Fundamental groups of small covers

Wu, Lisu

School of Mathematical Sciences, Fudan University

The 5th Korea Toric Topology Winter Workshop

Gyeongju, Korea, January 21-23, 2019

Content

Small cover

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such that

$\forall\ f = F_1 \cap F_2 \cap \cdots \cap F_k$,
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Rk: $\mathcal{F}(P) \triangleq \{F_1, F_2, \cdots, F_m\}$.

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- Define right-angled Coxeter group of P

$$W = \langle s_F, \forall\, F \in \mathcal{F}(P) \mid s_F^2 = 1, (s_F s_{F'})^2 = 1, F \cap F' \neq \varnothing \rangle$$

- The Borel construction

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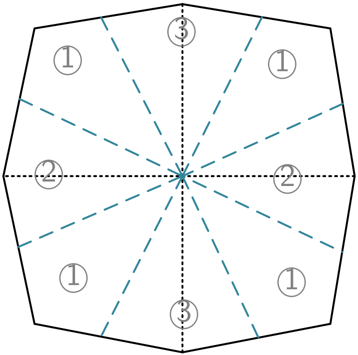
- $M \to BP \to B\mathbb{Z}_2^n$ induces an right-split exact sequence

$$\begin{tikzcd} 1 \arrow[r] & \pi_1(M) \arrow[r] & W \arrow[r, shift left, "\phi"] & \mathbb{Z}_2^n \arrow[l, shift left, "\gamma"] \arrow[r] & 1 \end{tikzcd}$$

where $\phi(s_F) = \lambda(F),\ \forall F \in \mathcal{F}(P)$.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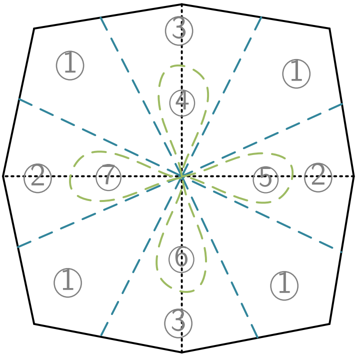
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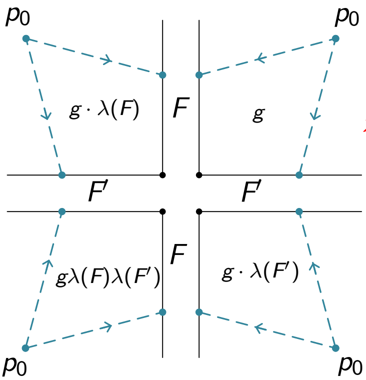
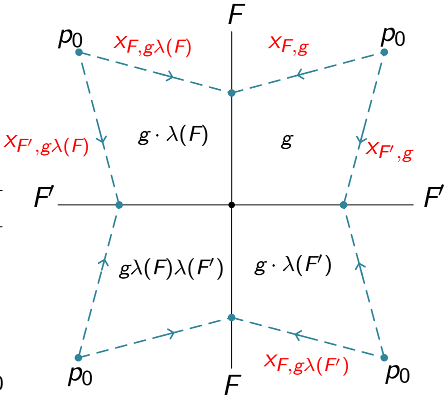
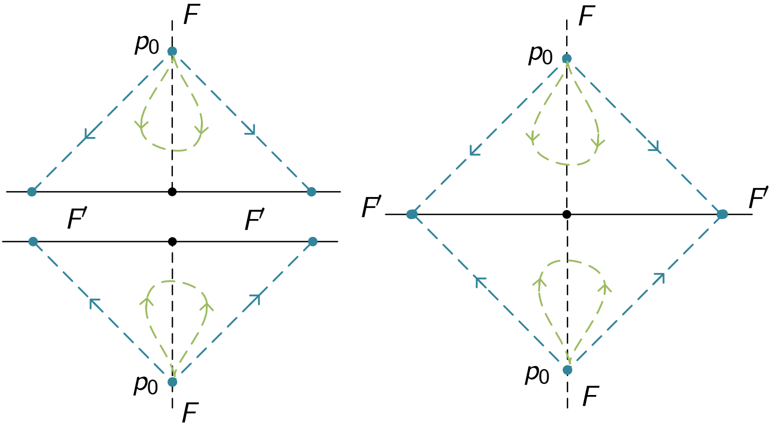




