Relations

Written by Rachel Singh, last updated Oct 1, 2018

About

Let's look at properties of relations, as well as Order Relations. Next time, we will look at Equivalence Relations.

Topics

1. Binary Relations
2. Order Relations
3. Properties of Relations
4. Partial and Total Order
5. More Practice

Binary Relations

2. Binary Relations

"In mathematics, a binary relation on a set A is a collection of ordered pairs of elements of A. In other words, it is a subset of the Cartesian product $A^2 = A \times A$.

More generally, a binary relation between two sets A and B is a subset of A × B."

From https://en.wikipedia.org/wiki/Binary_relation

In other words, a binary relation $R : A \rightarrow B$ has a **subset of** the **cartesian product A x B** as its **rule**.

Notes

Domain: Set of all possible inputs

Codomain: Set of all possible outputs.

$f : A \rightarrow B$
function f, with input from set A, & output from set B.

$R : A \rightarrow B$
A relation *R* has a subset of *A x B* as its rule.

2. Binary Relations

Let's say we have
A = { 1, 2 }   and   B = { a, b, c },
and a relation R : A → B

The Rule can be the entirety of A x B:

$$\{ (1, a), (1, b), (1, c), (2, a), (2, b), (2, c) \}$$

Or it can just be a **subset** of A x B:

$$\{ (1, a), (1, c), (2, b) \}$$

And this would fit the definition of a binary relation.

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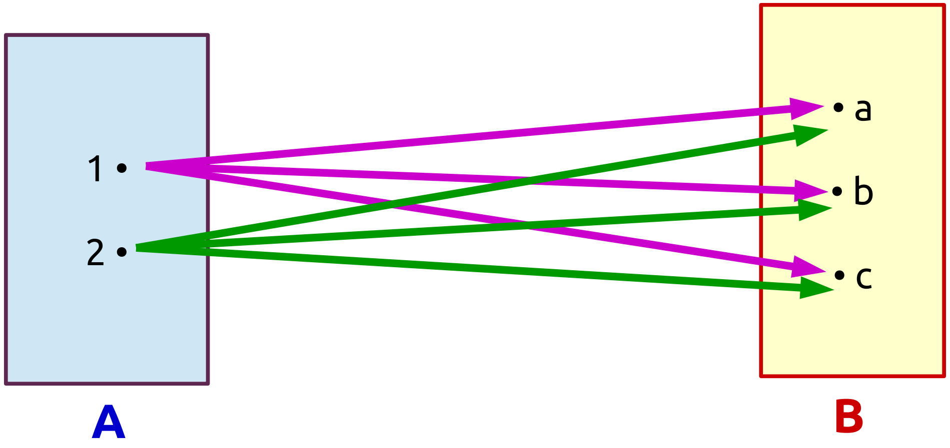
2. Binary Relations

A = { 1, 2 } and B = { a, b, c }, R : A → B

If the rule is all of A x B,
{ (1, a), (1, b), (1, c), (2, a), (2, b), (2, c) },
it the relation will look like this:



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$f : A \to B$
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$R : A \to B$
A relation *R* has a subset of *A x B* as its rule.

2. Binary Relations

Practice: Given A = { 1, 2 }, B = { a, b, c }, and the relation S with the rule: { (1, a), (2, b), (1, c) }, diagram the relation.

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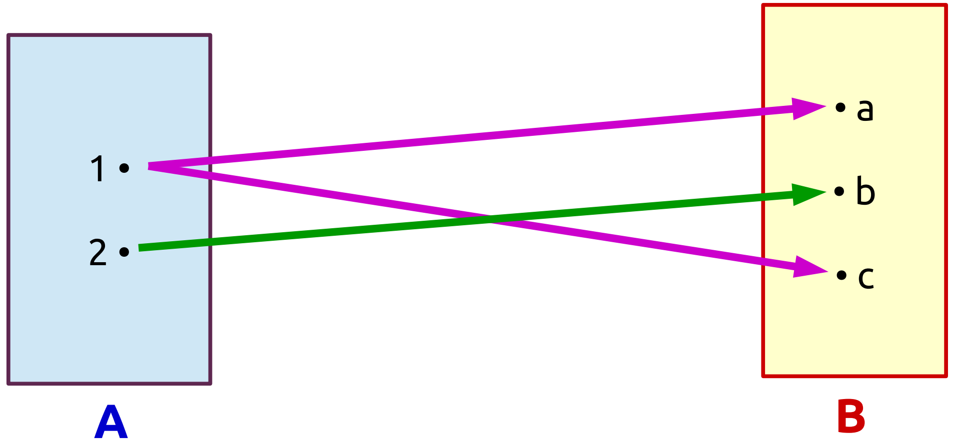

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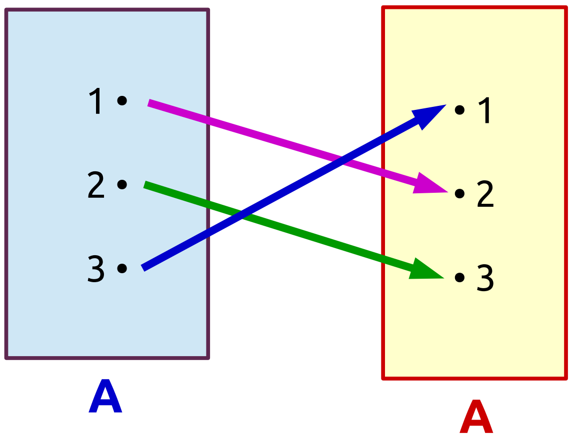
2. Binary Relations

If a binary relation has the same set as the domain and codomain, we can diagram it with the arrow diagram…



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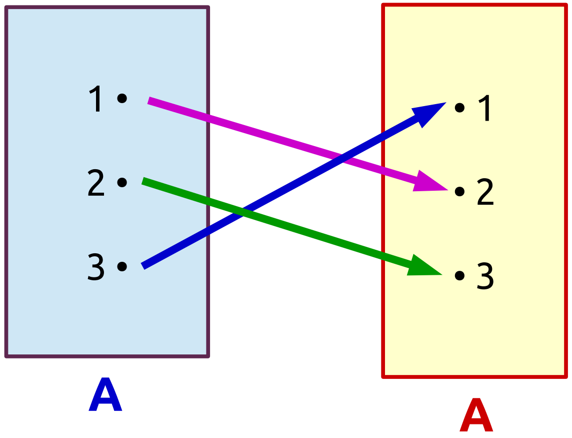
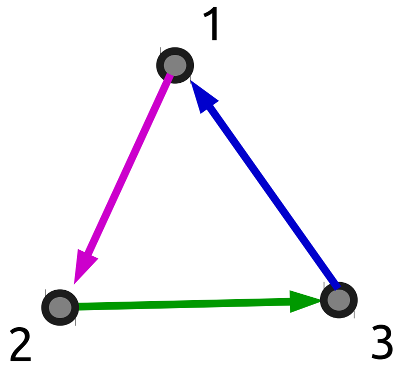


Or with a graph like this:



Diagramming like this will come in handy later with more complex relations.

