Topological full groups of étale groupoids

Hiroki Matui
matui@math.s.chiba-u.ac.jp

Chiba University

March 13, 2013
Geometry of groups 2013
Les Diablerets

Outline

(minimal) topological dynamical system on a Cantor set

(group action, equivalence relation, one-sided SFT...)

$\longrightarrow$ étale groupoid G whose $G^{(0)}$ is a Cantor set

$\longrightarrow$ topological full group $[[G]] \subset \mathrm{Homeo}(G^{(0)})$

C^*-algebra $C^*_r(G)$ and its K-groups $K_i(C^*_r(G))$

Properties of $[[G]]$ (and its commutator subgroup $D([[G]])$):

- $[[G]]$ (and $D([[G]])$) 'remembers' G.
- $D([[G]])$ is (often) simple.
- What is $[[G]]/D([[G]])$?
- Is $[[G]]$ amenable?
- $[[G]]$ is sometimes finitely generated.
- $[[G]]$ is sometimes finitely presented.

Étale groupoids

A groupoid G is a 'group-like' algebraic object,
in which the product may not be defined for all pairs in G.

- $g \in G$ is thought of as an arrow $\bullet \xleftarrow{g} \bullet$.
- $r : g \mapsto gg^{-1}$ is called the range map.
- $s : g \mapsto g^{-1}g$ is called the source map.
- $G^{(0)} = r(G) = s(G) \subset G$ is called the unit space.

Thus, G is a small category in which every morphism is invertible.

A topological groupoid G is étale if the range map and the source map $r, s : G \to G^{(0)}$ are local homeomorphisms.
A groupoid G is essentially principal
if the interior of $\{g \in G \mid r(g) = s(g)\}$ is $G^{(0)}$.

Topological full groups

From now on, we always assume that G is essentially principal and $G^{(0)}$ is a Cantor set.
A compact open set $U \subset G$ is a G-set if $r|U$ and $s|U$ are injective.
Then $\pi_U = (r|U) \circ (s|U)^{-1}$ is a partial homeomorphism on $G^{(0)}$.
The topological full group $[[G]]$ of G is defined by

$$[[G]] = \left\{ \pi_U \in \mathrm{Homeo}(G^{(0)}) \mid r(U) = s(U) = G^{(0)} \right\}.$$

Homology groups

$H_n(G)$ are the homology groups of the chain complex

$$0 \longleftarrow C_c(G^{(0)}, \mathbb{Z}) \xleftarrow{\delta_1} C_c(G^{(1)}, \mathbb{Z}) \xleftarrow{\delta_2} C_c(G^{(2)}, \mathbb{Z}) \xleftarrow{\delta_3} \dots,$$

where $G^{(n)}$ is the space of composable strings of n elements.

For $\alpha = \pi_U \in [[G]]$, we have $\delta_1(1_U) = 0$, because $r(U) = s(U)$.
Thus 1_U is a 1-cycle.
We define the index map $I : [[G]] \to H_1(G)$ by $I(\alpha) = [1_U]$.
It is easy to see that I is a homomorphism.
Set $[[G]]_0 = \mathrm{Ker}\, I$.

We study the groups

$$D([[G]]) \subset [[G]]_0 \subset [[G]].$$

Examples of étale groupoids (1/3)

Let $\varphi : \Gamma \curvearrowright X$ be an essentially free action of a discrete group Γ on a Cantor set X.
$G_\varphi = \Gamma \times X$ is an étale groupoid with

$$(\gamma', \varphi_\gamma(x)) \cdot (\gamma, x) = (\gamma'\gamma, x), \quad (\gamma, x)^{-1} = (\gamma^{-1}, \varphi_\gamma(x)).$$

G_φ is called the transformation groupoid.
The unit space $G_\varphi^{(0)} = \{1\} \times X$ is identified with X.

$[[G_\varphi]]$ consists of $\alpha \in \mathrm{Homeo}(X)$ for which there exists a continuous map $c : X \to \Gamma$ such that $\alpha(x) = \varphi_{c(x)}(x)$ $\forall x \in X$.