Cell-①

Relation-1: $x_{F,g}x_{F,g\lambda(F)} = 1$

Relation-2: $x_{F,g}x_{F',g\lambda(F)} = x_{F',g}x_{F,g\lambda(F')}$



Relation-2: $x_{F,g}x_{F',g\lambda(F)} = x_{F',g}x_{F,g\lambda(F')}$

Relation-3: $x_{F,g} = 1,\ p_0 \subset F$

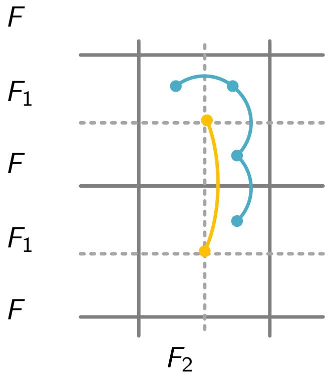
Presentation of $\pi_1(M)$

Presentation of $\pi_1(M, p_0)$

$$\begin{aligned}\pi_1(M, p_0) = \langle x_{F,g}, \forall\, F, g \,|\, & x_{F,g} x_{F,g\lambda(F)} = 1; \\ & x_{F,g} x_{F',g\lambda(F)} = x_{F',g} x_{F,g\lambda(F')},\ \ F \cap F' \neq \varnothing; \\ & x_{F,g} = 1, p_0 \in F; \rangle\end{aligned}$$

Relation between $\pi_1(M)$ and W

$$\mathcal{M} = Q \times \pi_1(M)/\sim = P \times W/\sim$$



Rk: $\lambda(F_1, F_2, F, F') = (e_1, e_2, e_1 e_2, e_2)$.

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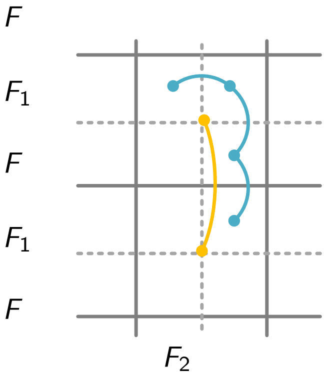

$x_{F,1}(Q, 1) \mapsto (Q, x_{F,1})$

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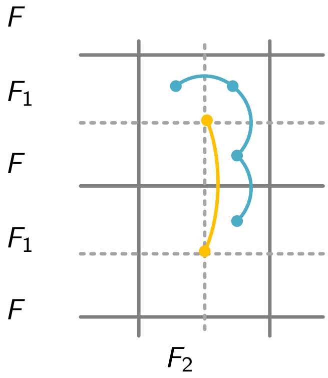

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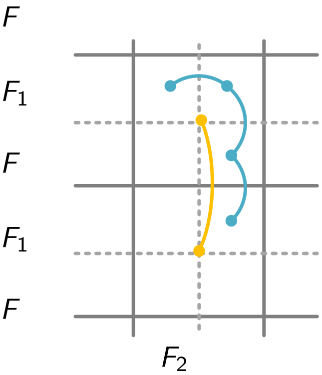

$$x_{F,1}(Q,1) \mapsto (Q, x_{F,1})$$

$$s_F(P,1) \mapsto (P, s_F)$$

$$\begin{tikzcd}
x_{F,1}(P,1) \arrow[r, mapsto] \arrow[d, dotted, mapsto] & (P, s_{F_2}s_{F_1}s_F) \\
\gamma(\lambda(F)) \cdot s_F(P,1) \arrow[r, mapsto] & s_{F_2}s_{F_1}s_F(P,1) \arrow[u, mapsto]
\end{tikzcd}$$

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Relation between $\pi_1(M)$ and W

$$\begin{aligned}
\alpha : \pi_1(M, p_0) &\longrightarrow W \\
x_{F,g} &\longmapsto \quad \gamma(g\lambda(F)) \cdot \gamma(\lambda(F)) s_F \cdot (\gamma(g\lambda(F)))^{-1} \\
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1 \longrightarrow \pi_1(M) \xrightarrow{\alpha} W \xrightarrow{\phi} \mathbb{Z}_2^n \longrightarrow 1 \tag{1}
$$

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M \arrow[r, dotted] \arrow[d, "\pi"'] & \pi_1(M) \arrow[d, "\alpha"] \\
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Idea

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Idea

$$\begin{tikzcd} M \arrow[r, dotted] \arrow[d, "\pi"'] & \color{red}{\pi_1(M)} \arrow[d, red, "\alpha"] \\ P \arrow[r, dotted] & \color{red}{W} \end{tikzcd}$$

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$$\begin{tikzcd} M \arrow[r, dotted] \arrow[d, "\pi"'] & \pi_1(M) \arrow[d, "\alpha"] \\ {\color{red}P} \arrow[r, dotted, red] & {\color{red}W} \end{tikzcd}$$

Idea

$$\begin{tikzcd}[column sep=huge, row sep=huge]
M \arrow[r, dotted, "\text{hard}"'] \arrow[d, "\pi"'] & \pi_1(M) \arrow[d, "\alpha"] \\
P \arrow[r, dotted, "\text{easy}"] & W
\arrow[from=1-1, to=2-2, phantom, "\downarrow"]
\end{tikzcd}$$

For any proper face f of P,

- Define $\mathcal{F}(f^{\perp}) \triangleq \{F \in \mathcal{F}(P) \mid \dim(f \cap F) = \dim(f) - 1\}$. So $\mathcal{F}(f^{\perp})$ consists of those facets of P that intersect f transversely.

