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

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
    $\cancel{\forall a, b, \in S \,.\, a\,R\,b \Rightarrow \neg(b\,R\,a)}$
    $\forall a, b, \in S \,.\, a\,R\,b \wedge b\,R\,a \Rightarrow a = b$

Partial orders

- An equivalence class is a relation that is:
- A partial order is a relation that is:

$<=$

$>=$

$\subseteq$

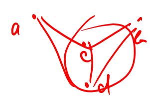
Partial orders

- 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)

$\{5\}$ $\{7\}$ $\subseteq$

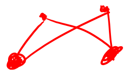
Lub and glb

- 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 $a \leq c$, $b \leq c$, 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

- 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 $a \leq c$, $b \leq c$, 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 don't always exists:



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 $a \leq c$, $b \leq c$, 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 don't always exists:

glb of b & c ?

Lattices

- A lattice is a tuple (S, $\sqsubseteq$, $\perp$, $\top$, $\sqcup$, $\sqcap$) such that:
  - (S, $\sqsubseteq$) is a poset
  - $\forall\, a \in S\,.\,\perp \sqsubseteq a$
  - $\forall\, a \in S\,.\,a \sqsubseteq \top$
  - 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

$a \sqcap b$

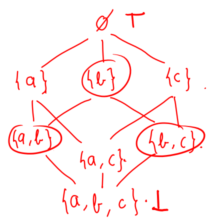
Examples of lattices

- Powerset lattice

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

$\perp \sqsubseteq \top$

$\{a,b,c\} \supseteq \emptyset$



$\sqsubseteq \triangleq \supseteq$

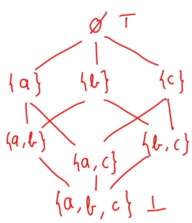
$\sqcup \triangleq \cap$

$\sqcap \triangleq \cup$

Examples of lattices

- Powerset lattice

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



$\sqsubseteq \triangleq \supseteq$

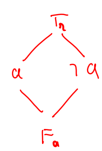
$\sqcup \triangleq \cap$

$\sqcap \triangleq \cup$

Examples of lattices

- Booleans expressions

one var



$\sqsubseteq \triangleq \rightarrow$

$\sqcup^J \triangleq \vee$

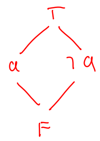
$\sqcap^M \triangleq \wedge$

Examples of lattices

- Booleans expressions

one way

$\top$



$\sqsubseteq \triangleq \Rightarrow$

$\sqcup \triangleq \vee$

$\sqcap \triangleq \wedge$

$\perp$

Examples of lattices

- Booleans expressions

two ways

T

⋮

F

Examples of lattices

- Booleans expressions

two ways

T

⋮ 16 expressions ...

$2^{(2^n)}$

a	b	
0	0	□
0	1	□
1	0	□
1	1	□

F