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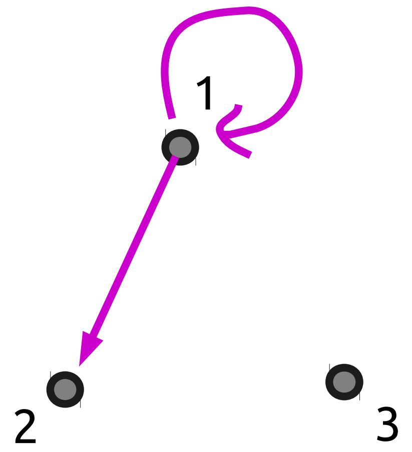
2. Binary Relations

Practice: Finish drawing the diagram for the following relation.

$A = \{ 1, 2, 3 \}$

$R : A \to A$

Rule: $\{ (1,1), (1,2), (1,3), (2,3), (3,2) \}$



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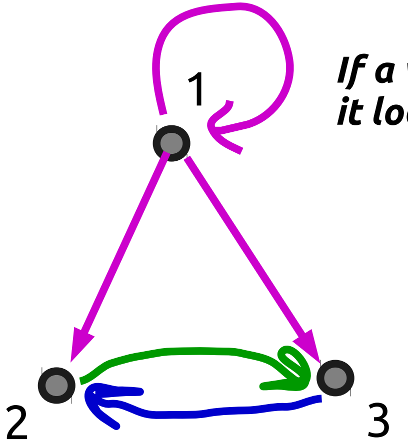


If a value points to itself, it looks like a loop.

Notes

Domain: Set of all possible inputs

Codomain: Set of all possible outputs.

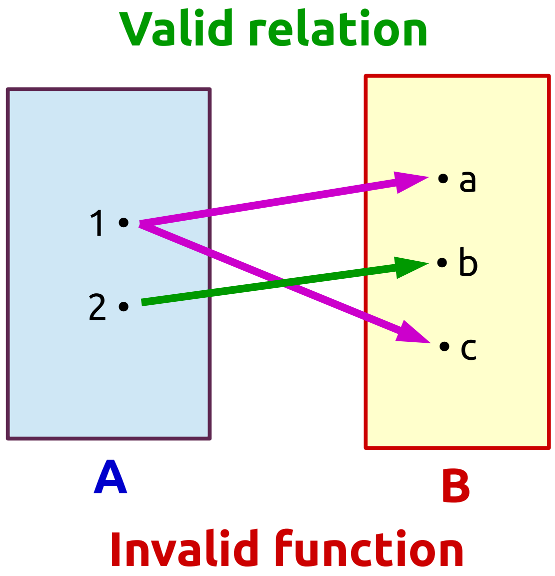
f : *A* → *B*
function f, with input from set A, & output from set B.

R : *A* → *B*
A relation *R* has a subset of *A* x *B* as its rule.

2. Binary Relations

Remember that a function must map each value from the set A to one and only one value from the set B.

A relation doesn't have this restriction.



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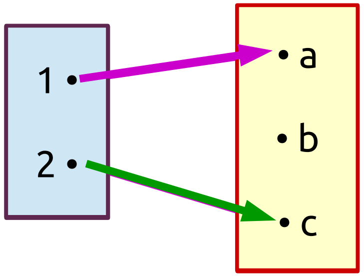
Practice: Identify whether the following relations are also functions.

1



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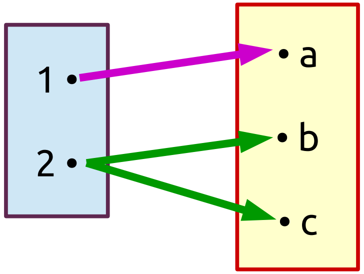
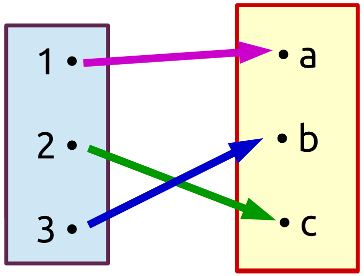


3



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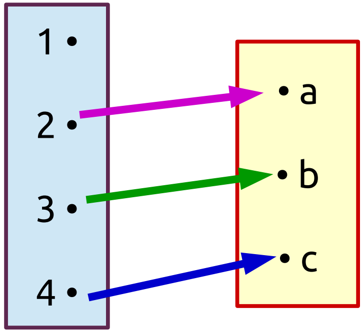

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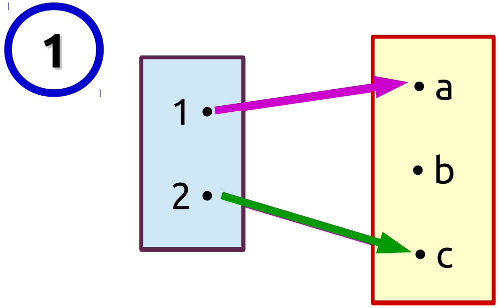
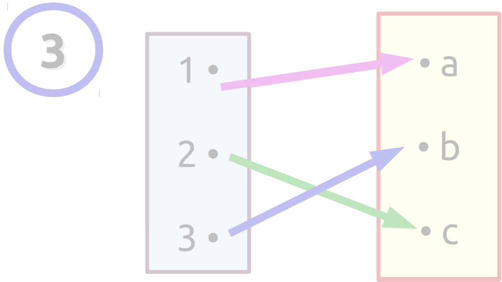
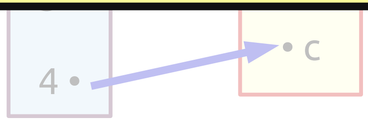


This is a valid function; each input from A maps to one and only one output in B.

It is OK that the output "b" doesn't have anything mapped to it.





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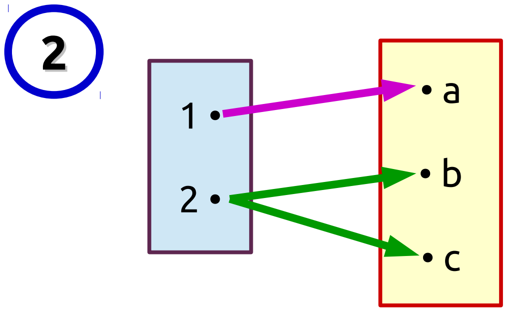
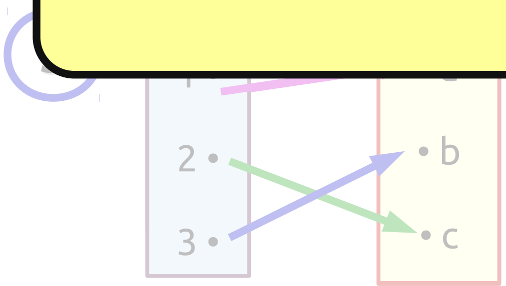
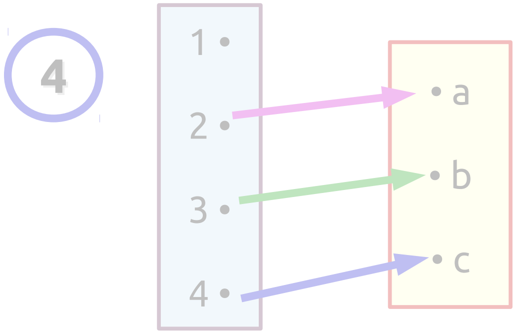
2. Binary Relations

Practice: Identify whether the following relations are also functions.

