Mereology 6

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Atomistic and atomless mereologies

Atoms

- An atom is an entity with no proper parts
- Definition: A x ≡¬(∃y) PP yx
- Questions
  - Are there atoms?
  - If yes is everything *entirely* made up of atoms?
  - Does *everything* comprise at *least of some* atoms?
  - Is *everything* made up of *atomless gunk*?

Axioms of different strength and character are added to the mereology at hand

Mereology is neutral

- All options are logically compatible with mereology developed so far
- Principles regarding atomism can be added to mereology at any level:
  M, MM, EM, CM, CEM, GEM
- Principles of atomicity and atomlessness themselves are *mutually incompatible*
- Need to be added *in separation* to mereology

Atomlessness

- There are no atoms
- Everything made up of atomless gunk
- ¬A x

Atomicity

Weak atomicity and atomicity

- Weak atomicity
  - There are atoms through not everything needs to have a complete atomic decomposition
  - AT0 (∃x) Ax
  - AT0 ensures that there is at least one atom
- Atomicity
  - every entity has an atom as part
  - AT1: (∃y)(Ay & P yx)

Atomic essentialism (AT2)

- Comes in two equivalent versions
  - AT2(a): ¬P xy ⇒(∃z)(A z & P zx & ¬P zy)
    (Atomic version of SSP)
    ¬P xy ⇒(∃z)(P zx & ¬O zy) (SSP)
  - AT2(b): (z)(A z ⇒ (P zx ⇒P zy)) ⇒ P xy
- Assignment:
  - prove the equivalence of AT2(a) and AT2(b)
  - prove that AT2 implies SSP, I.e., M+AT2 |- SSP

Equivalence of AT2(a) and AT2(b)

- Use the following logical equivalences:
  - Trans
  - QN
  - DN
  - DeM
  - Impl

AT2(a) ⇔ AT2(b)

1.	¬P xy ⇒ (∃z)(A z & P zx & ¬P zy)	ass
2.	¬(∃z)(A z & P zx & ¬P zy) ⇒ ¬¬P xy	1 trans
3.	¬(∃z)(A z & P zx & ¬P zy) ⇒ P xy	2 DN
4.	(z)¬(A z & P zx & ¬P zy) ⇒ P xy	3 QN
5.	(z)(¬A z or ¬ (P zx & ¬P zy)) ⇒ P xy	4 DeM
6.	(z)(¬A z or (P zx ⇒P zy)) ⇒ P xy	5 Imp
7.	(z)(A z ⇒ (P zx ⇒P zy)) ⇒ P xy	6 Imp

M+AT2 |- ¬P xy ⇒ (∃z)(P zx & ¬O xy)

0.	P xy⇒PP xy or x=y	
1.	¬P xy	ass
2.	(∃z)(Az & P zx & ¬P zy)	1 AT2 MP
3.	Az & P zx & ¬P zy	
4.	O zy	ass
5.	(∃u)(P uz & P uy)	4 D_O
6.	P uz & P uy	
7.	P uz	6 simp
8.	PP uz or u=z	7,0 MP
9.	u=z	ass
10.	¬P uy	(3 simp), 9 Id
11.	P uy & ¬P uy	(6 simp), 10 conj
12.	¬ (u=z)	9-11 IP
13.	PP uz	8,12 DS
14.	(∃u) PP uz	13 EG
15.	¬ A z	14 D_A
16.	A z & ¬ A z	(3 simp), 15 conj
17.	¬ O zy	4-16 IP
18.	P zx & ¬ O zy	(3 simp), 17 conj
19.	(∃u) (P zx & ¬ O zy)	18 EG
20.	¬P xy ⇒ (∃u) (P zx & ¬ O zy)	1-19 CP

Atomic essentialism (AT2)

- Comes in two equivalent versions
  - AT2(a): $\neg P\ xy \Rightarrow (\exists z)(A\ z\ \&\ P\ zx\ \&\ \neg P\ zy)$
    (Atomic version of SSP)
    $\neg P\ xy \Rightarrow (\exists z)(P\ zx\ \&\ \neg O\ zy)$ (SSP)
  - AT2(b): $(z)(A\ z \Rightarrow (P\ zx \Rightarrow P\ zy)) \Rightarrow P\ xy$
- Assignment:
  - prove the equivalence of AT2(a) and AT2(b)
  - prove that AT2 implies SSP, I.e., M+AT2 |- SSP

Atomic essentialism (2)

Given AT2 we can prove that

- Two things are identical iff they have the same atoms as parts
- $x=y \Leftrightarrow (z)(A\ z \Rightarrow P\ zx \Leftrightarrow P\ zy)$
- Very strong:
  - For identity it is sufficient to look at the atoms.
  - Other parts do not matter

