Function Composition

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Function composition

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Function composition is

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home

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Function Composition

▸ Start

Function Composition

Start

X

Function Composition

Start

$$X \quad \xrightarrow{f}$$

Function Composition

Start

$$X \xrightarrow{f} \quad Y$$

Function Composition

Start

$$X \xrightarrow{f} Y \xrightarrow{g}$$

Function Composition

Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z$$

Function Composition

Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z$$

x

Function Composition

▸ Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z$$

$$x \xrightarrow{f}$$

Function Composition

▸ Start

$$\mathrm{X} \xrightarrow{f} \mathrm{Y} \xrightarrow{g} \mathrm{Z}$$

$$x \xrightarrow{f} y$$

Function Composition

Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z$$

$$x \xrightarrow{f} y \xrightarrow{g}$$

Function Composition

Start

$$
\begin{array}{ccccc}
X & \xrightarrow{f} & Y & \xrightarrow{g} & Z \\
x & \xrightarrow{f} & y & \xrightarrow{g} & z
\end{array}
$$

Function Composition

Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z$$

$$x \xrightarrow{f} y \xrightarrow{g} z$$

$$x$$

Function Composition

Start

$$\begin{array}{ccccc} X & \xrightarrow{f} & Y & \xrightarrow{g} & Z \\ x & \xrightarrow{f} & y & \xrightarrow{g} & z \\ x & \xrightarrow{f} & & & \end{array}$$

Function Composition

Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z$$

$$x \xrightarrow{f} y \xrightarrow{g} z$$

$$x \xrightarrow{f} f(x)$$

Function Composition

▸ Start

$$
\begin{array}{ccccc}
X & \xrightarrow{f} & Y & \xrightarrow{g} & Z \\
x & \xrightarrow{f} & y & \xrightarrow{g} & z \\
x & \xrightarrow{f} & f(x) & \xrightarrow{g} &
\end{array}
$$

Function Composition

Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z$$

$$x \xrightarrow{f} y \xrightarrow{g} z$$

$$x \xrightarrow{f} f(x) \xrightarrow{g} g(f(x))$$

Function Content Composition

Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z \qquad X$$

$$x \xrightarrow{f} y \xrightarrow{g} z$$

$$x \xrightarrow{f} f(x) \xrightarrow{g} g(f(x))$$

Function Composition

Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z \qquad X \xrightarrow{g\circ f}$$

$$x \xrightarrow{f} y \xrightarrow{g} z$$

$$x \xrightarrow{f} f(x) \xrightarrow{g} g(f(x))$$

Function Composition

Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z \qquad X \xrightarrow{g\circ f} Z$$

$$x \xrightarrow{f} y \xrightarrow{g} z$$

$$x \xrightarrow{f} f(x) \xrightarrow{g} g(f(x))$$

Function Composition

Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z \qquad X \xrightarrow{g\circ f} Z$$

$$x \xrightarrow{f} y \xrightarrow{g} z \qquad x$$

$$x \xrightarrow{f} f(x) \xrightarrow{g} g(f(x))$$

Function Composition

▸ Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z \qquad X \xrightarrow{g \circ f} Z$$

$$x \xrightarrow{f} y \xrightarrow{g} z \qquad x \xrightarrow{g \circ f}$$

$$x \xrightarrow{f} f(x) \xrightarrow{g} g(f(x))$$

Function Composition

Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z \qquad X \xrightarrow{g\circ f} Z$$

$$x \xrightarrow{f} y \xrightarrow{g} z \qquad x \xrightarrow{g\circ f} z$$

$$x \xrightarrow{f} f(x) \xrightarrow{g} g(f(x))$$

Function Composition

Start

$$\mathrm{X} \xrightarrow{f} \mathrm{Y} \xrightarrow{g} \mathrm{Z} \qquad \mathrm{X} \xrightarrow{g\circ f} \mathrm{Z}$$

$$x \xrightarrow{f} y \xrightarrow{g} z \qquad x \xrightarrow{g\circ f} z$$

$$x \xrightarrow{f} f(x) \xrightarrow{g} g(f(x)) \qquad x$$

Function Composition

Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z \qquad X \xrightarrow{g \circ f} Z$$

$$x \xrightarrow{f} y \xrightarrow{g} z \qquad x \xrightarrow{g \circ f} z$$

$$x \xrightarrow{f} f(x) \xrightarrow{g} g(f(x)) \qquad x \xrightarrow{g \circ f}$$

Function Composition

Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z \qquad X \xrightarrow{g\circ f} Z$$

$$x \xrightarrow{f} y \xrightarrow{g} z \qquad x \xrightarrow{g\circ f} z$$

$$x \xrightarrow{f} f(x) \xrightarrow{g} g(f(x)) \qquad x \xrightarrow{g\circ f} (g\circ f)(x)$$