This is not a function because the input value “2” maps to two different outputs, “b” and “c”.







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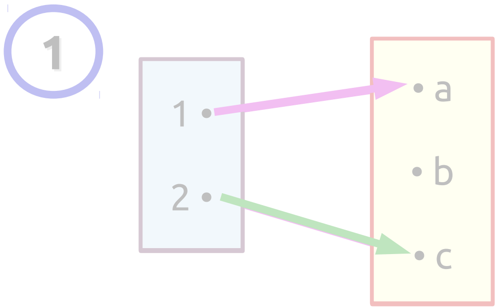

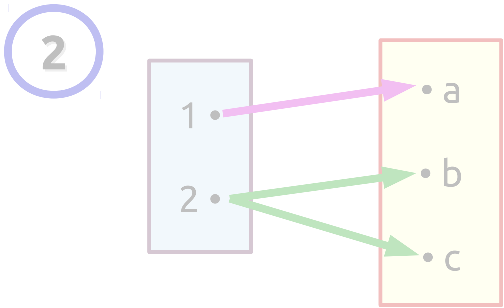

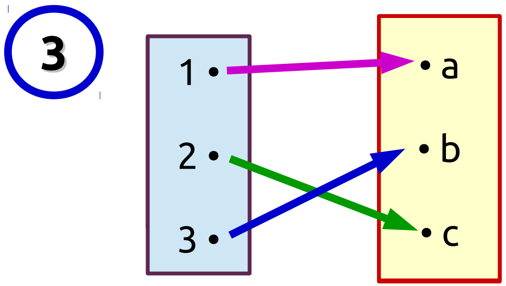

This is a valid function.

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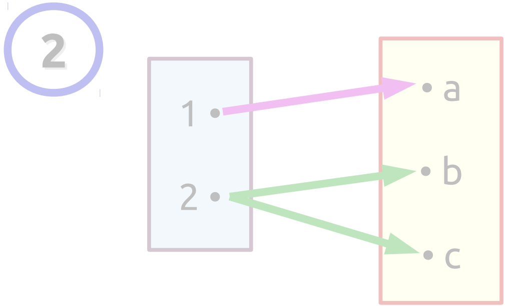
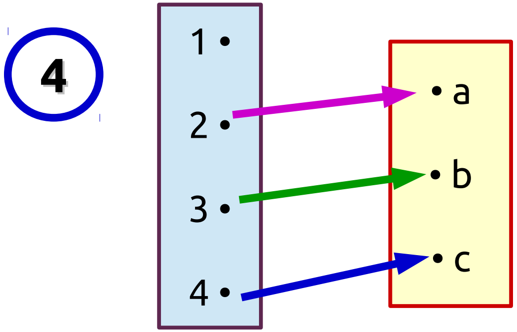
2. Binary Relations

Practice: Identify whether the following relations are also functions.

This is not a valid function because the input value “1” is not being mapped to anything.

While there can be elements in the codomain not mapped *to*, everything in the domain must be mapped *to something*.





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Order Relations

2. Order Relations

An **Order Relation** is a Relation that specifies the *order* in the relation; i.e., being bigger, smaller, etc.

Notes

A **binary relation** has some set A as its domain and codomain, and the rule is some subset (or equal to) the cartesian product AxA.

Example: A = { 1, 2, 3 },
Relation R on set A, with the rule
"(x, y)" in R if $x > y$"

This means we plug in two values from A as x and y inputs, and the output is
"the relation exists" if $x > y$, or
"the relation doesn't exist" if $x <= y$.

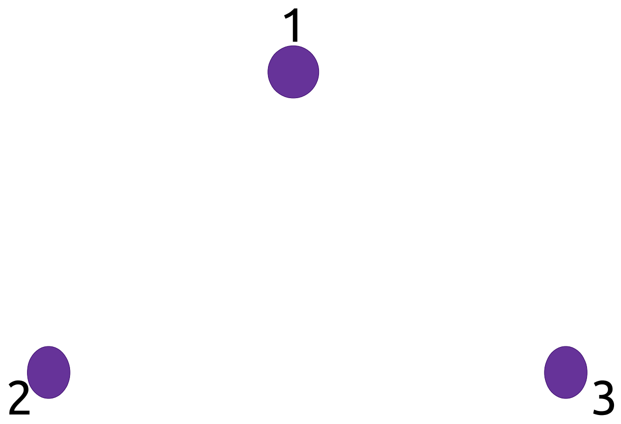
Notes

A **binary relation** has some set A as its domain and codomain, and the rule is some subset (or equal to) the cartesian product AxA.

Example: A = { 1, 2, 3 },
Relation R on set A, with the rule
"(x, y)" in R if x > y"

First, let's plug in (1,1).

1 > 1 is false,
so no relation line is drawn.



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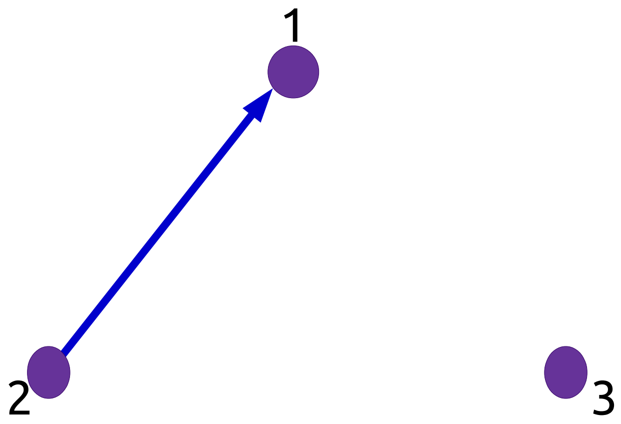
Next, let's do (2, 1).

2 > 1 is true, so we draw a directional arrow between these nodes from x to y.



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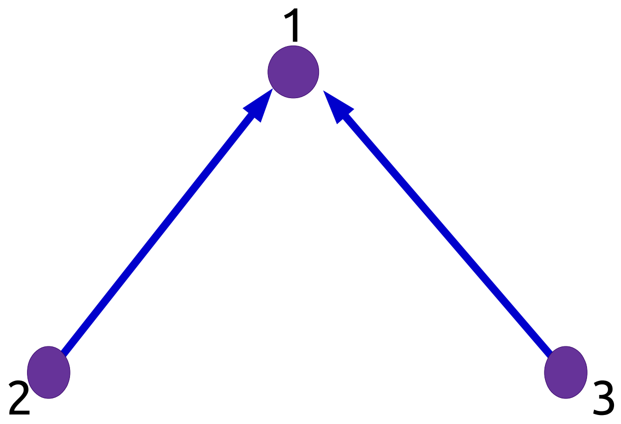
Then for (3, 1).

