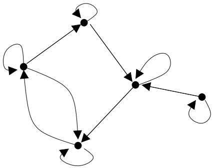
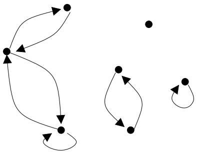
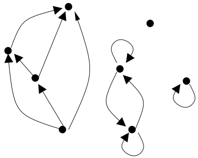
Operators	$x + y$	$p \vee q$	$A \cup B$
	$-x$	$\sim p$	$\overline{A}$
Distribution	$x \cdot (y + z)$	$p \wedge (q \vee r)$	$A \cap (B \cup C)$
	$= x \cdot y + x \cdot z$	$\equiv (p \wedge q) \vee (p \wedge r)$	$= (A \cap B) \cup (A \cap C)$
Identity	$x + 0 = x$	$p \vee T \equiv p$	$A \cup \emptyset = A$
	$x \cdot 1 = x$	$p \wedge F \equiv p$	$A \cap \mathcal{U} = A$

A **relation** from one set to another	R	set of pairs	subset of $X \times Y$ $R \subseteq X \times Y$	isEnrolledIn, isTaughtBy
A **relation** on a set	R	set of pairs	subset of $X \times X$ $R \subseteq X \times X$	eats, divides
The **image** of an element under a relation	$\mathcal{I}_R(a)$	set	set of things that a is related to $\mathcal{I}_R(a) = \{b \in Y \mid (a, b) \in R\}$	classes Bob is enrolled in, numbers that 4 divides
The **image** of a set under a relation	$\mathcal{I}_R(A)$	set	set of things that things in A are related to $\mathcal{I}_R(A) = \{b \in Y \mid \exists\ a \in A \mid (a, b) \in R\}$	classes Bob, Larry, or Alice are taking, numbers that 2, 3, or 5 divide
The **inverse** of a relation	R^{-1}	relation	the arrows/pairs of R reversed $R^{-1} = \{(b, a) \in Y \times X \mid (a, b) \in R\}$	hasOnRoster, teaches, isEatenBy, isDivisibleBy
The **composition** of two relations	$S \circ R$	relation	two hops combined to one hop (Assume $S \subseteq Y \times Z$) $S \circ R = \{(a, c) \in X \times Z \mid \exists\ b \in Y$ $\mid (a, b) \in R \wedge (b, c) \in S\}$	hasAsProfessor, eatsSomethingThatEats
The **identity** relation on a set	i_X	relation	everything is related only to itself $i_X = \{(x, x) \mid x \in X\}$	$=$

	Reflexivity	**Symmetry**	**Transitivity**
Informal	Everything is related to itself	All pairs are mutual	Anything reachable by two hops is reachable by one hop
Formal	$\forall\ x \in X,\ (x,x) \in R$	$\forall\ x,y \in X,\ (x,y) \in R \rightarrow (y,x) \in R$ OR $\forall (x,y) \in R,\ (y,x) \in R$	$\forall x,y,z \in X,$ $(x,y),(y,z) \in R \rightarrow (x,z) \in R$ OR $\forall (x,y),(y,z) \in R, (x,z) \in R$
Visual			
Examples	$\subseteq$, $\leq$, $\geq$, $\equiv$, i, isAquaintedWith, waterVerticallyAligned	$\equiv$, isOppositeOf, isOnSameRiver, isAquaintedWith	$<$, $\leq$, $>$, $\geq$, $\subseteq$, isTallerThan, isAncestorOf, isWestOf

