Hazel Phi: 11-type-constructors

July 30, 2021

Syntax

Kind	κ	$::=$	$\mathtt{Type} \mid \mathtt{KHole} \mid \mathsf{S}_{\kappa}(\tau) \mid \Pi_{t::\kappa_1}.\kappa_2$
User Types	$\hat{\tau}$	$::=$	$t \mid \mathtt{bse} \mid \hat{\tau_1} \oplus \hat{\tau_2} \mid \llparenthesis\rrparenthesis^{\mathtt{u}} \mid \llparenthesis\hat{\tau}\rrparenthesis^{\mathtt{u}} \mid \lambda t::\mathtt{Type}.\hat{\tau} \mid \hat{\tau_1}\ \hat{\tau_2}$
Internal Types	τ	$::=$	$t \mid \mathtt{bse} \mid \tau_1 \oplus \tau_2 \mid \llparenthesis\rrparenthesis^{\mathtt{u}} \mid \llparenthesis\tau\rrparenthesis^{\mathtt{u}} \mid \llparenthesis t\rrparenthesis^{\mathtt{u}} \mid \lambda t::\kappa.\tau \mid \tau_1\ \tau_2$
Base Types	$\mathtt{bse}$	$::=$	$\mathtt{Int} \mid \mathtt{Float} \mid \mathtt{Bool}$
BinOp	$\oplus$	$::=$	$\times \mid + \mid \rightarrow$
Type Pattern			
User Expression			
Internal Expression			

Declaratives

$\boxed{\Delta;\Phi \vdash \tau ::> \kappa}$ τ has principal (well formed) kind κ

$$\dfrac{\Delta;\Phi \vdash \mathsf{OK}}{\Delta;\Phi \vdash \mathtt{bse} ::> \mathsf{S}_{\mathtt{Type}}(\mathtt{bse})}\ \texttt{PK-Base} \qquad \dfrac{\Delta;\Phi_1, t::\kappa, \Phi_2 \vdash \mathsf{OK}}{\Delta;\Phi \vdash t ::> \mathsf{S}_{\kappa}(t)}\ \texttt{PK-Var} \qquad \dfrac{\Delta;\Phi \vdash \tau_1::\mathtt{Type} \quad \Delta;\Phi \vdash \tau_2::\mathtt{Type}}{\Delta;\Phi \vdash \tau_1 \oplus \tau_2 ::> \mathsf{S}_{\mathtt{Type}}(\tau_1 \oplus \tau_2)}\ \texttt{PK-}\oplus$$

$$\dfrac{\Delta_1, \mathtt{u}::\kappa, \Delta_2;\Phi \vdash \mathsf{OK}}{\Delta;\Phi \vdash \llparenthesis\rrparenthesis^{\mathtt{u}} ::> \mathsf{S}_{\kappa}(\llparenthesis\rrparenthesis^{\mathtt{u}})}\ \texttt{PK-EHole} \qquad \dfrac{\Delta_1, \mathtt{u}::\kappa, \Delta_2;\Phi \vdash \mathsf{OK} \quad \Delta;\Phi \vdash \tau::\kappa_1}{\Delta;\Phi \vdash \llparenthesis\tau\rrparenthesis^{\mathtt{u}} ::> \mathsf{S}_{\kappa}(\llparenthesis\tau\rrparenthesis^{\mathtt{u}})}\ \texttt{PK-NEHole}$$

$$\dfrac{\Delta_1, \mathtt{u}::\kappa, \Delta_2;\Phi \vdash \mathsf{OK} \quad t \notin \Phi}{\Delta;\Phi \vdash \llparenthesis t\rrparenthesis^{\mathtt{u}} ::> \mathsf{S}_{\kappa}(\llparenthesis t\rrparenthesis^{\mathtt{u}})}\ \texttt{PK-Unbound} \qquad \dfrac{\Delta;\underline{\Phi, t::\kappa_1} \vdash \tau ::> \kappa_2}{\Delta;\Phi \vdash \lambda t::\kappa_1.\tau ::> \mathsf{S}_{\Pi_{t::\kappa_1}.\kappa_2}(\lambda t::\kappa_1.\tau)}\ \texttt{PK-}\lambda$$

$$\dfrac{\Delta;\Phi \vdash \tau_1 ::> \kappa \quad \Delta;\Phi \vdash \kappa \mathrel{\blacktriangleright_{\Pi}} \Pi_{t::\kappa_1}.\kappa_2 \quad \Delta;\Phi \vdash \tau_2::\kappa_1}{\Delta;\Phi \vdash \tau_1\ \tau_2 ::> [\tau_2/t]\kappa_2}\ \texttt{PK-Ap}$$