Assignment

- Prove that
  $x=y \Leftrightarrow (z)(A\ z \Rightarrow P\ zx \Leftrightarrow P\ zy)$
  follows from AT2
- i.e.,
  M+ AT2 |-- $x=y \Leftrightarrow (z)(A\ z \Rightarrow P\ zx \Leftrightarrow P\ zy)$
- Hint:
  - it is easier to use AT2(b)
  - Use $(P \Rightarrow (Q\ \&\ R)) \Rightarrow ((P \Rightarrow Q)\&(P \Rightarrow R))$

M+ AT2 |-- $(z)(A\ z \Rightarrow P\ zx \Leftrightarrow P\ zy) \Rightarrow x=y$

0.	$(P \Rightarrow (Q\ \&\ R)) \Rightarrow ((P \Rightarrow Q)\&(P \Rightarrow R))$	
1.	$(z)(A\ z \Rightarrow P\ zx \Leftrightarrow P\ zy)$	ass
2.	$A\ z \Rightarrow P\ zx \Leftrightarrow P\ zy$	1 UI
3.	$A\ z \Rightarrow ((P\ zx \Rightarrow P\ zy)\&\ (P\ zy \Rightarrow P\ zx))$	2 Eq
4.	$(A\ z \Rightarrow (P\ zx \Rightarrow P\ zy))\ \&\ (A\ z \Rightarrow (P\ zy \Rightarrow P\ zx))$	3, 0 MP
5.	$(A\ z \Rightarrow (P\ zx \Rightarrow P\ zy))$	4 simp
6.	$(z)(A\ z \Rightarrow (P\ zx \Rightarrow P\ zy))$	5 UG
7.	$P\ xy$	6,AT2 MP
8.	$(A\ z \Rightarrow (P\ zy \Rightarrow P\ zx))$	4 simp
9.	$(z)(A\ z \Rightarrow (P\ zy \Rightarrow P\ zx))$	8 UG
10.	$P\ yx$	9,AT2 MP
11.	$P\ xy\ \&\ P\ yx$	7,10 conj
12.	$x=y$	11, M2 MP
13.	$(z)(A\ z \Rightarrow P\ zx \Leftrightarrow P\ zy) \Rightarrow x=y$	1-12 CP

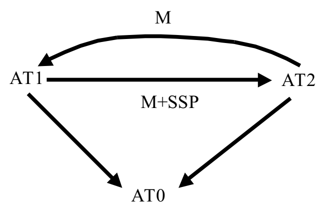
M+ AT2 |-- $x=y \Rightarrow (z)(A\ z \Rightarrow P\ zx \Leftrightarrow P\ zy)$

1.	$x=y$	ass
2.	Az	ass
3.	$P\ zx$	ass
4.	$P\ zy$	3,1 Id
5.	$P\ zx \Rightarrow P\ zy$	3-4 CP
6.	$P\ zy$	ass
7.	$P\ zx$	6,1 Id
8.	$P\ zy \Rightarrow P\ zx$	6-7 CP
9.	$P\ zx \Leftrightarrow P\ zy$	(5,8 conj) Eq
10.	$Az \Rightarrow (P\ zx \Leftrightarrow P\ zy)$	2-9 CP
11.	$(z)(Az \Rightarrow (P\ zx \Leftrightarrow P\ zy))$	10 UG
12.	$x=y \Rightarrow (z)(A\ z \Rightarrow P\ zx \Leftrightarrow P\ zy)$	1-11 CP

- We proved that
  $x=y \Leftrightarrow (z)(A\ z \Rightarrow P\ zx \Leftrightarrow P\ zy)$
  follows from AT2
- i.e.,
  M+ AT2 |-- $x=y \Leftrightarrow (z)(A\ z \Rightarrow P\ zx \Leftrightarrow P\ zy)$

Relations between AT0,AT1,AT2

Masolo & Vieu 01



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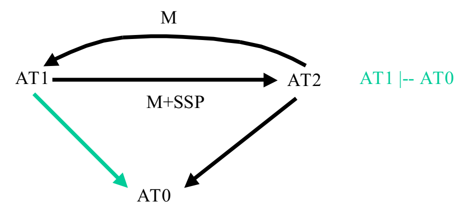

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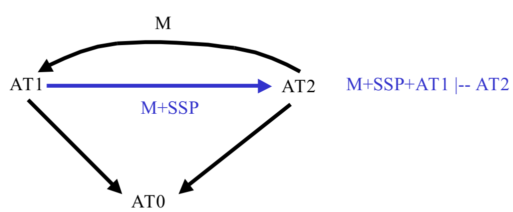

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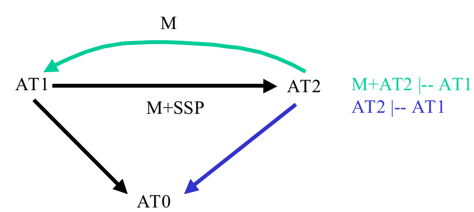

