

- For each given relation $R_i \subseteq M_i^2$, determine whether it is *reflexive*, *irreflexive*, *coreflexive*, *symmetric*, *antisymmetric*, *asymmetric*, *transitive*, *antitransitive*, *semiconnex*, *connex*, *left/right Euclidean*. Provide a counterexample for each non-complying property (e.g., “transitivity does not hold for $x, y, z = (3, 1, 2)$ ”). Organize your answer in a table (e.g., columns – relations, rows – properties).
 - $M_1 = \mathbb{R}$
 $x R_1 y \leftrightarrow |x - y| \leq 1$
 - $M_2 = \mathcal{P}(\{a, b, c\})$
 $R_2 = “\subseteq”$
 - $M_3 = \{a, b, c, d\}$ $\|R_3\| = \begin{bmatrix} 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 1 \\ 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}$
 - $M_4 = \{\text{“rock”, “scissors”, “paper”}\}$
 $R_4 = \{\langle x, y \rangle \mid x \text{ beats } y\}$
- Prove (rigorously) or disprove (by providing a counterexample) the following statements about arbitrary homogeneous relations $R \subseteq M^2$ and $S \subseteq M^2$:
 - If R and S are *reflexive*, then $R \cap S$ is so.
 - If R and S are *symmetric*, then $R \cap S$ is so.
 - If R and S are *transitive*, then $R \cap S$ is so.
 - If R and S are *reflexive*, then $R \cup S$ is so.
 - If R and S are *symmetric*, then $R \cup S$ is so.
 - If R and S are *transitive*, then $R \cup S$ is so.
- An equinumerosity relation \sim over sets is defined as follows: $A \sim B \leftrightarrow |A| = |B|$.
 - Show that \sim is an equivalence relation over finite sets.
 - Show that \sim is an equivalence relation over infinite sets¹.
 - Find the quotient set of $\mathcal{P}(\{a, b, c, d\})$ by \sim .
- Let R_θ be a relation of θ -similarity (clearly, $\theta \in [0; 1] \subseteq \mathbb{R}$) of finite non-empty sets defined as follows: a set A is said to be θ -similar to B iff the Jaccard index $\text{Jac}(A, B) = \frac{|A \cap B|}{|A \cup B|}$ for these sets is at least θ , i.e. $\langle A, B \rangle \in R_\theta \leftrightarrow \text{Jac}(A, B) \geq \theta$.
 - Determine whether θ -similarity is a tolerance relation.
 - Determine whether θ -similarity is an equivalence relation.
 - Draw the graph of a relation $R_\theta \subseteq \{A_i\}^2$, where $\theta = 0.25$, $A_1 = \{1, 2, 5, 6\}$, $A_2 = \{2, 3, 4, 5, 7, 9\}$, $A_3 = \{1, 4, 5, 6\}$, $A_4 = \{3, 7, 9\}$, $A_5 = \{1, 5, 6, 8, 9\}$.
- The characteristic function f_S of a set S is defined as follows:

$$f_S(x) = \begin{cases} 1 & \text{if } x \in S \\ 0 & \text{if } x \notin S \end{cases}$$

Let A and B be finite sets. Show that for all $x \in \mathfrak{U}$:

 - $f_{\bar{A}}(x) = 1 - f_A(x)$
 - $f_{A \cap B}(x) = f_A(x) \cdot f_B(x)$
 - $f_{A \cup B}(x) = f_A(x) + f_B(x) - f_A(x) \cdot f_B(x)$
 - $f_{A \oplus B}(x) = f_A(x) + f_B(x) - 2f_A(x) \cdot f_B(x)$
- Find the error in the “proof” of the following “theorem”.

“Theorem”: Let R be a relation on a set A that is symmetric and transitive. Then R is reflexive.

“Proof”: Let $a \in A$. Take an element $b \in A$ such that $\langle a, b \rangle \in R$. Because R is symmetric, we also have $\langle b, a \rangle \in R$. Now using the transitive property, we can conclude that $\langle a, a \rangle \in R$ because $\langle a, b \rangle \in R$ and $\langle b, a \rangle \in R$.
- Give an example of a relation R on the set $\{a, b, c\}$ such that the symmetric closure of the reflexive closure of the transitive closure of R is not transitive.

¹ For infinite sets, $|A| = |B|$ means there is a bijection between A and B .

8. Prove or disprove the following statements about the functions f and g :
 - (a) If f and g are injections, then $g \circ f$ is also an injection.
 - (b) If f and g are surjections, then $g \circ f$ is also a surjection.
 - (c) If f and $f \circ g$ are injections, then g is also an injection.
 - (d) If f and $f \circ g$ are surjections, then g is also a surjection.
9. Let $H = \{1, 2, 4, 5, 10, 12, 20\}$. Consider a divisibility relation $R \subseteq H^2$ defined as follows: $xRy \leftrightarrow y : x$.
 - (a) Sort R (as a set of pairs) lexicographically².
 - (b) Show that R is a partial order.
 - (c) Determine whether R is a linear (total) order.
 - (d) Draw the Hasse diagram for a graded poset $\langle H, R, \rho \rangle$, where $\rho : H \rightarrow \mathbb{N}_0$ is a grading function which maps a number $n \in H$ to the sum of all exponents appearing in its prime factorization, e.g., $\rho(20) = \rho(2^2 \cdot 5^1) = 2 + 1 = 3$, so the number 20 would have the 3rd rank (bottom-up).
 - (e) Find the minimal, minimum (least), maximal and maximum (greatest) elements in the poset $\langle H, R \rangle$. If there are multiple or none, explain why.
 - (f) Perform a topological sort⁴ of the poset $\langle H, R \rangle$.
10. Prove that the transitive closure R^+ is in fact transitive.

Definition. $R^+ = \bigcup_{n \in \mathbb{N}^+} R^n$ is a transitive closure of $R \subseteq M^2$, where

 - * $R^{k+1} = R^k \circ R$ is a compositional (functional) power³,
 - * $R^1 = R$,
 - * $S \circ R = \{\langle x, y \rangle \mid \exists z : (x R z) \wedge (z S y)\}$ is a composition (relative product) of relations R and S .
11. Prove that a set S is infinite if and only if there is a proper subset $A \subset S$ such that there is a one-to-one correspondence (bijection) between A and S .
12. Given a set S and two partitions P_1 and P_2 of S , we define the relation $P_1 \leq P_2$ as follows: partition P_1 is considered a *refinement* of the partition P_2 if every set in P_1 is a subset of one of the sets in P_2 . Show that the set of all partitions of a set S with the refinement relation \leq is a lattice.

² Lexicographic order for pairs: $\langle a, b \rangle \leq \langle a', b' \rangle \leftrightarrow (a < a') \vee ((a = a') \wedge (b \leq b'))$

³ Note: this is *not* a Cartesian power, despite of the same notation R^n . Another possible notation for compositional power is $R^{\circ n}$, but it is too wild to use it here.