$\{(1, 2), (2, 3), (5, 2), (1, 5), (2, 5), (1, 3)\}$

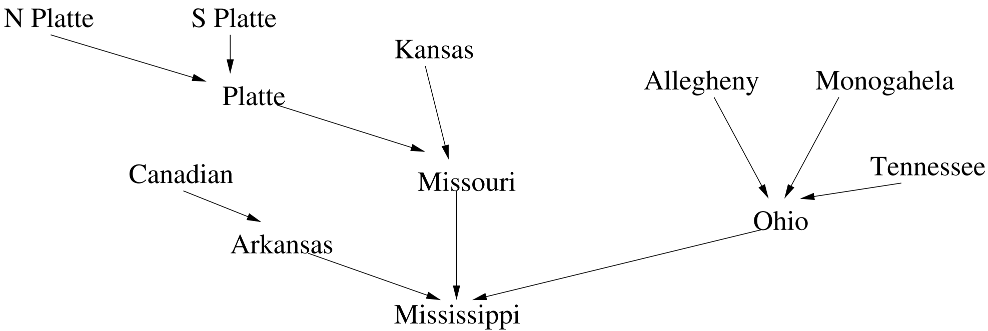
$\{(1, 2), (2, 3), (5, 2), (1, 5), (2, 5), (1, 3)\}$

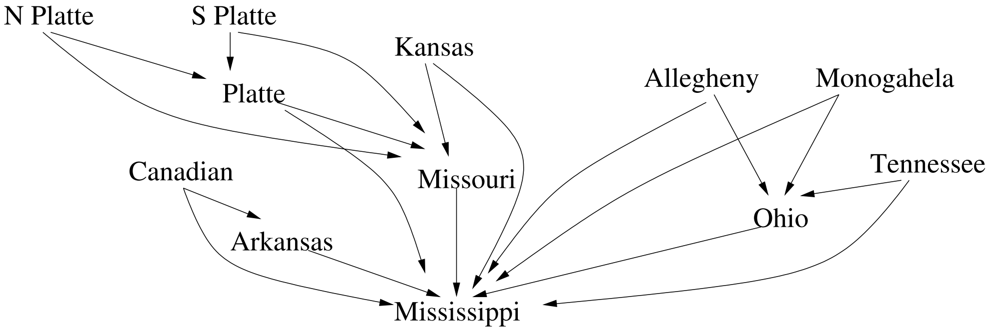
$\{(1, 2), (2, 3), (5, 2), (1, 5), (2, 5), (1, 3)\}$

$\{(1, 2), (2, 3), (5, 2), (1, 5), (2, 5), (1, 3)\}$

Domain	First relation	Second relation
Rivers	*flows into* The Platte flows into the Missouri, and the Missouri flows into the Mississippi.	*is tributary to* The Platte is a tributary to the Missouri; both the Platte and the Missouri are tributaries to the Mississippi.
People	*is parent of* Bill is Jane's parent; Jane is Leroy's parent	*is ancestor of* Bill is Jane's ancestor; Leroy has both Jane and Bill as ancestors.

Domain	First relation	Second relation
Animals	*eats* Rabbit eats clover; coyote eats rabbit.	*derives nutrients from* Coyote derives nutrients from rabbit; rabbit derives nutrients from clover; both coyote and rabbit ultimately derive nutrients from clover.
$\mathbb{Z}$	*is one less than* 2 is one less than 3; 3 is one less than 4	$<$ $2 < 3; \quad 3 < 4; \quad 2 < 4.$


N Platte
S Platte
Kansas
Platte
Allegheny
Monogahela
Canadian
Missouri
Tennessee
Ohio
Arkansas
Mississippi


N Platte
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Allegheny
Monogahela
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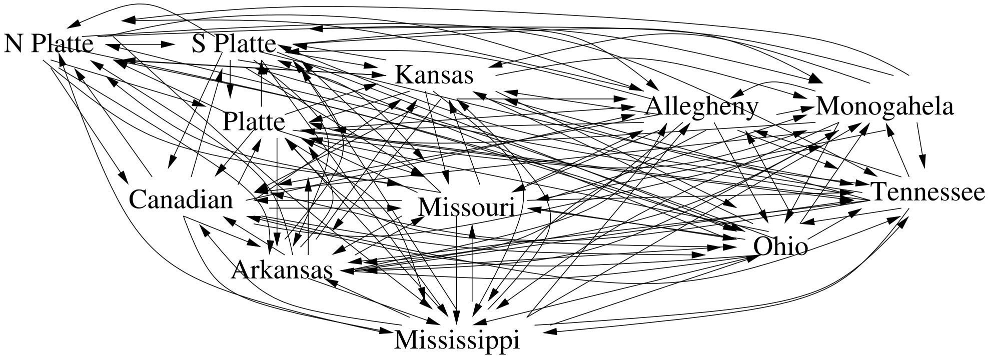
Mississippi