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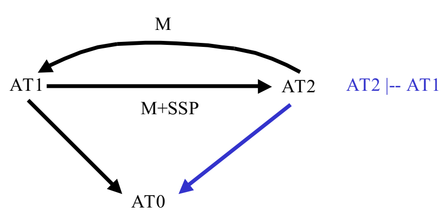
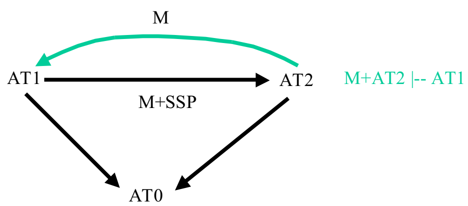


M+AT2 |-- (∃x)Az

0.	¬P xy ⇒(∃z)(A z & P zx & ¬P zy)	
1.	¬(∃x)Ax	ass
2.	(x) ¬ Ax	1 QN
3.	¬ Ax	2 UI
4.	¬¬ (∃y)PP yx	3 D_A
5.	(∃y)PP yx	4 DeM
6.	PP yx	
7.	P yx & ¬(x=y)	6 D_{PP}
8.	¬(x=y)	7 simp
9.	¬(P xy & P yx)	8, M2 MT
10.	¬P xy or ¬ P yx	9 DeM
11.	¬P xy	(7 simp),10 DS
12.	(∃z)(A z & P zx & ¬P zy)	11, 0 MP
13.	A z & P zx & ¬P zy	
14.	Az	13 simp
15.	(∃x) Ax	14 EG
16.	(∃x) Ax & ¬(∃x)Ax	15, 1 conj
17.	(∃x) Ax	1-16 IP

Relations between AT0,AT1,AT2

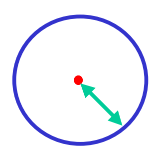


M+AT2 |-- (∃z)(Az & P zx)

0.	(z)((A z &P zx) ⇒P zy)) ⇒ P xy	
1.	¬(∃z)(Az & P zx)	ass
2.	(z) ¬(Az & P zx)	1 QN
3.	(z)(¬ P zx or ¬Az)	2 DeM
4.	¬ P xx or ¬Ax	3 UI
5.	¬Ax	4, M1 DS
6.	¬ ¬(∃y)PP yx	5 D_A
7.	(∃y)PP yx	6 DN
8.	P yx & ¬ (y=x)	7 D_{PP}
9.	A z &P zx	ass
10.	¬ P zx or ¬Az	3 UI
11.	¬Az	(9 simp),10 DS
12.	Az & ¬Az	(9 simp), 11 conj
13.	(Az & ¬Az) or P zy	12 add
14.	(Az or P zy) & (¬Az or P zy)	13 dist
15.	(¬ Az ⇒ P zy) & (Az ⇒P zy)	14 Imp
16.	¬ Az or Az	ExMiddle
17.	P zy or Pzy	15, 16 CD
18.	P zy	17 taut
19.	(A z &P zx) ⇒ P zy	9-18 CP
20.	(z)((A z &P zx) ⇒ P zy)	19 UG
21.	P xy	20, 0 MP
22.	P yx & P xy	(8 simp), 21 conj
23.	x=y	22, M2 MP
24.	¬ (y=x) & x=y	(8 simp) 23 conj
25.	(∃z)(Az & P zx)	1-24 IP

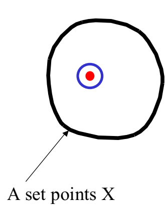
Point set topology

Neighborhoods of points



- Assume the set of points or the Euclidian plane
- A *neighborhood* of a Point P is a disk of radius v with center P

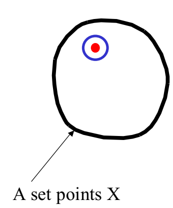
Sets and neighborhoods



Classification of points with respect to X

- Interior points wrt. X:
  - Points which have a neighborhood which *contains only members of X*

Sets and neighborhoods



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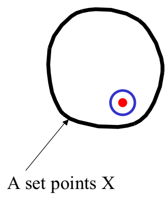

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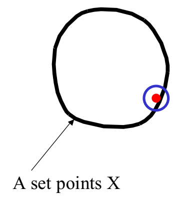
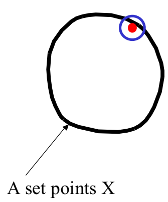
Sets and neighborhoods



Boundary points wrt. X :

- Points which have a neighborhood which
  - contains members of X
  - And contains non-members of X

Sets and neighborhoods



Boundary points:

- Points which have a neighborhood which
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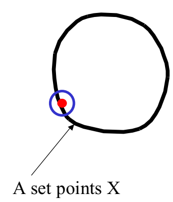
Sets and neighborhoods



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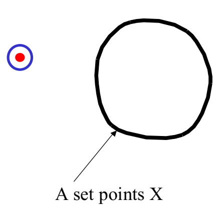
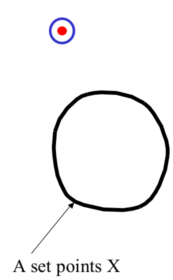
Sets and neighborhoods



