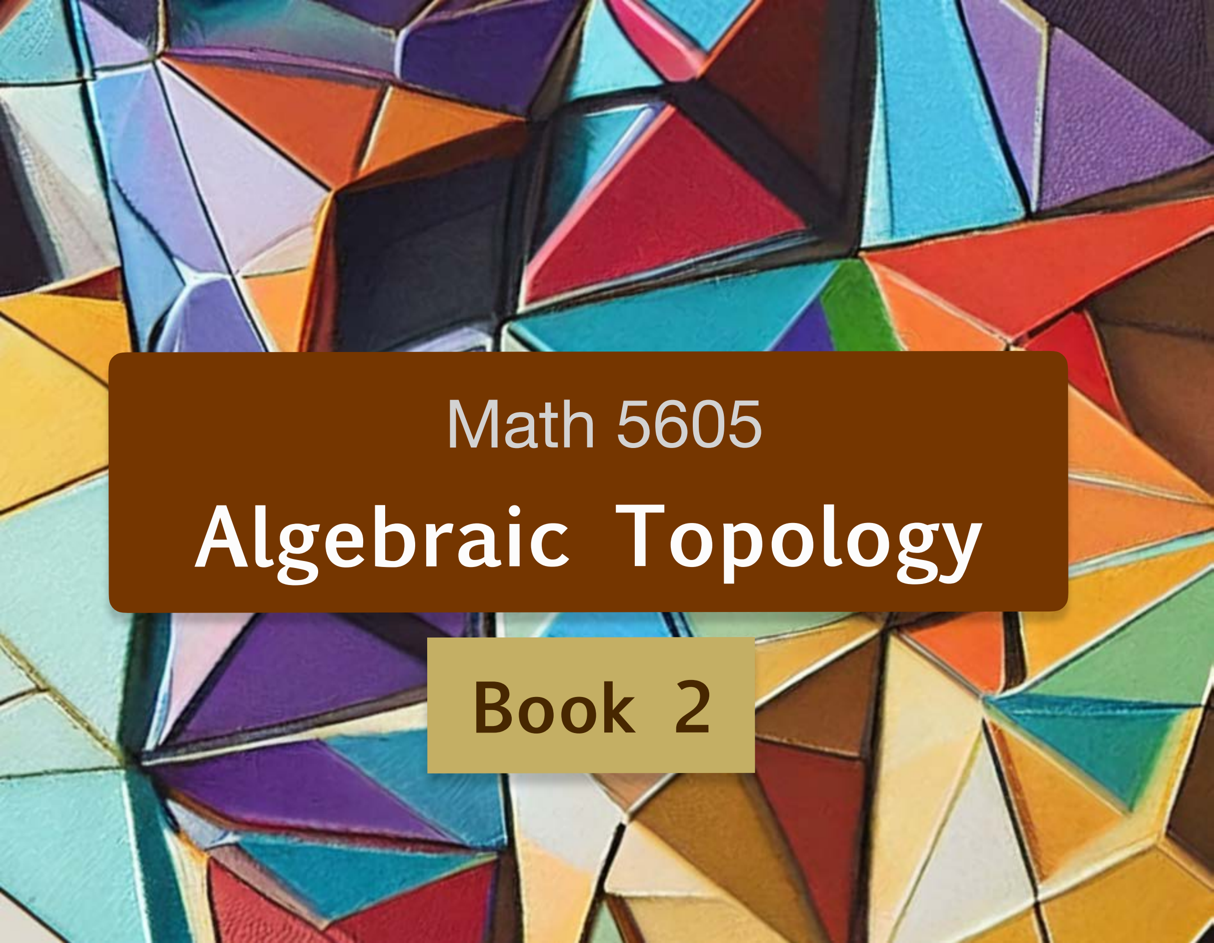
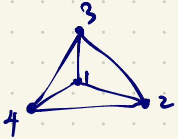


Math 5605

Algebraic Topology

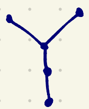
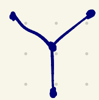
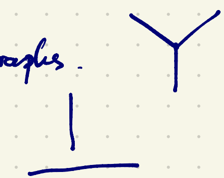
Book 2

When are two covering maps of X equivalent? Say $Y \xrightarrow{f} X$, $Y' \xrightarrow{f'} X$ are covering maps.

eg. $X =$ 

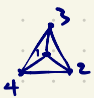
Graph i.e. combinatorial graph with vertices $\{1,2,3,4\}$ and edges $\{\{1,2\}, \{1,3\}, \ldots, \{3,4\}\}$.

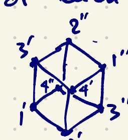
X is the geometric realization of this graph formed as a disjoint union of copies of $[0,1]$ with endpoints identified as required by the picture.

 and  have the same geometric realization although they are different graphs. 