N Platte
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Kansas
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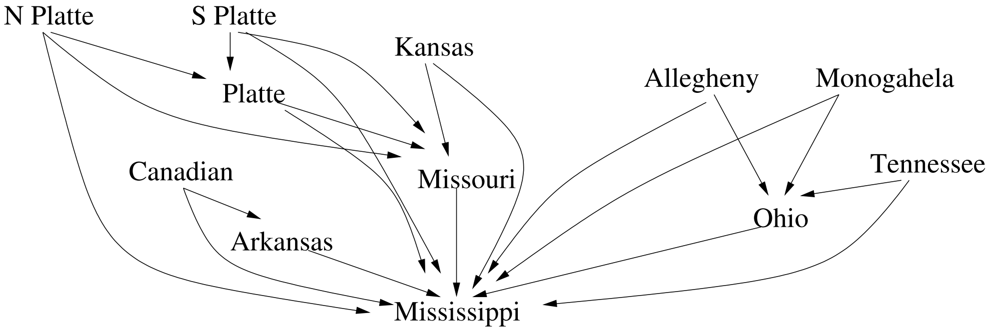
Arkansas
Mississippi


N Platte
S Platte
Kansas
Allegheny
Monogahela
Platte
Tennessee
Canadian
Missouri
Ohio
Arkansas
Mississippi

Theorem 5.12 *The transitive closure of a relation R is unique.*

Proof. *Suppose S and T are relations fulfilling the requirements for being transitive closures of R. By items 1 and 2, S is transitive and $R \subseteq S$, so by item 3, $T \subseteq S$. By items 1 and 2, T is transitive and $R \subseteq T$, so by item 3, $S \subseteq T$. Therefore $S = T$ by the definition of set equality.* $\square$

Theorem 5.13 *If R is a relation on a set A, then*

$$R^{\infty} = \bigcup_{i=1}^{\infty} R^i = \{(x,y) \mid \exists\ i \in \mathbb{N} \text{ such that } (x,y) \in R^i\}$$

is the transitive closure of R.

Proof. *Suppose R is a relation on a set A.*
Suppose $a, b, c \in A$, $(a,b), (b,c) \in R^{\infty}$. By the definition of R^{∞}, there exist $i, j \in \mathbb{N}$ such that $(a,b) \in R^i$ and $(b,c) \in R^j$. By the definition of relation composition and Exercise 5.7.4, $(a,c) \in R^j \circ R^i = R^{i+j}$. $R^{i+j} \subseteq R^{\infty}$ by the definition of R^{∞}. By the definition of subset, $(a,c) \in R^{\infty}$. Hence, R^{∞} is transitive by definition.
Suppose $a, b \in A$ and $(a,b) \in R$. By the definition of R^{∞} (taking $i = 1$), $(a,b) \in R^{\infty}$, and so $R \subseteq R^{\infty}$, by definition of subset.
Suppose S is a transitive relation on A and $R \subseteq S$. Further suppose $(a,b) \in R^{\infty}$. Then, by definition of R^{∞}, there exists $i \in \mathbb{N}$ such that $(a,b) \in R^i$. By Lemma 5.14, $(a,b) \in S$. Hence $R^{\infty} \subseteq S$ by definition of subset.
Therefore, R^{∞} is the transitive closure of R. $\square$