Exterior points wrt X:

- Points which have a neighborhood which soes NOTcontain members of X

Sets and neighborhoods



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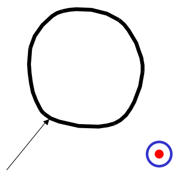
Sets and neighborhoods

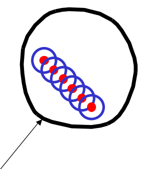


A set points X

Exterior points wrt X:

- Points which have a neighborhood which soes NOTcontain members of X

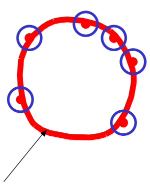
The interior of a Set



A set points X

- X is a set
- i(X) the interior of X
- Is the set which contains all of Xs interior points
- $i(X) \subseteq X$

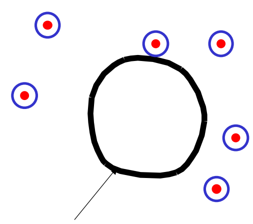
The boundary of a Set



A set points X

- X is a set
- b(X) the boundary of X
- Is the set which contains all of Xs boundary points
- b(X) contains some points which are not elements of X

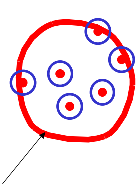
The exterior of a Set



A set points X

- X is a set
- e(X) the exterior of X
- Is the set which contains all of Xs exterior points
- e(X) contains points only which are not elements of X

The closure of a Set



A set points X

- X is a set
- cl(X) the closure of X
- Is the set which contains all of Xs *interior and boundary* points
- cl(X) contains some points which are not elements of X

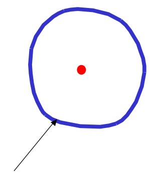
Relationships between interior, boundary, closure, and exterior

- $i(X) \subseteq X$
- $i(X) \cap b(X) = \varnothing$
- $cl(X)= i(X) \cup b(X)$
- Let P be the points of the plane and $X \subseteq P$ then we have $P = i(X) \cup b(X) \cup e(X)$

Regular open sets

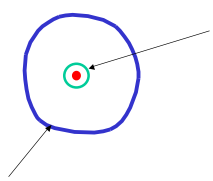
- A set is *open* iff it contains only *interior points*
- A set is *regular open* iff it is identical to the *interior of its closure*
- *RO X ≡ X=I(cl(X))*

Non-regular open sets

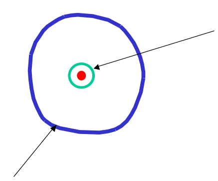


- Let X be a set without the point P
- Let i(X) be the interior of X
- i(X) is open
- i(X) is NOT regular

Non-regular open sets

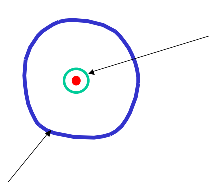


Non-regular open sets



P ∈ cl(X)

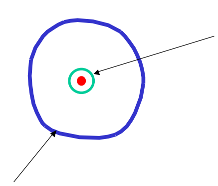
Non-regular open sets



P ∈ cl(X)

P is *NOT* a boundary point of the closure of X

Non-regular open sets



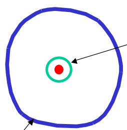
P ∈ cl(X)

P is *NOT* a boundary point of the closure of X

P ∈ i(cl(X))

Non-regular open sets

P ∉ X



P is a *boundary* point of X

$P \in cl(X)$

P is *NOT* a boundary point of the closure of X

A set points X

$P \in i(cl(X))$

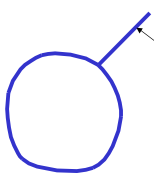
$i(X) \neq i(cl(X))$

i(X) is not regular open

Regular closed sets

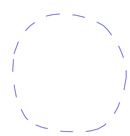
- A set is *closed* iff it contains only *interior and boundary points*
- A set is *regular closed* iff it is identical to the *closure of its interior*
- *RC X ≡ X=cl(i(X))*

Non-regular closed sets



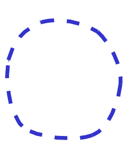
X is a closed set of points which has a boundary spike without interior

Non-regular closed sets



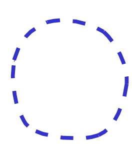
The interior of X, i(X), does not contain boundary points – The spike is gone

Non-regular closed sets



The closure of the interior of X, cl(i(X)), contains only boundary points which are close to its interior

Non-regular closed sets



The closure of the interior of X, cl(i(X)), contains only boundary points which ore close to its interior

The spike remains gone

$X \neq cl(i(X))$

X is NOT regular closed

Regular sets are topologically nice and regular – no lower dimensional holes or spikes

Topologies

- A set Z with a system of (regular) open sets ***Z*** such that
  - $Z \in \boldsymbol{Z}$
  - $\varnothing \in \boldsymbol{Z}$
  - ***Z*** is closed under finite (regularized) unions
    If $X \in \boldsymbol{Z}$ & $Y \in \boldsymbol{Z}$ then $X \cup Y \in \boldsymbol{Z}$
  - ***Z*** is closed under arbitrary (regularized) intersections
    If $U \subseteq \boldsymbol{Z}$ then $\bigcap_{Y \in U} \in \boldsymbol{Z}$