A homomorphism of graphs $\Gamma \xrightarrow{f} \Gamma'$ is a map $V(\Gamma) \xrightarrow{f} V(\Gamma')$ preserving adjacency i.e. $x \sim y$ in Γ $\Rightarrow$ $f(x) \sim f(y)$ in Γ'.
($x, y \in V(\Gamma)$
$\{x,y\} \in E(\Gamma)$)

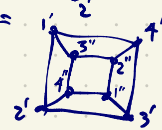
A covering map of graphs is a homomorphism inducing a bijection on the neighbours of each vertex of Γ (and the preimage of the neighbours of each vertex $y \in \Gamma'$ are copies of the neighbors of y.)

Eg. a double cover of $X =$ 

is the 1-skeleton of the cube $Y =$ 

$Y \to X$

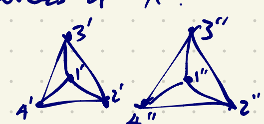
$1', 1'' \mapsto 1$
$2', 2'' \mapsto 2$
$3', 3'' \mapsto 3$
$4', 4'' \mapsto 4$

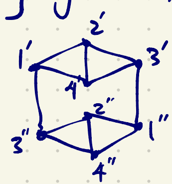
$Y =$ 

The covering space is $Y \to X$ (or informally just Y).

Some other double covers of X:

Trivial double cover

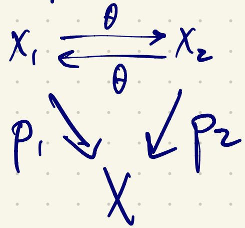
$X \sqcup X$ 



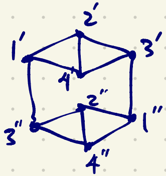
$Z \to X$
$1', 1'' \mapsto 1$
$\vdots$
$4', 4'' \mapsto 4$

When are two covers of X equivalent (isomorphic, i.e. essentially the same)?

Let $p_1: X_1 \to X$, $p_2: X_2 \to X$ be covering spaces of X. We say $\theta: X_1 \to X_2$ is an <u>equivalence</u> or <u>isomorphism</u> of the two covers if θ is a homeomorphism and $p_2 \circ \theta = p_1$, i.e. this diagram commutes.



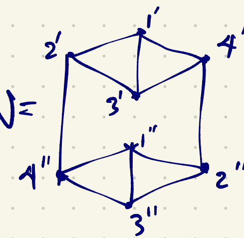
Eg.



$Z \to X$
$1', 1'' \mapsto 1$
$\vdots$
$4', 4'' \mapsto 4$

is not equivalent to $Y \to X$. But what about

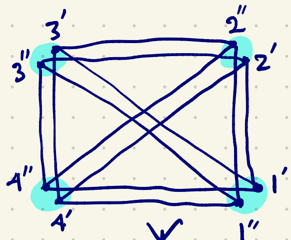
$W =$



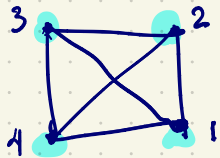
$W \to X$
$1', 1'' \mapsto 1$
$2', 2'' \mapsto 2$
$3', 3'' \mapsto 3$
$4', 4'' \mapsto 4$

Is this equivalent to $Z \to X$? No...

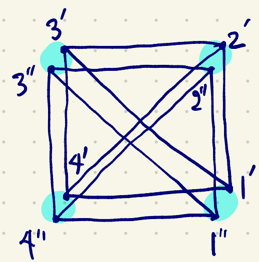
Another picture of these covers:



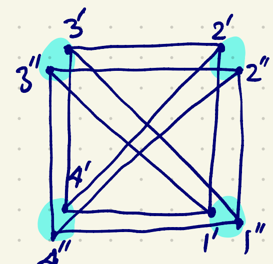
Y



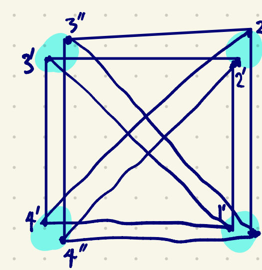
X



$X \sqcup X$

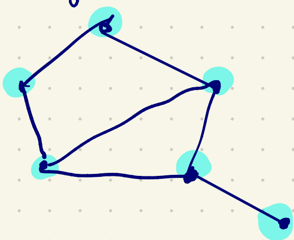


Y



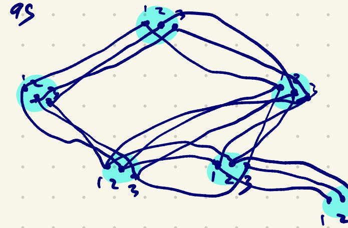
W

To construct an r-fold cover of X, create one copy of $[r] = \{1,2,\cdots,r\}$ for each vertex of X. Then for each edge of X, match up the corresponding fibres in the cover using a chosen permutation.