Function Composition

Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z \qquad X \xrightarrow{g \circ f} Z$$

$$x \xrightarrow{f} y \xrightarrow{g} z \qquad x \xrightarrow{g \circ f} z$$

$$x \xrightarrow{f} f(x) \xrightarrow{g} g(f(x)) \qquad x \xrightarrow{g \circ f} (g \circ f)(x)$$

$$\therefore$$

Function Composition

Start

$$\begin{array}{ccccc} X & \xrightarrow{f} & Y & \xrightarrow{g} & Z \\ x & \xrightarrow{f} & y & \xrightarrow{g} & z \\ x & \xrightarrow{f} & f(x) & \xrightarrow{g} & g(f(x)) \end{array} \qquad \begin{array}{ccc} X & \xrightarrow{g \circ f} & Z \\ x & \xrightarrow{g \circ f} & z \\ x & \xrightarrow{g \circ f} & (g \circ f)(x) \end{array}$$

$$\therefore \ \forall x$$

Function Composition

▸ Start

$$\begin{array}{ccccc} X & \xrightarrow{f} & Y & \xrightarrow{g} & Z \\ x & \xrightarrow{f} & y & \xrightarrow{g} & z \\ x & \xrightarrow{f} & f(x) & \xrightarrow{g} & g(f(x)) \end{array} \qquad \begin{array}{ccc} X & \xrightarrow{g \circ f} & Z \\ x & \xrightarrow{g \circ f} & z \\ x & \xrightarrow{g \circ f} & (g \circ f)(x) \end{array}$$

$$\therefore \ \forall x \in X,$$

Function Composition

▸ Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z \qquad X \xrightarrow{g \circ f} Z$$

$$x \xrightarrow{f} y \xrightarrow{g} z \qquad x \xrightarrow{g \circ f} z$$

$$x \xrightarrow{f} f(x) \xrightarrow{g} g(f(x)) \qquad x \xrightarrow{g \circ f} (g \circ f)(x)$$

$$\therefore\ \forall x \in X,\ ($$

Function Composition

▸ Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z \qquad X \xrightarrow{g\circ f} Z$$

$$x \xrightarrow{f} y \xrightarrow{g} z \qquad x \xrightarrow{g\circ f} z$$

$$x \xrightarrow{f} f(x) \xrightarrow{g} g(f(x)) \qquad x \xrightarrow{g\circ f} (g \circ f)(x)$$

$$\therefore\ \forall x \in X,\ (g$$

Function Composition

Start

$$
\begin{array}{ccccc}
X & \xrightarrow{f} & Y & \xrightarrow{g} & Z \\
x & \xrightarrow{f} & y & \xrightarrow{g} & z \\
x & \xrightarrow{f} & f(x) & \xrightarrow{g} & g(f(x))
\end{array}
\qquad
\begin{array}{ccc}
X & \xrightarrow{g \circ f} & Z \\
x & \xrightarrow{g \circ f} & z \\
x & \xrightarrow{g \circ f} & (g \circ f)(x)
\end{array}
$$

$$\therefore \ \forall x \in X, \ (g \circ$$

Function Composition

▸ Start

$$
\begin{array}{ccccccccc}
X & \xrightarrow{f} & Y & \xrightarrow{g} & Z & & X & \xrightarrow{g\circ f} & Z \\
x & \xrightarrow{f} & y & \xrightarrow{g} & z & & x & \xrightarrow{g\circ f} & z \\
x & \xrightarrow{f} & f(x) & \xrightarrow{g} & g(f(x)) & & x & \xrightarrow{g\circ f} & (g\circ f)(x)
\end{array}
$$

$$\therefore\ \forall x \in X,\ (g \circ f$$

Function Composition

▸ Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z \qquad X \xrightarrow{g\circ f} Z$$

$$x \xrightarrow{f} y \xrightarrow{g} z \qquad x \xrightarrow{g\circ f} z$$

$$x \xrightarrow{f} f(x) \xrightarrow{g} g(f(x)) \qquad x \xrightarrow{g\circ f} (g\circ f)(x)$$

$$\therefore\ \forall x \in X,\ (g\circ f)$$

Function Composition

Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z \qquad X \xrightarrow{g \circ f} Z$$
$$x \xrightarrow{f} y \xrightarrow{g} z \qquad x \xrightarrow{g \circ f} z$$
$$x \xrightarrow{f} f(x) \xrightarrow{g} g(f(x)) \qquad x \xrightarrow{g \circ f} (g \circ f)(x)$$
$$\therefore \ \forall x \in X, \ (g \circ f)(x)$$

Function Composition

Start

$$\begin{array}{ccccc} X & \xrightarrow{f} & Y & \xrightarrow{g} & Z \\ x & \xrightarrow{f} & y & \xrightarrow{g} & z \\ x & \xrightarrow{f} & f(x) & \xrightarrow{g} & g(f(x)) \end{array} \qquad \begin{array}{ccc} X & \xrightarrow{g\circ f} & Z \\ x & \xrightarrow{g\circ f} & z \\ x & \xrightarrow{g\circ f} & (g\circ f)(x) \end{array}$$

$$\therefore\ \forall x \in X,\ (g \circ f)(x) =$$

Function Composition

▸ Start

$$
\begin{array}{ccccccccc}
X & \xrightarrow{f} & Y & \xrightarrow{g} & Z & \quad & X & \xrightarrow{g\circ f} & Z \\
x & \xrightarrow{f} & y & \xrightarrow{g} & z & & x & \xrightarrow{g\circ f} & z \\
x & \xrightarrow{f} & f(x) & \xrightarrow{g} & g(f(x)) & & x & \xrightarrow{g\circ f} & (g\circ f)(x)
\end{array}
$$