$\boxed{\Delta;\Phi \vdash \tau::\kappa}$ τ is well formed at kind κ

$$\dfrac{\Delta;\Phi \vdash \tau ::> \mathsf{S}_{\kappa}(\tau)}{\Delta;\Phi \vdash \tau::\kappa}\ \texttt{WFaK-1} \qquad \dfrac{\Delta;\Phi \vdash \tau ::> \kappa_1 \quad \Delta;\Phi \vdash \kappa_1 \lesssim \kappa}{\Delta;\Phi \vdash \tau::\kappa}\ \texttt{WFaK-Subsump}$$

$$\dfrac{\Delta;\Phi \vdash \tau ::> \kappa}{\Delta;\Phi \vdash \tau::\kappa}\ \texttt{WFaK-Reit} \qquad \dfrac{\Delta;\Phi \vdash \tau::\kappa}{\Delta;\Phi \vdash \tau::\mathsf{S}_{\kappa}(\tau)}\ \texttt{WFaK-Self}$$

$$\dfrac{\Delta;\Phi \vdash \tau::\Pi_{t::\kappa_3}.\kappa_4 \quad \Delta;\Phi \vdash \Pi_{t::\kappa_3}.\kappa_4 \lesssim \Pi_{t::\kappa_1}.\kappa_2}{\Delta;\Phi \vdash \tau::\Pi_{t::\kappa_1}.\kappa_2}\ \texttt{WFaK-}\Pi\texttt{CSKTrans} \qquad \dfrac{\Delta;\Phi \vdash \tau::\mathsf{S}_{\kappa}(\tau_1) \quad \Delta;\Phi \vdash \tau_1::\kappa}{\Delta;\Phi \vdash \tau::\kappa}\ \texttt{WFaK-Flatten}$$

$\boxed{\Delta;\Phi \vdash \kappa \mathrel{\blacktriangleright_{\Pi}} \Pi_{t::\kappa_1}.\kappa_2}$ κ has matched Π-kind $\Pi_{t::\kappa_1}.\kappa_2$

$$\dfrac{\Delta;\Phi \vdash \mathsf{OK}}{\Delta;\Phi \vdash \mathtt{KHole} \mathrel{\blacktriangleright_{\Pi}} \Pi_{t::\mathtt{KHole}}.\mathtt{KHole}}\ \blacktriangleright_{\Pi}\texttt{-KHole} \qquad \dfrac{\Delta;\Phi \vdash \kappa \equiv \mathsf{S}_{\mathtt{KHole}}(\tau)}{\Delta;\Phi \vdash \kappa \mathrel{\blacktriangleright_{\Pi}} \Pi_{t::\mathsf{S}_{\mathtt{KHole}}(\tau)}.\mathsf{S}_{\mathtt{KHole}}(\tau\ t)}\ \blacktriangleright_{\Pi}\texttt{-SKHole} \qquad \dfrac{\Delta;\Phi \vdash \kappa \equiv \Pi_{t::\kappa_1}.\kappa_2}{\Delta;\Phi \vdash \kappa \mathrel{\blacktriangleright_{\Pi}} \Pi_{t::\kappa_1}.\kappa_2}\ \blacktriangleright_{\Pi}\texttt{-}\Pi$$

$\boxed{\Delta;\Phi \vdash \kappa_1 \equiv \kappa_2}$ κ_1 is equivalent to κ_2

$$\dfrac{\Delta;\Phi \vdash \kappa\ \mathsf{OK}}{\Delta;\Phi \vdash \kappa \equiv \kappa}\ \texttt{KEquiv-Refl} \qquad \dfrac{\Delta;\Phi \vdash \kappa_2 \equiv \kappa_1}{\Delta;\Phi \vdash \kappa_1 \equiv \kappa_2}\ \texttt{KEquiv-Symm} \qquad \dfrac{\Delta;\Phi \vdash \kappa_1 \equiv \kappa_3 \quad \Delta;\Phi \vdash \kappa_3 \equiv \kappa_2}{\Delta;\Phi \vdash \kappa_1 \equiv \kappa_2}\ \texttt{KEquiv-Trans}$$

$$\dfrac{\Delta;\Phi \vdash \tau::\mathsf{S}_{\kappa}(\tau_1)}{\Delta;\Phi \vdash \mathsf{S}_{\mathsf{S}_{\kappa}(\tau_1)}(\tau) \equiv \mathsf{S}_{\kappa}(\tau_1)}\ \texttt{KEquiv-SKind}_{\texttt{SKind}} \qquad \dfrac{\Delta;\Phi \vdash \tau::\Pi_{t::\kappa_1}.\kappa_2}{\Delta;\Phi \vdash \mathsf{S}_{\Pi_{t::\kappa_1}.\kappa_2}(\tau) \equiv \Pi_{t_1::\kappa_1}.\mathsf{S}_{[t_1/t]\kappa_2}(\tau\ t_1)}\ \texttt{KEquiv-SKind}_{\Pi}$$