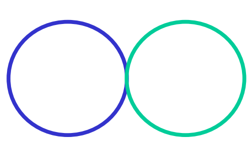
Topologies

- A set Z with a system of (regular) closed sets *Z* such that
  - $Z \in \boldsymbol{Z}$
  - $\varnothing \in \boldsymbol{Z}$
  - ***Z*** is closed under finite (regularized) intersections
    If $X \in \boldsymbol{Z}$ & $Y \in \boldsymbol{Z}$ then $X \cap Y \in \boldsymbol{Z}$
  - ***Z*** is closed under arbitrary (regularized) unions
    If $U \subseteq \boldsymbol{Z}$ then $\bigcup_{Y \in U} \in \boldsymbol{Z}$

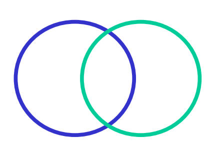
Connectedness

- Two sets X and Y are connected iff
  - X intersects the closure of Y or Y intersects the closure of X
  - $X \cap cl(Y) \neq \varnothing$ or $Y \cap cl(X) \neq \varnothing$
- Important:
  - For connectedness the interiors do NOT need to overlap
  - Connected sets do NOT need to share interior points
- Regular closed sets: connected if they share at least one point of their closures

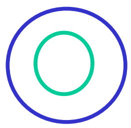
X is connected to Y



X is connected to Y



X is connected to Y



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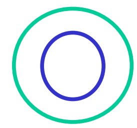

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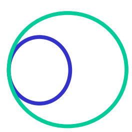


Mereotopology –
the formal theory of parthood and connectedness

Need for topology (Varzi)

- Mereological reasoning cannot do justice to the notion of a *whole*
- Distinction between
  - one-piece, self-connected wholes like stone, whistle
  - Scattered entities made up of several disconnected parts like a broken glass, a bikini, a sum of two disjoint cats

  cannot be expressed in mereology

Need for topology (2)

- In GEM for any connection of parts there is in principle a complete whole:
  the mereological sum
- There is no way, within mereology, to draw a distinction between 'good' and 'bad' sums – between
  - Integral wholes and
  - Scattered sums of disperate entities

Way out:

- Mereological account must be supplemented with a topological machinery of some sort
- Mereology a *part-of* theory
- Mereotopology is *part-whole* theory
- Add a primitive binary relation *C xy* interpreted as *x* is-topologically-connected-to *y*

Why not using point set topology?

- Point set topology is based on set theory
- If we found our topological theory on sets then we import all philosophical problems of sets:
  - Need for (minimal) elements
  - How can infinitely many non-extended points constitute extended entities?
  - See Barry's 'topological foundations of cognitive science' paper for more arguments

BUT !!

- Using point set topology at the level of models is gooooood!
- Helps us
  - To better understand our theories
  - To find proofs and counter models

Ground topology

Ground mereology - M

- Axioms
  - M1 P xx
  - M2 P xy & P yx ⇒ x = y
  - M3 P xy & P yz ⇒ P xz
- Defined relations:
  - Overlap
  - Underlap
  - Proper part

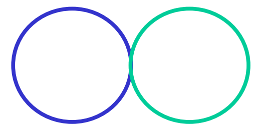
Interpretation of ground mereology in a topological space T=(Z,*Z*)

- P xy is interpreted as $i(X) \subseteq i(Y)$ with X,Y $\in$ ***Z***
- From the interpretation of P it follows that O xy holds if and X and Y share at least one *interior* point

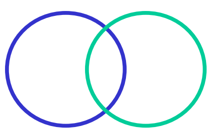
Ground topology

- Primitive relation *C xy*
- Interpretation *x* is-connected-to *y*
- If *x* and *y* are interpreted of regular closed sets of some topological space then *C xy* is interpreted as the relation which holds iff the closures of X and Y share at least one point

C xy



C xy



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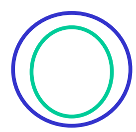

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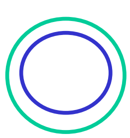
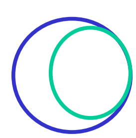
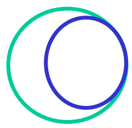


C xy

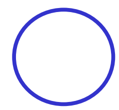


$C\ xy$



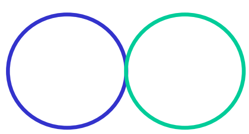
Axioms of ground topology

- C1: C is reflexive
  C xx



Axioms of ground topology

- C1: C is reflexive
  C xx
- C2: C is symmetric
  C xy ⇒ C yx



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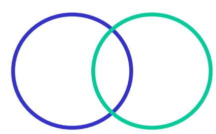