$$\therefore\ \forall x \in X,\ (g\circ f)(x) = g$$

Function Composition

▸ Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z \qquad X \xrightarrow{g\circ f} Z$$

$$x \xrightarrow{f} y \xrightarrow{g} z \qquad x \xrightarrow{g\circ f} z$$

$$x \xrightarrow{f} f(x) \xrightarrow{g} g(f(x)) \qquad x \xrightarrow{g\circ f} (g\circ f)(x)$$

$$\therefore\ \forall x \in X,\ (g\circ f)(x) = g($$

Function Composition

Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z \qquad X \xrightarrow{g\circ f} Z$$
$$x \xrightarrow{f} y \xrightarrow{g} z \qquad x \xrightarrow{g\circ f} z$$
$$x \xrightarrow{f} f(x) \xrightarrow{g} g(f(x)) \qquad x \xrightarrow{g\circ f} (g\circ f)(x)$$
$$\therefore\ \forall x \in X,\ (g\circ f)(x) = g(f$$

Function Composition

Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z \qquad X \xrightarrow{g\circ f} Z$$

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$$\therefore\ \forall x \in X,\ (g\circ f)(x) = g(f(x))$$

Function Composition

Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z \qquad X \xrightarrow{g\circ f} Z$$

$$x \xrightarrow{f} y \xrightarrow{g} z \qquad x \xrightarrow{g\circ f} z$$

$$x \xrightarrow{f} f(x) \xrightarrow{g} g(f(x)) \qquad x \xrightarrow{g\circ f} (g\circ f)(x)$$

$$\therefore\ \forall x \in X,\ (g\circ f)(x) = g(f(x))$$

Function Composition

Start

$$\begin{array}{ccccccccc} X & \xrightarrow{f} & Y & \xrightarrow{g} & Z & & X & \xrightarrow{g\circ f} & Z \\ x & \xrightarrow{f} & y & \xrightarrow{g} & z & & x & \xrightarrow{g\circ f} & z \\ x & \xrightarrow{f} & f(x) & \xrightarrow{g} & g(f(x)) & & x & \xrightarrow{g\circ f} & (g\circ f)(x) \end{array}$$

$$\therefore\ \forall x \in X,\ (g\circ f)(x) = g(f(x))$$

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Function Composition

▸ Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z \qquad X \xrightarrow{g\circ f} Z$$
$$x \xrightarrow{f} y \xrightarrow{g} z \qquad x \xrightarrow{g\circ f} z$$
$$x \xrightarrow{f} f(x) \xrightarrow{g} g(f(x)) \qquad x \xrightarrow{g\circ f} (g\circ f)(x)$$
$$\therefore\ \forall x \in X,\ (g\circ f)(x) = g(f(x))$$

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Function Composition

Start

$$\begin{array}{ccccccccc} X & \xrightarrow{f} & Y & \xrightarrow{g} & Z & & X & \xrightarrow{g\circ f} & Z \\ x & \xrightarrow{f} & y & \xrightarrow{g} & z & & x & \xrightarrow{g\circ f} & z \\ x & \xrightarrow{f} & f(x) & \xrightarrow{g} & g(f(x)) & & x & \xrightarrow{g\circ f} & (g\circ f)(x) \end{array}$$

$$\therefore\ \forall x \in X,\ (g\circ f)(x) = g(f(x))$$

$((h$

Function Composition

Start

$$\begin{array}{ccccccccc} X & \xrightarrow{f} & Y & \xrightarrow{g} & Z & & X & \xrightarrow{g\circ f} & Z \\ x & \xrightarrow{f} & y & \xrightarrow{g} & z & & x & \xrightarrow{g\circ f} & z \\ x & \xrightarrow{f} & f(x) & \xrightarrow{g} & g(f(x)) & & x & \xrightarrow{g\circ f} & (g\circ f)(x) \end{array}$$

$$\therefore\ \forall x \in X,\ (g\circ f)(x) = g(f(x))$$

$((h \circ$

Function Composition

▸ Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z \qquad X \xrightarrow{g \circ f} Z$$
$$x \xrightarrow{f} y \xrightarrow{g} z \qquad x \xrightarrow{g \circ f} z$$
$$x \xrightarrow{f} f(x) \xrightarrow{g} g(f(x)) \qquad x \xrightarrow{g \circ f} (g \circ f)(x)$$
$$\therefore\ \forall x \in X,\ (g \circ f)(x) = g(f(x))$$

$$(\,(h \circ g$$

Function Composition

Start

$$
\begin{array}{ccccccccc}
X & \xrightarrow{f} & Y & \xrightarrow{g} & Z & \quad & X & \xrightarrow{g\circ f} & Z \\
x & \xrightarrow{f} & y & \xrightarrow{g} & z & & x & \xrightarrow{g\circ f} & z \\
x & \xrightarrow{f} & f(x) & \xrightarrow{g} & g(f(x)) & & x & \xrightarrow{g\circ f} & (g \circ f)(x)
\end{array}
$$