3 > 1 is true, so we draw another arrow from x to y.



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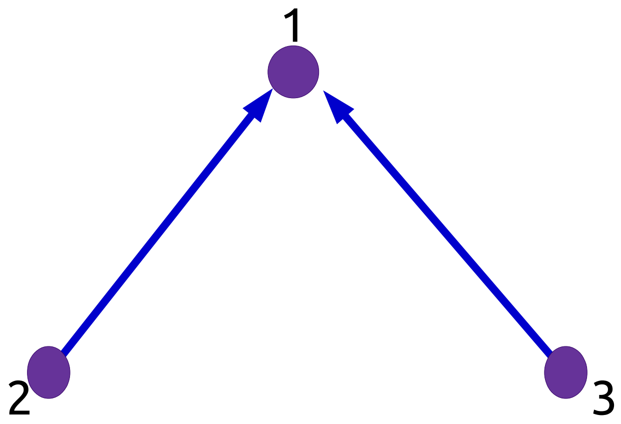
Example: A = { 1, 2, 3 },
Relation R on set A, with the rule "(x, y)" in R if x > y"

And we keep checking for every element from AxA…



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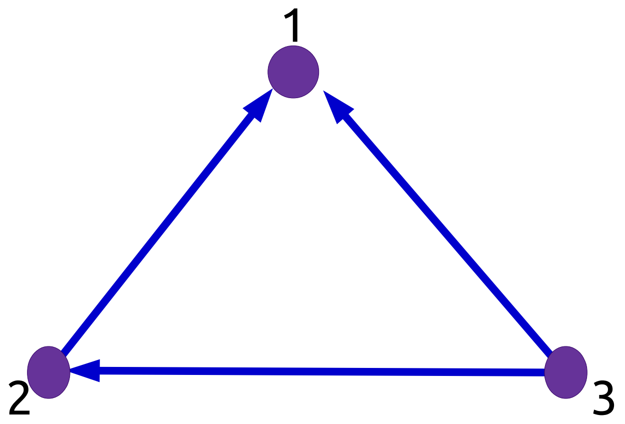
2. Order Relations

Example: A = { 1, 2, 3 },
Relation R on set A, with the rule
"(x, y)" in R if x > y"

	1	2	3
1	(1,1) false	(1,2) false	(1,3) false
2	(2,1) true	(2,2) false	(2,3) false
3	(3,1) true	(3,2) true	(3,3) false



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A **binary relation** has some set A as its domain and codomain, and the rule is some subset (or equal to) the cartesian product AxA.

Practice: Draw the arrow diagram for the relation R on the set {1, 2, 3} with the rule “(x,y) ∈ R if the product of x and y is even”.

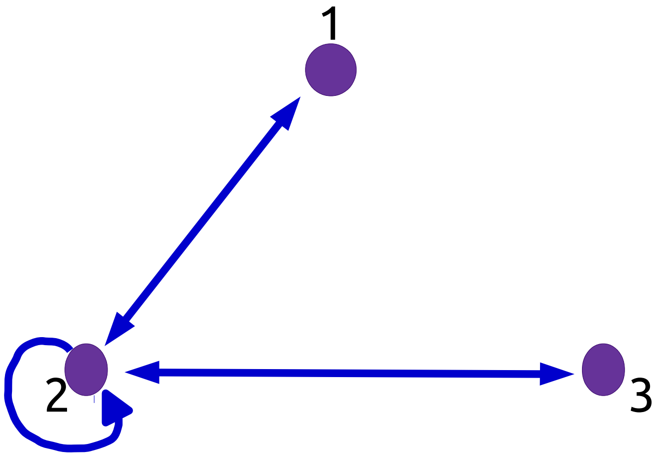
Notes

A **binary relation** has some set A as its domain and codomain, and the rule is some subset (or equal to) the cartesian product AxA.

2. Order Relations

Practice: Draw the arrow diagram for the relation R on the set {1, 2, 3} with the rule "(x,y) ∈ R if the product of x and y is even".

	1	2	3
1	(1,1) 1x1 = 1 false	(1,2) 1x2 = 2 true	(1,3) 1x3 = 3 false
2	(2,1) 2x1 = 2 true	(2,2) 2x2 = 4 true	(2,3) 2x3 = 6 true
3	(3,1) 3x1 = 3 false	(3,2) 3x2 = 6 true	(3,3) 3x3 = 9 false



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A **binary relation** has some set A as its domain and codomain, and the rule is some subset (or equal to) the cartesian product AxA.

Practice: Draw the arrow diagram for the relation R on the set $\wp(\{1,2\})$ with the rule "(x,y) ∈ R if the product of x ⊆ y".

Hint: Remember that the power set of {1, 2} is:

$$\{ \emptyset, \{1\}, \{2\}, \{1,2\} \}$$

And x ⊆ y is "x is a subset, or equal to, y"

Notes

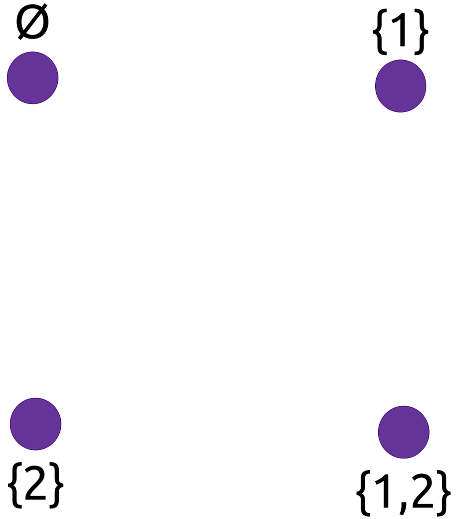
A **binary relation** has some set A as its domain and codomain, and the rule is some subset (or equal to) the cartesian product AxA.

2. Order Relations

Practice: Draw the arrow diagram for the relation R on the set $\wp(\{1,2\})$ with the rule "(x,y) ∈ R if the product of $x \subseteq y$".

Here are the nodes for this graph.

Also, Ø is considered a subset of each of the other sets.



