarrow F_3 \vdash F_6, F_7, \Delta_5}{\bullet h_4 : \Delta_1, F_2 \rightarrow F_3 \vdash \Delta_5, F_6 \vee F_7} \vee_R \quad \rightsquigarrow \quad \frac{\overline{h_4 : \Delta_1, F_3 \vdash \Delta_5, F_6, F_7}}{\bullet h_4 : \Delta_1, F_3 \vdash \Delta_5, F_6 \vee F_7} \frac{ax/ind}{\vee_R}$$

- Case rule \perp_R

$$\frac{h_4 : \Delta_1, F_2 \rightarrow F_3 \vdash \Delta_5}{\bullet h_4 : \Delta_1, F_2 \rightarrow F_3 \vdash \perp, \Delta_5} \perp_R \quad \rightsquigarrow \quad \frac{\overline{h_4 : \Delta_1, F_3 \vdash \Delta_5}}{\bullet h_4 : \Delta_1, F_3 \vdash \perp, \Delta_5} \frac{ax/ind}{\perp_R}$$

- Case rule \top_R

$$\frac{}{\bullet h_4 : \Delta_1, F_2 \rightarrow F_3 \vdash \top, \Delta_5} \top_R \quad \rightsquigarrow \quad \frac{}{\bullet h_4 : \Delta_1, F_3 \vdash \top, \Delta_5} \top_R$$

- Case rule $A4$

$$\frac{h_3 : \Box \Gamma_4 \vdash F_6}{\bullet h_3 : \Box \Gamma_4, \Delta_7, F_1 \rightarrow F_2 \vdash \Delta_5, [\Box F_6]} A4 \quad \rightsquigarrow \quad \frac{\overline{h_3 : \Box \Gamma_4 \vdash F_6}^{ax}}{\bullet h_3 : \Delta_7, F_2, \Box \Gamma_4 \vdash \Delta_5, [\Box F_6]} A4$$

- Case rule \rightarrow_L

$$\frac{h_3 : \Delta_7, F_1 \rightarrow F_2 \vdash F_4, \Delta_6 \quad h_3 : F_5, \Delta_7, F_1 \rightarrow F_2 \vdash \Delta_6}{\bullet h_3 : (\Delta_7, F_1 \rightarrow F_2), F_4 \rightarrow F_5 \vdash \Delta_6} \rightarrow_L \quad \rightsquigarrow \quad \frac{\overline{h_3 : \Delta_7, F_2 \vdash \Delta_6, F_4}^{ax/ind} \quad \overline{h_3 : \Delta_7, F_2, F_5 \vdash \Delta_6}^{ax/ind}}{\bullet h_3 : \Delta_7, F_2, F_4 \rightarrow F_5 \vdash \Delta_6} \rightarrow_L$$

$$\frac{h_1 : \Delta_2 \vdash F_3, \Delta_5 \quad h_1 : F_4, \Delta_2 \vdash \Delta_5}{\bullet h_1 : \Delta_2, F_3 \rightarrow F_4 \vdash \Delta_5} \rightarrow_L \quad \rightsquigarrow \quad \frac{\overline{h_1 : \Delta_2, F_4 \vdash \Delta_5}^{ax}}{\bullet h_1 : \Delta_2, F_4 \vdash \Delta_5} H$$

- Case rule \wedge_L

$$\frac{h_3 : F_4, F_5, \Delta_7, F_1 \rightarrow F_2 \vdash \Delta_6}{\bullet h_3 : (\Delta_7, F_1 \rightarrow F_2), F_4 \wedge F_5 \vdash \Delta_6} \wedge_L \quad \rightsquigarrow \quad \frac{\overline{h_3 : \Delta_7, F_2, F_4, F_5 \vdash \Delta_6}^{ax/ind}}{\bullet h_3 : \Delta_7, F_2, F_4 \wedge F_5 \vdash \Delta_6} \wedge_L$$

- Case rule \vee_L

$$\frac{h_3 : F_4, \Delta_7, F_1 \rightarrow F_2 \vdash \Delta_6 \quad h_3 : F_5, \Delta_7, F_1 \rightarrow F_2 \vdash \Delta_6}{\bullet h_3 : (\Delta_7, F_1 \rightarrow F_2), F_4 \vee F_5 \vdash \Delta_6} \vee_L \quad \rightsquigarrow \quad \frac{\overline{h_3 : \Delta_7, F_2, F_4 \vdash \Delta_6}^{ax/ind} \quad \overline{h_3 : \Delta_7, F_2, F_5 \vdash \Delta_6}^{ax/ind}}{\bullet h_3 : \Delta_7, F_2, F_4 \vee F_5 \vdash \Delta_6} \vee_L$$

- Case rule AT

$$\frac{h_3 : F_4, \Delta_6, [\Box F_4, F_1 \rightarrow F_2 \vdash \Delta_5]}{\bullet h_3 : (\Delta_6, F_1 \rightarrow F_2), [\Box F_4 \vdash \Delta_5]} AT \quad \rightsquigarrow \quad \frac{\overline{h_3 : \Delta_6, F_2, F_4, [\Box F_4 \vdash \Delta_5]}^{ax/ind}}{\bullet h_3 : \Delta_6, F_2, [\Box F_4 \vdash \Delta_5]} AT$$

- Case rule \perp_L

$$\frac{}{\bullet h_3 : \perp, \Delta_5, F_1 \rightarrow F_2 \vdash \Delta_4} \perp_L \quad \rightsquigarrow \quad \frac{}{\bullet h_3 : \perp, \Delta_5, F_2 \vdash \Delta_4} \perp_L$$

- Case rule I

$$\frac{}{\bullet h_3 : p_4, \Delta_6, F_1 \rightarrow F_2 \vdash p_4, \Delta_5} I \quad \rightsquigarrow \quad \frac{}{\bullet h_3 : \Delta_6, F_2, p_4 \vdash \Delta_5, p_4} I$$

- Case rule \top_L

$$\frac{h_3 : \Delta_5, F_1 \rightarrow F_2 \vdash \Delta_4}{\bullet h_3 : \top, \Delta_5, F_1 \rightarrow F_2 \vdash \Delta_4} \top_L \quad \rightsquigarrow \quad \frac{\overline{h_3 : \Delta_5, F_2 \vdash \Delta_4}^{ax/ind}}{\bullet h_3 : \top, \Delta_5, F_2 \vdash \Delta_4} \top_L$$

4.10 Status of \wedge_L : : Invertible

- Case rule \rightarrow_R

$$\frac{h_4 : F_6, \Delta_1, F_2 \wedge F_3 \vdash F_7, \Delta_5}{\bullet h_4 : \Delta_1, F_2 \wedge F_3 \vdash \Delta_5, F_6 \rightarrow F_7} \rightarrow_R \rightsquigarrow \frac{\frac{h_4 : \Delta_1, F_2, F_3, F_6 \vdash \Delta_5, F_7}{\bullet h_4 : \Delta_1, F_2, F_3 \vdash \Delta_5, F_6 \rightarrow F_7} \text{ ax/ind}}{\bullet h_4 : \Delta_1, F_2, F_3 \vdash \Delta_5, F_6 \rightarrow F_7} \rightarrow_R$$

- Case rule \wedge_R

$$\frac{h_4 : \Delta_1, F_2 \wedge F_3 \vdash F_6, \Delta_5 \quad h_4 : \Delta_1, F_2 \wedge F_3 \vdash F_7, \Delta_5}{\bullet h_4 : \Delta_1, F_2 \wedge F_3 \vdash \Delta_5, F_6 \wedge F_7} \wedge_R \rightsquigarrow \frac{\frac{h_4 : \Delta_1, F_2, F_3 \vdash \Delta_5, F_6}{\bullet h_4 : \Delta_1, F_2, F_3 \vdash \Delta_5, F_6 \wedge F_7} \text{ ax/ind} \quad \frac{h_4 : \Delta_1, F_2, F_3 \vdash \Delta_5, F_7}{\bullet h_4 : \Delta_1, F_2, F_3 \vdash \Delta_5, F_6 \wedge F_7} \text{ ax/ind}}{\bullet h_4 : \Delta_1, F_2, F_3 \vdash \Delta_5, F_6 \wedge F_7} \wedge_R$$

- Case rule \vee_R

$$\frac{h_4 : \Delta_1, F_2 \wedge F_3 \vdash F_6, F_7, \Delta_5}{\bullet h_4 : \Delta_1, F_2 \wedge F_3 \vdash \Delta_5, F_6 \vee F_7} \vee_R \rightsquigarrow \frac{\frac{h_4 : \Delta_1, F_2, F_3 \vdash \Delta_5, F_6, F_7}{\bullet h_4 : \Delta_1, F_2, F_3 \vdash \Delta_5, F_6 \vee F_7} \text{ ax/ind}}{\bullet h_4 : \Delta_1, F_2, F_3 \vdash \Delta_5, F_6 \vee F_7} \vee_R$$

- Case rule \perp_R

$$\frac{h_4 : \Delta_1, F_2 \wedge F_3 \vdash \Delta_5}{\bullet h_4 : \Delta_1, F_2 \wedge F_3 \vdash \perp, \Delta_5} \perp_R \rightsquigarrow \frac{\frac{h_4 : \Delta_1, F_2, F_3 \vdash \Delta_5}{\bullet h_4 : \Delta_1, F_2, F_3 \vdash \perp, \Delta_5} \text{ ax/ind}}{\bullet h_4 : \Delta_1, F_2, F_3 \vdash \perp, \Delta_5} \perp_R$$

- Case rule \top_R

$$\frac{}{\bullet h_4 : \Delta_1, F_2 \wedge F_3 \vdash \top, \Delta_5} \top_R \rightsquigarrow \frac{}{\bullet h_4 : \Delta_1, F_2, F_3 \vdash \top, \Delta_5} \top_R$$

- Case rule $A4$

$$\frac{h_3 : \Box \Gamma_4 \vdash F_6}{\bullet h_3 : \Box \Gamma_4, \Delta_7, F_1 \wedge F_2 \vdash \Delta_5, \Box F_6} A4 \rightsquigarrow \frac{\frac{h_3 : \Box \Gamma_4 \vdash F_6}{\bullet h_3 : \Delta_7, F_1, F_2, \Box \Gamma_4 \vdash \Delta_5, \Box F_6} \text{ ax}}{\bullet h_3 : \Delta_7, F_1, F_2, \Box \Gamma_4 \vdash \Delta_5, \Box F_6} A4$$

- Case rule \rightarrow_L

$$\frac{h_3 : \Delta_7, F_1 \wedge F_2 \vdash F_4, \Delta_6 \quad h_3 : F_5, \Delta_7, F_1 \wedge F_2 \vdash \Delta_6}{\bullet h_3 : (\Delta_7, F_1 \wedge F_2), F_4 \rightarrow F_5 \vdash \Delta_6} \rightarrow_L \rightsquigarrow \frac{\frac{h_3 : \Delta_7, F_1, F_2 \vdash \Delta_6, F_4}{\bullet h_3 : \Delta_7, F_1, F_2, F_4 \rightarrow F_5 \vdash \Delta_6} \text{ ax/ind} \quad \frac{h_3 : \Delta_7, F_1, F_2, F_5 \vdash \Delta_6}{\bullet h_3 : \Delta_7, F_1, F_2, F_4 \rightarrow F_5 \vdash \Delta_6} \text{ ax/ind}}{\bullet h_3 : \Delta_7, F_1, F_2, F_4 \rightarrow F_5 \vdash \Delta_6} \rightarrow_L$$

- Case rule \wedge_L

$$\frac{h_3 : F_4, F_5, \Delta_7, F_1 \wedge F_2 \vdash \Delta_6}{\bullet h_3 : (\Delta_7, F_1 \wedge F_2), F_4 \wedge F_5 \vdash \Delta_6} \wedge_L \rightsquigarrow \frac{\frac{h_3 : \Delta_7, F_1, F_2, F_4, F_5 \vdash \Delta_6}{\bullet h_3 : \Delta_7, F_1, F_2, F_4 \wedge F_5 \vdash \Delta_6} \text{ ax/ind}}{\bullet h_3 : \Delta_7, F_1, F_2, F_4 \wedge F_5 \vdash \Delta_6} \wedge_L$$

$$\frac{h_1 : F_3, F_4, \Delta_2 \vdash \Delta_5}{\bullet h_1 : \Delta_2, F_3 \wedge F_4 \vdash \Delta_5} \wedge_L \rightsquigarrow \frac{\frac{h_1 : \Delta_2, F_3, F_4 \vdash \Delta_5}{\bullet h_1 : \Delta_2, F_3, F_4 \vdash \Delta_5} \text{ ax}}{\bullet h_1 : \Delta_2, F_3, F_4 \vdash \Delta_5} \text{ H}$$

- Case rule \vee_L

$$\frac{h_3 : F_4, \Delta_7, F_1 \wedge F_2 \vdash \Delta_6 \quad h_3 : F_5, \Delta_7, F_1 \wedge F_2 \vdash \Delta_6}{\bullet h_3 : (\Delta_7, F_1 \wedge F_2), F_4 \vee F_5 \vdash \Delta_6} \vee_L \rightsquigarrow \frac{\frac{h_3 : \Delta_7, F_1, F_2, F_4 \vdash \Delta_6}{\bullet h_3 : \Delta_7, F_1, F_2, F_4 \vee F_5 \vdash \Delta_6} \text{ ax/ind} \quad \frac{h_3 : \Delta_7, F_1, F_2, F_5 \vdash \Delta_6}{\bullet h_3 : \Delta_7, F_1, F_2, F_4 \vee F_5 \vdash \Delta_6} \text{ ax/ind}}{\bullet h_3 : \Delta_7, F_1, F_2, F_4 \vee F_5 \vdash \Delta_6} \vee_L$$

- Case rule AT

$$\frac{h_3 : F_4, \Delta_6, []F_4, F_1 \wedge F_2 \vdash \Delta_5}{\bullet h_3 : (\Delta_6, F_1 \wedge F_2), []F_4 \vdash \Delta_5} AT \quad \rightsquigarrow \quad \frac{\overline{h_3 : \Delta_6, F_1, F_2, F_4, []F_4 \vdash \Delta_5}}{\bullet h_3 : \Delta_6, F_1, F_2, []F_4 \vdash \Delta_5} \text{ax/ind} AT$$

- Case rule \perp_L

$$\frac{}{\bullet h_3 : \perp, \Delta_5, F_1 \wedge F_2 \vdash \Delta_4} \perp_L \quad \rightsquigarrow \quad \frac{}{\bullet h_3 : \perp, \Delta_5, F_1, F_2 \vdash \Delta_4} \perp_L$$

- Case rule I

$$\frac{}{\bullet h_3 : p_4, \Delta_6, F_1 \wedge F_2 \vdash p_4, \Delta_5} I \quad \rightsquigarrow \quad \frac{}{\bullet h_3 : \Delta_6, F_1, F_2, p_4 \vdash \Delta_5, p_4} I$$

- Case rule \top_L

$$\frac{h_3 : \Delta_5, F_1 \wedge F_2 \vdash \Delta_4}{\bullet h_3 : \top, \Delta_5, F_1 \wedge F_2 \vdash \Delta_4} \top_L \quad \rightsquigarrow \quad \frac{\overline{h_3 : \Delta_5, F_1, F_2 \vdash \Delta_4}}{\bullet h_3 : \top, \Delta_5, F_1, F_2 \vdash \Delta_4} \text{ax/ind} \top_L$$

4.11 Status of \vee_L : (Left Premise): Invertible

- Case rule \rightarrow_R

$$\frac{h_4 : F_6, \Delta_1, F_2 \vee F_3 \vdash F_7, \Delta_5}{\bullet h_4 : \Delta_1, F_2 \vee F_3 \vdash \Delta_5, F_6 \rightarrow F_7} \rightarrow_R \quad \rightsquigarrow \quad \frac{\overline{h_4 : \Delta_1, F_2, F_6 \vdash \Delta_5, F_7}}{\bullet h_4 : \Delta_1, F_2 \vdash \Delta_5, F_6 \rightarrow F_7} \text{ax/ind} \rightarrow_R$$

- Case rule \wedge_R

$$\frac{h_4 : \Delta_1, F_2 \vee F_3 \vdash F_6, \Delta_5 \quad h_4 : \Delta_1, F_2 \vee F_3 \vdash F_7, \Delta_5}{\bullet h_4 : \Delta_1, F_2 \vee F_3 \vdash \Delta_5, F_6 \wedge F_7} \wedge_R \quad \rightsquigarrow \quad \frac{\overline{h_4 : \Delta_1, F_2 \vdash \Delta_5, F_6} \quad \overline{h_4 : \Delta_1, F_2 \vdash \Delta_5, F_7}}{\bullet h_4 : \Delta_1, F_2 \vdash \Delta_5, F_6 \wedge F_7} \text{ax/ind} \wedge_R$$

- Case rule \vee_R

$$\frac{h_4 : \Delta_1, F_2 \vee F_3 \vdash F_6, F_7, \Delta_5}{\bullet h_4 : \Delta_1, F_2 \vee F_3 \vdash \Delta_5, F_6 \vee F_7} \vee_R \quad \rightsquigarrow \quad \frac{\overline{h_4 : \Delta_1, F_2 \vdash \Delta_5, F_6, F_7}}{\bullet h_4 : \Delta_1, F_2 \vdash \Delta_5, F_6 \vee F_7} \text{ax/ind} \vee_R$$

- Case rule \perp_R

$$\frac{h_4 : \Delta_1, F_2 \vee F_3 \vdash \Delta_5}{\bullet h_4 : \Delta_1, F_2 \vee F_3 \vdash \perp, \Delta_5} \perp_R \quad \rightsquigarrow \quad \frac{\overline{h_4 : \Delta_1, F_2 \vdash \Delta_5}}{\bullet h_4 : \Delta_1, F_2 \vdash \perp, \Delta_5} \text{ax/ind} \perp_R$$

- Case rule \top_R

$$\frac{}{\bullet h_4 : \Delta_1, F_2 \vee F_3 \vdash \top, \Delta_5} \top_R \quad \rightsquigarrow \quad \frac{}{\bullet h_4 : \Delta_1, F_2 \vdash \top, \Delta_5} \top_R$$

- Case rule $A4$

$$\frac{h_3 : \Box \Gamma_4 \vdash F_6}{\bullet h_3 : \Box \Gamma_4, \Delta_7, F_1 \vee F_2 \vdash \Delta_5, [] F_6} A4 \rightsquigarrow \frac{\frac{h_3 : \Box \Gamma_4 \vdash F_6}{\bullet h_3 : \Delta_7, F_1, \Box \Gamma_4 \vdash \Delta_5, [] F_6} ax}{\bullet h_3 : \Delta_7, F_1, \Box \Gamma_4 \vdash \Delta_5, [] F_6} A4$$

- Case rule \rightarrow_L

$$\frac{h_3 : \Delta_7, F_1 \vee F_2 \vdash F_4, \Delta_6 \quad h_3 : F_5, \Delta_7, F_1 \vee F_2 \vdash \Delta_6}{\bullet h_3 : (\Delta_7, F_1 \vee F_2), F_4 \rightarrow F_5 \vdash \Delta_6} \rightarrow_L \rightsquigarrow \frac{\frac{h_3 : \Delta_7, F_1 \vdash \Delta_6, F_4}{\bullet h_3 : \Delta_7, F_1, F_4 \rightarrow F_5 \vdash \Delta_6} ax/ind \quad \frac{h_3 : \Delta_7, F_1, F_5 \vdash \Delta_6}{\bullet h_3 : \Delta_7, F_1, F_4 \rightarrow F_5 \vdash \Delta_6} ax/ind}{\bullet h_3 : \Delta_7, F_1, F_4 \rightarrow F_5 \vdash \Delta_6} \rightarrow_L$$

- Case rule \wedge_L

$$\frac{h_3 : F_4, F_5, \Delta_7, F_1 \vee F_2 \vdash \Delta_6}{\bullet h_3 : (\Delta_7, F_1 \vee F_2), F_4 \wedge F_5 \vdash \Delta_6} \wedge_L \rightsquigarrow \frac{\frac{h_3 : \Delta_7, F_1, F_4, F_5 \vdash \Delta_6}{\bullet h_3 : \Delta_7, F_1, F_4 \wedge F_5 \vdash \Delta_6} ax/ind}{\bullet h_3 : \Delta_7, F_1, F_4 \wedge F_5 \vdash \Delta_6} \wedge_L$$

- Case rule \vee_L

$$\frac{h_3 : F_4, \Delta_7, F_1 \vee F_2 \vdash \Delta_6 \quad h_3 : F_5, \Delta_7, F_1 \vee F_2 \vdash \Delta_6}{\bullet h_3 : (\Delta_7, F_1 \vee F_2), F_4 \vee F_5 \vdash \Delta_6} \vee_L \rightsquigarrow \frac{\frac{h_3 : \Delta_7, F_1, F_4 \vdash \Delta_6}{\bullet h_3 : \Delta_7, F_1, F_4 \vee F_5 \vdash \Delta_6} ax/ind \quad \frac{h_3 : \Delta_7, F_1, F_5 \vdash \Delta_6}{\bullet h_3 : \Delta_7, F_1, F_4 \vee F_5 \vdash \Delta_6} ax/ind}{\bullet h_3 : \Delta_7, F_1, F_4 \vee F_5 \vdash \Delta_6} \vee_L$$

$$\frac{h_1 : F_3, \Delta_2 \vdash \Delta_5 \quad h_1 : F_4, \Delta_2 \vdash \Delta_5}{\bullet h_1 : \Delta_2, F_3 \vee F_4 \vdash \Delta_5} \vee_L \rightsquigarrow \frac{\frac{h_1 : \Delta_2, F_3 \vdash \Delta_5}{\bullet h_1 : \Delta_2, F_3 \vee F_4 \vdash \Delta_5} ax}{\bullet h_1 : \Delta_2, F_3 \vee F_4 \vdash \Delta_5} H$$

- Case rule AT

$$\frac{h_3 : F_4, \Delta_6, [] F_4, F_1 \vee F_2 \vdash \Delta_5}{\bullet h_3 : (\Delta_6, F_1 \vee F_2), [] F_4 \vdash \Delta_5} AT \rightsquigarrow \frac{\frac{h_3 : \Delta_6, F_1, F_4, [] F_4 \vdash \Delta_5}{\bullet h_3 : \Delta_6, F_1, [] F_4 \vdash \Delta_5} ax/ind}{\bullet h_3 : \Delta_6, F_1, [] F_4 \vdash \Delta_5} AT$$

- Case rule \perp_L

$$\frac{}{\bullet h_3 : \perp, \Delta_5, F_1 \vee F_2 \vdash \Delta_4} \perp_L \rightsquigarrow \frac{}{\bullet h_3 : \perp, \Delta_5, F_1 \vdash \Delta_4} \perp_L$$

- Case rule I

$$\frac{}{\bullet h_3 : p_4, \Delta_6, F_1 \vee F_2 \vdash p_4, \Delta_5} I \rightsquigarrow \frac{}{\bullet h_3 : \Delta_6, F_1, p_4 \vdash \Delta_5, p_4} I$$

- Case rule \top_L

$$\frac{h_3 : \Delta_5, F_1 \vee F_2 \vdash \Delta_4}{\bullet h_3 : \top, \Delta_5, F_1 \vee F_2 \vdash \Delta_4} \top_L \rightsquigarrow \frac{\frac{h_3 : \Delta_5, F_1 \vdash \Delta_4}{\bullet h_3 : \top, \Delta_5, F_1 \vdash \Delta_4} ax/ind}{\bullet h_3 : \top, \Delta_5, F_1 \vdash \Delta_4} \top_L$$

4.12 Status of \vee_L (Right Premise): : Invertible

- Case rule \rightarrow_R

$$\frac{h_4 : F_6, \Delta_1, F_2 \vee F_3 \vdash F_7, \Delta_5}{\bullet h_4 : \Delta_1, F_2 \vee F_3 \vdash \Delta_5, F_6 \rightarrow F_7} \rightarrow_R \rightsquigarrow \frac{\frac{h_4 : \Delta_1, F_3 \vdash \Delta_5, F_7}{\bullet h_4 : \Delta_1, F_3 \vdash \Delta_5, F_6 \rightarrow F_7} \text{ax/ind}}{\bullet h_4 : \Delta_1, F_3 \vdash \Delta_5, F_6 \rightarrow F_7} \rightarrow_R$$

- Case rule \wedge_R

$$\frac{h_4 : \Delta_1, F_2 \vee F_3 \vdash F_6, \Delta_5 \quad h_4 : \Delta_1, F_2 \vee F_3 \vdash F_7, \Delta_5}{\bullet h_4 : \Delta_1, F_2 \vee F_3 \vdash \Delta_5, F_6 \wedge F_7} \wedge_R \rightsquigarrow \frac{\frac{h_4 : \Delta_1, F_3 \vdash \Delta_5, F_6}{\bullet h_4 : \Delta_1, F_3 \vdash \Delta_5, F_6 \wedge F_7} \text{ax/ind} \quad \frac{h_4 : \Delta_1, F_3 \vdash \Delta_5, F_7}{\bullet h_4 : \Delta_1, F_3 \vdash \Delta_5, F_6 \wedge F_7} \text{ax/ind}}{\bullet h_4 : \Delta_1, F_3 \vdash \Delta_5, F_6 \wedge F_7} \wedge_R$$

- Case rule \vee_R

$$\frac{h_4 : \Delta_1, F_2 \vee F_3 \vdash F_6, F_7, \Delta_5}{\bullet h_4 : \Delta_1, F_2 \vee F_3 \vdash \Delta_5, F_6 \vee F_7} \vee_R \rightsquigarrow \frac{\frac{h_4 : \Delta_1, F_3 \vdash \Delta_5, F_6, F_7}{\bullet h_4 : \Delta_1, F_3 \vdash \Delta_5, F_6 \vee F_7} \text{ax/ind}}{\bullet h_4 : \Delta_1, F_3 \vdash \Delta_5, F_6 \vee F_7} \vee_R$$

- Case rule \perp_R

$$\frac{h_4 : \Delta_1, F_2 \vee F_3 \vdash \Delta_5}{\bullet h_4 : \Delta_1, F_2 \vee F_3 \vdash \perp, \Delta_5} \perp_R \rightsquigarrow \frac{\frac{h_4 : \Delta_1, F_3 \vdash \Delta_5}{\bullet h_4 : \Delta_1, F_3 \vdash \perp, \Delta_5} \text{ax/ind}}{\bullet h_4 : \Delta_1, F_3 \vdash \perp, \Delta_5} \perp_R$$

- Case rule \top_R

$$\frac{}{\bullet h_4 : \Delta_1, F_2 \vee F_3 \vdash \top, \Delta_5} \top_R \rightsquigarrow \frac{}{\bullet h_4 : \Delta_1, F_3 \vdash \top, \Delta_5} \top_R$$

- Case rule $A4$

$$\frac{h_3 : \Box \Gamma_4 \vdash F_6}{\bullet h_3 : \Box \Gamma_4, \Delta_7, F_1 \vee F_2 \vdash \Delta_5, \Box F_6} A4 \rightsquigarrow \frac{\frac{h_3 : \Box \Gamma_4 \vdash F_6}{\bullet h_3 : \Delta_7, F_2, \Box \Gamma_4 \vdash \Delta_5, \Box F_6} \text{ax}}{\bullet h_3 : \Delta_7, F_2, \Box \Gamma_4 \vdash \Delta_5, \Box F_6} A4$$

- Case rule \rightarrow_L

$$\frac{h_3 : \Delta_7, F_1 \vee F_2 \vdash F_4, \Delta_6 \quad h_3 : F_5, \Delta_7, F_1 \vee F_2 \vdash \Delta_6}{\bullet h_3 : (\Delta_7, F_1 \vee F_2), F_4 \rightarrow F_5 \vdash \Delta_6} \rightarrow_L \rightsquigarrow \frac{\frac{h_3 : \Delta_7, F_2 \vdash \Delta_6, F_4}{\bullet h_3 : \Delta_7, F_2, F_4 \rightarrow F_5 \vdash \Delta_6} \text{ax/ind} \quad \frac{h_3 : \Delta_7, F_2, F_5 \vdash \Delta_6}{\bullet h_3 : \Delta_7, F_2, F_4 \rightarrow F_5 \vdash \Delta_6} \text{ax/ind}}{\bullet h_3 : \Delta_7, F_2, F_4 \rightarrow F_5 \vdash \Delta_6} \rightarrow_L$$

- Case rule \wedge_L

$$\frac{h_3 : F_4, F_5, \Delta_7, F_1 \vee F_2 \vdash \Delta_6}{\bullet h_3 : (\Delta_7, F_1 \vee F_2), F_4 \wedge F_5 \vdash \Delta_6} \wedge_L \rightsquigarrow \frac{\frac{h_3 : \Delta_7, F_2, F_4, F_5 \vdash \Delta_6}{\bullet h_3 : \Delta_7, F_2, F_4 \wedge F_5 \vdash \Delta_6} \text{ax/ind}}{\bullet h_3 : \Delta_7, F_2, F_4 \wedge F_5 \vdash \Delta_6} \wedge_L$$

- Case rule \vee_L

$$\frac{h_3 : F_4, \Delta_7, F_1 \vee F_2 \vdash \Delta_6 \quad h_3 : F_5, \Delta_7, F_1 \vee F_2 \vdash \Delta_6}{\bullet h_3 : (\Delta_7, F_1 \vee F_2), F_4 \vee F_5 \vdash \Delta_6} \vee_L \rightsquigarrow \frac{\frac{h_3 : \Delta_7, F_2, F_4 \vdash \Delta_6}{\bullet h_3 : \Delta_7, F_2, F_4 \vee F_5 \vdash \Delta_6} \text{ax/ind} \quad \frac{h_3 : \Delta_7, F_2, F_5 \vdash \Delta_6}{\bullet h_3 : \Delta_7, F_2, F_4 \vee F_5 \vdash \Delta_6} \text{ax/ind}}{\bullet h_3 : \Delta_7, F_2, F_4 \vee F_5 \vdash \Delta_6} \vee_L$$

$$\frac{h_1 : F_3, \Delta_2 \vdash \Delta_5 \quad h_1 : F_4, \Delta_2 \vdash \Delta_5}{\bullet h_1 : \Delta_2, F_3 \vee F_4 \vdash \Delta_5} \vee_L \rightsquigarrow \frac{\frac{h_1 : \Delta_2, F_4 \vdash \Delta_5}{\bullet h_1 : \Delta_2, F_4 \vdash \Delta_5} \text{ax}}{\bullet h_1 : \Delta_2, F_4 \vdash \Delta_5} H$$

- Case rule AT

$$\frac{h_3 : F_4, \Delta_6, []F_4, F_1 \vee F_2 \vdash \Delta_5}{\bullet h_3 : (\Delta_6, F_1 \vee F_2), []F_4 \vdash \Delta_5} AT \rightsquigarrow \frac{\frac{h_3 : \Delta_6, F_2, F_4, []F_4 \vdash \Delta_5}{\bullet h_3 : \Delta_6, F_2, []F_4 \vdash \Delta_5} ax/ind}{\bullet h_3 : \Delta_6, F_2, []F_4 \vdash \Delta_5} AT$$

- Case rule \perp_L

$$\frac{}{\bullet h_3 : \perp, \Delta_5, F_1 \vee F_2 \vdash \Delta_4} \perp_L \rightsquigarrow \frac{}{\bullet h_3 : \perp, \Delta_5, F_2 \vdash \Delta_4} \perp_L$$

- Case rule I

$$\frac{}{\bullet h_3 : p_4, \Delta_6, F_1 \vee F_2 \vdash p_4, \Delta_5} I \rightsquigarrow \frac{}{\bullet h_3 : \Delta_6, F_2, p_4 \vdash \Delta_5, p_4} I$$

- Case rule \top_L

$$\frac{h_3 : \Delta_5, F_1 \vee F_2 \vdash \Delta_4}{\bullet h_3 : \top, \Delta_5, F_1 \vee F_2 \vdash \Delta_4} \top_L \rightsquigarrow \frac{\frac{h_3 : \Delta_5, F_2 \vdash \Delta_4}{\bullet h_3 : \top, \Delta_5, F_2 \vdash \Delta_4} ax/ind}{\bullet h_3 : \top, \Delta_5, F_2 \vdash \Delta_4} \top_L$$

4.13 Status of AT : : Invertible

- Case rule \rightarrow_R

$$\frac{h_3 : F_5, \Delta_1, []F_2 \vdash F_6, \Delta_4}{\bullet h_3 : \Delta_1, []F_2 \vdash \Delta_4, F_5 \rightarrow F_6} \rightarrow_R \rightsquigarrow \frac{\frac{h_3 : \Delta_1, F_2, F_5, []F_2 \vdash \Delta_4, F_6}{\bullet h_3 : \Delta_1, F_2, []F_2 \vdash \Delta_4, F_5 \rightarrow F_6} ax/ind}{\bullet h_3 : \Delta_1, F_2, []F_2 \vdash \Delta_4, F_5 \rightarrow F_6} \rightarrow_R$$

- Case rule \wedge_R

$$\frac{h_3 : \Delta_1, []F_2 \vdash F_5, \Delta_4 \quad h_3 : \Delta_1, []F_2 \vdash F_6, \Delta_4}{\bullet h_3 : \Delta_1, []F_2 \vdash \Delta_4, F_5 \wedge F_6} \wedge_R \rightsquigarrow \frac{\frac{h_3 : \Delta_1, F_2, []F_2 \vdash \Delta_4, F_5}{\bullet h_3 : \Delta_1, F_2, []F_2 \vdash \Delta_4, F_5 \wedge F_6} ax/ind \quad \frac{h_3 : \Delta_1, F_2, []F_2 \vdash \Delta_4, F_6}{\bullet h_3 : \Delta_1, F_2, []F_2 \vdash \Delta_4, F_5 \wedge F_6} ax/ind}{\bullet h_3 : \Delta_1, F_2, []F_2 \vdash \Delta_4, F_5 \wedge F_6} \wedge_R$$

- Case rule \vee_R

$$\frac{h_3 : \Delta_1, []F_2 \vdash F_5, F_6, \Delta_4}{\bullet h_3 : \Delta_1, []F_2 \vdash \Delta_4, F_5 \vee F_6} \vee_R \rightsquigarrow \frac{\frac{h_3 : \Delta_1, F_2, []F_2 \vdash \Delta_4, F_5, F_6}{\bullet h_3 : \Delta_1, F_2, []F_2 \vdash \Delta_4, F_5 \vee F_6} ax/ind}{\bullet h_3 : \Delta_1, F_2, []F_2 \vdash \Delta_4, F_5 \vee F_6} \vee_R$$

- Case rule \perp_R

$$\frac{h_3 : \Delta_1, []F_2 \vdash \Delta_4}{\bullet h_3 : \Delta_1, []F_2 \vdash \perp, \Delta_4} \perp_R \rightsquigarrow \frac{\frac{h_3 : \Delta_1, F_2, []F_2 \vdash \Delta_4}{\bullet h_3 : \Delta_1, F_2, []F_2 \vdash \perp, \Delta_4} ax/ind}{\bullet h_3 : \Delta_1, F_2, []F_2 \vdash \perp, \Delta_4} \perp_R$$

- Case rule \top_R

$$\frac{}{\bullet h_3 : \Delta_1, []F_2 \vdash \top, \Delta_4} \top_R \rightsquigarrow \frac{}{\bullet h_3 : \Delta_1, F_2, []F_2 \vdash \top, \Delta_4} \top_R$$

- Case rule $A4$

$$\frac{\frac{h_2 : \Box \Gamma_6, []F_1 \vdash F_5}{\bullet h_2 : (\Box \Gamma_6, []F_1), \Delta_3 \vdash \Delta_4, []F_5} A4}{\bullet h_2 : \Delta_3, F_1, \Box \Gamma_6, []F_1 \vdash \Delta_4, []F_5} A4 \rightsquigarrow \frac{\frac{h_2 : \Box \Gamma_6, []F_1 \vdash F_5}{\bullet h_2 : \Delta_3, F_1, \Box \Gamma_6, []F_1 \vdash \Delta_4, []F_5} ax}{\bullet h_2 : \Delta_3, F_1, \Box \Gamma_6, []F_1 \vdash \Delta_4, []F_5} A4$$

$$\frac{\frac{h_2 : \Box \Gamma_3 \vdash F_5}{\bullet h_2 : \Box \Gamma_3, \Delta_6, []F_1 \vdash \Delta_4, []F_5} A4}{\bullet h_2 : \Delta_6, F_1, \Box \Gamma_3, []F_1 \vdash \Delta_4, []F_5} A4 \rightsquigarrow \frac{\frac{h_2 : \Box \Gamma_3 \vdash F_5}{\bullet h_2 : \Delta_6, F_1, \Box \Gamma_3, []F_1 \vdash \Delta_4, []F_5} ax}{\bullet h_2 : \Delta_6, F_1, \Box \Gamma_3, []F_1 \vdash \Delta_4, []F_5} A4$$

- Case rule \rightarrow_L

$$\frac{\frac{h_2 : \Delta_6, []F_1 \vdash F_3, \Delta_5 \quad h_2 : F_4, \Delta_6, []F_1 \vdash \Delta_5}{\bullet h_2 : (\Delta_6, []F_1), F_3 \rightarrow F_4 \vdash \Delta_5} \rightarrow_L}{\bullet h_2 : \Delta_6, F_1, []F_1, F_3 \rightarrow F_4 \vdash \Delta_5} \rightsquigarrow \frac{\frac{h_2 : \Delta_6, F_1, []F_1 \vdash \Delta_5, F_3}{\bullet h_2 : \Delta_6, F_1, []F_1, F_3 \rightarrow F_4 \vdash \Delta_5} ax/ind \quad \frac{h_2 : \Delta_6, F_1, F_4, []F_1 \vdash \Delta_5}{\bullet h_2 : \Delta_6, F_1, F_4, []F_1 \vdash \Delta_5} ax/ind}{\bullet h_2 : \Delta_6, F_1, []F_1, F_3 \rightarrow F_4 \vdash \Delta_5} \rightarrow_L$$

- Case rule \wedge_L

$$\frac{\frac{h_2 : F_3, F_4, \Delta_6, []F_1 \vdash \Delta_5}{\bullet h_2 : (\Delta_6, []F_1), F_3 \wedge F_4 \vdash \Delta_5} \wedge_L}{\bullet h_2 : \Delta_6, F_1, []F_1, F_3 \wedge F_4 \vdash \Delta_5} \rightsquigarrow \frac{\frac{h_2 : \Delta_6, F_1, F_3, F_4, []F_1 \vdash \Delta_5}{\bullet h_2 : \Delta_6, F_1, []F_1, F_3 \wedge F_4 \vdash \Delta_5} ax/ind}{\bullet h_2 : \Delta_6, F_1, []F_1, F_3 \wedge F_4 \vdash \Delta_5} \wedge_L$$

- Case rule \vee_L

$$\frac{\frac{h_2 : F_3, \Delta_6, []F_1 \vdash \Delta_5 \quad h_2 : F_4, \Delta_6, []F_1 \vdash \Delta_5}{\bullet h_2 : (\Delta_6, []F_1), F_3 \vee F_4 \vdash \Delta_5} \vee_L}{\bullet h_2 : \Delta_6, F_1, []F_1, F_3 \vee F_4 \vdash \Delta_5} \rightsquigarrow \frac{\frac{h_2 : \Delta_6, F_1, F_3, []F_1 \vdash \Delta_5}{\bullet h_2 : \Delta_6, F_1, []F_1, F_3 \vee F_4 \vdash \Delta_5} ax/ind \quad \frac{h_2 : \Delta_6, F_1, F_4, []F_1 \vdash \Delta_5}{\bullet h_2 : \Delta_6, F_1, F_4, []F_1 \vdash \Delta_5} ax/ind}{\bullet h_2 : \Delta_6, F_1, []F_1, F_3 \vee F_4 \vdash \Delta_5} \vee_L$$

- Case rule AT

$$\frac{\frac{h_2 : F_3, \Delta_5, []F_1, []F_3 \vdash \Delta_4}{\bullet h_2 : (\Delta_5, []F_1), []F_3 \vdash \Delta_4} AT}{\bullet h_2 : \Delta_5, F_1, []F_1, []F_3 \vdash \Delta_4} \rightsquigarrow \frac{\frac{h_2 : \Delta_5, F_1, F_3, []F_1, []F_3 \vdash \Delta_4}{\bullet h_2 : \Delta_5, F_1, []F_1, []F_3 \vdash \Delta_4} ax/ind}{\bullet h_2 : \Delta_5, F_1, []F_1, []F_3 \vdash \Delta_4} AT$$

$$\frac{\frac{h_1 : F_3, \Delta_2, []F_3 \vdash \Delta_4}{\bullet h_1 : \Delta_2, []F_3 \vdash \Delta_4} AT}{\bullet h_1 : \Delta_2, F_3, []F_3 \vdash \Delta_4} \rightsquigarrow \frac{\frac{h_1 : \Delta_2, F_3, F_3, []F_3 \vdash \Delta_4}{\bullet h_1 : \Delta_2, F_3, []F_3 \vdash \Delta_4} ax/ind}{\bullet h_1 : \Delta_2, F_3, []F_3 \vdash \Delta_4} AT$$

- Case rule \perp_L

$$\frac{}{\bullet h_2 : \perp, \Delta_4, []F_1 \vdash \Delta_3} \perp_L \rightsquigarrow \frac{}{\bullet h_2 : \perp, \Delta_4, F_1, []F_1 \vdash \Delta_3} \perp_L$$

- Case rule I

$$\frac{}{\bullet h_2 : p_3, \Delta_5, []F_1 \vdash p_3, \Delta_4} I \rightsquigarrow \frac{}{\bullet h_2 : \Delta_5, F_1, p_3, []F_1 \vdash \Delta_4, p_3} I$$

- Case rule \top_L

$$\frac{\frac{h_2 : \Delta_4, []F_1 \vdash \Delta_3}{\bullet h_2 : \top, \Delta_4, []F_1 \vdash \Delta_3} \top_L}{\bullet h_2 : \top, \Delta_4, F_1, []F_1 \vdash \Delta_3} \rightsquigarrow \frac{\frac{h_2 : \Delta_4, F_1, []F_1 \vdash \Delta_3}{\bullet h_2 : \top, \Delta_4, F_1, []F_1 \vdash \Delta_3} ax/ind}{\bullet h_2 : \top, \Delta_4, F_1, []F_1 \vdash \Delta_3} \top_L$$

4.14 Status of \perp_L : : Invertible

- Case rule \rightarrow_R

$$\frac{h_2 : \perp, F_4, \Delta_1 \vdash F_5, \Delta_3}{\bullet h_2 : \perp, \Delta_1 \vdash \Delta_3, F_4 \rightarrow F_5} \rightarrow_R \quad \rightsquigarrow \quad \text{trivial}$$

- Case rule \wedge_R

$$\frac{h_2 : \perp, \Delta_1 \vdash F_4, \Delta_3 \quad h_2 : \perp, \Delta_1 \vdash F_5, \Delta_3}{\bullet h_2 : \perp, \Delta_1 \vdash \Delta_3, F_4 \wedge F_5} \wedge_R \quad \rightsquigarrow \quad \text{trivial}$$

- Case rule \vee_R

$$\frac{h_2 : \perp, \Delta_1 \vdash F_4, F_5, \Delta_3}{\bullet h_2 : \perp, \Delta_1 \vdash \Delta_3, F_4 \vee F_5} \vee_R \quad \rightsquigarrow \quad \text{trivial}$$

- Case rule \perp_R

$$\frac{h_2 : \perp, \Delta_1 \vdash \Delta_3}{\bullet h_2 : \perp, \Delta_1 \vdash \perp, \Delta_3} \perp_R \quad \rightsquigarrow \quad \text{trivial}$$

- Case rule \top_R

$$\frac{}{\bullet h_2 : \perp, \Delta_1 \vdash \top, \Delta_3} \top_R \quad \rightsquigarrow \quad \text{trivial}$$

- Case rule $A4$

$$\frac{h_1 : \Box \Gamma_2 \vdash F_4}{\bullet h_1 : \Box \Gamma_2, \perp, \Delta_5 \vdash \Delta_3, [\Box F_4]} A4 \quad \rightsquigarrow \quad \text{trivial}$$

- Case rule \rightarrow_L

$$\frac{h_1 : \perp, \Delta_5 \vdash F_2, \Delta_4 \quad h_1 : \perp, F_3, \Delta_5 \vdash \Delta_4}{\bullet h_1 : (\perp, \Delta_5), F_2 \rightarrow F_3 \vdash \Delta_4} \rightarrow_L \quad \rightsquigarrow \quad \text{trivial}$$

- Case rule \wedge_L

$$\frac{h_1 : \perp, F_2, F_3, \Delta_5 \vdash \Delta_4}{\bullet h_1 : (\perp, \Delta_5), F_2 \wedge F_3 \vdash \Delta_4} \wedge_L \quad \rightsquigarrow \quad \text{trivial}$$

- Case rule \vee_L

$$\frac{h_1 : \perp, F_2, \Delta_5 \vdash \Delta_4 \quad h_1 : \perp, F_3, \Delta_5 \vdash \Delta_4}{\bullet h_1 : (\perp, \Delta_5), F_2 \vee F_3 \vdash \Delta_4} \vee_L \quad \rightsquigarrow \quad \text{trivial}$$

- Case rule AT

$$\frac{h_1 : \perp, F_2, \Delta_4, [\Box F_2 \vdash \Delta_3]}{\bullet h_1 : (\perp, \Delta_4), [\Box F_2 \vdash \Delta_3]} AT \quad \rightsquigarrow \quad \text{trivial}$$

- Case rule \perp_L

$$\frac{}{\bullet h_1 : \perp, \Delta_2 \vdash \Delta_3} \perp_L \rightsquigarrow \text{trivial}$$

- Case rule I

$$\frac{}{\bullet h_1 : p_2, \perp, \Delta_4 \vdash p_2, \Delta_3} I \rightsquigarrow \text{trivial}$$

- Case rule \top_L

$$\frac{h_1 : \perp, \Delta_3 \vdash \Delta_2}{\bullet h_1 : \top, \perp, \Delta_3 \vdash \Delta_2} \top_L \rightsquigarrow \text{trivial}$$

4.15 Status of I : : Invertible

- Case rule \rightarrow_R

$$\frac{h_3 : F_4, \Delta_1, p_2 \vdash F_5, \Delta_6, p_2}{\bullet h_3 : \Delta_1, p_2 \vdash (\Delta_6, p_2), F_4 \rightarrow F_5} \rightarrow_R \rightsquigarrow \text{trivial}$$

- Case rule \wedge_R

$$\frac{h_3 : \Delta_1, p_2 \vdash F_4, \Delta_6, p_2 \quad h_3 : \Delta_1, p_2 \vdash F_5, \Delta_6, p_2}{\bullet h_3 : \Delta_1, p_2 \vdash (\Delta_6, p_2), F_4 \wedge F_5} \wedge_R \rightsquigarrow \text{trivial}$$

- Case rule \vee_R

$$\frac{h_3 : \Delta_1, p_2 \vdash F_4, F_5, \Delta_6, p_2}{\bullet h_3 : \Delta_1, p_2 \vdash (\Delta_6, p_2), F_4 \vee F_5} \vee_R \rightsquigarrow \text{trivial}$$

- Case rule \perp_R

$$\frac{h_3 : \Delta_1, p_2 \vdash \Delta_4, p_2}{\bullet h_3 : \Delta_1, p_2 \vdash \perp, \Delta_4, p_2} \perp_R \rightsquigarrow \text{trivial}$$

- Case rule \top_R

$$\frac{}{\bullet h_3 : \Delta_1, p_2 \vdash \top, \Delta_4, p_2} \top_R \rightsquigarrow \text{trivial}$$

- Case rule $A4$

$$\frac{h_2 : \Box \Gamma_3 \vdash F_4}{\bullet h_2 : \Box \Gamma_3, \Delta_6, p_1 \vdash (\Delta_5, p_1), \Box F_4} A4 \rightsquigarrow \text{trivial}$$

- Case rule \rightarrow_L

$$\frac{h_3 : \Delta_6, p_1 \vdash F_4, \Delta_2, p_1 \quad h_3 : F_5, \Delta_6, p_1 \vdash \Delta_2, p_1}{\bullet h_3 : (\Delta_6, p_1), F_4 \rightarrow F_5 \vdash \Delta_2, p_1} \rightarrow_L \rightsquigarrow \text{trivial}$$

- Case rule \wedge_L

$$\frac{h_3 : F_4, F_5, \Delta_6, P_1 \vdash \Delta_2, P_1}{\bullet h_3 : (\Delta_6, P_1), F_4 \wedge F_5 \vdash \Delta_2, P_1} \wedge_L \rightsquigarrow \text{trivial}$$

- Case rule \vee_L

$$\frac{h_3 : F_4, \Delta_6, P_1 \vdash \Delta_2, P_1 \quad h_3 : F_5, \Delta_6, P_1 \vdash \Delta_2, P_1}{\bullet h_3 : (\Delta_6, P_1), F_4 \vee F_5 \vdash \Delta_2, P_1} \vee_L \rightsquigarrow \text{trivial}$$

- Case rule AT

$$\frac{h_3 : F_4, \Delta_5, P_1, []F_4 \vdash \Delta_2, P_1}{\bullet h_3 : (\Delta_5, P_1), []F_4 \vdash \Delta_2, P_1} AT \rightsquigarrow \text{trivial}$$

- Case rule \perp_L

$$\frac{}{\bullet h_3 : \perp, \Delta_4, P_1 \vdash \Delta_2, P_1} \perp_L \rightsquigarrow \text{trivial}$$

- Case rule I

$$\frac{}{\bullet h_2 : P_3, \Delta_5, P_1 \vdash P_3, \Delta_4, P_1} I \rightsquigarrow \text{trivial}$$

$$\frac{}{\bullet h_1 : P_3, \Delta_2 \vdash P_3, \Delta_4} I \rightsquigarrow \text{trivial}$$

- Case rule \top_L

$$\frac{h_3 : \Delta_4, P_1 \vdash \Delta_2, P_1}{\bullet h_3 : \top, \Delta_4, P_1 \vdash \Delta_2, P_1} \top_L \rightsquigarrow \text{trivial}$$

4.16 Status of \top_L : : Invertible

- Case rule \rightarrow_R

$$\frac{h_2 : \top, F_4, \Delta_1 \vdash F_5, \Delta_3}{\bullet h_2 : \top, \Delta_1 \vdash \Delta_3, F_4 \rightarrow F_5} \rightarrow_R \rightsquigarrow \frac{\frac{}{h_2 : \Delta_1, F_4 \vdash \Delta_3, F_5} \text{ax/ind}}{\bullet h_2 : \Delta_1 \vdash \Delta_3, F_4 \rightarrow F_5} \rightarrow_R$$

- Case rule \wedge_R

$$\frac{h_2 : \top, \Delta_1 \vdash F_4, \Delta_3 \quad h_2 : \top, \Delta_1 \vdash F_5, \Delta_3}{\bullet h_2 : \top, \Delta_1 \vdash \Delta_3, F_4 \wedge F_5} \wedge_R \rightsquigarrow \frac{\frac{}{h_2 : \Delta_1 \vdash \Delta_3, F_4} \text{ax/ind} \quad \frac{}{h_2 : \Delta_1 \vdash \Delta_3, F_5} \text{ax/ind}}{\bullet h_2 : \Delta_1 \vdash \Delta_3, F_4 \wedge F_5} \wedge_R$$

- Case rule \vee_R

$$\frac{h_2 : \top, \Delta_1 \vdash F_4, F_5, \Delta_3}{\bullet h_2 : \top, \Delta_1 \vdash \Delta_3, F_4 \vee F_5} \vee_R \rightsquigarrow \frac{\frac{}{h_2 : \Delta_1 \vdash \Delta_3, F_4, F_5} \text{ax/ind}}{\bullet h_2 : \Delta_1 \vdash \Delta_3, F_4 \vee F_5} \vee_R$$

- Case rule \perp_R

$$\frac{h_2 : \top, \Delta_1 \vdash \Delta_3}{\bullet h_2 : \top, \Delta_1 \vdash \perp, \Delta_3} \perp_R \rightsquigarrow \frac{\frac{h_2 : \Delta_1 \vdash \Delta_3}{\bullet h_2 : \Delta_1 \vdash \perp, \Delta_3} \text{ax/ind}}{\bullet h_2 : \Delta_1 \vdash \perp, \Delta_3} \perp_R$$

- Case rule \top_R

$$\frac{}{\bullet h_2 : \top, \Delta_1 \vdash \top, \Delta_3} \top_R \rightsquigarrow \frac{}{\bullet h_2 : \Delta_1 \vdash \top, \Delta_3} \top_R$$

- Case rule $A4$

$$\frac{h_1 : \Box \Gamma_2 \vdash F_4}{\bullet h_1 : \Box \Gamma_2, \top, \Delta_5 \vdash \Delta_3, []F_4} A4 \rightsquigarrow \frac{\frac{h_1 : \Box \Gamma_2 \vdash F_4}{\bullet h_1 : \Delta_5, \Box \Gamma_2 \vdash \Delta_3, []F_4} \text{ax}}{\bullet h_1 : \Delta_5, \Box \Gamma_2 \vdash \Delta_3, []F_4} A4$$

- Case rule \rightarrow_L

$$\frac{h_1 : \top, \Delta_5 \vdash F_2, \Delta_4 \quad h_1 : \top, F_3, \Delta_5 \vdash \Delta_4}{\bullet h_1 : (\top, \Delta_5), F_2 \rightarrow F_3 \vdash \Delta_4} \rightarrow_L \rightsquigarrow \frac{\frac{h_1 : \Delta_5 \vdash \Delta_4, F_2}{\bullet h_1 : \Delta_5, F_2 \rightarrow F_3 \vdash \Delta_4} \text{ax/ind} \quad \frac{h_1 : \Delta_5, F_3 \vdash \Delta_4}{\bullet h_1 : \Delta_5, F_2 \rightarrow F_3 \vdash \Delta_4} \text{ax/ind}}{\bullet h_1 : \Delta_5, F_2 \rightarrow F_3 \vdash \Delta_4} \rightarrow_L$$

- Case rule \wedge_L

$$\frac{h_1 : \top, F_2, F_3, \Delta_5 \vdash \Delta_4}{\bullet h_1 : (\top, \Delta_5), F_2 \wedge F_3 \vdash \Delta_4} \wedge_L \rightsquigarrow \frac{\frac{h_1 : \Delta_5, F_2, F_3 \vdash \Delta_4}{\bullet h_1 : \Delta_5, F_2 \wedge F_3 \vdash \Delta_4} \text{ax/ind}}{\bullet h_1 : \Delta_5, F_2 \wedge F_3 \vdash \Delta_4} \wedge_L$$

- Case rule \vee_L

$$\frac{h_1 : \top, F_2, \Delta_5 \vdash \Delta_4 \quad h_1 : \top, F_3, \Delta_5 \vdash \Delta_4}{\bullet h_1 : (\top, \Delta_5), F_2 \vee F_3 \vdash \Delta_4} \vee_L \rightsquigarrow \frac{\frac{h_1 : \Delta_5, F_2 \vdash \Delta_4}{\bullet h_1 : \Delta_5, F_2 \vee F_3 \vdash \Delta_4} \text{ax/ind} \quad \frac{h_1 : \Delta_5, F_3 \vdash \Delta_4}{\bullet h_1 : \Delta_5, F_2 \vee F_3 \vdash \Delta_4} \text{ax/ind}}{\bullet h_1 : \Delta_5, F_2 \vee F_3 \vdash \Delta_4} \vee_L$$

- Case rule AT

$$\frac{h_1 : \top, F_2, \Delta_4, []F_2 \vdash \Delta_3}{\bullet h_1 : (\top, \Delta_4), []F_2 \vdash \Delta_3} AT \rightsquigarrow \frac{\frac{h_1 : \Delta_4, F_2, []F_2 \vdash \Delta_3}{\bullet h_1 : \Delta_4, []F_2 \vdash \Delta_3} \text{ax/ind}}{\bullet h_1 : \Delta_4, []F_2 \vdash \Delta_3} AT$$

- Case rule \perp_L

$$\frac{}{\bullet h_1 : \perp, \top, \Delta_3 \vdash \Delta_2} \perp_L \rightsquigarrow \frac{}{\bullet h_1 : \perp, \Delta_3 \vdash \Delta_2} \perp_L$$

- Case rule I

$$\frac{}{\bullet h_1 : p_2, \top, \Delta_4 \vdash p_2, \Delta_3} I \rightsquigarrow \frac{}{\bullet h_1 : \Delta_4, p_2 \vdash \Delta_3, p_2} I$$

- Case rule \top_L

$$\frac{h_1 : \Delta_2 \vdash \Delta_3}{\bullet h_1 : \top, \Delta_2 \vdash \Delta_3} \top_L \rightsquigarrow \frac{\frac{h_1 : \Delta_2 \vdash \Delta_3}{\bullet h_1 : \Delta_2 \vdash \Delta_3} \text{ax}}{\bullet h_1 : \Delta_2 \vdash \Delta_3} \text{H}$$

5 Height preserving admissibility of contraction on the left

- Case(s) rule \rightarrow_R

$$\frac{h_3 : F_5, \Delta_1, \Delta_2, \Delta_2 \vdash F_6, \Delta_4}{\bullet h_3 : \Delta_1, \Delta_2, \Delta_2 \vdash \Delta_4, F_5 \rightarrow F_6} \rightarrow_R \rightsquigarrow \frac{\frac{h_3 : \Delta_1, \Delta_2, \Delta_2, F_5 \vdash \Delta_4, F_6}{\bullet h_3 : \Delta_1, \Delta_2, F_5 \vdash \Delta_4, F_6} \text{IH}}{\bullet h_3 : \Delta_1, \Delta_2 \vdash \Delta_4, F_5 \rightarrow F_6} \text{ax} \rightarrow_R$$

- Case(s) rule \wedge_R

$$\frac{h_3 : \Delta_1, \Delta_2, \Delta_2 \vdash F_5, \Delta_4 \quad h_3 : \Delta_1, \Delta_2, \Delta_2 \vdash F_6, \Delta_4}{\bullet h_3 : \Delta_1, \Delta_2, \Delta_2 \vdash \Delta_4, F_5 \wedge F_6} \wedge_R \rightsquigarrow \frac{\frac{h_3 : \Delta_1, \Delta_2, \Delta_2 \vdash \Delta_4, F_5}{\bullet h_3 : \Delta_1, \Delta_2 \vdash \Delta_4, F_5} \text{IH} \quad \frac{h_3 : \Delta_1, \Delta_2, \Delta_2 \vdash \Delta_4, F_6}{\bullet h_3 : \Delta_1, \Delta_2 \vdash \Delta_4, F_6} \text{IH}}{\bullet h_3 : \Delta_1, \Delta_2 \vdash \Delta_4, F_5 \wedge F_6} \wedge_R$$

- Case(s) rule \vee_R

$$\frac{h_3 : \Delta_1, \Delta_2, \Delta_2 \vdash F_5, F_6, \Delta_4}{\bullet h_3 : \Delta_1, \Delta_2, \Delta_2 \vdash \Delta_4, F_5 \vee F_6} \vee_R \rightsquigarrow \frac{\frac{h_3 : \Delta_1, \Delta_2, \Delta_2 \vdash \Delta_4, F_5}{\bullet h_3 : \Delta_1, \Delta_2 \vdash \Delta_4, F_5} \text{IH} \quad \frac{h_3 : \Delta_1, \Delta_2, \Delta_2 \vdash \Delta_4, F_6}{\bullet h_3 : \Delta_1, \Delta_2 \vdash \Delta_4, F_6} \text{IH}}{\bullet h_3 : \Delta_1, \Delta_2 \vdash \Delta_4, F_5 \vee F_6} \vee_R$$

- Case(s) rule \perp_R

$$\frac{h_3 : \Delta_1, \Delta_2, \Delta_2 \vdash \Delta_4}{\bullet h_3 : \Delta_1, \Delta_2, \Delta_2 \vdash \perp, \Delta_4} \perp_R \rightsquigarrow \frac{\frac{h_3 : \Delta_1, \Delta_2, \Delta_2 \vdash \Delta_4}{\bullet h_3 : \Delta_1, \Delta_2 \vdash \Delta_4} \text{IH}}{\bullet h_3 : \Delta_1, \Delta_2 \vdash \perp, \Delta_4} \text{ax} \perp_R$$

- Case(s) rule \top_R

$$\frac{}{\bullet h_3 : \Delta_1, \Delta_2, \Delta_2 \vdash \top, \Delta_4} \top_R \rightsquigarrow \frac{}{\bullet h_3 : \Delta_1, \Delta_2 \vdash \top, \Delta_4} \top_R$$

- Case(s) rule $A4$

$$\frac{h_1 : \Box r_4, \Box r_5, \Box r_5, \Box r_6 \vdash F_3}{\bullet h_1 : (\Box r_4, \Delta_7), (\Box r_5, \Box r_6, \Delta_8), \Box r_5, \Box r_6, \Delta_8 \vdash \Delta_2, [F_3]} A4 \rightsquigarrow \frac{\frac{h_1 : \Box r_4, \Box r_5, \Box r_5, \Box r_6 \vdash F_3}{\bullet h_1 : \Delta_7, \Delta_8, \Box r_4, \Box r_5, \Box r_6 \vdash \Delta_2, [F_3]} \text{IH}}{\bullet h_1 : \Delta_7, \Delta_8, \Box r_4, \Box r_5, \Box r_6 \vdash \Delta_2, [F_3]} \text{ax} A4$$

- Case(s) rule \rightarrow_L

$$\frac{h_2 : \Delta_1, \Delta_6, \Delta_6, F_3 \rightarrow F_4 \vdash F_3, \Delta_5 \quad h_2 : F_4, \Delta_1, \Delta_6, \Delta_6, F_3 \rightarrow F_4 \vdash \Delta_5}{\bullet h_2 : \Delta_1, (\Delta_6, F_3 \rightarrow F_4), \Delta_6, F_3 \rightarrow F_4 \vdash \Delta_5} \rightarrow_L \rightsquigarrow \frac{\frac{h_2 : \Delta_1, \Delta_6, \Delta_6 \vdash \Delta_5, F_3, F_3}{\bullet h_2 : \Delta_1, \Delta_6 \vdash \Delta_5, F_3, F_3} \text{IH} \quad \frac{h_2 : \Delta_1, \Delta_6, \Delta_6, F_4, F_4 \vdash \Delta_5}{\bullet h_2 : \Delta_1, \Delta_6, F_4 \vdash \Delta_5} \text{IH}}{\bullet h_2 : \Delta_1, \Delta_6, F_3 \rightarrow F_4 \vdash \Delta_5} \text{inv-th/ax} \rightarrow_L$$

$$\frac{h_2 : \Delta_1, \Delta_1, \Delta_6 \vdash F_3, \Delta_5 \quad h_2 : F_4, \Delta_1, \Delta_1, \Delta_6 \vdash \Delta_5}{\bullet h_2 : (\Delta_6, F_3 \rightarrow F_4), \Delta_1, \Delta_1 \vdash \Delta_5} \rightarrow_L \rightsquigarrow \frac{\frac{h_2 : \Delta_1, \Delta_1, \Delta_6 \vdash \Delta_5, F_3}{\bullet h_2 : \Delta_1, \Delta_6 \vdash \Delta_5, F_3} \text{IH} \quad \frac{h_2 : \Delta_1, \Delta_1, \Delta_6, F_4 \vdash \Delta_5}{\bullet h_2 : \Delta_1, \Delta_6, F_4 \vdash \Delta_5} \text{IH}}{\bullet h_2 : \Delta_1, \Delta_6, F_3 \rightarrow F_4 \vdash \Delta_5} \text{ax} \rightarrow_L$$

- Case(s) rule \wedge_L

$$\frac{h_2 : F_3, F_4, \Delta_1, \Delta_6, \Delta_6, F_3 \wedge F_4 \vdash \Delta_5}{\bullet h_2 : \Delta_1, (\Delta_6, F_3 \wedge F_4), \Delta_6, F_3 \wedge F_4 \vdash \Delta_5} \wedge_L \rightsquigarrow \frac{\frac{h_2 : \Delta_1, \Delta_6, \Delta_6, F_3, F_3, F_4, F_4 \vdash \Delta_5}{\bullet h_2 : \Delta_1, \Delta_6, F_3, F_4 \vdash \Delta_5} \text{IH} \quad \frac{h_2 : \Delta_1, \Delta_6, F_3, F_4 \vdash \Delta_5}{\bullet h_2 : \Delta_1, \Delta_6, F_3 \wedge F_4 \vdash \Delta_5} \text{inv-th/ax}}{\bullet h_2 : \Delta_1, \Delta_6, F_3 \wedge F_4 \vdash \Delta_5} \wedge_L$$

$$\frac{h_2 : F_3, F_4, \Delta_1, \Delta_1, \Delta_6 \vdash \Delta_5}{\bullet h_2 : (\Delta_6, F_3 \wedge F_4), \Delta_1, \Delta_1 \vdash \Delta_5} \wedge_L \rightsquigarrow \frac{\frac{h_2 : \Delta_1, \Delta_1, \Delta_6, F_3, F_4 \vdash \Delta_5}{\bullet h_2 : \Delta_1, \Delta_6, F_3, F_4 \vdash \Delta_5} \text{IH} \quad \frac{h_2 : \Delta_1, \Delta_6, F_3, F_4 \vdash \Delta_5}{\bullet h_2 : \Delta_1, \Delta_6, F_3 \wedge F_4 \vdash \Delta_5} \text{ax}}{\bullet h_2 : \Delta_1, \Delta_6, F_3 \wedge F_4 \vdash \Delta_5} \wedge_L$$

- Case(s) rule \vee_L

$$\begin{array}{c}
\frac{h_2 : F_3, \Delta_1, \Delta_6, \Delta_6, F_3 \vee F_4 \vdash \Delta_5 \quad h_2 : F_4, \Delta_1, \Delta_6, \Delta_6, F_3 \vee F_4 \vdash \Delta_5}{\bullet h_2 : \Delta_1, (\Delta_6, F_3 \vee F_4), \Delta_6, F_3 \vee F_4 \vdash \Delta_5} \vee_L \rightsquigarrow \frac{\frac{h_2 : \Delta_1, \Delta_6, \Delta_6, F_3, F_3 \vdash \Delta_5}{h_2 : \Delta_1, \Delta_6, F_3 \vdash \Delta_5} \text{inv-th/ax} \quad \frac{h_2 : \Delta_1, \Delta_6, \Delta_6, F_4, F_4 \vdash \Delta_5}{h_2 : \Delta_1, \Delta_6, F_4 \vdash \Delta_5} \text{inv-th/ax}}{\bullet h_2 : \Delta_1, \Delta_6, F_3 \vee F_4 \vdash \Delta_5} \vee_L
\end{array}$$

$$\begin{array}{c}
\frac{h_2 : F_3, \Delta_1, \Delta_1, \Delta_6 \vdash \Delta_5 \quad h_2 : F_4, \Delta_1, \Delta_1, \Delta_6 \vdash \Delta_5}{\bullet h_2 : (\Delta_6, F_3 \vee F_4), \Delta_1, \Delta_1 \vdash \Delta_5} \vee_L \rightsquigarrow \frac{\frac{h_2 : \Delta_1, \Delta_1, \Delta_6, F_3 \vdash \Delta_5}{h_2 : \Delta_1, \Delta_6, F_3 \vdash \Delta_5} \text{ax} \quad \frac{h_2 : \Delta_1, \Delta_1, \Delta_6, F_4 \vdash \Delta_5}{h_2 : \Delta_1, \Delta_6, F_4 \vdash \Delta_5} \text{ax}}{\bullet h_2 : \Delta_1, \Delta_6, F_3 \vee F_4 \vdash \Delta_5} \vee_L
\end{array}$$