$$\therefore\ \forall x \in X,\ (g \circ f)(x) = g(f(x))$$

$$(\ (h \circ g)$$

Function Composition

Start

$$
\begin{array}{ccccccccc}
X & \xrightarrow{f} & Y & \xrightarrow{g} & Z & & X & \xrightarrow{g\circ f} & Z \\
x & \xrightarrow{f} & y & \xrightarrow{g} & z & & x & \xrightarrow{g\circ f} & z \\
x & \xrightarrow{f} & f(x) & \xrightarrow{g} & g(f(x)) & & x & \xrightarrow{g\circ f} & (g\circ f)(x)
\end{array}
$$

$$\therefore\ \forall x \in X,\ (g\circ f)(x) = g(f(x))$$

$(\, (h \circ g) \ \circ$

Function Composition

Start

$$\begin{array}{ccccccccc} X & \xrightarrow{f} & Y & \xrightarrow{g} & Z & & X & \xrightarrow{g \circ f} & Z \\ x & \xrightarrow{f} & y & \xrightarrow{g} & z & & x & \xrightarrow{g \circ f} & z \\ x & \xrightarrow{f} & f(x) & \xrightarrow{g} & g(f(x)) & & x & \xrightarrow{g \circ f} & (g \circ f)(x) \end{array}$$

$$\therefore \ \forall x \in X, \ (g \circ f)(x) = g(f(x))$$

$$(\,(h \circ g)\ \circ f$$

Function Composition

▸ Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z \qquad X \xrightarrow{g\circ f} Z$$

$$x \xrightarrow{f} y \xrightarrow{g} z \qquad x \xrightarrow{g\circ f} z$$

$$x \xrightarrow{f} f(x) \xrightarrow{g} g(f(x)) \qquad x \xrightarrow{g\circ f} (g\circ f)(x)$$

$$\therefore\ \forall x \in X,\ (g\circ f)(x) = g(f(x))$$

$$(\,(h\circ g)\ \circ f)$$

Function Composition

Start

$$\begin{array}{ccccccccc} X & \xrightarrow{f} & Y & \xrightarrow{g} & Z & \quad & X & \xrightarrow{g\circ f} & Z \\ x & \xrightarrow{f} & y & \xrightarrow{g} & z & & x & \xrightarrow{g\circ f} & z \\ x & \xrightarrow{f} & f(x) & \xrightarrow{g} & g(f(x)) & & x & \xrightarrow{g\circ f} & (g\circ f)(x) \end{array}$$

$$\therefore\ \forall x \in X,\ (g\circ f)(x) = g(f(x))$$

$$\big(\,(h\circ g)\ \circ f\big)\,(x)$$

Function Composition

▸ Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z \qquad X \xrightarrow{g \circ f} Z$$
$$x \xrightarrow{f} y \xrightarrow{g} z \qquad x \xrightarrow{g \circ f} z$$
$$x \xrightarrow{f} f(x) \xrightarrow{g} g(f(x)) \qquad x \xrightarrow{g \circ f} (g \circ f)(x)$$
$$\therefore \ \forall x \in X, \ (g \circ f)(x) = g(f(x))$$

$$((h \circ g) \circ f)(x) =$$

Function Composition

▸ Start

$$
\begin{array}{ccccccccc}
X & \xrightarrow{f} & Y & \xrightarrow{g} & Z & & X & \xrightarrow{g \circ f} & Z \\
x & \xrightarrow{f} & y & \xrightarrow{g} & z & & x & \xrightarrow{g \circ f} & z \\
x & \xrightarrow{f} & f(x) & \xrightarrow{g} & g(f(x)) & & x & \xrightarrow{g \circ f} & (g \circ f)(x)
\end{array}
$$

$$\therefore\ \forall x \in X,\ (g \circ f)(x) = g(f(x))$$

$$((h \circ g) \circ f)(x) = ($$

Function Composition

Start

$$\begin{array}{ccccccccc} X & \xrightarrow{f} & Y & \xrightarrow{g} & Z & & X & \xrightarrow{g\circ f} & Z \\ x & \xrightarrow{f} & y & \xrightarrow{g} & z & & x & \xrightarrow{g\circ f} & z \\ x & \xrightarrow{f} & f(x) & \xrightarrow{g} & g(f(x)) & & x & \xrightarrow{g\circ f} & (g\circ f)(x) \end{array}$$

$$\therefore\ \forall x \in X,\ (g\circ f)(x) = g(f(x))$$

$$(\,(h\circ g)\ \circ f)\,(x) = \ (h$$

Function Composition

▸ Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z \qquad X \xrightarrow{g \circ f} Z$$

$$x \xrightarrow{f} y \xrightarrow{g} z \qquad x \xrightarrow{g \circ f} z$$

$$x \xrightarrow{f} f(x) \xrightarrow{g} g(f(x)) \qquad x \xrightarrow{g \circ f} (g \circ f)(x)$$

