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n–TRANSITIVITY OF CERTAIN DIFFEOMORPHISM GROUPS

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ABSTRACT. It is shown that some groups of diffeomorphisms of a manifold act n-transitively for each finite n.

Let M be a connected smooth manifold of dimension $\dim M \geq 2$. We say that a subgroup G of the group $\operatorname{Diff}(M)$ of all smooth diffeomorphisms acts **n-transitively on** M, if for any two ordered sets of n different points $(x_1, \dots, x_n)$ and $(y_1, \dots, y_n)$ in M there is a smooth diffeomorphism $f \in G$ such that $f(x_i) = y_i$ for each i.

Theorem. *Let M be a connected smooth (or real analytic) manifold of dimension $\dim M \geq 2$. Then the following subgroups of the group $\operatorname{Diff}(M)$ of all smooth diffeomorphisms with compact support act n-transitively on M, for each finite n:*

(1) *The group $\operatorname{Diff}_c(M)$ of all smooth diffeomorphisms with compact support.*
(2) *The group $\operatorname{Diff}^\omega(M)$ of all real analytic diffeomorphisms.*
(3) *If (M, σ) is a symplectic manifold, the group $\operatorname{Diff}_c(M, \sigma)$ of all symplectic diffeomorphisms with compact support, and even the subgroup of all globally Hamiltonian symplectomorphisms.*
(4) *If (M, σ) is a real analytic symplectic manifold, the group $\operatorname{Diff}^\omega(M, \sigma)$ of all real analytic symplectic diffeomorphisms, and even the subgroup of all globally Hamiltonian real analytic symplectomorphisms.*
(5) *If (M, μ) is a manifold with a smooth volume density, the group $\operatorname{Diff}_c(M, \mu)$ of all volume preserving diffeomorphisms with compact support.*
(6) *If (M, μ) is a manifold with a real analytic volume density, the group $\operatorname{Diff}^\omega(M, \mu)$ of all real analytic volume preserving diffeomorphisms.*
(7) *If (M, α) is a contact manifold, the group $\operatorname{Diff}_c(M, \alpha)$ of all contact diffeomorphisms with compact support.*
(8) *If (M, α) is a real analytic contact manifold, the group $\operatorname{Diff}^\omega(M, \alpha)$ of all real analytic contact diffeomorphisms.*

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Result (1) is folklore, the first trace is in [**8**]. The results (3), (5), and (7) are due to [**3**] for 1-transitivity, and to [**1**] in the general case. Result (2) is from [**7**]. We shall give here a short uniform proof, following an argument from [**7**]. That this argument suffices to prove all results was noted by the referee, many thanks to him.

Proof. Let us fix a finite $n \in \mathbb{N}$. Let $M^{(n)}$ denote the open submanifold of all n-tuples $(x_1, \dots, x_n) \in M^n$ of pairwise distinct points. Since M is connected and of dimension ≥ 2, each $M^{(n)}$ is connected.

The group $\operatorname{Diff}(M)$ acts on $M^{(n)}$ by the diagonal action, and we have to show, that any of the subgroups G described above acts transitively. We shall show below that for each G the G-orbit through any n-tuple $(x_1, \dots, x_n) \in M^{(n)}$ contains an open neighborhood of $(x_1, \dots, x_n)$ in $M^{(n)}$, thus any orbit is open; since $M^{(n)}$ is connected, there can then be only one orbit. $\square$

Lemma. *Let M be a real analytic manifold. Then for any real analytic vector bundle $E \to M$ the space $C^\omega(E)$ of real analytic sections of E is dense in the space $C^\infty(E)$ of smooth sections. In particular the space $\mathfrak{X}^\omega(M)$ of real analytic vector fields is dense in the space $\mathfrak{X}(M)$ of smooth vector fields, in the Whitney C^∞-topology.*

Proof. For functions instead of sections this is [**2**, Proposition 8]. Using results from [**2**] it can easily be extended to sections, as is done in [**6**, 7.5]. $\square$