- Case(s) rule AT

$$\begin{array}{c}
\frac{h_2 : F_3, \Delta_1, \Delta_5, \Delta_5, []F_3, []F_3 \vdash \Delta_4}{\bullet h_2 : \Delta_1, (\Delta_5, []F_3), \Delta_5, []F_3 \vdash \Delta_4} AT \rightsquigarrow \frac{\frac{h_2 : \Delta_1, \Delta_5, \Delta_5, F_3, []F_3, []F_3 \vdash \Delta_4}{h_2 : \Delta_1, \Delta_5, F_3, []F_3 \vdash \Delta_4} \text{ax} \quad \frac{h_2 : \Delta_1, \Delta_5, F_3, []F_3 \vdash \Delta_4}{\bullet h_2 : \Delta_1, \Delta_5, []F_3 \vdash \Delta_4} IH}{\bullet h_2 : \Delta_1, \Delta_5, []F_3 \vdash \Delta_4} AT
\end{array}$$

$$\begin{array}{c}
\frac{h_2 : F_3, \Delta_1, \Delta_1, \Delta_5, []F_3 \vdash \Delta_4}{\bullet h_2 : (\Delta_5, []F_3), \Delta_1, \Delta_1 \vdash \Delta_4} AT \rightsquigarrow \frac{\frac{h_2 : \Delta_1, \Delta_1, \Delta_5, F_3, []F_3 \vdash \Delta_4}{h_2 : \Delta_1, \Delta_5, F_3, []F_3 \vdash \Delta_4} \text{ax} \quad \frac{h_2 : \Delta_1, \Delta_5, F_3, []F_3 \vdash \Delta_4}{\bullet h_2 : \Delta_1, \Delta_5, []F_3 \vdash \Delta_4} IH}{\bullet h_2 : \Delta_1, \Delta_5, []F_3 \vdash \Delta_4} AT
\end{array}$$

- Case(s) rule \perp_L

$$\begin{array}{c}
\frac{}{\bullet h_2 : (\perp, \Delta_4), \Delta_1, \Delta_1 \vdash \Delta_3} \perp_L \rightsquigarrow \frac{}{\bullet h_2 : \perp, \Delta_1, \Delta_4 \vdash \Delta_3} \perp_L
\end{array}$$

$$\begin{array}{c}
\frac{}{\bullet h_2 : \Delta_1, (\perp, \Delta_4), \perp, \Delta_4 \vdash \Delta_3} \perp_L \rightsquigarrow \frac{}{\bullet h_2 : \perp, \Delta_1, \Delta_4 \vdash \Delta_3} \perp_L
\end{array}$$

- Case(s) rule I

$$\begin{array}{c}
\frac{}{\bullet h_2 : (\Delta_5, p_3), \Delta_1, \Delta_1 \vdash \Delta_4, p_3} I \rightsquigarrow \frac{}{\bullet h_2 : \Delta_1, \Delta_5, p_3 \vdash \Delta_4, p_3} I
\end{array}$$

$$\begin{array}{c}
\frac{}{\bullet h_2 : \Delta_1, (\Delta_5, p_3), \Delta_5, p_3 \vdash \Delta_4, p_3} I \rightsquigarrow \frac{}{\bullet h_2 : \Delta_1, \Delta_5, p_3 \vdash \Delta_4, p_3} I
\end{array}$$

- Case(s) rule \top_L

$$\begin{array}{c}
\frac{h_2 : \Delta_1, \Delta_1, \Delta_4 \vdash \Delta_3}{\bullet h_2 : (\top, \Delta_4), \Delta_1, \Delta_1 \vdash \Delta_3} \top_L \rightsquigarrow \frac{\frac{h_2 : \Delta_1, \Delta_1, \Delta_4 \vdash \Delta_3}{h_2 : \Delta_1, \Delta_4 \vdash \Delta_3} \text{ax} \quad \frac{h_2 : \Delta_1, \Delta_4 \vdash \Delta_3}{\bullet h_2 : \top, \Delta_1, \Delta_4 \vdash \Delta_3} IH}{\bullet h_2 : \top, \Delta_1, \Delta_4 \vdash \Delta_3} \top_L
\end{array}$$

$$\begin{array}{c}
\frac{h_2 : \top, \Delta_1, \Delta_4, \Delta_4 \vdash \Delta_3}{\bullet h_2 : \Delta_1, (\top, \Delta_4), \top, \Delta_4 \vdash \Delta_3} \top_L \rightsquigarrow \frac{\frac{h_2 : \Delta_1, \Delta_4, \Delta_4 \vdash \Delta_3}{h_2 : \Delta_1, \Delta_4 \vdash \Delta_3} \text{inv-th/ax} \quad \frac{h_2 : \Delta_1, \Delta_4 \vdash \Delta_3}{\bullet h_2 : \top, \Delta_1, \Delta_4 \vdash \Delta_3} IH}{\bullet h_2 : \top, \Delta_1, \Delta_4 \vdash \Delta_3} \top_L
\end{array}$$

6 Height preserving admissibility of contraction on the Right

- Case(s) rule \rightarrow_R

$$\begin{array}{c}
 \frac{h_2 : F_4, \Delta_3 \vdash F_5, \Delta_1, \Delta_6, \Delta_6, F_4 \rightarrow F_5}{\bullet h_2 : \Delta_3 \vdash \Delta_1, (\Delta_6, F_4 \rightarrow F_5), \Delta_6, F_4 \rightarrow F_5} \rightarrow_R \quad \rightsquigarrow \quad \frac{\frac{h_2 : \Delta_3, F_4, F_4 \vdash \Delta_1, \Delta_6, \Delta_6, F_5, F_5}{h_2 : \Delta_3, F_4 \vdash \Delta_1, \Delta_6, \Delta_6, F_5, F_5} \text{IH-Mutual} \quad \frac{h_2 : \Delta_3, F_4 \vdash \Delta_1, \Delta_6, F_5}{\bullet h_2 : \Delta_3 \vdash \Delta_1, \Delta_6, F_4 \rightarrow F_5} \text{IH}}{h_2 : \Delta_3, F_4 \vdash \Delta_1, \Delta_6, F_5} \text{inv-th/ax} \rightarrow_R \\
 \\
 \frac{h_2 : F_4, \Delta_3 \vdash F_5, \Delta_1, \Delta_1, \Delta_6}{\bullet h_2 : \Delta_3 \vdash (\Delta_6, F_4 \rightarrow F_5), \Delta_1, \Delta_1} \rightarrow_R \quad \rightsquigarrow \quad \frac{\frac{h_2 : \Delta_3, F_4 \vdash \Delta_1, \Delta_1, \Delta_6, F_5}{h_2 : \Delta_3, F_4 \vdash \Delta_1, \Delta_6, F_5} \text{ax} \quad \frac{h_2 : \Delta_3, F_4 \vdash \Delta_1, \Delta_6, F_5}{\bullet h_2 : \Delta_3 \vdash \Delta_1, \Delta_6, F_4 \rightarrow F_5} \text{IH}}{h_2 : \Delta_3, F_4 \vdash \Delta_1, \Delta_6, F_5} \text{IH} \rightarrow_R
 \end{array}$$

- Case(s) rule \wedge_R

$$\begin{array}{c}
 \frac{h_2 : \Delta_3 \vdash F_4, \Delta_1, \Delta_6, \Delta_6, F_4 \wedge F_5 \quad h_2 : \Delta_3 \vdash F_5, \Delta_1, \Delta_6, \Delta_6, F_4 \wedge F_5}{\bullet h_2 : \Delta_3 \vdash \Delta_1, (\Delta_6, F_4 \wedge F_5), \Delta_6, F_4 \wedge F_5} \wedge_R \quad \rightsquigarrow \quad \frac{\frac{h_2 : \Delta_3 \vdash \Delta_1, \Delta_6, \Delta_6, F_4, F_4}{h_2 : \Delta_3 \vdash \Delta_1, \Delta_6, F_4} \text{IH} \quad \frac{h_2 : \Delta_3 \vdash \Delta_1, \Delta_6, \Delta_6, F_5, F_5}{h_2 : \Delta_3 \vdash \Delta_1, \Delta_6, F_5} \text{IH}}{\bullet h_2 : \Delta_3 \vdash \Delta_1, \Delta_6, F_4 \wedge F_5} \text{inv-th/ax} \wedge_R \\
 \\
 \frac{h_2 : \Delta_3 \vdash F_4, \Delta_1, \Delta_1, \Delta_6 \quad h_2 : \Delta_3 \vdash F_5, \Delta_1, \Delta_1, \Delta_6}{\bullet h_2 : \Delta_3 \vdash (\Delta_6, F_4 \wedge F_5), \Delta_1, \Delta_1} \wedge_R \quad \rightsquigarrow \quad \frac{\frac{h_2 : \Delta_3 \vdash \Delta_1, \Delta_1, \Delta_6, F_4}{h_2 : \Delta_3 \vdash \Delta_1, \Delta_6, F_4} \text{ax} \quad \frac{h_2 : \Delta_3 \vdash \Delta_1, \Delta_1, \Delta_6, F_5}{h_2 : \Delta_3 \vdash \Delta_1, \Delta_6, F_5} \text{ax}}{\bullet h_2 : \Delta_3 \vdash \Delta_1, \Delta_6, F_4 \wedge F_5} \text{IH} \wedge_R
 \end{array}$$

- Case(s) rule \vee_R

$$\begin{array}{c}
 \frac{h_2 : \Delta_3 \vdash F_4, F_5, \Delta_1, \Delta_6, \Delta_6, F_4 \vee F_5}{\bullet h_2 : \Delta_3 \vdash \Delta_1, (\Delta_6, F_4 \vee F_5), \Delta_6, F_4 \vee F_5} \vee_R \quad \rightsquigarrow \quad \frac{\frac{h_2 : \Delta_3 \vdash \Delta_1, \Delta_6, \Delta_6, F_4, F_4, F_5, F_5}{h_2 : \Delta_3 \vdash \Delta_1, \Delta_6, F_4, F_5} \text{IH} \quad \frac{h_2 : \Delta_3 \vdash \Delta_1, \Delta_6, F_4, F_5}{\bullet h_2 : \Delta_3 \vdash \Delta_1, \Delta_6, F_4 \vee F_5} \text{inv-th/ax}}{h_2 : \Delta_3 \vdash \Delta_1, \Delta_6, F_4, F_5} \vee_R \\
 \\
 \frac{h_2 : \Delta_3 \vdash F_4, F_5, \Delta_1, \Delta_1, \Delta_6}{\bullet h_2 : \Delta_3 \vdash (\Delta_6, F_4 \vee F_5), \Delta_1, \Delta_1} \vee_R \quad \rightsquigarrow \quad \frac{\frac{h_2 : \Delta_3 \vdash \Delta_1, \Delta_1, \Delta_6, F_4, F_5}{h_2 : \Delta_3 \vdash \Delta_1, \Delta_6, F_4, F_5} \text{ax} \quad \frac{h_2 : \Delta_3 \vdash \Delta_1, \Delta_6, F_4, F_5}{\bullet h_2 : \Delta_3 \vdash \Delta_1, \Delta_6, F_4 \vee F_5} \text{IH}}{h_2 : \Delta_3 \vdash \Delta_1, \Delta_6, F_4, F_5} \vee_R
 \end{array}$$

- Case(s) rule \perp_R

$$\begin{array}{c}
 \frac{h_2 : \Delta_3 \vdash \Delta_1, \Delta_1, \Delta_4}{\bullet h_2 : \Delta_3 \vdash (\perp, \Delta_4), \Delta_1, \Delta_1} \perp_R \quad \rightsquigarrow \quad \frac{\frac{h_2 : \Delta_3 \vdash \Delta_1, \Delta_1, \Delta_4}{h_2 : \Delta_3 \vdash \Delta_1, \Delta_4} \text{ax} \quad \frac{h_2 : \Delta_3 \vdash \Delta_1, \Delta_4}{\bullet h_2 : \Delta_3 \vdash \perp, \Delta_1, \Delta_4} \text{IH}}{h_2 : \Delta_3 \vdash \Delta_1, \Delta_4} \perp_R \\
 \\
 \frac{h_2 : \Delta_3 \vdash \perp, \Delta_1, \Delta_4, \Delta_4}{\bullet h_2 : \Delta_3 \vdash \Delta_1, (\perp, \Delta_4), \perp, \Delta_4} \perp_R \quad \rightsquigarrow \quad \frac{\frac{h_2 : \Delta_3 \vdash \Delta_1, \Delta_4, \Delta_4}{h_2 : \Delta_3 \vdash \Delta_1, \Delta_4} \text{inv-th/ax} \quad \frac{h_2 : \Delta_3 \vdash \Delta_1, \Delta_4}{\bullet h_2 : \Delta_3 \vdash \perp, \Delta_1, \Delta_4} \text{IH}}{h_2 : \Delta_3 \vdash \Delta_1, \Delta_4} \perp_R
 \end{array}$$

- Case(s) rule \top_R

$$\begin{array}{c}
 \frac{}{\bullet h_2 : \Delta_3 \vdash (\top, \Delta_4), \Delta_1, \Delta_1} \top_R \quad \rightsquigarrow \quad \frac{}{\bullet h_2 : \Delta_3 \vdash \top, \Delta_1, \Delta_4} \top_R \\
 \\
 \frac{}{\bullet h_2 : \Delta_3 \vdash \Delta_1, (\top, \Delta_4), \top, \Delta_4} \top_R \quad \rightsquigarrow \quad \frac{}{\bullet h_2 : \Delta_3 \vdash \top, \Delta_1, \Delta_4} \top_R
 \end{array}$$

- Case(s) rule $A4$

$$\begin{array}{c}
 \frac{h_2 : \Box \Gamma_3 \vdash F_5}{\bullet h_2 : \Box \Gamma_3, \Delta_4 \vdash \Delta_1, (\Delta_6, [\Box F_5]), \Delta_6, [\Box F_5]} A4 \quad \rightsquigarrow \quad \frac{h_2 : \Box \Gamma_3 \vdash F_5}{\bullet h_2 : \Delta_4, \Box \Gamma_3 \vdash \Delta_1, \Delta_6, [\Box F_5]} \text{ax} A4 \\
 \\
 \frac{h_2 : \Box \Gamma_3 \vdash F_5}{\bullet h_2 : \Box \Gamma_3, \Delta_4 \vdash (\Delta_6, [\Box F_5]), \Delta_1, \Delta_1} A4 \quad \rightsquigarrow \quad \frac{h_2 : \Box \Gamma_3 \vdash F_5}{\bullet h_2 : \Delta_4, \Box \Gamma_3 \vdash \Delta_1, \Delta_6, [\Box F_5]} \text{ax} A4
 \end{array}$$

- Case(s) rule \rightarrow_L

$$\frac{h_3 : \Delta_4 \vdash F_5, \Delta_1, \Delta_2, \Delta_2 \quad h_3 : F_6, \Delta_4 \vdash \Delta_1, \Delta_2, \Delta_2}{\bullet h_3 : \Delta_4, F_5 \rightarrow F_6 \vdash \Delta_1, \Delta_2, \Delta_2} \rightarrow_L \quad \rightsquigarrow \quad \frac{\frac{h_3 : \Delta_4 \vdash \Delta_1, \Delta_2, \Delta_2, F_5}{h_3 : \Delta_4 \vdash \Delta_1, \Delta_2, F_5} \text{ax} \quad \frac{h_3 : \Delta_4, F_6 \vdash \Delta_1, \Delta_2, \Delta_2}{h_3 : \Delta_4, F_6 \vdash \Delta_1, \Delta_2} \text{IH}}{\bullet h_3 : \Delta_4, F_5 \rightarrow F_6 \vdash \Delta_1, \Delta_2} \rightarrow_L \text{IH}$$

- Case(s) rule \wedge_L

$$\frac{h_3 : F_5, F_6, \Delta_4 \vdash \Delta_1, \Delta_2, \Delta_2}{\bullet h_3 : \Delta_4, F_5 \wedge F_6 \vdash \Delta_1, \Delta_2, \Delta_2} \wedge_L \quad \rightsquigarrow \quad \frac{\frac{h_3 : \Delta_4, F_5, F_6 \vdash \Delta_1, \Delta_2, \Delta_2}{h_3 : \Delta_4, F_5, F_6 \vdash \Delta_1, \Delta_2} \text{ax}}{\bullet h_3 : \Delta_4, F_5 \wedge F_6 \vdash \Delta_1, \Delta_2} \wedge_L \text{IH}$$

- Case(s) rule \vee_L

$$\frac{h_3 : F_5, \Delta_4 \vdash \Delta_1, \Delta_2, \Delta_2 \quad h_3 : F_6, \Delta_4 \vdash \Delta_1, \Delta_2, \Delta_2}{\bullet h_3 : \Delta_4, F_5 \vee F_6 \vdash \Delta_1, \Delta_2, \Delta_2} \vee_L \quad \rightsquigarrow \quad \frac{\frac{h_3 : \Delta_4, F_5 \vdash \Delta_1, \Delta_2, \Delta_2}{h_3 : \Delta_4, F_5 \vdash \Delta_1, \Delta_2} \text{ax} \quad \frac{h_3 : \Delta_4, F_6 \vdash \Delta_1, \Delta_2, \Delta_2}{h_3 : \Delta_4, F_6 \vdash \Delta_1, \Delta_2} \text{IH}}{\bullet h_3 : \Delta_4, F_5 \vee F_6 \vdash \Delta_1, \Delta_2} \vee_L \text{IH}$$

- Case(s) rule AT

$$\frac{h_3 : F_5, \Delta_4, []F_5 \vdash \Delta_1, \Delta_2, \Delta_2}{\bullet h_3 : \Delta_4, []F_5 \vdash \Delta_1, \Delta_2, \Delta_2} AT \quad \rightsquigarrow \quad \frac{\frac{h_3 : \Delta_4, F_5, []F_5 \vdash \Delta_1, \Delta_2, \Delta_2}{h_3 : \Delta_4, F_5, []F_5 \vdash \Delta_1, \Delta_2} \text{ax}}{\bullet h_3 : \Delta_4, []F_5 \vdash \Delta_1, \Delta_2} AT \text{IH}$$

- Case(s) rule \perp_L

$$\frac{}{\bullet h_3 : \perp, \Delta_4 \vdash \Delta_1, \Delta_2, \Delta_2} \perp_L \quad \rightsquigarrow \quad \frac{}{\bullet h_3 : \perp, \Delta_4 \vdash \Delta_1, \Delta_2} \perp_L$$

- Case(s) rule I

$$\frac{}{\bullet h_2 : \Delta_3, p_4 \vdash \Delta_1, (\Delta_5, p_4), \Delta_5, p_4} I \quad \rightsquigarrow \quad \frac{}{\bullet h_2 : \Delta_3, p_4 \vdash \Delta_1, \Delta_5, p_4} I$$

$$\frac{}{\bullet h_2 : \Delta_3, p_4 \vdash (\Delta_5, p_4), \Delta_1, \Delta_1} I \quad \rightsquigarrow \quad \frac{}{\bullet h_2 : \Delta_3, p_4 \vdash \Delta_1, \Delta_5, p_4} I$$

- Case(s) rule \top_L

$$\frac{h_3 : \Delta_4 \vdash \Delta_1, \Delta_2, \Delta_2}{\bullet h_3 : \top, \Delta_4 \vdash \Delta_1, \Delta_2, \Delta_2} \top_L \quad \rightsquigarrow \quad \frac{\frac{h_3 : \Delta_4 \vdash \Delta_1, \Delta_2, \Delta_2}{h_3 : \Delta_4 \vdash \Delta_1, \Delta_2} \text{ax}}{\bullet h_3 : \top, \Delta_4 \vdash \Delta_1, \Delta_2} \top_L \text{IH}$$

7 Identity-Expansion

$$\frac{\frac{\frac{\overline{- : F_0 \vdash F_0} \text{ IH}}{- : F_0, \boxed{F_0 \vdash F_0}} W}{- : \boxed{F_0 \vdash F_0}} AT}{- : \boxed{F_0 \vdash \boxed{F_0}} A4}$$

$$\frac{\frac{\frac{\overline{- : F_0 \vdash F_0} \text{ IH}}{- : F_0 \vdash F_0, F_1} W}{- : F_0 \vee F_1 \vdash F_0, F_1} \vee_R}{\frac{\frac{\overline{- : F_1 \vdash F_1} \text{ IH}}{- : F_1 \vdash F_0, F_1} W}{- : F_0 \vee F_1 \vdash F_0 \vee F_1} \vee_L}$$

$$\frac{\frac{\frac{\overline{- : F_0 \vdash F_0} \text{ IH}}{- : F_0, F_1 \vdash F_0} W}{- : F_0, F_1 \vdash F_0 \wedge F_1} \wedge_L}{\frac{\frac{\overline{- : F_1 \vdash F_1} \text{ IH}}{- : F_0, F_1 \vdash F_1} W}{- : F_0 \wedge F_1 \vdash F_0 \wedge F_1} \wedge_R}$$

$$\frac{\frac{\frac{\overline{- : F_0 \vdash F_0} \text{ IH}}{- : F_0 \vdash F_0, F_1} W}{- : F_0, F_0 \rightarrow F_1 \vdash F_1} \rightarrow_R}{\frac{\frac{\overline{- : F_1 \vdash F_1} \text{ IH}}{- : F_0, F_1 \vdash F_1} W}{- : F_0 \rightarrow F_1 \vdash F_0 \rightarrow F_1} \rightarrow_L}$$

$$\frac{\overline{- : \top \vdash \top} \top_R}{- : \top \vdash \top}$$

$$\frac{\overline{- : \perp \vdash \perp} \perp_L}{- : \perp \vdash \perp}$$

8 Cut-Elimination

8.1 Status of \rightarrow_R : OK

- Case rule \rightarrow_R

$$\begin{array}{c}
\frac{\frac{h_1 : F_7, \Delta_6 \vdash F_8, \Delta_{10}, F_{11} \rightarrow F_{12}}{\bullet h_1 : \Delta_6 \vdash (\Delta_{10}, F_{11} \rightarrow F_{12}), F_7 \rightarrow F_8} \rightarrow_R \quad \frac{h_9 : F_{11}, \Delta_6, F_7 \rightarrow F_8 \vdash F_{12}, \Delta_{10}}{\bullet h_9 : \Delta_6, F_7 \rightarrow F_8 \vdash \Delta_{10}, F_{11} \rightarrow F_{12}} \rightarrow_R}{- : \Delta_6 \vdash \Delta_{10}, F_{11} \rightarrow F_{12}} \text{Cut} \\
\sim \\
\frac{\frac{h_1 : \Delta_6, F_{11}, F_7 \vdash \Delta_{10}, F_{12}, F_8}{\bullet h_1 : \Delta_6, F_{11} \vdash \Delta_{10}, F_{12}, F_7 \rightarrow F_8} \text{inv-th/ax} \rightarrow_R \quad \frac{h_9 : \Delta_6, F_{11}, F_7 \rightarrow F_8 \vdash \Delta_{10}, F_{12}}{\bullet h_9 : \Delta_6, F_{11} \vdash \Delta_{10}, F_{12}} \text{ax/W}}{- : \Delta_6, F_{11} \vdash \Delta_{10}, F_{12}} \text{hCut} \\
\rightarrow_R \\
- : \Delta_6 \vdash \Delta_{10}, F_{11} \rightarrow F_{12} \\
\sim \\
\frac{h_2 : F_9, \Delta_8 \vdash F_7, F_{10}, \Delta_{14}, F_{12} \rightarrow F_{13}}{\bullet h_2 : \Delta_8 \vdash ((\Delta_{14}, F_{12} \rightarrow F_{13}), F_9 \rightarrow F_{10}), F_7} \rightarrow_R \quad \frac{h_{11} : F_7, F_{12}, \Delta_8 \vdash F_{13}, \Delta_{14}, F_9 \rightarrow F_{10}}{\bullet h_{11} : \Delta_8, F_7 \vdash (\Delta_{14}, F_{12} \rightarrow F_{13}), F_9 \rightarrow F_{10}} \rightarrow_R}{- : \Delta_8 \vdash (\Delta_{14}, F_{12} \rightarrow F_{13}), F_9 \rightarrow F_{10}} \text{Cut} \\
\sim \\
\frac{h_2 : \Delta_8, F_{12}, F_9 \vdash \Delta_{14}, F_{10}, F_{13}, F_7}{\bullet h_2 : \Delta_8, F_{12} \vdash \Delta_{14}, F_{13}, F_7, F_9 \rightarrow F_{10}} \text{inv-th/ax} \rightarrow_R \quad \frac{h_{11} : \Delta_8, F_{12}, F_7 \vdash \Delta_{14}, F_{13}, F_9 \rightarrow F_{10}}{\bullet h_{11} : \Delta_8, F_{12} \vdash \Delta_{14}, F_{13}, F_9 \rightarrow F_{10}} \text{ax/W}}{- : \Delta_8, F_{12} \vdash \Delta_{14}, F_{13}, F_9 \rightarrow F_{10}} \text{hCut} \\
\rightarrow_R \\
- : \Delta_8 \vdash \Delta_{14}, F_{12} \rightarrow F_{13}, F_9 \rightarrow F_{10} \\
\sim \\
\frac{h_2 : F_{11}, \Delta_8 \vdash F_7, F_{12}, \Delta_{10}}{\bullet h_2 : \Delta_8 \vdash (\Delta_{10}, F_{11} \rightarrow F_{12}), F_7} \rightarrow_R \quad \frac{h_9 : F_7, F_{11}, \Delta_8 \vdash F_{12}, \Delta_{10}}{\bullet h_9 : \Delta_8, F_7 \vdash \Delta_{10}, F_{11} \rightarrow F_{12}} \rightarrow_R}{- : \Delta_8 \vdash \Delta_{10}, F_{11} \rightarrow F_{12}} \text{Cut} \\
\sim \\
\frac{h_2 : \Delta_8, F_{11} \vdash \Delta_{10}, F_{12}, F_7}{\bullet h_2 : \Delta_8, F_{11} \vdash \Delta_{10}, F_{12}, F_7} \text{ax/W} \quad \frac{h_9 : \Delta_8, F_{11}, F_7 \vdash \Delta_{10}, F_{12}}{\bullet h_9 : \Delta_8, F_{11}, F_7 \vdash \Delta_{10}, F_{12}} \text{ax/W}}{- : \Delta_8, F_{11} \vdash \Delta_{10}, F_{12}} \text{H} \\
\rightarrow_R \\
- : \Delta_8 \vdash \Delta_{10}, F_{11} \rightarrow F_{12}
\end{array}$$

- Case rule \wedge_R

$$\begin{array}{c}
\frac{h_1 : F_7, \Delta_6 \vdash F_8, \Delta_{10}, F_{11} \wedge F_{12}}{\bullet h_1 : \Delta_6 \vdash (\Delta_{10}, F_{11} \wedge F_{12}), F_7 \rightarrow F_8} \rightarrow_R \quad \frac{h_9 : \Delta_6, F_7 \rightarrow F_8 \vdash F_{11}, \Delta_{10} \quad h_9 : \Delta_6, F_7 \rightarrow F_8 \vdash F_{12}, \Delta_{10}}{\bullet h_9 : \Delta_6, F_7 \rightarrow F_8 \vdash \Delta_{10}, F_{11} \wedge F_{12}} \wedge_R}{- : \Delta_6 \vdash \Delta_{10}, F_{11} \wedge F_{12}} \text{Cut} \\
\sim \\
\frac{h_1 : \Delta_6, F_7 \vdash \Delta_{10}, F_{11}, F_8}{\bullet h_1 : \Delta_6 \vdash \Delta_{10}, F_{11}, F_7 \rightarrow F_8} \text{inv-th/ax} \rightarrow_R \quad \frac{h_9 : \Delta_6, F_7 \rightarrow F_8 \vdash \Delta_{10}, F_{11}}{\bullet h_9 : \Delta_6, F_7 \rightarrow F_8 \vdash \Delta_{10}, F_{11}} \text{ax/W}}{- : \Delta_6 \vdash \Delta_{10}, F_{11}} \text{hCut} \\
\rightarrow_R \\
- : \Delta_6 \vdash \Delta_{10}, F_{11} \wedge F_{12} \\
\sim \\
\frac{h_2 : F_9, \Delta_8 \vdash F_7, F_{10}, \Delta_{14}, F_{12} \wedge F_{13}}{\bullet h_2 : \Delta_8 \vdash ((\Delta_{14}, F_{12} \wedge F_{13}), F_9 \rightarrow F_{10}), F_7} \rightarrow_R \quad \frac{h_{11} : F_7, \Delta_8 \vdash F_{12}, \Delta_{14}, F_9 \rightarrow F_{10} \quad h_{11} : F_7, \Delta_8 \vdash F_{13}, \Delta_{14}, F_9 \rightarrow F_{10}}{\bullet h_{11} : \Delta_8, F_7 \vdash (\Delta_{14}, F_{12} \wedge F_{13}), F_9 \rightarrow F_{10}} \wedge_R}{- : \Delta_8 \vdash (\Delta_{14}, F_{12} \wedge F_{13}), F_9 \rightarrow F_{10}} \text{Cut} \\
\sim \\
\frac{h_2 : \Delta_8, F_9 \vdash \Delta_{14}, F_{10}, F_7, F_{12} \wedge F_{13}}{\bullet h_2 : \Delta_8, F_9 \vdash \Delta_{14}, F_{10}, F_7, F_{12} \wedge F_{13}} \text{ax/W} \quad \frac{h_{11} : \Delta_8, F_7, F_9 \vdash \Delta_{14}, F_{10}, F_{12}}{\bullet h_{11} : \Delta_8, F_7, F_9 \vdash \Delta_{14}, F_{10}, F_{12} \wedge F_{13}} \text{inv-th/ax}}{- : \Delta_8, F_9 \vdash \Delta_{14}, F_{10}, F_{12} \wedge F_{13}} \text{hCut} \\
\rightarrow_R \\
- : \Delta_8 \vdash \Delta_{14}, F_9 \rightarrow F_{10}, F_{12} \wedge F_{13}
\end{array}$$

- Case rule \vee_R

$$\begin{array}{c}
\frac{h_1 : F_7, \Delta_6 \vdash F_8, \Delta_{10}, F_{11} \vee F_{12}}{\bullet h_1 : \Delta_6 \vdash (\Delta_{10}, F_{11} \vee F_{12}), F_7 \rightarrow F_8} \rightarrow_R \quad \frac{h_9 : \Delta_6, F_7 \rightarrow F_8 \vdash F_{11}, F_{12}, \Delta_{10}}{\bullet h_9 : \Delta_6, F_7 \rightarrow F_8 \vdash \Delta_{10}, F_{11} \vee F_{12}} \vee_R \\
\hline
- : \Delta_6 \vdash \Delta_{10}, F_{11} \vee F_{12} \quad \text{Cut} \\
\hline
\frac{h_1 : \Delta_6, F_7 \vdash \Delta_{10}, F_{11}, F_{12}, F_8}{\bullet h_1 : \Delta_6 \vdash \Delta_{10}, F_{11}, F_{12}, F_7 \rightarrow F_8} \xrightarrow{\text{inv-th/ax}} \frac{h_9 : \Delta_6, F_7 \rightarrow F_8 \vdash \Delta_{10}, F_{11}, F_{12}}{\bullet h_9 : \Delta_6, F_7 \rightarrow F_8 \vdash \Delta_{10}, F_{11}, F_{12}} \text{ax/W} \\
\hline
- : \Delta_6 \vdash \Delta_{10}, F_{11}, F_{12} \quad \vee_R \\
- : \Delta_6 \vdash \Delta_{10}, F_{11} \vee F_{12} \quad \text{hCut} \\
\hline
\frac{h_2 : F_9, \Delta_8 \vdash F_7, F_{10}, \Delta_{14}, F_{12} \vee F_{13}}{\bullet h_2 : \Delta_8 \vdash ((\Delta_{14}, F_{12} \vee F_{13}), F_9 \rightarrow F_{10}), F_7} \rightarrow_R \quad \frac{h_{11} : F_7, \Delta_8 \vdash F_{12}, F_{13}, \Delta_{14}, F_9 \rightarrow F_{10}}{\bullet h_{11} : \Delta_8, F_7 \vdash (\Delta_{14}, F_{12} \vee F_{13}), F_9 \rightarrow F_{10}} \vee_R \\
\hline
- : \Delta_8 \vdash (\Delta_{14}, F_{12} \vee F_{13}), F_9 \rightarrow F_{10} \quad \text{Cut} \\
\hline
\frac{h_2 : F_9, \Delta_8 \vdash F_7, F_{10}, \Delta_{14}, F_{12} \vee F_{13}}{\bullet h_2 : \Delta_8 \vdash (\Delta_{14}, F_{12} \vee F_{13}), F_7 \rightarrow F_{10}} \text{ax/W} \quad \frac{h_{11} : \Delta_8, F_7, F_9 \vdash \Delta_{14}, F_{10}, F_{12}, F_{13}}{\bullet h_{11} : \Delta_8, F_7, F_9 \vdash \Delta_{14}, F_{10}, F_{12} \vee F_{13}} \text{inv-th/ax} \\
\hline
- : \Delta_8, F_9 \vdash \Delta_{14}, F_{10}, F_{12} \vee F_{13} \quad \vee_R \\
- : \Delta_8 \vdash \Delta_{14}, F_9 \rightarrow F_{10}, F_{12} \vee F_{13} \quad \text{hCut} \\
\hline
- : \Delta_8 \vdash \Delta_{14}, F_9 \rightarrow F_{10}, F_{12} \vee F_{13} \rightarrow_R
\end{array}$$

- Case rule \perp_R

$$\begin{array}{c}
\frac{h_1 : F_7, \Delta_6 \vdash F_8, \perp, \Delta_{10}}{\bullet h_1 : \Delta_6 \vdash (\perp, \Delta_{10}), F_7 \rightarrow F_8} \rightarrow_R \quad \frac{h_9 : \Delta_6, F_7 \rightarrow F_8 \vdash \Delta_{10}}{\bullet h_9 : \Delta_6, F_7 \rightarrow F_8 \vdash \perp, \Delta_{10}} \perp_R \\
\hline
- : \Delta_6 \vdash \perp, \Delta_{10} \quad \text{Cut} \\
\hline
\frac{\bullet h_1 : \Delta_6 \vdash \perp, \Delta_{10}, F_7 \rightarrow F_8}{- : \Delta_6 \vdash \perp, \Delta_{10}} \text{ax/W} \quad \frac{h_9 : \Delta_6, F_7 \rightarrow F_8 \vdash \perp, \Delta_{10}}{\bullet h_9 : \Delta_6, F_7 \rightarrow F_8 \vdash \perp, \Delta_{10}} \text{ax/W} \\
\hline
- : \Delta_6 \vdash \perp, \Delta_{10} \quad \text{hCut} \\
\hline
\frac{h_2 : F_9, \Delta_8 \vdash F_7, F_{10}, \perp, \Delta_{12}}{\bullet h_2 : \Delta_8 \vdash ((\perp, \Delta_{12}), F_9 \rightarrow F_{10}), F_7} \rightarrow_R \quad \frac{h_{11} : F_7, \Delta_8 \vdash \Delta_{12}, F_9 \rightarrow F_{10}}{\bullet h_{11} : \Delta_8, F_7 \vdash (\perp, \Delta_{12}), F_9 \rightarrow F_{10}} \perp_R \\
\hline
- : \Delta_8 \vdash (\perp, \Delta_{12}), F_9 \rightarrow F_{10} \quad \text{Cut} \\
\hline
\frac{\bullet h_2 : \Delta_8 \vdash \perp, \Delta_{12}, F_7, F_9 \rightarrow F_{10}}{- : \Delta_8 \vdash \perp, \Delta_{12}, F_9 \rightarrow F_{10}} \text{ax/W} \quad \frac{h_{11} : \Delta_8, F_7 \vdash \perp, \Delta_{12}, F_9 \rightarrow F_{10}}{\bullet h_{11} : \Delta_8, F_7 \vdash \perp, \Delta_{12}, F_9 \rightarrow F_{10}} \text{ax/W} \\
\hline
- : \Delta_8 \vdash \perp, \Delta_{12}, F_9 \rightarrow F_{10} \quad \text{hCut}
\end{array}$$

- Case rule \top_R

$$\begin{array}{c}
\frac{h_1 : F_7, \Delta_6 \vdash F_8, \top, \Delta_{10}}{\bullet h_1 : \Delta_6 \vdash (\top, \Delta_{10}), F_7 \rightarrow F_8} \rightarrow_R \quad \frac{h_9 : \Delta_6, F_7 \rightarrow F_8 \vdash \top, \Delta_{10}}{\bullet h_9 : \Delta_6, F_7 \rightarrow F_8 \vdash \top, \Delta_{10}} \top_R \\
\hline
- : \Delta_6 \vdash \top, \Delta_{10} \quad \text{Cut} \\
\hline
\frac{- : \Delta_6 \vdash \top, \Delta_{10}}{- : \Delta_6 \vdash \top, \Delta_{10}} \top_R \\
\hline
\frac{h_2 : F_9, \Delta_8 \vdash F_7, F_{10}, \top, \Delta_{12}}{\bullet h_2 : \Delta_8 \vdash ((\top, \Delta_{12}), F_9 \rightarrow F_{10}), F_7} \rightarrow_R \quad \frac{h_{11} : \Delta_8, F_7 \vdash (\top, \Delta_{12}), F_9 \rightarrow F_{10}}{\bullet h_{11} : \Delta_8, F_7 \vdash (\top, \Delta_{12}), F_9 \rightarrow F_{10}} \top_R \\
\hline
- : \Delta_8 \vdash (\top, \Delta_{12}), F_9 \rightarrow F_{10} \quad \text{Cut} \\
\hline
\frac{- : \Delta_8 \vdash \top, \Delta_{12}, F_9 \rightarrow F_{10}}{- : \Delta_8 \vdash \top, \Delta_{12}, F_9 \rightarrow F_{10}} \top_R
\end{array}$$

- Case rule $A4$

$$\begin{array}{c}
\frac{h_1 : F_6, \Box \Gamma_9, \Delta_{12} \vdash F_7, \Delta_{10}, \Box F_{11}}{\bullet h_1 : \Box \Gamma_9, \Delta_{12} \vdash (\Delta_{10}, \Box F_{11}), F_6 \rightarrow F_7} \rightarrow_R \quad \frac{h_8 : \Box \Gamma_9 \vdash F_{11}}{\bullet h_8 : (\Box \Gamma_9, \Delta_{12}), F_6 \rightarrow F_7 \vdash \Delta_{10}, \Box F_{11}} A4 \\
\hline
- : \Box \Gamma_9, \Delta_{12} \vdash \Delta_{10}, \Box F_{11} \quad \text{Cut} \\
\hline
\frac{- : \Box \Gamma_9 \vdash F_{11}}{- : \Delta_{12}, \Box \Gamma_9 \vdash \Delta_{10}, \Box F_{11}} \text{ax/W} \\
\hline
- : \Delta_{12}, \Box \Gamma_9 \vdash \Delta_{10}, \Box F_{11} \quad A4
\end{array}$$

$$\begin{array}{c}
\frac{h_2 : F_8, \Box \Gamma_{14}, \Delta_{11} \vdash \Box F_7, F_9, \Delta_{13}, \Box F_{12}}{\bullet h_2 : \Box \Gamma_{14}, \Delta_{11} \vdash ((\Delta_{13}, \Box F_{12}), F_8 \rightarrow F_9), \Box F_7} \rightarrow_R \quad \frac{h_{10} : \Box \Gamma_{14}, \Box F_7 \vdash F_{12}}{\bullet h_{10} : (\Box \Gamma_{14}, \Delta_{11}), \Box F_7 \vdash (\Delta_{13}, \Box F_{12}), F_8 \rightarrow F_9} \begin{array}{l} A4 \\ \text{Cut} \end{array} \\
\hline
- : \Box \Gamma_{14}, \Delta_{11} \vdash (\Delta_{13}, \Box F_{12}), F_8 \rightarrow F_9 \\
\hline
\sim \\
\frac{\frac{h_2 : \Delta_{11}, F_8, \Box \Gamma_{14} \vdash \Box F_7, \Delta_{13}, F_9, \Box F_{12}}{- : \Delta_{11}, F_8, \Box \Gamma_{14} \vdash \Delta_{13}, F_9, \Box F_{12}} \text{ ax/W} \quad \frac{h_{10} : \Box F_7, \Box \Gamma_{14} \vdash F_{12}}{\bullet h_{10} : \Box F_7, \Delta_{11}, F_8, \Box \Gamma_{14} \vdash \Delta_{13}, F_9, \Box F_{12}} \begin{array}{l} \text{ax/W} \\ A4 \end{array}}{\frac{- : \Delta_{11}, F_8, \Box \Gamma_{14} \vdash \Delta_{13}, F_9, \Box F_{12}}{- : \Delta_{11}, \Box \Gamma_{14} \vdash \Delta_{13}, \Box F_{12}, F_8 \rightarrow F_9} \rightarrow_R} \text{ hCut} \\
\hline
\frac{h_2 : F_8, \Box \Gamma_{11}, \Delta_{14} \vdash F_7, F_9, \Delta_{13}, \Box F_{12}}{\bullet h_2 : \Box \Gamma_{11}, \Delta_{14} \vdash ((\Delta_{13}, \Box F_{12}), F_8 \rightarrow F_9), F_7} \rightarrow_R \quad \frac{h_{10} : \Box \Gamma_{11} \vdash F_{12}}{\bullet h_{10} : (\Box \Gamma_{11}, \Delta_{14}), F_7 \vdash (\Delta_{13}, \Box F_{12}), F_8 \rightarrow F_9} \begin{array}{l} A4 \\ \text{Cut} \end{array} \\
\hline
- : \Box \Gamma_{11}, \Delta_{14} \vdash (\Delta_{13}, \Box F_{12}), F_8 \rightarrow F_9 \\
\hline
\sim \\
\frac{- : \Box \Gamma_{11} \vdash F_{12}}{- : \Delta_{14}, \Box \Gamma_{11} \vdash \Delta_{13}, \Box F_{12}, F_8 \rightarrow F_9} \begin{array}{l} \text{ax/W} \\ A4 \end{array}
\end{array}$$

• Case rule \rightarrow_L

$$\begin{array}{c}
\frac{h_1 : F_6, \Delta_{12}, F_9 \rightarrow F_{10} \vdash F_7, \Delta_{11}}{\bullet h_1 : \Delta_{12}, F_9 \rightarrow F_{10} \vdash \Delta_{11}, F_6 \rightarrow F_7} \rightarrow_R \quad \frac{h_8 : \Delta_{12}, F_6 \rightarrow F_7 \vdash F_9, \Delta_{11} \quad h_8 : F_{10}, \Delta_{12}, F_6 \rightarrow F_7 \vdash \Delta_{11}}{\bullet h_8 : (\Delta_{12}, F_9 \rightarrow F_{10}), F_6 \rightarrow F_7 \vdash \Delta_{11}} \begin{array}{l} \rightarrow_L \\ \text{Cut} \end{array} \\
\hline
- : \Delta_{12}, F_9 \rightarrow F_{10} \vdash \Delta_{11} \\
\hline
\sim \\
\frac{\frac{h_1 : \Delta_{12}, F_6 \vdash \Delta_{11}, F_7, F_9}}{\bullet h_1 : \Delta_{12} \vdash \Delta_{11}, F_9, F_6 \rightarrow F_7} \text{ inv-th/ax} \rightarrow_R \quad \frac{h_8 : \Delta_{12}, F_6 \rightarrow F_7 \vdash \Delta_{11}, F_9}{- : \Delta_{12} \vdash \Delta_{11}, F_9} \text{ ax/W} \quad \frac{\frac{h_1 : \Delta_{12}, F_{10}, F_6 \vdash \Delta_{11}, F_7}}{\bullet h_1 : \Delta_{12}, F_{10} \vdash \Delta_{11}, F_6 \rightarrow F_7} \text{ inv-th/ax} \rightarrow_R \quad \frac{h_8 : \Delta_{12}, F_{10}, F_6 \rightarrow F_7 \vdash \Delta_{11}}{- : \Delta_{12}, F_{10} \vdash \Delta_{11}} \text{ hCut} \\
\hline
- : \Delta_{12}, F_9 \rightarrow F_{10} \vdash \Delta_{11}
\end{array}$$

$$\begin{array}{c}
\frac{h_1 : F_8, \Delta_7 \vdash F_9, \Delta_{10}}{\bullet h_1 : \Delta_7 \vdash \Delta_{10}, F_8 \rightarrow F_9} \rightarrow_R \quad \frac{h_6 : \Delta_7 \vdash F_8, \Delta_{10} \quad h_6 : F_9, \Delta_7 \vdash \Delta_{10}}{\bullet h_6 : \Delta_7, F_8 \rightarrow F_9 \vdash \Delta_{10}} \begin{array}{l} \rightarrow_L \\ \text{Cut} \end{array} \\
\hline
- : \Delta_7 \vdash \Delta_{10} \\
\hline
\sim \\
\frac{- : \Delta_7, F_8 \vdash \Delta_{10}, F_9}{- : \Delta_7 \vdash \Delta_{10}, F_8} \text{ ax/W} \quad \frac{- : \Delta_7, F_8 \vdash \Delta_{10}, F_9}{- : \Delta_7, F_8 \vdash \Delta_{10}} \text{ ax/W} \quad \frac{- : \Delta_7, F_8, F_9 \vdash \Delta_{10}}{- : \Delta_7, F_8 \vdash \Delta_{10}} \text{ sCut} \\
\hline
- : \Delta_7 \vdash \Delta_{10}
\end{array}$$

$$\begin{array}{c}
\frac{h_2 : F_8, \Delta_{11} \vdash F_{12} \rightarrow F_{13}, F_9, \Delta_7}{\bullet h_2 : \Delta_{11} \vdash (\Delta_7, F_8 \rightarrow F_9), F_{12} \rightarrow F_{13}} \rightarrow_R \quad \frac{h_{10} : \Delta_{11} \vdash F_{12}, \Delta_7, F_8 \rightarrow F_9 \quad h_{10} : F_{13}, \Delta_{11} \vdash \Delta_7, F_8 \rightarrow F_9}{\bullet h_{10} : \Delta_{11}, F_{12} \rightarrow F_{13} \vdash \Delta_7, F_8 \rightarrow F_9} \begin{array}{l} \rightarrow_L \\ \text{Cut} \end{array} \\
\hline
- : \Delta_{11} \vdash \Delta_7, F_8 \rightarrow F_9 \\
\hline
\sim \\
\frac{h_2 : \Delta_{11}, F_8 \vdash \Delta_7, F_9, F_{12} \rightarrow F_{13}}{- : \Delta_{11}, F_8 \vdash \Delta_7, F_9} \text{ ax/W} \quad \frac{h_{10} : \Delta_{11}, F_8 \vdash \Delta_7, F_{12}, F_9}{\bullet h_{10} : \Delta_{11}, F_8, F_{12} \rightarrow F_{13} \vdash \Delta_7, F_9} \text{ inv-th/ax} \rightarrow_L \quad \frac{h_{10} : \Delta_{11}, F_{13}, F_8 \vdash \Delta_7, F_9}{- : \Delta_{11} \vdash \Delta_7, F_8 \rightarrow F_9} \text{ hCut} \\
\hline
- : \Delta_{11} \vdash \Delta_7, F_8 \rightarrow F_9
\end{array}$$

$$\begin{array}{c}
\frac{h_2 : F_9, \Delta_{14}, F_{12} \rightarrow F_{13} \vdash F_7, F_{10}, \Delta_8}{\bullet h_2 : \Delta_{14}, F_{12} \rightarrow F_{13} \vdash (\Delta_8, F_9 \rightarrow F_{10}), F_7} \rightarrow_R \quad \frac{h_{11} : F_7, \Delta_{14} \vdash F_{12}, \Delta_8, F_9 \rightarrow F_{10} \quad h_{11} : F_7, F_{13}, \Delta_{14} \vdash \Delta_8, F_9 \rightarrow F_{10}}{\bullet h_{11} : (\Delta_{14}, F_{12} \rightarrow F_{13}), F_7 \vdash \Delta_8, F_9 \rightarrow F_{10}} \begin{array}{l} \rightarrow_L \\ \text{Cut} \end{array} \\
\hline
- : \Delta_{14}, F_{12} \rightarrow F_{13} \vdash \Delta_8, F_9 \rightarrow F_{10} \\
\hline
\sim \\
\frac{h_2 : \Delta_{14}, F_9, F_{12} \rightarrow F_{13} \vdash \Delta_8, F_{10}, F_7}{- : \Delta_{14}, F_9, F_{12} \rightarrow F_{13} \vdash \Delta_8, F_{10}} \text{ ax/W} \quad \frac{h_{11} : \Delta_{14}, F_7, F_9 \vdash \Delta_8, F_{10}, F_{12}}{\bullet h_{11} : \Delta_{14}, F_7, F_9, F_{12} \rightarrow F_{13} \vdash \Delta_8, F_{10}} \text{ inv-th/ax} \rightarrow_L \quad \frac{h_{11} : \Delta_{14}, F_{13}, F_7, F_9 \vdash \Delta_8, F_{10}}{- : \Delta_{14}, F_{12} \rightarrow F_{13} \vdash \Delta_8, F_9 \rightarrow F_{10}} \text{ hCut} \\
\hline
- : \Delta_{14}, F_{12} \rightarrow F_{13} \vdash \Delta_8, F_9 \rightarrow F_{10}
\end{array}$$

• Case rule \wedge_L

$$\begin{array}{c}
\frac{h_1 : F_6, \Delta_{12}, F_9 \wedge F_{10} \vdash F_7, \Delta_{11} \quad \bullet h_1 : \Delta_{12}, F_9 \wedge F_{10} \vdash \Delta_{11}, F_6 \rightarrow F_7 \quad \rightarrow_R \quad \frac{h_8 : F_9, F_{10}, \Delta_{12}, F_6 \rightarrow F_7 \vdash \Delta_{11} \quad \bullet h_8 : (\Delta_{12}, F_9 \wedge F_{10}), F_6 \rightarrow F_7 \vdash \Delta_{11} \quad \wedge_L}{\bullet h_8 : (\Delta_{12}, F_9 \wedge F_{10}), F_6 \rightarrow F_7 \vdash \Delta_{11}} \text{Cut}}{\vdash : \Delta_{12}, F_9 \wedge F_{10} \vdash \Delta_{11}} \\
\sim \\
\frac{\frac{h_1 : \Delta_{12}, F_{10}, F_6, F_9 \vdash \Delta_{11}, F_7}{\bullet h_1 : \Delta_{12}, F_{10}, F_9 \vdash \Delta_{11}, F_6 \rightarrow F_7} \text{inv-th/ax} \quad \rightarrow_R \quad \frac{h_8 : \Delta_{12}, F_{10}, F_9, F_6 \rightarrow F_7 \vdash \Delta_{11}}{\vdash : \Delta_{12}, F_{10}, F_9 \vdash \Delta_{11}} \text{ax/W}}{\vdash : \Delta_{12}, F_9 \wedge F_{10} \vdash \Delta_{11}} \text{hCut} \\
\sim \\
\frac{h_2 : F_8, \Delta_{11} \vdash F_{12} \wedge F_{13}, F_9, \Delta_7 \quad \bullet h_2 : \Delta_{11} \vdash (\Delta_7, F_8 \rightarrow F_9), F_{12} \wedge F_{13} \quad \rightarrow_R \quad \frac{h_{10} : F_{12}, F_{13}, \Delta_{11} \vdash \Delta_7, F_8 \rightarrow F_9 \quad \bullet h_{10} : \Delta_{11}, F_{12} \wedge F_{13} \vdash \Delta_7, F_8 \rightarrow F_9 \quad \wedge_L}{\vdash : \Delta_{11} \vdash \Delta_7, F_8 \rightarrow F_9} \text{Cut}}{\vdash : \Delta_{11} \vdash \Delta_7, F_8 \rightarrow F_9} \\
\sim \\
\frac{\frac{h_2 : \Delta_{11}, F_8 \vdash \Delta_7, F_9, F_{12} \wedge F_{13}}{\vdash : \Delta_{11}, F_8 \vdash \Delta_7, F_9} \text{ax/W} \quad \frac{h_{10} : \Delta_{11}, F_{12}, F_{13}, F_8 \vdash \Delta_7, F_9}{\bullet h_{10} : \Delta_{11}, F_8, F_{12} \wedge F_{13} \vdash \Delta_7, F_9} \text{inv-th/ax}}{\vdash : \Delta_{11} \vdash \Delta_7, F_8 \rightarrow F_9} \wedge_L \\
\sim \\
\frac{h_2 : F_9, \Delta_{14}, F_{12} \wedge F_{13} \vdash F_7, F_{10}, \Delta_8 \quad \bullet h_2 : \Delta_{14}, F_{12} \wedge F_{13} \vdash (\Delta_8, F_9 \rightarrow F_{10}), F_7 \quad \rightarrow_R \quad \frac{h_{11} : F_7, F_{12}, F_{13}, \Delta_{14} \vdash \Delta_8, F_9 \rightarrow F_{10} \quad \bullet h_{11} : (\Delta_{14}, F_{12} \wedge F_{13}), F_7 \vdash \Delta_8, F_9 \rightarrow F_{10}}{\vdash : \Delta_{14}, F_{12} \wedge F_{13} \vdash \Delta_8, F_9 \rightarrow F_{10}} \wedge_L}{\vdash : \Delta_{14}, F_{12} \wedge F_{13} \vdash \Delta_8, F_9 \rightarrow F_{10}} \text{Cut} \\
\sim \\
\frac{\frac{h_2 : \Delta_{14}, F_9, F_{12} \wedge F_{13} \vdash \Delta_8, F_{10}, F_7}{\vdash : \Delta_{14}, F_9, F_{12} \wedge F_{13} \vdash \Delta_8, F_{10}} \text{ax/W} \quad \frac{h_{11} : \Delta_{14}, F_{12}, F_{13}, F_7, F_9 \vdash \Delta_8, F_{10}}{\bullet h_{11} : \Delta_{14}, F_7, F_9, F_{12} \wedge F_{13} \vdash \Delta_8, F_{10}} \text{inv-th/ax}}{\vdash : \Delta_{14}, F_9, F_{12} \wedge F_{13} \vdash \Delta_8, F_9 \rightarrow F_{10}} \wedge_L \\
\sim \\
\frac{\vdash : \Delta_{14}, F_9, F_{12} \wedge F_{13} \vdash \Delta_8, F_{10}}{\vdash : \Delta_{14}, F_{12} \wedge F_{13} \vdash \Delta_8, F_9 \rightarrow F_{10}} \text{hCut}
\end{array}$$

- Case rule \vee_L

$$\begin{array}{c}
\frac{h_1 : F_6, \Delta_{12}, F_9 \vee F_{10} \vdash F_7, \Delta_{11} \quad \bullet h_1 : \Delta_{12}, F_9 \vee F_{10} \vdash \Delta_{11}, F_6 \rightarrow F_7 \quad \rightarrow_R \quad \frac{h_8 : F_9, \Delta_{12}, F_6 \rightarrow F_7 \vdash \Delta_{11} \quad h_8 : F_{10}, \Delta_{12}, F_6 \rightarrow F_7 \vdash \Delta_{11}}{\bullet h_8 : (\Delta_{12}, F_9 \vee F_{10}), F_6 \rightarrow F_7 \vdash \Delta_{11}} \vee_L}{\vdash : \Delta_{12}, F_9 \vee F_{10} \vdash \Delta_{11}} \text{Cut} \\
\sim \\
\frac{\frac{h_1 : \Delta_{12}, F_6, F_9 \vdash \Delta_{11}, F_7}{\bullet h_1 : \Delta_{12}, F_9 \vdash \Delta_{11}, F_6 \rightarrow F_7} \text{inv-th/ax} \quad \rightarrow_R \quad \frac{h_8 : \Delta_{12}, F_9, F_6 \rightarrow F_7 \vdash \Delta_{11}}{\vdash : \Delta_{12}, F_9 \vdash \Delta_{11}} \text{ax/W}}{\vdash : \Delta_{12}, F_9 \vee F_{10} \vdash \Delta_{11}} \text{hCut} \\
\sim \\
\frac{h_2 : F_8, \Delta_{11} \vdash F_{12} \vee F_{13}, F_9, \Delta_7 \quad \bullet h_2 : \Delta_{11} \vdash (\Delta_7, F_8 \rightarrow F_9), F_{12} \vee F_{13} \quad \rightarrow_R \quad \frac{h_{10} : F_{12}, \Delta_{11} \vdash \Delta_7, F_8 \rightarrow F_9 \quad h_{10} : F_{13}, \Delta_{11} \vdash \Delta_7, F_8 \rightarrow F_9}{\bullet h_{10} : \Delta_{11}, F_{12} \vee F_{13} \vdash \Delta_7, F_8 \rightarrow F_9} \vee_L}{\vdash : \Delta_{11} \vdash \Delta_7, F_8 \rightarrow F_9} \text{Cut} \\
\sim \\
\frac{\frac{h_2 : \Delta_{11}, F_8 \vdash \Delta_7, F_9, F_{12} \vee F_{13}}{\vdash : \Delta_{11}, F_8 \vdash \Delta_7, F_9} \text{ax/W} \quad \frac{h_{10} : \Delta_{11}, F_{12}, F_8 \vdash \Delta_7, F_9}{\bullet h_{10} : \Delta_{11}, F_8, F_{12} \vee F_{13} \vdash \Delta_7, F_9} \text{inv-th/ax}}{\vdash : \Delta_{11} \vdash \Delta_7, F_8 \rightarrow F_9} \wedge_L \\
\sim \\
\frac{h_2 : F_9, \Delta_{14}, F_{12} \vee F_{13} \vdash F_7, F_{10}, \Delta_8 \quad \bullet h_2 : \Delta_{14}, F_{12} \vee F_{13} \vdash (\Delta_8, F_9 \rightarrow F_{10}), F_7 \quad \rightarrow_R \quad \frac{h_{11} : F_7, F_{12}, \Delta_{14} \vdash \Delta_8, F_9 \rightarrow F_{10} \quad h_{11} : F_7, F_{13}, \Delta_{14} \vdash \Delta_8, F_9 \rightarrow F_{10}}{\bullet h_{11} : (\Delta_{14}, F_{12} \vee F_{13}), F_7 \vdash \Delta_8, F_9 \rightarrow F_{10}} \vee_L}{\vdash : \Delta_{14}, F_{12} \vee F_{13} \vdash \Delta_8, F_9 \rightarrow F_{10}} \text{Cut} \\
\sim \\
\frac{\frac{h_2 : \Delta_{14}, F_9, F_{12} \vee F_{13} \vdash \Delta_8, F_{10}, F_7}{\vdash : \Delta_{14}, F_9, F_{12} \vee F_{13} \vdash \Delta_8, F_{10}} \text{ax/W} \quad \frac{h_{11} : \Delta_{14}, F_{12}, F_7, F_9 \vdash \Delta_8, F_{10}}{\bullet h_{11} : \Delta_{14}, F_7, F_9, F_{12} \vee F_{13} \vdash \Delta_8, F_{10}} \text{inv-th/ax}}{\vdash : \Delta_{14}, F_9, F_{12} \vee F_{13} \vdash \Delta_8, F_9 \rightarrow F_{10}} \wedge_L \\
\sim \\
\frac{\vdash : \Delta_{14}, F_9, F_{12} \vee F_{13} \vdash \Delta_8, F_{10}}{\vdash : \Delta_{14}, F_{12} \vee F_{13} \vdash \Delta_8, F_9 \rightarrow F_{10}} \text{hCut}
\end{array}$$

- Case rule AT

$$\begin{array}{c}
\frac{\frac{h_1 : F_6, \Delta_{11}, [F_9 \vdash F_7, \Delta_{10}]}{\bullet h_1 : \Delta_{11}, [F_9 \vdash \Delta_{10}, F_6 \rightarrow F_7]} \rightarrow_R \quad \frac{h_8 : F_9, \Delta_{11}, [F_9, F_6 \rightarrow F_7 \vdash \Delta_{10}]}{\bullet h_8 : (\Delta_{11}, [F_9]), F_6 \rightarrow F_7 \vdash \Delta_{10}} \begin{array}{l} AT \\ Cut \end{array}}{\neg : \Delta_{11}, [F_9 \vdash \Delta_{10}]} \\
\sim \\
\frac{\frac{\bullet h_1 : \Delta_{11}, F_9, [F_9 \vdash \Delta_{10}, F_6 \rightarrow F_7]}{\neg : \Delta_{11}, F_9, [F_9 \vdash \Delta_{10}]} \text{ ax/W} \quad \frac{h_8 : \Delta_{11}, F_9, [F_9, F_6 \rightarrow F_7 \vdash \Delta_{10}]}{\neg : \Delta_{11}, [F_9 \vdash \Delta_{10}]} \begin{array}{l} \text{ax/W} \\ hCut \end{array}}{\neg : \Delta_{11}, [F_9 \vdash \Delta_{10}]} \text{ AT} \\
\\
\frac{\frac{h_2 : F_8, \Delta_{11} \vdash [F_{12}, F_9, \Delta_7]}{\bullet h_2 : \Delta_{11} \vdash (\Delta_7, F_8 \rightarrow F_9), [F_{12}]} \rightarrow_R \quad \frac{h_{10} : F_{12}, \Delta_{11}, [F_{12} \vdash \Delta_7, F_8 \rightarrow F_9]}{\bullet h_{10} : \Delta_{11}, [F_{12} \vdash \Delta_7, F_8 \rightarrow F_9]} \begin{array}{l} AT \\ Cut \end{array}}{\neg : \Delta_{11} \vdash \Delta_7, F_8 \rightarrow F_9} \\
\sim \\
\frac{\frac{h_2 : \Delta_{11}, F_8 \vdash \Delta_7, F_9, [F_{12}]}{\neg : \Delta_{11}, F_8 \vdash \Delta_7, F_9} \text{ ax/W} \quad \frac{\frac{h_{10} : \Delta_{11}, F_{12}, F_8, [F_{12} \vdash \Delta_7, F_9]}{\bullet h_{10} : \Delta_{11}, F_8, [F_{12} \vdash \Delta_7, F_9]} \begin{array}{l} \text{inv-th/ax} \\ AT \end{array}}{\neg : \Delta_{11}, F_8 \vdash \Delta_7, F_9} \text{ hCut} \\
\rightarrow_R \\
\neg : \Delta_{11} \vdash \Delta_7, F_8 \rightarrow F_9 \\
\\
\frac{\frac{h_2 : F_9, \Delta_{13}, [F_{12} \vdash F_7, F_{10}, \Delta_8]}{\bullet h_2 : \Delta_{13}, [F_{12} \vdash (\Delta_8, F_9 \rightarrow F_{10}), F_7]} \rightarrow_R \quad \frac{h_{11} : F_7, F_{12}, \Delta_{13}, [F_{12} \vdash \Delta_8, F_9 \rightarrow F_{10}]}{\bullet h_{11} : (\Delta_{13}, [F_{12}]), F_7 \vdash \Delta_8, F_9 \rightarrow F_{10}} \begin{array}{l} AT \\ Cut \end{array}}{\neg : \Delta_{13}, [F_{12} \vdash \Delta_8, F_9 \rightarrow F_{10}]} \\
\sim \\
\frac{\bullet h_2 : \Delta_{13}, F_{12}, [F_{12} \vdash \Delta_8, F_7, F_9 \rightarrow F_{10}]}{\neg : \Delta_{13}, F_{12}, [F_{12} \vdash \Delta_8, F_9 \rightarrow F_{10}]} \text{ ax/W} \quad \frac{h_{11} : \Delta_{13}, F_{12}, F_7, [F_{12} \vdash \Delta_8, F_9 \rightarrow F_{10}]}{\neg : \Delta_{13}, [F_{12} \vdash \Delta_8, F_9 \rightarrow F_{10}]} \begin{array}{l} \text{ax/W} \\ hCut \end{array} \\
\rightarrow_R \\
\neg : \Delta_{13}, [F_{12} \vdash \Delta_8, F_9 \rightarrow F_{10}] \text{ AT}
\end{array}$$

- Case rule \perp_L

$$\begin{array}{c}
\frac{\frac{h_1 : F_6, \perp, \Delta_{10} \vdash F_7, \Delta_9}{\bullet h_1 : \perp, \Delta_{10} \vdash \Delta_9, F_6 \rightarrow F_7} \rightarrow_R \quad \frac{h_8 : (\perp, \Delta_{10}), F_6 \rightarrow F_7 \vdash \Delta_9}{\bullet h_8 : (\perp, \Delta_{10}), F_6 \rightarrow F_7 \vdash \Delta_9}}{\neg : \perp, \Delta_{10} \vdash \Delta_9} \begin{array}{l} \perp_L \\ Cut \end{array} \\
\sim \\
\neg : \perp, \Delta_{10} \vdash \Delta_9 \quad \perp_L \\
\\
\frac{\frac{h_2 : F_8, \Delta_{11} \vdash \perp, F_9, \Delta_7}{\bullet h_2 : \Delta_{11} \vdash (\Delta_7, F_8 \rightarrow F_9), \perp} \rightarrow_R \quad \frac{h_{10} : \Delta_{11}, \perp \vdash \Delta_7, F_8 \rightarrow F_9}{\bullet h_{10} : \Delta_{11}, \perp \vdash \Delta_7, F_8 \rightarrow F_9}}{\neg : \Delta_{11} \vdash \Delta_7, F_8 \rightarrow F_9} \begin{array}{l} \perp_L \\ Cut \end{array} \\
\sim \\
\frac{\frac{h_2 : \Delta_{11}, F_8 \vdash \perp, \Delta_7, F_9}{\neg : \Delta_{11}, F_8 \vdash \Delta_7, F_9} \text{ ax/W} \quad \frac{h_{10} : \perp, \Delta_{11}, F_8 \vdash \Delta_7, F_9}{\neg : \Delta_{11}, F_8 \vdash \Delta_7, F_9} \begin{array}{l} \perp_L \\ hCut \end{array}}{\neg : \Delta_{11} \vdash \Delta_7, F_8 \rightarrow F_9} \rightarrow_R \\
\\
\frac{\frac{h_2 : F_9, \perp, \Delta_{12} \vdash F_7, F_{10}, \Delta_8}{\bullet h_2 : \perp, \Delta_{12} \vdash (\Delta_8, F_9 \rightarrow F_{10}), F_7} \rightarrow_R \quad \frac{h_{11} : (\perp, \Delta_{12}), F_7 \vdash \Delta_8, F_9 \rightarrow F_{10}}{\bullet h_{11} : (\perp, \Delta_{12}), F_7 \vdash \Delta_8, F_9 \rightarrow F_{10}} \begin{array}{l} \perp_L \\ Cut \end{array}}{\neg : \perp, \Delta_{12} \vdash \Delta_8, F_9 \rightarrow F_{10}} \\
\sim \\
\neg : \perp, \Delta_{12} \vdash \Delta_8, F_9 \rightarrow F_{10} \quad \perp_L
\end{array}$$

- Case rule I

$$\begin{array}{c}
\frac{\frac{h_1 : F_6, \Delta_{11}, p_9 \vdash F_7, \Delta_{10}, p_9}{\bullet h_1 : \Delta_{11}, p_9 \vdash (\Delta_{10}, p_9), F_6 \rightarrow F_7} \rightarrow_R \quad \frac{h_8 : (\Delta_{11}, p_9), F_6 \rightarrow F_7 \vdash \Delta_{10}, p_9}{\bullet h_8 : (\Delta_{11}, p_9), F_6 \rightarrow F_7 \vdash \Delta_{10}, p_9}}{\neg : \Delta_{11}, p_9 \vdash \Delta_{10}, p_9} \begin{array}{l} I \\ Cut \end{array} \\
\sim \\
\neg : \Delta_{11}, p_9 \vdash \Delta_{10}, p_9 \quad I \\
\\
\frac{\frac{h_2 : F_7, \Delta_{10} \vdash p_{11}, F_8, \Delta_{12}, p_{11}}{\bullet h_2 : \Delta_{10} \vdash ((\Delta_{12}, p_{11}), F_7 \rightarrow F_8), p_{11}} \rightarrow_R \quad \frac{h_9 : \Delta_{10}, p_{11} \vdash (\Delta_{12}, p_{11}), F_7 \rightarrow F_8}{\bullet h_9 : \Delta_{10}, p_{11} \vdash (\Delta_{12}, p_{11}), F_7 \rightarrow F_8}}{\neg : \Delta_{10} \vdash (\Delta_{12}, p_{11}), F_7 \rightarrow F_8} \begin{array}{l} I \\ Cut \end{array} \\
\sim \\
\frac{\frac{h_2 : \Delta_{10}, F_7 \vdash \Delta_{12}, F_8, p_{11}, p_{11}}{\neg : \Delta_{10}, F_7 \vdash \Delta_{12}, F_8, p_{11}} \text{ ax/W} \quad \frac{h_9 : \Delta_{10}, F_7, p_{11} \vdash \Delta_{12}, F_8, p_{11}}{\neg : \Delta_{10}, F_7 \vdash \Delta_{12}, F_8, p_{11}} \begin{array}{l} I \\ hCut \end{array}}{\neg : \Delta_{10} \vdash \Delta_{12}, p_{11}, F_7 \rightarrow F_8} \rightarrow_R
\end{array}$$

$$\begin{array}{c}
\frac{h_2 : F_8, \Delta_{13}, p_{11} \vdash F_7, F_9, \Delta_{12}, p_{11}}{\bullet h_2 : \Delta_{13}, p_{11} \vdash ((\Delta_{12}, p_{11}), F_8 \rightarrow F_9), F_7} \rightarrow_R \quad \frac{h_{10} : (\Delta_{13}, p_{11}), F_7 \vdash (\Delta_{12}, p_{11}), F_8 \rightarrow F_9}{- : \Delta_{13}, p_{11} \vdash (\Delta_{12}, p_{11}), F_8 \rightarrow F_9} I \\
\text{Cut} \\
\sim \\
- : \Delta_{13}, p_{11} \vdash \Delta_{12}, p_{11}, F_8 \rightarrow F_9 \quad I
\end{array}$$