$$\dfrac{\Delta;\Phi \vdash \kappa_1 \equiv \kappa_2 \quad \Delta;\underline{\Phi, t::\kappa_1} \vdash \kappa_3 \equiv \kappa_4}{\Delta;\Phi \vdash \Pi_{t::\kappa_1}.\kappa_2 \equiv \Pi_{t::\kappa_3}.\kappa_4}\ \texttt{KEquiv-}\Pi \qquad \dfrac{\Delta;\Phi \vdash \tau_1 \overset{\kappa_1}{\equiv} \tau_2 \quad \Delta;\Phi \vdash \kappa_1 \equiv \kappa_2}{\Delta;\Phi \vdash \mathsf{S}_{\kappa_1}(\tau_1) \equiv \mathsf{S}_{\kappa_2}(\tau_2)}\ \texttt{KEquiv-SKind}$$

$\boxed{\Delta;\Phi \vdash \kappa_1 \lesssim \kappa_2}$ κ_1 is a consistent subkind of κ_2

$$\dfrac{\Delta;\Phi \vdash \kappa\ \mathsf{OK}}{\Delta;\Phi \vdash \mathtt{KHole} \lesssim \kappa}\ \texttt{CSK-KHoleL} \qquad \dfrac{\Delta;\Phi \vdash \kappa\ \mathsf{OK}}{\Delta;\Phi \vdash \kappa \lesssim \mathtt{KHole}}\ \texttt{CSK-KHoleR}$$

$$\dfrac{\Delta;\Phi \vdash \mathsf{S}_{\mathtt{KHole}}(\tau)\ \mathsf{OK} \quad \Delta;\Phi \vdash \kappa\ \mathsf{OK}}{\Delta;\Phi \vdash \mathsf{S}_{\mathtt{KHole}}(\tau) \lesssim \kappa}\ \texttt{CSK-SKind}_{\texttt{KHole}}\texttt{L} \qquad \dfrac{\Delta;\Phi \vdash \kappa\ \mathsf{OK} \quad \Delta;\Phi \vdash \mathsf{S}_{\mathtt{KHole}}(\tau)\ \mathsf{OK}}{\Delta;\Phi \vdash \kappa \lesssim \mathsf{S}_{\mathtt{KHole}}(\tau)}\ \texttt{CSK-SKind}_{\texttt{KHole}}\texttt{R}$$

$$\dfrac{\Delta;\Phi \vdash \kappa_1 \equiv \kappa_2}{\Delta;\Phi \vdash \kappa_1 \lesssim \kappa_2}\ \texttt{CSK-KEquiv} \qquad \dfrac{\Delta;\Phi \vdash \kappa_1 \equiv \kappa_3 \quad \Delta;\Phi \vdash \kappa_3 \lesssim \kappa_4 \quad \Delta;\Phi \vdash \kappa_4 \equiv \kappa_2}{\Delta;\Phi \vdash \kappa_1 \lesssim \kappa_2}\ \texttt{CSK-Normal}$$

$$\dfrac{\Delta;\Phi \vdash \mathsf{S}_{\kappa}(\tau)\ \mathsf{OK}}{\Delta;\Phi \vdash \mathsf{S}_{\kappa}(\tau) \lesssim \kappa}\ \texttt{CSK-SKind} \qquad \dfrac{\Delta;\Phi \vdash \kappa_3 \lesssim \kappa_1 \quad \Delta;\underline{\Phi, t::\kappa_3} \vdash \kappa_2 \lesssim \kappa_4}{\Delta;\Phi \vdash \Pi_{t::\kappa_1}.\kappa_2 \lesssim \Pi_{t::\kappa_3}.\kappa_4}\ \texttt{CSK-}\Pi$$

$$\dfrac{\Delta;\Phi \vdash \kappa_1 \lesssim \kappa_2 \quad \Delta;\Phi \vdash \tau_1 \overset{\kappa_1}{\equiv} \tau_2}{\Delta;\Phi \vdash \mathsf{S}_{\kappa_1}(\tau_1) \lesssim \mathsf{S}_{\kappa_2}(\tau_2)}\ \texttt{CSK-?}$$