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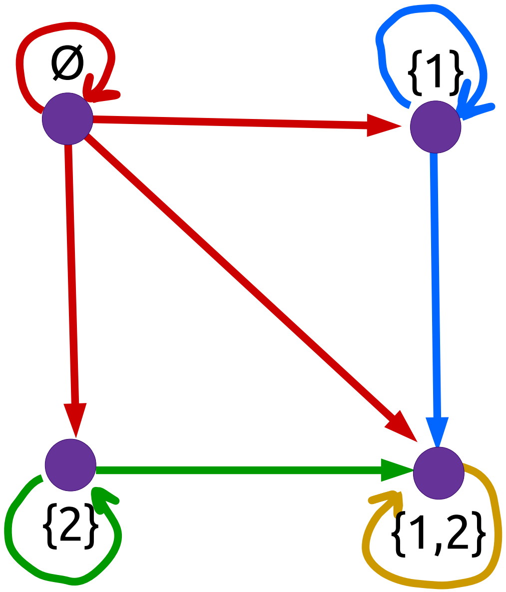
Practice: Draw the arrow diagram for the relation R on the set $\wp(\{1,2\})$ with the rule "(x,y) ∈ R if the product of x ⊆ y".

For this graph, the arrows each point in one direction when going between two different sets.

Note that every set is also ⊆ (subset or equal to) itself.



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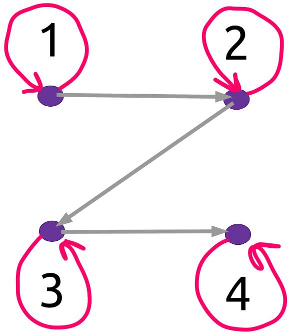
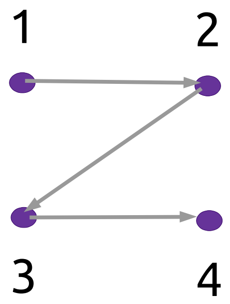
Properties of Relations

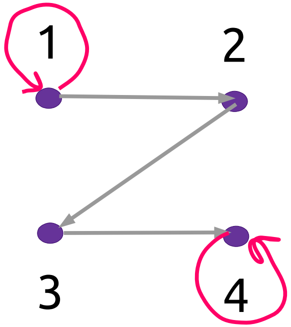
3. Properties of Relations



Reflexive: A relation is reflexive if, for all inputs *a*, (a,a) ∈ R.
Graphically, each node has a loop.

Irreflexive: A relation is irreflexive if, for all inputs *a*, (a,a) ∉ R.
Graphically, <u>no</u> nodes have a loop.





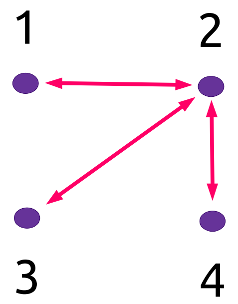
Neither: If there's a mix of loops and no loops, it is neither.

Notes

Reflexive:
(a,a) ∈ R for all inputs

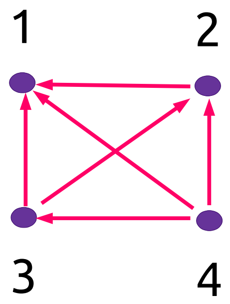
Irreflexive:
(a,a) ∉ R for all inputs

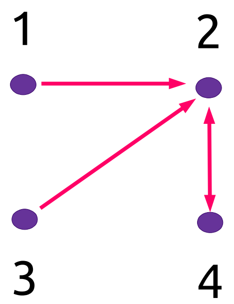
3. Properties of Relations



Symmetric: A relation is symmetric if for all inputs *a, b* ∈ A, if a ≠ b, and (a, b) ∈ R, and (b, a) ∈ R.
Graphically, each arrow goes both directions.

Antisymmetric: A relation is antisymmetric if for all inputs *a, b* ∈ A, if a ≠ b, and (a, b) ∈ R, then (b, a) ∉ R.
Graphically, every arrow goes only one direction.





Neither: There's a mix of one-sided and two-sided arrows.

Notes

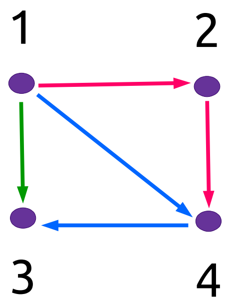
Reflexive:
(a,a) ∈ R for all inputs

Irreflexive:
(a,a) ∉ R for all inputs

Symmetric:
(a,b) ∈ R and (b,a) ∈ R for all inputs where a ≠ b

Antisymmetric:
(a,b) ∈ R and (b,a) ∉ R for all inputs where a ≠ b

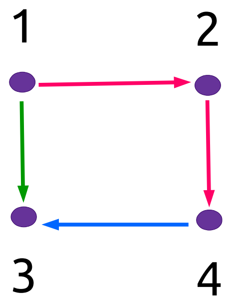
3. Properties of Relations



Transitive: A relation is transitive if, whenever you have (a,b)∈R and (b,c)∈R, you also have (a,c)∈R.
Graphically, if you can go from a to b, and from b to c, then you can go directly from a to b.

*Note: If there is no path a → b → c, then this does not invalidate whether it is transitive. A graph can still be classified as such.

Intransitive: A relation is intransitive if it is not transitive.



Notes

Reflexive:
(a,a) ∈ R for all inputs

Irreflexive:
(a,a) ∉ R for all inputs

Symmetric:
(a,b) ∈ R and (b,a) ∈ R for all inputs where a ≠ b

Antisymmetric:
(a,b) ∈ R and (b,a) ∉ R for all inputs where a ≠ b

Transitive:
If (a,b) ∈ R and (b,c) ∈ R, then (a, c) ∈ R.

3. Properties of Relations

Practice: Identify whether the following relation is

- Reflexive, irreflexive, or neither
- Symmetric, antisymmetric, or neither
- Transitive or intransitive

R = { (a,b) ∈ AxA : (1,1), (1,2), (1,4), (1,8), (2,2), (2,4), (2,8), (3,3), (3,6), (4,4), (4,8), (5,5), (6,6), (7,7), (8,8) }
With A = { 1, 2, 3, 4, 5, 6, 7, 8 }

Notes

Reflexive:
(a,a) ∈ R for all inputs

Irreflexive:
(a,a) ∉ R for all inputs

Symmetric:
(a,b) ∈ R and (b,a) ∈ R
for all inputs where a ≠ b

Antisymmetric:
(a,b) ∈ R and (b,a) ∉ R
for all inputs where a ≠ b

Transitive:
If (a,b) ∈ R and (b,c) ∈ R,
then (a, c) ∈ R.