- Case rule \top_L

$$\begin{array}{c}
\frac{h_1 : F_6, \top, \Delta_{10} \vdash F_7, \Delta_9}{\bullet h_1 : \top, \Delta_{10} \vdash \Delta_9, F_6 \rightarrow F_7} \rightarrow_R \quad \frac{h_8 : \Delta_{10}, F_6 \rightarrow F_7 \vdash \Delta_9}{\bullet h_8 : (\top, \Delta_{10}), F_6 \rightarrow F_7 \vdash \Delta_9} \top_L \\
\text{Cut} \\
- : \top, \Delta_{10} \vdash \Delta_9 \\
\sim \\
\frac{\bullet h_1 : \top, \Delta_{10} \vdash \Delta_9, F_6 \rightarrow F_7}{- : \top, \Delta_{10} \vdash \Delta_9} \text{ax/W} \quad \frac{h_8 : \top, \Delta_{10}, F_6 \rightarrow F_7 \vdash \Delta_9}{- : \top, \Delta_{10} \vdash \Delta_9} \text{hCut} \\
\\
\frac{h_2 : F_8, \Delta_{11} \vdash \top, F_9, \Delta_7}{\bullet h_2 : \Delta_{11} \vdash (\Delta_7, F_8 \rightarrow F_9), \top} \rightarrow_R \quad \frac{h_{10} : \Delta_{11} \vdash \Delta_7, F_8 \rightarrow F_9}{\bullet h_{10} : \Delta_{11}, \top \vdash \Delta_7, F_8 \rightarrow F_9} \top_L \\
\text{Cut} \\
- : \Delta_{11} \vdash \Delta_7, F_8 \rightarrow F_9 \\
\sim \\
- : \Delta_{11} \vdash \Delta_7, F_8 \rightarrow F_9 \quad \text{ax/W} \\
\\
\frac{h_2 : F_9, \top, \Delta_{12} \vdash F_7, F_{10}, \Delta_8}{\bullet h_2 : \top, \Delta_{12} \vdash (\Delta_8, F_9 \rightarrow F_{10}), F_7} \rightarrow_R \quad \frac{h_{11} : F_7, \Delta_{12} \vdash \Delta_8, F_9 \rightarrow F_{10}}{\bullet h_{11} : (\top, \Delta_{12}), F_7 \vdash \Delta_8, F_9 \rightarrow F_{10}} \top_L \\
\text{Cut} \\
- : \top, \Delta_{12} \vdash \Delta_8, F_9 \rightarrow F_{10} \\
\sim \\
\frac{\bullet h_2 : \top, \Delta_{12} \vdash \Delta_8, F_7, F_9 \rightarrow F_{10}}{- : \top, \Delta_{12} \vdash \Delta_8, F_9 \rightarrow F_{10}} \text{ax/W} \quad \frac{h_{11} : \top, \Delta_{12}, F_7 \vdash \Delta_8, F_9 \rightarrow F_{10}}{- : \top, \Delta_{12} \vdash \Delta_8, F_9 \rightarrow F_{10}} \text{hCut}
\end{array}$$

8.2 Status of \wedge_R : OK

- Case rule \rightarrow_R

$$\begin{array}{c}
\frac{h_1 : \Delta_6 \vdash F_7, \Delta_{10}, F_{11} \rightarrow F_{12} \quad h_1 : \Delta_6 \vdash F_8, \Delta_{10}, F_{11} \rightarrow F_{12}}{\bullet h_1 : \Delta_6 \vdash (\Delta_{10}, F_{11} \rightarrow F_{12}), F_7 \wedge F_8} \wedge_R \quad \frac{h_9 : F_{11}, \Delta_6, F_7 \wedge F_8 \vdash F_{12}, \Delta_{10}}{\bullet h_9 : \Delta_6, F_7 \wedge F_8 \vdash \Delta_{10}, F_{11} \rightarrow F_{12}} \rightarrow_R \\
\text{Cut} \\
- : \Delta_6 \vdash \Delta_{10}, F_{11} \rightarrow F_{12} \\
\sim \\
\frac{h_1 : \Delta_6, F_{11} \vdash \Delta_{10}, F_{12}, F_7}{\bullet h_1 : \Delta_6, F_{11} \vdash \Delta_{10}, F_{12}, F_7 \wedge F_8} \text{inv-th/ax} \quad \frac{h_1 : \Delta_6, F_{11} \vdash \Delta_{10}, F_{12}, F_8}{\bullet h_1 : \Delta_6, F_{11} \vdash \Delta_{10}, F_{12}, F_7 \wedge F_8} \text{inv-th/ax} \\
\wedge_R \quad \frac{h_9 : \Delta_6, F_{11}, F_7 \wedge F_8 \vdash \Delta_{10}, F_{12}}{\bullet h_9 : \Delta_6, F_{11}, F_7 \wedge F_8 \vdash \Delta_{10}, F_{12}} \text{ax/W} \\
\text{hCut} \\
- : \Delta_6, F_{11} \vdash \Delta_{10}, F_{12} \\
\rightarrow_R \\
- : \Delta_6 \vdash \Delta_{10}, F_{11} \rightarrow F_{12} \\
\\
\frac{h_2 : \Delta_8 \vdash F_7, F_9, \Delta_{14}, F_{12} \rightarrow F_{13} \quad h_2 : \Delta_8 \vdash F_7, F_{10}, \Delta_{14}, F_{12} \rightarrow F_{13}}{\bullet h_2 : \Delta_8 \vdash ((\Delta_{14}, F_{12} \rightarrow F_{13}), F_9 \wedge F_{10}), F_7} \wedge_R \quad \frac{h_{11} : F_7, F_{12}, \Delta_8 \vdash F_{13}, \Delta_{14}, F_9 \wedge F_{10}}{\bullet h_{11} : \Delta_8, F_7 \vdash (\Delta_{14}, F_{12} \rightarrow F_{13}), F_9 \wedge F_{10}} \rightarrow_R \\
\text{Cut} \\
- : \Delta_8 \vdash (\Delta_{14}, F_{12} \rightarrow F_{13}), F_9 \wedge F_{10} \\
\sim \\
\frac{h_2 : \Delta_8, F_{12} \vdash \Delta_{14}, F_{13}, F_7, F_9}{\bullet h_2 : \Delta_8, F_{12} \vdash \Delta_{14}, F_{13}, F_7, F_9 \wedge F_{10}} \text{inv-th/ax} \quad \frac{h_2 : \Delta_8, F_{12} \vdash \Delta_{14}, F_{10}, F_{13}, F_7}{\bullet h_2 : \Delta_8, F_{12} \vdash \Delta_{14}, F_{10}, F_{13}, F_7} \text{inv-th/ax} \\
\wedge_R \quad \frac{h_{11} : \Delta_8, F_{12}, F_7 \vdash \Delta_{14}, F_{13}, F_9 \wedge F_{10}}{\bullet h_{11} : \Delta_8, F_{12}, F_7 \vdash \Delta_{14}, F_{13}, F_9 \wedge F_{10}} \text{ax/W} \\
\text{hCut} \\
- : \Delta_8, F_{12} \vdash \Delta_{14}, F_{13}, F_9 \wedge F_{10} \\
\rightarrow_R \\
- : \Delta_8 \vdash \Delta_{14}, F_{12} \rightarrow F_{13}, F_9 \wedge F_{10}
\end{array}$$

- Case rule \wedge_R

$$\begin{array}{c}
\frac{h_1 : \Delta_6 \vdash F_7, \Delta_{10}, F_{11} \wedge F_{12} \quad h_1 : \Delta_6 \vdash F_8, \Delta_{10}, F_{11} \wedge F_{12}}{\bullet h_1 : \Delta_6 \vdash (\Delta_{10}, F_{11} \wedge F_{12}), F_7 \wedge F_8} \wedge_R \quad \frac{h_9 : \Delta_6, F_7 \wedge F_8 \vdash F_{11}, \Delta_{10} \quad h_9 : \Delta_6, F_7 \wedge F_8 \vdash F_{12}, \Delta_{10}}{\bullet h_9 : \Delta_6, F_7 \wedge F_8 \vdash \Delta_{10}, F_{11} \wedge F_{12}} \wedge_R \\
\text{Cut} \\
- : \Delta_6 \vdash \Delta_{10}, F_{11} \wedge F_{12} \\
\sim \\
\frac{h_1 : \Delta_6, F_7 \wedge F_8 \vdash \Delta_{10}, F_{11}}{- : \Delta_6, F_7 \wedge F_8 \vdash \Delta_{10}, F_{11}} \text{inv-th/ax} \quad \frac{h_1 : \Delta_6, F_7 \wedge F_8 \vdash \Delta_{10}, F_{12}}{- : \Delta_6, F_7 \wedge F_8 \vdash \Delta_{10}, F_{12}} \text{inv-th/ax} \\
\wedge_R \quad \frac{h_9 : \Delta_6, F_7 \wedge F_8 \vdash \Delta_{10}, F_{11} \wedge F_{12}}{- : \Delta_6, F_7 \wedge F_8 \vdash \Delta_{10}, F_{11} \wedge F_{12}} \text{sCut} \\
\text{ax/W} \quad \frac{- : \Delta_6 \vdash \Delta_{10}, F_7, F_{11} \wedge F_{12}}{- : \Delta_6 \vdash \Delta_{10}, F_7, F_{11} \wedge F_{12}} \text{ax/W} \quad \frac{- : \Delta_6, F_7 \vdash \Delta_{10}, F_{11} \wedge F_{12}}{- : \Delta_6, F_7 \vdash \Delta_{10}, F_{11} \wedge F_{12}} \text{sCut} \\
- : \Delta_6 \vdash \Delta_{10}, F_{11} \wedge F_{12}
\end{array}$$

$$\begin{array}{c}
\frac{h_2 : \Delta_8 \vdash F_7, F_9, \Delta_{14}, F_{12} \wedge F_{13} \quad h_2 : \Delta_8 \vdash F_7, F_{10}, \Delta_{14}, F_{12} \wedge F_{13}}{\bullet h_2 : \Delta_8 \vdash ((\Delta_{14}, F_{12} \wedge F_{13}), F_9 \wedge F_{10}), F_7} \wedge_R \quad \frac{h_{11} : F_7, \Delta_8 \vdash F_{12}, \Delta_{14}, F_9 \wedge F_{10}}{\bullet h_{11} : \Delta_8, F_7 \vdash (\Delta_{14}, F_{12} \wedge F_{13}), F_9 \wedge F_{10}} \\
\hline
- : \Delta_8 \vdash (\Delta_{14}, F_{12} \wedge F_{13}), F_9 \wedge F_{10} \\
\hline
\frac{\frac{h_2 : \Delta_8 \vdash \Delta_{14}, F_{12}, F_7, F_9 \quad \text{inv-th/ax}}{\bullet h_2 : \Delta_8 \vdash \Delta_{14}, F_{12}, F_7, F_9 \wedge F_{10}} \quad \frac{h_2 : \Delta_8 \vdash \Delta_{14}, F_{10}, F_{12}, F_7 \quad \text{inv-th/ax}}{\bullet h_2 : \Delta_8 \vdash \Delta_{14}, F_{10}, F_{12}, F_7} \wedge_R \quad \frac{h_{11} : \Delta_8, F_7 \vdash \Delta_{14}, F_{12}, F_9 \wedge F_{10} \quad \text{ax/W}}{\bullet h_{11} : \Delta_8, F_7 \vdash \Delta_{14}, F_{12}, F_9 \wedge F_{10}} \text{hCut}}{- : \Delta_8 \vdash \Delta_{14}, F_{12}, F_9 \wedge F_{10}} \\
\hline
- : \Delta_8 \vdash \Delta_{14}, F_{12} \wedge F_{13}, F_9 \wedge F_{10} \\
\hline
\frac{h_2 : \Delta_8 \vdash F_7, F_{11}, \Delta_{10} \quad h_2 : \Delta_8 \vdash F_7, F_{12}, \Delta_{10}}{\bullet h_2 : \Delta_8 \vdash (\Delta_{10}, F_{11} \wedge F_{12}), F_7} \wedge_R \quad \frac{h_9 : F_7, \Delta_8 \vdash F_{11}, \Delta_{10} \quad h_9 : F_7, \Delta_8 \vdash F_{12}, \Delta_{10}}{\bullet h_9 : \Delta_8, F_7 \vdash \Delta_{10}, F_{11} \wedge F_{12}} \wedge_R \\
\hline
- : \Delta_8 \vdash \Delta_{10}, F_{11} \wedge F_{12} \\
\hline
\frac{\frac{h_2 : \Delta_8 \vdash \Delta_{10}, F_{11}, F_7 \quad \text{ax/W}}{\bullet h_2 : \Delta_8 \vdash \Delta_{10}, F_{11}, F_7} \quad \frac{h_9 : \Delta_8, F_7 \vdash \Delta_{10}, F_{11} \quad \text{ax/W}}{\bullet h_9 : \Delta_8, F_7 \vdash \Delta_{10}, F_{11}} \text{H} \quad \frac{h_2 : \Delta_8 \vdash \Delta_{10}, F_{12}, F_7 \quad \text{ax/W}}{\bullet h_2 : \Delta_8 \vdash \Delta_{10}, F_{12}, F_7} \text{H} \quad \frac{h_9 : \Delta_8, F_7 \vdash \Delta_{10}, F_{12} \quad \text{ax/W}}{\bullet h_9 : \Delta_8, F_7 \vdash \Delta_{10}, F_{12}} \text{H}}{- : \Delta_8 \vdash \Delta_{10}, F_{11} \wedge F_{12}} \wedge_R
\end{array}$$

- Case rule \vee_R

$$\begin{array}{c}
\frac{h_1 : \Delta_6 \vdash F_7, \Delta_{10}, F_{11} \vee F_{12} \quad h_1 : \Delta_6 \vdash F_8, \Delta_{10}, F_{11} \vee F_{12}}{\bullet h_1 : \Delta_6 \vdash (\Delta_{10}, F_{11} \vee F_{12}), F_7 \wedge F_8} \wedge_R \quad \frac{h_9 : \Delta_6, F_7 \wedge F_8 \vdash F_{11}, F_{12}, \Delta_{10}}{\bullet h_9 : \Delta_6, F_7 \wedge F_8 \vdash \Delta_{10}, F_{11} \vee F_{12}} \vee_R \\
\hline
- : \Delta_6 \vdash \Delta_{10}, F_{11} \vee F_{12} \\
\hline
\frac{\frac{h_1 : \Delta_6 \vdash \Delta_{10}, F_{11}, F_{12}, F_7 \quad \text{inv-th/ax}}{\bullet h_1 : \Delta_6 \vdash \Delta_{10}, F_{11}, F_{12}, F_7 \wedge F_8} \quad \frac{h_1 : \Delta_6 \vdash \Delta_{10}, F_{11}, F_{12}, F_8 \quad \text{inv-th/ax}}{\bullet h_1 : \Delta_6 \vdash \Delta_{10}, F_{11}, F_{12}, F_8} \wedge_R \quad \frac{h_9 : \Delta_6, F_7 \wedge F_8 \vdash \Delta_{10}, F_{11}, F_{12} \quad \text{ax/W}}{\bullet h_9 : \Delta_6, F_7 \wedge F_8 \vdash \Delta_{10}, F_{11}, F_{12}} \text{hCut}}{- : \Delta_6 \vdash \Delta_{10}, F_{11}, F_{12}} \vee_R \\
\hline
- : \Delta_6 \vdash \Delta_{10}, F_{11} \vee F_{12} \\
\hline
\frac{h_2 : \Delta_8 \vdash F_7, F_9, \Delta_{14}, F_{12} \vee F_{13} \quad h_2 : \Delta_8 \vdash F_7, F_{10}, \Delta_{14}, F_{12} \vee F_{13}}{\bullet h_2 : \Delta_8 \vdash ((\Delta_{14}, F_{12} \vee F_{13}), F_9 \wedge F_{10}), F_7} \wedge_R \quad \frac{h_{11} : F_7, \Delta_8 \vdash F_{12}, F_{13}, \Delta_{14}, F_9 \wedge F_{10}}{\bullet h_{11} : \Delta_8, F_7 \vdash (\Delta_{14}, F_{12} \vee F_{13}), F_9 \wedge F_{10}} \vee_R \\
\hline
- : \Delta_8 \vdash (\Delta_{14}, F_{12} \vee F_{13}), F_9 \wedge F_{10} \\
\hline
\frac{\frac{h_2 : \Delta_8 \vdash \Delta_{14}, F_{12}, F_{13}, F_7, F_9 \quad \text{inv-th/ax}}{\bullet h_2 : \Delta_8 \vdash \Delta_{14}, F_{12}, F_{13}, F_7, F_9 \wedge F_{10}} \quad \frac{h_2 : \Delta_8 \vdash \Delta_{14}, F_{10}, F_{12}, F_{13}, F_7 \quad \text{inv-th/ax}}{\bullet h_2 : \Delta_8 \vdash \Delta_{14}, F_{10}, F_{12}, F_{13}, F_7} \wedge_R \quad \frac{h_{11} : \Delta_8, F_7 \vdash \Delta_{14}, F_{12}, F_{13}, F_9 \wedge F_{10} \quad \text{ax/W}}{\bullet h_{11} : \Delta_8, F_7 \vdash \Delta_{14}, F_{12}, F_{13}, F_9 \wedge F_{10}} \text{hCut}}{- : \Delta_8 \vdash \Delta_{14}, F_{12}, F_{13}, F_9 \wedge F_{10}} \vee_R \\
\hline
- : \Delta_8 \vdash \Delta_{14}, F_9 \wedge F_{10}, F_{12} \vee F_{13}
\end{array}$$

- Case rule \perp_R

$$\begin{array}{c}
\frac{h_1 : \Delta_6 \vdash F_7, \perp, \Delta_{10} \quad h_1 : \Delta_6 \vdash F_8, \perp, \Delta_{10}}{\bullet h_1 : \Delta_6 \vdash (\perp, \Delta_{10}), F_7 \wedge F_8} \wedge_R \quad \frac{h_9 : \Delta_6, F_7 \wedge F_8 \vdash \Delta_{10}}{\bullet h_9 : \Delta_6, F_7 \wedge F_8 \vdash \perp, \Delta_{10}} \perp_R \\
\hline
- : \Delta_6 \vdash \perp, \Delta_{10} \\
\hline
\frac{\frac{h_1 : \Delta_6 \vdash \perp, \Delta_{10}, F_7 \wedge F_8 \quad \text{ax/W}}{\bullet h_1 : \Delta_6 \vdash \perp, \Delta_{10}, F_7 \wedge F_8} \quad \frac{h_9 : \Delta_6, F_7 \wedge F_8 \vdash \perp, \Delta_{10} \quad \text{ax/W}}{\bullet h_9 : \Delta_6, F_7 \wedge F_8 \vdash \perp, \Delta_{10}} \text{hCut}}{- : \Delta_6 \vdash \perp, \Delta_{10}} \\
\hline
\frac{h_2 : \Delta_8 \vdash F_7, F_9, \perp, \Delta_{12} \quad h_2 : \Delta_8 \vdash F_7, F_{10}, \perp, \Delta_{12}}{\bullet h_2 : \Delta_8 \vdash ((\perp, \Delta_{12}), F_9 \wedge F_{10}), F_7} \wedge_R \quad \frac{h_{11} : F_7, \Delta_8 \vdash \Delta_{12}, F_9 \wedge F_{10}}{\bullet h_{11} : \Delta_8, F_7 \vdash (\perp, \Delta_{12}), F_9 \wedge F_{10}} \perp_R \\
\hline
- : \Delta_8 \vdash (\perp, \Delta_{12}), F_9 \wedge F_{10} \\
\hline
\frac{\frac{h_2 : \Delta_8 \vdash \perp, \Delta_{12}, F_7, F_9 \wedge F_{10} \quad \text{ax/W}}{\bullet h_2 : \Delta_8 \vdash \perp, \Delta_{12}, F_7, F_9 \wedge F_{10}} \quad \frac{h_{11} : \Delta_8, F_7 \vdash \perp, \Delta_{12}, F_9 \wedge F_{10} \quad \text{ax/W}}{\bullet h_{11} : \Delta_8, F_7 \vdash \perp, \Delta_{12}, F_9 \wedge F_{10}} \text{hCut}}{- : \Delta_8 \vdash \perp, \Delta_{12}, F_9 \wedge F_{10}}
\end{array}$$

- Case rule \top_R

$$\begin{array}{c}
\frac{h_1 : \Delta_6 \vdash F_7, \top, \Delta_{10} \quad h_1 : \Delta_6 \vdash F_8, \top, \Delta_{10}}{\bullet h_1 : \Delta_6 \vdash (\top, \Delta_{10}), F_7 \wedge F_8} \wedge_R \quad \frac{h_9 : \Delta_6, F_7 \wedge F_8 \vdash \top, \Delta_{10}}{\bullet h_9 : \Delta_6, F_7 \wedge F_8 \vdash \top, \Delta_{10}} \top_R \\
\hline
- : \Delta_6 \vdash \top, \Delta_{10} \\
\hline
- : \Delta_6 \vdash \top, \Delta_{10} \quad \top_R
\end{array}$$

- Case rule \wedge_L

$$\begin{array}{c}
\frac{\frac{h_1 : \Delta_{12}, F_9 \wedge F_{10} \vdash F_6, \Delta_{11} \quad h_1 : \Delta_{12}, F_9 \wedge F_{10} \vdash F_7, \Delta_{11}}{\bullet h_1 : \Delta_{12}, F_9 \wedge F_{10} \vdash \Delta_{11}, F_6 \wedge F_7} \wedge_R \quad \frac{h_8 : F_9, F_{10}, \Delta_{12}, F_6 \wedge F_7 \vdash \Delta_{11}}{\bullet h_8 : (\Delta_{12}, F_9 \wedge F_{10}), F_6 \wedge F_7 \vdash \Delta_{11}} \wedge_L}{\frac{}{- : \Delta_{12}, F_9 \wedge F_{10} \vdash \Delta_{11}} \text{Cut}} \\
\frac{}{\sim} \\
\frac{\frac{h_1 : \Delta_{12}, F_{10}, F_9 \vdash \Delta_{11}, F_6}{\bullet h_1 : \Delta_{12}, F_{10}, F_9 \vdash \Delta_{11}, F_6 \wedge F_7} \text{inv-th/ax} \quad \frac{h_1 : \Delta_{12}, F_{10}, F_9 \vdash \Delta_{11}, F_7}{\bullet h_1 : \Delta_{12}, F_{10}, F_9 \vdash \Delta_{11}, F_7} \text{inv-th/ax}}{\frac{}{- : \Delta_{12}, F_{10}, F_9 \vdash \Delta_{11}} \wedge_R} \wedge_L \\
\frac{}{\sim} \\
\frac{\frac{h_1 : \Delta_7 \vdash F_8, \Delta_{10} \quad h_1 : \Delta_7 \vdash F_9, \Delta_{10}}{\bullet h_1 : \Delta_7 \vdash \Delta_{10}, F_8 \wedge F_9} \wedge_R \quad \frac{h_6 : F_8, F_9, \Delta_7 \vdash \Delta_{10}}{\bullet h_6 : \Delta_7, F_8 \wedge F_9 \vdash \Delta_{10}} \wedge_L}{\frac{}{- : \Delta_7 \vdash \Delta_{10}} \text{Cut}} \\
\frac{}{\sim} \\
\frac{\frac{}{- : \Delta_7 \vdash \Delta_{10}, F_8} \text{ax/W} \quad \frac{}{- : \Delta_7, F_8 \vdash \Delta_{10}, F_9} \text{ax/W} \quad \frac{}{- : \Delta_7, F_8, F_9 \vdash \Delta_{10}} \text{ax/W}}{\frac{}{- : \Delta_7 \vdash \Delta_{10}} \text{sCut}} \\
\frac{}{\sim} \\
\frac{\frac{h_2 : \Delta_{11} \vdash F_{12} \wedge F_{13}, F_8, \Delta_7 \quad h_2 : \Delta_{11} \vdash F_{12} \wedge F_{13}, F_9, \Delta_7}{\bullet h_2 : \Delta_{11} \vdash (\Delta_7, F_8 \wedge F_9), F_{12} \wedge F_{13}} \wedge_R \quad \frac{h_{10} : F_{12}, F_{13}, \Delta_{11} \vdash \Delta_7, F_8 \wedge F_9}{\bullet h_{10} : \Delta_{11}, F_{12} \wedge F_{13} \vdash \Delta_7, F_8 \wedge F_9} \wedge_L}{\frac{}{- : \Delta_{11} \vdash \Delta_7, F_8 \wedge F_9} \text{Cut}} \\
\frac{}{\sim} \\
\frac{\frac{h_2 : \Delta_{11} \vdash \Delta_7, F_8, F_{12} \wedge F_{13}}{\bullet h_2 : \Delta_{11}, F_{12} \wedge F_{13} \vdash \Delta_7, F_8} \text{ax/W} \quad \frac{h_{10} : \Delta_{11}, F_{12}, F_{13} \vdash \Delta_7, F_8}{\bullet h_{10} : \Delta_{11}, F_{12} \wedge F_{13} \vdash \Delta_7, F_8} \text{inv-th/ax}}{\frac{}{- : \Delta_{11} \vdash \Delta_7, F_8} \wedge_L} \wedge_L \\
\frac{}{\sim} \\
\frac{\frac{h_2 : \Delta_{11} \vdash \Delta_7, F_8, F_{12} \wedge F_{13}}{\bullet h_2 : \Delta_{11}, F_{12} \wedge F_{13} \vdash \Delta_7, F_8} \text{ax/W} \quad \frac{h_{10} : \Delta_{11}, F_{12}, F_{13} \vdash \Delta_7, F_8}{\bullet h_{10} : \Delta_{11}, F_{12} \wedge F_{13} \vdash \Delta_7, F_8} \text{inv-th/ax}}{\frac{}{- : \Delta_{11} \vdash \Delta_7, F_8} \wedge_L} \wedge_L \\
\frac{}{\sim} \\
\frac{\frac{h_2 : \Delta_{14}, F_{12} \wedge F_{13} \vdash F_7, F_9, \Delta_8 \quad h_2 : \Delta_{14}, F_{12} \wedge F_{13} \vdash F_7, F_{10}, \Delta_8}{\bullet h_2 : \Delta_{14}, F_{12} \wedge F_{13} \vdash (\Delta_8, F_9 \wedge F_{10}), F_7} \wedge_R \quad \frac{h_{11} : F_7, F_{12}, F_{13}, \Delta_{14} \vdash \Delta_8, F_9 \wedge F_{10}}{\bullet h_{11} : (\Delta_{14}, F_{12} \wedge F_{13}), F_7 \vdash \Delta_8, F_9 \wedge F_{10}} \wedge_L}{\frac{}{- : \Delta_{14}, F_{12} \wedge F_{13} \vdash \Delta_8, F_9 \wedge F_{10}} \text{Cut}} \\
\frac{}{\sim} \\
\frac{\frac{h_2 : \Delta_{14}, F_{12}, F_{13} \vdash \Delta_8, F_7, F_9}{\bullet h_2 : \Delta_{14}, F_{12}, F_{13} \vdash \Delta_8, F_7, F_9 \wedge F_{10}} \text{inv-th/ax} \quad \frac{h_2 : \Delta_{14}, F_{12}, F_{13} \vdash \Delta_8, F_{10}, F_7}{\bullet h_2 : \Delta_{14}, F_{12}, F_{13} \vdash \Delta_8, F_{10}, F_7} \text{inv-th/ax}}{\frac{}{- : \Delta_{14}, F_{12}, F_{13} \vdash \Delta_8, F_9 \wedge F_{10}} \wedge_R} \wedge_L \\
\frac{}{\sim} \\
\frac{\frac{}{- : \Delta_{14}, F_{12}, F_{13} \vdash \Delta_8, F_9 \wedge F_{10}} \text{ax/W} \quad \frac{}{- : \Delta_{14}, F_{12} \wedge F_{13} \vdash \Delta_8, F_9 \wedge F_{10}} \text{ax/W}}{\frac{}{- : \Delta_{14}, F_{12} \wedge F_{13} \vdash \Delta_8, F_9 \wedge F_{10}} \text{hCut}}
\end{array}$$

- Case rule \vee_L

$$\begin{array}{c}
\frac{\frac{h_1 : \Delta_{12}, F_9 \vee F_{10} \vdash F_6, \Delta_{11} \quad h_1 : \Delta_{12}, F_9 \vee F_{10} \vdash F_7, \Delta_{11}}{\bullet h_1 : \Delta_{12}, F_9 \vee F_{10} \vdash \Delta_{11}, F_6 \wedge F_7} \wedge_R \quad \frac{h_8 : F_9, \Delta_{12}, F_6 \wedge F_7 \vdash \Delta_{11} \quad h_8 : F_{10}, \Delta_{12}, F_6 \wedge F_7 \vdash \Delta_{11}}{\bullet h_8 : (\Delta_{12}, F_9 \vee F_{10}), F_6 \wedge F_7 \vdash \Delta_{11}} \vee_L}{\frac{}{- : \Delta_{12}, F_9 \vee F_{10} \vdash \Delta_{11}} \text{Cut}} \\
\frac{}{\sim} \\
\frac{\frac{}{- : \Delta_{12}, F_6, F_7, F_9 \vdash \Delta_{11}} \text{inv-th/ax} \quad \frac{}{- : \Delta_{12}, F_{10}, F_6, F_7 \vdash \Delta_{11}} \text{inv-th/ax}}{\frac{}{- : \Delta_{12}, F_6, F_7, F_9 \vee F_{10} \vdash \Delta_{11}} \vee_L} \vee_L \\
\frac{}{\sim} \\
\frac{\frac{}{- : \Delta_{12}, F_6, F_9 \vee F_{10} \vdash \Delta_{11}, F_7} \text{ax/W} \quad \frac{}{- : \Delta_{12}, F_6, F_7, F_9 \vee F_{10} \vdash \Delta_{11}} \text{ax/W}}{\frac{}{- : \Delta_{12}, F_6, F_9 \vee F_{10} \vdash \Delta_{11}} \text{sCut}} \\
\frac{}{\sim} \\
\frac{\frac{}{- : \Delta_{12}, F_9 \vee F_{10} \vdash \Delta_{11}, F_6} \text{ax/W} \quad \frac{}{- : \Delta_{12}, F_6, F_9 \vee F_{10} \vdash \Delta_{11}} \text{sCut}}{\frac{}{- : \Delta_{12}, F_9 \vee F_{10} \vdash \Delta_{11}} \text{sCut}} \\
\frac{}{\sim} \\
\frac{\frac{h_2 : \Delta_{11} \vdash F_{12} \vee F_{13}, F_8, \Delta_7 \quad h_2 : \Delta_{11} \vdash F_{12} \vee F_{13}, F_9, \Delta_7}{\bullet h_2 : \Delta_{11} \vdash (\Delta_7, F_8 \wedge F_9), F_{12} \vee F_{13}} \wedge_R \quad \frac{h_{10} : F_{12}, \Delta_{11} \vdash \Delta_7, F_8 \wedge F_9 \quad h_{10} : F_{13}, \Delta_{11} \vdash \Delta_7, F_8 \wedge F_9}{\bullet h_{10} : \Delta_{11}, F_{12} \vee F_{13} \vdash \Delta_7, F_8 \wedge F_9} \vee_L}{\frac{}{- : \Delta_{11} \vdash \Delta_7, F_8 \wedge F_9} \text{Cut}} \\
\frac{}{\sim} \\
\frac{\frac{}{- : \Delta_{11} \vdash \Delta_7, F_{12}, F_{13}, F_8} \text{inv-th/ax} \quad \frac{}{- : \Delta_{11} \vdash \Delta_7, F_{12}, F_{13}, F_9} \text{inv-th/ax}}{\frac{}{- : \Delta_{11} \vdash \Delta_7, F_{12}, F_{13}, F_8 \wedge F_9} \wedge_R} \wedge_R \\
\frac{}{\sim} \\
\frac{\frac{}{- : \Delta_{11} \vdash \Delta_7, F_{12}, F_{13}, F_8 \wedge F_9} \text{ax/W} \quad \frac{}{- : \Delta_{11}, F_{13} \vdash \Delta_7, F_{12}, F_8 \wedge F_9} \text{ax/W}}{\frac{}{- : \Delta_{11} \vdash \Delta_7, F_{12}, F_8 \wedge F_9} \text{sCut}} \\
\frac{}{\sim} \\
\frac{\frac{}{- : \Delta_{11} \vdash \Delta_7, F_{12}, F_8 \wedge F_9} \text{ax/W} \quad \frac{}{- : \Delta_{11}, F_{12} \vdash \Delta_7, F_8 \wedge F_9} \text{ax/W}}{\frac{}{- : \Delta_{11} \vdash \Delta_7, F_8 \wedge F_9} \text{sCut}}
\end{array}$$

$$\begin{array}{c}
\frac{\frac{h_2 : \Delta_{14}, F_{12} \vee F_{13} \vdash F_7, F_9, \Delta_8 \quad h_2 : \Delta_{14}, F_{12} \vee F_{13} \vdash F_7, F_{10}, \Delta_8}{\bullet h_2 : \Delta_{14}, F_{12} \vee F_{13} \vdash (\Delta_8, F_9 \wedge F_{10}), F_7} \wedge_R \quad \frac{h_{11} : F_7, F_{12}, \Delta_{14} \vdash \Delta_8, F_9 \wedge F_{10}}{\bullet h_{11} : (\Delta_{14}, F_{12} \vee F_{13}) \vdash \Delta_8, F_9 \wedge F_{10}}}{- : \Delta_{14}, F_{12} \vee F_{13} \vdash \Delta_8, F_9 \wedge F_{10}} \rightsquigarrow \\
\frac{\frac{h_2 : \Delta_{14}, F_{12} \vee F_{13} \vdash \Delta_8, F_7, F_9}{- : \Delta_{14}, F_{12} \vee F_{13} \vdash \Delta_8, F_9} \text{ax/W} \quad \frac{\frac{h_{11} : \Delta_{14}, F_{12}, F_7 \vdash \Delta_8, F_9}{\bullet h_{11} : \Delta_{14}, F_7, F_{12} \vee F_{13} \vdash \Delta_8, F_9} \text{inv-th/ax} \quad \frac{h_{11} : \Delta_{14}, F_{13}, F_7 \vdash \Delta_8, F_9}{\bullet h_{11} : (\Delta_{14}, F_{12} \vee F_{13}) \vdash \Delta_8, F_9} \text{inv-th/ax}}{\bullet h_{11} : (\Delta_{14}, F_{12} \vee F_{13}) \vdash \Delta_8, F_9} \vee_L}{- : \Delta_{14}, F_{12} \vee F_{13} \vdash \Delta_8, F_9} \text{hCut} \\
- : \Delta_{14}, F_{12} \vee F_{13} \vdash \Delta_8, F_9 \wedge F_{10}
\end{array}$$

- Case rule AT

$$\begin{array}{c}
\frac{\frac{h_1 : \Delta_{11}, []F_9 \vdash F_6, \Delta_{10} \quad h_1 : \Delta_{11}, []F_9 \vdash F_7, \Delta_{10}}{\bullet h_1 : \Delta_{11}, []F_9 \vdash \Delta_{10}, F_6 \wedge F_7} \wedge_R \quad \frac{h_8 : F_9, \Delta_{11}, []F_9, F_6 \wedge F_7 \vdash \Delta_{10}}{\bullet h_8 : (\Delta_{11}, []F_9), F_6 \wedge F_7 \vdash \Delta_{10}} AT}{- : \Delta_{11}, []F_9 \vdash \Delta_{10}} \text{Cut} \\
\rightsquigarrow \\
\frac{\frac{\bullet h_1 : \Delta_{11}, F_9, []F_9 \vdash \Delta_{10}, F_6 \wedge F_7}{- : \Delta_{11}, F_9, []F_9 \vdash \Delta_{10}} \text{ax/W} \quad \frac{h_8 : \Delta_{11}, F_9, []F_9, F_6 \wedge F_7 \vdash \Delta_{10}}{\bullet h_8 : (\Delta_{11}, F_9), F_6 \wedge F_7 \vdash \Delta_{10}} \text{ax/W}}{\bullet h_8 : (\Delta_{11}, F_9), F_6 \wedge F_7 \vdash \Delta_{10}} \text{hCut} \\
- : \Delta_{11}, F_9, []F_9 \vdash \Delta_{10} \quad AT \\
- : \Delta_{11}, []F_9 \vdash \Delta_{10} \\
\frac{h_2 : \Delta_{11} \vdash []F_{12}, F_8, \Delta_7 \quad h_2 : \Delta_{11} \vdash []F_{12}, F_9, \Delta_7}{\bullet h_2 : \Delta_{11} \vdash (\Delta_7, F_8 \wedge F_9), []F_{12}} \wedge_R \quad \frac{h_{10} : F_{12}, \Delta_{11}, []F_{12} \vdash \Delta_7, F_8 \wedge F_9}{\bullet h_{10} : \Delta_{11}, []F_{12} \vdash \Delta_7, F_8 \wedge F_9} AT}{- : \Delta_{11} \vdash \Delta_7, F_8 \wedge F_9} \text{Cut} \\
\rightsquigarrow \\
\frac{\frac{h_2 : \Delta_{11} \vdash \Delta_7, F_8, []F_{12}}{\bullet h_2 : \Delta_{11} \vdash \Delta_7, F_8} \text{ax/W} \quad \frac{h_{10} : \Delta_{11}, F_{12}, []F_{12} \vdash \Delta_7, F_8}{\bullet h_{10} : \Delta_{11}, []F_{12} \vdash \Delta_7, F_8} \text{inv-th/ax}}{\bullet h_{10} : \Delta_{11}, []F_{12} \vdash \Delta_7, F_8} \text{hCut} \quad \frac{h_2 : \Delta_{11} \vdash \Delta_7, F_9, []F_{12}}{\bullet h_2 : \Delta_{11} \vdash \Delta_7, F_9} \text{ax/W} \quad \frac{h_{10} : \Delta_{11}, F_{12}, []F_{12} \vdash \Delta_7, F_9}{\bullet h_{10} : \Delta_{11}, []F_{12} \vdash \Delta_7, F_9} \text{inv-th/ax}}{\bullet h_{10} : \Delta_{11}, []F_{12} \vdash \Delta_7, F_9} \text{hCut} \\
- : \Delta_{11} \vdash \Delta_7, F_8 \quad - : \Delta_{11} \vdash \Delta_7, F_9 \quad \wedge_R \\
- : \Delta_{11} \vdash \Delta_7, F_8 \wedge F_9 \\
\frac{h_2 : \Delta_{13}, []F_{12} \vdash F_7, F_9, \Delta_8 \quad h_2 : \Delta_{13}, []F_{12} \vdash F_7, F_{10}, \Delta_8}{\bullet h_2 : \Delta_{13}, []F_{12} \vdash (\Delta_8, F_9 \wedge F_{10}), F_7} \wedge_R \quad \frac{h_{11} : F_7, F_{12}, \Delta_{13}, []F_{12} \vdash \Delta_8, F_9 \wedge F_{10}}{\bullet h_{11} : (\Delta_{13}, []F_{12}), F_7 \vdash \Delta_8, F_9 \wedge F_{10}} AT}{- : \Delta_{13}, []F_{12} \vdash \Delta_8, F_9 \wedge F_{10}} \text{Cut} \\
\rightsquigarrow \\
\frac{\frac{\bullet h_2 : \Delta_{13}, F_{12}, []F_{12} \vdash \Delta_8, F_7, F_9 \wedge F_{10}}{\bullet h_2 : \Delta_{13}, F_{12}, []F_{12} \vdash \Delta_8, F_9 \wedge F_{10}} \text{ax/W} \quad \frac{h_{11} : \Delta_{13}, F_{12}, F_7, []F_{12} \vdash \Delta_8, F_9 \wedge F_{10}}{\bullet h_{11} : (\Delta_{13}, F_{12}), F_7 \vdash \Delta_8, F_9 \wedge F_{10}} \text{ax/W}}{\bullet h_{11} : (\Delta_{13}, F_{12}), F_7 \vdash \Delta_8, F_9 \wedge F_{10}} \text{hCut} \\
- : \Delta_{13}, F_{12}, []F_{12} \vdash \Delta_8, F_9 \wedge F_{10} \quad AT \\
- : \Delta_{13}, []F_{12} \vdash \Delta_8, F_9 \wedge F_{10}
\end{array}$$

- Case rule \perp_L

$$\begin{array}{c}
\frac{\frac{h_1 : \perp, \Delta_{10} \vdash F_6, \Delta_9 \quad h_1 : \perp, \Delta_{10} \vdash F_7, \Delta_9}{\bullet h_1 : \perp, \Delta_{10} \vdash \Delta_9, F_6 \wedge F_7} \wedge_R \quad \frac{\bullet h_8 : (\perp, \Delta_{10}), F_6 \wedge F_7 \vdash \Delta_9}{\bullet h_8 : (\perp, \Delta_{10}), F_6 \wedge F_7 \vdash \Delta_9} \perp_L}{- : \perp, \Delta_{10} \vdash \Delta_9} \text{Cut} \\
\rightsquigarrow \\
- : \perp, \Delta_{10} \vdash \Delta_9 \quad \perp_L \\
\frac{h_2 : \Delta_{11} \vdash \perp, F_8, \Delta_7 \quad h_2 : \Delta_{11} \vdash \perp, F_9, \Delta_7}{\bullet h_2 : \Delta_{11} \vdash (\Delta_7, F_8 \wedge F_9), \perp} \wedge_R \quad \frac{\bullet h_{10} : \Delta_{11}, \perp \vdash \Delta_7, F_8 \wedge F_9}{\bullet h_{10} : \Delta_{11}, \perp \vdash \Delta_7, F_8 \wedge F_9} \perp_L}{- : \Delta_{11} \vdash \Delta_7, F_8 \wedge F_9} \text{Cut} \\
\rightsquigarrow \\
\frac{\frac{h_2 : \Delta_{11} \vdash \perp, \Delta_7, F_8}{\bullet h_2 : \Delta_{11} \vdash \perp, \Delta_7, F_8} \text{ax/W} \quad \frac{\bullet h_{10} : \perp, \Delta_{11} \vdash \Delta_7, F_8}{\bullet h_{10} : \perp, \Delta_{11} \vdash \Delta_7, F_8} \perp_L}{\bullet h_{10} : \perp, \Delta_{11} \vdash \Delta_7, F_8} \text{hCut} \quad \frac{h_2 : \Delta_{11} \vdash \perp, \Delta_7, F_9}{\bullet h_2 : \Delta_{11} \vdash \perp, \Delta_7, F_9} \text{ax/W} \quad \frac{\bullet h_{10} : \perp, \Delta_{11} \vdash \Delta_7, F_9}{\bullet h_{10} : \perp, \Delta_{11} \vdash \Delta_7, F_9} \perp_L}{\bullet h_{10} : \perp, \Delta_{11} \vdash \Delta_7, F_9} \text{hCut} \\
- : \Delta_{11} \vdash \Delta_7, F_8 \quad - : \Delta_{11} \vdash \Delta_7, F_9 \quad \wedge_R \\
- : \Delta_{11} \vdash \Delta_7, F_8 \wedge F_9 \\
\frac{h_2 : \perp, \Delta_{12} \vdash F_7, F_9, \Delta_8 \quad h_2 : \perp, \Delta_{12} \vdash F_7, F_{10}, \Delta_8}{\bullet h_2 : \perp, \Delta_{12} \vdash (\Delta_8, F_9 \wedge F_{10}), F_7} \wedge_R \quad \frac{\bullet h_{11} : (\perp, \Delta_{12}), F_7 \vdash \Delta_8, F_9 \wedge F_{10}}{\bullet h_{11} : (\perp, \Delta_{12}), F_7 \vdash \Delta_8, F_9 \wedge F_{10}} \perp_L}{- : \perp, \Delta_{12} \vdash \Delta_8, F_9 \wedge F_{10}} \text{Cut} \\
\rightsquigarrow \\
- : \perp, \Delta_{12} \vdash \Delta_8, F_9 \wedge F_{10} \quad \perp_L \\
- : \perp, \Delta_{12} \vdash \Delta_8, F_9 \wedge F_{10}
\end{array}$$

- Case rule I

$$\begin{array}{c}
\frac{h_1 : \Delta_{11}, p_9 \vdash F_6, \Delta_{10}, p_9 \quad h_1 : \Delta_{11}, p_9 \vdash F_7, \Delta_{10}, p_9}{\bullet h_1 : \Delta_{11}, p_9 \vdash (\Delta_{10}, p_9), F_6 \wedge F_7} \wedge_R \quad \frac{\bullet h_8 : (\Delta_{11}, p_9), F_6 \wedge F_7 \vdash \Delta_{10}, p_9}{- : \Delta_{11}, p_9 \vdash \Delta_{10}, p_9} I \\
\frac{}{\sim} \\
\frac{}{- : \Delta_{11}, p_9 \vdash \Delta_{10}, p_9} I \\
\frac{h_2 : \Delta_{10} \vdash p_{11}, F_7, \Delta_{12}, p_{11} \quad h_2 : \Delta_{10} \vdash p_{11}, F_8, \Delta_{12}, p_{11}}{\bullet h_2 : \Delta_{10} \vdash ((\Delta_{12}, p_{11}), F_7 \wedge F_8), p_{11}} \wedge_R \quad \frac{\bullet h_9 : \Delta_{10}, p_{11} \vdash (\Delta_{12}, p_{11}), F_7 \wedge F_8}{- : \Delta_{10} \vdash (\Delta_{12}, p_{11}), F_7 \wedge F_8} I \\
\frac{}{\sim} \\
\frac{h_2 : \Delta_{10} \vdash \Delta_{12}, F_7, p_{11}, p_{11}}{- : \Delta_{10} \vdash \Delta_{12}, F_7, p_{11}} \text{ax/W} \quad \frac{\bullet h_9 : \Delta_{10}, p_{11} \vdash \Delta_{12}, F_7, p_{11}}{- : \Delta_{10} \vdash \Delta_{12}, F_7, p_{11}} I \\
\frac{}{\sim} \\
\frac{h_2 : \Delta_{10} \vdash \Delta_{12}, F_8, p_{11}, p_{11}}{- : \Delta_{10} \vdash \Delta_{12}, F_8, p_{11}} \text{ax/W} \quad \frac{\bullet h_9 : \Delta_{10}, p_{11} \vdash \Delta_{12}, F_8, p_{11}}{- : \Delta_{10} \vdash \Delta_{12}, F_8, p_{11}} I \\
\frac{}{\sim} \\
\frac{}{- : \Delta_{10} \vdash \Delta_{12}, p_{11}, F_7 \wedge F_8} \wedge_R \\
\frac{h_2 : \Delta_{13}, p_{11} \vdash F_7, F_8, \Delta_{12}, p_{11} \quad h_2 : \Delta_{13}, p_{11} \vdash F_7, F_9, \Delta_{12}, p_{11}}{\bullet h_2 : \Delta_{13}, p_{11} \vdash ((\Delta_{12}, p_{11}), F_8 \wedge F_9), F_7} \wedge_R \quad \frac{\bullet h_{10} : (\Delta_{13}, p_{11}), F_7 \vdash (\Delta_{12}, p_{11}), F_8 \wedge F_9}{- : \Delta_{13}, p_{11} \vdash (\Delta_{12}, p_{11}), F_8 \wedge F_9} I \\
\frac{}{\sim} \\
\frac{}{- : \Delta_{13}, p_{11} \vdash \Delta_{12}, p_{11}, F_8 \wedge F_9} I
\end{array}$$

- Case rule \top_L

$$\begin{array}{c}
\frac{h_1 : \top, \Delta_{10} \vdash F_6, \Delta_9 \quad h_1 : \top, \Delta_{10} \vdash F_7, \Delta_9}{\bullet h_1 : \top, \Delta_{10} \vdash \Delta_9, F_6 \wedge F_7} \wedge_R \quad \frac{h_8 : \Delta_{10}, F_6 \wedge F_7 \vdash \Delta_9}{\bullet h_8 : (\top, \Delta_{10}), F_6 \wedge F_7 \vdash \Delta_9} \top_L \\
\frac{}{\sim} \\
\frac{}{- : \top, \Delta_{10} \vdash \Delta_9} \text{Cut} \\
\frac{}{\sim} \\
\frac{\bullet h_1 : \top, \Delta_{10} \vdash \Delta_9, F_6 \wedge F_7}{- : \top, \Delta_{10} \vdash \Delta_9} \text{ax/W} \quad \frac{h_8 : \top, \Delta_{10}, F_6 \wedge F_7 \vdash \Delta_9}{- : \top, \Delta_{10} \vdash \Delta_9} \text{ax/W} \\
\frac{}{\sim} \\
\frac{h_2 : \Delta_{11} \vdash \top, F_8, \Delta_7 \quad h_2 : \Delta_{11} \vdash \top, F_9, \Delta_7}{\bullet h_2 : \Delta_{11} \vdash (\Delta_7, F_8 \wedge F_9), \top} \wedge_R \quad \frac{h_{10} : \Delta_{11} \vdash \Delta_7, F_8 \wedge F_9}{\bullet h_{10} : \Delta_{11}, \top \vdash \Delta_7, F_8 \wedge F_9} \top_L \\
\frac{}{\sim} \\
\frac{}{- : \Delta_{11} \vdash \Delta_7, F_8 \wedge F_9} \text{Cut} \\
\frac{}{\sim} \\
\frac{}{- : \Delta_{11} \vdash \Delta_7, F_8 \wedge F_9} \text{ax/W} \\
\frac{h_2 : \top, \Delta_{12} \vdash F_7, F_9, \Delta_8 \quad h_2 : \top, \Delta_{12} \vdash F_7, F_{10}, \Delta_8}{\bullet h_2 : \top, \Delta_{12} \vdash (\Delta_8, F_9 \wedge F_{10}), F_7} \wedge_R \quad \frac{h_{11} : F_7, \Delta_{12} \vdash \Delta_8, F_9 \wedge F_{10}}{\bullet h_{11} : (\top, \Delta_{12}), F_7 \vdash \Delta_8, F_9 \wedge F_{10}} \top_L \\
\frac{}{\sim} \\
\frac{}{- : \top, \Delta_{12} \vdash \Delta_8, F_9 \wedge F_{10}} \text{Cut} \\
\frac{}{\sim} \\
\frac{\bullet h_2 : \top, \Delta_{12} \vdash \Delta_8, F_7, F_9 \wedge F_{10}}{- : \top, \Delta_{12} \vdash \Delta_8, F_9 \wedge F_{10}} \text{ax/W} \quad \frac{h_{11} : \top, \Delta_{12}, F_7 \vdash \Delta_8, F_9 \wedge F_{10}}{- : \top, \Delta_{12} \vdash \Delta_8, F_9 \wedge F_{10}} \text{ax/W} \\
\frac{}{\sim} \\
\frac{}{- : \top, \Delta_{12} \vdash \Delta_8, F_9 \wedge F_{10}} \text{hCut}
\end{array}$$

8.3 Status of \vee_R : OK

- Case rule \rightarrow_R

$$\begin{array}{c}
\frac{h_1 : \Delta_6 \vdash F_7, F_8, \Delta_{10}, F_{11} \rightarrow F_{12} \quad h_9 : F_{11}, \Delta_6, F_7 \vee F_8 \vdash F_{12}, \Delta_{10}}{\bullet h_1 : \Delta_6 \vdash (\Delta_{10}, F_{11} \rightarrow F_{12}), F_7 \vee F_8} \vee_R \quad \frac{\bullet h_9 : \Delta_6, F_7 \vee F_8 \vdash \Delta_{10}, F_{11} \rightarrow F_{12}}{- : \Delta_6 \vdash \Delta_{10}, F_{11} \rightarrow F_{12}} \rightarrow_R \\
\frac{}{\sim} \\
\frac{}{- : \Delta_6 \vdash \Delta_{10}, F_{11} \rightarrow F_{12}} \text{Cut} \\
\frac{}{\sim} \\
\frac{h_1 : \Delta_6, F_{11} \vdash \Delta_{10}, F_{12}, F_7, F_8}{\bullet h_1 : \Delta_6, F_{11} \vdash \Delta_{10}, F_{12}, F_7 \vee F_8} \text{inv-th/ax} \quad \frac{h_9 : \Delta_6, F_{11}, F_7 \vee F_8 \vdash \Delta_{10}, F_{12}}{- : \Delta_6, F_{11}, F_7 \vee F_8 \vdash \Delta_{10}, F_{12}} \text{ax/W} \\
\frac{}{\sim} \\
\frac{}{- : \Delta_6, F_{11} \vdash \Delta_{10}, F_{12}} \text{hCut} \\
\frac{}{\sim} \\
\frac{}{- : \Delta_6 \vdash \Delta_{10}, F_{11} \rightarrow F_{12}} \rightarrow_R
\end{array}$$

$$\frac{\frac{h_2 : \Delta_8 \vdash F_7, F_9, F_{10}, \Delta_{14}, F_{12} \rightarrow F_{13}}{\bullet h_2 : \Delta_8 \vdash ((\Delta_{14}, F_{12} \rightarrow F_{13}), F_9 \vee F_{10}), F_7} \vee_R \quad \frac{h_{11} : F_7, F_{12}, \Delta_8 \vdash F_{13}, \Delta_{14}, F_9 \vee F_{10}}{\bullet h_{11} : \Delta_8, F_7 \vdash (\Delta_{14}, F_{12} \rightarrow F_{13}), F_9 \vee F_{10}} \rightarrow_R}{- : \Delta_8 \vdash (\Delta_{14}, F_{12} \rightarrow F_{13}), F_9 \vee F_{10}} \text{Cut}$$

$$\frac{\frac{h_2 : \Delta_8, F_{12} \vdash \Delta_{14}, F_{10}, F_{13}, F_7, F_9}{\bullet h_2 : \Delta_8, F_{12} \vdash \Delta_{14}, F_{13}, F_7, F_9 \vee F_{10}} \text{inv-th/ax} \quad \frac{h_{11} : \Delta_8, F_{12}, F_7 \vdash \Delta_{14}, F_{13}, F_9 \vee F_{10}}{h_{11} : \Delta_8, F_{12}, F_7 \vdash \Delta_{14}, F_{13}, F_9 \vee F_{10}} \text{ax/W}}{- : \Delta_8, F_{12} \vdash \Delta_{14}, F_{13}, F_9 \vee F_{10}} \text{hCut}$$

$$\frac{- : \Delta_8, F_{12} \vdash \Delta_{14}, F_{13}, F_9 \vee F_{10}}{- : \Delta_8 \vdash \Delta_{14}, F_{12} \rightarrow F_{13}, F_9 \vee F_{10}} \rightarrow_R$$

- Case rule \wedge_R

$$\frac{\frac{h_1 : \Delta_6 \vdash F_7, F_8, \Delta_{10}, F_{11} \wedge F_{12}}{\bullet h_1 : \Delta_6 \vdash (\Delta_{10}, F_{11} \wedge F_{12}), F_7 \vee F_8} \vee_R \quad \frac{h_9 : \Delta_6, F_7 \vee F_8 \vdash F_{11}, \Delta_{10} \quad h_9 : \Delta_6, F_7 \vee F_8 \vdash F_{12}, \Delta_{10}}{\bullet h_9 : \Delta_6, F_7 \vee F_8 \vdash \Delta_{10}, F_{11} \wedge F_{12}} \wedge_R}{- : \Delta_6 \vdash \Delta_{10}, F_{11} \wedge F_{12}} \text{Cut}$$

$$\frac{\frac{h_1 : \Delta_6 \vdash \Delta_{10}, F_{11}, F_7, F_8}{\bullet h_1 : \Delta_6 \vdash \Delta_{10}, F_{11}, F_7 \vee F_8} \text{inv-th/ax} \quad \frac{h_9 : \Delta_6, F_7 \vee F_8 \vdash \Delta_{10}, F_{11}}{h_9 : \Delta_6, F_7 \vee F_8 \vdash \Delta_{10}, F_{11}} \text{ax/W}}{- : \Delta_6 \vdash \Delta_{10}, F_{11}} \text{hCut}$$

$$\frac{- : \Delta_6 \vdash \Delta_{10}, F_{11}}{- : \Delta_6 \vdash \Delta_{10}, F_{11} \wedge F_{12}} \wedge_R$$

$$\frac{\frac{h_2 : \Delta_8 \vdash F_7, F_9, F_{10}, \Delta_{14}, F_{12} \wedge F_{13}}{\bullet h_2 : \Delta_8 \vdash ((\Delta_{14}, F_{12} \wedge F_{13}), F_9 \vee F_{10}), F_7} \vee_R \quad \frac{h_{11} : F_7, \Delta_8 \vdash F_{12}, \Delta_{14}, F_9 \vee F_{10} \quad h_{11} : F_7, \Delta_8 \vdash F_{13}, \Delta_{14}, F_9 \vee F_{10}}{\bullet h_{11} : \Delta_8, F_7 \vdash (\Delta_{14}, F_{12} \wedge F_{13}), F_9 \vee F_{10}} \wedge_R}{- : \Delta_8 \vdash (\Delta_{14}, F_{12} \wedge F_{13}), F_9 \vee F_{10}} \text{Cut}$$

$$\frac{\frac{h_2 : \Delta_8 \vdash \Delta_{14}, F_{10}, F_7, F_9, F_{12} \wedge F_{13}}{\bullet h_2 : \Delta_8 \vdash \Delta_{14}, F_{10}, F_7, F_9, F_{12} \wedge F_{13}} \text{ax/W} \quad \frac{h_{11} : \Delta_8, F_7 \vdash \Delta_{14}, F_{10}, F_{12}, F_9}{\bullet h_{11} : \Delta_8, F_7 \vdash \Delta_{14}, F_{10}, F_9, F_{12} \wedge F_{13}} \text{inv-th/ax}}{- : \Delta_8 \vdash \Delta_{14}, F_{10}, F_9, F_{12} \wedge F_{13}} \text{hCut}$$

$$\frac{- : \Delta_8 \vdash \Delta_{14}, F_{10}, F_9, F_{12} \wedge F_{13}}{- : \Delta_8 \vdash \Delta_{14}, F_{12} \wedge F_{13}, F_9 \vee F_{10}} \vee_R$$

- Case rule \vee_R

$$\frac{\frac{h_1 : \Delta_6 \vdash F_7, F_8, \Delta_{10}, F_{11} \vee F_{12}}{\bullet h_1 : \Delta_6 \vdash (\Delta_{10}, F_{11} \vee F_{12}), F_7 \vee F_8} \vee_R \quad \frac{h_9 : \Delta_6, F_7 \vee F_8 \vdash F_{11}, F_{12}, \Delta_{10}}{\bullet h_9 : \Delta_6, F_7 \vee F_8 \vdash \Delta_{10}, F_{11} \vee F_{12}} \vee_R}{- : \Delta_6 \vdash \Delta_{10}, F_{11} \vee F_{12}} \text{Cut}$$

$$\frac{\frac{h_1 : \Delta_6 \vdash \Delta_{10}, F_{11}, F_{12}, F_7, F_8}{\bullet h_1 : \Delta_6 \vdash \Delta_{10}, F_{11}, F_{12}, F_7 \vee F_8} \text{inv-th/ax} \quad \frac{h_9 : \Delta_6, F_7 \vee F_8 \vdash \Delta_{10}, F_{11}, F_{12}}{h_9 : \Delta_6, F_7 \vee F_8 \vdash \Delta_{10}, F_{11}, F_{12}} \text{ax/W}}{- : \Delta_6 \vdash \Delta_{10}, F_{11}, F_{12}} \text{hCut}$$

$$\frac{- : \Delta_6 \vdash \Delta_{10}, F_{11}, F_{12}}{- : \Delta_6 \vdash \Delta_{10}, F_{11} \vee F_{12}} \vee_R$$

$$\frac{\frac{h_2 : \Delta_8 \vdash F_7, F_9, F_{10}, \Delta_{14}, F_{12} \vee F_{13}}{\bullet h_2 : \Delta_8 \vdash ((\Delta_{14}, F_{12} \vee F_{13}), F_9 \vee F_{10}), F_7} \vee_R \quad \frac{h_{11} : F_7, \Delta_8 \vdash F_{12}, F_{13}, \Delta_{14}, F_9 \vee F_{10}}{\bullet h_{11} : \Delta_8, F_7 \vdash (\Delta_{14}, F_{12} \vee F_{13}), F_9 \vee F_{10}} \vee_R}{- : \Delta_8 \vdash (\Delta_{14}, F_{12} \vee F_{13}), F_9 \vee F_{10}} \text{Cut}$$

$$\frac{\frac{h_2 : \Delta_8 \vdash \Delta_{14}, F_{10}, F_{12}, F_{13}, F_7, F_9}{\bullet h_2 : \Delta_8 \vdash \Delta_{14}, F_{12}, F_{13}, F_7, F_9 \vee F_{10}} \text{inv-th/ax} \quad \frac{h_{11} : \Delta_8, F_7 \vdash \Delta_{14}, F_{12}, F_{13}, F_9 \vee F_{10}}{h_{11} : \Delta_8, F_7 \vdash \Delta_{14}, F_{12}, F_{13}, F_9 \vee F_{10}} \text{ax/W}}{- : \Delta_8 \vdash \Delta_{14}, F_{12}, F_{13}, F_9 \vee F_{10}} \text{hCut}$$

$$\frac{- : \Delta_8 \vdash \Delta_{14}, F_{12}, F_{13}, F_9 \vee F_{10}}{- : \Delta_8 \vdash \Delta_{14}, F_{12} \vee F_{13}, F_9 \vee F_{10}} \vee_R$$

$$\frac{\frac{h_2 : \Delta_8 \vdash F_7, F_{11}, F_{12}, \Delta_{10}}{\bullet h_2 : \Delta_8 \vdash (\Delta_{10}, F_{11} \vee F_{12}), F_7} \vee_R \quad \frac{h_9 : F_7, \Delta_8 \vdash F_{11}, F_{12}, \Delta_{10}}{\bullet h_9 : \Delta_8, F_7 \vdash \Delta_{10}, F_{11} \vee F_{12}} \vee_R}{- : \Delta_8 \vdash \Delta_{10}, F_{11} \vee F_{12}} \text{Cut}$$

$$\frac{\frac{h_2 : \Delta_8 \vdash \Delta_{10}, F_{11}, F_{12}, F_7}{\bullet h_2 : \Delta_8 \vdash \Delta_{10}, F_{11}, F_{12}, F_7} \text{ax/W} \quad \frac{h_9 : \Delta_8, F_7 \vdash \Delta_{10}, F_{11}, F_{12}}{\bullet h_9 : \Delta_8, F_7 \vdash \Delta_{10}, F_{11}, F_{12}} \text{ax/W}}{- : \Delta_8 \vdash \Delta_{10}, F_{11}, F_{12}} \text{hCut}$$

$$\frac{- : \Delta_8 \vdash \Delta_{10}, F_{11}, F_{12}}{- : \Delta_8 \vdash \Delta_{10}, F_{11} \vee F_{12}} \vee_R$$

- Case rule \perp_R

$$\begin{array}{c}
\frac{h_1 : \Delta_6 \vdash F_7, F_8, \perp, \Delta_{10}}{\bullet h_1 : \Delta_6 \vdash (\perp, \Delta_{10}), F_7 \vee F_8} \vee_R \quad \frac{h_9 : \Delta_6, F_7 \vee F_8 \vdash \Delta_{10}}{\bullet h_9 : \Delta_6, F_7 \vee F_8 \vdash \perp, \Delta_{10}} \perp_R \\
\hline
- : \Delta_6 \vdash \perp, \Delta_{10} \quad \text{Cut} \\
\hline
\frac{}{\bullet h_1 : \Delta_6 \vdash \perp, \Delta_{10}, F_7 \vee F_8} \text{ax/W} \quad \frac{h_9 : \Delta_6, F_7 \vee F_8 \vdash \perp, \Delta_{10}}{\bullet h_9 : \Delta_6, F_7 \vee F_8 \vdash \perp, \Delta_{10}} \text{ax/W} \\
\hline
- : \Delta_6 \vdash \perp, \Delta_{10} \quad \text{hCut} \\
\hline
\frac{h_2 : \Delta_8 \vdash F_7, F_9, F_{10}, \perp, \Delta_{12}}{\bullet h_2 : \Delta_8 \vdash ((\perp, \Delta_{12}), F_9 \vee F_{10}), F_7} \vee_R \quad \frac{h_{11} : F_7, \Delta_8 \vdash \Delta_{12}, F_9 \vee F_{10}}{\bullet h_{11} : \Delta_8, F_7 \vdash (\perp, \Delta_{12}), F_9 \vee F_{10}} \perp_R \\
\hline
- : \Delta_8 \vdash (\perp, \Delta_{12}), F_9 \vee F_{10} \quad \text{Cut} \\
\hline
\frac{}{\bullet h_2 : \Delta_8 \vdash \perp, \Delta_{12}, F_7, F_9 \vee F_{10}} \text{ax/W} \quad \frac{h_{11} : \Delta_8, F_7 \vdash \perp, \Delta_{12}, F_9 \vee F_{10}}{\bullet h_{11} : \Delta_8, F_7 \vdash \perp, \Delta_{12}, F_9 \vee F_{10}} \text{ax/W} \\
\hline
- : \Delta_8 \vdash \perp, \Delta_{12}, F_9 \vee F_{10} \quad \text{hCut}
\end{array}$$

- Case rule \top_R

$$\begin{array}{c}
\frac{h_1 : \Delta_6 \vdash F_7, F_8, \top, \Delta_{10}}{\bullet h_1 : \Delta_6 \vdash (\top, \Delta_{10}), F_7 \vee F_8} \vee_R \quad \frac{}{\bullet h_9 : \Delta_6, F_7 \vee F_8 \vdash \top, \Delta_{10}} \top_R \\
\hline
- : \Delta_6 \vdash \top, \Delta_{10} \quad \text{Cut} \\
\hline
\frac{}{\bullet h_1 : \Delta_6 \vdash \top, \Delta_{10}} \top_R \\
\hline
\frac{h_2 : \Delta_8 \vdash F_7, F_9, F_{10}, \top, \Delta_{12}}{\bullet h_2 : \Delta_8 \vdash ((\top, \Delta_{12}), F_9 \vee F_{10}), F_7} \vee_R \quad \frac{}{\bullet h_{11} : \Delta_8, F_7 \vdash (\top, \Delta_{12}), F_9 \vee F_{10}} \top_R \\
\hline
- : \Delta_8 \vdash (\top, \Delta_{12}), F_9 \vee F_{10} \quad \text{Cut} \\
\hline
\frac{}{\bullet h_2 : \Delta_8 \vdash \top, \Delta_{12}, F_7, F_9 \vee F_{10}} \top_R \\
\hline
- : \Delta_8 \vdash \top, \Delta_{12}, F_9 \vee F_{10}
\end{array}$$