The cases (2) *and* (1). We choose a complete Riemannian metric g on M and we let $(Y_{ij})_{j=1}^m$ be an orthonormal basis of $T_{x_i}M$ with respect to g, for all i. Then we choose real analytic vector fields X_k for $1 \leq k \leq N = nm$ which satisfy the following conditions:

$$
\begin{aligned}
&|X_k(x_i) - Y_{ij}|_g < \varepsilon && \text{for } k = (i-1)m + j,\\
&|X_k(x_i)|_g < \varepsilon && \text{for all } k \notin [(i-1)m+1, im],\\
&|X_k(x)|_g < 2 && \text{for all } x \in M \text{ and all } k.
\end{aligned}
\tag{9}
$$

Since these conditions describe a Whitney C^0 open set, such vector fields exist by the lemma. The fields are bounded with respect to a complete Riemannian metric, so they have complete real analytic flows Fl^{X_k}, see e.g. [**4**]. We consider the real analytic mapping

$$
\begin{aligned}
f\colon \mathbb{R}^N &\to M^{(n)}\\
f(t_1, \dots, t_N) &:= \begin{pmatrix} (\mathrm{Fl}^{X_1}_{t_1} \circ \dots \circ \mathrm{Fl}^{X_N}_{t_N})(x_1) \\ \dots \\ (\mathrm{Fl}^{X_1}_{t_1} \circ \dots \circ \mathrm{Fl}^{X_N}_{t_N})(x_n) \end{pmatrix}
\end{aligned}
$$

which has values in the $\operatorname{Diff}^\omega(M)$-orbit through $(x_1,\dots,x_n)$. To get the tangent mapping at 0 of f we consider the partial derivatives

$$\frac{\partial}{\partial t_k}\Big|_0 f(0,\dots,0,t_k,0,\dots,0) = (X_k(x_1),\dots,X_k(x_n)).$$

If $\varepsilon > 0$ is small enough, this is near an orthonormal basis of $T_{(x_1,\dots,x_n)}M^{(n)}$ with respect to the product metric $g\times\dots\times g$. So $T_0 f$ is invertible and the image of f contains thus an open subset.

In case (1), we can choose smooth vector fields X_k with compact support which satisfy conditions (9). □

For the remaining cases we just indicate the changes which are necessary in this proof.

The cases (4) *and* (3). Let (M,σ) be a connected real analytic symplectic smooth manifold of dimension $m \geq 2$. We choose real analytic functions f_k for $1 \leq k \leq N = nm$ whose Hamiltonian vector fields $X_k = \operatorname{grad}^\sigma(f_k)$ satisfy conditions (9). Since these conditions describe Whitney C^1 open subsets, such functions exist by [**2**, Proposition 8]. Now we may finish the proof as above. □

Contact manifolds.

Let M be a smooth manifold of dimension $m = 2n+1 \geq 3$. A **contact form** on M is a 1-form $\alpha \in \Omega^1(M)$ such that $\alpha\wedge(d\alpha)^n \in \Omega^{2n+1}(M)$ is nowhere zero. This is sometimes called an **exact** contact structure. The pair (M,α) is called a **contact manifold** (see [**5**]). The **contact vector field** $X_\alpha \in \mathfrak{X}(M)$ is the unique vector field satisfying $i_{X_\alpha}\alpha = 1$ and $i_{X_\alpha}d\alpha = 0$.

A diffeomorphism $f \in \operatorname{Diff}(M)$ with $f^*\alpha = \lambda_f\cdot\alpha$ for a nowhere vanishing function $\lambda_f \in C^\infty(M,\mathbb{R}\setminus 0)$ is called a **contact diffeomorphism**. Note that then $\lambda_f = i_{X_\alpha}(\lambda_f\cdot\alpha) = i_{X_\alpha}f^*\alpha = f^*(i_{(f^{-1})^*X_\alpha}\alpha) = f^*(i_{f_*X_\alpha}\alpha)$. The group of all contact diffeomorphisms will be denoted by $\operatorname{Diff}(M,\alpha)$.