$\boxed{\Delta;\Phi \vdash \tau_1 \overset{\kappa}{\equiv} \tau_2}$ τ_1 is provably equivalent to τ_2 at kind κ

$$\dfrac{\Delta;\Phi \vdash \tau::\kappa}{\Delta;\Phi \vdash \tau \overset{\kappa}{\equiv} \tau}\ \texttt{EquivAK-Refl} \qquad \dfrac{\Delta;\Phi \vdash \tau_2 \overset{\kappa}{\equiv} \tau_1}{\Delta;\Phi \vdash \tau_1 \overset{\kappa}{\equiv} \tau_2}\ \texttt{EquivAK-Symm} \qquad \dfrac{\Delta;\Phi \vdash \tau_1 \overset{\kappa}{\equiv} \tau_3 \quad \Delta;\Phi \vdash \tau_3 \overset{\kappa}{\equiv} \tau_1}{\Delta;\Phi \vdash \tau_1 \overset{\kappa}{\equiv} \tau_2}\ \texttt{EquivAK-Trans}$$

$$\dfrac{\Delta;\Phi \vdash \tau_1 ::> \kappa_1 \quad \Delta;\Phi \vdash \kappa_1 \equiv \mathsf{S}_{\kappa}(\tau_2)}{\Delta;\Phi \vdash \tau_1 \overset{\kappa}{\equiv} \tau_2}\ \texttt{EquivAK-SKind}$$

$$\dfrac{\Delta;\Phi \vdash \tau_1::\Pi_{t::\kappa_1}.\kappa_3 \quad \Delta;\Phi \vdash \tau_2::\Pi_{t::\kappa_1}.\kappa_4 \quad \Delta;\underline{\Phi, t::\kappa_1} \vdash \tau_1\ t \overset{\kappa_2}{\equiv} \tau_2\ t}{\Delta;\Phi \vdash \tau_1 \overset{\Pi_{t::\kappa_1}.\kappa_2}{\equiv} \tau_2}\ \texttt{EquivAK-}\Pi \qquad \dfrac{\Delta;\Phi \vdash \tau_1 \overset{\Pi_{t::\kappa_1}.\kappa_2}{\equiv} \tau_3 \quad \Delta;\Phi \vdash \tau_2 \overset{\kappa_1}{\equiv} \tau_4}{\Delta;\Phi \vdash \tau_1\ \tau_2 \overset{[\tau_2/t]\kappa_2}{\equiv} \tau_3\ \tau_4}\ \texttt{EquivAK-Ap}$$

$$\dfrac{\Delta;\Phi \vdash \tau_1 \overset{\mathsf{S}_{\kappa}(\tau)}{\equiv} \tau_2}{\Delta;\Phi \vdash \tau_1 \overset{\kappa}{\equiv} \tau_2}\ (1)$$

$$\dfrac{\Delta;\Phi \vdash \tau_1 \overset{\mathtt{Type}}{\equiv} \tau_3 \quad \Delta;\Phi \vdash \tau_2 \overset{\mathtt{Type}}{\equiv} \tau_4}{\Delta;\Phi \vdash \tau_1 \oplus \tau_2 \overset{\mathtt{Type}}{\equiv} \tau_3 \oplus \tau_4}\ (2) \qquad \dfrac{\Delta;\Phi \vdash \kappa_1 \equiv \kappa_2 \quad \Delta;\underline{\Phi, t::\kappa_1} \vdash \tau_1 \overset{\kappa}{\equiv} \tau_2}{\Delta;\Phi \vdash \lambda t::\kappa_1.\tau_1 \overset{\Pi_{t::\kappa_1}.\kappa}{\equiv} \lambda t::\kappa_2.\tau_2}\ (3) \qquad \dfrac{\Delta;\Phi \vdash \tau_1 \overset{\kappa_1}{\equiv} \tau_2 \quad \Delta;\Phi \vdash \kappa_1 \equiv \kappa}{\Delta;\Phi \vdash \tau_1 \overset{\kappa}{\equiv} \tau_2}\ (4)$$

$\boxed{\Delta;\Phi \vdash \kappa\ \mathsf{OK}}$ κ is well formed

$$\dfrac{\Delta;\Phi \vdash \mathsf{OK}}{\Delta;\Phi \vdash \mathtt{Type}\ \mathsf{OK}}\ \texttt{KWF-Type} \qquad \dfrac{\Delta;\Phi \vdash \mathsf{OK}}{\Delta;\Phi \vdash \mathtt{KHole}\ \mathsf{OK}}\ \texttt{KWF-KHole} \qquad \dfrac{\Delta;\Phi \vdash \tau::\kappa}{\Delta;\Phi \vdash \mathsf{S}_{\kappa}(\tau)\ \mathsf{OK}}\ \texttt{KWF-SKind} \qquad \dfrac{\Delta;\underline{\Phi, t::\kappa_1} \vdash \kappa_2\ \mathsf{OK}}{\Delta;\Phi \vdash \Pi_{t::\kappa_1}.\kappa_2\ \mathsf{OK}}\ \texttt{KWF-}\Pi$$