- Case rule $A4$

$$\begin{array}{c}
\frac{h_1 : \Box \Gamma_9, \Delta_{12} \vdash F_6, F_7, \Delta_{10}, \Box F_{11}}{\bullet h_1 : \Box \Gamma_9, \Delta_{12} \vdash (\Delta_{10}, \Box F_{11}), F_6 \vee F_7} \vee_R \quad \frac{h_8 : \Box \Gamma_9 \vdash F_{11}}{\bullet h_8 : (\Box \Gamma_9, \Delta_{12}), F_6 \vee F_7 \vdash \Delta_{10}, \Box F_{11}} A4 \\
\hline
- : \Box \Gamma_9, \Delta_{12} \vdash \Delta_{10}, \Box F_{11} \quad \text{Cut} \\
\hline
\frac{}{\bullet h_1 : \Box \Gamma_9 \vdash F_{11}} \text{ax/W} \\
\hline
- : \Delta_{12}, \Box \Gamma_9 \vdash \Delta_{10}, \Box F_{11} \quad A4 \\
\hline
\frac{h_2 : \Box \Gamma_{14}, \Delta_{11} \vdash \Box F_7, F_8, F_9, \Delta_{13}, \Box F_{12}}{\bullet h_2 : \Box \Gamma_{14}, \Delta_{11} \vdash ((\Delta_{13}, \Box F_{12}), F_8 \vee F_9), \Box F_7} \vee_R \quad \frac{h_{10} : \Box \Gamma_{14}, \Box F_7 \vdash F_{12}}{\bullet h_{10} : (\Box \Gamma_{14}, \Delta_{11}), \Box F_7 \vdash (\Delta_{13}, \Box F_{12}), F_8 \vee F_9} A4 \\
\hline
- : \Box \Gamma_{14}, \Delta_{11} \vdash (\Delta_{13}, \Box F_{12}), F_8 \vee F_9 \quad \text{Cut} \\
\hline
\frac{}{\bullet h_2 : \Box \Gamma_{14} \vdash \Box F_7, \Delta_{13}, F_8, F_9, \Box F_{12}} \text{ax/W} \quad \frac{h_{10} : \Box F_7, \Box \Gamma_{14} \vdash F_{12}}{\bullet h_{10} : \Box F_7, \Delta_{11}, \Box \Gamma_{14} \vdash \Delta_{13}, F_8, F_9, \Box F_{12}} A4 \\
\hline
- : \Delta_{11}, \Box \Gamma_{14} \vdash \Delta_{13}, F_8, F_9, \Box F_{12} \quad \text{hCut} \\
\hline
\frac{}{\bullet h_2 : \Box \Gamma_{14} \vdash \Delta_{13}, \Box F_{12}, F_8 \vee F_9} \vee_R \\
\hline
\frac{h_2 : \Box \Gamma_{11}, \Delta_{14} \vdash F_7, F_8, F_9, \Delta_{13}, \Box F_{12}}{\bullet h_2 : \Box \Gamma_{11}, \Delta_{14} \vdash ((\Delta_{13}, \Box F_{12}), F_8 \vee F_9), F_7} \vee_R \quad \frac{h_{10} : \Box \Gamma_{11} \vdash F_{12}}{\bullet h_{10} : (\Box \Gamma_{11}, \Delta_{14}), F_7 \vdash (\Delta_{13}, \Box F_{12}), F_8 \vee F_9} A4 \\
\hline
- : \Box \Gamma_{11}, \Delta_{14} \vdash (\Delta_{13}, \Box F_{12}), F_8 \vee F_9 \quad \text{Cut} \\
\hline
\frac{}{\bullet h_2 : \Box \Gamma_{11} \vdash F_{12}} \text{ax/W} \\
\hline
- : \Delta_{14}, \Box \Gamma_{11} \vdash \Delta_{13}, \Box F_{12}, F_8 \vee F_9 \quad A4
\end{array}$$

- Case rule \rightarrow_L

$$\begin{array}{c}
\frac{\frac{h_1 : \Delta_{12}, F_9 \rightarrow F_{10} \vdash F_6, F_7, \Delta_{11}}{\bullet h_1 : \Delta_{12}, F_9 \rightarrow F_{10} \vdash \Delta_{11}, F_6 \vee F_7} \vee_R \quad \frac{h_8 : \Delta_{12}, F_6 \vee F_7 \vdash F_9, \Delta_{11} \quad h_8 : F_{10}, \Delta_{12}, F_6 \vee F_7 \vdash \Delta_{11}}{\bullet h_8 : (\Delta_{12}, F_9 \rightarrow F_{10}), F_6 \vee F_7 \vdash \Delta_{11}} \rightarrow_L}{- : \Delta_{12}, F_9 \rightarrow F_{10} \vdash \Delta_{11}} \text{Cut} \\
\rightsquigarrow \\
\frac{\frac{h_1 : \Delta_{12} \vdash \Delta_{11}, F_6, F_7, F_9}{\bullet h_1 : \Delta_{12} \vdash \Delta_{11}, F_9, F_6 \vee F_7} \vee_R \quad \frac{h_8 : \Delta_{12}, F_6 \vee F_7 \vdash \Delta_{11}, F_9}{- : \Delta_{12} \vdash \Delta_{11}, F_9} \text{ax/w} \quad \frac{h_1 : \Delta_{12}, F_{10} \vdash \Delta_{11}, F_6, F_7}{\bullet h_1 : \Delta_{12}, F_{10} \vdash \Delta_{11}, F_6 \vee F_7} \vee_R \quad \frac{h_8 : \Delta_{12}, F_{10}, F_6 \vee F_7 \vdash \Delta_{11}}{- : \Delta_{12}, F_{10} \vdash \Delta_{11}} \text{ax/w}}{- : \Delta_{12}, F_9 \rightarrow F_{10} \vdash \Delta_{11}} \text{hCut} \\
\rightsquigarrow \\
\frac{\frac{h_2 : \Delta_{11} \vdash F_{12} \rightarrow F_{13}, F_8, F_9, \Delta_7}{\bullet h_2 : \Delta_{11} \vdash (\Delta_7, F_8 \vee F_9), F_{12} \rightarrow F_{13}} \vee_R \quad \frac{h_{10} : \Delta_{11} \vdash F_{12}, \Delta_7, F_8 \vee F_9 \quad h_{10} : F_{13}, \Delta_{11} \vdash \Delta_7, F_8 \vee F_9}{\bullet h_{10} : \Delta_{11}, F_{12} \rightarrow F_{13} \vdash \Delta_7, F_8 \vee F_9} \rightarrow_L}{- : \Delta_{11} \vdash \Delta_7, F_8 \vee F_9} \text{Cut} \\
\rightsquigarrow \\
\frac{\frac{h_2 : \Delta_{11} \vdash \Delta_7, F_8, F_9, F_{12} \rightarrow F_{13}}{- : \Delta_{11} \vdash \Delta_7, F_8, F_9} \text{ax/w} \quad \frac{h_{10} : \Delta_{11} \vdash \Delta_7, F_{12}, F_8, F_9}{\bullet h_{10} : \Delta_{11}, F_{12} \rightarrow F_{13} \vdash \Delta_7, F_8, F_9} \text{inv-th/ax} \quad \frac{h_{10} : \Delta_{11}, F_{13} \vdash \Delta_7, F_8, F_9}{- : \Delta_{11}, F_{13} \vdash \Delta_7, F_8, F_9} \text{inv-th/ax}}{- : \Delta_{11} \vdash \Delta_7, F_8 \vee F_9} \text{hCut} \\
\rightsquigarrow \\
\frac{\frac{h_2 : \Delta_{14}, F_{12} \rightarrow F_{13} \vdash F_7, F_9, F_{10}, \Delta_8}{\bullet h_2 : \Delta_{14}, F_{12} \rightarrow F_{13} \vdash (\Delta_8, F_9 \vee F_{10}), F_7} \vee_R \quad \frac{h_{11} : F_7, \Delta_{14} \vdash F_{12}, \Delta_8, F_9 \vee F_{10} \quad h_{11} : F_7, F_{13}, \Delta_{14} \vdash \Delta_8, F_9 \vee F_{10}}{\bullet h_{11} : (\Delta_{14}, F_{12} \rightarrow F_{13}), F_7 \vdash \Delta_8, F_9 \vee F_{10}} \rightarrow_L}{- : \Delta_{14}, F_{12} \rightarrow F_{13} \vdash \Delta_8, F_9 \vee F_{10}} \text{Cut} \\
\rightsquigarrow \\
\frac{\frac{h_2 : \Delta_{14}, F_{12} \rightarrow F_{13} \vdash \Delta_8, F_{10}, F_7, F_9}{- : \Delta_{14}, F_{12} \rightarrow F_{13} \vdash \Delta_8, F_{10}, F_7, F_9} \text{ax/w} \quad \frac{h_{11} : \Delta_{14}, F_7 \vdash \Delta_8, F_{10}, F_{12}, F_9}{\bullet h_{11} : \Delta_{14}, F_7, F_{12} \rightarrow F_{13} \vdash \Delta_8, F_{10}, F_9} \text{inv-th/ax} \quad \frac{h_{11} : \Delta_{14}, F_{13}, F_7 \vdash \Delta_8, F_{10}, F_9}{- : \Delta_{14}, F_{13}, F_7 \vdash \Delta_8, F_{10}, F_9} \text{inv-th/ax}}{- : \Delta_{14}, F_{12} \rightarrow F_{13} \vdash \Delta_8, F_9 \vee F_{10}} \text{hCut}
\end{array}$$

- Case rule \wedge_L

$$\begin{array}{c}
\frac{\frac{h_1 : \Delta_{12}, F_9 \wedge F_{10} \vdash F_6, F_7, \Delta_{11}}{\bullet h_1 : \Delta_{12}, F_9 \wedge F_{10} \vdash \Delta_{11}, F_6 \vee F_7} \vee_R \quad \frac{h_8 : F_9, F_{10}, \Delta_{12}, F_6 \vee F_7 \vdash \Delta_{11}}{\bullet h_8 : (\Delta_{12}, F_9 \wedge F_{10}), F_6 \vee F_7 \vdash \Delta_{11}} \wedge_L}{- : \Delta_{12}, F_9 \wedge F_{10} \vdash \Delta_{11}} \text{Cut} \\
\rightsquigarrow \\
\frac{\frac{h_1 : \Delta_{12}, F_{10}, F_9 \vdash \Delta_{11}, F_6, F_7}{\bullet h_1 : \Delta_{12}, F_{10}, F_9 \vdash \Delta_{11}, F_6 \vee F_7} \vee_R \quad \frac{h_8 : \Delta_{12}, F_{10}, F_9, F_6 \vee F_7 \vdash \Delta_{11}}{- : \Delta_{12}, F_{10}, F_9 \vdash \Delta_{11}} \text{ax/w}}{- : \Delta_{12}, F_9 \wedge F_{10} \vdash \Delta_{11}} \text{hCut} \\
\rightsquigarrow \\
\frac{\frac{h_2 : \Delta_{11} \vdash F_{12} \wedge F_{13}, F_8, F_9, \Delta_7}{\bullet h_2 : \Delta_{11} \vdash (\Delta_7, F_8 \vee F_9), F_{12} \wedge F_{13}} \vee_R \quad \frac{h_{10} : F_{12}, F_{13}, \Delta_{11} \vdash \Delta_7, F_8 \vee F_9}{\bullet h_{10} : \Delta_{11}, F_{12} \wedge F_{13} \vdash \Delta_7, F_8 \vee F_9} \wedge_L}{- : \Delta_{11} \vdash \Delta_7, F_8 \vee F_9} \text{Cut} \\
\rightsquigarrow \\
\frac{\frac{h_2 : \Delta_{11} \vdash \Delta_7, F_8, F_9, F_{12} \wedge F_{13}}{- : \Delta_{11} \vdash \Delta_7, F_8, F_9} \text{ax/w} \quad \frac{h_{10} : \Delta_{11}, F_{12}, F_{13} \vdash \Delta_7, F_8, F_9}{\bullet h_{10} : \Delta_{11}, F_{12} \wedge F_{13} \vdash \Delta_7, F_8, F_9} \text{inv-th/ax} \quad \frac{h_{10} : \Delta_{11}, F_{12} \wedge F_{13} \vdash \Delta_7, F_8, F_9}{- : \Delta_{11}, F_{12} \wedge F_{13} \vdash \Delta_7, F_8, F_9} \wedge_L}{- : \Delta_{11} \vdash \Delta_7, F_8 \vee F_9} \text{hCut} \\
\rightsquigarrow \\
\frac{\frac{h_2 : \Delta_{14}, F_{12} \wedge F_{13} \vdash F_7, F_9, F_{10}, \Delta_8}{\bullet h_2 : \Delta_{14}, F_{12} \wedge F_{13} \vdash (\Delta_8, F_9 \vee F_{10}), F_7} \vee_R \quad \frac{h_{11} : F_7, F_{12}, F_{13}, \Delta_{14} \vdash \Delta_8, F_9 \vee F_{10}}{\bullet h_{11} : (\Delta_{14}, F_{12} \wedge F_{13}), F_7 \vdash \Delta_8, F_9 \vee F_{10}} \wedge_L}{- : \Delta_{14}, F_{12} \wedge F_{13} \vdash \Delta_8, F_9 \vee F_{10}} \text{Cut} \\
\rightsquigarrow \\
\frac{\frac{h_2 : \Delta_{14}, F_{12} \wedge F_{13} \vdash \Delta_8, F_{10}, F_7, F_9}{- : \Delta_{14}, F_{12} \wedge F_{13} \vdash \Delta_8, F_{10}, F_7, F_9} \text{ax/w} \quad \frac{h_{11} : \Delta_{14}, F_{12}, F_{13}, F_7 \vdash \Delta_8, F_{10}, F_9}{\bullet h_{11} : \Delta_{14}, F_{12} \wedge F_{13} \vdash \Delta_8, F_{10}, F_9} \text{inv-th/ax} \quad \frac{h_{11} : \Delta_{14}, F_{12} \wedge F_{13} \vdash \Delta_8, F_{10}, F_9}{- : \Delta_{14}, F_{12} \wedge F_{13} \vdash \Delta_8, F_{10}, F_9} \wedge_L}{- : \Delta_{14}, F_{12} \wedge F_{13} \vdash \Delta_8, F_9 \vee F_{10}} \text{hCut}
\end{array}$$

- Case rule \vee_L

$$\begin{array}{c}
\frac{\frac{h_1 : \Delta_{12}, F_9 \vee F_{10} \vdash F_6, F_7, \Delta_{11}}{\bullet h_1 : \Delta_{12}, F_9 \vee F_{10} \vdash \Delta_{11}, F_6 \vee F_7} \vee_R \quad \frac{h_8 : F_9, \Delta_{12}, F_6 \vee F_7 \vdash \Delta_{11} \quad h_8 : F_{10}, \Delta_{12}, F_6 \vee F_7 \vdash \Delta_{11}}{\bullet h_8 : (\Delta_{12}, F_9 \vee F_{10}), F_6 \vee F_7 \vdash \Delta_{11}} \vee_L}{- : \Delta_{12}, F_9 \vee F_{10} \vdash \Delta_{11}} \text{Cut} \\
\rightsquigarrow \\
\frac{\frac{h_1 : \Delta_{12}, F_9 \vdash \Delta_{11}, F_6, F_7}{\bullet h_1 : \Delta_{12}, F_9 \vdash \Delta_{11}, F_6 \vee F_7} \vee_R \quad \frac{\text{inv-th/ax}}{h_8 : \Delta_{12}, F_9, F_6 \vee F_7 \vdash \Delta_{11}} \quad \frac{\text{ax/W}}{h_8 : \Delta_{12}, F_9, F_6 \vee F_7 \vdash \Delta_{11}} \text{hCut}}{- : \Delta_{12}, F_9 \vdash \Delta_{11}} \\
\frac{- : \Delta_{12}, F_9 \vdash \Delta_{11} \quad \frac{\text{inv-th/ax}}{h_1 : \Delta_{12}, F_{10} \vdash \Delta_{11}, F_6, F_7} \vee_R \quad \frac{\text{ax/W}}{\bullet h_1 : \Delta_{12}, F_{10} \vdash \Delta_{11}, F_6 \vee F_7} \vee_R \quad \frac{h_8 : \Delta_{12}, F_{10}, F_6 \vee F_7 \vdash \Delta_{11}}{- : \Delta_{12}, F_{10} \vdash \Delta_{11}} \vee_L}{- : \Delta_{12}, F_9 \vee F_{10} \vdash \Delta_{11}} \text{hCut} \\
\rightsquigarrow \\
\frac{\frac{h_1 : \Delta_7 \vdash F_8, F_9, \Delta_{10}}{\bullet h_1 : \Delta_7 \vdash \Delta_{10}, F_8 \vee F_9} \vee_R \quad \frac{h_6 : F_8, \Delta_7 \vdash \Delta_{10} \quad h_6 : F_9, \Delta_7 \vdash \Delta_{10}}{\bullet h_6 : \Delta_7, F_8 \vee F_9 \vdash \Delta_{10}} \vee_L}{- : \Delta_7 \vdash \Delta_{10}} \text{Cut} \\
\rightsquigarrow \\
\frac{- : \Delta_7 \vdash \Delta_{10}, F_8, F_9}{- : \Delta_7 \vdash \Delta_{10}, F_8} \text{ax/W} \quad \frac{- : \Delta_7, F_9 \vdash \Delta_{10}, F_8}{- : \Delta_7 \vdash \Delta_{10}} \text{sCut} \quad \frac{- : \Delta_7, F_8 \vdash \Delta_{10}}{- : \Delta_7 \vdash \Delta_{10}} \text{sCut} \\
\rightsquigarrow \\
\frac{\frac{h_2 : \Delta_{11} \vdash F_{12} \vee F_{13}, F_8, F_9, \Delta_7}{\bullet h_2 : \Delta_{11} \vdash (\Delta_7, F_8 \vee F_9), F_{12} \vee F_{13}} \vee_R \quad \frac{h_{10} : F_{12}, \Delta_{11} \vdash \Delta_7, F_8 \vee F_9 \quad h_{10} : F_{13}, \Delta_{11} \vdash \Delta_7, F_8 \vee F_9}{\bullet h_{10} : \Delta_{11}, F_{12} \vee F_{13} \vdash \Delta_7, F_8 \vee F_9} \vee_L}{- : \Delta_{11} \vdash \Delta_7, F_8 \vee F_9} \text{Cut} \\
\rightsquigarrow \\
\frac{h_2 : \Delta_{11} \vdash \Delta_7, F_8, F_9, F_{12} \vee F_{13}}{- : \Delta_{11} \vdash \Delta_7, F_8, F_9} \text{ax/W} \quad \frac{\frac{h_{10} : \Delta_{11}, F_{12} \vdash \Delta_7, F_8, F_9}{\bullet h_{10} : \Delta_{11}, F_{12} \vee F_{13} \vdash \Delta_7, F_8, F_9} \text{inv-th/ax}}{- : \Delta_{11} \vdash \Delta_7, F_8, F_9} \text{hCut} \\
\frac{- : \Delta_{11} \vdash \Delta_7, F_8, F_9}{- : \Delta_{11} \vdash \Delta_7, F_8 \vee F_9} \vee_R \\
\rightsquigarrow \\
\frac{\frac{h_2 : \Delta_{14}, F_{12} \vee F_{13} \vdash F_7, F_9, F_{10}, \Delta_8}{\bullet h_2 : \Delta_{14}, F_{12} \vee F_{13} \vdash (\Delta_8, F_9 \vee F_{10}), F_7} \vee_R \quad \frac{h_{11} : F_7, F_{12}, \Delta_{14} \vdash \Delta_8, F_9 \vee F_{10} \quad h_{11} : F_7, F_{13}, \Delta_{14} \vdash \Delta_8, F_9 \vee F_{10}}{\bullet h_{11} : (\Delta_{14}, F_{12} \vee F_{13}), F_7 \vdash \Delta_8, F_9 \vee F_{10}} \vee_L}{- : \Delta_{14}, F_{12} \vee F_{13} \vdash \Delta_8, F_9 \vee F_{10}} \text{Cut} \\
\rightsquigarrow \\
\frac{h_2 : \Delta_{14}, F_{12} \vee F_{13} \vdash \Delta_8, F_{10}, F_7, F_9}{- : \Delta_{14}, F_{12} \vee F_{13} \vdash \Delta_8, F_{10}, F_7, F_9} \text{ax/W} \quad \frac{\frac{h_{11} : \Delta_{14}, F_{12}, F_7 \vdash \Delta_8, F_{10}, F_9}{\bullet h_{11} : \Delta_{14}, F_7, F_{12} \vee F_{13} \vdash \Delta_8, F_{10}, F_9} \text{inv-th/ax}}{- : \Delta_{14}, F_{12} \vee F_{13} \vdash \Delta_8, F_{10}, F_9} \text{hCut} \\
\frac{- : \Delta_{14}, F_{12} \vee F_{13} \vdash \Delta_8, F_{10}, F_9}{- : \Delta_{14}, F_{12} \vee F_{13} \vdash \Delta_8, F_9 \vee F_{10}} \vee_R
\end{array}$$

• Case rule AT

$$\begin{array}{c}
\frac{\frac{h_1 : \Delta_{11}, [F_9 \vdash F_6, F_7, \Delta_{10}]}{\bullet h_1 : \Delta_{11}, [F_9 \vdash \Delta_{10}, F_6 \vee F_7]} \vee_R \quad \frac{h_8 : F_9, \Delta_{11}, [F_9, F_6 \vee F_7 \vdash \Delta_{10}]}{\bullet h_8 : (\Delta_{11}, [F_9]), F_6 \vee F_7 \vdash \Delta_{10}} AT}{- : \Delta_{11}, [F_9 \vdash \Delta_{10}] \text{Cut}} \\
\rightsquigarrow \\
\frac{\bullet h_1 : \Delta_{11}, F_9, [F_9 \vdash \Delta_{10}, F_6 \vee F_7]}{- : \Delta_{11}, F_9, [F_9 \vdash \Delta_{10}]} \text{ax/W} \quad \frac{h_8 : \Delta_{11}, F_9, [F_9, F_6 \vee F_7 \vdash \Delta_{10}]}{- : \Delta_{11}, [F_9 \vdash \Delta_{10}]} \text{hCut} \\
\frac{- : \Delta_{11}, F_9, [F_9 \vdash \Delta_{10}]}{- : \Delta_{11}, [F_9 \vdash \Delta_{10}]} AT \\
\rightsquigarrow \\
\frac{\frac{h_2 : \Delta_{11} \vdash [F_{12}, F_8, F_9, \Delta_7]}{\bullet h_2 : \Delta_{11} \vdash (\Delta_7, F_8 \vee F_9), [F_{12}]} \vee_R \quad \frac{h_{10} : F_{12}, \Delta_{11}, [F_{12} \vdash \Delta_7, F_8 \vee F_9]}{\bullet h_{10} : \Delta_{11}, [F_{12} \vdash \Delta_7, F_8 \vee F_9]} AT}{- : \Delta_{11} \vdash \Delta_7, F_8 \vee F_9} \text{Cut} \\
\rightsquigarrow \\
\frac{h_2 : \Delta_{11} \vdash \Delta_7, F_8, F_9, [F_{12}]}{- : \Delta_{11} \vdash \Delta_7, F_8, F_9} \text{ax/W} \quad \frac{\frac{h_{10} : \Delta_{11}, F_{12}, [F_{12} \vdash \Delta_7, F_8, F_9]}{\bullet h_{10} : \Delta_{11}, [F_{12} \vdash \Delta_7, F_8, F_9]} \text{inv-th/ax}}{- : \Delta_{11} \vdash \Delta_7, F_8, F_9} AT \\
\frac{- : \Delta_{11} \vdash \Delta_7, F_8, F_9}{- : \Delta_{11} \vdash \Delta_7, F_8 \vee F_9} \vee_R \\
\rightsquigarrow \\
\frac{\frac{h_2 : \Delta_{13}, [F_{12} \vdash F_7, F_9, F_{10}, \Delta_8]}{\bullet h_2 : \Delta_{13}, [F_{12} \vdash (\Delta_8, F_9 \vee F_{10}), F_7]} \vee_R \quad \frac{h_{11} : F_7, F_{12}, \Delta_{13}, [F_{12} \vdash \Delta_8, F_9 \vee F_{10}]}{\bullet h_{11} : (\Delta_{13}, [F_{12}]), F_7 \vdash \Delta_8, F_9 \vee F_{10}} AT}{- : \Delta_{13}, [F_{12} \vdash \Delta_8, F_9 \vee F_{10}] \text{Cut}} \\
\rightsquigarrow \\
\frac{\bullet h_2 : \Delta_{13}, F_{12}, [F_{12} \vdash \Delta_8, F_7, F_9 \vee F_{10}]}{- : \Delta_{13}, F_{12}, [F_{12} \vdash \Delta_8, F_9 \vee F_{10}]} \text{ax/W} \quad \frac{h_{11} : \Delta_{13}, F_{12}, F_7, [F_{12} \vdash \Delta_8, F_9 \vee F_{10}]}{- : \Delta_{13}, [F_{12} \vdash \Delta_8, F_9 \vee F_{10}]} \text{hCut} \\
\frac{- : \Delta_{13}, F_{12}, [F_{12} \vdash \Delta_8, F_9 \vee F_{10}]}{- : \Delta_{13}, [F_{12} \vdash \Delta_8, F_9 \vee F_{10}]} AT
\end{array}$$

- Case rule \perp_L

$$\begin{array}{c}
\frac{\frac{h_1 : \perp, \Delta_{10} \vdash F_6, F_7, \Delta_9}{\bullet h_1 : \perp, \Delta_{10} \vdash \Delta_9, F_6 \vee F_7} \vee_R \quad \frac{}{\bullet h_8 : (\perp, \Delta_{10}), F_6 \vee F_7 \vdash \Delta_9} \perp_L}{\frac{}{- : \perp, \Delta_{10} \vdash \Delta_9} \text{Cut}} \\
\frac{}{\perp : \perp, \Delta_{10} \vdash \Delta_9} \sim \\
\frac{}{\perp : \perp, \Delta_{10} \vdash \Delta_9} \perp_L \\
\\
\frac{\frac{h_2 : \Delta_{11} \vdash \perp, F_8, F_9, \Delta_7}{\bullet h_2 : \Delta_{11} \vdash (\Delta_7, F_8 \vee F_9), \perp} \vee_R \quad \frac{}{\bullet h_{10} : \Delta_{11}, \perp \vdash \Delta_7, F_8 \vee F_9} \perp_L}{\frac{}{- : \Delta_{11} \vdash \Delta_7, F_8 \vee F_9} \text{Cut}} \\
\frac{}{\perp : \Delta_{11} \vdash \Delta_7, F_8 \vee F_9} \sim \\
\frac{\frac{h_2 : \Delta_{11} \vdash \perp, \Delta_7, F_8, F_9}{\bullet h_2 : \Delta_{11} \vdash \perp, \Delta_7, F_8, F_9} \text{ax/W} \quad \frac{}{\bullet h_{10} : \perp, \Delta_{11} \vdash \Delta_7, F_8, F_9} \perp_L}{\frac{}{\perp : \Delta_{11} \vdash \Delta_7, F_8, F_9} \text{hCut}} \\
\frac{}{\perp : \Delta_{11} \vdash \Delta_7, F_8 \vee F_9} \vee_R \\
\\
\frac{\frac{h_2 : \perp, \Delta_{12} \vdash F_7, F_9, F_{10}, \Delta_8}{\bullet h_2 : \perp, \Delta_{12} \vdash (\Delta_8, F_9 \vee F_{10}), F_7} \vee_R \quad \frac{}{\bullet h_{11} : (\perp, \Delta_{12}), F_7 \vdash \Delta_8, F_9 \vee F_{10}} \perp_L}{\frac{}{- : \perp, \Delta_{12} \vdash \Delta_8, F_9 \vee F_{10}} \text{Cut}} \\
\frac{}{\perp : \perp, \Delta_{12} \vdash \Delta_8, F_9 \vee F_{10}} \sim \\
\frac{}{\perp : \perp, \Delta_{12} \vdash \Delta_8, F_9 \vee F_{10}} \perp_L
\end{array}$$

- Case rule I

$$\begin{array}{c}
\frac{\frac{h_1 : \Delta_{11}, p_9 \vdash F_6, F_7, \Delta_{10}, p_9}{\bullet h_1 : \Delta_{11}, p_9 \vdash (\Delta_{10}, p_9), F_6 \vee F_7} \vee_R \quad \frac{}{\bullet h_8 : (\Delta_{11}, p_9), F_6 \vee F_7 \vdash \Delta_{10}, p_9} I}{\frac{}{- : \Delta_{11}, p_9 \vdash \Delta_{10}, p_9} \text{Cut}} \\
\frac{}{\perp : \Delta_{11}, p_9 \vdash \Delta_{10}, p_9} \sim \\
\frac{}{\perp : \Delta_{11}, p_9 \vdash \Delta_{10}, p_9} I \\
\\
\frac{\frac{h_2 : \Delta_{10} \vdash p_{11}, F_7, F_8, \Delta_{12}, p_{11}}{\bullet h_2 : \Delta_{10} \vdash ((\Delta_{12}, p_{11}), F_7 \vee F_8), p_{11}} \vee_R \quad \frac{}{\bullet h_9 : \Delta_{10}, p_{11} \vdash (\Delta_{12}, p_{11}), F_7 \vee F_8} I}{\frac{}{- : \Delta_{10} \vdash (\Delta_{12}, p_{11}), F_7 \vee F_8} \text{Cut}} \\
\frac{}{\perp : \Delta_{10} \vdash (\Delta_{12}, p_{11}), F_7 \vee F_8} \sim \\
\frac{\frac{h_2 : \Delta_{10} \vdash \Delta_{12}, F_7, F_8, p_{11}, p_{11}}{\bullet h_2 : \Delta_{10} \vdash \Delta_{12}, F_7, F_8, p_{11}, p_{11}} \text{ax/W} \quad \frac{}{\bullet h_9 : \Delta_{10}, p_{11} \vdash \Delta_{12}, F_7, F_8, p_{11}} I}{\frac{}{\perp : \Delta_{10} \vdash \Delta_{12}, F_7, F_8, p_{11}} \text{hCut}} \\
\frac{}{\perp : \Delta_{10} \vdash \Delta_{12}, p_{11}, F_7 \vee F_8} \vee_R \\
\\
\frac{\frac{h_2 : \Delta_{13}, p_{11} \vdash F_7, F_8, F_9, \Delta_{12}, p_{11}}{\bullet h_2 : \Delta_{13}, p_{11} \vdash ((\Delta_{12}, p_{11}), F_8 \vee F_9), F_7} \vee_R \quad \frac{}{\bullet h_{10} : (\Delta_{13}, p_{11}), F_7 \vdash (\Delta_{12}, p_{11}), F_8 \vee F_9} I}{\frac{}{- : \Delta_{13}, p_{11} \vdash (\Delta_{12}, p_{11}), F_8 \vee F_9} \text{Cut}} \\
\frac{}{\perp : \Delta_{13}, p_{11} \vdash (\Delta_{12}, p_{11}), F_8 \vee F_9} \sim \\
\frac{}{\perp : \Delta_{13}, p_{11} \vdash \Delta_{12}, p_{11}, F_8 \vee F_9} I
\end{array}$$

- Case rule \top_L

$$\begin{array}{c}
\frac{\frac{h_1 : \top, \Delta_{10} \vdash F_6, F_7, \Delta_9}{\bullet h_1 : \top, \Delta_{10} \vdash \Delta_9, F_6 \vee F_7} \vee_R \quad \frac{h_8 : \Delta_{10}, F_6 \vee F_7 \vdash \Delta_9}{\bullet h_8 : (\top, \Delta_{10}), F_6 \vee F_7 \vdash \Delta_9} \top_L}{\frac{}{- : \top, \Delta_{10} \vdash \Delta_9} \text{Cut}} \\
\frac{}{\perp : \top, \Delta_{10} \vdash \Delta_9} \sim \\
\frac{\frac{h_1 : \top, \Delta_{10} \vdash \Delta_9, F_6 \vee F_7}{\bullet h_1 : \top, \Delta_{10} \vdash \Delta_9, F_6 \vee F_7} \text{ax/W} \quad \frac{h_8 : \top, \Delta_{10}, F_6 \vee F_7 \vdash \Delta_9}{\bullet h_8 : \top, \Delta_{10}, F_6 \vee F_7 \vdash \Delta_9} \text{ax/W}}{\frac{}{\perp : \top, \Delta_{10} \vdash \Delta_9} \text{hCut}} \\
\\
\frac{\frac{h_2 : \Delta_{11} \vdash \top, F_8, F_9, \Delta_7}{\bullet h_2 : \Delta_{11} \vdash (\Delta_7, F_8 \vee F_9), \top} \vee_R \quad \frac{h_{10} : \Delta_{11} \vdash \Delta_7, F_8 \vee F_9}{\bullet h_{10} : \Delta_{11}, \top \vdash \Delta_7, F_8 \vee F_9} \top_L}{\frac{}{- : \Delta_{11} \vdash \Delta_7, F_8 \vee F_9} \text{Cut}} \\
\frac{}{\perp : \Delta_{11} \vdash \Delta_7, F_8 \vee F_9} \sim \\
\frac{}{\perp : \Delta_{11} \vdash \Delta_7, F_8 \vee F_9} \text{ax/W}
\end{array}$$

$$\begin{array}{c}
\frac{h_2 : \top, \Delta_{12} \vdash F_7, F_9, F_{10}, \Delta_8}{\bullet h_2 : \top, \Delta_{12} \vdash (\Delta_8, F_9 \vee F_{10}), F_7} \vee_R \quad \frac{h_{11} : F_7, \Delta_{12} \vdash \Delta_8, F_9 \vee F_{10}}{\bullet h_{11} : (\top, \Delta_{12}), F_7 \vdash \Delta_8, F_9 \vee F_{10}} \top_L \\
\hline
- : \top, \Delta_{12} \vdash \Delta_8, F_9 \vee F_{10} \quad \text{Cut} \\
\hline
\sim \\
\frac{\bullet h_2 : \top, \Delta_{12} \vdash \Delta_8, F_7, F_9 \vee F_{10}}{- : \top, \Delta_{12} \vdash \Delta_8, F_9 \vee F_{10}} \text{ax/W} \quad \frac{h_{11} : \top, \Delta_{12}, F_7 \vdash \Delta_8, F_9 \vee F_{10}}{- : \top, \Delta_{12} \vdash \Delta_8, F_9 \vee F_{10}} \text{ax/W} \\
\hline
- : \top, \Delta_{12} \vdash \Delta_8, F_9 \vee F_{10} \quad \text{hCut}
\end{array}$$

8.4 Status of \perp_R : OK

- Case rule \rightarrow_R

$$\begin{array}{c}
\frac{h_1 : \Delta_4 \vdash \Delta_6, F_7 \rightarrow F_8}{\bullet h_1 : \Delta_4 \vdash (\Delta_6, F_7 \rightarrow F_8), \perp} \perp_R \quad \frac{h_5 : \perp, F_7, \Delta_4 \vdash F_8, \Delta_6}{\bullet h_5 : \Delta_4, \perp \vdash \Delta_6, F_7 \rightarrow F_8} \rightarrow_R \\
\hline
- : \Delta_4 \vdash \Delta_6, F_7 \rightarrow F_8 \quad \text{Cut} \\
\hline
\sim \\
\frac{- : \Delta_4 \vdash \Delta_6, F_7 \rightarrow F_8}{- : \Delta_4 \vdash \Delta_6, F_7 \rightarrow F_8} \text{ax/W} \\
\hline
\frac{h_2 : \Delta_6 \vdash F_5, \Delta_{10}, F_8 \rightarrow F_9}{\bullet h_2 : \Delta_6 \vdash (\perp, \Delta_{10}, F_8 \rightarrow F_9), F_5} \perp_R \quad \frac{h_7 : F_5, F_8, \Delta_6 \vdash \perp, F_9, \Delta_{10}}{\bullet h_7 : \Delta_6, F_5 \vdash \perp, \Delta_{10}, F_8 \rightarrow F_9} \rightarrow_R \\
\hline
- : \Delta_6 \vdash \perp, \Delta_{10}, F_8 \rightarrow F_9 \quad \text{Cut} \\
\hline
\sim \\
\frac{h_2 : \Delta_6 \vdash \perp, \Delta_{10}, F_5, F_8 \rightarrow F_9}{- : \Delta_6 \vdash \perp, \Delta_{10}, F_8 \rightarrow F_9} \text{ax/W} \quad \frac{\bullet h_7 : \Delta_6, F_5 \vdash \perp, \Delta_{10}, F_8 \rightarrow F_9}{- : \Delta_6 \vdash \perp, \Delta_{10}, F_8 \rightarrow F_9} \text{ax/W} \\
\hline
- : \Delta_6 \vdash \perp, \Delta_{10}, F_8 \rightarrow F_9 \quad \text{hCut}
\end{array}$$

- Case rule \wedge_R

$$\begin{array}{c}
\frac{h_1 : \Delta_4 \vdash \Delta_6, F_7 \wedge F_8}{\bullet h_1 : \Delta_4 \vdash (\Delta_6, F_7 \wedge F_8), \perp} \perp_R \quad \frac{h_5 : \perp, \Delta_4 \vdash F_7, \Delta_6 \quad h_5 : \perp, \Delta_4 \vdash F_8, \Delta_6}{\bullet h_5 : \Delta_4, \perp \vdash \Delta_6, F_7 \wedge F_8} \wedge_R \\
\hline
- : \Delta_4 \vdash \Delta_6, F_7 \wedge F_8 \quad \text{Cut} \\
\hline
\sim \\
\frac{- : \Delta_4 \vdash \Delta_6, F_7 \wedge F_8}{- : \Delta_4 \vdash \Delta_6, F_7 \wedge F_8} \text{ax/W} \\
\hline
\frac{h_2 : \Delta_6 \vdash F_5, \Delta_{10}, F_8 \wedge F_9}{\bullet h_2 : \Delta_6 \vdash (\perp, \Delta_{10}, F_8 \wedge F_9), F_5} \perp_R \quad \frac{h_7 : F_5, \Delta_6 \vdash \perp, F_8, \Delta_{10} \quad h_7 : F_5, \Delta_6 \vdash \perp, F_9, \Delta_{10}}{\bullet h_7 : \Delta_6, F_5 \vdash \perp, \Delta_{10}, F_8 \wedge F_9} \wedge_R \\
\hline
- : \Delta_6 \vdash \perp, \Delta_{10}, F_8 \wedge F_9 \quad \text{Cut} \\
\hline
\sim \\
\frac{h_2 : \Delta_6 \vdash \perp, \Delta_{10}, F_5, F_8 \wedge F_9}{- : \Delta_6 \vdash \perp, \Delta_{10}, F_8 \wedge F_9} \text{ax/W} \quad \frac{\bullet h_7 : \Delta_6, F_5 \vdash \perp, \Delta_{10}, F_8 \wedge F_9}{- : \Delta_6 \vdash \perp, \Delta_{10}, F_8 \wedge F_9} \text{ax/W} \\
\hline
- : \Delta_6 \vdash \perp, \Delta_{10}, F_8 \wedge F_9 \quad \text{hCut}
\end{array}$$

- Case rule \vee_R

$$\begin{array}{c}
\frac{h_1 : \Delta_4 \vdash \Delta_6, F_7 \vee F_8}{\bullet h_1 : \Delta_4 \vdash (\Delta_6, F_7 \vee F_8), \perp} \perp_R \quad \frac{h_5 : \perp, \Delta_4 \vdash F_7, F_8, \Delta_6}{\bullet h_5 : \Delta_4, \perp \vdash \Delta_6, F_7 \vee F_8} \vee_R \\
\hline
- : \Delta_4 \vdash \Delta_6, F_7 \vee F_8 \quad \text{Cut} \\
\hline
\sim \\
\frac{- : \Delta_4 \vdash \Delta_6, F_7 \vee F_8}{- : \Delta_4 \vdash \Delta_6, F_7 \vee F_8} \text{ax/W} \\
\hline
\frac{h_2 : \Delta_6 \vdash F_5, \Delta_{10}, F_8 \vee F_9}{\bullet h_2 : \Delta_6 \vdash (\perp, \Delta_{10}, F_8 \vee F_9), F_5} \perp_R \quad \frac{h_7 : F_5, \Delta_6 \vdash \perp, F_8, F_9, \Delta_{10}}{\bullet h_7 : \Delta_6, F_5 \vdash \perp, \Delta_{10}, F_8 \vee F_9} \vee_R \\
\hline
- : \Delta_6 \vdash \perp, \Delta_{10}, F_8 \vee F_9 \quad \text{Cut} \\
\hline
\sim \\
\frac{h_2 : \Delta_6 \vdash \perp, \Delta_{10}, F_5, F_8 \vee F_9}{- : \Delta_6 \vdash \perp, \Delta_{10}, F_8 \vee F_9} \text{ax/W} \quad \frac{\bullet h_7 : \Delta_6, F_5 \vdash \perp, \Delta_{10}, F_8 \vee F_9}{- : \Delta_6 \vdash \perp, \Delta_{10}, F_8 \vee F_9} \text{ax/W} \\
\hline
- : \Delta_6 \vdash \perp, \Delta_{10}, F_8 \vee F_9 \quad \text{hCut}
\end{array}$$

- Case rule \perp_R

$$\begin{array}{c}
\frac{h_1 : \Delta_4 \vdash \perp, \Delta_6}{\bullet h_1 : \Delta_4 \vdash (\perp, \Delta_6), \perp} \perp_R \quad \frac{h_5 : \perp, \Delta_4 \vdash \Delta_6}{\bullet h_5 : \Delta_4, \perp \vdash \perp, \Delta_6} \perp_R \\
\hline
- : \Delta_4 \vdash \perp, \Delta_6 \quad \text{Cut} \\
\hline
\sim \\
\frac{- : \Delta_4 \vdash \perp, \Delta_6}{- : \Delta_4 \vdash \perp, \Delta_6} \text{ax/W}
\end{array}$$

$$\begin{array}{c}
\frac{h_2 : \Delta_6 \vdash F_5, \Delta_8}{\bullet h_2 : \Delta_6 \vdash (\perp, \Delta_8), F_5} \perp_R \quad \frac{h_7 : F_5, \Delta_6 \vdash \Delta_8}{\bullet h_7 : \Delta_6, F_5 \vdash \perp, \Delta_8} \perp_R \\
\hline
- : \Delta_6 \vdash \perp, \Delta_8 \quad \text{Cut} \\
\hline
\sim\!\!\sim \\
\frac{h_2 : \Delta_6 \vdash \perp, \Delta_8, F_5}{- : \Delta_6 \vdash \perp, \Delta_8} \text{ax/W} \quad \frac{\bullet h_7 : \Delta_6, F_5 \vdash \perp, \Delta_8}{\text{hCut}} \text{ax/W}
\end{array}$$

- Case rule \top_R

$$\begin{array}{c}
\frac{h_1 : \Delta_4 \vdash \top, \Delta_6}{\bullet h_1 : \Delta_4 \vdash (\top, \Delta_6), \perp} \perp_R \quad \frac{}{\bullet h_5 : \Delta_4, \perp \vdash \top, \Delta_6} \top_R \\
\hline
- : \Delta_4 \vdash \top, \Delta_6 \quad \text{Cut} \\
\hline
\sim\!\!\sim \\
- : \Delta_4 \vdash \top, \Delta_6 \quad \top_R \\
\hline
\frac{h_2 : \Delta_6 \vdash F_5, \top, \Delta_8}{\bullet h_2 : \Delta_6 \vdash (\perp, \top, \Delta_8), F_5} \perp_R \quad \frac{}{\bullet h_7 : \Delta_6, F_5 \vdash \perp, \top, \Delta_8} \top_R \\
\hline
- : \Delta_6 \vdash \perp, \top, \Delta_8 \quad \text{Cut} \\
\hline
\sim\!\!\sim \\
- : \Delta_6 \vdash \perp, \top, \Delta_8 \quad \top_R
\end{array}$$

- Case rule $A4$

$$\begin{array}{c}
\frac{h_1 : \Box \Gamma_5, \Delta_8 \vdash \Delta_6, [\Box F_7]}{\bullet h_1 : \Box \Gamma_5, \Delta_8 \vdash (\Delta_6, [\Box F_7]), \perp} \perp_R \quad \frac{h_4 : \Box \Gamma_5 \vdash F_7}{\bullet h_4 : (\Box \Gamma_5, \Delta_8), \perp \vdash \Delta_6, [\Box F_7]} A4 \\
\hline
- : \Box \Gamma_5, \Delta_8 \vdash \Delta_6, [\Box F_7] \quad \text{Cut} \\
\hline
\sim\!\!\sim \\
- : \Delta_8, \Box \Gamma_5 \vdash \Delta_6, [\Box F_7] \quad \text{ax/W} \\
\hline
\frac{h_2 : \Box \Gamma_{10}, \Delta_7 \vdash \Box F_5, \Delta_9, [\Box F_8]}{\bullet h_2 : \Box \Gamma_{10}, \Delta_7 \vdash (\perp, \Delta_9, [\Box F_8]), \Box F_5} \perp_R \quad \frac{h_6 : \Box \Gamma_{10}, \Box F_5 \vdash F_8}{\bullet h_6 : (\Box \Gamma_{10}, \Delta_7), \Box F_5 \vdash \perp, \Delta_9, [\Box F_8]} A4 \\
\hline
- : \Box \Gamma_{10}, \Delta_7 \vdash \perp, \Delta_9, [\Box F_8] \quad \text{Cut} \\
\hline
\sim\!\!\sim \\
\frac{h_2 : \Delta_7, \Box \Gamma_{10} \vdash \perp, \Box F_5, \Delta_9, [\Box F_8]}{- : \Delta_7, \Box \Gamma_{10} \vdash \perp, \Delta_9, [\Box F_8]} \text{ax/W} \quad \frac{\bullet h_6 : \Box F_5, \Delta_7, \Box \Gamma_{10} \vdash \perp, \Delta_9, [\Box F_8]}{\text{hCut}} \text{ax/W} \\
\hline
\frac{h_2 : \Box \Gamma_7, \Delta_{10} \vdash F_5, \Delta_9, [\Box F_8]}{\bullet h_2 : \Box \Gamma_7, \Delta_{10} \vdash (\perp, \Delta_9, [\Box F_8]), F_5} \perp_R \quad \frac{h_6 : \Box \Gamma_7 \vdash F_8}{\bullet h_6 : (\Box \Gamma_7, \Delta_{10}), F_5 \vdash \perp, \Delta_9, [\Box F_8]} A4 \\
\hline
- : \Box \Gamma_7, \Delta_{10} \vdash \perp, \Delta_9, [\Box F_8] \quad \text{Cut} \\
\hline
\sim\!\!\sim \\
\frac{- : \Box \Gamma_7 \vdash F_8}{- : \Delta_{10}, \Box \Gamma_7 \vdash \perp, \Delta_9, [\Box F_8]} \text{ax/W} \quad A4
\end{array}$$

- Case rule \rightarrow_L

$$\begin{array}{c}
\frac{h_1 : \Delta_8, F_5 \rightarrow F_6 \vdash \Delta_7}{\bullet h_1 : \Delta_8, F_5 \rightarrow F_6 \vdash \Delta_7, \perp} \perp_R \quad \frac{h_4 : \perp, \Delta_8 \vdash F_5, \Delta_7 \quad h_4 : \perp, F_6, \Delta_8 \vdash \Delta_7}{\bullet h_4 : (\Delta_8, F_5 \rightarrow F_6), \perp \vdash \Delta_7} \rightarrow_L \\
\hline
- : \Delta_8, F_5 \rightarrow F_6 \vdash \Delta_7 \quad \text{Cut} \\
\hline
\sim\!\!\sim \\
- : \Delta_8, F_5 \rightarrow F_6 \vdash \Delta_7 \quad \text{ax/W} \\
\hline
\frac{h_2 : \Delta_7 \vdash F_8 \rightarrow F_9, \Delta_5}{\bullet h_2 : \Delta_7 \vdash (\perp, \Delta_5), F_8 \rightarrow F_9} \perp_R \quad \frac{h_6 : \Delta_7 \vdash \perp, F_8, \Delta_5 \quad h_6 : F_9, \Delta_7 \vdash \perp, \Delta_5}{\bullet h_6 : \Delta_7, F_8 \rightarrow F_9 \vdash \perp, \Delta_5} \rightarrow_L \\
\hline
- : \Delta_7 \vdash \perp, \Delta_5 \quad \text{Cut} \\
\hline
\sim\!\!\sim \\
\frac{h_2 : \Delta_7 \vdash \perp, \Delta_5, F_8 \rightarrow F_9}{- : \Delta_7 \vdash \perp, \Delta_5} \text{ax/W} \quad \frac{\bullet h_6 : \Delta_7, F_8 \rightarrow F_9 \vdash \perp, \Delta_5}{\text{hCut}} \text{ax/W}
\end{array}$$

$$\begin{array}{c}
\frac{h_2 : \Delta_{10}, F_8 \rightarrow F_9 \vdash F_5, \Delta_6}{\bullet h_2 : \Delta_{10}, F_8 \rightarrow F_9 \vdash (\perp, \Delta_6), F_5} \perp_R \quad \frac{h_7 : F_5, \Delta_{10} \vdash \perp, F_8, \Delta_6 \quad h_7 : F_5, F_9, \Delta_{10} \vdash \perp, \Delta_6}{\bullet h_7 : (\Delta_{10}, F_8 \rightarrow F_9), F_5 \vdash \perp, \Delta_6} \rightarrow_L \\
\hline
- : \Delta_{10}, F_8 \rightarrow F_9 \vdash \perp, \Delta_6 \quad \text{Cut} \\
\hline
\frac{}{\sim} \\
\hline
\frac{h_2 : \Delta_{10}, F_8 \rightarrow F_9 \vdash \perp, \Delta_6, F_5}{- : \Delta_{10}, F_8 \rightarrow F_9 \vdash \perp, \Delta_6} \text{ax/W} \quad \frac{\bullet h_7 : \Delta_{10}, F_5, F_8 \rightarrow F_9 \vdash \perp, \Delta_6}{h_7 : \Delta_{10}, F_5, F_8 \rightarrow F_9 \vdash \perp, \Delta_6} \text{ax/W} \\
\hline
- : \Delta_{10}, F_8 \rightarrow F_9 \vdash \perp, \Delta_6 \quad \text{hCut}
\end{array}$$

- Case rule \wedge_L

$$\begin{array}{c}
\frac{h_1 : \Delta_8, F_5 \wedge F_6 \vdash \Delta_7}{\bullet h_1 : \Delta_8, F_5 \wedge F_6 \vdash \Delta_7, \perp} \perp_R \quad \frac{h_4 : \perp, F_5, F_6, \Delta_8 \vdash \Delta_7}{\bullet h_4 : (\Delta_8, F_5 \wedge F_6), \perp \vdash \Delta_7} \wedge_L \\
\hline
- : \Delta_8, F_5 \wedge F_6 \vdash \Delta_7 \quad \text{Cut} \\
\hline
\frac{}{\sim} \\
\hline
- : \Delta_8, F_5 \wedge F_6 \vdash \Delta_7 \quad \text{ax/W} \\
\hline
\frac{h_2 : \Delta_7 \vdash F_8 \wedge F_9, \Delta_5}{\bullet h_2 : \Delta_7 \vdash (\perp, \Delta_5), F_8 \wedge F_9} \perp_R \quad \frac{h_6 : F_8, F_9, \Delta_7 \vdash \perp, \Delta_5}{\bullet h_6 : \Delta_7, F_8 \wedge F_9 \vdash \perp, \Delta_5} \wedge_L \\
\hline
- : \Delta_7 \vdash \perp, \Delta_5 \quad \text{Cut} \\
\hline
\frac{}{\sim} \\
\hline
\frac{h_2 : \Delta_7 \vdash \perp, \Delta_5, F_8 \wedge F_9}{- : \Delta_7 \vdash \perp, \Delta_5} \text{ax/W} \quad \frac{\bullet h_6 : \Delta_7, F_8 \wedge F_9 \vdash \perp, \Delta_5}{h_6 : \Delta_7, F_8 \wedge F_9 \vdash \perp, \Delta_5} \text{ax/W} \\
\hline
- : \Delta_7 \vdash \perp, \Delta_5 \quad \text{hCut} \\
\hline
\frac{h_2 : \Delta_{10}, F_8 \wedge F_9 \vdash F_5, \Delta_6}{\bullet h_2 : \Delta_{10}, F_8 \wedge F_9 \vdash (\perp, \Delta_6), F_5} \perp_R \quad \frac{h_7 : F_5, F_8, F_9, \Delta_{10} \vdash \perp, \Delta_6}{\bullet h_7 : (\Delta_{10}, F_8 \wedge F_9), F_5 \vdash \perp, \Delta_6} \wedge_L \\
\hline
- : \Delta_{10}, F_8 \wedge F_9 \vdash \perp, \Delta_6 \quad \text{Cut} \\
\hline
\frac{}{\sim} \\
\hline
\frac{h_2 : \Delta_{10}, F_8 \wedge F_9 \vdash \perp, \Delta_6, F_5}{- : \Delta_{10}, F_8 \wedge F_9 \vdash \perp, \Delta_6} \text{ax/W} \quad \frac{\bullet h_7 : \Delta_{10}, F_5, F_8 \wedge F_9 \vdash \perp, \Delta_6}{h_7 : \Delta_{10}, F_5, F_8 \wedge F_9 \vdash \perp, \Delta_6} \text{ax/W} \\
\hline
- : \Delta_{10}, F_8 \wedge F_9 \vdash \perp, \Delta_6 \quad \text{hCut}
\end{array}$$

- Case rule \vee_L

$$\begin{array}{c}
\frac{h_1 : \Delta_8, F_5 \vee F_6 \vdash \Delta_7}{\bullet h_1 : \Delta_8, F_5 \vee F_6 \vdash \Delta_7, \perp} \perp_R \quad \frac{h_4 : \perp, F_5, \Delta_8 \vdash \Delta_7 \quad h_4 : \perp, F_6, \Delta_8 \vdash \Delta_7}{\bullet h_4 : (\Delta_8, F_5 \vee F_6), \perp \vdash \Delta_7} \vee_L \\
\hline
- : \Delta_8, F_5 \vee F_6 \vdash \Delta_7 \quad \text{Cut} \\
\hline
\frac{}{\sim} \\
\hline
- : \Delta_8, F_5 \vee F_6 \vdash \Delta_7 \quad \text{ax/W} \\
\hline
\frac{h_2 : \Delta_7 \vdash F_8 \vee F_9, \Delta_5}{\bullet h_2 : \Delta_7 \vdash (\perp, \Delta_5), F_8 \vee F_9} \perp_R \quad \frac{h_6 : F_8, \Delta_7 \vdash \perp, \Delta_5 \quad h_6 : F_9, \Delta_7 \vdash \perp, \Delta_5}{\bullet h_6 : \Delta_7, F_8 \vee F_9 \vdash \perp, \Delta_5} \vee_L \\
\hline
- : \Delta_7 \vdash \perp, \Delta_5 \quad \text{Cut} \\
\hline
\frac{}{\sim} \\
\hline
\frac{h_2 : \Delta_7 \vdash \perp, \Delta_5, F_8 \vee F_9}{- : \Delta_7 \vdash \perp, \Delta_5} \text{ax/W} \quad \frac{\bullet h_6 : \Delta_7, F_8 \vee F_9 \vdash \perp, \Delta_5}{h_6 : \Delta_7, F_8 \vee F_9 \vdash \perp, \Delta_5} \text{ax/W} \\
\hline
- : \Delta_7 \vdash \perp, \Delta_5 \quad \text{hCut} \\
\hline
\frac{h_2 : \Delta_{10}, F_8 \vee F_9 \vdash F_5, \Delta_6}{\bullet h_2 : \Delta_{10}, F_8 \vee F_9 \vdash (\perp, \Delta_6), F_5} \perp_R \quad \frac{h_7 : F_5, F_8, \Delta_{10} \vdash \perp, \Delta_6 \quad h_7 : F_5, F_9, \Delta_{10} \vdash \perp, \Delta_6}{\bullet h_7 : (\Delta_{10}, F_8 \vee F_9), F_5 \vdash \perp, \Delta_6} \vee_L \\
\hline
- : \Delta_{10}, F_8 \vee F_9 \vdash \perp, \Delta_6 \quad \text{Cut} \\
\hline
\frac{}{\sim} \\
\hline
\frac{h_2 : \Delta_{10}, F_8 \vee F_9 \vdash \perp, \Delta_6, F_5}{- : \Delta_{10}, F_8 \vee F_9 \vdash \perp, \Delta_6} \text{ax/W} \quad \frac{\bullet h_7 : \Delta_{10}, F_5, F_8 \vee F_9 \vdash \perp, \Delta_6}{h_7 : \Delta_{10}, F_5, F_8 \vee F_9 \vdash \perp, \Delta_6} \text{ax/W} \\
\hline
- : \Delta_{10}, F_8 \vee F_9 \vdash \perp, \Delta_6 \quad \text{hCut}
\end{array}$$

- Case rule AT

$$\begin{array}{c}
\frac{h_1 : \Delta_7, \Box F_5 \vdash \Delta_6}{\bullet h_1 : \Delta_7, \Box F_5 \vdash \Delta_6, \perp} \perp_R \quad \frac{h_4 : \perp, F_5, \Delta_7, \Box F_5 \vdash \Delta_6}{\bullet h_4 : (\Delta_7, \Box F_5), \perp \vdash \Delta_6} AT \\
\hline
- : \Delta_7, \Box F_5 \vdash \Delta_6 \quad \text{Cut} \\
\hline
\frac{}{\sim} \\
\hline
- : \Delta_7, \Box F_5 \vdash \Delta_6 \quad \text{ax/W}
\end{array}$$

$$\begin{array}{c}
\frac{h_2 : \Delta_7 \vdash \Box F_8, \Delta_5}{\bullet h_2 : \Delta_7 \vdash (\perp, \Delta_5), \Box F_8} \perp_R \quad \frac{h_6 : F_8, \Delta_7, \Box F_8 \vdash \perp, \Delta_5}{\bullet h_6 : \Delta_7, \Box F_8 \vdash \perp, \Delta_5} AT \\
\hline
- : \Delta_7 \vdash \perp, \Delta_5 \quad \text{Cut} \\
\hline
\frac{\frac{h_2 : \Delta_7 \vdash \perp, \Delta_5, \Box F_8}{- : \Delta_7 \vdash \perp, \Delta_5} \text{ax/W} \quad \frac{\bullet h_6 : \Delta_7, \Box F_8 \vdash \perp, \Delta_5}{\bullet h_6 : \Delta_7, \Box F_8 \vdash \perp, \Delta_5} \text{ax/W}}{- : \Delta_7 \vdash \perp, \Delta_5} \text{hCut} \\
\hline
\frac{h_2 : \Delta_9, \Box F_8 \vdash F_5, \Delta_6}{\bullet h_2 : \Delta_9, \Box F_8 \vdash (\perp, \Delta_6), F_5} \perp_R \quad \frac{h_7 : F_5, F_8, \Delta_9, \Box F_8 \vdash \perp, \Delta_6}{\bullet h_7 : (\Delta_9, \Box F_8), F_5 \vdash \perp, \Delta_6} AT \\
\hline
- : \Delta_9, \Box F_8 \vdash \perp, \Delta_6 \quad \text{Cut} \\
\hline
\frac{\frac{h_2 : \Delta_9, \Box F_8 \vdash \perp, \Delta_6, F_5}{- : \Delta_9, \Box F_8 \vdash \perp, \Delta_6} \text{ax/W} \quad \frac{\bullet h_7 : (\Delta_9, \Box F_8), F_5 \vdash \perp, \Delta_6}{\bullet h_7 : (\Delta_9, \Box F_8), F_5 \vdash \perp, \Delta_6} \text{ax/W}}{- : \Delta_9, \Box F_8 \vdash \perp, \Delta_6} \text{hCut}
\end{array}$$

- Case rule \perp_L

$$\begin{array}{c}
\frac{h_1 : \Delta_5 \vdash \Delta_6}{\bullet h_1 : \Delta_5 \vdash \Delta_6, \perp} \perp_R \quad \frac{}{\bullet h_4 : \Delta_5, \perp \vdash \Delta_6} \perp_L \\
\hline
- : \Delta_5 \vdash \Delta_6 \quad \text{Cut} \\
\hline
\frac{}{- : \Delta_5 \vdash \Delta_6} \text{ax/W} \\
\hline
\frac{h_2 : \Delta_7 \vdash \perp, \Delta_5}{\bullet h_2 : \Delta_7 \vdash (\perp, \Delta_5), \perp} \perp_R \quad \frac{}{\bullet h_6 : \Delta_7, \perp \vdash \perp, \Delta_5} \perp_L \\
\hline
- : \Delta_7 \vdash \perp, \Delta_5 \quad \text{Cut} \\
\hline
\frac{}{- : \Delta_7 \vdash \perp, \Delta_5} \text{ax/W} \\
\hline
\frac{h_2 : \perp, \Delta_8 \vdash F_5, \Delta_6}{\bullet h_2 : \perp, \Delta_8 \vdash (\perp, \Delta_6), F_5} \perp_R \quad \frac{}{\bullet h_7 : (\perp, \Delta_8), F_5 \vdash \perp, \Delta_6} \perp_L \\
\hline
- : \perp, \Delta_8 \vdash \perp, \Delta_6 \quad \text{Cut} \\
\hline
\frac{}{- : \perp, \Delta_8 \vdash \perp, \Delta_6} \perp_L
\end{array}$$

- Case rule I

$$\begin{array}{c}
\frac{h_1 : \Delta_7, p_5 \vdash \Delta_6, p_5}{\bullet h_1 : \Delta_7, p_5 \vdash (\Delta_6, p_5), \perp} \perp_R \quad \frac{}{\bullet h_4 : (\Delta_7, p_5), \perp \vdash \Delta_6, p_5} I \\
\hline
- : \Delta_7, p_5 \vdash \Delta_6, p_5 \quad \text{Cut} \\
\hline
\frac{}{- : \Delta_7, p_5 \vdash \Delta_6, p_5} I \\
\hline
\frac{h_2 : \Delta_6 \vdash p_7, \Delta_8, p_7}{\bullet h_2 : \Delta_6 \vdash (\perp, \Delta_8, p_7), p_7} \perp_R \quad \frac{}{\bullet h_5 : \Delta_6, p_7 \vdash \perp, \Delta_8, p_7} I \\
\hline
- : \Delta_6 \vdash \perp, \Delta_8, p_7 \quad \text{Cut} \\
\hline
\frac{\frac{h_2 : \Delta_6 \vdash \perp, \Delta_8, p_7, p_7}{- : \Delta_6 \vdash \perp, \Delta_8, p_7} \text{ax/W} \quad \frac{\bullet h_5 : \Delta_6, p_7 \vdash \perp, \Delta_8, p_7}{\bullet h_5 : \Delta_6, p_7 \vdash \perp, \Delta_8, p_7} I}{- : \Delta_6 \vdash \perp, \Delta_8, p_7} \text{hCut} \\
\hline
\frac{h_2 : \Delta_9, p_7 \vdash F_5, \Delta_8, p_7}{\bullet h_2 : \Delta_9, p_7 \vdash (\perp, \Delta_8, p_7), F_5} \perp_R \quad \frac{}{\bullet h_6 : (\Delta_9, p_7), F_5 \vdash \perp, \Delta_8, p_7} I \\
\hline
- : \Delta_9, p_7 \vdash \perp, \Delta_8, p_7 \quad \text{Cut} \\
\hline
\frac{}{- : \Delta_9, p_7 \vdash \perp, \Delta_8, p_7} I
\end{array}$$

- Case rule \top_L

$$\begin{array}{c}
\frac{h_1 : \top, \Delta_6 \vdash \Delta_5}{\bullet h_1 : \top, \Delta_6 \vdash \Delta_5, \perp} \perp_R \quad \frac{h_4 : \perp, \Delta_6 \vdash \Delta_5}{\bullet h_4 : (\top, \Delta_6), \perp \vdash \Delta_5} \top_L \\
\hline
- : \top, \Delta_6 \vdash \Delta_5 \quad \text{Cut} \\
\hline
\frac{}{- : \top, \Delta_6 \vdash \Delta_5} \text{ax/W}
\end{array}$$

$$\begin{array}{c}
\frac{\frac{h_2 : \Delta_7 \vdash \top, \Delta_5}{\bullet h_2 : \Delta_7 \vdash (\perp, \Delta_5), \top} \perp_R \quad \frac{h_6 : \Delta_7 \vdash \perp, \Delta_5}{\bullet h_6 : \Delta_7, \top \vdash \perp, \Delta_5} \top_L}{- : \Delta_7 \vdash \perp, \Delta_5} \text{Cut} \\
\rightsquigarrow \\
\frac{}{- : \Delta_7 \vdash \perp, \Delta_5} \text{ax/W} \\
\frac{\frac{h_2 : \top, \Delta_8 \vdash F_5, \Delta_6}{\bullet h_2 : \top, \Delta_8 \vdash (\perp, \Delta_6), F_5} \perp_R \quad \frac{h_7 : F_5, \Delta_8 \vdash \perp, \Delta_6}{\bullet h_7 : (\top, \Delta_8), F_5 \vdash \perp, \Delta_6} \top_L}{- : \top, \Delta_8 \vdash \perp, \Delta_6} \text{Cut} \\
\rightsquigarrow \\
\frac{\frac{h_2 : \top, \Delta_8 \vdash \perp, \Delta_6, F_5}{\bullet h_2 : \top, \Delta_8 \vdash \perp, \Delta_6, F_5} \text{ax/W} \quad \frac{\bullet h_7 : \top, \Delta_8, F_5 \vdash \perp, \Delta_6}{\bullet h_7 : \top, \Delta_8, F_5 \vdash \perp, \Delta_6} \text{ax/W}}{- : \top, \Delta_8 \vdash \perp, \Delta_6} \text{hCut}
\end{array}$$

8.5 Status of \top_R : OK

- Case rule \rightarrow_R

$$\begin{array}{c}
\frac{\frac{}{\bullet h_1 : \Delta_4 \vdash (\Delta_6, F_7 \rightarrow F_8), \top} \top_R \quad \frac{h_5 : \top, F_7, \Delta_4 \vdash F_8, \Delta_6}{\bullet h_5 : \Delta_4, \top \vdash \Delta_6, F_7 \rightarrow F_8} \rightarrow_R}{- : \Delta_4 \vdash \Delta_6, F_7 \rightarrow F_8} \text{Cut} \\
\rightsquigarrow \\
\frac{\frac{\bullet h_1 : \Delta_4, F_7 \vdash \top, \Delta_6, F_8}{\bullet h_1 : \Delta_4, F_7 \vdash \top, \Delta_6, F_8} \top_R \quad \frac{h_5 : \top, \Delta_4, F_7 \vdash \Delta_6, F_8}{\bullet h_5 : \top, \Delta_4, F_7 \vdash \Delta_6, F_8} \text{ax/W}}{- : \Delta_4, F_7 \vdash \Delta_6, F_8} \text{hCut} \\
\frac{}{- : \Delta_4 \vdash \Delta_6, F_7 \rightarrow F_8} \rightarrow_R \\
\frac{\frac{}{\bullet h_2 : \Delta_6 \vdash (\top, \Delta_{10}, F_8 \rightarrow F_9), F_5} \top_R \quad \frac{h_7 : F_5, F_8, \Delta_6 \vdash \top, F_9, \Delta_{10}}{\bullet h_7 : \Delta_6, F_5 \vdash \top, \Delta_{10}, F_8 \rightarrow F_9} \rightarrow_R}{- : \Delta_6 \vdash \top, \Delta_{10}, F_8 \rightarrow F_9} \text{Cut} \\
\rightsquigarrow \\
\frac{}{- : \Delta_6 \vdash \top, \Delta_{10}, F_8 \rightarrow F_9} \top_R
\end{array}$$

- Case rule \wedge_R

$$\begin{array}{c}
\frac{\frac{}{\bullet h_1 : \Delta_4 \vdash (\Delta_6, F_7 \wedge F_8), \top} \top_R \quad \frac{h_5 : \top, \Delta_4 \vdash F_7, \Delta_6 \quad h_5 : \top, \Delta_4 \vdash F_8, \Delta_6}{\bullet h_5 : \Delta_4, \top \vdash \Delta_6, F_7 \wedge F_8} \wedge_R}{- : \Delta_4 \vdash \Delta_6, F_7 \wedge F_8} \text{Cut} \\
\rightsquigarrow \\
\frac{\frac{\bullet h_1 : \Delta_4 \vdash \top, \Delta_6, F_7}{\bullet h_1 : \Delta_4 \vdash \top, \Delta_6, F_7} \top_R \quad \frac{h_5 : \top, \Delta_4 \vdash \Delta_6, F_7}{\bullet h_5 : \top, \Delta_4 \vdash \Delta_6, F_7} \text{ax/W}}{- : \Delta_4 \vdash \Delta_6, F_7} \text{hCut} \\
\frac{\frac{\bullet h_1 : \Delta_4 \vdash \top, \Delta_6, F_8}{\bullet h_1 : \Delta_4 \vdash \top, \Delta_6, F_8} \top_R \quad \frac{h_5 : \top, \Delta_4 \vdash \Delta_6, F_8}{\bullet h_5 : \top, \Delta_4 \vdash \Delta_6, F_8} \text{ax/W}}{- : \Delta_4 \vdash \Delta_6, F_8} \text{hCut} \\
\frac{}{- : \Delta_4 \vdash \Delta_6, F_7 \wedge F_8} \wedge_R \\
\frac{\frac{}{\bullet h_2 : \Delta_6 \vdash (\top, \Delta_{10}, F_8 \wedge F_9), F_5} \top_R \quad \frac{h_7 : F_5, \Delta_6 \vdash \top, F_8, \Delta_{10} \quad h_7 : F_5, \Delta_6 \vdash \top, F_9, \Delta_{10}}{\bullet h_7 : \Delta_6, F_5 \vdash \top, \Delta_{10}, F_8 \wedge F_9} \wedge_R}{- : \Delta_6 \vdash \top, \Delta_{10}, F_8 \wedge F_9} \text{Cut} \\
\rightsquigarrow \\
\frac{}{- : \Delta_6 \vdash \top, \Delta_{10}, F_8 \wedge F_9} \top_R
\end{array}$$