$$\therefore \ \forall x \in X, \ (g \circ f)(x) = g(f(x))$$

$$((h \circ g) \circ f)(x) = (h \circ$$

Function Composition

▸ Start

$$\begin{array}{ccccccccc} \mathrm{X} & \xrightarrow{f} & \mathrm{Y} & \xrightarrow{g} & \mathrm{Z} & \quad & \mathrm{X} & \xrightarrow{g\circ f} & \mathrm{Z} \\ x & \xrightarrow{f} & y & \xrightarrow{g} & z & & x & \xrightarrow{g\circ f} & z \\ x & \xrightarrow{f} & f(x) & \xrightarrow{g} & g(f(x)) & & x & \xrightarrow{g\circ f} & (g\circ f)(x) \end{array}$$

$$\therefore\ \forall x \in \mathrm{X},\ (g\circ f)(x) = g(f(x))$$

$$(\,(h\circ g)\ \circ f)\,(x) = \ (h\circ g$$

Function Composition

▸ Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z \qquad X \xrightarrow{g\circ f} Z$$
$$x \xrightarrow{f} y \xrightarrow{g} z \qquad x \xrightarrow{g\circ f} z$$
$$x \xrightarrow{f} f(x) \xrightarrow{g} g(f(x)) \qquad x \xrightarrow{g\circ f} (g\circ f)(x)$$
$$\therefore\ \forall x \in X,\ (g\circ f)(x) = g(f(x))$$

$$((h\circ g)\circ f)(x) = (h\circ g)$$

Function Composition

Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z \qquad X \xrightarrow{g\circ f} Z$$

$$x \xrightarrow{f} y \xrightarrow{g} z \qquad x \xrightarrow{g\circ f} z$$

$$x \xrightarrow{f} f(x) \xrightarrow{g} g(f(x)) \qquad x \xrightarrow{g\circ f} (g\circ f)(x)$$

$$\therefore\ \forall x \in X,\ (g\circ f)(x) = g(f(x))$$

$$((h\circ g)\circ f)(x) = (h\circ g)\ ($$

Function Composition

Start

$$\begin{array}{ccccccccc} X & \xrightarrow{f} & Y & \xrightarrow{g} & Z & & X & \xrightarrow{g \circ f} & Z \\ x & \xrightarrow{f} & y & \xrightarrow{g} & z & & x & \xrightarrow{g \circ f} & z \\ x & \xrightarrow{f} & f(x) & \xrightarrow{g} & g(f(x)) & & x & \xrightarrow{g \circ f} & (g \circ f)(x) \end{array}$$

$$\therefore \; \forall x \in X, \; (g \circ f)(x) = g(f(x))$$

$$((h \circ g) \circ f)(x) = (h \circ g)\,(f$$

Function Composition

Start

$$
\begin{array}{ccccccccc}
X & \xrightarrow{f} & Y & \xrightarrow{g} & Z & \quad & X & \xrightarrow{g\circ f} & Z \\
x & \xrightarrow{f} & y & \xrightarrow{g} & z & & x & \xrightarrow{g\circ f} & z \\
x & \xrightarrow{f} & f(x) & \xrightarrow{g} & g(f(x)) & & x & \xrightarrow{g\circ f} & (g\circ f)(x)
\end{array}
$$

$$\therefore\ \forall x \in X,\ (g\circ f)(x) = g(f(x))$$

$$((h\circ g)\circ f)(x) = (h\circ g)\ (f\ (x)$$

Function Composition

Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z \qquad X \xrightarrow{g\circ f} Z$$

$$x \xrightarrow{f} y \xrightarrow{g} z \qquad x \xrightarrow{g\circ f} z$$

$$x \xrightarrow{f} f(x) \xrightarrow{g} g(f(x)) \qquad x \xrightarrow{g\circ f} (g\circ f)(x)$$

$$\therefore\ \forall x \in X,\ (g \circ f)(x) = g(f(x))$$

$$((h \circ g) \circ f)(x) = (h \circ g)(f(x))$$

Function Composition

▸ Start

$$\begin{array}{ccccc} X & \xrightarrow{f} & Y & \xrightarrow{g} & Z \\ x & \xrightarrow{f} & y & \xrightarrow{g} & z \\ x & \xrightarrow{f} & f(x) & \xrightarrow{g} & g(f(x)) \end{array} \qquad \begin{array}{ccc} X & \xrightarrow{g\circ f} & Z \\ x & \xrightarrow{g\circ f} & z \\ x & \xrightarrow{g\circ f} & (g\circ f)(x) \end{array}$$

$$\therefore\ \forall x \in X,\ (g\circ f)(x) = g(f(x))$$

$$((h\circ g)\circ f)(x) = (h\circ g)\ (f\ (x)\ ) = h$$

Function Composition

▸ Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z \qquad X \xrightarrow{g \circ f} Z$$
$$x \xrightarrow{f} y \xrightarrow{g} z \qquad x \xrightarrow{g \circ f} z$$
$$x \xrightarrow{f} f(x) \xrightarrow{g} g(f(x)) \qquad x \xrightarrow{g \circ f} (g \circ f)(x)$$
$$\therefore \ \forall x \in X, \ (g \circ f)(x) = g(f(x))$$

$$((h \circ g) \circ f)(x) = (h \circ g)(f(x)) = h($$

Function Composition

Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z \qquad X \xrightarrow{g \circ f} Z$$