$\boxed{\Delta;\Phi \vdash \mathsf{OK}}$ Context is well formed

$$\dfrac{}{\cdot;\cdot \vdash \mathsf{OK}}\ \texttt{CWF-Nil} \qquad \dfrac{t \notin \Phi \quad \Delta;\Phi \vdash \kappa\ \mathsf{OK}}{\Delta;\underline{\Phi, t::\kappa} \vdash \mathsf{OK}}\ \texttt{CWF-TypVar} \qquad \dfrac{\mathtt{u} \notin \Delta \quad \Delta;\Phi \vdash \kappa\ \mathsf{OK}}{\underline{\Delta, \mathtt{u}::\kappa};\Phi \vdash \mathsf{OK}}\ \texttt{CWF-Hole}$$

Metatheory

subderivation preserving inferences:

- premiss
- COK (Context OK)
- PoS (premiss of subderivation)

Lemma 1 (COK)**.** *If $\Delta;\Phi \vdash \mathcal{J}$, then $\Delta;\Phi \vdash OK$ in a subderivation (where $\Delta;\Phi \vdash \mathcal{J} \neq \Delta;\Phi \vdash OK$)*

Proof. By induction on derivations.
No interesting cases. □

Lemma 2 (Exchange)**.**
If $\Delta;\Phi_1, t_{L1}::\kappa_{L1}, t_{L2}::\kappa_{L2}, \Phi_2 \vdash \mathcal{J}$ and $\Delta;\Phi_1, t_{L2}::\kappa_{L2}, t_{L1}::\kappa_{L1}, \Phi_2 \vdash OK$, then $\Delta;\Phi_1, t_{L2}::\kappa_{L2}, t_{L1}::\kappa_{L1}, \Phi_2 \vdash \mathcal{J}$

Proof. By induction on derivations.
No interesting cases.
(Only rules with Φ extended in the consequent are interesting, which is only CWF-TypVar, but when $\mathcal{J}$ is CWF, Exchange is identity) □

Corollary 3 (Marked-Exchange)**.**
If $\Delta;\underline{\underline{\Phi, t_{L1}::\kappa_{L1}}, t_{L2}::\kappa_{L2}} \vdash \mathcal{J}$ and $\Delta;\underline{\underline{\Phi, t_{L2}::\kappa_{L2}}, t_{L1}::\kappa_{L1}} \vdash OK$, then $\Delta;\underline{\underline{\Phi, t_{L2}::\kappa_{L2}}, t_{L1}::\kappa_{L1}} \vdash \mathcal{J}$

Proof. Exchange when $\Phi_2 = \cdot$ □

Lemma 4 (Weakening)**.**
If $\Delta;\Phi \vdash \mathcal{J}$ and $\Delta;\underline{\Phi, t_L::\kappa_L} \vdash OK$ and $t_L \notin \mathcal{J}$ and $\forall t \in \kappa_L, t \notin \mathcal{J}$, then $\Delta;\underline{\Phi, t_L::\kappa_L} \vdash \mathcal{J}$

Proof. By induction on derivations.
When applying Weakening in the induction, check that the left premiss is always a subderivation, and check variable exclusion conditions are satisfied (usually checked elsewhere in the derivation).

