Background material

Relations

- A relation over a set S is a set $R \subseteq S \times S$
  - We write a R b for $(a,b) \in R$
- A relation R is:
  - reflexive iff

    $\forall\, a \in S \,.\, a\ R\ a$
  - transitive iff

    $\forall\, a \in S, b \in S, c \in S \,.\, a\ R\ b \wedge b\ R\ c \Rightarrow a\ R\ c$
  - symmetric iff

    $\forall\, a, b \in S \,.\, a\ R\ b \Rightarrow b\ R\ a$
  - anti-symmetric iff

    $\forall\, a, b, \in S \,.\, a\ R\ b \Rightarrow \neg(b\ R\ a)$

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    $\forall\, a, b, \in S \,.\, a \; R \; b \wedge b \; R \; a \Rightarrow a = b$

Partial orders

- An equivalence class is a relation that is:

- A partial order is a relation that is:

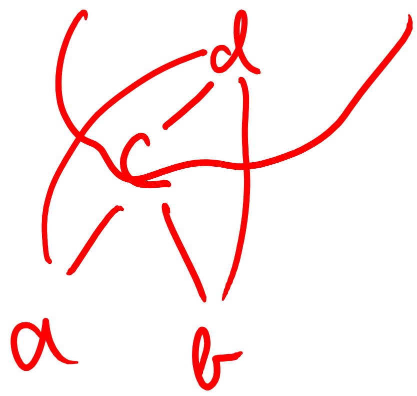
Partial orders

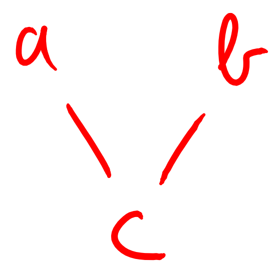
- An equivalence class is a relation that is:
  - reflexive, transitive, symmetric
- A partial order is a relation that is:
  - reflexive, transitive, anti-symmetric
- A partially ordered set (a poset) is a pair $(S, \leq)$ of a set S and a partial order $\leq$ over the set
- Examples of posets: $(2^S, \subseteq)$, $(Z, \leq)$, (Z, divides)

$\wp(S)$

Lub and glb

- Given a poset $(S, \leq)$, and two elements $a \in S$ and $b \in S$, then the:
  - least upper bound (lub) is an element c such that
    ub $\boxed{a \leq c, b \leq c}$, and $\forall\, d \in S\ .\ (a \leq d \wedge b \leq d) \Rightarrow c \leq d$
  - greatest lower bound (glb) is an element c such that $c \leq a$, $c \leq b$, and $\forall\, d \in S\ .\ (d \leq a \wedge d \leq b) \Rightarrow d \leq c$





Lub and glb

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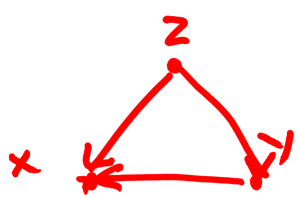
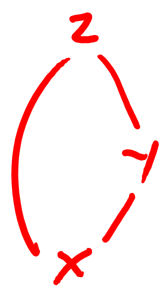
- lub and glb don't always exists:





Lub and glb

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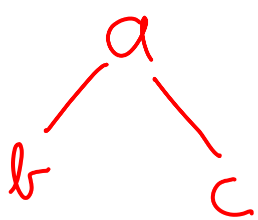


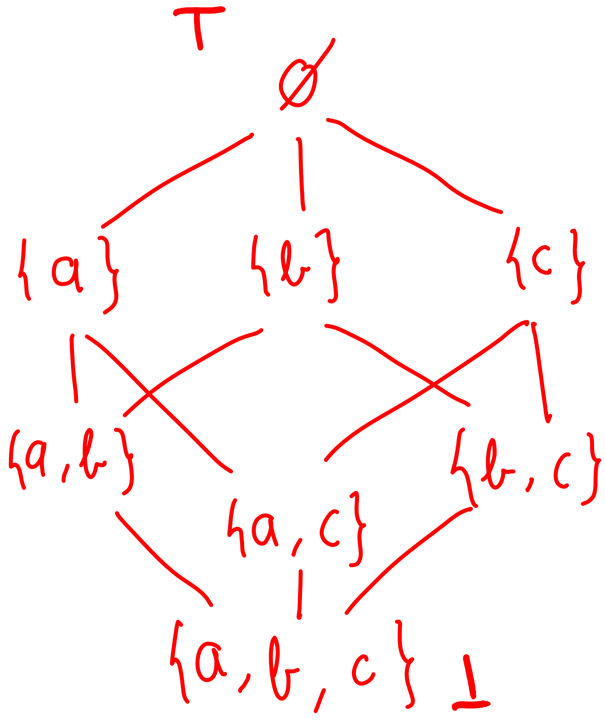
glb of b & c ?