- Case rule \vee_R

$$\begin{array}{c}
\frac{\frac{}{\bullet h_1 : \Delta_4 \vdash (\Delta_6, F_7 \vee F_8), \top} \top_R \quad \frac{h_5 : \top, \Delta_4 \vdash F_7, F_8, \Delta_6}{\bullet h_5 : \Delta_4, \top \vdash \Delta_6, F_7 \vee F_8} \vee_R}{- : \Delta_4 \vdash \Delta_6, F_7 \vee F_8} \text{Cut} \\
\rightsquigarrow \\
\frac{\frac{\bullet h_1 : \Delta_4 \vdash \top, \Delta_6, F_7, F_8}{\bullet h_1 : \Delta_4 \vdash \top, \Delta_6, F_7, F_8} \top_R \quad \frac{h_5 : \top, \Delta_4 \vdash \Delta_6, F_7, F_8}{\bullet h_5 : \top, \Delta_4 \vdash \Delta_6, F_7, F_8} \text{ax/W}}{- : \Delta_4 \vdash \Delta_6, F_7, F_8} \text{hCut} \\
\frac{}{- : \Delta_4 \vdash \Delta_6, F_7 \vee F_8} \vee_R \\
\frac{\frac{}{\bullet h_2 : \Delta_6 \vdash (\top, \Delta_{10}, F_8 \vee F_9), F_5} \top_R \quad \frac{h_7 : F_5, \Delta_6 \vdash \top, F_8, F_9, \Delta_{10}}{\bullet h_7 : \Delta_6, F_5 \vdash \top, \Delta_{10}, F_8 \vee F_9} \vee_R}{- : \Delta_6 \vdash \top, \Delta_{10}, F_8 \vee F_9} \text{Cut} \\
\rightsquigarrow \\
\frac{}{- : \Delta_6 \vdash \top, \Delta_{10}, F_8 \vee F_9} \top_R
\end{array}$$

- Case rule \perp_R

$$\begin{array}{c}
\frac{\frac{\frac{}{\bullet h_1 : \Delta_4 \vdash (\perp, \Delta_6), \top} \top_R \quad \frac{h_5 : \top, \Delta_4 \vdash \Delta_6}{\bullet h_5 : \Delta_4, \top \vdash \perp, \Delta_6} \perp_R}{- : \Delta_4 \vdash \perp, \Delta_6} \text{Cut} \\
\sim \\
\frac{\frac{\bullet h_1 : \Delta_4 \vdash \perp, \top, \Delta_6}{- : \Delta_4 \vdash \perp, \Delta_6} \text{ax/W} \quad \frac{h_5 : \top, \Delta_4 \vdash \perp, \Delta_6}{h_5 : \top, \Delta_4 \vdash \perp, \Delta_6} \text{hCut}}{- : \Delta_4 \vdash \perp, \Delta_6} \\
\\
\frac{\frac{\frac{}{\bullet h_2 : \Delta_6 \vdash (\top, \perp, \Delta_8), F_5} \top_R \quad \frac{h_7 : F_5, \Delta_6 \vdash \top, \Delta_8}{\bullet h_7 : \Delta_6, F_5 \vdash \top, \perp, \Delta_8} \perp_R}{- : \Delta_6 \vdash \top, \perp, \Delta_8} \text{Cut} \\
\sim \\
\frac{- : \Delta_6 \vdash \top, \perp, \Delta_8}{- : \Delta_6 \vdash \perp, \top, \Delta_8} \top_R
\end{array}$$

- Case rule \top_R

$$\begin{array}{c}
\frac{\frac{\frac{}{\bullet h_1 : \Delta_4 \vdash (\top, \Delta_6), \top} \top_R \quad \frac{\frac{}{\bullet h_5 : \Delta_4, \top \vdash \top, \Delta_6} \top_R}{- : \Delta_4 \vdash \top, \Delta_6} \text{Cut}}{\sim} \top_R \\
\frac{- : \Delta_4 \vdash \top, \Delta_6}{- : \Delta_4 \vdash \top, \Delta_6} \top_R \\
\\
\frac{\frac{\frac{}{\bullet h_2 : \Delta_6 \vdash (\top, \Delta_8), F_5} \top_R \quad \frac{\frac{}{\bullet h_7 : \Delta_6, F_5 \vdash \top, \Delta_8} \top_R}{- : \Delta_6 \vdash \top, \Delta_8} \text{Cut}}{\sim} \top_R \\
\frac{- : \Delta_6 \vdash \top, \Delta_8}{- : \Delta_6 \vdash \top, \Delta_8} \top_R
\end{array}$$

- Case rule $A4$

$$\begin{array}{c}
\frac{\frac{\frac{}{\bullet h_1 : \Box \Gamma_5, \Delta_8 \vdash (\Delta_6, [\top F_7]), \top} \top_R \quad \frac{h_4 : \Box \Gamma_5 \vdash F_7}{\bullet h_4 : (\Box \Gamma_5, \Delta_8), \top \vdash \Delta_6, [\top F_7]} A4}{- : \Box \Gamma_5, \Delta_8 \vdash \Delta_6, [\top F_7]} \text{Cut} \\
\sim \\
\frac{\frac{- : \Box \Gamma_5 \vdash F_7}{- : \Delta_8, \Box \Gamma_5 \vdash \Delta_6, [\top F_7]} \text{ax/W}}{- : \Delta_8, \Box \Gamma_5 \vdash \Delta_6, [\top F_7]} A4 \\
\\
\frac{\frac{\frac{}{\bullet h_2 : \Box \Gamma_{10}, \Delta_7 \vdash (\top, \Delta_9, [\top F_8]), \Box F_5} \top_R \quad \frac{h_6 : \Box \Gamma_{10}, \Box F_5 \vdash F_8}{\bullet h_6 : (\Box \Gamma_{10}, \Delta_7), \Box F_5 \vdash \top, \Delta_9, [\top F_8]} A4}{- : \Box \Gamma_{10}, \Delta_7 \vdash \top, \Delta_9, [\top F_8]} \text{Cut} \\
\sim \\
\frac{- : \Delta_7, \Box \Gamma_{10} \vdash \top, \Delta_9, [\top F_8]}{- : \Delta_7, \Box \Gamma_{10} \vdash \top, \Delta_9, [\top F_8]} \top_R \\
\\
\frac{\frac{\frac{}{\bullet h_2 : \Box \Gamma_7, \Delta_{10} \vdash (\top, \Delta_9, [\top F_8]), F_5} \top_R \quad \frac{h_6 : \Box \Gamma_7 \vdash F_8}{\bullet h_6 : (\Box \Gamma_7, \Delta_{10}), F_5 \vdash \top, \Delta_9, [\top F_8]} A4}{- : \Box \Gamma_7, \Delta_{10} \vdash \top, \Delta_9, [\top F_8]} \text{Cut} \\
\sim \\
\frac{- : \Delta_{10}, \Box \Gamma_7 \vdash \top, \Delta_9, [\top F_8]}{- : \Delta_{10}, \Box \Gamma_7 \vdash \top, \Delta_9, [\top F_8]} \top_R
\end{array}$$

- Case rule \rightarrow_L

$$\begin{array}{c}
\frac{\frac{\frac{}{\bullet h_1 : \Delta_8, F_5 \rightarrow F_6 \vdash \Delta_7, \top} \top_R \quad \frac{h_4 : \top, \Delta_8 \vdash F_5, \Delta_7 \quad h_4 : \top, F_6, \Delta_8 \vdash \Delta_7}{\bullet h_4 : (\Delta_8, F_5 \rightarrow F_6), \top \vdash \Delta_7} \rightarrow_L}{- : \Delta_8, F_5 \rightarrow F_6 \vdash \Delta_7} \text{Cut} \\
\sim \\
\frac{\frac{\frac{\bullet h_1 : \Delta_8 \vdash \top, \Delta_7, F_5}{- : \Delta_8 \vdash \Delta_7, F_5} \top_R \quad \frac{h_4 : \top, \Delta_8 \vdash \Delta_7, F_5}{h_4 : \top, \Delta_8 \vdash \Delta_7, F_5} \text{ax/W}}{\sim} \text{hCut} \quad \frac{\frac{\frac{}{\bullet h_1 : \Delta_8, F_6 \vdash \top, \Delta_7} \top_R \quad h_4 : \top, \Delta_8, F_6 \vdash \Delta_7}{- : \Delta_8, F_6 \vdash \Delta_7} \text{ax/W}}{- : \Delta_8, F_5 \rightarrow F_6 \vdash \Delta_7} \text{hCut} \rightarrow_L
\end{array}$$

$$\begin{array}{c}
\frac{\frac{\bullet h_2 : \Delta_7 \vdash (\top, \Delta_5), F_8 \rightarrow F_9}{- : \Delta_7 \vdash \top, \Delta_5} \top_R \quad \frac{h_6 : \Delta_7 \vdash \top, F_8, \Delta_5 \quad h_6 : F_9, \Delta_7 \vdash \top, \Delta_5}{\bullet h_6 : \Delta_7, F_8 \rightarrow F_9 \vdash \top, \Delta_5} \rightarrow_L}{\text{Cut}} \\
\rightsquigarrow \\
\frac{}{- : \Delta_7 \vdash \top, \Delta_5} \top_R \\
\\
\frac{\frac{\bullet h_2 : \Delta_{10}, F_8 \rightarrow F_9 \vdash (\top, \Delta_6), F_5}{- : \Delta_{10}, F_8 \rightarrow F_9 \vdash \top, \Delta_6} \top_R \quad \frac{h_7 : F_5, \Delta_{10} \vdash \top, F_8, \Delta_6 \quad h_7 : F_5, F_9, \Delta_{10} \vdash \top, \Delta_6}{\bullet h_7 : (\Delta_{10}, F_8 \rightarrow F_9), F_5 \vdash \top, \Delta_6} \rightarrow_L}{\text{Cut}} \\
\rightsquigarrow \\
\frac{}{- : \Delta_{10}, F_8 \rightarrow F_9 \vdash \top, \Delta_6} \top_R
\end{array}$$

- Case rule \wedge_L

$$\begin{array}{c}
\frac{\frac{\bullet h_1 : \Delta_8, F_5 \wedge F_6 \vdash \Delta_7, \top}{- : \Delta_8, F_5 \wedge F_6 \vdash \Delta_7} \top_R \quad \frac{h_4 : \top, F_5, F_6, \Delta_8 \vdash \Delta_7}{\bullet h_4 : (\Delta_8, F_5 \wedge F_6), \top \vdash \Delta_7} \wedge_L}{\text{Cut}} \\
\rightsquigarrow \\
\frac{\frac{\bullet h_1 : \Delta_8, F_5, F_6 \vdash \top, \Delta_7}{- : \Delta_8, F_5, F_6 \vdash \top, \Delta_7} \top_R \quad \frac{h_4 : \top, \Delta_8, F_5, F_6 \vdash \Delta_7}{\bullet h_4 : (\Delta_8, F_5 \wedge F_6), \top \vdash \Delta_7} \text{ax/W}}{- : \Delta_8, F_5 \wedge F_6 \vdash \Delta_7} \wedge_L \\
\\
\frac{\frac{\bullet h_2 : \Delta_7 \vdash (\top, \Delta_5), F_8 \wedge F_9}{- : \Delta_7 \vdash \top, \Delta_5} \top_R \quad \frac{h_6 : F_8, F_9, \Delta_7 \vdash \top, \Delta_5}{\bullet h_6 : \Delta_7, F_8 \wedge F_9 \vdash \top, \Delta_5} \wedge_L}{\text{Cut}} \\
\rightsquigarrow \\
\frac{}{- : \Delta_7 \vdash \top, \Delta_5} \top_R \\
\\
\frac{\frac{\bullet h_2 : \Delta_{10}, F_8 \wedge F_9 \vdash (\top, \Delta_6), F_5}{- : \Delta_{10}, F_8 \wedge F_9 \vdash \top, \Delta_6} \top_R \quad \frac{h_7 : F_5, F_8, F_9, \Delta_{10} \vdash \top, \Delta_6}{\bullet h_7 : (\Delta_{10}, F_8 \wedge F_9), F_5 \vdash \top, \Delta_6} \wedge_L}{\text{Cut}} \\
\rightsquigarrow \\
\frac{}{- : \Delta_{10}, F_8 \wedge F_9 \vdash \top, \Delta_6} \top_R
\end{array}$$

- Case rule \vee_L

$$\begin{array}{c}
\frac{\frac{\bullet h_1 : \Delta_8, F_5 \vee F_6 \vdash \Delta_7, \top}{- : \Delta_8, F_5 \vee F_6 \vdash \Delta_7} \top_R \quad \frac{h_4 : \top, F_5, \Delta_8 \vdash \Delta_7 \quad h_4 : \top, F_6, \Delta_8 \vdash \Delta_7}{\bullet h_4 : (\Delta_8, F_5 \vee F_6), \top \vdash \Delta_7} \vee_L}{\text{Cut}} \\
\rightsquigarrow \\
\frac{\frac{\bullet h_1 : \Delta_8, F_5 \vdash \top, \Delta_7}{- : \Delta_8, F_5 \vdash \top, \Delta_7} \top_R \quad \frac{h_4 : \top, \Delta_8, F_5 \vdash \Delta_7}{\bullet h_4 : (\Delta_8, F_5 \vee F_6), \top \vdash \Delta_7} \text{ax/W}}{- : \Delta_8, F_5 \vdash \top, \Delta_7} \vee_L \\
\\
\frac{\frac{\bullet h_2 : \Delta_7 \vdash (\top, \Delta_5), F_8 \vee F_9}{- : \Delta_7 \vdash \top, \Delta_5} \top_R \quad \frac{h_6 : F_8, \Delta_7 \vdash \top, \Delta_5 \quad h_6 : F_9, \Delta_7 \vdash \top, \Delta_5}{\bullet h_6 : \Delta_7, F_8 \vee F_9 \vdash \top, \Delta_5} \vee_L}{\text{Cut}} \\
\rightsquigarrow \\
\frac{}{- : \Delta_7 \vdash \top, \Delta_5} \top_R \\
\\
\frac{\frac{\bullet h_2 : \Delta_{10}, F_8 \vee F_9 \vdash (\top, \Delta_6), F_5}{- : \Delta_{10}, F_8 \vee F_9 \vdash \top, \Delta_6} \top_R \quad \frac{h_7 : F_5, F_8, \Delta_{10} \vdash \top, \Delta_6 \quad h_7 : F_5, F_9, \Delta_{10} \vdash \top, \Delta_6}{\bullet h_7 : (\Delta_{10}, F_8 \vee F_9), F_5 \vdash \top, \Delta_6} \vee_L}{\text{Cut}} \\
\rightsquigarrow \\
\frac{}{- : \Delta_{10}, F_8 \vee F_9 \vdash \top, \Delta_6} \top_R
\end{array}$$

- Case rule AT

$$\begin{array}{c}
\frac{\frac{}{\bullet h_1 : \Delta_7, []F_5 \vdash \Delta_6, \top} \top_R \quad \frac{h_4 : \top, F_5, \Delta_7, []F_5 \vdash \Delta_6}{\bullet h_4 : (\Delta_7, []F_5), \top \vdash \Delta_6} AT}{- : \Delta_7, []F_5 \vdash \Delta_6} \text{Cut} \\
\sim \\
\frac{\frac{\bullet h_1 : \Delta_7, F_5, []F_5 \vdash \top, \Delta_6}{- : \Delta_7, F_5, []F_5 \vdash \Delta_6} \text{ax/W} \quad \frac{h_4 : \top, \Delta_7, F_5, []F_5 \vdash \Delta_6}{\bullet h_4 : (\Delta_7, []F_5), \top \vdash \Delta_6} \text{ax/W}}{- : \Delta_7, []F_5 \vdash \Delta_6} \text{hCut} \\
\sim \\
\frac{}{- : \Delta_7, []F_5 \vdash \Delta_6} AT
\end{array}$$

$$\begin{array}{c}
\frac{\frac{}{\bullet h_2 : \Delta_7 \vdash (\top, \Delta_5), []F_8} \top_R \quad \frac{h_6 : F_8, \Delta_7, []F_8 \vdash \top, \Delta_5}{\bullet h_6 : \Delta_7, []F_8 \vdash \top, \Delta_5} AT}{- : \Delta_7 \vdash \top, \Delta_5} \text{Cut} \\
\sim \\
\frac{}{- : \Delta_7 \vdash \top, \Delta_5} \top_R
\end{array}$$

$$\begin{array}{c}
\frac{\frac{}{\bullet h_2 : \Delta_9, []F_8 \vdash (\top, \Delta_6), F_5} \top_R \quad \frac{h_7 : F_5, F_8, \Delta_9, []F_8 \vdash \top, \Delta_6}{\bullet h_7 : (\Delta_9, []F_8), F_5 \vdash \top, \Delta_6} AT}{- : \Delta_9, []F_8 \vdash \top, \Delta_6} \text{Cut} \\
\sim \\
\frac{}{- : \Delta_9, []F_8 \vdash \top, \Delta_6} \top_R
\end{array}$$

- Case rule \perp_L

$$\begin{array}{c}
\frac{\frac{}{\bullet h_1 : \perp, \Delta_6 \vdash \Delta_5, \top} \top_R \quad \frac{}{\bullet h_4 : (\perp, \Delta_6), \top \vdash \Delta_5} \perp_L}{- : \perp, \Delta_6 \vdash \Delta_5} \text{Cut} \\
\sim \\
\frac{}{- : \perp, \Delta_6 \vdash \Delta_5} \perp_L
\end{array}$$

$$\begin{array}{c}
\frac{\frac{}{\bullet h_2 : \Delta_7 \vdash (\top, \Delta_5), \perp} \top_R \quad \frac{}{\bullet h_6 : \Delta_7, \perp \vdash \top, \Delta_5} \perp_L}{- : \Delta_7 \vdash \top, \Delta_5} \text{Cut} \\
\sim \\
\frac{}{- : \Delta_7 \vdash \top, \Delta_5} \top_R
\end{array}$$

$$\begin{array}{c}
\frac{\frac{}{\bullet h_2 : \perp, \Delta_8 \vdash (\top, \Delta_6), F_5} \top_R \quad \frac{}{\bullet h_7 : (\perp, \Delta_8), F_5 \vdash \top, \Delta_6} \perp_L}{- : \perp, \Delta_8 \vdash \top, \Delta_6} \text{Cut} \\
\sim \\
\frac{}{- : \perp, \Delta_8 \vdash \top, \Delta_6} \top_R
\end{array}$$

- Case rule I

$$\begin{array}{c}
\frac{\frac{}{\bullet h_1 : \Delta_7, p_5 \vdash (\Delta_6, p_5), \top} \top_R \quad \frac{}{\bullet h_4 : (\Delta_7, p_5), \top \vdash \Delta_6, p_5} I}{- : \Delta_7, p_5 \vdash \Delta_6, p_5} \text{Cut} \\
\sim \\
\frac{}{- : \Delta_7, p_5 \vdash \Delta_6, p_5} I
\end{array}$$

$$\begin{array}{c}
\frac{\frac{}{\bullet h_2 : \Delta_6 \vdash (\top, \Delta_8, p_7), p_7} \top_R \quad \frac{}{\bullet h_5 : \Delta_6, p_7 \vdash \top, \Delta_8, p_7} I}{- : \Delta_6 \vdash \top, \Delta_8, p_7} \text{Cut} \\
\sim \\
\frac{}{- : \Delta_6 \vdash \top, \Delta_8, p_7} \top_R
\end{array}$$

$$\begin{array}{c}
\frac{\frac{}{\bullet h_2 : \Delta_9, p_7 \vdash (\top, \Delta_8, p_7), F_5} \top_R \quad \frac{}{\bullet h_6 : (\Delta_9, p_7), F_5 \vdash \top, \Delta_8, p_7} I}{- : \Delta_9, p_7 \vdash \top, \Delta_8, p_7} \text{Cut} \\
\sim \\
\frac{}{- : \Delta_9, p_7 \vdash \top, \Delta_8, p_7} \top_R
\end{array}$$

- Case rule \top_L

$$\begin{array}{c}
\frac{\frac{}{\bullet h_1 : \Delta_5 \vdash \Delta_6, \top} \top_R \quad \frac{h_4 : \Delta_5 \vdash \Delta_6}{\bullet h_4 : \Delta_5, \top \vdash \Delta_6} \top_L}{- : \Delta_5 \vdash \Delta_6} \text{Cut} \\
\sim \\
\frac{}{- : \Delta_5 \vdash \Delta_6} \text{ax/W}
\end{array}$$

$$\begin{array}{c}
\frac{\frac{\frac{}{\bullet h_2 : \Delta_7 \vdash (\top, \Delta_5), \top} \top_R \quad \frac{h_6 : \Delta_7 \vdash \top, \Delta_5}{\bullet h_6 : \Delta_7, \top \vdash \top, \Delta_5} \top_L}{- : \Delta_7 \vdash \top, \Delta_5} \text{Cut}}{\sim} \\
\frac{}{- : \Delta_7 \vdash \top, \Delta_5} \top_R \\
\frac{}{- : \Delta_7 \vdash \top, \Delta_5} \top_R \\
\frac{\frac{\frac{}{\bullet h_2 : \top, \Delta_8 \vdash (\top, \Delta_6), F_5} \top_R \quad \frac{h_7 : F_5, \Delta_8 \vdash \top, \Delta_6}{\bullet h_7 : (\top, \Delta_8), F_5 \vdash \top, \Delta_6} \top_L}{- : \top, \Delta_8 \vdash \top, \Delta_6} \text{Cut}}{\sim} \\
\frac{}{- : \top, \Delta_8 \vdash \top, \Delta_6} \top_R
\end{array}$$

8.6 Status of A4: OK

- Case rule \rightarrow_R

$$\begin{array}{c}
\frac{\frac{h_1 : \Box \Gamma_6 \vdash F_8}{\bullet h_1 : \Box \Gamma_6, \Delta_7 \vdash (\Delta_{10}, F_{11} \rightarrow F_{12}), \Box F_8} A4 \quad \frac{h_9 : \Box \Gamma_6, F_{11}, \Delta_7, \Box F_8 \vdash F_{12}, \Delta_{10}}{\bullet h_9 : (\Box \Gamma_6, \Delta_7), \Box F_8 \vdash \Delta_{10}, F_{11} \rightarrow F_{12}} \rightarrow_R}{- : \Box \Gamma_6, \Delta_7 \vdash \Delta_{10}, F_{11} \rightarrow F_{12}} \text{Cut} \\
\sim \\
\frac{\frac{h_1 : \Box \Gamma_6 \vdash F_8}{\bullet h_1 : \Delta_7, F_{11}, \Box \Gamma_6 \vdash \Delta_{10}, F_{12}, \Box F_8} \text{ax/W} \quad \frac{h_9 : \Delta_7, F_{11}, \Box \Gamma_6, \Box F_8 \vdash \Delta_{10}, F_{12}}{\bullet h_9 : (\Delta_7, F_{11}, \Box \Gamma_6), \Box F_8 \vdash \Delta_{10}, F_{12}} A4}{- : \Delta_7, F_{11}, \Box \Gamma_6 \vdash \Delta_{10}, F_{12}} \text{hCut} \\
\frac{}{- : \Delta_7, F_{11}, \Box \Gamma_6 \vdash \Delta_{10}, F_{12}} \rightarrow_R \\
\frac{}{- : \Delta_7, \Box \Gamma_6 \vdash \Delta_{10}, F_{11} \rightarrow F_{12}} \rightarrow_R \\
\frac{\frac{h_2 : \Box \Gamma_7 \vdash F_{10}}{\bullet h_2 : \Box \Gamma_7, \Delta_9 \vdash ((\Delta_{14}, F_{12} \rightarrow F_{13}), \Box F_{10}), F_8} A4 \quad \frac{h_{11} : \Box \Gamma_7, F_8, F_{12}, \Delta_9 \vdash F_{13}, \Delta_{14}, \Box F_{10}}{\bullet h_{11} : (\Box \Gamma_7, \Delta_9), F_8 \vdash (\Delta_{14}, F_{12} \rightarrow F_{13}), \Box F_{10}} \rightarrow_R}{- : \Box \Gamma_7, \Delta_9 \vdash (\Delta_{14}, F_{12} \rightarrow F_{13}), \Box F_{10}} \text{Cut} \\
\sim \\
\frac{}{- : \Box \Gamma_7 \vdash F_{10}} \text{ax/W} \\
\frac{}{- : \Delta_9, \Box \Gamma_7 \vdash \Delta_{14}, \Box F_{10}, F_{12} \rightarrow F_{13}} A4
\end{array}$$

- Case rule \wedge_R

$$\begin{array}{c}
\frac{\frac{h_1 : \Box \Gamma_6 \vdash F_8}{\bullet h_1 : \Box \Gamma_6, \Delta_7 \vdash (\Delta_{10}, F_{11} \wedge F_{12}), \Box F_8} A4 \quad \frac{h_9 : \Box \Gamma_6, \Delta_7, \Box F_8 \vdash F_{11}, \Delta_{10} \quad h_9 : \Box \Gamma_6, \Delta_7, \Box F_8 \vdash F_{12}, \Delta_{10}}{\bullet h_9 : (\Box \Gamma_6, \Delta_7), \Box F_8 \vdash \Delta_{10}, F_{11} \wedge F_{12}} \text{Cut}}{- : \Box \Gamma_6, \Delta_7 \vdash \Delta_{10}, F_{11} \wedge F_{12}} \wedge_R \\
\sim \\
\frac{\frac{h_1 : \Box \Gamma_6 \vdash F_8}{\bullet h_1 : \Delta_7, \Box \Gamma_6 \vdash \Delta_{10}, F_{11}, \Box F_8} \text{ax/W} \quad \frac{h_9 : \Delta_7, \Box \Gamma_6, \Box F_8 \vdash \Delta_{10}, F_{11}}{\bullet h_9 : (\Delta_7, \Box \Gamma_6), \Box F_8 \vdash \Delta_{10}, F_{11}} A4}{- : \Delta_7, \Box \Gamma_6 \vdash \Delta_{10}, F_{11}} \text{hCut} \\
\frac{\frac{h_1 : \Box \Gamma_6 \vdash F_8}{\bullet h_1 : \Delta_7, \Box \Gamma_6 \vdash \Delta_{10}, F_{11}, \Box F_8} \text{ax/W} \quad \frac{h_9 : \Delta_7, \Box \Gamma_6, \Box F_8 \vdash \Delta_{10}, F_{12}}{\bullet h_9 : (\Delta_7, \Box \Gamma_6), \Box F_8 \vdash \Delta_{10}, F_{12}} A4}{- : \Delta_7, \Box \Gamma_6 \vdash \Delta_{10}, F_{12}} \text{hCut} \\
\frac{}{- : \Delta_7, \Box \Gamma_6 \vdash \Delta_{10}, F_{11} \wedge F_{12}} \wedge_R \\
\frac{\frac{h_2 : \Box \Gamma_7 \vdash F_{10}}{\bullet h_2 : \Box \Gamma_7, \Delta_9 \vdash ((\Delta_{14}, F_{12} \wedge F_{13}), \Box F_{10}), F_8} A4 \quad \frac{h_{11} : \Box \Gamma_7, F_8, \Delta_9 \vdash F_{12}, \Delta_{14}, \Box F_{10} \quad h_{11} : \Box \Gamma_7, F_8, \Delta_9 \vdash F_{13}, \Delta_{14}, \Box F_{10}}{\bullet h_{11} : (\Box \Gamma_7, \Delta_9), F_8 \vdash (\Delta_{14}, F_{12} \wedge F_{13}), \Box F_{10}} \text{Cut}}{- : \Box \Gamma_7, \Delta_9 \vdash (\Delta_{14}, F_{12} \wedge F_{13}), \Box F_{10}} \wedge_R \\
\sim \\
\frac{}{- : \Box \Gamma_7 \vdash F_{10}} \text{ax/W} \\
\frac{}{- : \Delta_9, \Box \Gamma_7 \vdash \Delta_{14}, \Box F_{10}, F_{12} \wedge F_{13}} A4
\end{array}$$

- Case rule \vee_R

$$\begin{array}{c}
\frac{\frac{h_1 : \Box \Gamma_6 \vdash F_8}{\bullet h_1 : \Box \Gamma_6, \Delta_7 \vdash (\Delta_{10}, F_{11} \vee F_{12}), \Box F_8} A4 \quad \frac{h_9 : \Box \Gamma_6, \Delta_7, \Box F_8 \vdash F_{11}, F_{12}, \Delta_{10}}{\bullet h_9 : (\Box \Gamma_6, \Delta_7), \Box F_8 \vdash \Delta_{10}, F_{11} \vee F_{12}} \vee_R}{- : \Box \Gamma_6, \Delta_7 \vdash \Delta_{10}, F_{11} \vee F_{12}} \text{Cut} \\
\sim \\
\frac{\frac{h_1 : \Box \Gamma_6 \vdash F_8}{\bullet h_1 : \Delta_7, \Box \Gamma_6 \vdash \Delta_{10}, F_{11}, F_{12}, \Box F_8} \text{ax/W} \quad \frac{h_9 : \Delta_7, \Box \Gamma_6, \Box F_8 \vdash \Delta_{10}, F_{11}, F_{12}}{\bullet h_9 : (\Delta_7, \Box \Gamma_6), \Box F_8 \vdash \Delta_{10}, F_{11}, F_{12}} A4}{- : \Delta_7, \Box \Gamma_6 \vdash \Delta_{10}, F_{11}, F_{12}} \text{hCut} \\
\frac{}{- : \Delta_7, \Box \Gamma_6 \vdash \Delta_{10}, F_{11}, F_{12}} \vee_R \\
\frac{}{- : \Delta_7, \Box \Gamma_6 \vdash \Delta_{10}, F_{11} \vee F_{12}} \vee_R
\end{array}$$

$$\begin{array}{c}
\frac{h_2 : \Box \Gamma_7 \vdash F_{10}}{\bullet h_2 : \Box \Gamma_7, \Delta_9 \vdash ((\Delta_{14}, F_{12} \vee F_{13}), [\Box F_{10}], F_8)} \quad A4 \quad \frac{h_{11} : \Box \Gamma_7, F_8, \Delta_9 \vdash F_{12}, F_{13}, \Delta_{14}, [\Box F_{10}]}{\bullet h_{11} : (\Box \Gamma_7, \Delta_9), F_8 \vdash (\Delta_{14}, F_{12} \vee F_{13}), [\Box F_{10}]} \quad \vee_R \\
\hline
- : \Box \Gamma_7, \Delta_9 \vdash (\Delta_{14}, F_{12} \vee F_{13}), [\Box F_{10}] \quad \text{Cut} \\
\hline
\rightsquigarrow \\
\frac{- : \Box \Gamma_7 \vdash F_{10} \quad \text{ax/W}}{- : \Delta_9, \Box \Gamma_7 \vdash \Delta_{14}, [\Box F_{10}, F_{12} \vee F_{13}]} \quad A4
\end{array}$$

- Case rule \perp_R

$$\begin{array}{c}
\frac{h_1 : \Box \Gamma_6 \vdash F_8}{\bullet h_1 : \Box \Gamma_6, \Delta_7 \vdash (\perp, \Delta_{10}), [\Box F_8]} \quad A4 \quad \frac{h_9 : \Box \Gamma_6, \Delta_7, [\Box F_8] \vdash \Delta_{10}}{\bullet h_9 : (\Box \Gamma_6, \Delta_7), [\Box F_8] \vdash \perp, \Delta_{10}} \quad \perp_R \\
\hline
- : \Box \Gamma_6, \Delta_7 \vdash \perp, \Delta_{10} \quad \text{Cut} \\
\hline
\rightsquigarrow \\
\frac{\bullet h_1 : \Delta_7, \Box \Gamma_6 \vdash \perp, \Delta_{10}, [\Box F_8] \quad \text{ax/W}}{- : \Delta_7, \Box \Gamma_6 \vdash \perp, \Delta_{10}} \quad \text{hCut} \\
\hline
\frac{h_2 : \Box \Gamma_7 \vdash F_{10}}{\bullet h_2 : \Box \Gamma_7, \Delta_9 \vdash ((\perp, \Delta_{12}), [\Box F_{10}], F_8)} \quad A4 \quad \frac{h_{11} : \Box \Gamma_7, F_8, \Delta_9 \vdash \Delta_{12}, [\Box F_{10}]}{\bullet h_{11} : (\Box \Gamma_7, \Delta_9), F_8 \vdash (\perp, \Delta_{12}), [\Box F_{10}]} \quad \perp_R \\
\hline
- : \Box \Gamma_7, \Delta_9 \vdash (\perp, \Delta_{12}), [\Box F_{10}] \quad \text{Cut} \\
\hline
\rightsquigarrow \\
\frac{- : \Box \Gamma_7 \vdash F_{10} \quad \text{ax/W}}{- : \Delta_9, \Box \Gamma_7 \vdash \perp, \Delta_{12}, [\Box F_{10}]} \quad A4
\end{array}$$

- Case rule \top_R

$$\begin{array}{c}
\frac{h_1 : \Box \Gamma_6 \vdash F_8}{\bullet h_1 : \Box \Gamma_6, \Delta_7 \vdash (\top, \Delta_{10}), [\Box F_8]} \quad A4 \quad \frac{h_9 : (\Box \Gamma_6, \Delta_7), [\Box F_8] \vdash \top, \Delta_{10}}{\bullet h_9 : (\Box \Gamma_6, \Delta_7), [\Box F_8] \vdash \top, \Delta_{10}} \quad \top_R \\
\hline
- : \Box \Gamma_6, \Delta_7 \vdash \top, \Delta_{10} \quad \text{Cut} \\
\hline
\rightsquigarrow \\
\frac{- : \Delta_7, \Box \Gamma_6 \vdash \top, \Delta_{10}}{- : \Delta_7, \Box \Gamma_6 \vdash \top, \Delta_{10}} \quad \top_R \\
\hline
\frac{h_2 : \Box \Gamma_7 \vdash F_{10}}{\bullet h_2 : \Box \Gamma_7, \Delta_9 \vdash ((\top, \Delta_{12}), [\Box F_{10}], F_8)} \quad A4 \quad \frac{h_{11} : (\Box \Gamma_7, \Delta_9), F_8 \vdash (\top, \Delta_{12}), [\Box F_{10}]}{\bullet h_{11} : (\Box \Gamma_7, \Delta_9), F_8 \vdash (\top, \Delta_{12}), [\Box F_{10}]} \quad \top_R \\
\hline
- : \Box \Gamma_7, \Delta_9 \vdash (\top, \Delta_{12}), [\Box F_{10}] \quad \text{Cut} \\
\hline
\rightsquigarrow \\
\frac{- : \Delta_9, \Box \Gamma_7 \vdash \top, \Delta_{12}, [\Box F_{10}]}{- : \Delta_9, \Box \Gamma_7 \vdash \top, \Delta_{12}, [\Box F_{10}]} \quad \top_R
\end{array}$$

- Case rule $A4$

$$\begin{array}{c}
\frac{h_1 : \Box \Gamma_{10}, \Box \Gamma_{12} \vdash F_6}{\bullet h_1 : (\Box \Gamma_{10}, \Box \Gamma_{12}), \Box \Gamma_{11}, \Delta_{13} \vdash (\Delta_8, [\Box F_9]), [\Box F_6]} \quad A4 \quad \frac{h_7 : \Box \Gamma_{10}, \Box \Gamma_{11}, [\Box F_6] \vdash F_9}{\bullet h_7 : ((\Box \Gamma_{10}, \Box \Gamma_{12}), \Box \Gamma_{11}, \Delta_{13}), [\Box F_6] \vdash \Delta_8, [\Box F_9]} \quad A4 \\
\hline
- : (\Box \Gamma_{10}, \Box \Gamma_{12}), \Box \Gamma_{11}, \Delta_{13} \vdash \Delta_8, [\Box F_9] \quad \text{Cut} \\
\hline
\rightsquigarrow \\
\frac{\frac{h_1 : \Box \Gamma_{10}, \Box \Gamma_{12} \vdash F_6 \quad \text{ax/W}}{\bullet h_1 : \Box \Gamma_{10}, \Box \Gamma_{11}, \Box \Gamma_{12} \vdash F_9, [\Box F_6]} \quad A4 \quad \frac{h_7 : \Box \Gamma_{10}, \Box \Gamma_{11}, \Box \Gamma_{12}, [\Box F_6] \vdash F_9}{\bullet h_7 : ((\Box \Gamma_{10}, \Box \Gamma_{12}), \Box \Gamma_{11}, \Delta_{13}), [\Box F_6] \vdash \Delta_8, [\Box F_9]} \quad \text{ax/W}}{- : \Box \Gamma_{10}, \Box \Gamma_{11}, \Box \Gamma_{12} \vdash F_9} \quad \text{hCut} \\
\hline
- : \Delta_{13}, \Box \Gamma_{10}, \Box \Gamma_{11}, \Box \Gamma_{12} \vdash \Delta_8, [\Box F_9] \quad A4 \\
\hline
\frac{h_1 : \Box \Gamma_{10}, \Box \Gamma_{12} \vdash F_6}{\bullet h_1 : (\Box \Gamma_{10}, \Box \Gamma_{12}), \Box \Gamma_{11}, \Delta_{13} \vdash (\Delta_8, [\Box F_9]), [\Box F_6]} \quad A4 \quad \frac{h_7 : \Box \Gamma_{10}, \Box \Gamma_{11} \vdash F_9}{\bullet h_7 : ((\Box \Gamma_{10}, \Box \Gamma_{12}), \Box \Gamma_{11}, \Delta_{13}), [\Box F_6] \vdash \Delta_8, [\Box F_9]} \quad A4 \\
\hline
- : (\Box \Gamma_{10}, \Box \Gamma_{12}), \Box \Gamma_{11}, \Delta_{13} \vdash \Delta_8, [\Box F_9] \quad \text{Cut} \\
\hline
\rightsquigarrow \\
\frac{- : \Box \Gamma_{10}, \Box \Gamma_{11} \vdash F_9 \quad \text{ax/W}}{- : \Delta_{13}, \Box \Gamma_{10}, \Box \Gamma_{11}, \Box \Gamma_{12} \vdash \Delta_8, [\Box F_9]} \quad A4 \\
\hline
\frac{h_2 : \Box \Gamma_{12}, \Box \Gamma_{14} \vdash F_8}{\bullet h_2 : (\Box \Gamma_{12}, \Box \Gamma_{14}), \Box \Gamma_{13}, \Delta_{15} \vdash ((\Delta_{11}, [\Box F_{10}]), [\Box F_8]), \Box F_7} \quad A4 \quad \frac{h_9 : \Box \Gamma_{12}, \Box \Gamma_{13}, \Box F_7 \vdash F_{10}}{\bullet h_9 : ((\Box \Gamma_{12}, \Box \Gamma_{14}), \Box \Gamma_{13}, \Delta_{15}), \Box F_7 \vdash (\Delta_{11}, [\Box F_{10}]), [\Box F_8]} \quad A4 \\
\hline
- : (\Box \Gamma_{12}, \Box \Gamma_{14}), \Box \Gamma_{13}, \Delta_{15} \vdash (\Delta_{11}, [\Box F_{10}]), [\Box F_8] \quad \text{Cut} \\
\hline
\rightsquigarrow \\
\frac{- : \Box \Gamma_{12}, \Box \Gamma_{14} \vdash F_8 \quad \text{ax/W}}{- : \Delta_{15}, \Box \Gamma_{12}, \Box \Gamma_{13}, \Box \Gamma_{14} \vdash \Delta_{11}, [\Box F_{10}], [\Box F_8]} \quad A4
\end{array}$$

$$\begin{array}{c}
\frac{\frac{h_2 : \Box\Gamma_{11}, \Box\Gamma_{13} \vdash F_{10}}{\bullet h_2 : (\Box\Gamma_{11}, \Box\Gamma_{13}), \Box\Gamma_{12}, \Delta_{14} \vdash (\Delta_9, \llbracket F_{10} \rrbracket, \Box F_7)} A4}{- : (\Box\Gamma_{11}, \Box\Gamma_{13}), \Box\Gamma_{12}, \Delta_{14} \vdash \Delta_9, \llbracket F_{10} \rrbracket} A4 \\
\Downarrow \\
\frac{\frac{- : \Box\Gamma_{11}, \Box\Gamma_{13} \vdash F_{10}}{- : \Delta_{14}, \Box\Gamma_{11}, \Box\Gamma_{12}, \Box\Gamma_{13} \vdash \Delta_9, \llbracket F_{10} \rrbracket} ax/W}{- : \Box\Gamma_{11}, \Box\Gamma_{13} \vdash F_{10}} A4 \\
\\
\frac{\frac{h_2 : \Box\Gamma_{12}, \Box\Gamma_{14} \vdash F_8}{\bullet h_2 : (\Box\Gamma_{12}, \Box\Gamma_{14}), \Box\Gamma_{13}, \Delta_{15} \vdash ((\Delta_{11}, \llbracket F_{10} \rrbracket, \Box F_8), F_7)} A4}{- : (\Box\Gamma_{12}, \Box\Gamma_{14}), \Box\Gamma_{13}, \Delta_{15} \vdash (\Delta_{11}, \llbracket F_{10} \rrbracket, \Box F_8)} A4 \\
\Downarrow \\
\frac{\frac{- : \Box\Gamma_{12}, \Box\Gamma_{13} \vdash F_{10}}{- : \Delta_{15}, \Box\Gamma_{12}, \Box\Gamma_{13}, \Box\Gamma_{14} \vdash \Delta_{11}, \llbracket F_{10} \rrbracket, \Box F_8} ax/W}{- : \Delta_{15}, \Box\Gamma_{12}, \Box\Gamma_{13}, \Box\Gamma_{14} \vdash \Delta_{11}, \llbracket F_{10} \rrbracket, \Box F_8} A4 \\
\\
\frac{\frac{h_2 : \Box\Gamma_{11}, \Box\Gamma_{13} \vdash F_{10}}{\bullet h_2 : (\Box\Gamma_{11}, \Box\Gamma_{13}), \Box\Gamma_{12}, \Delta_{14} \vdash (\Delta_9, \llbracket F_{10} \rrbracket, F_7)} A4}{- : (\Box\Gamma_{11}, \Box\Gamma_{13}), \Box\Gamma_{12}, \Delta_{14} \vdash \Delta_9, \llbracket F_{10} \rrbracket} A4 \\
\Downarrow \\
\frac{\frac{- : \Box\Gamma_{11}, \Box\Gamma_{12} \vdash F_{10}}{- : \Delta_{14}, \Box\Gamma_{11}, \Box\Gamma_{12}, \Box\Gamma_{13} \vdash \Delta_9, \llbracket F_{10} \rrbracket} ax/W}{- : \Box\Gamma_{11}, \Box\Gamma_{12} \vdash F_{10}} A4
\end{array}$$

$$\begin{array}{c}
\frac{\frac{h_1 : \Box \Gamma_6 \vdash F_7}{\bullet h_1 : \Box \Gamma_6, \Delta_{12}, F_9 \rightarrow F_{10} \vdash \Delta_{11}, [\Box F_7] A4} \quad A4}{\bullet h_8 : (\Box \Gamma_6, \Delta_{12}, F_9 \rightarrow F_{10}), [\Box F_7 \vdash \Delta_{11}] \text{Cut}} \rightarrow_L \\
\frac{}{- : \Box \Gamma_6, \Delta_{12}, F_9 \rightarrow F_{10} \vdash \Delta_{11}} \rightsquigarrow \\
\frac{\frac{\frac{h_1 : \Box \Gamma_6 \vdash F_7}{\bullet h_1 : \Delta_{12}, \Box \Gamma_6 \vdash \Delta_{11}, F_9, [\Box F_7] A4} \quad A4}{- : \Delta_{12}, \Box \Gamma_6 \vdash \Delta_{11}, F_9} \quad \frac{\frac{h_8 : \Delta_{12}, \Box \Gamma_6, [\Box F_7 \vdash \Delta_{11}, F_9] \text{ax/W}}{hCut} \quad \frac{\frac{h_1 : \Box \Gamma_6 \vdash F_7}{\bullet h_1 : \Delta_{12}, F_{10}, \Box \Gamma_6 \vdash \Delta_{11}, [\Box F_7] A4} \quad A4}{- : \Delta_{12}, F_{10}, \Box \Gamma_6 \vdash \Delta_{11}} \text{hCut}}{- : \Delta_{12}, \Box \Gamma_6, F_9 \rightarrow F_{10} \vdash \Delta_{11}} \rightarrow_L \\
\frac{\frac{h_2 : \Box \Gamma_7 \vdash F_{10}}{\bullet h_2 : \Box \Gamma_7, \Delta_8 \vdash (\Delta_9, [\Box F_{10}]), F_{12} \rightarrow F_{13}} \quad A4}{- : \Box \Gamma_7, \Delta_8 \vdash \Delta_9, [\Box F_{10}]} \quad \frac{\frac{h_{11} : \Box \Gamma_7, \Delta_8 \vdash F_{12}, \Delta_9, [\Box F_{10}] \quad h_{11} : \Box \Gamma_7, F_{13}, \Delta_8 \vdash \Delta_9, [\Box F_{10}]}{\bullet h_{11} : (\Box \Gamma_7, \Delta_8), F_{12} \rightarrow F_{13} \vdash \Delta_9, [\Box F_{10}]} \text{Cut}} \rightarrow_L \\
\frac{}{- : \Box \Gamma_7, \Delta_8 \vdash \Delta_9, [\Box F_{10}]} \rightsquigarrow \\
\frac{\frac{}{- : \Box \Gamma_7 \vdash F_{10}}{\text{ax/W}} \quad A4}{- : \Delta_8, \Box \Gamma_7 \vdash \Delta_9, [\Box F_{10}]} \quad A4 \\
\frac{\frac{h_2 : \Box \Gamma_7 \vdash F_{10}}{\bullet h_2 : \Box \Gamma_7, \Delta_{14}, F_{12} \rightarrow F_{13} \vdash (\Delta_9, [\Box F_{10}]), F_8} \quad A4}{- : \Box \Gamma_7, \Delta_{14}, F_{12} \rightarrow F_{13} \vdash \Delta_9, [\Box F_{10}]} \quad \frac{\frac{h_{11} : \Box \Gamma_7, F_8, \Delta_{14} \vdash F_{12}, \Delta_9, [\Box F_{10}] \quad h_{11} : \Box \Gamma_7, F_8, F_{13}, \Delta_{14} \vdash \Delta_9, [\Box F_{10}]}{\bullet h_{11} : (\Box \Gamma_7, \Delta_{14}, F_{12} \rightarrow F_{13}), F_8 \vdash \Delta_9, [\Box F_{10}]} \text{Cut}} \rightarrow_L \\
\frac{}{- : \Box \Gamma_7, \Delta_{14}, F_{12} \rightarrow F_{13} \vdash \Delta_9, [\Box F_{10}]} \rightsquigarrow \\
\frac{\frac{}{- : \Box \Gamma_7 \vdash F_{10}}{\text{ax/W}} \quad A4}{- : \Delta_{14}, \Box \Gamma_7, F_{12} \rightarrow F_{13} \vdash \Delta_9, [\Box F_{10}]} \quad A4
\end{array}$$

$$\begin{array}{c}
\frac{h_2 : \Box \Gamma_7 \vdash F_{10}}{\bullet h_2 : \Box \Gamma_7, \Delta_8 \vdash (\Delta_9, \Box F_{10}), F_{12} \wedge F_{13}} A4 \quad \frac{h_{11} : \Box \Gamma_7, F_{12}, F_{13}, \Delta_8 \vdash \Delta_9, \Box F_{10}}{\bullet h_{11} : (\Box \Gamma_7, \Delta_8), F_{12} \wedge F_{13} \vdash \Delta_9, \Box F_{10}} \wedge_L \\
\hline
- : \Box \Gamma_7, \Delta_8 \vdash \Delta_9, \Box F_{10} \quad \text{Cut} \\
\hline
\sim \\
\frac{\frac{}{- : \Box \Gamma_7 \vdash F_{10}} \text{ax/W}}{- : \Delta_8, \Box \Gamma_7 \vdash \Delta_9, \Box F_{10}} A4 \\
\hline
\frac{h_2 : \Box \Gamma_7 \vdash F_{10}}{\bullet h_2 : \Box \Gamma_7, \Delta_{14}, F_{12} \wedge F_{13} \vdash (\Delta_9, \Box F_{10}), F_8} A4 \quad \frac{h_{11} : \Box \Gamma_7, F_8, F_{12}, F_{13}, \Delta_{14} \vdash \Delta_9, \Box F_{10}}{\bullet h_{11} : (\Box \Gamma_7, \Delta_{14}, F_{12} \wedge F_{13}), F_8 \vdash \Delta_9, \Box F_{10}} \wedge_L \\
\hline
- : \Box \Gamma_7, \Delta_{14}, F_{12} \wedge F_{13} \vdash \Delta_9, \Box F_{10} \quad \text{Cut} \\
\hline
\sim \\
\frac{\frac{}{- : \Box \Gamma_7 \vdash F_{10}} \text{ax/W}}{- : \Delta_{14}, \Box \Gamma_7, F_{12} \wedge F_{13} \vdash \Delta_9, \Box F_{10}} A4
\end{array}$$

- Case rule \vee_L

$$\begin{array}{c}
\frac{h_1 : \Box \Gamma_6 \vdash F_7}{\bullet h_1 : \Box \Gamma_6, \Delta_{12}, F_9 \vee F_{10} \vdash \Delta_{11}, \Box F_7} A4 \quad \frac{h_8 : \Box \Gamma_6, F_9, \Delta_{12}, \Box F_7 \vdash \Delta_{11} \quad h_8 : \Box \Gamma_6, F_{10}, \Delta_{12}, \Box F_7 \vdash \Delta_{11}}{\bullet h_8 : (\Box \Gamma_6, \Delta_{12}, F_9 \vee F_{10}), \Box F_7 \vdash \Delta_{11}} \vee_L \\
\hline
- : \Box \Gamma_6, \Delta_{12}, F_9 \vee F_{10} \vdash \Delta_{11} \quad \text{Cut} \\
\hline
\sim \\
\frac{\frac{h_1 : \Box \Gamma_6 \vdash F_7}{\bullet h_1 : \Delta_{12}, F_9, \Box \Gamma_6 \vdash \Delta_{11}, \Box F_7} \text{ax/W} A4 \quad \frac{h_8 : \Delta_{12}, F_9, \Box \Gamma_6, \Box F_7 \vdash \Delta_{11}}{\bullet h_8 : \Delta_{12}, F_{10}, \Box \Gamma_6 \vdash \Delta_{11}, \Box F_7} \text{ax/W} \quad \frac{h_1 : \Box \Gamma_6 \vdash F_7}{\bullet h_1 : \Delta_{12}, F_{10}, \Box \Gamma_6 \vdash \Delta_{11}, \Box F_7} \text{ax/W} \quad \frac{h_8 : \Delta_{12}, F_{10}, \Box \Gamma_6, \Box F_7 \vdash \Delta_{11}}{\bullet h_8 : \Delta_{12}, F_{10}, \Box \Gamma_6 \vdash \Delta_{11}, \Box F_7} \text{hCut}}{- : \Delta_{12}, F_9, \Box \Gamma_6 \vdash \Delta_{11}} \vee_L \\
\hline
- : \Delta_{12}, \Box \Gamma_6, F_9 \vee F_{10} \vdash \Delta_{11} \\
\hline
\frac{h_2 : \Box \Gamma_7 \vdash F_{10}}{\bullet h_2 : \Box \Gamma_7, \Delta_8 \vdash (\Delta_9, \Box F_{10}), F_{12} \vee F_{13}} A4 \quad \frac{h_{11} : \Box \Gamma_7, F_{12}, \Delta_8 \vdash \Delta_9, \Box F_{10} \quad h_{11} : \Box \Gamma_7, F_{13}, \Delta_8 \vdash \Delta_9, \Box F_{10}}{\bullet h_{11} : (\Box \Gamma_7, \Delta_8), F_{12} \vee F_{13} \vdash \Delta_9, \Box F_{10}} \vee_L \\
\hline
- : \Box \Gamma_7, \Delta_8 \vdash \Delta_9, \Box F_{10} \quad \text{Cut} \\
\hline
\sim \\
\frac{\frac{}{- : \Box \Gamma_7 \vdash F_{10}} \text{ax/W}}{- : \Delta_8, \Box \Gamma_7 \vdash \Delta_9, \Box F_{10}} A4 \\
\hline
\frac{h_2 : \Box \Gamma_7 \vdash F_{10}}{\bullet h_2 : \Box \Gamma_7, \Delta_{14}, F_{12} \vee F_{13} \vdash (\Delta_9, \Box F_{10}), F_8} A4 \quad \frac{h_{11} : \Box \Gamma_7, F_8, F_{12}, \Delta_{14} \vdash \Delta_9, \Box F_{10} \quad h_{11} : \Box \Gamma_7, F_8, F_{13}, \Delta_{14} \vdash \Delta_9, \Box F_{10}}{\bullet h_{11} : (\Box \Gamma_7, \Delta_{14}, F_{12} \vee F_{13}), F_8 \vdash \Delta_9, \Box F_{10}} \vee_L \\
\hline
- : \Box \Gamma_7, \Delta_{14}, F_{12} \vee F_{13} \vdash \Delta_9, \Box F_{10} \quad \text{Cut} \\
\hline
\sim \\
\frac{\frac{}{- : \Box \Gamma_7 \vdash F_{10}} \text{ax/W}}{- : \Delta_{14}, \Box \Gamma_7, F_{12} \vee F_{13} \vdash \Delta_9, \Box F_{10}} A4
\end{array}$$

- Case rule AT

$$\begin{array}{c}
\frac{h_1 : \Box \Gamma_{11}, \Box F_9 \vdash F_7}{\bullet h_1 : (\Box \Gamma_{11}, \Box F_9), \Delta_6 \vdash \Delta_{10}, \Box F_7} A4 \quad \frac{h_8 : \Box \Gamma_{11}, F_9, \Delta_6, \Box F_7, \Box F_9 \vdash \Delta_{10}}{\bullet h_8 : ((\Box \Gamma_{11}, \Box F_9), \Delta_6), \Box F_7 \vdash \Delta_{10}} AT \\
\hline
- : (\Box \Gamma_{11}, \Box F_9), \Delta_6 \vdash \Delta_{10} \quad \text{Cut} \\
\hline
\sim \\
\frac{\frac{h_1 : \Delta_6, F_9, \Box \Gamma_{11}, \Box F_9 \vdash \Delta_{10}, \Box F_7}{\bullet h_1 : \Delta_6, F_9, \Box \Gamma_{11}, \Box F_9 \vdash \Delta_{10}, \Box F_7} \text{ax/W} \quad \frac{h_8 : \Delta_6, F_9, \Box \Gamma_{11}, \Box F_7, \Box F_9 \vdash \Delta_{10}}{\bullet h_8 : \Delta_6, F_9, \Box \Gamma_{11}, \Box F_9 \vdash \Delta_{10}} \text{ax/W}}{- : \Delta_6, F_9, \Box \Gamma_{11}, \Box F_9 \vdash \Delta_{10}} \text{hCut} \\
\hline
- : \Delta_6, \Box \Gamma_{11}, \Box F_9 \vdash \Delta_{10} \quad AT \\
\hline
\frac{h_1 : \Box \Gamma_6 \vdash F_7}{\bullet h_1 : \Box \Gamma_6, \Delta_{11}, \Box F_9 \vdash \Delta_{10}, \Box F_7} A4 \quad \frac{h_8 : \Box \Gamma_6, F_9, \Delta_{11}, \Box F_7, \Box F_9 \vdash \Delta_{10}}{\bullet h_8 : (\Box \Gamma_6, \Delta_{11}, \Box F_9), \Box F_7 \vdash \Delta_{10}} AT \\
\hline
- : \Box \Gamma_6, \Delta_{11}, \Box F_9 \vdash \Delta_{10} \quad \text{Cut} \\
\hline
\sim \\
\frac{\frac{h_1 : \Delta_{11}, F_9, \Box \Gamma_6, \Box F_9 \vdash \Delta_{10}, \Box F_7}{\bullet h_1 : \Delta_{11}, F_9, \Box \Gamma_6, \Box F_9 \vdash \Delta_{10}, \Box F_7} \text{ax/W} \quad \frac{h_8 : \Delta_{11}, F_9, \Box \Gamma_6, \Box F_7, \Box F_9 \vdash \Delta_{10}}{\bullet h_8 : \Delta_{11}, F_9, \Box \Gamma_6, \Box F_9 \vdash \Delta_{10}} \text{ax/W}}{- : \Delta_{11}, F_9, \Box \Gamma_6, \Box F_9 \vdash \Delta_{10}} \text{hCut} \\
\hline
- : \Delta_{11}, \Box \Gamma_6, \Box F_9 \vdash \Delta_{10} \quad AT
\end{array}$$

$$\begin{array}{c}
\frac{\frac{h_1 : \Box \Gamma_6 \vdash F_9}{\bullet h_1 : \Box \Gamma_6, \Delta_7 \vdash \Delta_{10}, [\Box F_9]} A4 \quad \frac{h_8 : \Box \Gamma_6, F_9, \Delta_7, [\Box F_9 \vdash \Delta_{10}] AT}{\bullet h_8 : (\Box \Gamma_6, \Delta_7), [\Box F_9 \vdash \Delta_{10}] AT} AT}{- : \Box \Gamma_6, \Delta_7 \vdash \Delta_{10}} Cut \\
\sim\!\!\sim \\
\frac{\frac{- : \Delta_7, \Box \Gamma_6 \vdash \Delta_{10}, F_9}{- : \Delta_7, \Box \Gamma_6 \vdash \Delta_{10}} ax/W \quad \frac{\frac{\bullet h_1 : \Delta_7, F_9, \Box \Gamma_6 \vdash \Delta_{10}, [\Box F_9]}{ax/W} \quad \frac{h_8 : \Delta_7, F_9, \Box \Gamma_6, [\Box F_9 \vdash \Delta_{10}] ax/W}{- : \Delta_7, F_9, \Box \Gamma_6 \vdash \Delta_{10}} hCut}{- : \Delta_7, \Box \Gamma_6 \vdash \Delta_{10}} sCut \\
\\
\frac{\frac{h_2 : \Box \Gamma_{13}, [\Box F_{12} \vdash F_{10}]}{\bullet h_2 : (\Box \Gamma_{13}, [\Box F_{12}]), \Delta_8 \vdash (\Delta_9, [\Box F_{10}]), F_7} A4 \quad \frac{h_{11} : \Box \Gamma_{13}, F_7, F_{12}, \Delta_8, [\Box F_{12} \vdash \Delta_9, [\Box F_{10}]] AT}{\bullet h_{11} : ((\Box \Gamma_{13}, [\Box F_{12}]), \Delta_8), F_7 \vdash \Delta_9, [\Box F_{10}]] AT} AT}{- : (\Box \Gamma_{13}, [\Box F_{12}]), \Delta_8 \vdash \Delta_9, [\Box F_{10}]} Cut \\
\sim\!\!\sim \\
\frac{- : \Box \Gamma_{13}, [\Box F_{12} \vdash F_{10}]}{- : \Delta_8, \Box \Gamma_{13}, [\Box F_{12} \vdash \Delta_9, [\Box F_{10}]]} ax/W \quad A4 \\
\\
\frac{\frac{h_2 : \Box \Gamma_7 \vdash F_{10}}{\bullet h_2 : \Box \Gamma_7, \Delta_8 \vdash (\Delta_9, [\Box F_{10}]), [\Box F_{12}]} A4 \quad \frac{h_{11} : \Box \Gamma_7, F_{12}, \Delta_8, [\Box F_{12} \vdash \Delta_9, [\Box F_{10}]] AT}{\bullet h_{11} : (\Box \Gamma_7, \Delta_8), [\Box F_{12} \vdash \Delta_9, [\Box F_{10}]] AT} AT}{- : \Box \Gamma_7, \Delta_8 \vdash \Delta_9, [\Box F_{10}]} Cut \\
\sim\!\!\sim \\
\frac{- : \Box \Gamma_7 \vdash F_{10}}{- : \Delta_8, \Box \Gamma_7 \vdash \Delta_9, [\Box F_{10}]]} ax/W \quad A4 \\
\\
\frac{\frac{h_2 : \Box \Gamma_7 \vdash F_{10}}{\bullet h_2 : \Box \Gamma_7, \Delta_{13}, [\Box F_{12} \vdash (\Delta_9, [\Box F_{10}]), F_8]} A4 \quad \frac{h_{11} : \Box \Gamma_7, F_8, F_{12}, \Delta_{13}, [\Box F_{12} \vdash \Delta_9, [\Box F_{10}]] AT}{\bullet h_{11} : (\Box \Gamma_7, \Delta_{13}, [\Box F_{12}]), F_8 \vdash \Delta_9, [\Box F_{10}]] AT} AT}{- : \Box \Gamma_7, \Delta_{13}, [\Box F_{12} \vdash \Delta_9, [\Box F_{10}]]} Cut \\
\sim\!\!\sim \\
\frac{- : \Box \Gamma_7 \vdash F_{10}}{- : \Delta_{13}, \Box \Gamma_7, [\Box F_{12} \vdash \Delta_9, [\Box F_{10}]]} ax/W \quad A4
\end{array}$$

- Case rule \perp_L

$$\begin{array}{c}
\frac{\frac{h_1 : \Box \Gamma_6 \vdash F_7}{\bullet h_1 : \Box \Gamma_6, \perp, \Delta_{10} \vdash \Delta_9, [\Box F_7]} A4 \quad \frac{}{\bullet h_8 : (\Box \Gamma_6, \perp, \Delta_{10}), [\Box F_7 \vdash \Delta_9]} \perp_L}{- : \Box \Gamma_6, \perp, \Delta_{10} \vdash \Delta_9} Cut \\
\sim\!\!\sim \\
\frac{}{- : \perp, \Delta_{10}, \Box \Gamma_6 \vdash \Delta_9} \perp_L \\
\\
\frac{\frac{h_2 : \Box \Gamma_7 \vdash F_{10}}{\bullet h_2 : \Box \Gamma_7, \Delta_8 \vdash (\Delta_9, [\Box F_{10}]), \perp} A4 \quad \frac{}{\bullet h_{11} : (\Box \Gamma_7, \Delta_8), \perp \vdash \Delta_9, [\Box F_{10}]} \perp_L}{- : \Box \Gamma_7, \Delta_8 \vdash \Delta_9, [\Box F_{10}]} Cut \\
\sim\!\!\sim \\
\frac{- : \Box \Gamma_7 \vdash F_{10}}{- : \Delta_8, \Box \Gamma_7 \vdash \Delta_9, [\Box F_{10}]]} ax/W \quad A4 \\
\\
\frac{\frac{h_2 : \Box \Gamma_7 \vdash F_{10}}{\bullet h_2 : \Box \Gamma_7, \perp, \Delta_{12} \vdash (\Delta_9, [\Box F_{10}]), F_8} A4 \quad \frac{}{\bullet h_{11} : (\Box \Gamma_7, \perp, \Delta_{12}), F_8 \vdash \Delta_9, [\Box F_{10}]} \perp_L}{- : \Box \Gamma_7, \perp, \Delta_{12} \vdash \Delta_9, [\Box F_{10}]} Cut \\
\sim\!\!\sim \\
\frac{}{- : \perp, \Delta_{12}, \Box \Gamma_7 \vdash \Delta_9, [\Box F_{10}]]} \perp_L
\end{array}$$

- Case rule I

$$\frac{\frac{h_1 : \Box \Gamma_6 \vdash F_7}{\bullet h_1 : \Box \Gamma_6, \Delta_{11}, p_9 \vdash (\Delta_{10}, p_9), [\Box F_7]} A4 \quad \frac{}{\bullet h_8 : (\Box \Gamma_6, \Delta_{11}, p_9), [\Box F_7 \vdash \Delta_{10}, p_9]} I}{- : \Box \Gamma_6, \Delta_{11}, p_9 \vdash \Delta_{10}, p_9} Cut \\
\sim\!\!\sim \\
\frac{}{- : \Delta_{11}, \Box \Gamma_6, p_9 \vdash \Delta_{10}, p_9} I$$

$$\begin{array}{c}
\frac{h_2 : \Box \Gamma_7 \vdash F_9}{\bullet h_2 : \Box \Gamma_7, \Delta_8 \vdash ((\Delta_{12}, p_{11}), [F_9], p_{11})} A4 \quad \frac{\bullet h_{10} : (\Box \Gamma_7, \Delta_8), p_{11} \vdash (\Delta_{12}, p_{11}), [F_9]}{I} \\
\hline
- : \Box \Gamma_7, \Delta_8 \vdash (\Delta_{12}, p_{11}), [F_9] \quad \text{Cut} \\
\hline
\sim \\
\frac{\frac{}{- : \Box \Gamma_7 \vdash F_9} \text{ax/W}}{- : \Delta_8, \Box \Gamma_7 \vdash \Delta_{12}, p_{11}, [F_9]} A4 \\
\hline
\frac{h_2 : \Box \Gamma_7 \vdash F_9}{\bullet h_2 : \Box \Gamma_7, \Delta_{13}, p_{11} \vdash ((\Delta_{12}, p_{11}), [F_9], F_8)} A4 \quad \frac{\bullet h_{10} : (\Box \Gamma_7, \Delta_{13}, p_{11}), F_8 \vdash (\Delta_{12}, p_{11}), [F_9]}{I} \\
\hline
- : \Box \Gamma_7, \Delta_{13}, p_{11} \vdash (\Delta_{12}, p_{11}), [F_9] \quad \text{Cut} \\
\hline
\sim \\
\frac{}{- : \Delta_{13}, \Box \Gamma_7, p_{11} \vdash \Delta_{12}, p_{11}, [F_9]} I
\end{array}$$

- Case rule \top_L

$$\begin{array}{c}
\frac{h_1 : \Box \Gamma_6 \vdash F_7}{\bullet h_1 : \Box \Gamma_6, \top, \Delta_{10} \vdash \Delta_9, [F_7]} A4 \quad \frac{h_8 : \Box \Gamma_6, \Delta_{10}, [F_7] \vdash \Delta_9}{\bullet h_8 : (\Box \Gamma_6, \top, \Delta_{10}), [F_7] \vdash \Delta_9} \top_L \\
\hline
- : \Box \Gamma_6, \top, \Delta_{10} \vdash \Delta_9 \quad \text{Cut} \\
\hline
\sim \\
\frac{\frac{}{\bullet h_1 : \top, \Delta_{10}, \Box \Gamma_6 \vdash \Delta_9, [F_7]} \text{ax/W} \quad \frac{h_8 : \top, \Delta_{10}, \Box \Gamma_6, [F_7] \vdash \Delta_9}{h_8} \text{ax/W}}{- : \top, \Delta_{10}, \Box \Gamma_6 \vdash \Delta_9} \text{hCut} \\
\hline
\frac{h_2 : \Box \Gamma_7 \vdash F_{10}}{\bullet h_2 : \Box \Gamma_7, \Delta_8 \vdash (\Delta_9, [F_{10}]), \top} A4 \quad \frac{h_{11} : \Box \Gamma_7, \Delta_8 \vdash \Delta_9, [F_{10}]}{\bullet h_{11} : (\Box \Gamma_7, \Delta_8), \top \vdash \Delta_9, [F_{10}]} \top_L \\
\hline
- : \Box \Gamma_7, \Delta_8 \vdash \Delta_9, [F_{10}] \quad \text{Cut} \\
\hline
\sim \\
\frac{}{- : \Delta_8, \Box \Gamma_7 \vdash \Delta_9, [F_{10}]} \text{ax/W} \\
\hline
\frac{h_2 : \Box \Gamma_7 \vdash F_{10}}{\bullet h_2 : \Box \Gamma_7, \top, \Delta_{12} \vdash (\Delta_9, [F_{10}]), F_8} A4 \quad \frac{h_{11} : \Box \Gamma_7, F_8, \Delta_{12} \vdash \Delta_9, [F_{10}]}{\bullet h_{11} : (\Box \Gamma_7, \top, \Delta_{12}), F_8 \vdash \Delta_9, [F_{10}]} \top_L \\
\hline
- : \Box \Gamma_7, \top, \Delta_{12} \vdash \Delta_9, [F_{10}] \quad \text{Cut} \\
\hline
\sim \\
\frac{}{- : \Box \Gamma_7 \vdash F_{10}} \text{ax/W} \\
\hline
\frac{}{- : \top, \Delta_{12}, \Box \Gamma_7 \vdash \Delta_9, [F_{10}]} A4
\end{array}$$