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- A submanifold Σ in M is called $\underline{\pi_1\text{-injective}}$ if the inclusion $\Sigma \hookrightarrow M$ induces a monomorphism in the fundamental group.
- A *k-circuit* in the simple polytope P is a simple loop on the boundary of P which intersects transversely with the interior of exactly k distinct edges, and a k-circuit is called *prismatic* if the endpoints of those edges are distinct.

Theorem (Wu-Yu, 2017)

Let M be a small cover over a simple polytope P and f be a proper face of P. The following two statements are equivalent.

- *The facial submanifold M_f is π_1-injective.*
- *For any $F, F' \in \mathcal{F}(f^{\perp})$, we have $f \cap F \cap F' \neq \varnothing$ whenever $F \cap F' \neq \varnothing$.*

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Rk: We can determine the kernel of $i_* : \pi_1(M_f) \longrightarrow \pi_1(M)$.

Other results

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Proposition (Wu-Yu, 2017)

For any small cover M over a 3-dimensional simple polytope P, there always exists a facet F of P so that the facial submanifold M_F is π_1-injective.

Let M be a 3-small cover over $P(\neq \Delta^3)$, the following facts was referred in DJ's paper(corrected):

- If there exist prismatic 3-circuits in P, then M can be decomposed into pieces glued along S^2 or $\mathbb{R}P^2$.

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- If there exist prismatic 3-circuits in P, then M can be decomposed into pieces glued along S^2 or $\mathbb{R}P^2$.
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- If there is no prismatic 3-circuit but 4-circuits in P, then M can be decomposed into geometric pieces glued along tori or Klein bottles.
- If there is no prismatic 3 or 4-circuit in P, then M is hyperbolic.

Let M be a connected 3-manifold.

- M is called prime if $M = M_1 \# M_2$ implies $M_1 = S^3$ or $M_2 = S^3$.

Prime decomposition theorem

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- M is called <u>P^2-irreducible</u> if it is irreducible and contains no two-sided $\mathbb{R}P^2$.

Theorem (Kneser, Prime Decomposition Theorem)

Every compact oriented 3 manifold M factors as a connected sum of prime manifolds, $M \cong M_1 \# \cdots \# M_n$, and this decomposition is unique up to insertion or deletion of S^3 summands.

Proposition

Let M be a 3-dimensional small cover over a simple polytope P, then M is P^2-irreducible if and only if there is no prismatic 3-circuit in P.

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In particular, the prime decomposition of an oriented 3-small cover is equivalent to cutting surgery along prismatic 3-circuits in P.

JSJ-decomposition theorem

- A compact 3-manifold M is called atoroidal if it contains no essential torus.

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Theorem (Jaco-Shalen-Johannson, Torus Decomposition Theorem)

Let M be an oriented, irreducible, closed 3-manifold. There exists a (possibly empty) collection of disjointly embedded incompressible tori $T_1, \cdots, T_m$ such that each component of M cut along $T_1 \cup \cdots \cup T_m$ is atoroidal or Seifert fibered. Any such collection of tori with a minimal number of components is unique up to isotopy.

Theorem (Perelman, Geometrization Theorem)

Let M be a irreducible colsed 3-manifold. There exists a (possibly empty) collection of disjointly embedded incompressible surface $S_1, \cdots, S_m$ which are either tori or Klein bottles, such that each component of M cut along $S_1 \cup \cdots \cup S_m$ is geometric. Any such collection of tori with a minimal number of components is unique up to isotopy.

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Proposition

Let M be a 3-small cover over a simple polytope P, then M is atoroidal if and only if there is no prismatic 4-circuit in P.
In particular, the JSJ decomposition or geometric decomposition of a 3-small cover is equivalent to cutting surgery along prismatic 4-circuits in P.

Theorem (Thurston, Hyperbolization Theorem)

Every P^2-irreducible, atoroidal, closed 3-manifold with infinite fundamental group is hyperbolic.

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Proposition

Let M be a 3-small cover over a simple polytope $P(\neq \Delta^3)$, then M is hyperbolic if and only if there is no prismatic 3 or 4-circuit in P.

Proposition

A small cover M over a simple 3-polytope P can admit a Riemannian metric with nonnegative scalar curvature if and only if P is combinatorially equivalent to the cube $[0,1]^3$ or a polytope obtained from Δ^3 by a sequence of vertex cuts. In particular, all the oriented 3-dimensional small covers that can admit Riemannian metrics with non-negative scalar curvature are the two oriented real Bott manifolds in dimension 3 and the connected sum of k copies of $\mathbb{R}P^3$ for any $k \geq 1$.

End of Talk

The 5th Korea Toric Topology Winter Workshop

Gyeongju, Korea. 10:30 - 11:10 January 22, 2019

Some references

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Email: `wulisuwulisu@qq.com`
Homepage: `http://algebraic.top/`