Lattices

- A lattice is a tuple $(S, \sqsubseteq, \bot, \top, \sqcup, \sqcap)$ such that:
  - $(S, \sqsubseteq)$ is a poset
  - $\forall a \in S \,.\, \bot \sqsubseteq a$
  - $\forall a \in S \,.\, a \sqsubseteq \top$
  - Every two elements from S have a lub and a glb
  - $\sqcup$ is the least upper bound operator, called a join
  - $\sqcap$ is the greatest lower bound operator, called a meet

Examples of lattices

- Powerset lattice



$S \triangleq \mathcal{P}(\{a, b, c\})$

$\sqsubseteq \triangleq \supseteq$

$\sqcup \triangleq \cap$

$\sqcap \triangleq \cup$

$s_1 \sqsubseteq s_2$ $\quad$ $s_1 \subseteq s_2$

$s_1 \supseteq s_2$

Examples of lattices

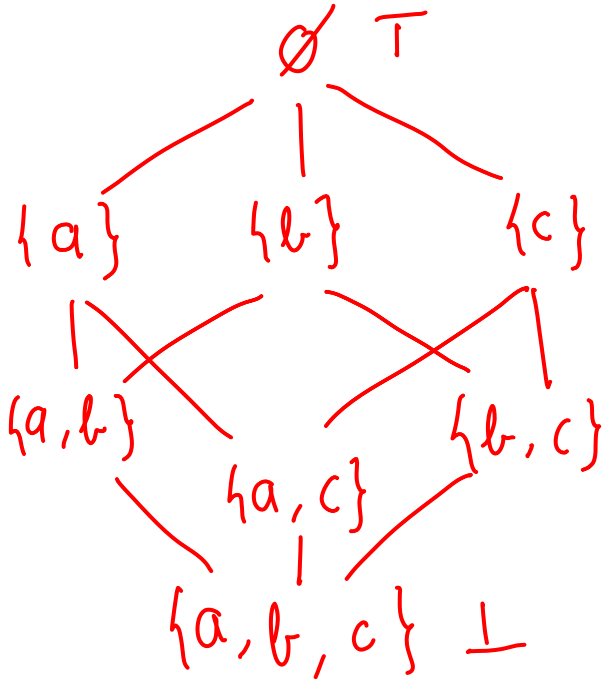
- Powerset lattice

$S \triangleq 2^{\{a,b,c\}}$

$\sqsubseteq \; \triangleq \; \supseteq$

$\sqcup \; \triangleq \; \cap$

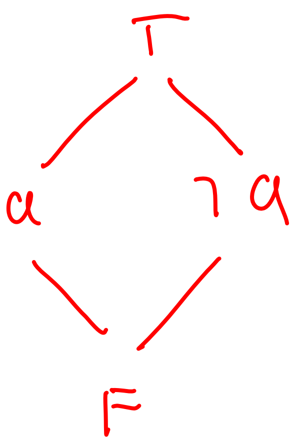
$\sqcap \; \triangleq \; \cup$



Examples of lattices

- Booleans expressions

one var



$\sqsubseteq \triangleq$	$\Rightarrow$	$\Leftarrow$
$\sqcup \triangleq$	$\vee$	$\wedge$
$\sqcap \triangleq$	$\wedge$	$\vee$

a	R	F	a	¬a	T
0	x	0	0	1	1
1	y	0	1	0	1

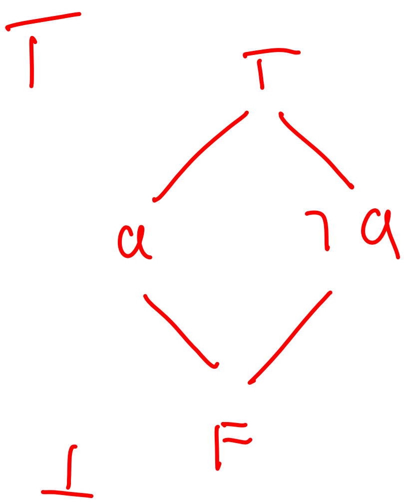
$T \sqsubseteq T \quad a \sqsubseteq a \quad \neg a \sqsubseteq \neg a \quad F \sqsubseteq F$

$F \sqsubseteq a \quad F \sqsubseteq \neg a \quad a \sqsubseteq T \quad \neg a \sqsubseteq T$

Examples of lattices

- Booleans expressions

one var



$\sqsubseteq \triangleq \Rightarrow$

$\sqcup \triangleq \vee$

$\sqcap \triangleq \wedge$

Examples of lattices

- Booleans expressions

two vars

T

⋮

F

Examples of lattices

- Booleans expressions

two vars

T

⋮ 16 expressions ...

$2^{(2^n)}$

a	b	
0	0	$\square$
0	1	$\square$
1	0	$\square$
1	1	$\square$

F