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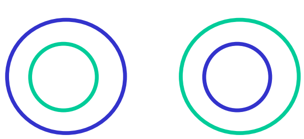

Axioms of ground topology

- C1: C is reflexive
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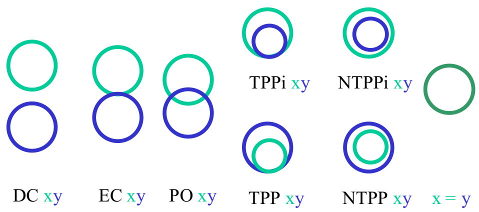
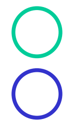
- C2: C is symmetric
  C xy ⇒ C yx
- C3: relation between P and C
  if x is a part of y then everything that is connected to x is also connected to y
  P xy ⇒ (z)(C zx ⇒ C zy)

The RCC8-relations



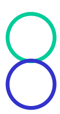
The RCC8-relations



DC xy

DC xy ≡ ¬C xy

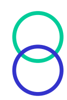
The RCC8-relations



EC xy

EC xy ≡ C xy & ¬O xy

The RCC8-relations

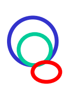


PO xy

PO xy ≡ O xy & ≡¬P xy & ≡¬P xy

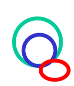
The RCC8-relations

TPP xy ≡ PP xy & (∃z)(EC zx & EC zy)



TPP xy

The RCC8-relations



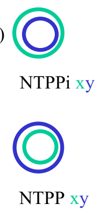
TPPi xy

TPPi xy ≡ PP xy & (∃z)(EC zx & EC zy)

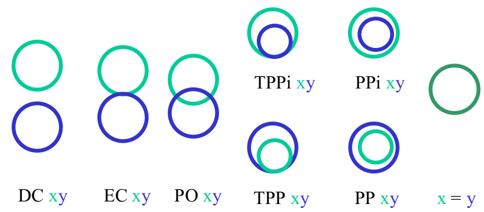
The RCC8-relations

NTPPi xy ≡ PP xy & ¬(∃z)(EC zx & EC zy)

NTPP xy ≡ PP xy & ¬(∃z)(EC zx & EC zy)



The RCC8-relations



Assignments

Prove the following theorems

1. DC, EC, PO are symmetric
   e.g., DC xy ⇒ DC yx
2. (N)TPP and (N)TPPi are asymmetric
   e.g., TPP xy ⇒ ¬TPPi xy

The RCC8 lattice

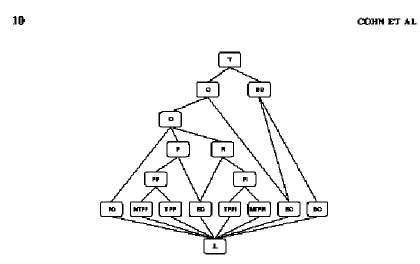
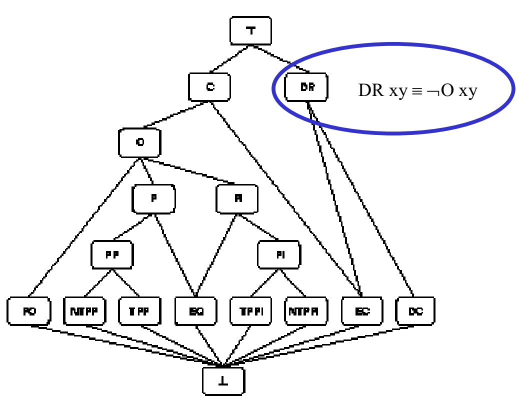
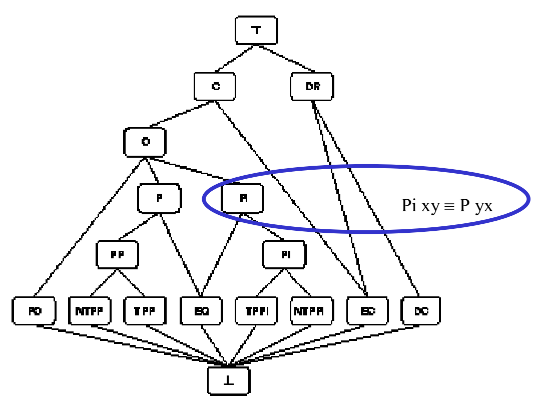
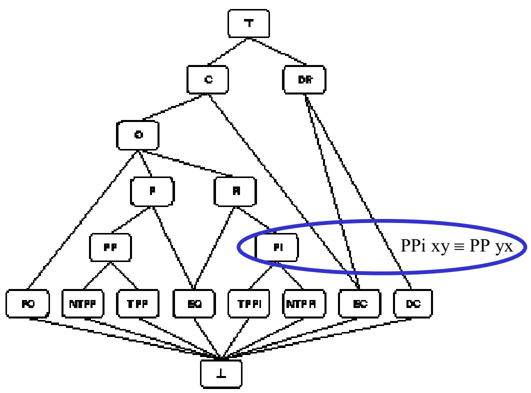
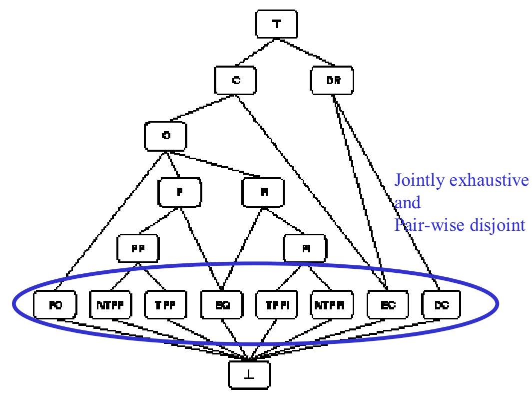