A vector field $X\in\mathfrak{X}(M)$ is called a contact vector field if $\mathcal{L}_X\alpha = \mu_X\cdot\alpha$ for a smooth function $\mu_X \in C^\infty(M,\mathbb{R})$. The linear space of all contact vector fields will be denoted by $\mathfrak{X}_\alpha(M)$ and it is clearly a Lie algebra. Contraction with α is a linear mapping again denoted by $\alpha\colon \mathfrak{X}_\alpha(M)\to C^\infty(M,\mathbb{R})$. It is bijective since we may apply i_{X_α} to the equation $\mathcal{L}_X\alpha = i_X\,d\alpha + d\alpha(X) = \mu_X\cdot\alpha$ and get $0 + i_{X_\alpha}d\alpha(X) = \mu_X$; but the equation uniquely determines X from $\alpha(X)$ and μ_X. The inverse $f\mapsto \operatorname{grad}^\alpha(f)$ of $\alpha\colon\mathfrak{X}_\alpha(M)\to C^\infty(M,\mathbb{R})$ is a linear differential operator of order 1.

The cases (8) *and* (7). Let (M,α) be a connected real analytic contact manifold of dimension $m\geq 2$. We choose real analytic functions f_k for $1\leq k\leq N = nm$ such that their contact vector fields $X_k = \operatorname{grad}^\alpha(f_k)$ satisfy conditions (9).

Since these conditions describe Whitney C^1 open subsets, such functions exist by [**2**, Proposition 8]. Now we may finish the proof as above. $\square$

The cases (6) *and* (5). Let (M,μ) be a connected real analytic manifold of dimension $m \geq 2$ with a real analytic positive volume density. We can find a real analytic Riemannian metric γ on M whose volume form is μ. Then the divergence of a vector field $X \in \mathrm{Vect}(M)$ is $\operatorname{div} X = *d * X^\flat$, where $X^\flat = \gamma(X) \in \Omega^1(M)$ (here we view $\gamma\colon TM \to T^*M$) and $*$ is the Hodge star operator of γ. We also choose a complete Riemannian metric g.

First we assume that M is orientable. We choose real analytic $(m-2)$-forms β_k for $1 \leq k \leq N = nm$ such that the vector fields $X_k = (-1)^{m+1}\gamma^{-1} * d\beta_k$ satisfy conditions (9). Since these conditions describe Whitney C^1 open subsets, such $(m-2)$-forms exist by the lemma. The real analytic vector fields X_k are then divergence free since $\operatorname{div} X_k = *d*\gamma X_k = *dd\beta_k = 0$ Now we may finish the proof as usual.

For non-orientable M, we let $\pi\colon \tilde M \to M$ be the real analytic connected oriented double cover of M, and let $\varphi\colon \tilde M \to \tilde M$ be the real analytic involutive covering map. We let $\pi^{-1}(x_i) = \{x_i^1, x_i^2\}$, and we pull back both metrics to $\tilde M$, so $\tilde\gamma := \pi^*\gamma$ and $\tilde g := \pi^* g$. We choose real analytic $(m-2)$-forms $\beta_k \in \Omega^{m-2}(\tilde M)$ for $1 \leq k \leq N = nm$ whose vector fields $X_{\beta_k} = (-1)^{m+1}\tilde\gamma^{-1} * d\beta_k$ satisfy the following conditions, where we put $Y_{ij}^p := T_{x_{ij}^p}\pi^{-1} \cdot Y_{ij}$ for $p = 1, 2$:

$$
\begin{aligned}
&|X_{\beta_k}(x_i^p) - Y_{ij}^p|_{\tilde g} < \varepsilon && \text{for } k = (i-1)m + j, p = 1,2,\\
&|X_{\beta_k}(x_i^p)|_{\tilde g} < \varepsilon && \text{for all } k \notin [(i-1)m+1, im], p = 1,2,\\
&|X_{\beta_k}|_{\tilde g} < 2 && \text{for all } x \in \tilde M \text{ and all } k.
\end{aligned}
\tag{10}
$$

Since these conditions describe Whitney C^1 open subsets, such $(m-2)$-forms exist by the lemma. Then the vector fields $\frac{1}{2}(X_{\beta_k} + \varphi_* X_{\beta_k})$ still satisfy the conditions (10), are still divergence free and induce divergence free vector fields $Z_{\beta_k} \in \mathfrak{X}(M)$ which satisfy the conditions (9) on M as in the oriented case, and we may finish the proof as above. $\square$

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