3. Properties of Relations

Practice: Identify whether the following relation is
- Reflexive, irreflexive, or neither
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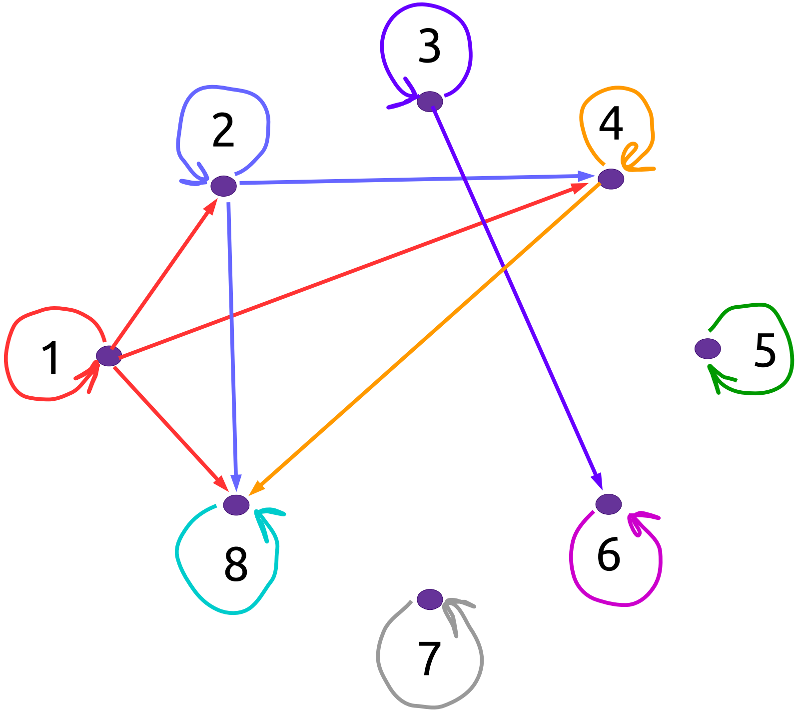
R = { (a,b) ∈ AxA :
(1,1), (1,2), (1,4), (1,8),
(2,2), (2,4), (2,8), (3,3),
(3,6), (4,4), (4,8), (5,5),
(6,6), (7,7), (8,8) }
With A = { 1, 2, 3, 4, 5, 6, 7, 8 }



Reflexive,
Antisymmetric,
Transitive

Notes

Reflexive:
(a,a) ∈ R for all inputs

Irreflexive:
(a,a) ∉ R for all inputs

Symmetric:
(a,b) ∈ R and (b,a) ∈ R for all inputs where a ≠ b

Antisymmetric:
(a,b) ∈ R and (b,a) ∉ R for all inputs where a ≠ b

Transitive:
If (a,b) ∈ R and (b,c) ∈ R, then (a, c) ∈ R.

3. Properties of Relations

Practice: Identify whether the following relation is

- Reflexive, irreflexive, or neither
- Symmetric, antisymmetric, or neither
- Transitive or intransitive

R = { (a,b) ∈ AxA : a + b is even,
With A = { 1, 2, 3, 4, 5, 6, 7, 8 }

Notes

Reflexive:
(a,a) ∈ R for all inputs

Irreflexive:
(a,a) ∉ R for all inputs

Symmetric:
(a,b) ∈ R and (b,a) ∈ R
for all inputs where a ≠ b

Antisymmetric:
(a,b) ∈ R and (b,a) ∉ R
for all inputs where a ≠ b

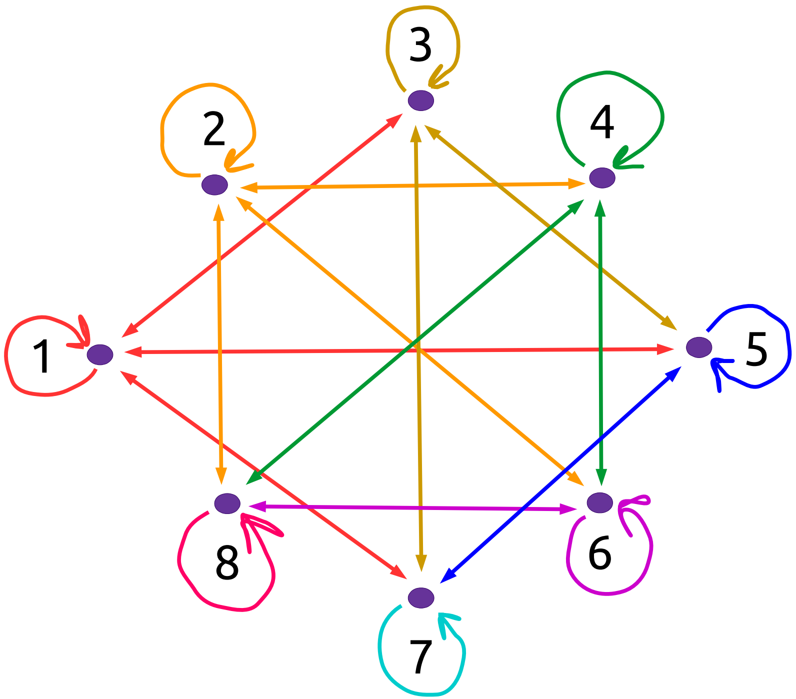
Transitive:
If (a,b) ∈ R and (b,c) ∈ R,
then (a, c) ∈ R.

3. Properties of Relations

Practice: Identify whether the following relation is
- Reflexive, irreflexive, or neither
- Symmetric, antisymmetric, or neither
- Transitive or intransitive

R = { (a,b) ∈ AxA : a + b is even,
With A = { 1, 2, 3, 4, 5, 6, 7, 8 }

Reflexive,
Symmetric,
Transitive



{ (1,1), (1,3), (1,5), (1,7), (3,1), (3,3), (3,5), (3,7), (5,1), (5,3), (5,5), (5,7), (7,1), (7,3), (7,5), (7,7),

(2,2), (2,4), (2,6), (2,8), (4,2), (4,4), (4,6), (4,8), (6,2), (6,4), (6,6), (6,8), (8,2), (8,4), (8,6), (8,8) }

Notes

Reflexive:
(a,a) ∈ R for all inputs

Irreflexive:
(a,a) ∉ R for all inputs

Symmetric:
(a,b) ∈ R and (b,a) ∈ R
for all inputs where a ≠ b

Antisymmetric:
(a,b) ∈ R and (b,a) ∉ R
for all inputs where a ≠ b

Transitive:
If (a,b) ∈ R and (b,c) ∈ R,
then (a, c) ∈ R.

Partial and Total Order

4. Properties of Relations

Partial order: A relation *R* on a set *A* is called a partial order on *A* if *R* is antisymmetric, transitive, and reflexive.
From Discrete Mathematics, Ensley & Crawley, page 302

Strict partial order: A relation *R* on *A* is a strict partial ordering if it is antisymmetric, transitive, and irreflexive.
From Discrete Mathematics, Ensley & Crawley, page 308

Total order: *R* is a total ordering on *A* if *R* is a reflexive, transitive, and antisymmetric relation on *A* that also satisfies the property: For all a, b ∈ A, if a ≠ b, either (a, b) ∈ R or (b, a) ∈ R.

Strict total ordering: If *R* is antisymmetric, transitive, and irreflexive and satisfies the property of the total order form.
From Discrete Mathematics, Ensley & Crawley, page 309

Notes

Reflexive:
(a,a) ∈ R for all inputs

Irreflexive:
(a,a) ∉ R for all inputs

Symmetric:
(a,b) ∈ R and (b,a) ∈ R for all inputs where a ≠ b

Antisymmetric:
(a,b) ∈ R and (b,a) ∉ R for all inputs where a ≠ b

Transitive:
If (a,b) ∈ R and (b,c) ∈ R, then (a, c) ∈ R.