Weakening

$$
\begin{prooftree}
\AxiomC{}
\RightLabel{premiss}
\UnaryInfC{$\Delta; \Phi, t{::}\kappa_1 \vdash \tau ::> \kappa_2$}
\AxiomC{}
\RightLabel{IH}
\UnaryInfC{$\Delta; \Phi, t_L{::}\kappa_L \vdash \mathsf{OK}$}
\RightLabel{PoS}
\UnaryInfC{$t_L \notin \Phi$}
\AxiomC{}
\RightLabel{IH}
\UnaryInfC{$t_L \notin \mathcal{J}$}
\AxiomC{}
\UnaryInfC{$t \in \mathcal{J}$}
\BinaryInfC{$t_L \neq t$}
\AxiomC{}
\RightLabel{IH}
\UnaryInfC{$t_L \notin \mathcal{J}$}
\UnaryInfC{$t_L \notin \kappa_1$}
\TrinaryInfC{$t_L \notin \Phi, t{::}\kappa_1$}
\AxiomC{}
\RightLabel{IH}
\UnaryInfC{$\Delta; \Phi, t_L{::}\kappa_L \vdash \mathsf{OK}$}
\RightLabel{PoS}
\UnaryInfC{$\Delta; \Phi \vdash \kappa_L\ \mathsf{OK}$}
\AxiomC{}
\RightLabel{premiss}
\UnaryInfC{$\Delta; \Phi, t{::}\kappa_1 \vdash \tau ::> \kappa_2$}
\RightLabel{COK}
\UnaryInfC{$\Delta; \Phi, t{::}\kappa_1 \vdash \mathsf{OK}$}
\RightLabel{Weakening}
\BinaryInfC{$\Delta; \Phi, t{::}\kappa_1 \vdash \kappa_L\ \mathsf{OK}$}
\RightLabel{CWF-TypVar}
\BinaryInfC{$\Delta; \Phi, t{::}\kappa_1, t_L{::}\kappa_L \vdash \mathsf{OK}$}
\RightLabel{Weakening}
\BinaryInfC{$\Delta; \Phi, t{::}\kappa_1, t_L{::}\kappa_L \vdash \tau ::> \kappa_2$}
\AxiomC{}
\RightLabel{premiss}
\UnaryInfC{$\Delta; \Phi, t{::}\kappa_1 \vdash \tau ::> \kappa_2$}
\RightLabel{COK}
\UnaryInfC{$\Delta; \Phi, t{::}\kappa_1 \vdash \mathsf{OK}$}
\RightLabel{PoS}
\UnaryInfC{$t \notin \Phi$}
\AxiomC{}
\RightLabel{IH}
\UnaryInfC{$t_L \notin \mathcal{J}$}
\AxiomC{}
\UnaryInfC{$t \in \mathcal{J}$}
\BinaryInfC{$t \neq t_L$}
\AxiomC{}
\RightLabel{IH}
\UnaryInfC{$\forall \dot{t} \in \kappa_L, \dot{t} \notin \mathcal{J}$}
\AxiomC{}
\UnaryInfC{$t \in \mathcal{J}$}
\BinaryInfC{$t \notin \kappa_L$}
\TrinaryInfC{$t \notin \Phi, t_L{::}\kappa_L$}
\AxiomC{}
\RightLabel{premiss}
\UnaryInfC{$\Delta; \Phi, t{::}\kappa_1 \vdash \tau ::> \kappa_2$}
\RightLabel{COK}
\UnaryInfC{$\Delta; \Phi, t{::}\kappa_1 \vdash \mathsf{OK}$}
\RightLabel{PoS}
\UnaryInfC{$\Delta; \Phi \vdash \kappa_1\ \mathsf{OK}$}
\AxiomC{}
\RightLabel{IH}
\UnaryInfC{$\Delta; \Phi, t_L{::}\kappa_L \vdash \mathsf{OK}$}
\RightLabel{Weakening}
\BinaryInfC{$\Delta; \Phi, t_L{::}\kappa_L \vdash \kappa_1\ \mathsf{OK}$}
\RightLabel{CWF-TypVar}
\BinaryInfC{$\Delta; \Phi, t_L{::}\kappa_L, t{::}\kappa_1 \vdash \mathsf{OK}$}
\RightLabel{Marked-Exchange}
\BinaryInfC{$\Delta; \Phi, t_L{::}\kappa_L, t{::}\kappa_1 \vdash \tau ::> \kappa_2$}
\RightLabel{PK-λ}
\UnaryInfC{$\Delta; \Phi, t_L{::}\kappa_L \vdash \lambda t{::}\kappa_1.\tau ::> \mathsf{S}_{\Pi_{t::\kappa_1}.\kappa_2}(\lambda t{::}\kappa_1.\tau)$}
\end{prooftree}
$$