8.7 Status of \rightarrow_L : OK

- Case rule \rightarrow_R

$$\begin{array}{c}
\frac{h_3 : \Delta_8 \vdash F_7, F_9, \Delta_{12}, F_{13} \rightarrow F_{14} \quad h_3 : F_{10}, \Delta_8 \vdash F_7, \Delta_{12}, F_{13} \rightarrow F_{14}}{\bullet h_3 : \Delta_8, F_9 \rightarrow F_{10} \vdash (\Delta_{12}, F_{13} \rightarrow F_{14}), F_7} \rightarrow_L \quad \frac{h_{11} : F_7, F_{13}, \Delta_8, F_9 \rightarrow F_{10} \vdash F_{14}, \Delta_{12}}{\bullet h_{11} : (\Delta_8, F_9 \rightarrow F_{10}), F_7 \vdash \Delta_{12}, F_{13} \rightarrow F_{14}} \rightarrow_R \\
\hline
- : \Delta_8, F_9 \rightarrow F_{10} \vdash \Delta_{12}, F_{13} \rightarrow F_{14} \quad \text{Cut} \\
\hline
\sim \\
\frac{\frac{h_3 : \Delta_8, F_{13} \vdash \Delta_{12}, F_{14}, F_7, F_9}{\bullet h_3 : \Delta_8, F_{13}, F_9 \rightarrow F_{10} \vdash \Delta_{12}, F_{14}, F_7} \text{inv-th/ax} \quad \frac{h_3 : \Delta_8, F_{10}, F_{13} \vdash \Delta_{12}, F_{14}, F_7}{\rightarrow_L} \text{inv-th/ax}}{\frac{- : \Delta_8, F_{13}, F_9 \rightarrow F_{10} \vdash \Delta_{12}, F_{14}}{- : \Delta_8, F_9 \rightarrow F_{10} \vdash \Delta_{12}, F_{13} \rightarrow F_{14}} \rightarrow_R} \text{ax/W} \\
\hline
\text{hCut}
\end{array}$$

- Case rule \wedge_R

$$\begin{array}{c}
\frac{h_3 : \Delta_8 \vdash F_7, F_9, \Delta_{12}, F_{13} \wedge F_{14} \quad h_3 : F_{10}, \Delta_8 \vdash F_7, \Delta_{12}, F_{13} \wedge F_{14}}{\bullet h_3 : \Delta_8, F_9 \rightarrow F_{10} \vdash (\Delta_{12}, F_{13} \wedge F_{14}), F_7} \rightarrow_L \quad \frac{h_{11} : F_7, \Delta_8, F_9 \rightarrow F_{10} \vdash F_{13}, \Delta_{12}}{\bullet h_{11} : (\Delta_8, F_9 \rightarrow F_{10}), F_7 \vdash \Delta_{12}, F_{13} \wedge F_{14}} \rightarrow_R \\
\hline
- : \Delta_8, F_9 \rightarrow F_{10} \vdash \Delta_{12}, F_{13} \wedge F_{14} \\
\hline
\sim \\
\frac{\frac{h_3 : \Delta_8 \vdash \Delta_{12}, F_{13}, F_7, F_9}{\bullet h_3 : \Delta_8, F_9 \rightarrow F_{10} \vdash \Delta_{12}, F_{13}, F_7} \text{inv-th/ax} \quad \frac{h_3 : \Delta_8, F_{10} \vdash \Delta_{12}, F_{13}, F_7}{\rightarrow_L} \text{inv-th/ax}}{\frac{- : \Delta_8, F_9 \rightarrow F_{10} \vdash \Delta_{12}, F_{13}}{- : \Delta_8, F_9 \rightarrow F_{10} \vdash \Delta_{12}, F_{13} \wedge F_{14}} \text{ax/W}} \text{hCut} \\
\hline
\text{inv}
\end{array}$$

- Case rule \vee_R

$$\begin{array}{c}
\frac{h_3 : \Delta_8 \vdash F_7, F_9, \Delta_{12}, F_{13} \vee F_{14} \quad h_3 : F_{10}, \Delta_8 \vdash F_7, \Delta_{12}, F_{13} \vee F_{14}}{\bullet h_3 : \Delta_8, F_9 \rightarrow F_{10} \vdash (\Delta_{12}, F_{13} \vee F_{14}), F_7} \rightarrow_L \quad \frac{h_{11} : F_7, \Delta_8, F_9 \rightarrow F_{10} \vdash F_{13}, F_{14}, \Delta_{12}}{\bullet h_{11} : (\Delta_8, F_9 \rightarrow F_{10}), F_7 \vdash \Delta_{12}, F_{13} \vee F_{14}} \vee_R \\
\frac{}{- : \Delta_8, F_9 \rightarrow F_{10} \vdash \Delta_{12}, F_{13} \vee F_{14}} \text{Cut} \\
\sim \\
\frac{\frac{h_3 : \Delta_8 \vdash \Delta_{12}, F_{13}, F_{14}, F_7, F_9}{\bullet h_3 : \Delta_8, F_9 \rightarrow F_{10} \vdash \Delta_{12}, F_{13}, F_{14}, F_7} \text{inv-th/ax} \quad \frac{h_3 : \Delta_8, F_{10} \vdash \Delta_{12}, F_{13}, F_{14}, F_7}{\bullet h_{11} : \Delta_8, F_7, F_9 \rightarrow F_{10} \vdash \Delta_{12}, F_{13}, F_{14}} \text{inv-th/ax}}{\frac{}{- : \Delta_8, F_9 \rightarrow F_{10} \vdash \Delta_{12}, F_{13}, F_{14}} \vee_R} \text{ax/W} \\
\frac{}{- : \Delta_8, F_9 \rightarrow F_{10} \vdash \Delta_{12}, F_{13} \vee F_{14}} \text{hCut}
\end{array}$$

- Case rule \perp_R

$$\begin{array}{c}
\frac{h_3 : \Delta_8 \vdash F_7, F_9, \perp, \Delta_{12} \quad h_3 : F_{10}, \Delta_8 \vdash F_7, \perp, \Delta_{12}}{\bullet h_3 : \Delta_8, F_9 \rightarrow F_{10} \vdash (\perp, \Delta_{12}), F_7} \rightarrow_L \quad \frac{h_{11} : F_7, \Delta_8, F_9 \rightarrow F_{10} \vdash \Delta_{12}}{\bullet h_{11} : (\Delta_8, F_9 \rightarrow F_{10}), F_7 \vdash \perp, \Delta_{12}} \perp_R \\
\frac{}{- : \Delta_8, F_9 \rightarrow F_{10} \vdash \perp, \Delta_{12}} \text{Cut} \\
\sim \\
\frac{\frac{\bullet h_3 : \Delta_8, F_9 \rightarrow F_{10} \vdash \perp, \Delta_{12}, F_7}{\bullet h_3 : \Delta_8, F_9 \rightarrow F_{10} \vdash \perp, \Delta_{12}} \text{ax/W} \quad \frac{h_{11} : \Delta_8, F_7, F_9 \rightarrow F_{10} \vdash \perp, \Delta_{12}}{\bullet h_{11} : \Delta_8, F_7, F_9 \rightarrow F_{10} \vdash \perp, \Delta_{12}} \text{ax/W}}{\frac{}{- : \Delta_8, F_9 \rightarrow F_{10} \vdash \perp, \Delta_{12}} \text{hCut}}
\end{array}$$

- Case rule \top_R

$$\begin{array}{c}
\frac{h_3 : \Delta_8 \vdash F_7, F_9, \top, \Delta_{12} \quad h_3 : F_{10}, \Delta_8 \vdash F_7, \top, \Delta_{12}}{\bullet h_3 : \Delta_8, F_9 \rightarrow F_{10} \vdash (\top, \Delta_{12}), F_7} \rightarrow_L \quad \frac{}{\bullet h_{11} : (\Delta_8, F_9 \rightarrow F_{10}), F_7 \vdash \top, \Delta_{12}} \top_R \\
\frac{}{- : \Delta_8, F_9 \rightarrow F_{10} \vdash \top, \Delta_{12}} \text{Cut} \\
\sim \\
\frac{}{- : \Delta_8, F_9 \rightarrow F_{10} \vdash \top, \Delta_{12}} \top_R
\end{array}$$

- Case rule $A4$

$$\begin{array}{c}
\frac{h_3 : \Box \Gamma_{13}, \Delta_{14} \vdash \Box F_7, F_8, \Delta_{11}, \Box F_{12} \quad h_3 : F_9, \Box \Gamma_{13}, \Delta_{14} \vdash \Box F_7, \Delta_{11}, \Box F_{12}}{\bullet h_3 : (\Box \Gamma_{13}, \Delta_{14}), F_8 \rightarrow F_9 \vdash (\Delta_{11}, \Box F_{12}), \Box F_7} \rightarrow_L \quad \frac{h_{10} : \Box \Gamma_{13}, \Box F_7 \vdash F_{12}}{\bullet h_{10} : ((\Box \Gamma_{13}, \Delta_{14}), F_8 \rightarrow F_9), \Box F_7 \vdash \Delta_{11}, \Box F_{12}} \text{Cut} \\
\frac{}{- : (\Box \Gamma_{13}, \Delta_{14}), F_8 \rightarrow F_9 \vdash \Delta_{11}, \Box F_{12}} \sim \\
\frac{\frac{h_3 : \Delta_{14}, \Box \Gamma_{13} \vdash \Box F_7, \Delta_{11}, F_8, \Box F_{12}}{\bullet h_{10} : \Box F_7, \Delta_{14}, \Box \Gamma_{13} \vdash \Delta_{11}, F_8, \Box F_{12}} \text{ax/W} \quad \frac{h_{10} : \Box F_7, \Box \Gamma_{13} \vdash F_{12}}{\bullet h_{10} : \Box F_7, \Delta_{14}, \Box \Gamma_{13} \vdash \Delta_{11}, F_8, \Box F_{12}} \text{ax/W}}{\frac{}{- : \Delta_{14}, \Box \Gamma_{13} \vdash \Delta_{11}, F_8, \Box F_{12}} \text{hCut}} \text{A4} \\
\frac{}{- : \Delta_{14}, \Box \Gamma_{13}, F_8 \rightarrow F_9 \vdash \Delta_{11}, \Box F_{12}} \sim \\
\frac{h_3 : \Box \Gamma_{11}, \Delta_{14} \vdash F_7, F_8, \Delta_{12}, \Box F_{13} \quad h_3 : F_9, \Box \Gamma_{11}, \Delta_{14} \vdash F_7, \Delta_{12}, \Box F_{13}}{\bullet h_3 : (\Box \Gamma_{11}, \Delta_{14}), F_8 \rightarrow F_9 \vdash (\Delta_{12}, \Box F_{13}), F_7} \rightarrow_L \quad \frac{h_{10} : \Box \Gamma_{11} \vdash F_{13}}{\bullet h_{10} : ((\Box \Gamma_{11}, \Delta_{14}), F_8 \rightarrow F_9), F_7 \vdash \Delta_{12}, \Box F_{13}} \text{Cut} \\
\frac{}{- : (\Box \Gamma_{11}, \Delta_{14}), F_8 \rightarrow F_9 \vdash \Delta_{12}, \Box F_{13}} \sim \\
\frac{}{- : \Box \Gamma_{11} \vdash F_{13}} \text{ax/W} \text{A4} \\
\frac{}{- : \Delta_{14}, \Box \Gamma_{11}, F_8 \rightarrow F_9 \vdash \Delta_{12}, \Box F_{13}}
\end{array}$$

- Case rule \rightarrow_L

$$\begin{array}{c}
\frac{h_3 : \Delta_7 \vdash F_{11} \rightarrow F_{12}, F_8, \Delta_{13} \quad h_3 : F_9, \Delta_7 \vdash F_{11} \rightarrow F_{12}, \Delta_{13}}{\bullet h_3 : \Delta_7, F_8 \rightarrow F_9 \vdash \Delta_{13}, F_{11} \rightarrow F_{12}} \rightarrow_L \quad \frac{h_{10} : \Delta_7, F_8 \rightarrow F_9 \vdash F_{11}, \Delta_{13} \quad h_{10} : F_{12}, \Delta_7, F_8 \rightarrow F_9 \vdash \Delta_{13}}{\bullet h_{10} : (\Delta_7, F_8 \rightarrow F_9), F_{11} \rightarrow F_{12} \vdash \Delta_{13}} \text{Cut} \\
\frac{}{- : \Delta_7, F_8 \rightarrow F_9 \vdash \Delta_{13}} \sim \\
\frac{\frac{}{- : \Delta_7, F_{11} \vdash \Delta_{13}, F_{12}, F_8} \text{inv-th/ax} \quad \frac{}{- : \Delta_7, F_{11}, F_9 \vdash \Delta_{13}, F_{12}} \text{inv-th/ax}}{\frac{}{- : \Delta_7, F_{11}, F_8 \rightarrow F_9 \vdash \Delta_{13}, F_{12}} \rightarrow_L} \text{ax/W} \\
\frac{}{- : \Delta_7, F_8 \rightarrow F_9 \vdash \Delta_{13}, F_{11}} \text{ax/W} \quad \frac{}{- : \Delta_7, F_{11}, F_8 \rightarrow F_9 \vdash \Delta_{13}} \text{sCut} \\
\frac{}{- : \Delta_7, F_8 \rightarrow F_9 \vdash \Delta_{13}}
\end{array}$$

$$\begin{array}{c}
\frac{\frac{h_3 : \Delta_{14}, F_{11} \rightarrow F_{12} \vdash F_7, F_8, \Delta_{13} \quad h_3 : F_9, \Delta_{14}, F_{11} \rightarrow F_{12} \vdash F_7, \Delta_{13}}{\bullet h_3 : (\Delta_{14}, F_{11} \rightarrow F_{12}), F_8 \rightarrow F_9 \vdash \Delta_{13}, F_7} \rightarrow_L \quad \frac{h_{10} : F_7, \Delta_{14}, F_8 \rightarrow F_9 \vdash F_{11}, \Delta_{13}}{\bullet h_{10} : ((\Delta_{14}, F_{11} \rightarrow F_{12}), F_8 \rightarrow F_9) \vdash \Delta_{13}} \rightarrow_L}{- : (\Delta_{14}, F_{11} \rightarrow F_{12}), F_8 \rightarrow F_9 \vdash \Delta_{13}} \sim \\
\frac{\frac{\frac{h_3 : \Delta_{14} \vdash \Delta_{13}, F_{11}, F_7, F_8}{\bullet h_3 : \Delta_{14}, F_8 \rightarrow F_9 \vdash \Delta_{13}, F_{11}, F_7} \text{ inv-th/ax} \quad \frac{h_3 : \Delta_{14}, F_9 \vdash \Delta_{13}, F_{11}, F_7}{\rightarrow_L} \text{ inv-th/ax}}{\rightarrow_L} \quad \frac{h_{10} : \Delta_{14}, F_7, F_8 \rightarrow F_9 \vdash \Delta_{13}, F_{11}}{\text{ax/W}} \quad \frac{h_3 : \Delta_{14}, F_{12} \vdash \Delta_{13}, F_7, F_8}{\bullet h_3 : \Delta_{14}, F_{12} \vdash \Delta_{13}, F_7, F_8} \text{ i}}{\frac{- : \Delta_{14}, F_8 \rightarrow F_9 \vdash \Delta_{13}, F_{11}}{- : \Delta_{14}, F_{11} \rightarrow F_{12}, F_8 \rightarrow F_9 \vdash \Delta_{13}} \text{ hCut}} \\
\frac{\frac{h_3 : \Delta_8 \vdash F_7, F_{10}, \Delta_{12} \quad h_3 : F_{11}, \Delta_8 \vdash F_7, \Delta_{12}}{\bullet h_3 : \Delta_8, F_{10} \rightarrow F_{11} \vdash \Delta_{12}, F_7} \rightarrow_L \quad \frac{h_9 : F_7, \Delta_8 \vdash F_{10}, \Delta_{12} \quad h_9 : F_7, F_{11}, \Delta_8 \vdash \Delta_{12}}{\bullet h_9 : (\Delta_8, F_{10} \rightarrow F_{11}), F_7 \vdash \Delta_{12}} \rightarrow_L}{- : \Delta_8, F_{10} \rightarrow F_{11} \vdash \Delta_{12}} \text{ Cut} \\
\frac{\frac{h_3 : \Delta_8 \vdash \Delta_{12}, F_{10}, F_7}{\rightarrow_L} \text{ ax/W} \quad \frac{h_9 : \Delta_8, F_7 \vdash \Delta_{12}, F_{10}}{\bullet h_9 : \Delta_8, F_7 \vdash \Delta_{12}, F_{10}} \text{ H}}{\rightarrow_L} \quad \frac{h_3 : \Delta_8, F_{11} \vdash \Delta_{12}, F_7}{\rightarrow_L} \text{ ax/W} \quad \frac{h_9 : \Delta_8, F_{11}, F_7 \vdash \Delta_{12}}{\bullet h_9 : \Delta_8, F_{11}, F_7 \vdash \Delta_{12}} \text{ H}}{\rightarrow_L} \text{ hCut}
\end{array}$$

- Case rule \wedge_L

$$\begin{array}{c}
\frac{\frac{h_3 : \Delta_7 \vdash F_{11} \wedge F_{12}, F_8, \Delta_{13} \quad h_3 : F_9, \Delta_7 \vdash F_{11} \wedge F_{12}, \Delta_{13}}{\bullet h_3 : \Delta_7, F_8 \rightarrow F_9 \vdash \Delta_{13}, F_{11} \wedge F_{12}} \rightarrow_L \quad \frac{h_{10} : F_{11}, F_{12}, \Delta_7, F_8 \rightarrow F_9 \vdash \Delta_{13}}{\bullet h_{10} : (\Delta_7, F_8 \rightarrow F_9), F_{11} \wedge F_{12} \vdash \Delta_{13}} \wedge_L}{- : \Delta_7, F_8 \rightarrow F_9 \vdash \Delta_{13}} \text{ Cut} \\
\frac{\frac{h_3 : \Delta_7 \vdash \Delta_{13}, F_8, F_{11} \wedge F_{12}}{\rightarrow_L} \text{ ax/W} \quad \frac{h_{10} : \Delta_7, F_{11}, F_{12} \vdash \Delta_{13}, F_8}{\bullet h_{10} : \Delta_7, F_{11} \wedge F_{12} \vdash \Delta_{13}, F_8} \text{ inv-th/ax}}{\rightarrow_L} \quad \frac{h_3 : \Delta_7, F_9 \vdash \Delta_{13}, F_{11} \wedge F_{12}}{\rightarrow_L} \text{ ax/W} \quad \frac{h_{10} : \Delta_7, F_{11}, F_{12}, F_9 \vdash \Delta_{13}}{\bullet h_{10} : \Delta_7, F_9, F_{11} \wedge F_{12} \vdash \Delta_{13}} \text{ inv-t}}{\rightarrow_L} \text{ hCut} \\
\frac{h_3 : \Delta_{14}, F_{11} \wedge F_{12} \vdash F_7, F_8, \Delta_{13} \quad h_3 : F_9, \Delta_{14}, F_{11} \wedge F_{12} \vdash F_7, \Delta_{13}}{\bullet h_3 : (\Delta_{14}, F_{11} \wedge F_{12}), F_8 \rightarrow F_9 \vdash \Delta_{13}, F_7} \rightarrow_L \quad \frac{h_{10} : F_7, F_{11}, F_{12}, \Delta_{14}, F_8 \rightarrow F_9 \vdash \Delta_{13}}{\bullet h_{10} : ((\Delta_{14}, F_{11} \wedge F_{12}), F_8 \rightarrow F_9), F_7 \vdash \Delta_{13}} \wedge_L}{- : (\Delta_{14}, F_{11} \wedge F_{12}), F_8 \rightarrow F_9 \vdash \Delta_{13}} \text{ Cut} \\
\frac{\frac{h_3 : \Delta_{14}, F_{11}, F_{12} \vdash \Delta_{13}, F_7, F_8}{\bullet h_3 : \Delta_{14}, F_{11}, F_{12}, F_8 \rightarrow F_9 \vdash \Delta_{13}, F_7} \text{ inv-th/ax} \quad \frac{h_3 : \Delta_{14}, F_{11}, F_{12}, F_9 \vdash \Delta_{13}, F_7}{\rightarrow_L} \text{ inv-th/ax}}{\rightarrow_L} \quad \frac{h_{10} : \Delta_{14}, F_{11}, F_{12}, F_7, F_8 \rightarrow F_9 \vdash \Delta_{13}}{\rightarrow_L} \text{ ax/W}}{\rightarrow_L} \text{ hCut}
\end{array}$$

- Case rule \vee_L

$$\begin{array}{c}
\frac{\frac{h_3 : \Delta_7 \vdash F_{11} \vee F_{12}, F_8, \Delta_{13} \quad h_3 : F_9, \Delta_7 \vdash F_{11} \vee F_{12}, \Delta_{13}}{\bullet h_3 : \Delta_7, F_8 \rightarrow F_9 \vdash \Delta_{13}, F_{11} \vee F_{12}} \rightarrow_L \quad \frac{h_{10} : F_{11}, \Delta_7, F_8 \rightarrow F_9 \vdash \Delta_{13} \quad h_{10} : F_{12}, \Delta_7, F_8 \rightarrow F_9 \vdash \Delta_{13}}{\bullet h_{10} : (\Delta_7, F_8 \rightarrow F_9), F_{11} \vee F_{12} \vdash \Delta_{13}} \vee_L}{- : \Delta_7, F_8 \rightarrow F_9 \vdash \Delta_{13}} \text{ Cut} \\
\frac{\frac{- : \Delta_7 \vdash \Delta_{13}, F_{11}, F_{12}, F_8}{\rightarrow_L} \text{ inv-th/ax} \quad \frac{- : \Delta_7, F_9 \vdash \Delta_{13}, F_{11}, F_{12}}{\rightarrow_L} \text{ inv-th/ax}}{\rightarrow_L} \quad \frac{- : \Delta_7, F_{12}, F_8 \rightarrow F_9 \vdash \Delta_{13}, F_{11}}{\rightarrow_L} \text{ ax/W}}{\rightarrow_L} \text{ sCut} \\
\frac{h_3 : \Delta_{14}, F_{11} \vee F_{12} \vdash F_7, F_8, \Delta_{13} \quad h_3 : F_9, \Delta_{14}, F_{11} \vee F_{12} \vdash F_7, \Delta_{13}}{\bullet h_3 : (\Delta_{14}, F_{11} \vee F_{12}), F_8 \rightarrow F_9 \vdash \Delta_{13}, F_7} \rightarrow_L \quad \frac{h_{10} : F_7, F_{11}, \Delta_{14}, F_8 \rightarrow F_9 \vdash \Delta_{13}}{\bullet h_{10} : ((\Delta_{14}, F_{11} \vee F_{12}), F_8 \rightarrow F_9) \vdash \Delta_{13}} \vee_L}{- : (\Delta_{14}, F_{11} \vee F_{12}), F_8 \rightarrow F_9 \vdash \Delta_{13}} \text{ Cut} \\
\frac{\frac{h_3 : \Delta_{14}, F_{11} \vee F_{12} \vdash \Delta_{13}, F_7, F_8}{\rightarrow_L} \text{ ax/W} \quad \frac{h_{10} : \Delta_{14}, F_{11}, F_7 \vdash \Delta_{13}, F_8}{\bullet h_{10} : \Delta_{14}, F_7, F_{11} \vee F_{12} \vdash \Delta_{13}, F_8} \text{ inv-th/ax}}{\rightarrow_L} \quad \frac{h_{10} : \Delta_{14}, F_{12}, F_7 \vdash \Delta_{13}, F_8}{\rightarrow_L} \text{ inv-th/ax}}{\rightarrow_L} \text{ hCut}
\end{array}$$

- Case rule AT

$$\begin{array}{c}
\frac{\frac{h_3 : \Delta_7 \vdash \boxed{F_{11}}, F_8, \Delta_{12} \quad h_3 : F_9, \Delta_7 \vdash \boxed{F_{11}}, \Delta_{12}}{\bullet h_3 : \Delta_7, F_8 \rightarrow F_9 \vdash \Delta_{12}, \boxed{F_{11}}} \rightarrow_L \quad \frac{h_{10} : F_{11}, \Delta_7, \boxed{F_{11}}, F_8 \rightarrow F_9 \vdash \Delta_{12}}{\bullet h_{10} : (\Delta_7, F_8 \rightarrow F_9), \boxed{F_{11}} \vdash \Delta_{12}} AT}{\frac{}{- : \Delta_7, F_8 \rightarrow F_9 \vdash \Delta_{12}} \text{Cut}} \\
\sim \\
\frac{\frac{h_3 : \Delta_7 \vdash \Delta_{12}, F_8, \boxed{F_{11}}}{\bullet h_3 : \Delta_7 \vdash \Delta_{12}, F_8} ax/W \quad \frac{\frac{h_{10} : \Delta_7, F_{11}, \boxed{F_{11}} \vdash \Delta_{12}, F_8}{\bullet h_{10} : \Delta_7, \boxed{F_{11}} \vdash \Delta_{12}, F_8} inv\text{-}th/ax \quad \frac{}{- : \Delta_7, F_8 \rightarrow F_9 \vdash \Delta_{12}} AT}{\frac{}{- : \Delta_7 \vdash \Delta_{12}, F_8} hCut} \quad \frac{\frac{h_3 : \Delta_7, F_9 \vdash \Delta_{12}, \boxed{F_{11}}}{\bullet h_{10} : \Delta_7, F_9, \boxed{F_{11}} \vdash \Delta_{12}} ax/W \quad \frac{\frac{h_{10} : \Delta_7, F_{11}, F_9, \boxed{F_{11}} \vdash \Delta_{12}}{\bullet h_{10} : \Delta_7, F_9, \boxed{F_{11}} \vdash \Delta_{12}} inv\text{-}th/ax \quad \frac{}{- : \Delta_7, F_9 \vdash \Delta_{12}} AT}{\frac{}{- : \Delta_7, F_9 \vdash \Delta_{12}} hCut} \rightarrow_L \\
\frac{}{- : \Delta_7, F_8 \rightarrow F_9 \vdash \Delta_{12}}
\end{array}$$

$$\begin{array}{c}
\frac{h_3 : \Delta_{13}, \boxed{F_{11}} \vdash F_7, F_8, \Delta_{12} \quad h_3 : F_9, \Delta_{13}, \boxed{F_{11}} \vdash F_7, \Delta_{12}}{\bullet h_3 : (\Delta_{13}, \boxed{F_{11}}), F_8 \rightarrow F_9 \vdash \Delta_{12}, F_7} \rightarrow_L \quad \frac{h_{10} : F_7, F_{11}, \Delta_{13}, \boxed{F_{11}}, F_8 \rightarrow F_9 \vdash \Delta_{12}}{\bullet h_{10} : ((\Delta_{13}, \boxed{F_{11}}), F_8 \rightarrow F_9), F_7 \vdash \Delta_{12}} AT}{\frac{}{- : (\Delta_{13}, \boxed{F_{11}}), F_8 \rightarrow F_9 \vdash \Delta_{12}} \text{Cut}} \\
\sim \\
\frac{\frac{\bullet h_3 : \Delta_{13}, F_{11}, \boxed{F_{11}}, F_8 \rightarrow F_9 \vdash \Delta_{12}, F_7}{\bullet h_3 : \Delta_{13}, F_{11}, \boxed{F_{11}}, F_8 \rightarrow F_9 \vdash \Delta_{12}} ax/W \quad \frac{h_{10} : \Delta_{13}, F_{11}, F_7, \boxed{F_{11}}, F_8 \rightarrow F_9 \vdash \Delta_{12}}{\bullet h_{10} : (\Delta_{13}, F_{11}, F_7, \boxed{F_{11}}), F_8 \rightarrow F_9 \vdash \Delta_{12}} ax/W}{\frac{}{- : \Delta_{13}, F_{11}, \boxed{F_{11}}, F_8 \rightarrow F_9 \vdash \Delta_{12}} hCut} \quad \frac{}{- : \Delta_{13}, \boxed{F_{11}}, F_8 \rightarrow F_9 \vdash \Delta_{12}} AT
\end{array}$$

- Case rule \perp_L

$$\begin{array}{c}
\frac{h_3 : \Delta_7 \vdash \perp, F_8, \Delta_{11} \quad h_3 : F_9, \Delta_7 \vdash \perp, \Delta_{11}}{\bullet h_3 : \Delta_7, F_8 \rightarrow F_9 \vdash \Delta_{11}, \perp} \rightarrow_L \quad \frac{h_{10} : (\Delta_7, F_8 \rightarrow F_9), \perp \vdash \Delta_{11}}{\bullet h_{10} : (\Delta_7, F_8 \rightarrow F_9), \perp \vdash \Delta_{11}} \perp_L}{\frac{}{- : \Delta_7, F_8 \rightarrow F_9 \vdash \Delta_{11}} \text{Cut}} \\
\sim \\
\frac{\frac{h_3 : \Delta_7 \vdash \perp, \Delta_{11}, F_8}{\bullet h_3 : \Delta_7 \vdash \perp, \Delta_{11}, F_8} ax/W \quad \frac{\frac{h_{10} : \perp, \Delta_7 \vdash \Delta_{11}, F_8}{\bullet h_{10} : \perp, \Delta_7 \vdash \Delta_{11}, F_8} \perp_L \quad \frac{}{- : \Delta_7, F_8 \rightarrow F_9 \vdash \Delta_{11}} hCut}{\frac{}{- : \Delta_7 \vdash \Delta_{11}, F_8} hCut} \quad \frac{\frac{h_3 : \Delta_7, F_9 \vdash \perp, \Delta_{11}}{\bullet h_{10} : \Delta_7, F_9 \vdash \perp, \Delta_{11}} ax/W \quad \frac{\frac{h_{10} : \perp, \Delta_7, F_9 \vdash \Delta_{11}}{\bullet h_{10} : \perp, \Delta_7, F_9 \vdash \Delta_{11}} \perp_L}{\frac{}{- : \Delta_7, F_9 \vdash \Delta_{11}} hCut} \rightarrow_L \\
\frac{}{- : \Delta_7, F_8 \rightarrow F_9 \vdash \Delta_{11}}
\end{array}$$

$$\begin{array}{c}
\frac{h_3 : \perp, \Delta_{12} \vdash F_7, F_8, \Delta_{11} \quad h_3 : F_9, \perp, \Delta_{12} \vdash F_7, \Delta_{11}}{\bullet h_3 : (\perp, \Delta_{12}), F_8 \rightarrow F_9 \vdash \Delta_{11}, F_7} \rightarrow_L \quad \frac{h_{10} : ((\perp, \Delta_{12}), F_8 \rightarrow F_9), F_7 \vdash \Delta_{11}}{\bullet h_{10} : ((\perp, \Delta_{12}), F_8 \rightarrow F_9), F_7 \vdash \Delta_{11}} \perp_L}{\frac{}{- : (\perp, \Delta_{12}), F_8 \rightarrow F_9 \vdash \Delta_{11}} \text{Cut}} \\
\sim \\
\frac{}{- : \perp, \Delta_{12}, F_8 \rightarrow F_9 \vdash \Delta_{11}} \perp_L
\end{array}$$

- Case rule I

$$\begin{array}{c}
\frac{h_3 : \Delta_7 \vdash p_{11}, F_8, \Delta_{12}, p_{11} \quad h_3 : F_9, \Delta_7 \vdash p_{11}, \Delta_{12}, p_{11}}{\bullet h_3 : \Delta_7, F_8 \rightarrow F_9 \vdash (\Delta_{12}, p_{11}), p_{11}} \rightarrow_L \quad \frac{h_{10} : (\Delta_7, F_8 \rightarrow F_9), p_{11} \vdash \Delta_{12}, p_{11}}{\bullet h_{10} : (\Delta_7, F_8 \rightarrow F_9), p_{11} \vdash \Delta_{12}, p_{11}} I}{\frac{}{- : \Delta_7, F_8 \rightarrow F_9 \vdash \Delta_{12}, p_{11}} \text{Cut}} \\
\sim \\
\frac{\frac{h_3 : \Delta_7 \vdash \Delta_{12}, F_8, p_{11}, p_{11}}{\bullet h_{10} : \Delta_7, p_{11} \vdash \Delta_{12}, F_8, p_{11}} ax/W \quad \frac{\frac{h_{10} : \Delta_7, p_{11} \vdash \Delta_{12}, F_8, p_{11}}{\bullet h_{10} : \Delta_7, p_{11} \vdash \Delta_{12}, F_8, p_{11}} I \quad \frac{}{- : \Delta_7, F_8 \rightarrow F_9 \vdash \Delta_{12}, p_{11}} hCut}{\frac{}{- : \Delta_7 \vdash \Delta_{12}, F_8, p_{11}} hCut} \quad \frac{\frac{h_3 : \Delta_7, F_9 \vdash \Delta_{12}, p_{11}, p_{11}}{\bullet h_{10} : \Delta_7, F_9, p_{11} \vdash \Delta_{12}, p_{11}} ax/W \quad \frac{\frac{h_{10} : \Delta_7, F_9, p_{11} \vdash \Delta_{12}, p_{11}}{\bullet h_{10} : \Delta_7, F_9, p_{11} \vdash \Delta_{12}, p_{11}} I \quad \frac{}{- : \Delta_7, F_9 \vdash \Delta_{12}, p_{11}} hCut}{\frac{}{- : \Delta_7, F_9 \vdash \Delta_{12}, p_{11}} hCut} \rightarrow_L \\
\frac{}{- : \Delta_7, F_8 \rightarrow F_9 \vdash \Delta_{12}, p_{11}}
\end{array}$$

$$\begin{array}{c}
\frac{h_3 : \Delta_{13}, p_{11} \vdash F_7, F_8, \Delta_{12}, p_{11} \quad h_3 : F_9, \Delta_{13}, p_{11} \vdash F_7, \Delta_{12}, p_{11}}{\bullet h_3 : (\Delta_{13}, p_{11}), F_8 \rightarrow F_9 \vdash (\Delta_{12}, p_{11}), F_7} \rightarrow_L \quad \frac{h_{10} : ((\Delta_{13}, p_{11}), F_8 \rightarrow F_9), F_7 \vdash \Delta_{12}, p_{11}}{\bullet h_{10} : ((\Delta_{13}, p_{11}), F_8 \rightarrow F_9), F_7 \vdash \Delta_{12}, p_{11}} I}{\frac{}{- : (\Delta_{13}, p_{11}), F_8 \rightarrow F_9 \vdash \Delta_{12}, p_{11}} \text{Cut}} \\
\sim \\
\frac{}{- : \Delta_{13}, p_{11}, F_8 \rightarrow F_9 \vdash \Delta_{12}, p_{11}} I
\end{array}$$

- Case rule \top_L

$$\begin{array}{c}
\frac{h_3 : \Delta_7 \vdash \top, F_8, \Delta_{11} \quad h_3 : F_9, \Delta_7 \vdash \top, \Delta_{11}}{\bullet h_3 : \Delta_7, F_8 \rightarrow F_9 \vdash \Delta_{11}, \top} \rightarrow_L \quad \frac{h_{10} : \Delta_7, F_8 \rightarrow F_9 \vdash \Delta_{11}}{\bullet h_{10} : (\Delta_7, F_8 \rightarrow F_9), \top \vdash \Delta_{11}} \top_L}{\frac{}{- : \Delta_7, F_8 \rightarrow F_9 \vdash \Delta_{11}} \text{Cut}} \\
\sim \\
\frac{}{- : \Delta_7, F_8 \rightarrow F_9 \vdash \Delta_{11}} ax/W
\end{array}$$

$$\begin{array}{c}
\frac{h_3 : \top, \Delta_{12} \vdash F_7, F_8, \Delta_{11} \quad h_3 : F_9, \top, \Delta_{12} \vdash F_7, \Delta_{11}}{\bullet h_3 : (\top, \Delta_{12}), F_8 \rightarrow F_9 \vdash \Delta_{11}, F_7} \rightarrow_L \quad \frac{h_{10} : F_7, \Delta_{12}, F_8 \rightarrow F_9 \vdash \Delta_{11}}{\bullet h_{10} : ((\top, \Delta_{12}), F_8 \rightarrow F_9), F_7 \vdash \Delta_{11}} \top_L \\
\hline
- : (\top, \Delta_{12}), F_8 \rightarrow F_9 \vdash \Delta_{11} \quad \text{Cut} \\
\hline
\frac{\frac{\bullet h_3 : \top, \Delta_{12}, F_8 \rightarrow F_9 \vdash \Delta_{11}, F_7}{- : \top, \Delta_{12}, F_8 \rightarrow F_9 \vdash \Delta_{11}} \text{ax/W} \quad \frac{h_{10} : \top, \Delta_{12}, F_7, F_8 \rightarrow F_9 \vdash \Delta_{11}}{- : \top, \Delta_{12}, F_8 \rightarrow F_9 \vdash \Delta_{11}} \text{ax/W} \\
\hline
- : \top, \Delta_{12}, F_8 \rightarrow F_9 \vdash \Delta_{11} \quad \text{hCut}
\end{array}$$

8.8 Status of \wedge_L : OK

- Case rule \rightarrow_R

$$\begin{array}{c}
\frac{h_3 : F_9, F_{10}, \Delta_8 \vdash F_7, \Delta_{12}, F_{13} \rightarrow F_{14}}{\bullet h_3 : \Delta_8, F_9 \wedge F_{10} \vdash (\Delta_{12}, F_{13} \rightarrow F_{14}), F_7} \wedge_L \quad \frac{h_{11} : F_7, F_{13}, \Delta_8, F_9 \wedge F_{10} \vdash F_{14}, \Delta_{12}}{\bullet h_{11} : (\Delta_8, F_9 \wedge F_{10}), F_7 \vdash \Delta_{12}, F_{13} \rightarrow F_{14}} \rightarrow_R \\
\hline
- : \Delta_8, F_9 \wedge F_{10} \vdash \Delta_{12}, F_{13} \rightarrow F_{14} \quad \text{Cut} \\
\hline
\frac{\frac{h_3 : \Delta_8, F_{10}, F_{13}, F_9 \vdash \Delta_{12}, F_{14}, F_7}{\bullet h_3 : \Delta_8, F_{13}, F_9 \wedge F_{10} \vdash \Delta_{12}, F_{14}, F_7} \text{inv-th/ax} \quad \frac{h_{11} : \Delta_8, F_{13}, F_7, F_9 \wedge F_{10} \vdash \Delta_{12}, F_{14}}{- : \Delta_8, F_{13}, F_9 \wedge F_{10} \vdash \Delta_{12}, F_{14}} \text{ax/W} \\
\hline
- : \Delta_8, F_{13}, F_9 \wedge F_{10} \vdash \Delta_{12}, F_{14} \quad \text{hCut} \\
\hline
- : \Delta_8, F_9 \wedge F_{10} \vdash \Delta_{12}, F_{13} \rightarrow F_{14} \quad \rightarrow_R
\end{array}$$

- Case rule \wedge_R

$$\begin{array}{c}
\frac{h_3 : F_9, F_{10}, \Delta_8 \vdash F_7, \Delta_{12}, F_{13} \wedge F_{14}}{\bullet h_3 : \Delta_8, F_9 \wedge F_{10} \vdash (\Delta_{12}, F_{13} \wedge F_{14}), F_7} \wedge_L \quad \frac{h_{11} : F_7, \Delta_8, F_9 \wedge F_{10} \vdash F_{13}, \Delta_{12} \quad h_{11} : F_7, \Delta_8, F_9 \wedge F_{10} \vdash F_{14}, \Delta_{12}}{\bullet h_{11} : (\Delta_8, F_9 \wedge F_{10}), F_7 \vdash \Delta_{12}, F_{13} \wedge F_{14}} \wedge_R \\
\hline
- : \Delta_8, F_9 \wedge F_{10} \vdash \Delta_{12}, F_{13} \wedge F_{14} \quad \text{Cut} \\
\hline
\frac{\frac{h_3 : \Delta_8, F_{10}, F_9 \vdash \Delta_{12}, F_7, F_{13} \wedge F_{14}}{\bullet h_3 : \Delta_8, F_{10}, F_9 \vdash \Delta_{12}, F_7, F_{13} \wedge F_{14}} \text{ax/W} \quad \frac{h_{11} : \Delta_8, F_{10}, F_7, F_9 \vdash \Delta_{12}, F_{13}}{\bullet h_{11} : \Delta_8, F_{10}, F_7, F_9 \vdash \Delta_{12}, F_{13} \wedge F_{14}} \text{inv-th/ax} \\
\hline
- : \Delta_8, F_{10}, F_9 \vdash \Delta_{12}, F_{13} \wedge F_{14} \quad \text{hCut} \\
\hline
- : \Delta_8, F_9 \wedge F_{10} \vdash \Delta_{12}, F_{13} \wedge F_{14} \quad \wedge_L
\end{array}$$

- Case rule \vee_R

$$\begin{array}{c}
\frac{h_3 : F_9, F_{10}, \Delta_8 \vdash F_7, \Delta_{12}, F_{13} \vee F_{14}}{\bullet h_3 : \Delta_8, F_9 \wedge F_{10} \vdash (\Delta_{12}, F_{13} \vee F_{14}), F_7} \wedge_L \quad \frac{h_{11} : F_7, \Delta_8, F_9 \wedge F_{10} \vdash F_{13}, F_{14}, \Delta_{12}}{\bullet h_{11} : (\Delta_8, F_9 \wedge F_{10}), F_7 \vdash \Delta_{12}, F_{13} \vee F_{14}} \vee_R \\
\hline
- : \Delta_8, F_9 \wedge F_{10} \vdash \Delta_{12}, F_{13} \vee F_{14} \quad \text{Cut} \\
\hline
\frac{\frac{h_3 : \Delta_8, F_{10}, F_9 \vdash \Delta_{12}, F_{13}, F_{14}, F_7}{\bullet h_3 : \Delta_8, F_9 \wedge F_{10} \vdash \Delta_{12}, F_{13}, F_{14}, F_7} \text{inv-th/ax} \quad \frac{h_{11} : \Delta_8, F_7, F_9 \wedge F_{10} \vdash \Delta_{12}, F_{13}, F_{14}}{- : \Delta_8, F_7, F_9 \wedge F_{10} \vdash \Delta_{12}, F_{13}, F_{14}} \text{ax/W} \\
\hline
- : \Delta_8, F_9 \wedge F_{10} \vdash \Delta_{12}, F_{13}, F_{14} \quad \text{hCut} \\
\hline
- : \Delta_8, F_9 \wedge F_{10} \vdash \Delta_{12}, F_{13} \vee F_{14} \quad \vee_R
\end{array}$$

- Case rule \perp_R

$$\begin{array}{c}
\frac{h_3 : F_9, F_{10}, \Delta_8 \vdash F_7, \perp, \Delta_{12}}{\bullet h_3 : \Delta_8, F_9 \wedge F_{10} \vdash (\perp, \Delta_{12}), F_7} \wedge_L \quad \frac{h_{11} : F_7, \Delta_8, F_9 \wedge F_{10} \vdash \Delta_{12}}{\bullet h_{11} : (\Delta_8, F_9 \wedge F_{10}), F_7 \vdash \perp, \Delta_{12}} \perp_R \\
\hline
- : \Delta_8, F_9 \wedge F_{10} \vdash \perp, \Delta_{12} \quad \text{Cut} \\
\hline
\frac{\frac{\bullet h_3 : \Delta_8, F_9 \wedge F_{10} \vdash \perp, \Delta_{12}, F_7}{- : \Delta_8, F_9 \wedge F_{10} \vdash \perp, \Delta_{12}} \text{ax/W} \quad \frac{h_{11} : \Delta_8, F_7, F_9 \wedge F_{10} \vdash \perp, \Delta_{12}}{- : \Delta_8, F_7, F_9 \wedge F_{10} \vdash \perp, \Delta_{12}} \text{ax/W} \\
\hline
- : \Delta_8, F_9 \wedge F_{10} \vdash \perp, \Delta_{12} \quad \text{hCut}
\end{array}$$

- Case rule \top_R

$$\begin{array}{c}
\frac{h_3 : F_9, F_{10}, \Delta_8 \vdash F_7, \top, \Delta_{12}}{\bullet h_3 : \Delta_8, F_9 \wedge F_{10} \vdash (\top, \Delta_{12}), F_7} \wedge_L \quad \frac{h_{11} : (\Delta_8, F_9 \wedge F_{10}), F_7 \vdash \top, \Delta_{12}}{\bullet h_{11} : (\Delta_8, F_9 \wedge F_{10}), F_7 \vdash \top, \Delta_{12}} \top_R \\
\hline
- : \Delta_8, F_9 \wedge F_{10} \vdash \top, \Delta_{12} \quad \text{Cut} \\
\hline
- : \Delta_8, F_9 \wedge F_{10} \vdash \top, \Delta_{12} \quad \top_R
\end{array}$$

- Case rule $A4$

$$\begin{array}{c}
\frac{h_3 : F_8, F_9, \Box \Gamma_{13}, \Delta_{14} \vdash \Box F_7, \Delta_{11}, [\Box F_{12}] \quad \bullet h_3 : (\Box \Gamma_{13}, \Delta_{14}), F_8 \wedge F_9 \vdash (\Delta_{11}, [\Box F_{12}], \Box F_7)}{\vdash : (\Box \Gamma_{13}, \Delta_{14}), F_8 \wedge F_9 \vdash \Delta_{11}, [\Box F_{12}]} \wedge_L \quad \frac{h_{10} : \Box \Gamma_{13}, \Box F_7 \vdash F_{12}}{\bullet h_{10} : ((\Box \Gamma_{13}, \Delta_{14}), F_8 \wedge F_9), \Box F_7 \vdash \Delta_{11}, [\Box F_{12}]} A4 \\
\vdash : (\Box \Gamma_{13}, \Delta_{14}), F_8 \wedge F_9 \vdash \Delta_{11}, [\Box F_{12}] \quad \text{Cut} \\
\rightsquigarrow \\
\frac{\frac{h_3 : \Delta_{14}, F_8, F_9, \Box \Gamma_{13} \vdash \Box F_7, \Delta_{11}, [\Box F_{12}]}{\vdash : \Delta_{14}, F_8, F_9, \Box \Gamma_{13} \vdash \Delta_{11}, [\Box F_{12}]} ax/W \quad \frac{h_{10} : \Box F_7, \Box \Gamma_{13} \vdash F_{12}}{\bullet h_{10} : \Box F_7, \Delta_{14}, F_8, F_9, \Box \Gamma_{13} \vdash \Delta_{11}, [\Box F_{12}]} ax/W}{\vdash : \Delta_{14}, F_8, F_9, \Box \Gamma_{13} \vdash \Delta_{11}, [\Box F_{12}]} A4 \\
\vdash : \Delta_{14}, \Box \Gamma_{13}, F_8 \wedge F_9 \vdash \Delta_{11}, [\Box F_{12}] \quad \wedge_L \\
\vdash : \Delta_{14}, F_8, F_9, \Box \Gamma_{13} \vdash \Box F_7, \Delta_{12}, [\Box F_{13}] \quad \bullet h_3 : (\Box \Gamma_{11}, \Delta_{14}), F_8 \wedge F_9 \vdash (\Delta_{12}, [\Box F_{13}], F_7)}{\vdash : (\Box \Gamma_{11}, \Delta_{14}), F_8 \wedge F_9 \vdash \Delta_{12}, [\Box F_{13}]} \wedge_L \quad \frac{h_{10} : \Box \Gamma_{11} \vdash F_{13}}{\bullet h_{10} : ((\Box \Gamma_{11}, \Delta_{14}), F_8 \wedge F_9), F_7 \vdash \Delta_{12}, [\Box F_{13}]} A4 \\
\vdash : (\Box \Gamma_{11}, \Delta_{14}), F_8 \wedge F_9 \vdash \Delta_{12}, [\Box F_{13}] \quad \text{Cut} \\
\rightsquigarrow \\
\frac{\vdash : \Box \Gamma_{11} \vdash F_{13}}{\vdash : \Delta_{14}, \Box \Gamma_{11}, F_8 \wedge F_9 \vdash \Delta_{12}, [\Box F_{13}]} ax/W \quad A4
\end{array}$$

- Case rule \rightarrow_L

$$\begin{array}{c}
\frac{h_3 : F_8, F_9, \Delta_7 \vdash F_{11} \rightarrow F_{12}, \Delta_{13}}{\bullet h_3 : \Delta_7, F_8 \wedge F_9 \vdash \Delta_{13}, F_{11} \rightarrow F_{12}} \wedge_L \quad \frac{h_{10} : \Delta_7, F_8 \wedge F_9 \vdash F_{11}, \Delta_{13} \quad h_{10} : F_{12}, \Delta_7, F_8 \wedge F_9 \vdash \Delta_{13}}{\bullet h_{10} : (\Delta_7, F_8 \wedge F_9), F_{11} \rightarrow F_{12} \vdash \Delta_{13}} \rightarrow_L \\
\vdash : \Delta_7, F_8 \wedge F_9 \vdash \Delta_{13} \quad \text{Cut} \\
\rightsquigarrow \\
\frac{h_3 : \Delta_7, F_8, F_9 \vdash \Delta_{13}, F_{11} \rightarrow F_{12}}{\vdash : \Delta_7, F_8, F_9 \vdash \Delta_{13}} ax/W \quad \frac{h_{10} : \Delta_7, F_8, F_9 \vdash \Delta_{13}, F_{11}}{\bullet h_{10} : \Delta_7, F_8, F_9, F_{11} \rightarrow F_{12} \vdash \Delta_{13}} inv-th/ax \quad \frac{h_{10} : \Delta_7, F_{12}, F_8, F_9 \vdash \Delta_{13}}{\vdash : \Delta_7, F_{12}, F_8, F_9 \vdash \Delta_{13}} inv-th/ax}{\vdash : \Delta_7, F_8, F_9 \vdash \Delta_{13}} \rightarrow_L \\
\vdash : \Delta_7, F_8 \wedge F_9 \vdash \Delta_{13} \quad \wedge_L \\
\vdash : \Delta_7, F_8 \wedge F_9 \vdash \Delta_{13} \\
\frac{h_3 : F_8, F_9, \Delta_{14}, F_{11} \rightarrow F_{12} \vdash F_7, \Delta_{13}}{\bullet h_3 : (\Delta_{14}, F_{11} \rightarrow F_{12}), F_8 \wedge F_9 \vdash \Delta_{13}, F_7} \wedge_L \quad \frac{h_{10} : F_7, \Delta_{14}, F_8 \wedge F_9 \vdash F_{11}, \Delta_{13} \quad h_{10} : F_7, F_{12}, \Delta_{14}, F_8 \wedge F_9 \vdash \Delta_{13}}{\bullet h_{10} : ((\Delta_{14}, F_{11} \rightarrow F_{12}), F_8 \wedge F_9), F_7 \vdash \Delta_{13}} \rightarrow_L \\
\vdash : (\Delta_{14}, F_{11} \rightarrow F_{12}), F_8 \wedge F_9 \vdash \Delta_{13} \quad \text{Cut} \\
\rightsquigarrow \\
\frac{h_3 : \Delta_{14}, F_8, F_9, F_{11} \rightarrow F_{12} \vdash \Delta_{13}, F_7}{\vdash : \Delta_{14}, F_8, F_9, F_{11} \rightarrow F_{12} \vdash \Delta_{13}} ax/W \quad \frac{h_{10} : \Delta_{14}, F_7, F_8, F_9 \vdash \Delta_{13}, F_{11}}{\bullet h_{10} : \Delta_{14}, F_7, F_8, F_9, F_{11} \rightarrow F_{12} \vdash \Delta_{13}} inv-th/ax \quad \frac{h_{10} : \Delta_{14}, F_{12}, F_7, F_8, F_9 \vdash \Delta_{13}}{\vdash : \Delta_{14}, F_{12}, F_7, F_8, F_9 \vdash \Delta_{13}} inv-th/ax}{\vdash : \Delta_{14}, F_7, F_8, F_9, F_{11} \rightarrow F_{12} \vdash \Delta_{13}} \rightarrow_L \\
\vdash : \Delta_{14}, F_8, F_9, F_{11} \rightarrow F_{12} \vdash \Delta_{13} \quad \wedge_L \\
\vdash : \Delta_{14}, F_{11} \rightarrow F_{12}, F_8 \wedge F_9 \vdash \Delta_{13}
\end{array}$$

- Case rule \wedge_L

$$\begin{array}{c}
\frac{h_3 : F_8, F_9, \Delta_7 \vdash F_{11} \wedge F_{12}, \Delta_{13}}{\bullet h_3 : \Delta_7, F_8 \wedge F_9 \vdash \Delta_{13}, F_{11} \wedge F_{12}} \wedge_L \quad \frac{h_{10} : F_{11}, F_{12}, \Delta_7, F_8 \wedge F_9 \vdash \Delta_{13}}{\bullet h_{10} : (\Delta_7, F_8 \wedge F_9), F_{11} \wedge F_{12} \vdash \Delta_{13}} \wedge_L \\
\vdash : \Delta_7, F_8 \wedge F_9 \vdash \Delta_{13} \quad \text{Cut} \\
\rightsquigarrow \\
\frac{h_3 : \Delta_7, F_8, F_9 \vdash \Delta_{13}, F_{11} \wedge F_{12}}{\vdash : \Delta_7, F_8, F_9 \vdash \Delta_{13}} ax/W \quad \frac{h_{10} : \Delta_7, F_{11}, F_{12}, F_8, F_9 \vdash \Delta_{13}}{\bullet h_{10} : \Delta_7, F_8, F_9, F_{11} \wedge F_{12} \vdash \Delta_{13}} inv-th/ax \quad \frac{h_{10} : \Delta_7, F_8, F_9, F_{11} \wedge F_{12} \vdash \Delta_{13}}{\vdash : \Delta_7, F_8, F_9, F_{11} \wedge F_{12} \vdash \Delta_{13}} hCut}{\vdash : \Delta_7, F_8 \wedge F_9 \vdash \Delta_{13}} \wedge_L \\
\vdash : \Delta_7, F_8 \wedge F_9 \vdash \Delta_{13} \\
\frac{h_3 : F_8, F_9, \Delta_{14}, F_{11} \wedge F_{12} \vdash F_7, \Delta_{13}}{\bullet h_3 : (\Delta_{14}, F_{11} \wedge F_{12}), F_8 \wedge F_9 \vdash \Delta_{13}, F_7} \wedge_L \quad \frac{h_{10} : F_7, F_{11}, F_{12}, \Delta_{14}, F_8 \wedge F_9 \vdash \Delta_{13}}{\bullet h_{10} : ((\Delta_{14}, F_{11} \wedge F_{12}), F_8 \wedge F_9), F_7 \vdash \Delta_{13}} \wedge_L \\
\vdash : (\Delta_{14}, F_{11} \wedge F_{12}), F_8 \wedge F_9 \vdash \Delta_{13} \quad \text{Cut} \\
\rightsquigarrow \\
\frac{h_3 : \Delta_{14}, F_{11}, F_{12}, F_8, F_9 \vdash \Delta_{13}, F_7}{\bullet h_3 : \Delta_{14}, F_{11}, F_{12}, F_8 \wedge F_9 \vdash \Delta_{13}, F_7} inv-th/ax \quad \frac{h_{10} : \Delta_{14}, F_{11}, F_{12}, F_7, F_8 \wedge F_9 \vdash \Delta_{13}}{\vdash : \Delta_{14}, F_{11}, F_{12}, F_8 \wedge F_9 \vdash \Delta_{13}} ax/W \quad \frac{h_{10} : \Delta_{14}, F_{11}, F_{12}, F_7, F_8 \wedge F_9 \vdash \Delta_{13}}{\vdash : \Delta_{14}, F_{11}, F_{12}, F_8 \wedge F_9 \vdash \Delta_{13}} hCut}{\vdash : \Delta_{14}, F_{11} \wedge F_{12}, F_8 \wedge F_9 \vdash \Delta_{13}} \wedge_L \\
\vdash : \Delta_{14}, F_{11} \wedge F_{12}, F_8 \wedge F_9 \vdash \Delta_{13}
\end{array}$$

$$\begin{array}{c}
\frac{h_3 : F_{10}, F_{11}, \Delta_8 \vdash F_7, \Delta_{12}}{\bullet h_3 : \Delta_8, F_{10} \wedge F_{11} \vdash \Delta_{12}, F_7} \wedge_L \quad \frac{h_9 : F_7, F_{10}, F_{11}, \Delta_8 \vdash \Delta_{12}}{\bullet h_9 : (\Delta_8, F_{10} \wedge F_{11}), F_7 \vdash \Delta_{12}} \wedge_L \\
\hline
- : \Delta_8, F_{10} \wedge F_{11} \vdash \Delta_{12} \\
\sim \\
\frac{\frac{h_3 : \Delta_8, F_{10}, F_{11} \vdash \Delta_{12}, F_7}{- : \Delta_8, F_{10}, F_{11} \vdash \Delta_{12}} \text{ax/W} \quad \frac{\frac{h_9 : \Delta_8, F_{10}, F_{11}, F_7 \vdash \Delta_{12}}{\bullet h_9 : \Delta_8, F_{10}, F_{11}, F_7 \vdash \Delta_{12}} \text{ax/W} \quad \frac{}{H} \text{H}}{\bullet h_9 : \Delta_8, F_{10}, F_{11}, F_7 \vdash \Delta_{12}} \text{hCut} \\
\hline
- : \Delta_8, F_{10} \wedge F_{11} \vdash \Delta_{12} \quad \wedge_L \\
- : \Delta_8, F_{10} \wedge F_{11} \vdash \Delta_{12}
\end{array}$$

- Case rule \vee_L

$$\begin{array}{c}
\frac{h_3 : F_8, F_9, \Delta_7 \vdash F_{11} \vee F_{12}, \Delta_{13}}{\bullet h_3 : \Delta_7, F_8 \wedge F_9 \vdash \Delta_{13}, F_{11} \vee F_{12}} \wedge_L \quad \frac{h_{10} : F_{11}, \Delta_7, F_8 \wedge F_9 \vdash \Delta_{13} \quad h_{10} : F_{12}, \Delta_7, F_8 \wedge F_9 \vdash \Delta_{13}}{\bullet h_{10} : (\Delta_7, F_8 \wedge F_9), F_{11} \vee F_{12} \vdash \Delta_{13}} \vee_L \\
\hline
- : \Delta_7, F_8 \wedge F_9 \vdash \Delta_{13} \\
\sim \\
\frac{\frac{h_3 : \Delta_7, F_8, F_9 \vdash \Delta_{13}, F_{11} \vee F_{12}}{- : \Delta_7, F_8, F_9 \vdash \Delta_{13}} \text{ax/W} \quad \frac{\frac{h_{10} : \Delta_7, F_{11}, F_8, F_9 \vdash \Delta_{13}}{\bullet h_{10} : \Delta_7, F_8, F_9, F_{11} \vee F_{12} \vdash \Delta_{13}} \text{inv-th/ax} \quad \frac{h_{10} : \Delta_7, F_{12}, F_8, F_9 \vdash \Delta_{13}}{\bullet h_{10} : \Delta_7, F_8, F_9, F_{11} \vee F_{12} \vdash \Delta_{13}} \text{inv-th/ax}}{\bullet h_{10} : \Delta_7, F_8, F_9, F_{11} \vee F_{12} \vdash \Delta_{13}} \vee_L \\
\hline
- : \Delta_7, F_8, F_9 \vdash \Delta_{13} \quad \wedge_L \\
- : \Delta_7, F_8 \wedge F_9 \vdash \Delta_{13} \\
\frac{h_3 : F_8, F_9, \Delta_{14}, F_{11} \vee F_{12} \vdash F_7, \Delta_{13}}{\bullet h_3 : (\Delta_{14}, F_{11} \vee F_{12}), F_8 \wedge F_9 \vdash \Delta_{13}, F_7} \wedge_L \quad \frac{h_{10} : F_7, F_{11}, \Delta_{14}, F_8 \wedge F_9 \vdash \Delta_{13} \quad h_{10} : F_7, F_{12}, \Delta_{14}, F_8 \wedge F_9 \vdash \Delta_{13}}{\bullet h_{10} : ((\Delta_{14}, F_{11} \vee F_{12}), F_8 \wedge F_9), F_7 \vdash \Delta_{13}} \vee_L \\
\hline
- : (\Delta_{14}, F_{11} \vee F_{12}), F_8 \wedge F_9 \vdash \Delta_{13} \\
\sim \\
\frac{\frac{h_3 : \Delta_{14}, F_8, F_9, F_{11} \vee F_{12} \vdash \Delta_{13}, F_7}{- : \Delta_{14}, F_8, F_9, F_{11} \vee F_{12} \vdash \Delta_{13}} \text{ax/W} \quad \frac{\frac{h_{10} : \Delta_{14}, F_{11}, F_7, F_8, F_9 \vdash \Delta_{13}}{\bullet h_{10} : \Delta_{14}, F_7, F_8, F_9, F_{11} \vee F_{12} \vdash \Delta_{13}} \text{inv-th/ax} \quad \frac{h_{10} : \Delta_{14}, F_{12}, F_7, F_8, F_9 \vdash \Delta_{13}}{\bullet h_{10} : \Delta_{14}, F_7, F_8, F_9, F_{11} \vee F_{12} \vdash \Delta_{13}} \text{inv-th/ax}}{\bullet h_{10} : \Delta_{14}, F_7, F_8, F_9, F_{11} \vee F_{12} \vdash \Delta_{13}} \vee_L \\
\hline
- : \Delta_{14}, F_8, F_9, F_{11} \vee F_{12} \vdash \Delta_{13} \quad \wedge_L \\
- : \Delta_{14}, F_8 \wedge F_9, F_{11} \vee F_{12} \vdash \Delta_{13}
\end{array}$$

- Case rule AT

$$\begin{array}{c}
\frac{h_3 : F_8, F_9, \Delta_7 \vdash \boxed{F_{11}}, \Delta_{12}}{\bullet h_3 : \Delta_7, F_8 \wedge F_9 \vdash \Delta_{12}, \boxed{F_{11}}} \wedge_L \quad \frac{h_{10} : F_{11}, \Delta_7, \boxed{F_{11}}, F_8 \wedge F_9 \vdash \Delta_{12}}{\bullet h_{10} : (\Delta_7, F_8 \wedge F_9), \boxed{F_{11}} \vdash \Delta_{12}} AT \\
\hline
- : \Delta_7, F_8 \wedge F_9 \vdash \Delta_{12} \\
\sim \\
\frac{\frac{h_3 : \Delta_7, F_8, F_9 \vdash \Delta_{12}, \boxed{F_{11}}}{- : \Delta_7, F_8, F_9 \vdash \Delta_{12}} \text{ax/W} \quad \frac{\frac{h_{10} : \Delta_7, F_{11}, F_8, F_9, \boxed{F_{11}} \vdash \Delta_{12}}{\bullet h_{10} : \Delta_7, F_8, F_9, \boxed{F_{11}} \vdash \Delta_{12}} \text{inv-th/ax} \quad \frac{}{AT} AT}}{\bullet h_{10} : \Delta_7, F_8, F_9, \boxed{F_{11}} \vdash \Delta_{12}} AT \\
\hline
- : \Delta_7, F_8, F_9 \vdash \Delta_{12} \quad \wedge_L \\
- : \Delta_7, F_8 \wedge F_9 \vdash \Delta_{12} \\
\frac{h_3 : F_8, F_9, \Delta_{13}, \boxed{F_{11}} \vdash F_7, \Delta_{12}}{\bullet h_3 : (\Delta_{13}, \boxed{F_{11}}), F_8 \wedge F_9 \vdash \Delta_{12}, F_7} \wedge_L \quad \frac{h_{10} : F_7, F_{11}, \Delta_{13}, \boxed{F_{11}}, F_8 \wedge F_9 \vdash \Delta_{12}}{\bullet h_{10} : ((\Delta_{13}, \boxed{F_{11}}), F_8 \wedge F_9), F_7 \vdash \Delta_{12}} AT \\
\hline
- : (\Delta_{13}, \boxed{F_{11}}), F_8 \wedge F_9 \vdash \Delta_{12} \\
\sim \\
\frac{\frac{h_3 : \Delta_{13}, F_{11}, \boxed{F_{11}}, F_8 \wedge F_9 \vdash \Delta_{12}, F_7}{- : \Delta_{13}, F_{11}, \boxed{F_{11}}, F_8 \wedge F_9 \vdash \Delta_{12}} \text{ax/W} \quad \frac{h_{10} : \Delta_{13}, F_{11}, F_7, \boxed{F_{11}}, F_8 \wedge F_9 \vdash \Delta_{12}}{\bullet h_{10} : \Delta_{13}, F_{11}, F_7, \boxed{F_{11}}, F_8 \wedge F_9 \vdash \Delta_{12}} \text{ax/W}}{\bullet h_{10} : \Delta_{13}, F_{11}, F_7, \boxed{F_{11}}, F_8 \wedge F_9 \vdash \Delta_{12}} \text{hCut} \\
\hline
- : \Delta_{13}, F_{11}, \boxed{F_{11}}, F_8 \wedge F_9 \vdash \Delta_{12} \quad AT \\
- : \Delta_{13}, \boxed{F_{11}}, F_8 \wedge F_9 \vdash \Delta_{12}
\end{array}$$

- Case rule \perp_L

$$\begin{array}{c}
\frac{h_3 : F_8, F_9, \Delta_7 \vdash \perp, \Delta_{11}}{\bullet h_3 : \Delta_7, F_8 \wedge F_9 \vdash \Delta_{11}, \perp} \wedge_L \quad \frac{h_{10} : (\Delta_7, F_8 \wedge F_9), \perp \vdash \Delta_{11}}{\bullet h_{10} : (\Delta_7, F_8 \wedge F_9), \perp \vdash \Delta_{11}} \perp_L \\
\hline
- : \Delta_7, F_8 \wedge F_9 \vdash \Delta_{11} \\
\sim \\
\frac{\frac{h_3 : \Delta_7, F_8, F_9 \vdash \perp, \Delta_{11}}{- : \Delta_7, F_8, F_9 \vdash \perp} \text{ax/W} \quad \frac{h_{10} : \perp, \Delta_7, F_8, F_9 \vdash \Delta_{11}}{\bullet h_{10} : \perp, \Delta_7, F_8, F_9 \vdash \Delta_{11}} \perp_L}{\bullet h_{10} : \perp, \Delta_7, F_8, F_9 \vdash \Delta_{11}} \text{hCut} \\
\hline
- : \Delta_7, F_8, F_9 \vdash \perp \quad \wedge_L \\
- : \Delta_7, F_8 \wedge F_9 \vdash \Delta_{11}
\end{array}$$

$$\begin{array}{c}
\frac{h_3 : F_8, F_9, \perp, \Delta_{12} \vdash F_7, \Delta_{11}}{\bullet h_3 : (\perp, \Delta_{12}), F_8 \wedge F_9 \vdash \Delta_{11}, F_7} \wedge_L \quad \frac{}{\bullet h_{10} : ((\perp, \Delta_{12}), F_8 \wedge F_9), F_7 \vdash \Delta_{11}} \perp_L \\
\hline
- : (\perp, \Delta_{12}), F_8 \wedge F_9 \vdash \Delta_{11} \quad \text{Cut} \\
\hline
\sim \\
\hline
- : \perp, \Delta_{12}, F_8 \wedge F_9 \vdash \Delta_{11} \quad \perp_L
\end{array}$$