$$x \xrightarrow{f} y \xrightarrow{g} z \qquad x \xrightarrow{g \circ f} z$$

$$x \xrightarrow{f} f(x) \xrightarrow{g} g(f(x)) \qquad x \xrightarrow{g \circ f} (g \circ f)(x)$$

$$\therefore \ \forall x \in X, \ (g \circ f)(x) = g(f(x))$$

$$((h \circ g) \circ f)(x) = (h \circ g)(f(x)) = h(g$$

Function Composition

Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z \qquad X \xrightarrow{g\circ f} Z$$

$$x \xrightarrow{f} y \xrightarrow{g} z \qquad x \xrightarrow{g\circ f} z$$

$$x \xrightarrow{f} f(x) \xrightarrow{g} g(f(x)) \qquad x \xrightarrow{g\circ f} (g \circ f)(x)$$

$$\therefore\ \forall x \in X,\ (g \circ f)(x) = g(f(x))$$

$$((h \circ g) \circ f)(x) = (h \circ g)(f(x)) = h(g($$

Function Composition

Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z \qquad X \xrightarrow{g \circ f} Z$$

$$x \xrightarrow{f} y \xrightarrow{g} z \qquad x \xrightarrow{g \circ f} z$$

$$x \xrightarrow{f} f(x) \xrightarrow{g} g(f(x)) \qquad x \xrightarrow{g \circ f} (g \circ f)(x)$$

$$\therefore\ \forall x \in X,\ (g \circ f)(x) = g(f(x))$$

$$((h \circ g) \circ f)(x) = (h \circ g)(f(x)) = h(g(f$$

Function Composition

▸ Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z \qquad X \xrightarrow{g \circ f} Z$$

$$x \xrightarrow{f} y \xrightarrow{g} z \qquad x \xrightarrow{g \circ f} z$$

$$x \xrightarrow{f} f(x) \xrightarrow{g} g(f(x)) \qquad x \xrightarrow{g \circ f} (g \circ f)(x)$$

$$\therefore \ \forall x \in X, \ (g \circ f)(x) = g(f(x))$$

$$((h \circ g) \circ f)(x) = (h \circ g)\ (f(x)) = h(g(f(x)$$

Function Composition

▸ Start

$$
\begin{array}{ccccccccc}
X & \xrightarrow{f} & Y & \xrightarrow{g} & Z & \quad & X & \xrightarrow{g\circ f} & Z \\
x & \xrightarrow{f} & y & \xrightarrow{g} & z & & x & \xrightarrow{g\circ f} & z \\
x & \xrightarrow{f} & f(x) & \xrightarrow{g} & g(f(x)) & & x & \xrightarrow{g\circ f} & (g\circ f)(x)
\end{array}
$$

$$\therefore\ \forall x \in X,\ (g\circ f)(x) = g(f(x))$$

$$((h\circ g)\circ f)(x) = (h\circ g)\,(f\,(x)) = h\,(g\,(f\,(x)))$$

Function Composition

Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z \qquad X \xrightarrow{g\circ f} Z$$

$$x \xrightarrow{f} y \xrightarrow{g} z \qquad x \xrightarrow{g\circ f} z$$

$$x \xrightarrow{f} f(x) \xrightarrow{g} g(f(x)) \qquad x \xrightarrow{g\circ f} (g\circ f)(x)$$

$$\therefore\ \forall x \in X,\ (g\circ f)(x) = g(f(x))$$

$$((h\circ g)\circ f)(x) = (h\circ g)(f(x)) = h(g(f(x)))$$

Function Composition

Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z \qquad X \xrightarrow{g \circ f} Z$$

$$x \xrightarrow{f} y \xrightarrow{g} z \qquad x \xrightarrow{g \circ f} z$$

$$x \xrightarrow{f} f(x) \xrightarrow{g} g(f(x)) \qquad x \xrightarrow{g \circ f} (g \circ f)(x)$$

$$\therefore \ \forall x \in X, \ (g \circ f)(x) = g(f(x))$$

$$((h \circ g) \circ f)(x) = (h \circ g)(f(x)) = h(g(f(x)))$$

$$=$$

Function Composition

▸ Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z \qquad X \xrightarrow{g\circ f} Z$$

$$x \xrightarrow{f} y \xrightarrow{g} z \qquad x \xrightarrow{g\circ f} z$$

$$x \xrightarrow{f} f(x) \xrightarrow{g} g(f(x)) \qquad x \xrightarrow{g\circ f} (g\circ f)(x)$$

$$\therefore\ \forall x \in X,\ (g\circ f)(x) = g(f(x))$$

$$((h\circ g)\circ f)(x) = (h\circ g)(f(x)) = h(g(f(x)))$$

$$= h$$

Function Composition

▸ Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z \qquad X \xrightarrow{g \circ f} Z$$
$$x \xrightarrow{f} y \xrightarrow{g} z \qquad x \xrightarrow{g \circ f} z$$
$$x \xrightarrow{f} f(x) \xrightarrow{g} g(f(x)) \qquad x \xrightarrow{g \circ f} (g \circ f)(x)$$
$$\therefore \ \forall x \in X, \ (g \circ f)(x) = g(f(x))$$