7. More practice

5. More practice

Practice: Diagram the relation R : A → B
Where A = $\wp(\{1,2,3\})$
and B = { 0, 1, 2, 3 }
With the rule (x, y) ∈ R if n(x) = y.

Hints: First, A is the power-set of { 1, 2, 3 }. This means, expanded out, all its elements are:

{ {}, {1}, {2}, {3}, {1, 2}, {1, 3}, {2, 3}, {1, 2, 3} }

Notes

Domain: Set of all possible inputs

Codomain: Set of all possible outputs.

$f : A \to B$
function f, with input from set A, & output from set B.

$R : A \to B$
A relation *R* has a subset of *A x B* as its rule.

5. More practice

Practice: Diagram the relation R : A → B

Where A = $\wp(\{1,2,3\})$ = { {}, {1}, {2}, {3}, {1, 2}, {1, 3}, {2, 3}, {1, 2, 3} }

and B = { 0, 1, 2, 3 }

With the rule (x, y) ∈ R if n(x) = y.

Hints: Second, the rule (x, y) ∈ R if n(x) = y means that the relation exists if n(x) (the size of the input set x) matches the y value.

Notes

Domain: Set of all possible inputs

Codomain: Set of all possible outputs.

$f : A \to B$
function f, with input from set A, & output from set B.

$R : A \to B$
A relation *R* has a subset of *A* x *B* as its rule.

5. More practice

Practice: Diagram the relation R : A → B

Where A = $\wp(\{1, 2, 3\})$ = { {}, {1}, {2}, {3}, {1, 2}, {1, 3}, {2, 3}, {1, 2, 3} }

and B = { 0, 1, 2, 3 }

With the rule (x, y) ∈ R if n(x) = y.

Hints: Second, the rule (x, y) ∈ R if n(x) = y means that the relation exists if n(x) (the size of the input set x) matches the y value.

If we choose some arbitrary input value x from the set A, we will have a set like {1}, or {1, 3}, or {1, 2, 3}.

Notes

Domain: Set of all possible inputs

Codomain: Set of all possible outputs.

$f : A \to B$
function f, with input from set A, & output from set B.

$R : A \to B$
A relation *R* has a subset of *A* x *B* as its rule.

5. More practice

Practice: Diagram the relation R : A → B

Where A = $\wp(\{1, 2, 3\})$ = { {}, {1}, {2}, {3}, {1, 2}, {1, 3}, {2, 3}, {1, 2, 3} }

and B = { 0, 1, 2, 3 }

With the rule (x, y) ∈ R if n(x) = y.

Hints: Second, the rule (x, y) ∈ R if n(x) = y means that the relation exists if n(x) (the size of the input set x) matches the y value.

The relationship between the value x and some output y exists if n(x) = y.

Notes

Domain: Set of all possible inputs

Codomain: Set of all possible outputs.

$f : A \to B$
function f, with input from set A, & output from set B.

$R : A \to B$
A relation *R* has a subset of *A* x *B* as its rule.

5. More practice

Practice: Diagram the relation R : A → B

Where A = $\wp(\{1,2,3\})$ = { {}, {1}, {2}, {3}, {1, 2}, {1, 3}, {2, 3}, {1, 2, 3} }

and B = { 0, 1, 2, 3 }

With the rule (x, y) ∈ R if n(x) = y.

Hints: Second, the rule (x, y) ∈ R if n(x) = y means that the relation exists if n(x) (the size of the input set x) matches the y value.

So if we choose the input x = {1, 3}, it has a relationship with the output y = 2.

The size of n({1, 3}) is 2.

Notes

Domain: Set of all possible inputs

Codomain: Set of all possible outputs.

$f : A \to B$
function f, with input from set A, & output from set B.

$R : A \to B$
A relation *R* has a subset of *A* x *B* as its rule.

5. More practice

Practice: Diagram the relation R : A → B
Where A = $\wp(\{1,2,3\})$ = { {}, {1}, {2}, {3}, {1, 2}, {1, 3}, {2, 3}, {1, 2, 3} }
and B = { 0, 1, 2, 3 }
With the rule (x, y) ∈ R if n(x) = y.

Hints: Second, the rule (x, y) ∈ R if n(x) = y means that the relation exists if n(x) (the size of the input set x) matches the y value.

So if we choose the input x = {1, 3}, it has a relationship with the output y = 2.

The size of n({1, 3}) is 2.

Notes

Domain: Set of all possible inputs

Codomain: Set of all possible outputs.

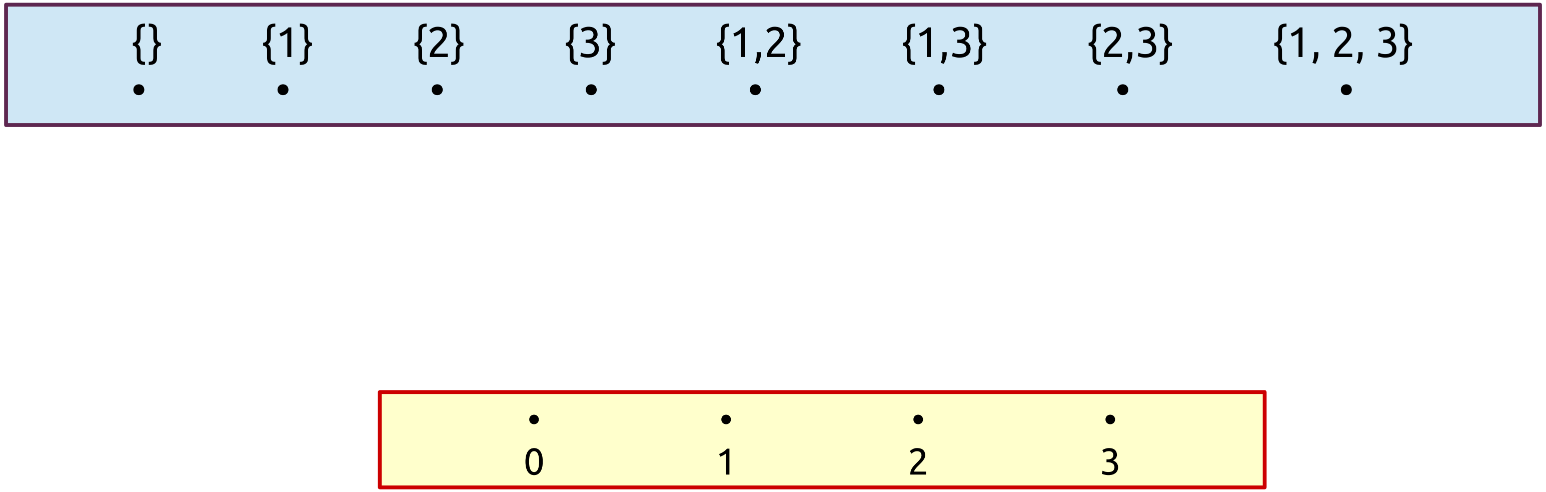
$f : A \rightarrow B$
function f, with input from set A, & output from set B.