- Case rule I

$$\begin{array}{c}
\frac{h_3 : F_8, F_9, \Delta_7 \vdash p_{11}, \Delta_{12}, p_{11}}{\bullet h_3 : \Delta_7, F_8 \wedge F_9 \vdash (\Delta_{12}, p_{11}), p_{11}} \wedge_L \quad \frac{}{\bullet h_{10} : (\Delta_7, F_8 \wedge F_9), p_{11} \vdash \Delta_{12}, p_{11}} I \\
\hline
- : \Delta_7, F_8 \wedge F_9 \vdash \Delta_{12}, p_{11} \quad \text{Cut} \\
\hline
\sim \\
\hline
\frac{h_3 : \Delta_7, F_8, F_9 \vdash \Delta_{12}, p_{11}, p_{11}}{\bullet h_3 : \Delta_7, F_8, F_9 \vdash \Delta_{12}, p_{11}} \text{ax/W} \quad \frac{}{\bullet h_{10} : \Delta_7, F_8, F_9, p_{11} \vdash \Delta_{12}, p_{11}} I \\
\hline
- : \Delta_7, F_8, F_9 \vdash \Delta_{12}, p_{11} \quad \text{hCut} \\
\hline
- : \Delta_7, F_8 \wedge F_9 \vdash \Delta_{12}, p_{11} \quad \wedge_L
\end{array}$$

$$\begin{array}{c}
\frac{h_3 : F_8, F_9, \Delta_{13}, p_{11} \vdash F_7, \Delta_{12}, p_{11}}{\bullet h_3 : (\Delta_{13}, p_{11}), F_8 \wedge F_9 \vdash (\Delta_{12}, p_{11}), F_7} \wedge_L \quad \frac{}{\bullet h_{10} : ((\Delta_{13}, p_{11}), F_8 \wedge F_9), F_7 \vdash \Delta_{12}, p_{11}} I \\
\hline
- : (\Delta_{13}, p_{11}), F_8 \wedge F_9 \vdash \Delta_{12}, p_{11} \quad \text{Cut} \\
\hline
\sim \\
\hline
- : \Delta_{13}, p_{11}, F_8 \wedge F_9 \vdash \Delta_{12}, p_{11} \quad I
\end{array}$$

- Case rule \top_L

$$\begin{array}{c}
\frac{h_3 : F_8, F_9, \Delta_7 \vdash \top, \Delta_{11}}{\bullet h_3 : \Delta_7, F_8 \wedge F_9 \vdash \Delta_{11}, \top} \wedge_L \quad \frac{h_{10} : \Delta_7, F_8 \wedge F_9 \vdash \Delta_{11}}{\bullet h_{10} : (\Delta_7, F_8 \wedge F_9), \top \vdash \Delta_{11}} \top_L \\
\hline
- : \Delta_7, F_8 \wedge F_9 \vdash \Delta_{11} \quad \text{Cut} \\
\hline
\sim \\
\hline
- : \Delta_7, F_8 \wedge F_9 \vdash \Delta_{11} \quad \text{ax/W}
\end{array}$$

$$\begin{array}{c}
\frac{h_3 : F_8, F_9, \top, \Delta_{12} \vdash F_7, \Delta_{11}}{\bullet h_3 : (\top, \Delta_{12}), F_8 \wedge F_9 \vdash \Delta_{11}, F_7} \wedge_L \quad \frac{h_{10} : F_7, \Delta_{12}, F_8 \wedge F_9 \vdash \Delta_{11}}{\bullet h_{10} : ((\top, \Delta_{12}), F_8 \wedge F_9), F_7 \vdash \Delta_{11}} \top_L \\
\hline
- : (\top, \Delta_{12}), F_8 \wedge F_9 \vdash \Delta_{11} \quad \text{Cut} \\
\hline
\sim \\
\hline
\frac{\bullet h_3 : \top, \Delta_{12}, F_8 \wedge F_9 \vdash \Delta_{11}, F_7}{- : \top, \Delta_{12}, F_8 \wedge F_9 \vdash \Delta_{11}} \text{ax/W} \quad \frac{h_{10} : \top, \Delta_{12}, F_7, F_8 \wedge F_9 \vdash \Delta_{11}}{- : \top, \Delta_{12}, F_7, F_8 \wedge F_9 \vdash \Delta_{11}} \text{hCut}
\end{array}$$

8.9 Status of \vee_L : OK

- Case rule \rightarrow_R

$$\begin{array}{c}
\frac{h_3 : F_9, \Delta_8 \vdash F_7, \Delta_{12}, F_{13} \rightarrow F_{14} \quad h_3 : F_{10}, \Delta_8 \vdash F_7, \Delta_{12}, F_{13} \rightarrow F_{14}}{\bullet h_3 : \Delta_8, F_9 \vee F_{10} \vdash (\Delta_{12}, F_{13} \rightarrow F_{14}), F_7} \vee_L \quad \frac{h_{11} : F_7, F_{13}, \Delta_8, F_9 \vee F_{10} \vdash F_{14}, \Delta_{12}}{\bullet h_{11} : (\Delta_8, F_9 \vee F_{10}), F_7 \vdash \Delta_{12}, F_{13} \rightarrow F_{14}} \rightarrow_R \\
\hline
- : \Delta_8, F_9 \vee F_{10} \vdash \Delta_{12}, F_{13} \rightarrow F_{14} \quad \text{Cut} \\
\hline
\sim \\
\hline
\frac{h_3 : \Delta_8, F_{13}, F_9 \vdash \Delta_{12}, F_{14}, F_7}{\bullet h_3 : \Delta_8, F_{13}, F_9 \vee F_{10} \vdash \Delta_{12}, F_{14}, F_7} \text{inv-th/ax} \quad \frac{h_3 : \Delta_8, F_{10}, F_{13} \vdash \Delta_{12}, F_{14}, F_7}{\bullet h_3 : \Delta_8, F_{10}, F_{13} \vee F_{10} \vdash \Delta_{12}, F_{14}, F_7} \text{inv-th/ax} \\
\hline
\frac{h_{11} : \Delta_8, F_{13}, F_7, F_9 \vee F_{10} \vdash \Delta_{12}, F_{14}}{- : \Delta_8, F_{13}, F_9 \vee F_{10} \vdash \Delta_{12}, F_{14}} \text{ax/W} \quad \text{hCut} \\
\hline
- : \Delta_8, F_9 \vee F_{10} \vdash \Delta_{12}, F_{13} \rightarrow F_{14} \quad \rightarrow_R
\end{array}$$

- Case rule \wedge_R

$$\begin{array}{c}
\frac{h_3 : F_9, \Delta_8 \vdash F_7, \Delta_{12}, F_{13} \wedge F_{14} \quad h_3 : F_{10}, \Delta_8 \vdash F_7, \Delta_{12}, F_{13} \wedge F_{14}}{\bullet h_3 : \Delta_8, F_9 \vee F_{10} \vdash (\Delta_{12}, F_{13} \wedge F_{14}), F_7} \vee_L \quad \frac{h_{11} : F_7, \Delta_8, F_9 \vee F_{10} \vdash F_{13}, \Delta_{12}}{\bullet h_{11} : (\Delta_8, F_9 \vee F_{10}), F_7 \vdash \Delta_{12}, F_{13} \wedge F_{14}} \wedge_R \\
\hline
- : \Delta_8, F_9 \vee F_{10} \vdash \Delta_{12}, F_{13} \wedge F_{14} \quad \text{Cut} \\
\hline
\sim \\
\hline
\frac{h_3 : \Delta_8, F_9 \vdash \Delta_{12}, F_{13}, F_7}{\bullet h_3 : \Delta_8, F_9 \vee F_{10} \vdash \Delta_{12}, F_{13}, F_7} \text{inv-th/ax} \quad \frac{h_3 : \Delta_8, F_{10} \vdash \Delta_{12}, F_{13}, F_7}{\bullet h_3 : \Delta_8, F_{10} \vee F_{10} \vdash \Delta_{12}, F_{13}, F_7} \text{inv-th/ax} \\
\hline
\frac{h_{11} : \Delta_8, F_7, F_9 \vee F_{10} \vdash \Delta_{12}, F_{13}}{- : \Delta_8, F_7, F_9 \vee F_{10} \vdash \Delta_{12}, F_{13}} \text{ax/W} \quad \text{hCut} \quad \frac{h_3 : \Delta_8, F_9 \vdash \Delta_{12}, F_{14}, F_7}{\bullet h_3 : \Delta_8, F_9 \vee F_{10} \vdash \Delta_{12}, F_{14}, F_7} \text{inv-th/ax} \\
\hline
- : \Delta_8, F_9 \vee F_{10} \vdash \Delta_{12}, F_{13} \wedge F_{14}
\end{array}$$

- Case rule \vee_R

$$\begin{array}{c}
\frac{h_3 : F_9, \Delta_8 \vdash F_7, \Delta_{12}, F_{13} \vee F_{14} \quad h_3 : F_{10}, \Delta_8 \vdash F_7, \Delta_{12}, F_{13} \vee F_{14}}{\bullet h_3 : \Delta_8, F_9 \vee F_{10} \vdash (\Delta_{12}, F_{13} \vee F_{14}), F_7} \vee_L \quad \frac{h_{11} : F_7, \Delta_8, F_9 \vee F_{10} \vdash F_{13}, F_{14}, \Delta_{12}}{\bullet h_{11} : (\Delta_8, F_9 \vee F_{10}), F_7 \vdash \Delta_{12}, F_{13} \vee F_{14}} \vee_R \\
\frac{\bullet h_3 : \Delta_8, F_9 \vee F_{10} \vdash (\Delta_{12}, F_{13} \vee F_{14}), F_7 \quad \bullet h_{11} : (\Delta_8, F_9 \vee F_{10}), F_7 \vdash \Delta_{12}, F_{13} \vee F_{14}}{- : \Delta_8, F_9 \vee F_{10} \vdash \Delta_{12}, F_{13} \vee F_{14}} \text{Cut} \\
\sim \\
\frac{\frac{h_3 : \Delta_8, F_9 \vdash \Delta_{12}, F_{13}, F_{14}, F_7}{\bullet h_3 : \Delta_8, F_9 \vee F_{10} \vdash \Delta_{12}, F_{13}, F_{14}, F_7} \text{inv-th/ax} \quad \frac{h_3 : \Delta_8, F_{10} \vdash \Delta_{12}, F_{13}, F_{14}, F_7}{\bullet h_3 : \Delta_8, F_9 \vee F_{10} \vdash \Delta_{12}, F_{13}, F_{14}, F_7} \text{inv-th/ax}}{\frac{- : \Delta_8, F_9 \vee F_{10} \vdash \Delta_{12}, F_{13}, F_{14}}{- : \Delta_8, F_9 \vee F_{10} \vdash \Delta_{12}, F_{13} \vee F_{14}} \vee_L} \text{ax/W} \\
\frac{- : \Delta_8, F_9 \vee F_{10} \vdash \Delta_{12}, F_{13}, F_{14}}{- : \Delta_8, F_9 \vee F_{10} \vdash \Delta_{12}, F_{13} \vee F_{14}} \vee_R \quad \frac{h_{11} : \Delta_8, F_7, F_9 \vee F_{10} \vdash \Delta_{12}, F_{13}, F_{14}}{\bullet h_{11} : (\Delta_8, F_9 \vee F_{10}), F_7 \vdash \Delta_{12}, F_{13} \vee F_{14}} \text{hCut}
\end{array}$$

- Case rule \perp_R

$$\begin{array}{c}
\frac{h_3 : F_9, \Delta_8 \vdash F_7, \perp, \Delta_{12} \quad h_3 : F_{10}, \Delta_8 \vdash F_7, \perp, \Delta_{12}}{\bullet h_3 : \Delta_8, F_9 \vee F_{10} \vdash (\perp, \Delta_{12}), F_7} \vee_L \quad \frac{h_{11} : F_7, \Delta_8, F_9 \vee F_{10} \vdash \Delta_{12}}{\bullet h_{11} : (\Delta_8, F_9 \vee F_{10}), F_7 \vdash \perp, \Delta_{12}} \perp_R \\
\frac{\bullet h_3 : \Delta_8, F_9 \vee F_{10} \vdash (\perp, \Delta_{12}), F_7 \quad \bullet h_{11} : (\Delta_8, F_9 \vee F_{10}), F_7 \vdash \perp, \Delta_{12}}{- : \Delta_8, F_9 \vee F_{10} \vdash \perp, \Delta_{12}} \text{Cut} \\
\sim \\
\frac{\bullet h_3 : \Delta_8, F_9 \vee F_{10} \vdash \perp, \Delta_{12}, F_7}{- : \Delta_8, F_9 \vee F_{10} \vdash \perp, \Delta_{12}} \text{ax/W} \quad \frac{h_{11} : \Delta_8, F_7, F_9 \vee F_{10} \vdash \perp, \Delta_{12}}{\bullet h_{11} : (\Delta_8, F_9 \vee F_{10}), F_7 \vdash \perp, \Delta_{12}} \text{ax/W} \\
\frac{- : \Delta_8, F_9 \vee F_{10} \vdash \perp, \Delta_{12}}{- : \Delta_8, F_9 \vee F_{10} \vdash \perp, \Delta_{12}} \text{hCut}
\end{array}$$

- Case rule \top_R

$$\begin{array}{c}
\frac{h_3 : F_9, \Delta_8 \vdash F_7, \top, \Delta_{12} \quad h_3 : F_{10}, \Delta_8 \vdash F_7, \top, \Delta_{12}}{\bullet h_3 : \Delta_8, F_9 \vee F_{10} \vdash (\top, \Delta_{12}), F_7} \vee_L \quad \frac{h_{11} : (\Delta_8, F_9 \vee F_{10}), F_7 \vdash \top, \Delta_{12}}{\bullet h_{11} : (\Delta_8, F_9 \vee F_{10}), F_7 \vdash \top, \Delta_{12}} \top_R \\
\frac{\bullet h_3 : \Delta_8, F_9 \vee F_{10} \vdash (\top, \Delta_{12}), F_7 \quad \bullet h_{11} : (\Delta_8, F_9 \vee F_{10}), F_7 \vdash \top, \Delta_{12}}{- : \Delta_8, F_9 \vee F_{10} \vdash \top, \Delta_{12}} \text{Cut} \\
\sim \\
\frac{- : \Delta_8, F_9 \vee F_{10} \vdash \top, \Delta_{12}}{- : \Delta_8, F_9 \vee F_{10} \vdash \top, \Delta_{12}} \top_R
\end{array}$$

- Case rule $A4$

$$\begin{array}{c}
\frac{h_3 : F_8, \Box \Gamma_{13}, \Delta_{14} \vdash \Box F_7, \Delta_{11}, \Box F_{12} \quad h_3 : F_9, \Box \Gamma_{13}, \Delta_{14} \vdash \Box F_7, \Delta_{11}, \Box F_{12}}{\bullet h_3 : (\Box \Gamma_{13}, \Delta_{14}), F_8 \vee F_9 \vdash (\Delta_{11}, \Box F_{12}), \Box F_7} \vee_L \quad \frac{h_{10} : \Box \Gamma_{13}, \Box F_7 \vdash F_{12}}{\bullet h_{10} : ((\Box \Gamma_{13}, \Delta_{14}), F_8 \vee F_9), \Box F_7 \vdash \Delta_{11}, \Box F_{12}} \text{Cut} \\
\frac{\bullet h_3 : (\Box \Gamma_{13}, \Delta_{14}), F_8 \vee F_9 \vdash (\Delta_{11}, \Box F_{12}), \Box F_7 \quad \bullet h_{10} : ((\Box \Gamma_{13}, \Delta_{14}), F_8 \vee F_9), \Box F_7 \vdash \Delta_{11}, \Box F_{12}}{- : (\Box \Gamma_{13}, \Delta_{14}), F_8 \vee F_9 \vdash \Delta_{11}, \Box F_{12}} \text{Cut} \\
\sim \\
\frac{\frac{h_3 : \Delta_{14}, F_8, \Box \Gamma_{13} \vdash \Box F_7, \Delta_{11}, \Box F_{12}}{- : \Delta_{14}, F_8, \Box \Gamma_{13} \vdash \Delta_{11}, \Box F_{12}} \text{ax/W} \quad \frac{h_{10} : \Box F_7, \Box \Gamma_{13} \vdash F_{12}}{\bullet h_{10} : \Box F_7, \Delta_{14}, F_8, \Box \Gamma_{13} \vdash \Delta_{11}, \Box F_{12}} \text{ax/W}}{\frac{- : \Delta_{14}, F_8, \Box \Gamma_{13} \vdash \Delta_{11}, \Box F_{12}}{- : \Delta_{14}, \Box \Gamma_{13}, F_8 \vee F_9 \vdash \Delta_{11}, \Box F_{12}} \text{hCut}} \text{A4} \\
\frac{h_3 : F_8, \Box \Gamma_{11}, \Delta_{14} \vdash F_7, \Delta_{12}, \Box F_{13} \quad h_3 : F_9, \Box \Gamma_{11}, \Delta_{14} \vdash F_7, \Delta_{12}, \Box F_{13}}{\bullet h_3 : (\Box \Gamma_{11}, \Delta_{14}), F_8 \vee F_9 \vdash (\Delta_{12}, \Box F_{13}), F_7} \vee_L \quad \frac{h_{10} : \Box \Gamma_{11} \vdash F_{13}}{\bullet h_{10} : ((\Box \Gamma_{11}, \Delta_{14}), F_8 \vee F_9), F_7 \vdash \Delta_{12}, \Box F_{13}} \text{A4} \\
\frac{\bullet h_3 : (\Box \Gamma_{11}, \Delta_{14}), F_8 \vee F_9 \vdash (\Delta_{12}, \Box F_{13}), F_7 \quad \bullet h_{10} : ((\Box \Gamma_{11}, \Delta_{14}), F_8 \vee F_9), F_7 \vdash \Delta_{12}, \Box F_{13}}{- : (\Box \Gamma_{11}, \Delta_{14}), F_8 \vee F_9 \vdash \Delta_{12}, \Box F_{13}} \text{Cut} \\
\sim \\
\frac{- : \Box \Gamma_{11} \vdash F_{13}}{- : \Delta_{14}, \Box \Gamma_{11}, F_8 \vee F_9 \vdash \Delta_{12}, \Box F_{13}} \text{ax/W} \quad \text{A4}
\end{array}$$

- Case rule \rightarrow_L

$$\begin{array}{c}
\frac{h_3 : F_8, \Delta_7 \vdash F_{11} \rightarrow F_{12}, \Delta_{13} \quad h_3 : F_9, \Delta_7 \vdash F_{11} \rightarrow F_{12}, \Delta_{13}}{\bullet h_3 : \Delta_7, F_8 \vee F_9 \vdash \Delta_{13}, F_{11} \rightarrow F_{12}} \vee_L \quad \frac{h_{10} : \Delta_7, F_8 \vee F_9 \vdash F_{11}, \Delta_{13} \quad h_{10} : F_{12}, \Delta_7, F_8 \vee F_9 \vdash \Delta_{13}}{\bullet h_{10} : (\Delta_7, F_8 \vee F_9), F_{11} \rightarrow F_{12} \vdash \Delta_{13}} \rightarrow_L \\
\frac{\bullet h_3 : \Delta_7, F_8 \vee F_9 \vdash \Delta_{13}, F_{11} \rightarrow F_{12} \quad \bullet h_{10} : (\Delta_7, F_8 \vee F_9), F_{11} \rightarrow F_{12} \vdash \Delta_{13}}{- : \Delta_7, F_8 \vee F_9 \vdash \Delta_{13}} \text{Cut} \\
\sim \\
\frac{\frac{- : \Delta_7, F_{11}, F_8 \vdash \Delta_{13}, F_{12}}{- : \Delta_7, F_{11}, F_8 \vee F_9 \vdash \Delta_{13}, F_{12}} \text{inv-th/ax} \quad \frac{- : \Delta_7, F_{11}, F_9 \vdash \Delta_{13}, F_{12}}{- : \Delta_7, F_{11}, F_8 \vee F_9 \vdash \Delta_{13}, F_{12}} \text{inv-th/ax}}{\frac{- : \Delta_7, F_{11}, F_8 \vee F_9 \vdash \Delta_{13}, F_{12}}{- : \Delta_7, F_{11}, F_8 \vee F_9 \vdash \Delta_{13}} \vee_L} \text{ax/W} \\
\frac{- : \Delta_7, F_8 \vee F_9 \vdash \Delta_{13}, F_{11}}{- : \Delta_7, F_8 \vee F_9 \vdash \Delta_{13}} \text{ax/W} \quad \frac{- : \Delta_7, F_{11}, F_8 \vee F_9 \vdash \Delta_{13}}{- : \Delta_7, F_{11}, F_8 \vee F_9 \vdash \Delta_{13}} \text{sCut}
\end{array}$$

$$\begin{array}{c}
\frac{h_3 : F_8, \Delta_{14}, F_{11} \rightarrow F_{12} \vdash F_7, \Delta_{13} \quad h_3 : F_9, \Delta_{14}, F_{11} \rightarrow F_{12} \vdash F_7, \Delta_{13}}{\bullet h_3 : (\Delta_{14}, F_{11} \rightarrow F_{12}), F_8 \vee F_9 \vdash \Delta_{13}, F_7} \vee_L \quad \frac{h_{10} : F_7, \Delta_{14}, F_8 \vee F_9 \vdash F_{11}, \Delta_{13}}{\bullet h_{10} : ((\Delta_{14}, F_{11} \rightarrow F_{12}), F_8 \vee F_9) \vdash F_{11}, \Delta_{13}} \\
\frac{}{- : (\Delta_{14}, F_{11} \rightarrow F_{12}), F_8 \vee F_9 \vdash \Delta_{13}}{\sim} \\
\frac{\frac{h_3 : \Delta_{14}, F_8 \vdash \Delta_{13}, F_{11}, F_7}{\bullet h_3 : \Delta_{14}, F_8 \vee F_9 \vdash \Delta_{13}, F_{11}, F_7} \text{ inv-th/ax} \quad \frac{h_3 : \Delta_{14}, F_9 \vdash \Delta_{13}, F_{11}, F_7}{\vee_L} \text{ inv-th/ax}}{- : \Delta_{14}, F_8 \vee F_9 \vdash \Delta_{13}, F_{11}} \text{ ax/W} \quad \frac{h_{10} : \Delta_{14}, F_7, F_8 \vee F_9 \vdash \Delta_{13}, F_{11}}{h_{10} : \Delta_{14}, F_{12}, F_8 \vdash \Delta_{13}, F_7} \text{ ax/W} \\
\frac{}{- : \Delta_{14}, F_{11} \rightarrow F_{12}, F_8 \vee F_9 \vdash \Delta_{13}}{hCut} \quad \frac{}{- : \Delta_{14}, F_{11} \rightarrow F_{12}, F_8 \vee F_9 \vdash \Delta_{13}}{hCut}
\end{array}$$

- Case rule \wedge_L

$$\begin{array}{c}
\frac{h_3 : F_8, \Delta_7 \vdash F_{11} \wedge F_{12}, \Delta_{13} \quad h_3 : F_9, \Delta_7 \vdash F_{11} \wedge F_{12}, \Delta_{13}}{\bullet h_3 : \Delta_7, F_8 \vee F_9 \vdash \Delta_{13}, F_{11} \wedge F_{12}} \vee_L \quad \frac{h_{10} : F_{11}, F_{12}, \Delta_7, F_8 \vee F_9 \vdash \Delta_{13}}{\bullet h_{10} : (\Delta_7, F_8 \vee F_9), F_{11} \wedge F_{12} \vdash \Delta_{13}} \wedge_L \\
\frac{}{- : \Delta_7, F_8 \vee F_9 \vdash \Delta_{13}}{\sim} \quad \frac{}{- : \Delta_7, F_8 \vee F_9 \vdash \Delta_{13}}{Cut} \\
\frac{\frac{h_3 : \Delta_7, F_8 \vdash \Delta_{13}, F_{11} \wedge F_{12}}{- : \Delta_7, F_8 \vdash \Delta_{13}} \text{ ax/W} \quad \frac{\frac{h_{10} : \Delta_7, F_{11}, F_{12}, F_8 \vdash \Delta_{13}}{\bullet h_{10} : \Delta_7, F_8, F_{11} \wedge F_{12} \vdash \Delta_{13}} \text{ inv-th/ax}}{\wedge_L} \text{ hCut}}{- : \Delta_7, F_8 \vee F_9 \vdash \Delta_{13}} \text{ ax/W} \quad \frac{\frac{h_{10} : \Delta_7, F_{11}, F_{12}, F_9 \vdash \Delta_{13}}{\bullet h_{10} : \Delta_7, F_9, F_{11} \wedge F_{12} \vdash \Delta_{13}} \text{ inv-th/ax}}{\wedge_L} \text{ hCut}}{- : \Delta_7, F_9 \vdash \Delta_{13}} \vee_L \\
\frac{}{- : \Delta_7, F_8 \vee F_9 \vdash \Delta_{13}}{\sim} \\
\frac{h_3 : F_8, \Delta_{14}, F_{11} \wedge F_{12} \vdash F_7, \Delta_{13} \quad h_3 : F_9, \Delta_{14}, F_{11} \wedge F_{12} \vdash F_7, \Delta_{13}}{\bullet h_3 : (\Delta_{14}, F_{11} \wedge F_{12}), F_8 \vee F_9 \vdash \Delta_{13}, F_7} \vee_L \quad \frac{h_{10} : F_7, F_{11}, F_{12}, \Delta_{14}, F_8 \vee F_9 \vdash \Delta_{13}}{\bullet h_{10} : ((\Delta_{14}, F_{11} \wedge F_{12}), F_8 \vee F_9), F_7 \vdash \Delta_{13}} \wedge_L \\
\frac{}{- : (\Delta_{14}, F_{11} \wedge F_{12}), F_8 \vee F_9 \vdash \Delta_{13}}{\sim} \quad \frac{}{- : (\Delta_{14}, F_{11} \wedge F_{12}), F_8 \vee F_9 \vdash \Delta_{13}}{Cut} \\
\frac{\frac{h_3 : \Delta_{14}, F_{11}, F_{12}, F_8 \vdash \Delta_{13}, F_7}{\bullet h_3 : \Delta_{14}, F_{11}, F_{12}, F_8 \vee F_9 \vdash \Delta_{13}, F_7} \text{ inv-th/ax}}{\vee_L} \text{ inv-th/ax} \quad \frac{h_{10} : \Delta_{14}, F_{11}, F_{12}, F_7, F_8 \vee F_9 \vdash \Delta_{13}}{h_{10} : \Delta_{14}, F_{11}, F_{12}, F_7, F_8 \vee F_9 \vdash \Delta_{13}} \text{ ax/W} \\
\frac{}{- : \Delta_{14}, F_{11}, F_{12}, F_8 \vee F_9 \vdash \Delta_{13}}{\wedge_L} \quad \frac{}{- : \Delta_{14}, F_{11} \wedge F_{12}, F_8 \vee F_9 \vdash \Delta_{13}}{\wedge_L}
\end{array}$$

- Case rule \vee_L

$$\begin{array}{c}
\frac{h_3 : F_8, \Delta_7 \vdash F_{11} \vee F_{12}, \Delta_{13} \quad h_3 : F_9, \Delta_7 \vdash F_{11} \vee F_{12}, \Delta_{13}}{\bullet h_3 : \Delta_7, F_8 \vee F_9 \vdash \Delta_{13}, F_{11} \vee F_{12}} \vee_L \quad \frac{h_{10} : F_{11}, \Delta_7, F_8 \vee F_9 \vdash \Delta_{13} \quad h_{10} : F_{12}, \Delta_7, F_8 \vee F_9 \vdash \Delta_{13}}{\bullet h_{10} : (\Delta_7, F_8 \vee F_9), F_{11} \vee F_{12} \vdash \Delta_{13}} \vee_L \\
\frac{}{- : \Delta_7, F_8 \vee F_9 \vdash \Delta_{13}}{\sim} \quad \frac{}{- : \Delta_7, F_8 \vee F_9 \vdash \Delta_{13}}{Cut} \\
\frac{\frac{}{- : \Delta_7, F_8 \vdash \Delta_{13}, F_{11}, F_{12}} \text{ inv-th/ax} \quad \frac{}{- : \Delta_7, F_9 \vdash \Delta_{13}, F_{11}, F_{12}} \text{ inv-th/ax}}{- : \Delta_7, F_8 \vee F_9 \vdash \Delta_{13}, F_{11}, F_{12}} \vee_L \quad \frac{}{- : \Delta_7, F_{12}, F_8 \vee F_9 \vdash \Delta_{13}, F_{11}} \text{ ax/W} \\
\frac{}{- : \Delta_7, F_8 \vee F_9 \vdash \Delta_{13}, F_{11}}{sCut} \quad \frac{}{- : \Delta_7, F_{11}, F_8 \vee F_9 \vdash \Delta_{13}} \text{ ax/W} \\
\frac{}{- : \Delta_7, F_8 \vee F_9 \vdash \Delta_{13}}{sCut} \\
\frac{h_3 : F_8, \Delta_{14}, F_{11} \vee F_{12} \vdash F_7, \Delta_{13} \quad h_3 : F_9, \Delta_{14}, F_{11} \vee F_{12} \vdash F_7, \Delta_{13}}{\bullet h_3 : (\Delta_{14}, F_{11} \vee F_{12}), F_8 \vee F_9 \vdash \Delta_{13}, F_7} \vee_L \quad \frac{h_{10} : F_7, F_{11}, \Delta_{14}, F_8 \vee F_9 \vdash \Delta_{13}}{\bullet h_{10} : ((\Delta_{14}, F_{11} \vee F_{12}), F_8 \vee F_9) \vdash \Delta_{13}} \\
\frac{}{- : (\Delta_{14}, F_{11} \vee F_{12}), F_8 \vee F_9 \vdash \Delta_{13}}{\sim} \\
\frac{\frac{h_3 : \Delta_{14}, F_{11}, F_8 \vdash \Delta_{13}, F_7}{\bullet h_3 : \Delta_{14}, F_{11}, F_8 \vee F_9 \vdash \Delta_{13}, F_7} \text{ inv-th/ax}}{\vee_L} \text{ inv-th/ax} \quad \frac{h_{10} : \Delta_{14}, F_{11}, F_7, F_8 \vee F_9 \vdash \Delta_{13}}{h_{10} : \Delta_{14}, F_{11}, F_7, F_8 \vee F_9 \vdash \Delta_{13}} \text{ ax/W} \\
\frac{}{- : \Delta_{14}, F_{11}, F_8 \vee F_9 \vdash \Delta_{13}}{hCut} \quad \frac{}{- : \Delta_{14}, F_{11} \vee F_{12}, F_8 \vee F_9 \vdash \Delta_{13}}{hCut} \\
\frac{}{- : \Delta_{14}, F_{11} \vee F_{12}, F_8 \vee F_9 \vdash \Delta_{13}}{\sim} \\
\frac{h_3 : F_{10}, \Delta_8 \vdash F_7, \Delta_{12} \quad h_3 : F_{11}, \Delta_8 \vdash F_7, \Delta_{12}}{\bullet h_3 : \Delta_8, F_{10} \vee F_{11} \vdash \Delta_{12}, F_7} \vee_L \quad \frac{h_9 : F_7, F_{10}, \Delta_8 \vdash \Delta_{12} \quad h_9 : F_7, F_{11}, \Delta_8 \vdash \Delta_{12}}{\bullet h_9 : (\Delta_8, F_{10} \vee F_{11}), F_7 \vdash \Delta_{12}} \vee_L \\
\frac{}{- : \Delta_8, F_{10} \vee F_{11} \vdash \Delta_{12}}{Cut} \\
\frac{}{- : \Delta_8, F_{10} \vee F_{11} \vdash \Delta_{12}}{\sim} \\
\frac{\frac{h_3 : \Delta_8, F_{10} \vdash \Delta_{12}, F_7}{\bullet h_3 : \Delta_8, F_{10}, F_7 \vdash \Delta_{12}} \text{ ax/W} \quad \frac{h_9 : \Delta_8, F_{10}, F_7 \vdash \Delta_{12}}{h_9 : \Delta_8, F_{10}, F_7 \vdash \Delta_{12}} \text{ H}}{\text{hCut}} \quad \frac{\frac{h_3 : \Delta_8, F_{11} \vdash \Delta_{12}, F_7}{\bullet h_3 : \Delta_8, F_{11}, F_7 \vdash \Delta_{12}} \text{ ax/W} \quad \frac{h_9 : \Delta_8, F_{11}, F_7 \vdash \Delta_{12}}{h_9 : \Delta_8, F_{11}, F_7 \vdash \Delta_{12}} \text{ H}}{\text{hCut}} \\
\frac{}{- : \Delta_8, F_{10} \vdash \Delta_{12}}{\vee_L} \quad \frac{}{- : \Delta_8, F_{11} \vdash \Delta_{12}}{\vee_L} \\
\frac{}{- : \Delta_8, F_{10} \vee F_{11} \vdash \Delta_{12}}{\sim}
\end{array}$$

- Case rule AT

$$\begin{array}{c}
\frac{\frac{h_3 : F_8, \Delta_7 \vdash \boxed{F_{11}}, \Delta_{12} \quad h_3 : F_9, \Delta_7 \vdash \boxed{F_{11}}, \Delta_{12}}{\bullet h_3 : \Delta_7, F_8 \vee F_9 \vdash \Delta_{12}, \boxed{F_{11}}} \vee_L \quad \frac{h_{10} : F_{11}, \Delta_7, \boxed{F_{11}}, F_8 \vee F_9 \vdash \Delta_{12}}{\bullet h_{10} : (\Delta_7, F_8 \vee F_9), \boxed{F_{11}} \vdash \Delta_{12}} AT}{- : \Delta_7, F_8 \vee F_9 \vdash \Delta_{12}} Cut \\
\sim \\
\frac{\frac{h_3 : \Delta_7, F_8 \vdash \Delta_{12}, \boxed{F_{11}}}{- : \Delta_7, F_8 \vdash \Delta_{12}} ax/W \quad \frac{\frac{h_{10} : \Delta_7, F_{11}, F_8, \boxed{F_{11}} \vdash \Delta_{12}}{\bullet h_{10} : \Delta_7, F_8, \boxed{F_{11}} \vdash \Delta_{12}} inv-th/ax \quad AT}{hCut} \quad \frac{\frac{h_3 : \Delta_7, F_9 \vdash \Delta_{12}, \boxed{F_{11}}}{- : \Delta_7, F_9 \vdash \Delta_{12}} ax/W \quad \frac{\frac{h_{10} : \Delta_7, F_{11}, F_9, \boxed{F_{11}} \vdash \Delta_{12}}{\bullet h_{10} : \Delta_7, F_9, \boxed{F_{11}} \vdash \Delta_{12}} inv-th/ax \quad AT}{hCut}}{\vee_L} \\
- : \Delta_7, F_8 \vee F_9 \vdash \Delta_{12}
\end{array}$$

$$\begin{array}{c}
\frac{h_3 : F_8, \Delta_{13}, \boxed{F_{11}} \vdash F_7, \Delta_{12} \quad h_3 : F_9, \Delta_{13}, \boxed{F_{11}} \vdash F_7, \Delta_{12}}{\bullet h_3 : (\Delta_{13}, \boxed{F_{11}}), F_8 \vee F_9 \vdash \Delta_{12}, F_7} \vee_L \quad \frac{h_{10} : F_7, F_{11}, \Delta_{13}, \boxed{F_{11}}, F_8 \vee F_9 \vdash \Delta_{12}}{\bullet h_{10} : ((\Delta_{13}, \boxed{F_{11}}), F_8 \vee F_9), F_7 \vdash \Delta_{12}} AT}{- : (\Delta_{13}, \boxed{F_{11}}), F_8 \vee F_9 \vdash \Delta_{12}} Cut \\
\sim \\
\frac{\frac{\bullet h_3 : \Delta_{13}, F_{11}, \boxed{F_{11}}, F_8 \vee F_9 \vdash \Delta_{12}, F_7}{- : \Delta_{13}, F_{11}, \boxed{F_{11}}, F_8 \vee F_9 \vdash \Delta_{12}} ax/W \quad \frac{h_{10} : \Delta_{13}, F_{11}, F_7, \boxed{F_{11}}, F_8 \vee F_9 \vdash \Delta_{12}}{hCut}}{AT} \\
- : \Delta_{13}, \boxed{F_{11}}, F_8 \vee F_9 \vdash \Delta_{12}
\end{array}$$

- Case rule \perp_L

$$\begin{array}{c}
\frac{h_3 : F_8, \Delta_7 \vdash \perp, \Delta_{11} \quad h_3 : F_9, \Delta_7 \vdash \perp, \Delta_{11}}{\bullet h_3 : \Delta_7, F_8 \vee F_9 \vdash \Delta_{11}, \perp} \vee_L \quad \frac{\bullet h_{10} : (\Delta_7, F_8 \vee F_9), \perp \vdash \Delta_{11}}{- : \Delta_7, F_8 \vee F_9 \vdash \Delta_{11}} \perp_L}{Cut} \\
\sim \\
\frac{\frac{h_3 : \Delta_7, F_8 \vdash \perp, \Delta_{11}}{- : \Delta_7, F_8 \vdash \Delta_{11}} ax/W \quad \frac{\bullet h_{10} : \perp, \Delta_7, F_8 \vdash \Delta_{11}}{hCut} \quad \frac{h_3 : \Delta_7, F_9 \vdash \perp, \Delta_{11}}{- : \Delta_7, F_9 \vdash \Delta_{11}} ax/W \quad \frac{\bullet h_{10} : \perp, \Delta_7, F_9 \vdash \Delta_{11}}{hCut}}{\vee_L} \\
- : \Delta_7, F_8 \vee F_9 \vdash \Delta_{11}
\end{array}$$

$$\begin{array}{c}
\frac{h_3 : F_8, \perp, \Delta_{12} \vdash F_7, \Delta_{11} \quad h_3 : F_9, \perp, \Delta_{12} \vdash F_7, \Delta_{11}}{\bullet h_3 : (\perp, \Delta_{12}), F_8 \vee F_9 \vdash \Delta_{11}, F_7} \vee_L \quad \frac{\bullet h_{10} : ((\perp, \Delta_{12}), F_8 \vee F_9), F_7 \vdash \Delta_{11}}{- : (\perp, \Delta_{12}), F_8 \vee F_9 \vdash \Delta_{11}} \perp_L}{Cut} \\
\sim \\
- : \perp, \Delta_{12}, F_8 \vee F_9 \vdash \Delta_{11} \quad \perp_L
\end{array}$$

- Case rule I

$$\begin{array}{c}
\frac{h_3 : F_8, \Delta_7 \vdash p_{11}, \Delta_{12}, p_{11} \quad h_3 : F_9, \Delta_7 \vdash p_{11}, \Delta_{12}, p_{11}}{\bullet h_3 : \Delta_7, F_8 \vee F_9 \vdash (\Delta_{12}, p_{11}), p_{11}} \vee_L \quad \frac{\bullet h_{10} : (\Delta_7, F_8 \vee F_9), p_{11} \vdash \Delta_{12}, p_{11}}{- : \Delta_7, F_8 \vee F_9 \vdash \Delta_{12}, p_{11}} I}{Cut} \\
\sim \\
\frac{\frac{h_3 : \Delta_7, F_8 \vdash \Delta_{12}, p_{11}, p_{11}}{- : \Delta_7, F_8 \vdash \Delta_{12}, p_{11}} ax/W \quad \frac{\bullet h_{10} : \Delta_7, F_8, p_{11} \vdash \Delta_{12}, p_{11}}{hCut} \quad \frac{h_3 : \Delta_7, F_9 \vdash \Delta_{12}, p_{11}, p_{11}}{- : \Delta_7, F_9 \vdash \Delta_{12}, p_{11}} ax/W \quad \frac{\bullet h_{10} : \Delta_7, F_9, p_{11} \vdash \Delta_{12}, p_{11}}{hCut}}{\vee_L} \\
- : \Delta_7, F_8 \vee F_9 \vdash \Delta_{12}, p_{11}
\end{array}$$

$$\begin{array}{c}
\frac{h_3 : F_8, \Delta_{13}, p_{11} \vdash F_7, \Delta_{12}, p_{11} \quad h_3 : F_9, \Delta_{13}, p_{11} \vdash F_7, \Delta_{12}, p_{11}}{\bullet h_3 : (\Delta_{13}, p_{11}), F_8 \vee F_9 \vdash (\Delta_{12}, p_{11}), F_7} \vee_L \quad \frac{\bullet h_{10} : ((\Delta_{13}, p_{11}), F_8 \vee F_9), F_7 \vdash \Delta_{12}, p_{11}}{- : (\Delta_{13}, p_{11}), F_8 \vee F_9 \vdash \Delta_{12}, p_{11}} I}{Cut} \\
\sim \\
- : \Delta_{13}, p_{11}, F_8 \vee F_9 \vdash \Delta_{12}, p_{11} \quad I
\end{array}$$

- Case rule \top_L

$$\begin{array}{c}
\frac{h_3 : F_8, \Delta_7 \vdash \top, \Delta_{11} \quad h_3 : F_9, \Delta_7 \vdash \top, \Delta_{11}}{\bullet h_3 : \Delta_7, F_8 \vee F_9 \vdash \Delta_{11}, \top} \vee_L \quad \frac{h_{10} : \Delta_7, F_8 \vee F_9 \vdash \Delta_{11}}{\bullet h_{10} : (\Delta_7, F_8 \vee F_9), \top \vdash \Delta_{11}} \top_L}{Cut} \\
\sim \\
- : \Delta_7, F_8 \vee F_9 \vdash \Delta_{11} \quad ax/W
\end{array}$$

$$\begin{array}{c}
\frac{h_3 : F_8, \top, \Delta_{12} \vdash F_7, \Delta_{11} \quad h_3 : F_9, \top, \Delta_{12} \vdash F_7, \Delta_{11}}{\bullet h_3 : (\top, \Delta_{12}), F_8 \vee F_9 \vdash \Delta_{11}, F_7} \vee_L \quad \frac{h_{10} : F_7, \Delta_{12}, F_8 \vee F_9 \vdash \Delta_{11}}{\bullet h_{10} : ((\top, \Delta_{12}), F_8 \vee F_9), F_7 \vdash \Delta_{11}} \top_L \\
\hline
- : (\top, \Delta_{12}), F_8 \vee F_9 \vdash \Delta_{11} \quad \text{Cut} \\
\hline
\frac{\bullet h_3 : \top, \Delta_{12}, F_8 \vee F_9 \vdash \Delta_{11}, F_7 \quad \text{ax/W} \quad h_{10} : \top, \Delta_{12}, F_7, F_8 \vee F_9 \vdash \Delta_{11} \quad \text{ax/W}}{- : \top, \Delta_{12}, F_8 \vee F_9 \vdash \Delta_{11}} \text{hCut}
\end{array}$$

8.10 Status of AT : OK

- Case rule \rightarrow_R

$$\begin{array}{c}
\frac{h_3 : F_8, \Delta_7, [F_8 \vdash F_6, \Delta_{10}, F_{11} \rightarrow F_{12}] \quad \bullet h_3 : \Delta_7, [F_8 \vdash (\Delta_{10}, F_{11} \rightarrow F_{12}), F_6]}{\bullet h_3 : \Delta_7, [F_8 \vdash \Delta_{10}, F_{11} \rightarrow F_{12}] \quad \text{AT}} \quad \frac{h_9 : F_6, F_{11}, \Delta_7, [F_8 \vdash F_{12}, \Delta_{10}] \quad \bullet h_9 : (\Delta_7, [F_8]), F_6 \vdash \Delta_{10}, F_{11} \rightarrow F_{12}}{\bullet h_9 : (\Delta_7, [F_8]), F_6 \vdash \Delta_{10}, F_{11} \rightarrow F_{12}} \rightarrow_R \\
\hline
- : \Delta_7, [F_8 \vdash \Delta_{10}, F_{11} \rightarrow F_{12}] \quad \text{Cut} \\
\hline
\frac{\bullet h_3 : \Delta_7, F_8, [F_8 \vdash \Delta_{10}, F_6, F_{11} \rightarrow F_{12}] \quad \text{ax/W} \quad \bullet h_9 : \Delta_7, F_6, F_8, [F_8 \vdash \Delta_{10}, F_{11} \rightarrow F_{12}] \quad \text{ax/W}}{- : \Delta_7, F_8, [F_8 \vdash \Delta_{10}, F_{11} \rightarrow F_{12}] \quad \text{hCut}} \\
\hline
- : \Delta_7, [F_8 \vdash \Delta_{10}, F_{11} \rightarrow F_{12}] \quad \text{AT} \\
\hline
- : \Delta_7, [F_8 \vdash \Delta_{10}, F_{11} \rightarrow F_{12}]
\end{array}$$

- Case rule \wedge_R

$$\begin{array}{c}
\frac{h_3 : F_8, \Delta_7, [F_8 \vdash F_6, \Delta_{10}, F_{11} \wedge F_{12}] \quad \bullet h_3 : \Delta_7, [F_8 \vdash (\Delta_{10}, F_{11} \wedge F_{12}), F_6]}{\bullet h_3 : \Delta_7, [F_8 \vdash \Delta_{10}, F_{11} \wedge F_{12}] \quad \text{AT}} \quad \frac{h_9 : F_6, \Delta_7, [F_8 \vdash F_{11}, \Delta_{10}] \quad h_9 : F_6, \Delta_7, [F_8 \vdash F_{12}, \Delta_{10}]}{\bullet h_9 : (\Delta_7, [F_8]), F_6 \vdash \Delta_{10}, F_{11} \wedge F_{12}} \wedge_R \\
\hline
- : \Delta_7, [F_8 \vdash \Delta_{10}, F_{11} \wedge F_{12}] \quad \text{Cut} \\
\hline
\frac{\bullet h_3 : \Delta_7, F_8, [F_8 \vdash \Delta_{10}, F_6, F_{11} \wedge F_{12}] \quad \text{ax/W} \quad \bullet h_9 : \Delta_7, F_6, F_8, [F_8 \vdash \Delta_{10}, F_{11} \wedge F_{12}] \quad \text{ax/W}}{- : \Delta_7, F_8, [F_8 \vdash \Delta_{10}, F_{11} \wedge F_{12}] \quad \text{hCut}} \\
\hline
- : \Delta_7, [F_8 \vdash \Delta_{10}, F_{11} \wedge F_{12}] \quad \text{AT} \\
\hline
- : \Delta_7, [F_8 \vdash \Delta_{10}, F_{11} \wedge F_{12}]
\end{array}$$

- Case rule \vee_R

$$\begin{array}{c}
\frac{h_3 : F_8, \Delta_7, [F_8 \vdash F_6, \Delta_{10}, F_{11} \vee F_{12}] \quad \bullet h_3 : \Delta_7, [F_8 \vdash (\Delta_{10}, F_{11} \vee F_{12}), F_6]}{\bullet h_3 : \Delta_7, [F_8 \vdash \Delta_{10}, F_{11} \vee F_{12}] \quad \text{AT}} \quad \frac{h_9 : F_6, \Delta_7, [F_8 \vdash F_{11}, F_{12}, \Delta_{10}]}{\bullet h_9 : (\Delta_7, [F_8]), F_6 \vdash \Delta_{10}, F_{11} \vee F_{12}} \vee_R \\
\hline
- : \Delta_7, [F_8 \vdash \Delta_{10}, F_{11} \vee F_{12}] \quad \text{Cut} \\
\hline
\frac{\bullet h_3 : \Delta_7, F_8, [F_8 \vdash \Delta_{10}, F_6, F_{11} \vee F_{12}] \quad \text{ax/W} \quad \bullet h_9 : \Delta_7, F_6, F_8, [F_8 \vdash \Delta_{10}, F_{11} \vee F_{12}] \quad \text{ax/W}}{- : \Delta_7, F_8, [F_8 \vdash \Delta_{10}, F_{11} \vee F_{12}] \quad \text{hCut}} \\
\hline
- : \Delta_7, [F_8 \vdash \Delta_{10}, F_{11} \vee F_{12}] \quad \text{AT} \\
\hline
- : \Delta_7, [F_8 \vdash \Delta_{10}, F_{11} \vee F_{12}]
\end{array}$$

- Case rule \perp_R

$$\begin{array}{c}
\frac{h_3 : F_8, \Delta_7, [F_8 \vdash F_6, \perp, \Delta_{10}] \quad \bullet h_3 : \Delta_7, [F_8 \vdash (\perp, \Delta_{10}), F_6]}{\bullet h_3 : \Delta_7, [F_8 \vdash \perp, \Delta_{10}] \quad \text{AT}} \quad \frac{h_9 : F_6, \Delta_7, [F_8 \vdash \Delta_{10}]}{\bullet h_9 : (\Delta_7, [F_8]), F_6 \vdash \perp, \Delta_{10}} \perp_R \\
\hline
- : \Delta_7, [F_8 \vdash \perp, \Delta_{10}] \quad \text{Cut} \\
\hline
\frac{\bullet h_3 : \Delta_7, [F_8 \vdash \perp, \Delta_{10}, F_6] \quad \text{ax/W} \quad h_9 : \Delta_7, F_6, [F_8 \vdash \perp, \Delta_{10}] \quad \text{ax/W}}{- : \Delta_7, [F_8 \vdash \perp, \Delta_{10}] \quad \text{hCut}}
\end{array}$$

- Case rule \top_R

$$\begin{array}{c}
\frac{h_3 : F_8, \Delta_7, [F_8 \vdash F_6, \top, \Delta_{10}] \quad \bullet h_3 : \Delta_7, [F_8 \vdash (\top, \Delta_{10}), F_6]}{\bullet h_3 : \Delta_7, [F_8 \vdash \top, \Delta_{10}] \quad \text{AT}} \quad \frac{\bullet h_9 : (\Delta_7, [F_8]), F_6 \vdash \top, \Delta_{10}}{\bullet h_9 : (\Delta_7, [F_8]), F_6 \vdash \top, \Delta_{10}} \top_R \\
\hline
- : \Delta_7, [F_8 \vdash \top, \Delta_{10}] \quad \text{Cut} \\
\hline
- : \Delta_7, [F_8 \vdash \top, \Delta_{10}] \quad \top_R
\end{array}$$

- Case rule $A4$

$$\begin{array}{c}
\frac{h_3 : F_7, (\Box \Gamma_{12}, \Delta_9), [\Box F_6, \Delta_{10}, \Box F_{11}] \quad \bullet h_3 : ((\Box \Gamma_{12}, \Delta_9), [F_7], \Box F_6 \vdash \Delta_{10}, \Box F_{11}) \quad AT}{- : (\Box \Gamma_{12}, \Delta_9), [F_7 \vdash \Delta_{10}, \Box F_{11}]} \quad \begin{array}{c} A4 \\ Cut \end{array} \\
\sim \\
\frac{\frac{h_3 : \Delta_9, F_7, \Box \Gamma_{12}, [F_7 \vdash \Box F_6, \Delta_{10}, \Box F_{11}] \quad \bullet h_8 : \Box F_6, \Delta_9, F_7, \Box \Gamma_{12}, [F_7 \vdash \Delta_{10}, \Box F_{11}] \quad ax/W}{- : \Delta_9, F_7, \Box \Gamma_{12}, [F_7 \vdash \Delta_{10}, \Box F_{11}] \quad AT} \quad hCut}{- : \Delta_9, \Box \Gamma_{12}, [F_7 \vdash \Delta_{10}, \Box F_{11}]} \\
\\
\frac{h_3 : F_7, (\Box \Gamma_{11}, \Delta_{12}), [F_7 \vdash F_6, \Delta_9, \Box F_{10}] \quad \bullet h_3 : ((\Box \Gamma_{11}, \Delta_{12}), [F_7], F_6 \vdash \Delta_9, \Box F_{10}) \quad AT}{- : (\Box \Gamma_{11}, \Delta_{12}), [F_7 \vdash \Delta_9, \Box F_{10}]} \quad \begin{array}{c} A4 \\ Cut \end{array} \\
\sim \\
\frac{- : \Box \Gamma_{11}, [F_7 \vdash F_{10}] \quad ax/W}{- : \Delta_{12}, \Box \Gamma_{11}, [F_7 \vdash \Delta_9, \Box F_{10}]} \quad A4 \\
\\
\frac{h_3 : F_7, (\Box \Gamma_{11}, \Delta_{12}), [F_7 \vdash \Box F_6, \Delta_9, \Box F_{10}] \quad \bullet h_3 : ((\Box \Gamma_{11}, \Delta_{12}), [F_7], \Box F_6 \vdash \Delta_9, \Box F_{10}) \quad AT}{- : (\Box \Gamma_{11}, \Delta_{12}), [F_7 \vdash \Delta_9, \Box F_{10}]} \quad \begin{array}{c} A4 \\ Cut \end{array} \\
\sim \\
\frac{\frac{h_3 : \Delta_{12}, F_7, \Box \Gamma_{11}, [F_7 \vdash \Box F_6, \Delta_9, \Box F_{10}] \quad \bullet h_8 : \Box F_6, \Delta_{12}, F_7, \Box \Gamma_{11}, [F_7 \vdash \Delta_9, \Box F_{10}] \quad ax/W}{- : \Delta_{12}, F_7, \Box \Gamma_{11}, [F_7 \vdash \Delta_9, \Box F_{10}] \quad AT} \quad hCut}{- : \Delta_{12}, \Box \Gamma_{11}, [F_7 \vdash \Delta_9, \Box F_{10}]} \\
\\
\frac{h_3 : F_7, (\Box \Gamma_9, \Delta_{12}), [F_7 \vdash F_6, \Delta_{10}, \Box F_{11}] \quad \bullet h_3 : ((\Box \Gamma_9, \Delta_{12}), [F_7], F_6 \vdash \Delta_{10}, \Box F_{11}) \quad AT}{- : (\Box \Gamma_9, \Delta_{12}), [F_7 \vdash \Delta_{10}, \Box F_{11}]} \quad \begin{array}{c} A4 \\ Cut \end{array} \\
\sim \\
\frac{- : \Box \Gamma_9 \vdash F_{11} \quad ax/W}{- : \Delta_{12}, \Box \Gamma_9, [F_7 \vdash \Delta_{10}, \Box F_{11}]} \quad A4
\end{array}$$

• Case rule \rightarrow_L

$$\begin{array}{c}
\frac{h_3 : F_7, \Delta_6, [F_7 \vdash F_9 \rightarrow F_{10}, \Delta_{11}] \quad \bullet h_3 : (\Delta_6, [F_7 \vdash \Delta_{11}, F_9 \rightarrow F_{10}]) \quad AT}{- : \Delta_6, [F_7 \vdash \Delta_{11}]} \quad \begin{array}{c} A4 \\ Cut \end{array} \\
\sim \\
\frac{\frac{h_3 : \Delta_6, F_7, [F_7 \vdash \Delta_{11}, F_9 \rightarrow F_{10}] \quad \bullet h_8 : \Delta_6, F_7, [F_7, F_9 \rightarrow F_{10} \vdash \Delta_{11}] \quad ax/W}{- : \Delta_6, F_7, [F_7 \vdash \Delta_{11}] \quad AT} \quad hCut}{- : \Delta_6, [F_7 \vdash \Delta_{11}]} \\
\\
\frac{h_3 : F_7, (\Delta_{12}, F_9 \rightarrow F_{10}), [F_7 \vdash F_6, \Delta_{11}] \quad \bullet h_3 : ((\Delta_{12}, F_9 \rightarrow F_{10}), [F_7], F_6 \vdash \Delta_{11}) \quad AT}{- : (\Delta_{12}, F_9 \rightarrow F_{10}), [F_7 \vdash \Delta_{11}]} \quad \begin{array}{c} A4 \\ Cut \end{array} \\
\sim \\
\frac{\frac{h_3 : \Delta_{12}, F_7, [F_7, F_9 \rightarrow F_{10} \vdash \Delta_{11}, F_6] \quad \bullet h_8 : \Delta_{12}, F_6, F_7, [F_7, F_9 \rightarrow F_{10} \vdash \Delta_{11}] \quad ax/W}{- : \Delta_{12}, F_7, [F_7, F_9 \rightarrow F_{10} \vdash \Delta_{11}] \quad AT} \quad hCut}{- : \Delta_{12}, [F_7, F_9 \rightarrow F_{10} \vdash \Delta_{11}]} \quad A4
\end{array}$$

• Case rule \wedge_L

$$\begin{array}{c}
\frac{h_3 : F_7, \Delta_6, [F_7 \vdash F_9 \wedge F_{10}, \Delta_{11}] \quad \bullet h_3 : (\Delta_6, [F_7 \vdash \Delta_{11}, F_9 \wedge F_{10}]) \quad AT}{- : \Delta_6, [F_7 \vdash \Delta_{11}]} \quad \begin{array}{c} A4 \\ Cut \end{array} \\
\sim \\
\frac{\frac{h_3 : \Delta_6, F_7, [F_7 \vdash \Delta_{11}, F_9 \wedge F_{10}] \quad \bullet h_8 : \Delta_6, F_7, [F_7, F_9 \wedge F_{10} \vdash \Delta_{11}] \quad ax/W}{- : \Delta_6, F_7, [F_7 \vdash \Delta_{11}] \quad AT} \quad hCut}{- : \Delta_6, [F_7 \vdash \Delta_{11}]}
\end{array}$$

$$\begin{array}{c}
\frac{h_3 : F_7, (\Delta_{12}, F_9 \wedge F_{10}), [F_7 \vdash F_6, \Delta_{11}] \quad AT \quad \frac{h_8 : F_6, F_9, F_{10}, \Delta_{12}, [F_7 \vdash \Delta_{11}] \quad \wedge_L}{\bullet h_8 : ((\Delta_{12}, F_9 \wedge F_{10}), [F_7], F_6 \vdash \Delta_{11})} \quad \text{Cut}}{\vdash : (\Delta_{12}, F_9 \wedge F_{10}), [F_7 \vdash \Delta_{11}]} \\
\sim \\
\frac{\frac{h_3 : \Delta_{12}, F_7, [F_7, F_9 \wedge F_{10} \vdash \Delta_{11}, F_6] \quad ax/W \quad \bullet h_8 : \Delta_{12}, F_6, F_7, [F_7, F_9 \wedge F_{10} \vdash \Delta_{11}] \quad ax/W}{\vdash : \Delta_{12}, F_7, [F_7, F_9 \wedge F_{10} \vdash \Delta_{11}] \quad hCut} \quad AT}{\vdash : \Delta_{12}, [F_7, F_9 \wedge F_{10} \vdash \Delta_{11}]}
\end{array}$$

- Case rule \vee_L

$$\begin{array}{c}
\frac{h_3 : F_7, \Delta_6, [F_7 \vdash F_9 \vee F_{10}, \Delta_{11}] \quad AT \quad \frac{h_8 : F_9, \Delta_6, [F_7 \vdash \Delta_{11}] \quad h_8 : F_{10}, \Delta_6, [F_7 \vdash \Delta_{11}] \quad \vee_L}{\bullet h_8 : (\Delta_6, [F_7], F_9 \vee F_{10} \vdash \Delta_{11})} \quad \text{Cut}}{\vdash : \Delta_6, [F_7 \vdash \Delta_{11}]} \\
\sim \\
\frac{\frac{h_3 : \Delta_6, F_7, [F_7 \vdash \Delta_{11}, F_9 \vee F_{10}] \quad ax/W \quad \bullet h_8 : \Delta_6, F_7, [F_7, F_9 \vee F_{10} \vdash \Delta_{11}] \quad ax/W}{\vdash : \Delta_6, F_7, [F_7 \vdash \Delta_{11}] \quad hCut} \quad AT}{\vdash : \Delta_6, [F_7 \vdash \Delta_{11}]} \\
\\
\frac{h_3 : F_7, (\Delta_{12}, F_9 \vee F_{10}), [F_7 \vdash F_6, \Delta_{11}] \quad AT \quad \frac{h_8 : F_6, F_9, \Delta_{12}, [F_7 \vdash \Delta_{11}] \quad h_8 : F_6, F_{10}, \Delta_{12}, [F_7 \vdash \Delta_{11}] \quad \vee_L}{\bullet h_8 : ((\Delta_{12}, F_9 \vee F_{10}), [F_7], F_6 \vdash \Delta_{11})} \quad \text{Cut}}{\vdash : (\Delta_{12}, F_9 \vee F_{10}), [F_7 \vdash \Delta_{11}]} \\
\sim \\
\frac{\frac{h_3 : \Delta_{12}, F_7, [F_7, F_9 \vee F_{10} \vdash \Delta_{11}, F_6] \quad ax/W \quad \bullet h_8 : \Delta_{12}, F_6, F_7, [F_7, F_9 \vee F_{10} \vdash \Delta_{11}] \quad ax/W}{\vdash : \Delta_{12}, F_7, [F_7, F_9 \vee F_{10} \vdash \Delta_{11}] \quad hCut} \quad AT}{\vdash : \Delta_{12}, [F_7, F_9 \vee F_{10} \vdash \Delta_{11}]}
\end{array}$$

- Case rule AT

$$\begin{array}{c}
\frac{h_3 : F_7, \Delta_6, [F_7 \vdash [F_9, \Delta_{10}]] \quad AT \quad \frac{h_8 : F_9, \Delta_6, [F_7, [F_9 \vdash \Delta_{10}]] \quad AT}{\bullet h_8 : (\Delta_6, [F_7], [F_9 \vdash \Delta_{10}])} \quad \text{Cut}}{\vdash : \Delta_6, [F_7 \vdash \Delta_{10}]} \\
\sim \\
\frac{h_3 : \Delta_6, F_7, [F_7 \vdash \Delta_{10}, [F_9]] \quad ax/W \quad \bullet h_8 : \Delta_6, F_7, [F_7, [F_9 \vdash \Delta_{10}]] \quad ax/W}{\vdash : \Delta_6, F_7, [F_7 \vdash \Delta_{10}] \quad hCut} \quad AT}{\vdash : \Delta_6, [F_7 \vdash \Delta_{10}]} \\
\\
\frac{h_3 : F_7, (\Delta_{11}, [F_9]), [F_7 \vdash F_6, \Delta_{10}] \quad AT \quad \frac{h_8 : F_6, F_9, \Delta_{11}, [F_7, [F_9 \vdash \Delta_{10}]] \quad AT}{\bullet h_8 : ((\Delta_{11}, [F_9]), [F_7], F_6 \vdash \Delta_{10})} \quad \text{Cut}}{\vdash : (\Delta_{11}, [F_9]), [F_7 \vdash \Delta_{10}]} \\
\sim \\
\frac{h_3 : \Delta_{11}, F_7, [F_7, [F_9 \vdash \Delta_{10}, F_6]] \quad ax/W \quad \bullet h_8 : \Delta_{11}, F_6, F_7, [F_7, [F_9 \vdash \Delta_{10}]] \quad ax/W}{\vdash : \Delta_{11}, F_7, [F_7, [F_9 \vdash \Delta_{10}]] \quad hCut} \quad AT}{\vdash : \Delta_{11}, [F_7, [F_9 \vdash \Delta_{10}]} \\
\\
\frac{h_3 : F_9, \Delta_7, [F_9 \vdash F_6, \Delta_{10}] \quad AT \quad \frac{h_8 : F_6, F_9, \Delta_7, [F_9 \vdash \Delta_{10}] \quad AT}{\bullet h_8 : (\Delta_7, [F_9], F_6 \vdash \Delta_{10})} \quad \text{Cut}}{\vdash : \Delta_7, [F_9 \vdash \Delta_{10}]} \\
\sim \\
\frac{h_3 : \Delta_7, F_9, [F_9 \vdash \Delta_{10}, F_6] \quad ax/W \quad \bullet h_8 : \Delta_7, F_6, F_9, [F_9 \vdash \Delta_{10}] \quad ax/W}{\vdash : \Delta_7, F_9, [F_9 \vdash \Delta_{10}] \quad hCut} \quad AT}{\vdash : \Delta_7, [F_9 \vdash \Delta_{10}]}
\end{array}$$

- Case rule \perp_L

$$\begin{array}{c}
\frac{\frac{h_3 : F_7, \Delta_6, [\Box F_7 \vdash \perp, \Delta_9]}{\bullet h_3 : \Delta_6, [\Box F_7 \vdash \Delta_9, \perp]} AT \quad \frac{}{\bullet h_8 : (\Delta_6, [\Box F_7], \perp \vdash \Delta_9)} \perp_L}{\frac{}{- : \Delta_6, [\Box F_7 \vdash \Delta_9]} \text{Cut}} \\
\rightsquigarrow \\
\frac{\frac{h_3 : \Delta_6, F_7, [\Box F_7 \vdash \perp, \Delta_9]}{\bullet h_3 : \perp, \Delta_6, F_7, [\Box F_7 \vdash \Delta_9]} ax/W \quad \frac{}{\bullet h_8 : \perp, \Delta_6, F_7, [\Box F_7 \vdash \Delta_9]} \perp_L}{\frac{}{- : \Delta_6, F_7, [\Box F_7 \vdash \Delta_9]} hCut} \\
\frac{}{- : \Delta_6, [\Box F_7 \vdash \Delta_9]} AT
\end{array}$$

$$\begin{array}{c}
\frac{h_3 : F_7, (\perp, \Delta_{10}), [\Box F_7 \vdash F_6, \Delta_9]}{\bullet h_3 : (\perp, \Delta_{10}), [\Box F_7 \vdash \Delta_9, F_6]} AT \quad \frac{}{\bullet h_8 : ((\perp, \Delta_{10}), [\Box F_7], F_6 \vdash \Delta_9)} \perp_L}{\frac{}{- : (\perp, \Delta_{10}), [\Box F_7 \vdash \Delta_9]} \text{Cut}} \\
\rightsquigarrow \\
\frac{}{- : \perp, \Delta_{10}, [\Box F_7 \vdash \Delta_9]} \perp_L
\end{array}$$

- Case rule I

$$\begin{array}{c}
\frac{h_3 : F_7, \Delta_6, [\Box F_7 \vdash p_9, \Delta_{10}, p_9]}{\bullet h_3 : \Delta_6, [\Box F_7 \vdash (\Delta_{10}, p_9), p_9]} AT \quad \frac{}{\bullet h_8 : (\Delta_6, [\Box F_7], p_9 \vdash \Delta_{10}, p_9)} I}{\frac{}{- : \Delta_6, [\Box F_7 \vdash \Delta_{10}, p_9]} \text{Cut}} \\
\rightsquigarrow \\
\frac{\frac{h_3 : \Delta_6, F_7, [\Box F_7 \vdash \Delta_{10}, p_9, p_9]}{\bullet h_3 : \Delta_6, F_7, p_9, [\Box F_7 \vdash \Delta_{10}, p_9]} ax/W \quad \frac{}{\bullet h_8 : \Delta_6, F_7, p_9, [\Box F_7 \vdash \Delta_{10}, p_9]} I}{\frac{}{- : \Delta_6, F_7, [\Box F_7 \vdash \Delta_{10}, p_9]} hCut} \\
\frac{}{- : \Delta_6, [\Box F_7 \vdash \Delta_{10}, p_9]} AT
\end{array}$$

$$\begin{array}{c}
\frac{h_3 : F_7, (\Delta_{11}, p_9), [\Box F_7 \vdash F_6, \Delta_{10}, p_9]}{\bullet h_3 : (\Delta_{11}, p_9), [\Box F_7 \vdash (\Delta_{10}, p_9), F_6]} AT \quad \frac{}{\bullet h_8 : ((\Delta_{11}, p_9), [\Box F_7], F_6 \vdash \Delta_{10}, p_9)} I}{\frac{}{- : (\Delta_{11}, p_9), [\Box F_7 \vdash \Delta_{10}, p_9]} \text{Cut}} \\
\rightsquigarrow \\
\frac{}{- : \Delta_{11}, p_9, [\Box F_7 \vdash \Delta_{10}, p_9]} I
\end{array}$$

- Case rule \top_L

$$\begin{array}{c}
\frac{h_3 : F_7, \Delta_6, [\Box F_7 \vdash \top, \Delta_9]}{\bullet h_3 : \Delta_6, [\Box F_7 \vdash \Delta_9, \top]} AT \quad \frac{h_8 : \Delta_6, [\Box F_7 \vdash \Delta_9]}{\bullet h_8 : (\Delta_6, [\Box F_7], \top \vdash \Delta_9)} \top_L}{\frac{}{- : \Delta_6, [\Box F_7 \vdash \Delta_9]} \text{Cut}} \\
\rightsquigarrow \\
\frac{}{- : \Delta_6, [\Box F_7 \vdash \Delta_9]} ax/W
\end{array}$$

$$\begin{array}{c}
\frac{h_3 : F_7, (\top, \Delta_{10}), [\Box F_7 \vdash F_6, \Delta_9]}{\bullet h_3 : (\top, \Delta_{10}), [\Box F_7 \vdash \Delta_9, F_6]} AT \quad \frac{h_8 : F_6, \Delta_{10}, [\Box F_7 \vdash \Delta_9]}{\bullet h_8 : ((\top, \Delta_{10}), [\Box F_7], F_6 \vdash \Delta_9)} \top_L}{\frac{}{- : (\top, \Delta_{10}), [\Box F_7 \vdash \Delta_9]} \text{Cut}} \\
\rightsquigarrow \\
\frac{\frac{}{\bullet h_3 : \top, \Delta_{10}, [\Box F_7 \vdash \Delta_9, F_6]} ax/W \quad \frac{}{\bullet h_8 : \top, \Delta_{10}, F_6, [\Box F_7 \vdash \Delta_9]} ax/W}{\frac{}{- : \top, \Delta_{10}, [\Box F_7 \vdash \Delta_9]} hCut}
\end{array}$$