$H_n(G_\varphi)$ are canonically isomorphic to the group homology $H_n(\Gamma, C(X, \mathbb{Z}))$.

Examples of étale groupoids (2/3)

Let $(\mathcal{V}, \mathcal{E})$ be an irreducible finite directed graph and let M be the adjacency matrix.

Set

$$X = \{(x_k)_k \in \mathcal{E}^{\mathbb{N}} \mid t(x_k) = i(x_{k+1}) \quad \forall k \in \mathbb{N}\},$$

Let $\sigma : X \to X$ be the shift, i.e. $\sigma((x_k)_k) = (x_{k+1})_k$.

(X, σ) is a one-sided shift of finite type (SFT).

Examples of étale groupoids (3/3)

Set

$$G = \left\{ (x,n,y) \in X \times \mathbb{Z} \times X \mid \exists k,l \in \mathbb{N},\ n = k-l,\ \sigma^k(x)=\sigma^l(y) \right\}.$$

G is an étale groupoid with

$$(x,n,y)\cdot(y,n',y') = (x,n+n',y'), \quad (x,n,y)^{-1} = (y,-n,x).$$

We call G an SFT groupoid.

We have

$$H_n(G) = \begin{cases} \mathrm{Coker}(\mathrm{id} - M^t) & n = 0 \\ \mathrm{Ker}(\mathrm{id} - M^t) & n = 1 \\ 0 & n \geq 2, \end{cases}$$

where M is acting on $\mathbb{Z}^{\mathcal{V}}$.

Isomorphism theorem

Theorem (M)

For minimal groupoids G_1 and G_2, the following are equivalent.

1. *G_1 is isomorphic to G_2 as an étale groupoid.*
2. *$[[G_1]]$ is isomorphic to $[[G_2]]$ as a group.*
3. *$[[G_1]]_0$ is isomorphic to $[[G_2]]_0$ as a group.*
4. *$D([[G_1]])$ is isomorphic to $D([[G_2]])$ as a group.*

This generalizes the result of T. Giordano, I. F. Putnam and C. F. Skau (for minimal $\mathbb{Z}$-actions) and the result of K. Matsumoto (for SFT groupoids). K. Medynets also obtains a similar result.
The proof is based on an algebraic characterization of transpositions in $[[G]]$.

Purely infinite groupoids

Definition (M)

G is said to be purely infinite if for any clopen set $A \subset G^{(0)}$ there exist G-sets $U, V \subset G$ such that $s(U) = s(V) = A$, $r(U) \cup r(V) \subset A$ and $r(U) \cap r(V) = \emptyset$.

A purely infinite groupoid G admits no invariant probability measures on $G^{(0)}$.

Lemma (M)

Any SFT groupoid G is purely infinite and minimal.

Simplicity of commutator subgroups

Theorem (M)

Suppose that G is either G_φ for $\varphi : \mathbb{Z}^N \curvearrowright X$ or purely infinite.

1. *The index map $I : [[G]] \to H_1(G)$ is surjective.*
2. *Assume further that G is minimal. Then $D([[G]])$ is simple.*

It follows that the abelianization $[[G]]_{\mathsf{ab}} = [[G]]/D([[G]])$ has $H_1(G) \cong [[G]]/[[G]]_0$ as its quotient.

We may think of $[[G]]_0$ and $D([[G]])$ as 'symmetric group' and 'alternating group' acting on the Cantor set.
This is the reason why $D([[G]])$ is simple.

Minimal $\mathbb{Z}$-actions

Theorem (M 2006)

Let $\varphi : \mathbb{Z} \curvearrowright X$ be a minimal $\mathbb{Z}$-action on a Cantor set X.

1. $[[G_\varphi]]_{\mathsf{ab}}$ *is isomorphic to* $(H_0(G_\varphi) \otimes \mathbb{Z}_2) \oplus \mathbb{Z}$.
2. $D([[G_\varphi]])$ *is finitely generated if and only if* φ *is expansive (i.e. two-sided subshift).*
3. $D([[G_\varphi]])$ *is never finitely presented.*

Theorem (K. Juschenko and N. Monod 2012)

Let $\varphi : \mathbb{Z} \curvearrowright X$ be a minimal $\mathbb{Z}$-action on a Cantor set X. Then $[[G_\varphi]]$ is amenable.