$$((h \circ g) \circ f)(x) = (h \circ g)(f(x)) = h(g(f(x)))$$

$$= h($$

Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z \qquad X \xrightarrow{g\circ f} Z$$
$$x \xrightarrow{f} y \xrightarrow{g} z \qquad x \xrightarrow{g\circ f} z$$
$$x \xrightarrow{f} f(x) \xrightarrow{g} g(f(x)) \qquad x \xrightarrow{g\circ f} (g\circ f)(x)$$
$$\therefore \ \forall x \in X, \ (g \circ f)(x) = g(f(x))$$

$$((h \circ g) \circ f)(x) = (h \circ g)(f(x)) = h(g(f(x)))$$

$$= h(($$

Function Composition

▸ Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z \qquad X \xrightarrow{g\circ f} Z$$
$$x \xrightarrow{f} y \xrightarrow{g} z \qquad x \xrightarrow{g\circ f} z$$
$$x \xrightarrow{f} f(x) \xrightarrow{g} g(f(x)) \qquad x \xrightarrow{g\circ f} (g\circ f)(x)$$
$$\therefore\ \forall x \in X,\ (g\circ f)(x) = g(f(x))$$

$$((h\circ g)\circ f)(x) = (h\circ g)(f(x)) = h(g(f(x)))$$

$$= h((g$$

Function Composition

Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z \qquad X \xrightarrow{g \circ f} Z$$

$$x \xrightarrow{f} y \xrightarrow{g} z \qquad x \xrightarrow{g \circ f} z$$

$$x \xrightarrow{f} f(x) \xrightarrow{g} g(f(x)) \qquad x \xrightarrow{g \circ f} (g \circ f)(x)$$

$$\therefore \ \forall x \in X, \ (g \circ f)(x) = g(f(x))$$

$$((h \circ g) \circ f)(x) = (h \circ g)(f(x)) = h(g(f(x)))$$

$$= h((g \circ$$

Function Composition

▸ Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z \qquad X \xrightarrow{g\circ f} Z$$

$$x \xrightarrow{f} y \xrightarrow{g} z \qquad x \xrightarrow{g\circ f} z$$

$$x \xrightarrow{f} f(x) \xrightarrow{g} g(f(x)) \qquad x \xrightarrow{g\circ f} (g\circ f)(x)$$

$$\therefore\ \forall x \in X,\ (g\circ f)(x) = g(f(x))$$

$$((h\circ g)\circ f)(x) = (h\circ g)(f(x)) = h(g(f(x)))$$

$$= h((g\circ f$$

Function Composition

▸ Start

$$\begin{array}{ccccccccc} X & \xrightarrow{f} & Y & \xrightarrow{g} & Z & \quad & X & \xrightarrow{g \circ f} & Z \\ x & \xrightarrow{f} & y & \xrightarrow{g} & z & & x & \xrightarrow{g \circ f} & z \\ x & \xrightarrow{f} & f(x) & \xrightarrow{g} & g(f(x)) & & x & \xrightarrow{g \circ f} & (g \circ f)(x) \end{array}$$

$$\therefore \ \forall x \in X, \ (g \circ f)(x) = g(f(x))$$

$$((h \circ g) \circ f)(x) = (h \circ g)(f(x)) = h(g(f(x)))$$

$$= h((g \circ f)$$

Function Composition

Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z \qquad X \xrightarrow{g\circ f} Z$$
$$x \xrightarrow{f} y \xrightarrow{g} z \qquad x \xrightarrow{g\circ f} z$$
$$x \xrightarrow{f} f(x) \xrightarrow{g} g(f(x)) \qquad x \xrightarrow{g\circ f} (g\circ f)(x)$$
$$\therefore\ \forall x \in X,\ (g\circ f)(x) = g(f(x))$$

$$((h\circ g)\circ f)(x) = (h\circ g)(f(x)) = h(g(f(x)))$$

$$= h((g\circ f)(x))$$

Function Composition

▸ Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z \qquad X \xrightarrow{g\circ f} Z$$
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$$x \xrightarrow{f} f(x) \xrightarrow{g} g(f(x)) \qquad x \xrightarrow{g\circ f} (g\circ f)(x)$$
$$\therefore\ \forall x \in X,\ (g\circ f)(x) = g(f(x))$$

$$((h\circ g)\circ f)(x) = (h\circ g)(f(x)) = h(g(f(x)))$$

$$= h((g\circ f)(x))$$

▸ Start

$$\begin{array}{ccccccccc} X & \xrightarrow{f} & Y & \xrightarrow{g} & Z & & X & \xrightarrow{g\circ f} & Z \\ x & \xrightarrow{f} & y & \xrightarrow{g} & z & & x & \xrightarrow{g\circ f} & z \\ x & \xrightarrow{f} & f(x) & \xrightarrow{g} & g(f(x)) & & x & \xrightarrow{g\circ f} & (g\circ f)(x) \end{array}$$