$R : A \rightarrow B$
A relation *R* has a subset of *A* x *B* as its rule.

5. More practice

Practice: Diagram the relation R : A → B
Where A = $\wp(\{1,2,3\})$ = { {}, {1}, {2}, {3}, {1, 2}, {1, 3}, {2, 3}, {1, 2, 3} }
and B = { 0, 1, 2, 3 }
With the rule (x, y) ∈ R if n(x) = y.

So, given this information, try to finish this diagram:



Notes

Domain: Set of all possible inputs

Codomain: Set of all possible outputs.

$f : A \to B$
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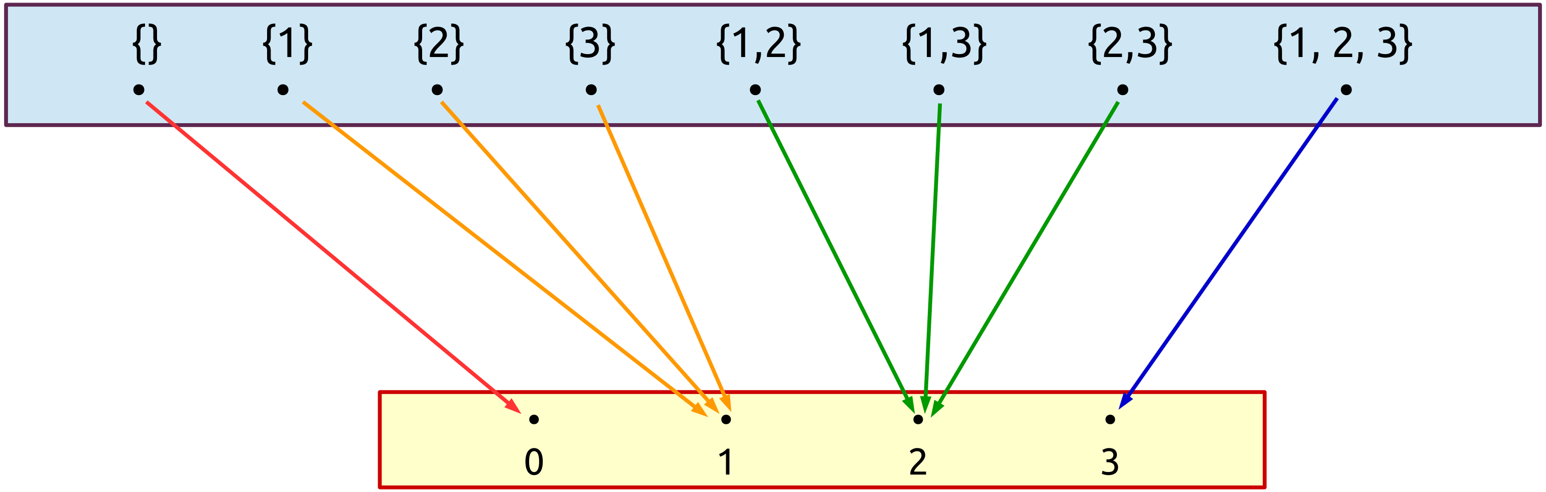
$R : A \to B$
A relation *R* has a subset of *A x B* as its rule.

5. More practice

Practice: Diagram the relation R : A → B
Where A = $\wp(\{1, 2, 3\})$ = { {}, {1}, {2}, {3}, {1, 2}, {1, 3}, {2, 3}, {1, 2, 3} }
and B = { 0, 1, 2, 3 }
With the rule (x, y) ∈ R if n(x) = y.

So, given this information, try to finish this diagram:



Notes

Domain: Set of all possible inputs

Codomain: Set of all possible outputs.

$f : A \to B$
function f, with input from set A, & output from set B.

$R : A \to B$
A relation *R* has a subset of *A x B* as its rule.

5. More practice

Practice: Diagram the relation R : A → A
Where A = { 1, 2, 3, 4, 5, 6 }
With the rule (x, y) ∈ R if x – y is a positive even integer.

Notes

Domain: Set of all possible inputs

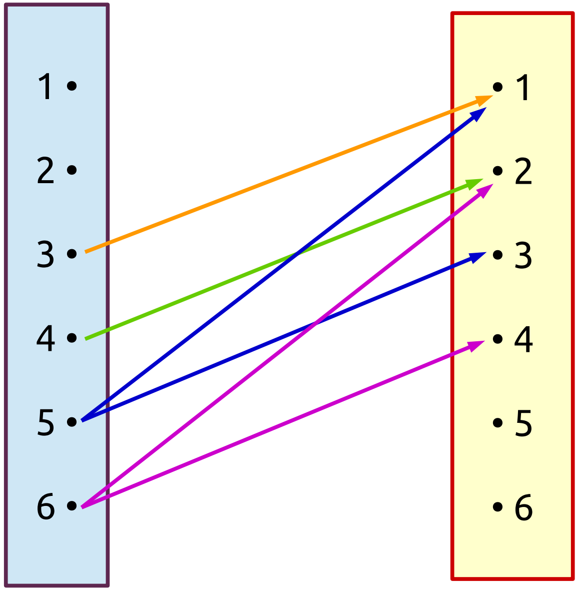
Codomain: Set of all possible outputs.

$f : A \rightarrow B$
function f, with input from set A, & output from set B.

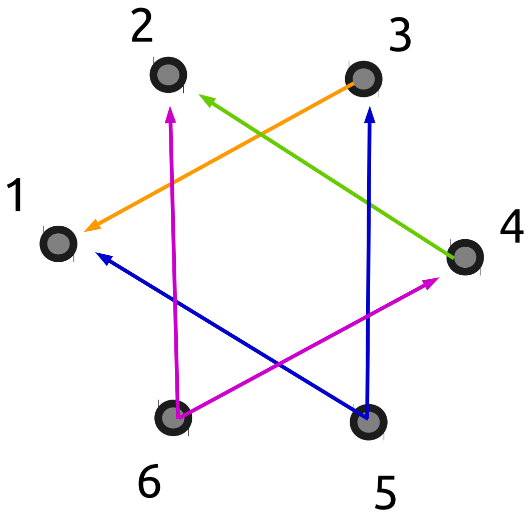
$R : A \rightarrow B$
A relation *R* has a subset of *A x B* as its rule.

5. More practice

Practice: Diagram the relation R : A → A
Where A = { 1, 2, 3, 4, 5, 6 }
With the rule (x, y) ∈ R if x – y is a positive even integer.



OR



Notes

Domain: Set of all possible inputs

Codomain: Set of all possible outputs.

f : A → B
function f, with input from set A, & output from set B.

R : A → B
A relation *R* has a subset of *A x B* as its rule.

Conclusion

This time we covered Order Relations. Next time we will talk about Equivalence Relations, where we are identifying whether two inputs are "equivalent" or "the same".