This provides the first examples of finitely generated simple amenable infinite groups.

Preliminaries

Let $(\mathcal{V},\mathcal{E})$, M and (X,σ) be as before.
The SFT groupoid of (X,σ) (or of M) is

$$G = \left\{(x,n,y) \in X \times \mathbb{Z} \times X \mid \exists k,l \in \mathbb{N},\ n = k-l,\ \sigma^k(x)=\sigma^l(y)\right\}.$$

Any element $\alpha \in [[G]] \subset \mathrm{Homeo}(X)$ is locally equal to a partial homeomorphism of the form

$$(e_1, e_2, \dots, e_k, x_1, x_2, \dots) \mapsto (f_1, f_2, \dots, f_l, x_1, x_2, \dots),$$

where $(e_1, e_2, \dots, e_k)$ and $(f_1, f_2, \dots, f_l)$ are paths on the graph $(\mathcal{V},\mathcal{E})$ such that $i(e_k) = i(f_l)$.

Matsumoto's classification theorem

For G and $Y \subset G^{(0)}$, we let $G|Y = \{g \in G \mid r(g), s(g) \in Y\}$ be the reduction of G to Y.

Theorem (K. Matsumoto 2011)

For $i = 1, 2$, let (X_i, σ_i) and M_i be as before. Let G_i be the étale groupoid for (X_i, σ_i) and let $Y_i \subset X_i$ be a clopen subset. If

$$\exists \varphi : H_0(G_1) \overset{\cong}{\to} H_0(G_2), \quad \varphi([1_{Y_1}]_{G_1}) = [1_{Y_2}]_{G_2},$$

$$\det(\mathrm{id} - M_1^t) = \det(\mathrm{id} - M_2^t),$$

then $G_1|Y_1 \cong G_2|Y_2$ as an étale groupoid.

We have:

- $\# H_0(G) = \infty \iff \det(\mathrm{id} - M^t) = 0$
- When $\# H_0(G) < \infty$, $\# H_0(G) = |\det(\mathrm{id} - M^t)|$.

Higman-Thompson groups

In 1965 R. Thompson gave the first example of a finitely presented infinite simple group. G. Higman and K. S. Brown later generalized it to infinite families $F_{n,r} \subset T_{n,r} \subset V_{n,r}$ for $n \in \mathbb{N} \setminus \{1\}$ and $r \in \mathbb{N}$.

The group $V_{n,r}$ consists of PL right continuous bijections $f : [0, r) \to [0, r)$ with finitely many singularities, all in $\mathbb{Z}[1/n]$, slopes lying in powers of n, and mapping $\mathbb{Z}[1/n] \cap [0, r)$ to itself. $V_{n,r}$ is called the Higman-Thompson group.

It is known that $V_{n,r}$ is finitely presented, $D(V_{n,r})$ is simple, and $V_{n,r}/D(V_{n,r})$ is trivial when n is even and is $\mathbb{Z}_2$ when n is odd.

$F_{n,r}$ is a subgroup of $V_{n,r}$ consisting of continuous maps f.
$F_{n,r}$ is also finitely presented.
It is not yet known if $F_{n,r}$ is amenable or not.

Nekrashevych's observation

Theorem (V. V. Nekrashevych 2004)

When (X, σ) is the full shift over n symbols, the topological full group $[[G]]$ is isomorphic to $V_{n,1}$.

The continuous map $\rho : \{0, 1, \ldots, n-1\}^{\mathbb{N}} \to [0, 1]$ defined by

$$\rho((x_k)_k) = \sum_{k=1}^{\infty} \frac{x_k}{n^k}$$

induces the isomorphism $[[G]] \cong V_{n,1}$.

$[[G]]$ for general SFT groupoids G may be thought of as a generalization of the Higman-Thompson group $V_{n,r}$.