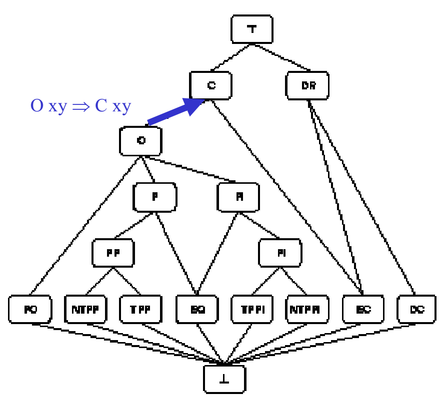
Figure 4. A subsumption lattice of dyadic relations defined in terms of C





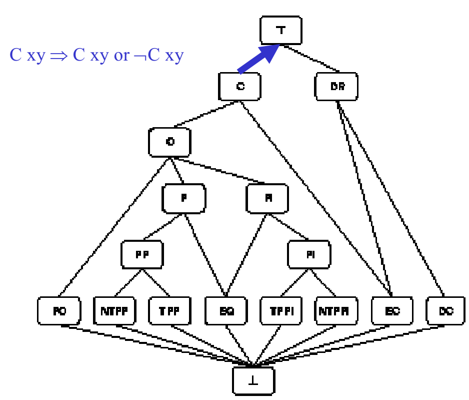






O xy ⇒ C xy

0.	P xy ⇒ (z)(C zx ⇒ C zy)	C3
1.	O xy	ass
2.	(∃z)(P zx & P zy)	1 D_O
3.	P zx & P zy	
4.	P zx	3 simp
5.	(u)(C uz ⇒ C ux)	4,0 MP
6.	C yz ⇒ C yx	5 UI
7.	P zy	3 simp
8.	(u)(C uz ⇒ C uy)	7,0 MP
9.	C zz ⇒ C zy	8 UI
10.	C zy	9, C1 MP
11.	C yz	10, C2 MP
12.	C yx	11, 6 MP
13.	C xy	12, C2 MP
14.	O xy ⇒ C xy	1-13 CP



More assignments

- Prove the following theorems
  - PO xy ⇒ O xy
  - ¬(PO xy & NTPP xy)
  - DC xy ⇒ DR xy
  - EC xy ⇒ DR xy
  - ¬(EC xy & DC xy)

  using their definitions and C1-C3

Summary

Weak atomicity and atomicity

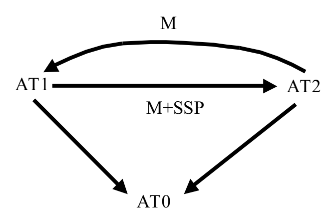
- Weak atomicity
  - There are atoms through not everything needs to have a complete atomic decomposition
  - AT0 $(\exists x)\, Ax$
  - AT0 ensures that there is at least one atom
- Atomicity
  - every entity has an atom as part
  - AT1: $(\exists y)(Ay \,\&\, P\, yx)$

Atomic essentialism (AT2)

- Comes in two equivalent versions
  - AT2(a): $\neg P\, xy \Rightarrow (\exists z)(A\, z \,\&\, P\, zx \,\&\, \neg P\, zy)$
    (Atomic version of SSP)
    $\neg P\, xy \Rightarrow (\exists z)(P\, zx \,\&\, \neg O\, zy)$ (SSP)
  - AT2(b): $(z)(A\, z \Rightarrow (P\, zx \Rightarrow P\, zy)) \Rightarrow P\, xy$
- Assignment:
  - prove the equivalence of AT2(a) and AT2(b)
  - prove that AT2 implies SSP, I.e., M+AT2 |- SSP

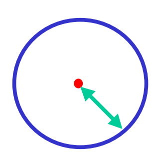
Relations between AT0,AT1,AT2

Masolo & Vieu 01



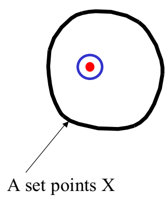
Point set topology

Neighborhoods of points



- Assume the set of points or the Euclidian plane
- A *neighborhood* of a Point P is a disk of radius v with center P