$$\therefore \ \forall x \in X, \ (g \circ f)(x) = g(f(x))$$

$$((h \circ g) \circ f)(x) = (h \circ g)(f(x)) = h(g(f(x)))$$

$$= h((g \circ f)(x)) =$$

Function Composition

Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z \qquad X \xrightarrow{g\circ f} Z$$

$$x \xrightarrow{f} y \xrightarrow{g} z \qquad x \xrightarrow{g\circ f} z$$

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$$((h\circ g)\circ f)(x) = (h\circ g)(f(x)) = h(g(f(x)))$$

$$= h((g\circ f)(x)) = ($$

Function Composition

Start

$$\begin{array}{ccccccccc} X & \xrightarrow{f} & Y & \xrightarrow{g} & Z & & X & \xrightarrow{g\circ f} & Z \\ x & \xrightarrow{f} & y & \xrightarrow{g} & z & & x & \xrightarrow{g\circ f} & z \\ x & \xrightarrow{f} & f(x) & \xrightarrow{g} & g(f(x)) & & x & \xrightarrow{g\circ f} & (g\circ f)(x) \end{array}$$

$$\therefore\ \forall x \in X,\ (g \circ f)(x) = g(f(x))$$

$$((h \circ g) \circ f)(x) = (h \circ g)\ (f(x)) = h(g(f(x)))$$

$$= h((g \circ f)\ (x)) = (h$$

Function Composition

Start

$$\begin{array}{ccccccccc} X & \xrightarrow{f} & Y & \xrightarrow{g} & Z & & X & \xrightarrow{g \circ f} & Z \\ x & \xrightarrow{f} & y & \xrightarrow{g} & z & & x & \xrightarrow{g \circ f} & z \\ x & \xrightarrow{f} & f(x) & \xrightarrow{g} & g(f(x)) & & x & \xrightarrow{g \circ f} & (g \circ f)(x) \end{array}$$

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$$((h \circ g) \circ f)(x) = (h \circ g)(f(x)) = h(g(f(x)))$$

$$= h((g \circ f)(x)) = (h \circ$$

Function Composition

Start

$$\begin{array}{ccccccccc} X & \xrightarrow{f} & Y & \xrightarrow{g} & Z & & X & \xrightarrow{g \circ f} & Z \\ x & \xrightarrow{f} & y & \xrightarrow{g} & z & & x & \xrightarrow{g \circ f} & z \\ x & \xrightarrow{f} & f(x) & \xrightarrow{g} & g(f(x)) & & x & \xrightarrow{g \circ f} & (g \circ f)(x) \end{array}$$

$$\therefore \ \forall x \in X, \ (g \circ f)(x) = g(f(x))$$

$$((h \circ g) \circ f)(x) = (h \circ g)(f(x)) = h(g(f(x)))$$

$$= h((g \circ f)(x)) = (h \circ ($$

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▸ Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z \qquad X \xrightarrow{g\circ f} Z$$

$$x \xrightarrow{f} y \xrightarrow{g} z \qquad x \xrightarrow{g\circ f} z$$

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\begin{array}{ccccc}
X & \xrightarrow{f} & Y & \xrightarrow{g} & Z \\
x & \xrightarrow{f} & y & \xrightarrow{g} & z \\
x & \xrightarrow{f} & f(x) & \xrightarrow{g} & g(f(x))
\end{array}
\qquad
\begin{array}{ccc}
X & \xrightarrow{g\circ f} & Z \\
x & \xrightarrow{g\circ f} & z \\
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$$

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X & \xrightarrow{f} & Y & \xrightarrow{g} & Z & & X & \xrightarrow{g\circ f} & Z \\
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Function Composition

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Function Composition

▸ Start

$$\begin{array}{ccccccccc} X & \xrightarrow{f} & Y & \xrightarrow{g} & Z & & X & \xrightarrow{g \circ f} & Z \\ x & \xrightarrow{f} & y & \xrightarrow{g} & z & & x & \xrightarrow{g \circ f} & z \\ x & \xrightarrow{f} & f(x) & \xrightarrow{g} & g(f(x)) & & x & \xrightarrow{g \circ f} & (g \circ f)(x) \end{array}$$

$$\therefore \ \forall x \in X, \ (g \circ f)(x) = g(f(x))$$

$$((h \circ g) \circ f)(x) = (h \circ g)(f(x)) = h(g(f(x)))$$

$$= h((g \circ f)(x)) = (h \circ (g \circ f))(x)$$

$$\therefore \ \forall x \in X, ((h \circ g) \circ f)(x) = (h \circ (g \circ f))(x)$$

$$(h \circ g$$

Function Composition

▸ Start

$$X \xrightarrow{f} Y \xrightarrow{g} Z \qquad X \xrightarrow{g \circ f} Z$$

$$x \xrightarrow{f} y \xrightarrow{g} z \qquad x \xrightarrow{g \circ f} z$$

$$x \xrightarrow{f} f(x) \xrightarrow{g} g(f(x)) \qquad x \xrightarrow{g \circ f} (g \circ f)(x)$$

$$\therefore \ \forall x \in X, \ (g \circ f)(x) = g(f(x))$$

$$((h \circ g) \circ f)(x) = (h \circ g)(f(x)) = h(g(f(x)))$$

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Function Composition

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