The results

For G and $Y \subset G^{(0)}$, we let $G|Y = \{g \in G \mid r(g), s(g) \in Y\}$ be the reduction of G to Y.

Theorem (M)

Let G be an SFT groupoid and let $Y \subset X$ be a clopen set.

1. $[[G|Y]]$ *(and $[[G|Y]]_0$ and $D([[G|Y]])$) 'remembers' $G|Y$.*
2. $D([[G|Y]])$ *is simple.*
3. $[[G|Y]]$ *has the Haagerup property. (due to B. Hughes)*
4. $[[G|Y]]_{\mathrm{ab}}$ *is isomorphic to $(H_0(G) \otimes \mathbb{Z}_2) \oplus H_1(G)$.*
5. $[[G|Y]]$ *is of type F_∞, and hence is finitely presented.*
6. $[[G|Y]]_0$ *and $D([[G|Y]])$ are finitely generated.*

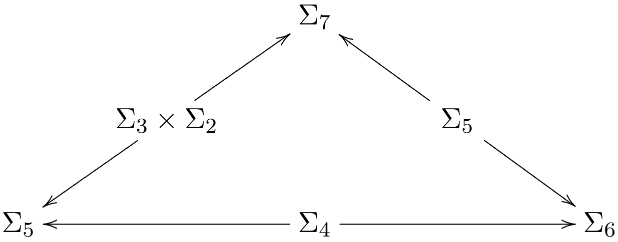
Brown's criterion

Theorem (K. S. Brown 1987)

Suppose that a group Γ admits a contractible Γ-complex Z such that the stabilizer of every cell is of type F_∞. Let $\{Z_q\}_{q\in\mathbb{N}}$ be a filtration of Z such that each Z_q is finite mod Γ. Suppose that the connectivity of the pair (Z_{q+1}, Z_q) tends to ∞ as q tends to ∞. Then Γ is of type F_∞.

Finite presentation (1/2)

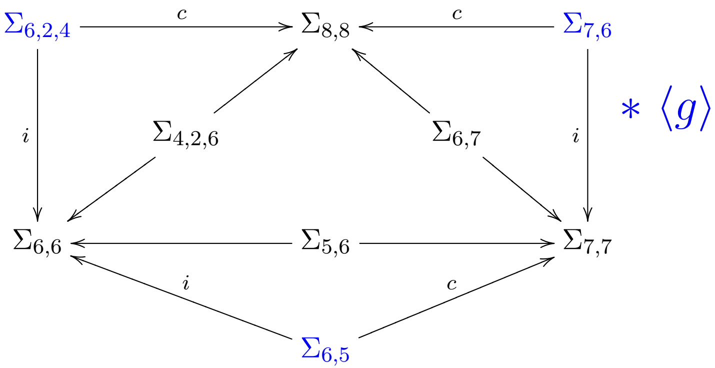
Let $M = [2]$ (i.e. the full shift over 2 symbols).
$[[G]]$ is the Higman-Thompson group $V_{2,1}$ and
it is described by the following diagram (due to K. S. Brown).



Finite presentation (2/2)

Let $M = \begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix}$. We have $H_0(G) = H_1(G) = \mathbb{Z}$.

$[[G]]$ is described as follows.



with relations " $g^{-1} i(\cdot) g = c(\cdot)$ "

References

- T. Giordano, I. F. Putnam and C. F. Skau, *Full groups of Cantor minimal systems*, Israel J. Math. 111 (1999), 285–320.
- K. Matsumoto, *Classification of Cuntz-Krieger algebras by orbit equivalence of topological Markov shifts*, to appear in Proc. Amer. Math. Soc.
- H. Matui, *Some remarks on topological full groups of Cantor minimal systems*, Internat. J. Math. 17 (2006), 231–251.
- H. Matui, *Homology and topological full groups of étale groupoids on totally disconnected spaces*, Proc. London Math. Soc. 104 (2012), 27–56.
- H. Matui, *Topological full groups of one-sided shifts of finite type*, preprint.
- J. Renault, *A Groupoid Approach to C^*-algebras*, Lecture Notes in Mathematics 793, Springer, Berlin, 1980.