$$
\begin{prooftree}
\AxiomC{}
\RightLabel{premiss}
\UnaryInfC{$\Delta; \Phi \vdash \kappa_1 \equiv \kappa_2$}
\AxiomC{}
\RightLabel{IH}
\UnaryInfC{$\Delta; \Phi, t_L{::}\kappa_L \vdash \mathsf{OK}$}
\RightLabel{Weakening}
\BinaryInfC{$\Delta; \Phi, t_L{::}\kappa_L \vdash \kappa_1 \equiv \kappa_2$}
\AxiomC{}
\RightLabel{premiss}
\UnaryInfC{$\Delta; \Phi, t{::}\kappa_1 \vdash \tau ::> \kappa_2$}
\AxiomC{}
\RightLabel{IH}
\UnaryInfC{$\Delta; \Phi, t_L{::}\kappa_L \vdash \mathsf{OK}$}
\RightLabel{PoS}
\UnaryInfC{$t_L \notin \Phi$}
\AxiomC{}
\RightLabel{IH}
\UnaryInfC{$t_L \notin \mathcal{J}$}
\AxiomC{}
\UnaryInfC{$t \in \mathcal{J}$}
\BinaryInfC{$t_L \neq t$}
\AxiomC{}
\RightLabel{IH}
\UnaryInfC{$t_L \notin \mathcal{J}$}
\UnaryInfC{$t_L \notin \kappa_1$}
\TrinaryInfC{$t_L \notin \Phi, t{::}\kappa_1$}
\AxiomC{}
\RightLabel{IH}
\UnaryInfC{$\Delta; \Phi, t_L{::}\kappa_L \vdash \mathsf{OK}$}
\RightLabel{PoS}
\UnaryInfC{$\Delta; \Phi \vdash \kappa_L\ \mathsf{OK}$}
\AxiomC{}
\RightLabel{premiss}
\UnaryInfC{$\Delta; \Phi, t{::}\kappa_1 \vdash \kappa_3 \equiv \kappa_4$}
\RightLabel{COK}
\UnaryInfC{$\Delta; \Phi, t{::}\kappa_1 \vdash \mathsf{OK}$}
\RightLabel{Weakening}
\BinaryInfC{$\Delta; \Phi, t{::}\kappa_1 \vdash \kappa_L\ \mathsf{OK}$}
\RightLabel{CWF-TypVar}
\BinaryInfC{$\Delta; \Phi, t{::}\kappa_1, t_L{::}\kappa_L \vdash \mathsf{OK}$}
\RightLabel{Weakening}
\BinaryInfC{$\Delta; \Phi, t{::}\kappa_1, t_L{::}\kappa_L \vdash \tau ::> \kappa_2$}
\AxiomC{}
\RightLabel{premiss}
\UnaryInfC{$\Delta; \Phi, t{::}\kappa_1 \vdash \kappa_3 \equiv \kappa_4$}
\RightLabel{COK}
\UnaryInfC{$\Delta; \Phi, t{::}\kappa_1 \vdash \mathsf{OK}$}
\RightLabel{PoS}
\UnaryInfC{$t \notin \Phi$}
\AxiomC{}
\RightLabel{IH}
\UnaryInfC{$t_L \notin \mathcal{J}$}
\AxiomC{}
\UnaryInfC{$t \in \mathcal{J}$}
\BinaryInfC{$t \neq t_L$}
\AxiomC{}
\RightLabel{IH}
\UnaryInfC{$\forall \dot{t} \in \kappa_L, \dot{t} \notin \mathcal{J}$}
\AxiomC{}
\UnaryInfC{$t \in \mathcal{J}$}
\BinaryInfC{$t \notin \kappa_L$}
\TrinaryInfC{$t \notin \Phi, t_L{::}\kappa_L$}
\AxiomC{}
\RightLabel{premiss}
\UnaryInfC{$\Delta; \Phi, t{::}\kappa_1 \vdash \kappa_3 \equiv \kappa_4$}
\RightLabel{COK}
\UnaryInfC{$\Delta; \Phi, t{::}\kappa_1 \vdash \mathsf{OK}$}
\RightLabel{PoS}
\UnaryInfC{$\Delta; \Phi \vdash \kappa_1\ \mathsf{OK}$}
\AxiomC{}
\RightLabel{IH}
\UnaryInfC{$\Delta; \Phi, t_L{::}\kappa_L \vdash \mathsf{OK}$}
\RightLabel{Weakening}
\BinaryInfC{$\Delta; \Phi, t_L{::}\kappa_L \vdash \kappa_1\ \mathsf{OK}$}
\RightLabel{CWF-TypVar}
\BinaryInfC{$\Delta; \Phi, t_L{::}\kappa_L, t{::}\kappa_1 \vdash \mathsf{OK}$}
\RightLabel{Marked-Exchange}
\BinaryInfC{$\Delta; \Phi, t_L{::}\kappa_L, t{::}\kappa_1 \vdash \kappa_3 \equiv \kappa_4$}
\RightLabel{KEquiv-Π}
\BinaryInfC{$\Delta; \Phi, t_L{::}\kappa_L \vdash \Pi_{t::\kappa_1}.\kappa_2 \equiv \Pi_{t::\kappa_3}.\kappa_4$}
\end{prooftree}
$$

$$\cfrac{}{sim}\ \texttt{CSK-}\Pi$$

$$\cfrac{}{sim}\ \texttt{EquivAK-}\Pi \qquad \cfrac{}{sim}\ \texttt{KWF-}\Pi$$

□

Lemma 5 (OK-PK). *If* $\Delta;\Phi \vdash \tau ::> \kappa$, *then* $\Delta;\Phi \vdash \kappa$ *OK*

Lemma 6 (OK-WFaK). *If* $\Delta;\Phi \vdash \tau{::}\kappa$, *then* $\Delta;\Phi \vdash \kappa$ *OK*

Lemma 7 (OK-MatchPi). *If* $\Delta;\Phi \vdash \kappa \overset{\blacktriangleright}{\Pi} \Pi_{t::\kappa_1}.\kappa_2$, *then* $\Delta;\Phi \vdash \kappa$ *OK and* $\Delta;\Phi \vdash \Pi_{t::\kappa_1}.\kappa_2$ *OK*

Lemma 8 (OK-KEquiv). *If* $\Delta;\Phi \vdash \kappa_1 \equiv \kappa_2$, *then* $\Delta;\Phi \vdash \kappa_1$ *OK and* $\Delta;\Phi \vdash \kappa_2$ *OK*