8.11 Status of \perp_L : OK

- Case rule \rightarrow_R

$$\begin{array}{c}
\frac{}{\bullet h_3 : \perp, \Delta_6 \vdash (\Delta_8, F_9 \rightarrow F_{10}), F_5} \perp_L \quad \frac{h_7 : \perp, F_5, F_9, \Delta_6 \vdash F_{10}, \Delta_8}{\bullet h_7 : (\perp, \Delta_6), F_5 \vdash \Delta_8, F_9 \rightarrow F_{10}} \rightarrow_R}{\frac{}{- : \perp, \Delta_6 \vdash \Delta_8, F_9 \rightarrow F_{10}} \text{Cut}} \\
\rightsquigarrow \\
\frac{}{- : \perp, \Delta_6 \vdash \Delta_8, F_9 \rightarrow F_{10}} \perp_L
\end{array}$$

- Case rule \wedge_R

$$\begin{array}{c}
\frac{\bullet h_3 : \perp, \Delta_6 \vdash (\Delta_8, F_9 \wedge F_{10}), F_5}{\perp_L} \quad \frac{\frac{h_7 : \perp, F_5, \Delta_6 \vdash F_9, \Delta_8 \quad h_7 : \perp, F_5, \Delta_6 \vdash F_{10}, \Delta_8}{\bullet h_7 : (\perp, \Delta_6), F_5 \vdash \Delta_8, F_9 \wedge F_{10}} \wedge_R}{\text{Cut}} \\
\frac{}{- : \perp, \Delta_6 \vdash \Delta_8, F_9 \wedge F_{10}} \rightsquigarrow \\
\frac{}{- : \perp, \Delta_6 \vdash \Delta_8, F_9 \wedge F_{10}} \perp_L
\end{array}$$

- Case rule \vee_R

$$\begin{array}{c}
\frac{\bullet h_3 : \perp, \Delta_6 \vdash (\Delta_8, F_9 \vee F_{10}), F_5}{\perp_L} \quad \frac{\frac{h_7 : \perp, F_5, \Delta_6 \vdash F_9, F_{10}, \Delta_8}{\bullet h_7 : (\perp, \Delta_6), F_5 \vdash \Delta_8, F_9 \vee F_{10}} \vee_R}{\text{Cut}} \\
\frac{}{- : \perp, \Delta_6 \vdash \Delta_8, F_9 \vee F_{10}} \rightsquigarrow \\
\frac{}{- : \perp, \Delta_6 \vdash \Delta_8, F_9 \vee F_{10}} \perp_L
\end{array}$$

- Case rule \perp_R

$$\begin{array}{c}
\frac{\bullet h_3 : \perp, \Delta_6 \vdash (\perp, \Delta_8), F_5}{\perp_L} \quad \frac{\frac{h_7 : \perp, F_5, \Delta_6 \vdash \Delta_8}{\bullet h_7 : (\perp, \Delta_6), F_5 \vdash \perp, \Delta_8} \perp_R}{\text{Cut}} \\
\frac{}{- : \perp, \Delta_6 \vdash \perp, \Delta_8} \rightsquigarrow \\
\frac{}{- : \perp, \Delta_6 \vdash \perp, \Delta_8} \perp_L
\end{array}$$

- Case rule \top_R

$$\begin{array}{c}
\frac{\bullet h_3 : \perp, \Delta_6 \vdash (\top, \Delta_8), F_5}{\perp_L} \quad \frac{\frac{h_7 : (\perp, \Delta_6), F_5 \vdash \top, \Delta_8}{\bullet h_7 : (\perp, \Delta_6), F_5 \vdash \top, \Delta_8} \top_R}{\text{Cut}} \\
\frac{}{- : \perp, \Delta_6 \vdash \top, \Delta_8} \rightsquigarrow \\
\frac{}{- : \perp, \Delta_6 \vdash \top, \Delta_8} \top_R
\end{array}$$

- Case rule $A4$

$$\begin{array}{c}
\frac{\bullet h_3 : \perp, \Box \Gamma_9, \Delta_{10} \vdash (\Delta_7, \Box F_8), \Box F_5}{\perp_L} \quad \frac{\frac{h_6 : \Box \Gamma_9, \Box F_5 \vdash F_8}{\bullet h_6 : (\perp, \Box \Gamma_9, \Delta_{10}), \Box F_5 \vdash \Delta_7, \Box F_8} A4}{\text{Cut}} \\
\frac{}{- : \perp, \Box \Gamma_9, \Delta_{10} \vdash \Delta_7, \Box F_8} \rightsquigarrow \\
\frac{}{- : \perp, \Delta_{10}, \Box \Gamma_9 \vdash \Delta_7, \Box F_8} \perp_L \\
\\
\frac{\bullet h_3 : \perp, \Box \Gamma_7, \Delta_{10} \vdash (\Delta_8, \Box F_9), F_5}{\perp_L} \quad \frac{\frac{h_6 : \Box \Gamma_7 \vdash F_9}{\bullet h_6 : (\perp, \Box \Gamma_7, \Delta_{10}), F_5 \vdash \Delta_8, \Box F_9} A4}{\text{Cut}} \\
\frac{}{- : \perp, \Box \Gamma_7, \Delta_{10} \vdash \Delta_8, \Box F_9} \rightsquigarrow \\
\frac{}{- : \perp, \Delta_{10}, \Box \Gamma_7 \vdash \Delta_8, \Box F_9} \perp_L
\end{array}$$

- Case rule \rightarrow_L

$$\begin{array}{c}
\frac{\bullet h_3 : \perp, \Delta_5 \vdash \Delta_9, F_7 \rightarrow F_8}{\perp_L} \quad \frac{\frac{h_6 : \perp, \Delta_5 \vdash F_7, \Delta_9 \quad h_6 : \perp, F_8, \Delta_5 \vdash \Delta_9}{\bullet h_6 : (\perp, \Delta_5), F_7 \rightarrow F_8 \vdash \Delta_9} \rightarrow_L}{\text{Cut}} \\
\frac{}{- : \perp, \Delta_5 \vdash \Delta_9} \rightsquigarrow \\
\frac{}{- : \perp, \Delta_5 \vdash \Delta_9} \perp_L \\
\\
\frac{\bullet h_3 : \perp, \Delta_{10}, F_7 \rightarrow F_8 \vdash \Delta_9, F_5}{\perp_L} \quad \frac{\frac{h_6 : \perp, F_5, \Delta_{10} \vdash F_7, \Delta_9 \quad h_6 : \perp, F_5, F_8, \Delta_{10} \vdash \Delta_9}{\bullet h_6 : (\perp, \Delta_{10}, F_7 \rightarrow F_8), F_5 \vdash \Delta_9} \rightarrow_L}{\text{Cut}} \\
\frac{}{- : \perp, \Delta_{10}, F_7 \rightarrow F_8 \vdash \Delta_9} \rightsquigarrow \\
\frac{}{- : \perp, \Delta_{10}, F_7 \rightarrow F_8 \vdash \Delta_9} \perp_L
\end{array}$$

- Case rule \wedge_L

$$\begin{array}{c}
\frac{\frac{\bullet h_3 : \perp, \Delta_5 \vdash \Delta_9, F_7 \wedge F_8}{\vdash : \perp, \Delta_5 \vdash \Delta_9} \perp_L \quad \frac{\frac{h_6 : \perp, F_7, F_8, \Delta_5 \vdash \Delta_9}{\bullet h_6 : (\perp, \Delta_5), F_7 \wedge F_8 \vdash \Delta_9} \wedge_L}{\vdash : \perp, \Delta_5 \vdash \Delta_9} \text{Cut} \\
\rightsquigarrow \\
\frac{}{\vdash : \perp, \Delta_5 \vdash \Delta_9} \perp_L
\end{array}$$

$$\begin{array}{c}
\frac{\frac{\bullet h_3 : \perp, \Delta_{10}, F_7 \wedge F_8 \vdash \Delta_9, F_5}{\vdash : \perp, \Delta_{10}, F_7 \wedge F_8 \vdash \Delta_9} \perp_L \quad \frac{\frac{h_6 : \perp, F_5, F_7, F_8, \Delta_{10} \vdash \Delta_9}{\bullet h_6 : (\perp, \Delta_{10}, F_7 \wedge F_8), F_5 \vdash \Delta_9} \wedge_L}{\vdash : \perp, \Delta_{10}, F_7 \wedge F_8 \vdash \Delta_9} \text{Cut} \\
\rightsquigarrow \\
\frac{}{\vdash : \perp, \Delta_{10}, F_7 \wedge F_8 \vdash \Delta_9} \perp_L
\end{array}$$

- Case rule \vee_L

$$\begin{array}{c}
\frac{\frac{\bullet h_3 : \perp, \Delta_5 \vdash \Delta_9, F_7 \vee F_8}{\vdash : \perp, \Delta_5 \vdash \Delta_9} \perp_L \quad \frac{\frac{h_6 : \perp, F_7, \Delta_5 \vdash \Delta_9 \quad h_6 : \perp, F_8, \Delta_5 \vdash \Delta_9}{\bullet h_6 : (\perp, \Delta_5), F_7 \vee F_8 \vdash \Delta_9} \vee_L}{\vdash : \perp, \Delta_5 \vdash \Delta_9} \text{Cut} \\
\rightsquigarrow \\
\frac{}{\vdash : \perp, \Delta_5 \vdash \Delta_9} \perp_L
\end{array}$$

$$\begin{array}{c}
\frac{\frac{\bullet h_3 : \perp, \Delta_{10}, F_7 \vee F_8 \vdash \Delta_9, F_5}{\vdash : \perp, \Delta_{10}, F_7 \vee F_8 \vdash \Delta_9} \perp_L \quad \frac{\frac{h_6 : \perp, F_5, F_7, \Delta_{10} \vdash \Delta_9 \quad h_6 : \perp, F_5, F_8, \Delta_{10} \vdash \Delta_9}{\bullet h_6 : (\perp, \Delta_{10}, F_7 \vee F_8), F_5 \vdash \Delta_9} \vee_L}{\vdash : \perp, \Delta_{10}, F_7 \vee F_8 \vdash \Delta_9} \text{Cut} \\
\rightsquigarrow \\
\frac{}{\vdash : \perp, \Delta_{10}, F_7 \vee F_8 \vdash \Delta_9} \perp_L
\end{array}$$

- Case rule AT

$$\begin{array}{c}
\frac{\frac{\bullet h_3 : \perp, \Delta_5 \vdash \Delta_8, [\Box F_7]}{\vdash : \perp, \Delta_5 \vdash \Delta_8} \perp_L \quad \frac{\frac{h_6 : \perp, F_7, \Delta_5, [\Box F_7] \vdash \Delta_8}{\bullet h_6 : (\perp, \Delta_5), [\Box F_7] \vdash \Delta_8} AT}{\vdash : \perp, \Delta_5 \vdash \Delta_8} \text{Cut} \\
\rightsquigarrow \\
\frac{}{\vdash : \perp, \Delta_5 \vdash \Delta_8} \perp_L
\end{array}$$

$$\begin{array}{c}
\frac{\frac{\bullet h_3 : \perp, \Delta_9, [\Box F_7] \vdash \Delta_8, F_5}{\vdash : \perp, \Delta_9, [\Box F_7] \vdash \Delta_8} \perp_L \quad \frac{\frac{h_6 : \perp, F_5, F_7, \Delta_9, [\Box F_7] \vdash \Delta_8}{\bullet h_6 : (\perp, \Delta_9, [\Box F_7]), F_5 \vdash \Delta_8} AT}{\vdash : \perp, \Delta_9, [\Box F_7] \vdash \Delta_8} \text{Cut} \\
\rightsquigarrow \\
\frac{}{\vdash : \perp, \Delta_9, [\Box F_7] \vdash \Delta_8} \perp_L
\end{array}$$

- Case rule \perp_L

$$\begin{array}{c}
\frac{\frac{\bullet h_3 : \perp, \Delta_6 \vdash \Delta_8, F_5}{\vdash : \perp, \Delta_6 \vdash \Delta_8} \perp_L \quad \frac{\frac{\bullet h_7 : (\perp, \Delta_6), F_5 \vdash \Delta_8}{\vdash : \perp, \Delta_6 \vdash \Delta_8} \perp_L}{\vdash : \perp, \Delta_6 \vdash \Delta_8} \text{Cut} \\
\rightsquigarrow \\
\frac{}{\vdash : \perp, \Delta_6 \vdash \Delta_8} \perp_L
\end{array}$$

- Case rule I

$$\begin{array}{c}
\frac{\frac{\bullet h_3 : \perp, \Delta_5 \vdash (\Delta_8, p_7), p_7}{\vdash : \perp, \Delta_5 \vdash \Delta_8, p_7} \perp_L \quad \frac{\frac{\bullet h_6 : (\perp, \Delta_5), p_7 \vdash \Delta_8, p_7}{\vdash : \perp, \Delta_5 \vdash \Delta_8, p_7} I}{\vdash : \perp, \Delta_5 \vdash \Delta_8, p_7} \text{Cut} \\
\rightsquigarrow \\
\frac{}{\vdash : \perp, \Delta_5 \vdash \Delta_8, p_7} \perp_L
\end{array}$$

$$\begin{array}{c}
\frac{\frac{\bullet h_3 : \perp, \Delta_9, p_7 \vdash (\Delta_8, p_7), F_5}{\vdash : \perp, \Delta_9, p_7 \vdash \Delta_8, p_7} \perp_L \quad \frac{\frac{\bullet h_6 : (\perp, \Delta_9, p_7), F_5 \vdash \Delta_8, p_7}{\vdash : \perp, \Delta_9, p_7 \vdash \Delta_8, p_7} I}{\vdash : \perp, \Delta_9, p_7 \vdash \Delta_8, p_7} \text{Cut} \\
\rightsquigarrow \\
\frac{}{\vdash : \perp, \Delta_9, p_7 \vdash \Delta_8, p_7} \perp_L
\end{array}$$

- Case rule \top_L

$$\begin{array}{c}
\frac{\frac{\bullet h_3 : \perp, \Delta_5 \vdash \Delta_7, \top}{\vdash : \perp, \Delta_5 \vdash \Delta_7} \perp_L \quad \frac{h_6 : \perp, \Delta_5 \vdash \Delta_7}{\bullet h_6 : (\perp, \Delta_5), \top \vdash \Delta_7} \top_L}{\vdash : \perp, \Delta_5 \vdash \Delta_7} \text{Cut} \\
\sim \\
\frac{\vdash : \perp, \Delta_5 \vdash \Delta_7}{\vdash : \perp, \Delta_5 \vdash \Delta_7} \perp_L \\
\\
\frac{\frac{\bullet h_3 : \perp, \top, \Delta_8 \vdash \Delta_7, F_5}{\vdash : \perp, \top, \Delta_8 \vdash \Delta_7} \perp_L \quad \frac{h_6 : \perp, F_5, \Delta_8 \vdash \Delta_7}{\bullet h_6 : (\perp, \top, \Delta_8), F_5 \vdash \Delta_7} \top_L}{\vdash : \perp, \top, \Delta_8 \vdash \Delta_7} \text{Cut} \\
\sim \\
\frac{\vdash : \perp, \top, \Delta_8 \vdash \Delta_7}{\vdash : \perp, \top, \Delta_8 \vdash \Delta_7} \perp_L
\end{array}$$

8.12 Status of I : OK

- Case rule \rightarrow_R

$$\begin{array}{c}
\frac{\frac{\bullet h_1 : \Delta_5, p_6 \vdash (\Delta_8, F_9 \rightarrow F_{10}), p_6}{\vdash : \Delta_5, p_6 \vdash \Delta_8, F_9 \rightarrow F_{10}} I \quad \frac{h_7 : F_9, \Delta_5, p_6, p_6 \vdash F_{10}, \Delta_8}{\bullet h_7 : (\Delta_5, p_6), p_6 \vdash \Delta_8, F_9 \rightarrow F_{10}} \rightarrow_R}{\vdash : \Delta_5, p_6 \vdash \Delta_8, F_9 \rightarrow F_{10}} \text{Cut} \\
\sim \\
\frac{\frac{\bullet h_1 : \Delta_5, F_9, p_6 \vdash \Delta_8, F_{10}, p_6}{\vdash : \Delta_5, F_9, p_6 \vdash \Delta_8, F_{10}} I \quad \frac{h_7 : \Delta_5, F_9, p_6, p_6 \vdash \Delta_8, F_{10}}{\bullet h_7 : (\Delta_5, F_9, p_6), p_6 \vdash \Delta_8, F_{10}} \text{ax/w}}{\vdash : \Delta_5, p_6 \vdash \Delta_8, F_9 \rightarrow F_{10}} \text{hCut} \rightarrow_R \\
\\
\frac{\frac{\bullet h_2 : \Delta_7, p_8 \vdash ((\Delta_{12}, F_{10} \rightarrow F_{11}), p_8), F_6}{\vdash : \Delta_7, p_8 \vdash (\Delta_{12}, F_{10} \rightarrow F_{11}), p_8} I \quad \frac{h_9 : F_6, F_{10}, \Delta_7, p_8 \vdash F_{11}, \Delta_{12}, p_8}{\bullet h_9 : (\Delta_7, p_8), F_6 \vdash (\Delta_{12}, F_{10} \rightarrow F_{11}), p_8}}{\vdash : \Delta_7, p_8 \vdash (\Delta_{12}, F_{10} \rightarrow F_{11}), p_8} \rightarrow_R \text{Cut} \\
\sim \\
\frac{\vdash : \Delta_7, p_8 \vdash \Delta_{12}, p_8, F_{10} \rightarrow F_{11}}{\vdash : \Delta_7, p_8 \vdash \Delta_{12}, p_8, F_{10} \rightarrow F_{11}} I
\end{array}$$

- Case rule \wedge_R

$$\begin{array}{c}
\frac{\frac{\bullet h_1 : \Delta_5, p_6 \vdash (\Delta_8, F_9 \wedge F_{10}), p_6}{\vdash : \Delta_5, p_6 \vdash \Delta_8, F_9 \wedge F_{10}} I \quad \frac{h_7 : \Delta_5, p_6, p_6 \vdash F_9, \Delta_8 \quad h_7 : \Delta_5, p_6, p_6 \vdash F_{10}, \Delta_8}{\bullet h_7 : (\Delta_5, p_6), p_6 \vdash \Delta_8, F_9 \wedge F_{10}} \wedge_R}{\vdash : \Delta_5, p_6 \vdash \Delta_8, F_9 \wedge F_{10}} \text{Cut} \\
\sim \\
\frac{\frac{\bullet h_1 : \Delta_5, p_6 \vdash \Delta_8, F_9, p_6}{\vdash : \Delta_5, p_6 \vdash \Delta_8, F_9} I \quad \frac{h_7 : \Delta_5, p_6, p_6 \vdash \Delta_8, F_9}{\bullet h_7 : (\Delta_5, p_6), p_6 \vdash \Delta_8, F_9} \text{ax/w}}{\vdash : \Delta_5, p_6 \vdash \Delta_8, F_9} \text{hCut} \quad \frac{\frac{\bullet h_1 : \Delta_5, p_6 \vdash \Delta_8, F_{10}, p_6}{\vdash : \Delta_5, p_6 \vdash \Delta_8, F_{10}} I \quad \frac{h_7 : \Delta_5, p_6, p_6 \vdash \Delta_8, F_{10}}{\bullet h_7 : (\Delta_5, p_6), p_6 \vdash \Delta_8, F_{10}} \text{ax/w}}{\vdash : \Delta_5, p_6 \vdash \Delta_8, F_{10}} \text{hCut} \wedge_R \\
\\
\frac{\frac{\bullet h_2 : \Delta_7, p_8 \vdash ((\Delta_{12}, F_{10} \wedge F_{11}), p_8), F_6}{\vdash : \Delta_7, p_8 \vdash (\Delta_{12}, F_{10} \wedge F_{11}), p_8} I \quad \frac{h_9 : F_6, \Delta_7, p_8 \vdash F_{10}, \Delta_{12}, p_8 \quad h_9 : F_6, \Delta_7, p_8 \vdash F_{11}, \Delta_{12}, p_8}{\bullet h_9 : (\Delta_7, p_8), F_6 \vdash (\Delta_{12}, F_{10} \wedge F_{11}), p_8}}{\vdash : \Delta_7, p_8 \vdash (\Delta_{12}, F_{10} \wedge F_{11}), p_8} \wedge_R \text{Cut} \\
\sim \\
\frac{\vdash : \Delta_7, p_8 \vdash \Delta_{12}, p_8, F_{10} \wedge F_{11}}{\vdash : \Delta_7, p_8 \vdash \Delta_{12}, p_8, F_{10} \wedge F_{11}} I
\end{array}$$

- Case rule \vee_R

$$\begin{array}{c}
\frac{\frac{\bullet h_1 : \Delta_5, p_6 \vdash (\Delta_8, F_9 \vee F_{10}), p_6}{\vdash : \Delta_5, p_6 \vdash \Delta_8, F_9 \vee F_{10}} I \quad \frac{h_7 : \Delta_5, p_6, p_6 \vdash F_9, F_{10}, \Delta_8}{\bullet h_7 : (\Delta_5, p_6), p_6 \vdash \Delta_8, F_9 \vee F_{10}} \vee_R}{\vdash : \Delta_5, p_6 \vdash \Delta_8, F_9 \vee F_{10}} \text{Cut} \\
\sim \\
\frac{\frac{\bullet h_1 : \Delta_5, p_6 \vdash \Delta_8, F_{10}, F_9, p_6}{\vdash : \Delta_5, p_6 \vdash \Delta_8, F_{10}, F_9} I \quad \frac{h_7 : \Delta_5, p_6, p_6 \vdash \Delta_8, F_{10}, F_9}{\bullet h_7 : (\Delta_5, p_6), p_6 \vdash \Delta_8, F_{10}, F_9} \text{ax/w}}{\vdash : \Delta_5, p_6 \vdash \Delta_8, F_{10}, F_9} \text{hCut} \vee_R \\
\\
\frac{\vdash : \Delta_5, p_6 \vdash \Delta_8, F_9 \vee F_{10}}{\vdash : \Delta_5, p_6 \vdash \Delta_8, F_9 \vee F_{10}} \vee_R
\end{array}$$

$$\begin{array}{c}
\frac{\bullet h_2 : \Delta_7, p_8 \vdash ((\Delta_{12}, F_{10} \vee F_{11}), p_8), F_6}{- : \Delta_7, p_8 \vdash (\Delta_{12}, F_{10} \vee F_{11}), p_8} I \quad \frac{h_9 : F_6, \Delta_7, p_8 \vdash F_{10}, F_{11}, \Delta_{12}, p_8}{\bullet h_9 : (\Delta_7, p_8), F_6 \vdash (\Delta_{12}, F_{10} \vee F_{11}), p_8} \vee_R \\
\text{Cut} \\
\frac{}{- : \Delta_7, p_8 \vdash \Delta_{12}, p_8, F_{10} \vee F_{11}} I
\end{array}$$

- Case rule \perp_R

$$\begin{array}{c}
\frac{\bullet h_1 : \Delta_5, p_6 \vdash (\perp, \Delta_8), p_6}{- : \Delta_5, p_6 \vdash \perp, \Delta_8} I \quad \frac{h_7 : \Delta_5, p_6, p_6 \vdash \Delta_8}{\bullet h_7 : (\Delta_5, p_6), p_6 \vdash \perp, \Delta_8} \perp_R \\
\text{Cut} \\
\frac{}{- : \Delta_5, p_6 \vdash \perp, \Delta_8} \rightsquigarrow \\
\frac{\bullet h_1 : \Delta_5, p_6 \vdash \perp, \Delta_8, p_6}{- : \Delta_5, p_6 \vdash \perp, \Delta_8} \text{ax/W} \quad \frac{h_7 : \Delta_5, p_6, p_6 \vdash \perp, \Delta_8}{h_7 : \Delta_5, p_6, p_6 \vdash \perp, \Delta_8} \text{ax/W} \\
\text{hCut} \\
\frac{}{- : \Delta_5, p_6 \vdash \perp, \Delta_8} \\
\frac{\bullet h_2 : \Delta_7, p_8 \vdash ((\perp, \Delta_{10}), p_8), F_6}{- : \Delta_7, p_8 \vdash (\perp, \Delta_{10}), p_8} I \quad \frac{h_9 : F_6, \Delta_7, p_8 \vdash \Delta_{10}, p_8}{\bullet h_9 : (\Delta_7, p_8), F_6 \vdash (\perp, \Delta_{10}), p_8} \perp_R \\
\text{Cut} \\
\frac{}{- : \Delta_7, p_8 \vdash \perp, \Delta_{10}, p_8} I
\end{array}$$

- Case rule \top_R

$$\begin{array}{c}
\frac{\bullet h_1 : \Delta_5, p_6 \vdash (\top, \Delta_8), p_6}{- : \Delta_5, p_6 \vdash \top, \Delta_8} I \quad \frac{\bullet h_7 : (\Delta_5, p_6), p_6 \vdash \top, \Delta_8}{- : \Delta_5, p_6 \vdash \top, \Delta_8} \top_R \\
\text{Cut} \\
\frac{}{- : \Delta_5, p_6 \vdash \top, \Delta_8} \rightsquigarrow \\
\frac{}{- : \Delta_5, p_6 \vdash \top, \Delta_8} \top_R \\
\frac{\bullet h_2 : \Delta_7, p_8 \vdash ((\top, \Delta_{10}), p_8), F_6}{- : \Delta_7, p_8 \vdash (\top, \Delta_{10}), p_8} I \quad \frac{\bullet h_9 : (\Delta_7, p_8), F_6 \vdash (\top, \Delta_{10}), p_8}{- : \Delta_7, p_8 \vdash (\top, \Delta_{10}), p_8} \top_R \\
\text{Cut} \\
\frac{}{- : \Delta_7, p_8 \vdash \top, \Delta_{10}, p_8} \top_R
\end{array}$$

- Case rule A4

$$\begin{array}{c}
\frac{\bullet h_1 : (\Box \Gamma_7, \Delta_{10}), p_5 \vdash (\Delta_8, \llbracket F_9 \rrbracket), p_5}{- : (\Box \Gamma_7, \Delta_{10}), p_5 \vdash \Delta_8, \llbracket F_9 \rrbracket} I \quad \frac{h_6 : \Box \Gamma_7 \vdash F_9}{\bullet h_6 : ((\Box \Gamma_7, \Delta_{10}), p_5), p_5 \vdash \Delta_8, \llbracket F_9 \rrbracket} A4 \\
\text{Cut} \\
\frac{}{- : (\Box \Gamma_7, \Delta_{10}), p_5 \vdash \Delta_8, \llbracket F_9 \rrbracket} \rightsquigarrow \\
\frac{}{- : \Box \Gamma_7 \vdash F_9} \text{ax/W} \\
\frac{}{- : \Delta_{10}, \Box \Gamma_7, p_5 \vdash \Delta_8, \llbracket F_9 \rrbracket} A4 \\
\frac{\bullet h_2 : (\Box \Gamma_{11}, \Delta_{12}), p_7 \vdash ((\Delta_{10}, \llbracket F_9 \rrbracket), p_7), \Box F_6}{- : (\Box \Gamma_{11}, \Delta_{12}), p_7 \vdash (\Delta_{10}, \llbracket F_9 \rrbracket), p_7} I \quad \frac{h_8 : \Box \Gamma_{11}, \Box F_6 \vdash F_9}{\bullet h_8 : ((\Box \Gamma_{11}, \Delta_{12}), p_7), \Box F_6 \vdash (\Delta_{10}, \llbracket F_9 \rrbracket), p_7} A4 \\
\text{Cut} \\
\frac{}{- : (\Box \Gamma_{11}, \Delta_{12}), p_7 \vdash (\Delta_{10}, \llbracket F_9 \rrbracket), p_7} \rightsquigarrow \\
\frac{}{- : \Delta_{12}, \Box \Gamma_{11}, p_7 \vdash \Delta_{10}, p_7, \llbracket F_9 \rrbracket} I \\
\frac{\bullet h_2 : (\Box \Gamma_9, \Delta_{12}), p_7 \vdash ((\Delta_{11}, \llbracket F_{10} \rrbracket), p_7), F_6}{- : (\Box \Gamma_9, \Delta_{12}), p_7 \vdash (\Delta_{11}, \llbracket F_{10} \rrbracket), p_7} I \quad \frac{h_8 : \Box \Gamma_9 \vdash F_{10}}{\bullet h_8 : ((\Box \Gamma_9, \Delta_{12}), p_7), F_6 \vdash (\Delta_{11}, \llbracket F_{10} \rrbracket), p_7} A4 \\
\text{Cut} \\
\frac{}{- : (\Box \Gamma_9, \Delta_{12}), p_7 \vdash (\Delta_{11}, \llbracket F_{10} \rrbracket), p_7} \rightsquigarrow \\
\frac{}{- : \Delta_{12}, \Box \Gamma_9, p_7 \vdash \Delta_{11}, p_7, \llbracket F_{10} \rrbracket} I
\end{array}$$

- Case rule \rightarrow_L

$$\begin{array}{c}
\frac{\frac{\bullet h_1 : (\Delta_{10}, F_7 \rightarrow F_8), p_5 \vdash \Delta_9, p_5}{- : (\Delta_{10}, F_7 \rightarrow F_8), p_5 \vdash \Delta_9} I \quad \frac{h_6 : \Delta_{10}, p_5, p_5 \vdash F_7, \Delta_9 \quad h_6 : F_8, \Delta_{10}, p_5, p_5 \vdash \Delta_9}{\bullet h_6 : ((\Delta_{10}, F_7 \rightarrow F_8), p_5), p_5 \vdash \Delta_9} \rightarrow_L}{- : (\Delta_{10}, F_7 \rightarrow F_8), p_5 \vdash \Delta_9} \text{Cut} \\
\sim \\
\frac{\frac{\bullet h_1 : \Delta_{10}, p_5 \vdash \Delta_9, F_7, p_5}{- : \Delta_{10}, p_5 \vdash \Delta_9, F_7} I \quad \frac{h_6 : \Delta_{10}, p_5, p_5 \vdash \Delta_9, F_7}{h_6 : \Delta_{10}, F_8, p_5, p_5 \vdash \Delta_9} \text{ax/W} \quad \frac{\bullet h_1 : \Delta_{10}, F_8, p_5 \vdash \Delta_9, p_5}{- : \Delta_{10}, F_8, p_5 \vdash \Delta_9} I \quad \frac{h_6 : \Delta_{10}, F_8, p_5, p_5 \vdash \Delta_9}{- : \Delta_{10}, F_8, p_5, p_5 \vdash \Delta_9} \text{ax/W}}{- : \Delta_{10}, p_5, F_7 \rightarrow F_8 \vdash \Delta_9} \text{hCut} \rightarrow_L \\
\\
\frac{\frac{\bullet h_2 : \Delta_6, p_7 \vdash (\Delta_8, p_7), F_{10} \rightarrow F_{11}}{- : \Delta_6, p_7 \vdash (\Delta_8, p_7), F_{10} \rightarrow F_{11}} I \quad \frac{h_9 : \Delta_6, p_7 \vdash F_{10}, \Delta_8, p_7 \quad h_9 : F_{11}, \Delta_6, p_7 \vdash \Delta_8, p_7}{\bullet h_9 : (\Delta_6, p_7), F_{10} \rightarrow F_{11} \vdash \Delta_8, p_7} \rightarrow_L}{- : \Delta_6, p_7 \vdash \Delta_8, p_7} \text{Cut} \\
\sim \\
\frac{- : \Delta_6, p_7 \vdash \Delta_8, p_7}{- : \Delta_6, p_7 \vdash \Delta_8, p_7} I \\
\\
\frac{\frac{\bullet h_2 : (\Delta_{12}, F_{10} \rightarrow F_{11}), p_7 \vdash (\Delta_8, p_7), F_6}{- : (\Delta_{12}, F_{10} \rightarrow F_{11}), p_7 \vdash (\Delta_8, p_7), F_6} I \quad \frac{h_9 : F_6, \Delta_{12}, p_7 \vdash F_{10}, \Delta_8, p_7 \quad h_9 : F_6, F_{11}, \Delta_{12}, p_7 \vdash \Delta_8, p_7}{\bullet h_9 : ((\Delta_{12}, F_{10} \rightarrow F_{11}), p_7), F_6 \vdash \Delta_8, p_7} \rightarrow_L}{- : (\Delta_{12}, F_{10} \rightarrow F_{11}), p_7 \vdash \Delta_8, p_7} \text{Cut} \\
\sim \\
\frac{- : \Delta_{12}, p_7, F_{10} \rightarrow F_{11} \vdash \Delta_8, p_7}{- : \Delta_{12}, p_7, F_{10} \rightarrow F_{11} \vdash \Delta_8, p_7} I
\end{array}$$

- Case rule \wedge_L

$$\begin{array}{c}
\frac{\frac{\bullet h_1 : (\Delta_{10}, F_7 \wedge F_8), p_5 \vdash \Delta_9, p_5}{- : (\Delta_{10}, F_7 \wedge F_8), p_5 \vdash \Delta_9} I \quad \frac{h_6 : F_7, F_8, \Delta_{10}, p_5, p_5 \vdash \Delta_9}{\bullet h_6 : ((\Delta_{10}, F_7 \wedge F_8), p_5), p_5 \vdash \Delta_9} \wedge_L}{- : (\Delta_{10}, F_7 \wedge F_8), p_5 \vdash \Delta_9} \text{Cut} \\
\sim \\
\frac{\frac{\bullet h_1 : \Delta_{10}, F_7, F_8, p_5 \vdash \Delta_9, p_5}{- : \Delta_{10}, F_7, F_8, p_5 \vdash \Delta_9} I \quad \frac{h_6 : \Delta_{10}, F_7, F_8, p_5, p_5 \vdash \Delta_9}{h_6 : \Delta_{10}, F_7, F_8, p_5, p_5 \vdash \Delta_9} \text{ax/W}}{- : \Delta_{10}, p_5, F_7 \wedge F_8 \vdash \Delta_9} \text{hCut} \wedge_L \\
\\
\frac{\frac{\bullet h_2 : \Delta_6, p_7 \vdash (\Delta_8, p_7), F_{10} \wedge F_{11}}{- : \Delta_6, p_7 \vdash (\Delta_8, p_7), F_{10} \wedge F_{11}} I \quad \frac{h_9 : F_{10}, F_{11}, \Delta_6, p_7 \vdash \Delta_8, p_7}{\bullet h_9 : (\Delta_6, p_7), F_{10} \wedge F_{11} \vdash \Delta_8, p_7} \wedge_L}{- : \Delta_6, p_7 \vdash \Delta_8, p_7} \text{Cut} \\
\sim \\
\frac{- : \Delta_6, p_7 \vdash \Delta_8, p_7}{- : \Delta_6, p_7 \vdash \Delta_8, p_7} I \\
\\
\frac{\frac{\bullet h_2 : (\Delta_{12}, F_{10} \wedge F_{11}), p_7 \vdash (\Delta_8, p_7), F_6}{- : (\Delta_{12}, F_{10} \wedge F_{11}), p_7 \vdash (\Delta_8, p_7), F_6} I \quad \frac{h_9 : F_6, F_{10}, F_{11}, \Delta_{12}, p_7 \vdash \Delta_8, p_7}{\bullet h_9 : ((\Delta_{12}, F_{10} \wedge F_{11}), p_7), F_6 \vdash \Delta_8, p_7} \wedge_L}{- : (\Delta_{12}, F_{10} \wedge F_{11}), p_7 \vdash \Delta_8, p_7} \text{Cut} \\
\sim \\
\frac{- : \Delta_{12}, p_7, F_{10} \wedge F_{11} \vdash \Delta_8, p_7}{- : \Delta_{12}, p_7, F_{10} \wedge F_{11} \vdash \Delta_8, p_7} I
\end{array}$$

- Case rule \vee_L

$$\begin{array}{c}
\frac{\frac{\bullet h_1 : (\Delta_{10}, F_7 \vee F_8), p_5 \vdash \Delta_9, p_5}{- : (\Delta_{10}, F_7 \vee F_8), p_5 \vdash \Delta_9} I \quad \frac{h_6 : F_7, \Delta_{10}, p_5, p_5 \vdash \Delta_9 \quad h_6 : F_8, \Delta_{10}, p_5, p_5 \vdash \Delta_9}{\bullet h_6 : ((\Delta_{10}, F_7 \vee F_8), p_5), p_5 \vdash \Delta_9} \vee_L}{- : (\Delta_{10}, F_7 \vee F_8), p_5 \vdash \Delta_9} \text{Cut} \\
\sim \\
\frac{\frac{\bullet h_1 : \Delta_{10}, F_7, p_5 \vdash \Delta_9, p_5}{- : \Delta_{10}, F_7, p_5 \vdash \Delta_9} I \quad \frac{h_6 : \Delta_{10}, F_7, p_5, p_5 \vdash \Delta_9}{h_6 : \Delta_{10}, F_7, p_5, p_5 \vdash \Delta_9} \text{ax/W} \quad \frac{\bullet h_1 : \Delta_{10}, F_8, p_5 \vdash \Delta_9, p_5}{- : \Delta_{10}, F_8, p_5 \vdash \Delta_9} I \quad \frac{h_6 : \Delta_{10}, F_8, p_5, p_5 \vdash \Delta_9}{- : \Delta_{10}, F_8, p_5, p_5 \vdash \Delta_9} \text{ax/W}}{- : \Delta_{10}, p_5, F_7 \vee F_8 \vdash \Delta_9} \text{hCut} \vee_L \\
\\
\frac{\frac{\bullet h_2 : \Delta_6, p_7 \vdash (\Delta_8, p_7), F_{10} \vee F_{11}}{- : \Delta_6, p_7 \vdash (\Delta_8, p_7), F_{10} \vee F_{11}} I \quad \frac{h_9 : F_{10}, \Delta_6, p_7 \vdash \Delta_8, p_7 \quad h_9 : F_{11}, \Delta_6, p_7 \vdash \Delta_8, p_7}{\bullet h_9 : (\Delta_6, p_7), F_{10} \vee F_{11} \vdash \Delta_8, p_7} \vee_L}{- : \Delta_6, p_7 \vdash \Delta_8, p_7} \text{Cut} \\
\sim \\
\frac{- : \Delta_6, p_7 \vdash \Delta_8, p_7}{- : \Delta_6, p_7 \vdash \Delta_8, p_7} I \\
\\
\frac{\frac{\bullet h_2 : (\Delta_{12}, F_{10} \vee F_{11}), p_7 \vdash (\Delta_8, p_7), F_6}{- : (\Delta_{12}, F_{10} \vee F_{11}), p_7 \vdash (\Delta_8, p_7), F_6} I \quad \frac{h_9 : F_6, F_{10}, \Delta_{12}, p_7 \vdash \Delta_8, p_7 \quad h_9 : F_6, F_{11}, \Delta_{12}, p_7 \vdash \Delta_8, p_7}{\bullet h_9 : ((\Delta_{12}, F_{10} \vee F_{11}), p_7), F_6 \vdash \Delta_8, p_7} \vee_L}{- : (\Delta_{12}, F_{10} \vee F_{11}), p_7 \vdash \Delta_8, p_7} \text{Cut} \\
\sim \\
\frac{- : \Delta_{12}, p_7, F_{10} \vee F_{11} \vdash \Delta_8, p_7}{- : \Delta_{12}, p_7, F_{10} \vee F_{11} \vdash \Delta_8, p_7} I
\end{array}$$

- Case rule AT

$$\begin{array}{c}
\frac{\frac{}{\bullet h_1 : (\Delta_9, \llbracket F_7 \rrbracket, p_5 \vdash \Delta_8, p_5} I \quad \frac{h_6 : F_7, \Delta_9, p_5, p_5, \llbracket F_7 \rrbracket \vdash \Delta_8}{\bullet h_6 : ((\Delta_9, \llbracket F_7 \rrbracket, p_5), p_5 \vdash \Delta_8} AT}{- : (\Delta_9, \llbracket F_7 \rrbracket, p_5 \vdash \Delta_8} Cut \\
\frac{}{\bullet h_1 : \Delta_9, F_7, p_5, \llbracket F_7 \rrbracket \vdash \Delta_8, p_5} I \quad \frac{h_6 : \Delta_9, F_7, p_5, p_5, \llbracket F_7 \rrbracket \vdash \Delta_8}{\bullet h_6 : ((\Delta_9, \llbracket F_7 \rrbracket, p_5), p_5 \vdash \Delta_8} ax/W}{- : \Delta_9, F_7, p_5, \llbracket F_7 \rrbracket \vdash \Delta_8} hCut \\
\frac{}{- : \Delta_9, p_5, \llbracket F_7 \rrbracket \vdash \Delta_8} AT
\end{array}$$

$$\begin{array}{c}
\frac{}{\bullet h_2 : \Delta_6, p_7 \vdash (\Delta_8, p_7), \llbracket F_{10} \rrbracket} I \quad \frac{h_9 : F_{10}, \Delta_6, p_7, \llbracket F_{10} \rrbracket \vdash \Delta_8, p_7}{\bullet h_9 : (\Delta_6, p_7), \llbracket F_{10} \rrbracket \vdash \Delta_8, p_7} AT}{- : \Delta_6, p_7 \vdash \Delta_8, p_7} Cut \\
\frac{}{- : \Delta_6, p_7 \vdash \Delta_8, p_7} I
\end{array}$$

$$\begin{array}{c}
\frac{}{\bullet h_2 : (\Delta_{11}, \llbracket F_{10} \rrbracket, p_7 \vdash (\Delta_8, p_7), F_6} I \quad \frac{h_9 : F_6, F_{10}, \Delta_{11}, p_7, \llbracket F_{10} \rrbracket \vdash \Delta_8, p_7}{\bullet h_9 : ((\Delta_{11}, \llbracket F_{10} \rrbracket, p_7), F_6 \vdash \Delta_8, p_7} AT}{- : (\Delta_{11}, \llbracket F_{10} \rrbracket, p_7 \vdash \Delta_8, p_7} Cut \\
\frac{}{- : \Delta_{11}, p_7, \llbracket F_{10} \rrbracket \vdash \Delta_8, p_7} I
\end{array}$$

- Case rule \perp_L

$$\begin{array}{c}
\frac{}{\bullet h_1 : (\perp, \Delta_8), p_5 \vdash \Delta_7, p_5} I \quad \frac{}{\bullet h_6 : ((\perp, \Delta_8), p_5), p_5 \vdash \Delta_7} \perp_L}{- : (\perp, \Delta_8), p_5 \vdash \Delta_7} Cut \\
\frac{}{- : \perp, \Delta_8, p_5 \vdash \Delta_7} \perp_L
\end{array}$$

$$\begin{array}{c}
\frac{}{\bullet h_2 : \Delta_6, p_7 \vdash (\Delta_8, p_7), \perp} I \quad \frac{}{\bullet h_9 : (\Delta_6, p_7), \perp \vdash \Delta_8, p_7} \perp_L}{- : \Delta_6, p_7 \vdash \Delta_8, p_7} Cut \\
\frac{}{- : \Delta_6, p_7 \vdash \Delta_8, p_7} I
\end{array}$$

$$\begin{array}{c}
\frac{}{\bullet h_2 : (\perp, \Delta_{10}), p_7 \vdash (\Delta_8, p_7), F_6} I \quad \frac{}{\bullet h_9 : ((\perp, \Delta_{10}), p_7), F_6 \vdash \Delta_8, p_7} \perp_L}{- : (\perp, \Delta_{10}), p_7 \vdash \Delta_8, p_7} Cut \\
\frac{}{- : \perp, \Delta_{10}, p_7 \vdash \Delta_8, p_7} \perp_L
\end{array}$$

- Case rule I

$$\begin{array}{c}
\frac{}{\bullet h_1 : \Delta_5, p_7 \vdash (\Delta_8, p_7), p_7} I \quad \frac{}{\bullet h_6 : (\Delta_5, p_7), p_7 \vdash \Delta_8, p_7} I}{- : \Delta_5, p_7 \vdash \Delta_8, p_7} Cut \\
\frac{}{- : \Delta_5, p_7 \vdash \Delta_8, p_7} I
\end{array}$$

$$\begin{array}{c}
\frac{}{\bullet h_1 : (\Delta_9, p_7), p_5 \vdash (\Delta_8, p_7), p_5} I \quad \frac{}{\bullet h_6 : ((\Delta_9, p_7), p_5), p_5 \vdash \Delta_8, p_7} I}{- : (\Delta_9, p_7), p_5 \vdash \Delta_8, p_7} Cut \\
\frac{}{- : \Delta_9, p_5, p_7 \vdash \Delta_8, p_7} I
\end{array}$$

$$\begin{array}{c}
\frac{}{\bullet h_2 : \Delta_6, p_7 \vdash ((\Delta_{10}, p_9), p_7), p_9} I \quad \frac{}{\bullet h_8 : (\Delta_6, p_7), p_9 \vdash (\Delta_{10}, p_9), p_7} I}{- : \Delta_6, p_7 \vdash (\Delta_{10}, p_9), p_7} Cut \\
\frac{}{- : \Delta_6, p_7 \vdash \Delta_{10}, p_7, p_9} I
\end{array}$$

$$\begin{array}{c}
\frac{}{\bullet h_2 : (\Delta_{11}, p_9), p_7 \vdash ((\Delta_{10}, p_9), p_7), F_6} I \quad \frac{}{\bullet h_8 : ((\Delta_{11}, p_9), p_7), F_6 \vdash (\Delta_{10}, p_9), p_7} I}{- : (\Delta_{11}, p_9), p_7 \vdash (\Delta_{10}, p_9), p_7} Cut \\
\frac{}{- : \Delta_{11}, p_7, p_9 \vdash \Delta_{10}, p_7, p_9} I
\end{array}$$

$$\begin{array}{c}
\frac{\bullet h_2 : \Delta_7, p_9 \vdash (\Delta_{10}, p_9), F_6}{- : \Delta_7, p_9 \vdash \Delta_{10}, p_9} I \quad \frac{\bullet h_8 : (\Delta_7, p_9), F_6 \vdash \Delta_{10}, p_9}{- : \Delta_7, p_9 \vdash \Delta_{10}, p_9} I \\
\text{Cut} \\
\vdots \\
\frac{}{- : \Delta_7, p_9 \vdash \Delta_{10}, p_9} I
\end{array}$$

- Case rule \top_L

$$\begin{array}{c}
\frac{\bullet h_1 : (\top, \Delta_8), p_5 \vdash \Delta_7, p_5}{- : (\top, \Delta_8), p_5 \vdash \Delta_7} I \quad \frac{h_6 : \Delta_8, p_5, p_5 \vdash \Delta_7}{\bullet h_6 : ((\top, \Delta_8), p_5), p_5 \vdash \Delta_7} \top_L \\
\text{Cut} \\
\vdots \\
\frac{\bullet h_1 : \top, \Delta_8, p_5 \vdash \Delta_7, p_5}{- : \top, \Delta_8, p_5 \vdash \Delta_7} I \quad \frac{h_6 : \top, \Delta_8, p_5, p_5 \vdash \Delta_7}{- : \top, \Delta_8, p_5 \vdash \Delta_7} \text{ax/W} \\
\text{hCut} \\
\vdots \\
\frac{\bullet h_2 : \Delta_6, p_7 \vdash (\Delta_8, p_7), \top}{- : \Delta_6, p_7 \vdash \Delta_8, p_7} I \quad \frac{h_9 : \Delta_6, p_7 \vdash \Delta_8, p_7}{\bullet h_9 : (\Delta_6, p_7), \top \vdash \Delta_8, p_7} \top_L \\
\text{Cut} \\
\vdots \\
\frac{\bullet h_2 : (\top, \Delta_{10}), p_7 \vdash (\Delta_8, p_7), F_6}{- : (\top, \Delta_{10}), p_7 \vdash \Delta_8, p_7} I \quad \frac{h_9 : F_6, \Delta_{10}, p_7 \vdash \Delta_8, p_7}{\bullet h_9 : ((\top, \Delta_{10}), p_7), F_6 \vdash \Delta_8, p_7} \top_L \\
\text{Cut} \\
\vdots \\
\frac{}{- : \top, \Delta_{10}, p_7 \vdash \Delta_8, p_7} I
\end{array}$$

8.13 Status of \top_L : OK

- Case rule \rightarrow_R

$$\begin{array}{c}
\frac{h_3 : \Delta_6 \vdash F_5, \Delta_8, F_9 \rightarrow F_{10}}{\bullet h_3 : \top, \Delta_6 \vdash (\Delta_8, F_9 \rightarrow F_{10}), F_5} \top_L \quad \frac{h_7 : \top, F_5, F_9, \Delta_6 \vdash F_{10}, \Delta_8}{\bullet h_7 : (\top, \Delta_6), F_5 \vdash \Delta_8, F_9 \rightarrow F_{10}} \rightarrow_R \\
\text{Cut} \\
\vdots \\
\frac{h_3 : \top, \Delta_6 \vdash \Delta_8, F_5, F_9 \rightarrow F_{10}}{- : \top, \Delta_6 \vdash \Delta_8, F_9 \rightarrow F_{10}} \text{ax/W} \quad \frac{\bullet h_7 : \top, \Delta_6, F_5 \vdash \Delta_8, F_9 \rightarrow F_{10}}{- : \top, \Delta_6 \vdash \Delta_8, F_9 \rightarrow F_{10}} \text{hCut}
\end{array}$$

- Case rule \wedge_R

$$\begin{array}{c}
\frac{h_3 : \Delta_6 \vdash F_5, \Delta_8, F_9 \wedge F_{10}}{\bullet h_3 : \top, \Delta_6 \vdash (\Delta_8, F_9 \wedge F_{10}), F_5} \top_L \quad \frac{h_7 : \top, F_5, \Delta_6 \vdash F_9, \Delta_8 \quad h_7 : \top, F_5, \Delta_6 \vdash F_{10}, \Delta_8}{\bullet h_7 : (\top, \Delta_6), F_5 \vdash \Delta_8, F_9 \wedge F_{10}} \wedge_R \\
\text{Cut} \\
\vdots \\
\frac{h_3 : \top, \Delta_6 \vdash \Delta_8, F_5, F_9 \wedge F_{10}}{- : \top, \Delta_6 \vdash \Delta_8, F_9 \wedge F_{10}} \text{ax/W} \quad \frac{\bullet h_7 : \top, \Delta_6, F_5 \vdash \Delta_8, F_9 \wedge F_{10}}{- : \top, \Delta_6 \vdash \Delta_8, F_9 \wedge F_{10}} \text{hCut}
\end{array}$$

- Case rule \vee_R

$$\begin{array}{c}
\frac{h_3 : \Delta_6 \vdash F_5, \Delta_8, F_9 \vee F_{10}}{\bullet h_3 : \top, \Delta_6 \vdash (\Delta_8, F_9 \vee F_{10}), F_5} \top_L \quad \frac{h_7 : \top, F_5, \Delta_6 \vdash F_9, F_{10}, \Delta_8}{\bullet h_7 : (\top, \Delta_6), F_5 \vdash \Delta_8, F_9 \vee F_{10}} \vee_R \\
\text{Cut} \\
\vdots \\
\frac{h_3 : \top, \Delta_6 \vdash \Delta_8, F_5, F_9 \vee F_{10}}{- : \top, \Delta_6 \vdash \Delta_8, F_9 \vee F_{10}} \text{ax/W} \quad \frac{\bullet h_7 : \top, \Delta_6, F_5 \vdash \Delta_8, F_9 \vee F_{10}}{- : \top, \Delta_6 \vdash \Delta_8, F_9 \vee F_{10}} \text{hCut}
\end{array}$$

- Case rule \perp_R

$$\begin{array}{c}
\frac{h_3 : \Delta_6 \vdash F_5, \perp, \Delta_8}{\bullet h_3 : \top, \Delta_6 \vdash (\perp, \Delta_8), F_5} \top_L \quad \frac{h_7 : \top, F_5, \Delta_6 \vdash \Delta_8}{\bullet h_7 : (\top, \Delta_6), F_5 \vdash \perp, \Delta_8} \perp_R \\
\hline
- : \top, \Delta_6 \vdash \perp, \Delta_8 \quad \text{Cut} \\
\hline
\sim\!\!\sim \\
\frac{h_3 : \top, \Delta_6 \vdash \perp, \Delta_8, F_5}{- : \top, \Delta_6 \vdash \perp, \Delta_8} \text{ax/W} \quad \frac{\bullet h_7 : \top, \Delta_6, F_5 \vdash \perp, \Delta_8}{- : \top, \Delta_6 \vdash \perp, \Delta_8} \text{ax/W} \\
\hline
\text{hCut}
\end{array}$$

- Case rule \top_R

$$\begin{array}{c}
\frac{h_3 : \Delta_6 \vdash F_5, \top, \Delta_8}{\bullet h_3 : \top, \Delta_6 \vdash (\top, \Delta_8), F_5} \top_L \quad \frac{}{\bullet h_7 : (\top, \Delta_6), F_5 \vdash \top, \Delta_8} \top_R \\
\hline
- : \top, \Delta_6 \vdash \top, \Delta_8 \quad \text{Cut} \\
\hline
\sim\!\!\sim \\
\frac{}{- : \top, \Delta_6 \vdash \top, \Delta_8} \top_R
\end{array}$$

- Case rule $A4$

$$\begin{array}{c}
\frac{h_3 : \Box \Gamma_9, \Delta_{10} \vdash \Box F_5, \Delta_7, [] F_8}{\bullet h_3 : \top, \Box \Gamma_9, \Delta_{10} \vdash (\Delta_7, [] F_8), \Box F_5} \top_L \quad \frac{h_6 : \Box \Gamma_9, \Box F_5 \vdash F_8}{\bullet h_6 : (\top, \Box \Gamma_9, \Delta_{10}), \Box F_5 \vdash \Delta_7, [] F_8} A4 \\
\hline
- : \top, \Box \Gamma_9, \Delta_{10} \vdash \Delta_7, [] F_8 \quad \text{Cut} \\
\hline
\sim\!\!\sim \\
\frac{h_3 : \top, \Delta_{10}, \Box \Gamma_9 \vdash \Box F_5, \Delta_7, [] F_8}{- : \top, \Delta_{10}, \Box \Gamma_9 \vdash \Delta_7, [] F_8} \text{ax/W} \quad \frac{\bullet h_6 : \top, \Box F_5, \Delta_{10}, \Box \Gamma_9 \vdash \Delta_7, [] F_8}{- : \top, \Delta_{10}, \Box \Gamma_9 \vdash \Delta_7, [] F_8} \text{ax/W} \\
\hline
\text{hCut} \\
\hline
\frac{h_3 : \Box \Gamma_7, \Delta_{10} \vdash F_5, \Delta_8, [] F_9}{\bullet h_3 : \top, \Box \Gamma_7, \Delta_{10} \vdash (\Delta_8, [] F_9), F_5} \top_L \quad \frac{h_6 : \Box \Gamma_7 \vdash F_9}{\bullet h_6 : (\top, \Box \Gamma_7, \Delta_{10}), F_5 \vdash \Delta_8, [] F_9} A4 \\
\hline
- : \top, \Box \Gamma_7, \Delta_{10} \vdash \Delta_8, [] F_9 \quad \text{Cut} \\
\hline
\sim\!\!\sim \\
\frac{}{- : \Box \Gamma_7 \vdash F_9} \text{ax/W} \\
\hline
\frac{}{- : \top, \Delta_{10}, \Box \Gamma_7 \vdash \Delta_8, [] F_9} A4
\end{array}$$

- Case rule \rightarrow_L

$$\begin{array}{c}
\frac{h_3 : \Delta_5 \vdash F_7 \rightarrow F_8, \Delta_9}{\bullet h_3 : \top, \Delta_5 \vdash \Delta_9, F_7 \rightarrow F_8} \top_L \quad \frac{h_6 : \top, \Delta_5 \vdash F_7, \Delta_9 \quad h_6 : \top, F_8, \Delta_5 \vdash \Delta_9}{\bullet h_6 : (\top, \Delta_5), F_7 \rightarrow F_8 \vdash \Delta_9} \rightarrow_L \\
\hline
- : \top, \Delta_5 \vdash \Delta_9 \quad \text{Cut} \\
\hline
\sim\!\!\sim \\
\frac{h_3 : \top, \Delta_5 \vdash \Delta_9, F_7 \rightarrow F_8}{- : \top, \Delta_5 \vdash \Delta_9} \text{ax/W} \quad \frac{\bullet h_6 : \top, \Delta_5, F_7 \rightarrow F_8 \vdash \Delta_9}{- : \top, \Delta_5 \vdash \Delta_9} \text{ax/W} \\
\hline
\text{hCut} \\
\hline
\frac{h_3 : \Delta_{10}, F_7 \rightarrow F_8 \vdash F_5, \Delta_9}{\bullet h_3 : \top, \Delta_{10}, F_7 \rightarrow F_8 \vdash \Delta_9, F_5} \top_L \quad \frac{h_6 : \top, F_5, \Delta_{10} \vdash F_7, \Delta_9 \quad h_6 : \top, F_5, F_8, \Delta_{10} \vdash \Delta_9}{\bullet h_6 : (\top, \Delta_{10}, F_7 \rightarrow F_8), F_5 \vdash \Delta_9} \rightarrow_L \\
\hline
- : \top, \Delta_{10}, F_7 \rightarrow F_8 \vdash \Delta_9 \quad \text{Cut} \\
\hline
\sim\!\!\sim \\
\frac{h_3 : \top, \Delta_{10}, F_7 \rightarrow F_8 \vdash \Delta_9, F_5}{- : \top, \Delta_{10}, F_7 \rightarrow F_8 \vdash \Delta_9} \text{ax/W} \quad \frac{\bullet h_6 : \top, \Delta_{10}, F_5, F_7 \rightarrow F_8 \vdash \Delta_9}{- : \top, \Delta_{10}, F_7 \rightarrow F_8 \vdash \Delta_9} \text{ax/W} \\
\hline
\text{hCut}
\end{array}$$

- Case rule \wedge_L

$$\begin{array}{c}
\frac{h_3 : \Delta_5 \vdash F_7 \wedge F_8, \Delta_9}{\bullet h_3 : \top, \Delta_5 \vdash \Delta_9, F_7 \wedge F_8} \top_L \quad \frac{h_6 : \top, F_7, F_8, \Delta_5 \vdash \Delta_9}{\bullet h_6 : (\top, \Delta_5), F_7 \wedge F_8 \vdash \Delta_9} \wedge_L \\
\hline
- : \top, \Delta_5 \vdash \Delta_9 \quad \text{Cut} \\
\hline
\sim\!\!\sim \\
\frac{h_3 : \top, \Delta_5 \vdash \Delta_9, F_7 \wedge F_8}{- : \top, \Delta_5 \vdash \Delta_9} \text{ax/W} \quad \frac{\bullet h_6 : \top, \Delta_5, F_7 \wedge F_8 \vdash \Delta_9}{- : \top, \Delta_5 \vdash \Delta_9} \text{ax/W} \\
\hline
\text{hCut} \\
\hline
\frac{h_3 : \Delta_{10}, F_7 \wedge F_8 \vdash F_5, \Delta_9}{\bullet h_3 : \top, \Delta_{10}, F_7 \wedge F_8 \vdash \Delta_9, F_5} \top_L \quad \frac{h_6 : \top, F_5, F_7, F_8, \Delta_{10} \vdash \Delta_9}{\bullet h_6 : (\top, \Delta_{10}, F_7 \wedge F_8), F_5 \vdash \Delta_9} \wedge_L \\
\hline
- : \top, \Delta_{10}, F_7 \wedge F_8 \vdash \Delta_9 \quad \text{Cut} \\
\hline
\sim\!\!\sim \\
\frac{h_3 : \top, \Delta_{10}, F_7 \wedge F_8 \vdash \Delta_9, F_5}{- : \top, \Delta_{10}, F_7 \wedge F_8 \vdash \Delta_9} \text{ax/W} \quad \frac{\bullet h_6 : \top, \Delta_{10}, F_5, F_7 \wedge F_8 \vdash \Delta_9}{- : \top, \Delta_{10}, F_7 \wedge F_8 \vdash \Delta_9} \text{ax/W} \\
\hline
\text{hCut}
\end{array}$$

- Case rule \vee_L

$$\begin{array}{c}
\frac{\frac{h_3 : \Delta_5 \vdash F_7 \vee F_8, \Delta_9}{\bullet h_3 : \top, \Delta_5 \vdash \Delta_9, F_7 \vee F_8} \top_L \quad \frac{h_6 : \top, F_7, \Delta_5 \vdash \Delta_9 \quad h_6 : \top, F_8, \Delta_5 \vdash \Delta_9}{\bullet h_6 : (\top, \Delta_5), F_7 \vee F_8 \vdash \Delta_9} \vee_L}{- : \top, \Delta_5 \vdash \Delta_9} \text{Cut} \\
\rightsquigarrow \\
\frac{\frac{h_3 : \top, \Delta_5 \vdash \Delta_9, F_7 \vee F_8}{- : \top, \Delta_5 \vdash \Delta_9} \text{ax/W} \quad \frac{\bullet h_6 : \top, \Delta_5, F_7 \vee F_8 \vdash \Delta_9}{- : \top, \Delta_5 \vdash \Delta_9} \text{hCut}}{- : \top, \Delta_5 \vdash \Delta_9} \\
\\
\frac{\frac{h_3 : \Delta_{10}, F_7 \vee F_8 \vdash F_5, \Delta_9}{\bullet h_3 : \top, \Delta_{10}, F_7 \vee F_8 \vdash \Delta_9, F_5} \top_L \quad \frac{h_6 : \top, F_5, F_7, \Delta_{10} \vdash \Delta_9 \quad h_6 : \top, F_5, F_8, \Delta_{10} \vdash \Delta_9}{\bullet h_6 : (\top, \Delta_{10}, F_7 \vee F_8), F_5 \vdash \Delta_9} \vee_L}{- : \top, \Delta_{10}, F_7 \vee F_8 \vdash \Delta_9} \text{Cut} \\
\rightsquigarrow \\
\frac{\frac{h_3 : \top, \Delta_{10}, F_7 \vee F_8 \vdash \Delta_9, F_5}{- : \top, \Delta_{10}, F_7 \vee F_8 \vdash \Delta_9} \text{ax/W} \quad \frac{\bullet h_6 : \top, \Delta_{10}, F_5, F_7 \vee F_8 \vdash \Delta_9}{- : \top, \Delta_{10}, F_7 \vee F_8 \vdash \Delta_9} \text{hCut}}{- : \top, \Delta_{10}, F_7 \vee F_8 \vdash \Delta_9}
\end{array}$$

- Case rule AT

$$\begin{array}{c}
\frac{\frac{h_3 : \Delta_5 \vdash \boxed{F_7}, \Delta_8}{\bullet h_3 : \top, \Delta_5 \vdash \Delta_8, \boxed{F_7}} \top_L \quad \frac{h_6 : \top, F_7, \Delta_5, \boxed{F_7} \vdash \Delta_8}{\bullet h_6 : (\top, \Delta_5), \boxed{F_7} \vdash \Delta_8} AT}{- : \top, \Delta_5 \vdash \Delta_8} \text{Cut} \\
\rightsquigarrow \\
\frac{\frac{h_3 : \top, \Delta_5 \vdash \Delta_8, \boxed{F_7}}{- : \top, \Delta_5 \vdash \Delta_8} \text{ax/W} \quad \frac{\bullet h_6 : \top, \Delta_5, \boxed{F_7} \vdash \Delta_8}{- : \top, \Delta_5 \vdash \Delta_8} \text{hCut}}{- : \top, \Delta_5 \vdash \Delta_8} \\
\\
\frac{\frac{h_3 : \Delta_9, \boxed{F_7} \vdash F_5, \Delta_8}{\bullet h_3 : \top, \Delta_9, \boxed{F_7} \vdash \Delta_8, F_5} \top_L \quad \frac{h_6 : \top, F_5, F_7, \Delta_9, \boxed{F_7} \vdash \Delta_8}{\bullet h_6 : (\top, \Delta_9, \boxed{F_7}), F_5 \vdash \Delta_8} AT}{- : \top, \Delta_9, \boxed{F_7} \vdash \Delta_8} \text{Cut} \\
\rightsquigarrow \\
\frac{\frac{h_3 : \top, \Delta_9, \boxed{F_7} \vdash \Delta_8, F_5}{- : \top, \Delta_9, \boxed{F_7} \vdash \Delta_8} \text{ax/W} \quad \frac{\bullet h_6 : \top, \Delta_9, F_5, \boxed{F_7} \vdash \Delta_8}{- : \top, \Delta_9, \boxed{F_7} \vdash \Delta_8} \text{hCut}}{- : \top, \Delta_9, \boxed{F_7} \vdash \Delta_8}
\end{array}$$

- Case rule \perp_L

$$\begin{array}{c}
\frac{\frac{h_3 : \Delta_5 \vdash \perp, \Delta_7}{\bullet h_3 : \top, \Delta_5 \vdash \Delta_7, \perp} \top_L \quad \frac{}{\bullet h_6 : (\top, \Delta_5), \perp \vdash \Delta_7} \perp_L}{- : \top, \Delta_5 \vdash \Delta_7} \text{Cut} \\
\rightsquigarrow \\
\frac{\frac{h_3 : \top, \Delta_5 \vdash \perp, \Delta_7}{- : \top, \Delta_5 \vdash \Delta_7} \text{ax/W} \quad \frac{\bullet h_6 : \perp, \top, \Delta_5 \vdash \Delta_7}{- : \top, \Delta_5 \vdash \Delta_7} \perp_L}{- : \top, \Delta_5 \vdash \Delta_7} \text{hCut} \\
\\
\frac{\frac{h_3 : \perp, \Delta_8 \vdash F_5, \Delta_7}{\bullet h_3 : \top, \perp, \Delta_8 \vdash \Delta_7, F_5} \top_L \quad \frac{}{\bullet h_6 : (\top, \perp, \Delta_8), F_5 \vdash \Delta_7} \perp_L}{- : \top, \perp, \Delta_8 \vdash \Delta_7} \text{Cut} \\
\rightsquigarrow \\
\frac{}{- : \perp, \top, \Delta_8 \vdash \Delta_7} \perp_L
\end{array}$$

- Case rule I

$$\begin{array}{c}
\frac{\frac{h_3 : \Delta_5 \vdash p_7, \Delta_8, p_7}{\bullet h_3 : \top, \Delta_5 \vdash (\Delta_8, p_7), p_7} \top_L \quad \frac{}{\bullet h_6 : (\top, \Delta_5), p_7 \vdash \Delta_8, p_7} I}{- : \top, \Delta_5 \vdash \Delta_8, p_7} \text{Cut} \\
\rightsquigarrow \\
\frac{\frac{h_3 : \top, \Delta_5 \vdash \Delta_8, p_7, p_7}{- : \top, \Delta_5 \vdash \Delta_8, p_7} \text{ax/W} \quad \frac{\bullet h_6 : \top, \Delta_5, p_7 \vdash \Delta_8, p_7}{- : \top, \Delta_5 \vdash \Delta_8, p_7} I}{- : \top, \Delta_5 \vdash \Delta_8, p_7} \text{hCut} \\
\\
\frac{\frac{h_3 : \Delta_9, p_7 \vdash F_5, \Delta_8, p_7}{\bullet h_3 : \top, \Delta_9, p_7 \vdash (\Delta_8, p_7), F_5} \top_L \quad \frac{}{\bullet h_6 : (\top, \Delta_9, p_7), F_5 \vdash \Delta_8, p_7} I}{- : \top, \Delta_9, p_7 \vdash \Delta_8, p_7} \text{Cut} \\
\rightsquigarrow \\
\frac{}{- : \top, \Delta_9, p_7 \vdash \Delta_8, p_7} I
\end{array}$$

- Case rule \top_L

$$\begin{array}{c}
\frac{\frac{h_3 : \Delta_6 \vdash F_5, \Delta_8}{\bullet h_3 : \top, \Delta_6 \vdash \Delta_8, F_5} \top_L \quad \frac{h_7 : F_5, \Delta_6 \vdash \Delta_8}{\bullet h_7 : (\top, \Delta_6), F_5 \vdash \Delta_8} \top_L}{- : \top, \Delta_6 \vdash \Delta_8} \text{Cut} \\
\sim\!\!\!\rightarrow \\
\frac{\frac{h_3 : \top, \Delta_6 \vdash \Delta_8, F_5}{- : \top, \Delta_6 \vdash \Delta_8} \text{ax/W} \quad \frac{\bullet h_7 : \top, \Delta_6, F_5 \vdash \Delta_8}{- : \top, \Delta_6 \vdash \Delta_8} \text{ax/W}}{- : \top, \Delta_6 \vdash \Delta_8} \text{hCut}
\end{array}$$