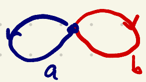


X

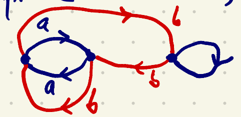
A triple cover $Y \to X$ is constructed as

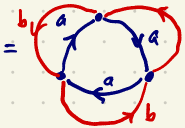


Why is 2 more special than other positive integers (the oddest prime of all)?

Consider X = 

has many triple covers including

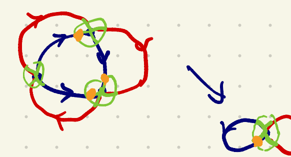
Y_1 = 

Y_2 = 

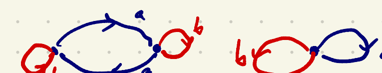
The covering maps $Y_1 \to X$ and $Y_2 \to X$ are not equivalent.

An equivalence between $Y \to X$ and itself (automorphism of the cover) is a <u>deck transformation</u>. This is the same as a homeomorphism $Y \to Y$ which preserves fibres.

In the example above, $Y_2 \to X$ has 3 automorphisms (deck transformations). But $Y_1 \to X$ has only one (trivial) deck transformation.



In a connected r-fold cover, there are at most r deck transformations. If equality holds, the covering space is <u>normal</u> or <u>Galois</u>. (not the same as normal space in point set topology). Double covers are always normal.

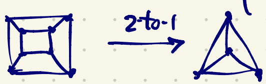
Y_3 = 

In group theory, subgroups of index 2 are normal.

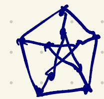
In the case of (separable) extensions of fields, the extension is normal.

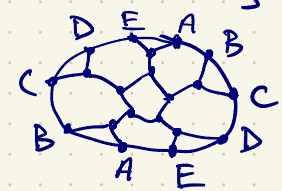
For a field extension $E \supseteq F$, the degree of the extension is $[E:F]$ = dimension of E as a vector space over F. The number of F-automorphisms of E (i.e. $\sigma: E \to E$ automorphism fixing $\sigma(a) = a$ for all $a \in F$) is at most $[E:F]$. If this number is equal, it's a normal or Galois extension. Extensions of degree 2 (quadratic extensions) are always normal.

Double covers: examples



dodecahedral graph $\longrightarrow$ Petersen

$\longrightarrow$ 



$S^2 \longrightarrow P^2\mathbb{R}$

real proj. plane

S^n is not a top. group unless $n \in \{1, 3\}$.

$S^1 = \{z \in \mathbb{C} : |z| = 1\}$.

$S^3 = \{z \in \mathbb{H} : |z| = 1\}$ $\qquad \mathbb{H} = \{a + bi + cj + dk : a, b, c, d \in \mathbb{R}\}$ $\qquad i^2 = j^2 = k^2 = ijk = -1$

$\cong SU_2(\mathbb{C}) = \left\{A = \begin{bmatrix} \alpha & \beta \\ \gamma & \delta \end{bmatrix} : \alpha, \beta, \gamma, \delta \in \mathbb{C},\ AA^* = A^*A = I,\ \det A = 1\right\}$

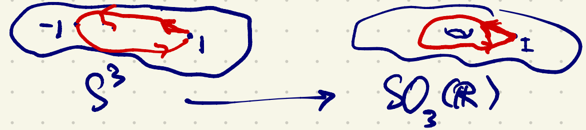
$SO_3(\mathbb{R}) = \{A \in \mathbb{R}^{3\times 3} : AA^T = A^TA = I,\ \det A = 1\}$

$O_3(\mathbb{R}) = \{A \in \mathbb{R}^{3\times 3} : AA^T = A^TA = I\}$ has two connected components

$Z(S^3) = \{\pm 1\}$

Fact: $S^3 \cong SU_2(\mathbb{C}) \longrightarrow SO_3(\mathbb{R})$ is a double cover.

$PSU_2(\mathbb{C}) = S^3 / Z(S^3) \cong SO_3(\mathbb{R}) \overset{\text{homeomorphism}}{\cong} P^3\mathbb{R}$.



In general for $n \geq 3$, $\pi_1(SO_n(\mathbb{R})) \cong \mathbb{Z}/2\mathbb{Z}$.

$Spin_n(\mathbb{R}) \longrightarrow SO_n(\mathbb{R})$ is its universal cover; a simply connected double cover

constructed from Clifford Algebras (generalizing $\mathbb{H}$).