Lemma 9 (OK-CSK). *If* $\Delta;\Phi \vdash \kappa_1 \lesssim \kappa_2$, *then* $\Delta;\Phi \vdash \kappa_1$ *OK and* $\Delta;\Phi \vdash \kappa_2$ *OK*

Lemma 10 (OK-EquivAK). *If* $\Delta;\Phi \vdash \tau_1 \overset{\kappa}{\equiv} \tau_2$, *then* $\Delta;\Phi \vdash \tau_1{::}\kappa$ *and* $\Delta;\Phi \vdash \tau_2{::}\kappa$ *and* $\Delta;\Phi \vdash \kappa$ *OK*

Lemma 11 (OK-Substitution).
If $\Delta;\Phi \vdash \tau_L{::}\kappa_{L1}$ *and* $\Delta;\Phi, t_L{::}\kappa_{L1} \vdash \kappa_{L2}$ *OK, then* $\Delta;\Phi \vdash [\tau_L/t_L]\kappa_{L2}$ *OK*
(induction on $\Delta;\Phi, t_L{::}\kappa_{L1} \vdash \kappa_{L2}$ *OK)*

Lemma 12 (K-Substitution).
If $\Delta;\Phi \vdash \tau_{L1}{::}\kappa_{L1}$ *and* $\Delta;\Phi, t_L{::}\kappa_{L1} \vdash \tau_{L2}{::}\kappa_{L2}$, *then* $\Delta;\Phi \vdash [\tau_{L1}/t_L]\tau_{L2}{::}[\tau_{L1}/t_L]\kappa_{L2}$
(induction on $\Delta;\Phi, t_L{::}\kappa_{L1} \vdash \tau_{L2}{::}\kappa_{L2}$*)*

Proof. By simultaneous induction on derivations.
The interesting cases per lemma:

	OK-PK.	PK-Base	$\Delta;\Phi \vdash \mathtt{bse}{::}\mathsf{S}_{\mathtt{Type}}(\mathtt{bse})$	by (9)
			$\Delta;\Phi \vdash \mathtt{bse}{::}\mathtt{Type}$	by (10)
		*	$\Delta;\Phi \vdash \mathsf{S}_{\mathtt{Type}}(\mathtt{bse})$ OK	by (43)
		*	$\Delta;\Phi \vdash$ OK	by premiss
		PK-Ap		bad
	OK-WFaK.	(12)	$\Delta;\Phi \vdash \tau_2{::}\kappa$	by (10)
		*	$\Delta;\Phi \vdash \mathsf{S}_\kappa(\tau_2)$ OK	by (43)
	OK-KEquiv.	(22)	$\Delta;\Phi \vdash \tau\ t ::> \kappa$	
(PoS = premiss of subderivation)	OK-Substitution.	(41)	$\Delta;\Phi, t_L{::}\kappa_{L1} \vdash$ OK	premiss (41)
			$\Delta;\Phi \vdash \kappa_{L1}$ OK	by subderivation premiss (46)
		*	$\Delta;\Phi \vdash$ OK	by OK-KWF
		*	$\Delta;\Phi \vdash [\tau_L/t_L]\mathtt{Type}$ OK	by (41) and degenerate subst
		(43)	$\Delta;\Phi, t_L{::}\kappa_{L1} \vdash \tau{::}\kappa$	premiss (43)
			$\Delta;\Phi, t_L{::}\kappa_{L1} \vdash$ OK	by OK-WFaK
			$\Delta;\Phi \vdash \kappa_{L1}$ OK	by subderivation premiss (46)
		*	$\Delta;\Phi \vdash$ OK	by OK-KWF
			$\Delta;\Phi \vdash [\tau_{L1}/t_L]\tau{::}[\tau_{L1}/t_L]\kappa$	by K-Substitution on premiss
		*	$\Delta;\Phi \vdash [\tau_L/t_L]\mathsf{S}_\kappa(\tau)$ OK	by (43)

□

Lemma 13 (PK-Unicity). *If* $\Delta;\Phi \vdash \tau_L ::> \kappa_{L1}$ *and* $\Delta;\Phi \vdash \tau_L ::> \kappa_{L2}$ *then* κ_{L1} *is* κ_{L2}

Lemma 14. *If* $\Delta;\Phi \vdash \tau ::> \kappa_1$ *and* $\Delta;\Phi \vdash \tau{::}\kappa_2$, *then* $\Delta;\Phi \vdash \kappa_1 \lesssim \kappa_2$

Lemma 15. *If* $\Delta;\Phi \vdash \kappa_1 \lesssim \mathsf{S}_{\kappa_2}(\tau)$, *then* $\Delta;\Phi \vdash \kappa_1 \lesssim \kappa_2$