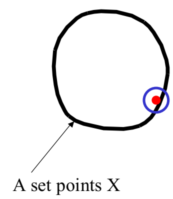
Sets and neighborhoods



Classification of points with respect to X

- Interior points wrt. X:
  - Points which have a neighborhood which *contains only members of X*

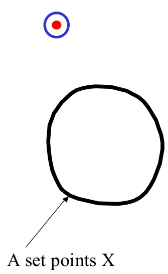
Sets and neighborhoods



Boundary points wrt. X :

- Points which have a neighborhood which
  - contains members of X
  - And contains non-members of X

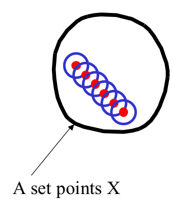
Sets and neighborhoods



Exterior points wrt X:

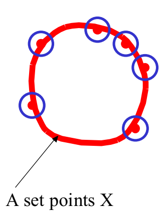
- Points which have a neighborhood which soes NOTcontain members of X

The interior of a Set



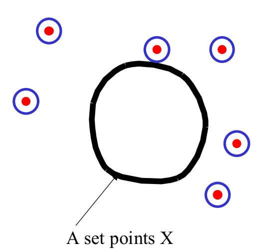
- X is a set
- i(X) the interior of X
- Is the set which contains all of Xs interior points
- $i(X) \subseteq X$

The boundary of a Set



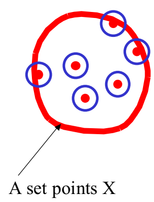
- X is a set
- b(X) the boundary of X
- Is the set which contains all of Xs boundary points
- b(X) contains some points which are not elements of X

The exterior of a Set



- X is a set
- e(X) the exterior of X
- Is the set which contains all of Xs exterior points
- e(X) contains points only which are not elements of X

The closure of a Set



- X is a set
- cl(X) the closure of X
- Is the set which contains all of Xs *interior and boundary* points
- cl(X) contains some points which are not elements of X

Relationships between interior, boundary, closure, and exterior

- $i(X) \subseteq X$
- $i(X) \cap b(X) = \varnothing$
- $cl(X) = i(X) \cup b(X)$
- Let P be the points of the plane and $X \subseteq P$ then we have
  $P = i(X) \cup b(X) \cup e(X)$

Regular open sets

- A set is *open* iff it contains only *interior points*
- A set is *regular open* iff it is identical to the *interior of its closure*
- *RO X* $\equiv$ *X=I(cl(X))*

Regular closed sets

- A set is *closed* iff it contains only *interior and boundary points*
- A set is *regular closed* iff it is identical to the *closure of its interior*
- *RC X* $\equiv$ *X=cl(i(X))*

Topologies

- A set Z with a system of (regular) closed sets *Z* such that
  - $Z \in \boldsymbol{Z}$
  - $\varnothing \in \boldsymbol{Z}$
  - ***Z*** is closed under finite (regularized) intersections
    If $X \in \boldsymbol{Z}$ & $Y \in \boldsymbol{Z}$ then $X \cap Y \in \boldsymbol{Z}$
  - ***Z*** is closed under arbitrary (regularized) unions
    If $U \subseteq \boldsymbol{Z}$ then $\bigcup_{Y \in U} \in \boldsymbol{Z}$

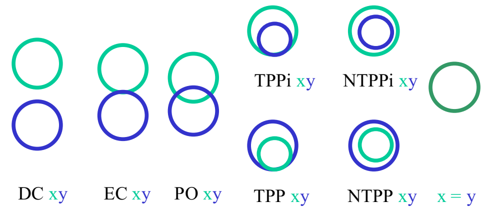
Connectedness

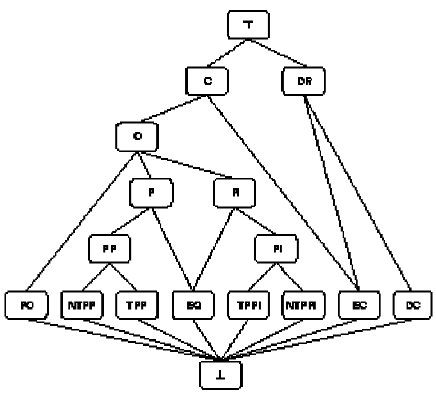
- Two sets X and Y are connected iff
  - X intersects the closure of Y or Y intersects the closure of X
  - $X \cap cl(Y) \neq \varnothing$ or $Y \cap cl(X) \neq \varnothing$
- Important:
  - For connectedness the interiors do NOT need to overlap
  - Connected sets do NOT need to share interior points
- Regular closed sets: connected if they share at least one point of their closures

Axioms of ground topology

- C1: C is reflexive
  C xx
- C2: C is symmetric
  C xy ⇒ C yx
- C3: relation between P and C
  if x is a part of y then everything that is connected to x is also connected to y
  P xy ⇒ (z)(C zx ⇒ C zy)

The RCC8-relations





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   using their definitions and C1-C3