Duistermaat – Heckman localisation formula and locus of vector fields.

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§0

About two years ago (summer 2012) Sasha Belavin explained how to calculate an integral

$$Z(t) = \int e^{t\, d_K \omega} \qquad (0.1)$$

(ω - 1-form, $d_K = d + \iota_K$). He ~~exp~~ showed first that this integral does not depend on t, then showed that it is localised at zeros of vector field K:

$$Z(t) \sim \frac{1}{\sqrt{\det \frac{\partial K}{\partial x}}}\Bigg|_{K=0}. \qquad (0.2)$$

It is typical localisation formula.

I tried to revive these calculations. ~~Hair~~ On one hand they are leading to Duistermaat – Heckman formula in more less general case.
On the other hand ~~we may discuss~~ it is interesting to analyze geometrical meaning of answer.

§1.

Two words about Duistermaat – Heckman localisation formula (DHL)-formula.

Let ~~M be compact manifold~~
(M^{2n}, Ω) be compact symplectic manifold

Let H be an Hamiltonian, such that the vector field

$$K = D_H : \quad \Omega \lrcorner D_H = -dH$$

is a compact vector field (i.e. it generates compact subgroup e^{tK} in the group of diffeomorphisms)

Then

$$\int \underbrace{\Omega^n}_{\underbrace{\Omega \wedge \dots \wedge \Omega}_{n\text{-times}}} e^{iH}$$ is localised at zero locus of vector field K and

$$\int \Omega^n e^{iH} = \sum_{x_i:\, K(x_i)=0} e^{\frac{i\pi}{4} \operatorname{sgn} H(x_i)} \frac{e^{iH(x_i)}}{\sqrt{\det \operatorname{Hess} H(x_i)}}$$

(we suppose that $K(x_i)$ are not-degenerate).

This is famous Duistermaat-Heckman formula.

We will consider here a special but very illuminating case of this formula.

[see in more detail the next file].

We consider now the following set up:

Let w be 1-form on M $(\dim M = 2n)$

such that $\Omega = dw$ defines symplectic structure.
(of course condition $\Omega = dw$ is in contradiction with compactness of M: $\int \Omega^n \neq 0$, but we ignore now this. E.g. we suppose that M is not compact)

Let K be a vector field such that

$$\mathcal{L}_K w = dw \lrcorner K + d(w \lrcorner K) = 0$$

Then it is evident that K is Hamiltonian vector field of $H = w \lrcorner K$

$$\Omega \lrcorner K = dw \lrcorner K = -d(w \lrcorner K) = -dH.$$

$$\begin{tikzcd} & w \arrow[dl, dash, "\Omega = d\Omega"'] \arrow[dr, dash, "H = w\lrcorner K"] & \\ \Omega & & H. \end{tikzcd}$$

$d_K w =$
$= (d + l_K) w =$
$= \Omega + H;$

We see that

$$\int \Omega^n e^{iH} = \int e^{iH + i\Omega} = \int e^{i d_K w}$$

We come to integral (0)

§ 2

Calculation of $\int e^{id_K w}$.

Consider

$$Z(t) = \int_M e^{itd_K w}$$ $\boxed{d_K^2 = \mathcal{L}_K}$

Show that $Z(t)$ does not depend on t.

$$\frac{dZ(t)}{dt} = i\int d_K w\, e^{itd_K w} =$$

$$= i\int_M d_K\left(w e^{itd_K w}\right) = i\int_M d\left(w e^{itd_K w}\right) = 0 \qquad (2.1)$$

(under some technical conditions),

[$\int \iota_K w = 0$ since form $\iota_K w$ has rank $\leq 2n-1$]

We see that $Z(t)$ does not depend on t.
Hence we can calculate $Z(t)$ at $t \to \infty$.

$$\int e^{itd_K w} = \int e^{it(\Omega + H)} =$$

$dw = \Omega$, $w \lrcorner K = H$. ($\mathcal{L}_K w = 0$)

$$= \sum \frac{i^n t^n}{n!}\int \Omega^n e^{itH} = \frac{i^m t^m}{m!}\int \Omega^m e^{itH} \qquad (2.2)$$

($\dim M = 2m$)

Calculate using stationary phase method:

$$dH = d(w \lrcorner K) = -dw \lrcorner K \qquad (2.3)$$

Locus of dH = locus of K

We see that at stationary point $dH = 0$ Hessian is:

$$\frac{\partial^2}{\partial x^i \partial x^k} H\Big|_{K=0} = \frac{\partial}{\partial x^i}\frac{\partial}{\partial x^k}(w_r K^r)\Big|_{K=0} = \frac{\partial}{\partial x^i}(\Omega_{kp} K^p) =$$

$$(d(w \lrcorner K) = -dw \lrcorner K)$$

$$= \underline{\Omega_{ip}\frac{\partial K^p}{\partial x^r}}$$

$$\underline{(H(x_i) = 0 \text{ for } K(x_i) = 0)}$$

Hence

$$\int \Omega^n e^{itH} \sim \sum \frac{\mathrm{Pf}\sqrt{\det\Omega}\, e^{itH(x_i)}}{\sqrt{\det\left(\Omega\cdot\frac{\partial K}{\partial x}\right)}} \sim$$

$$\sim \sum_{x_i} \frac{\cancel{e^{itH(x_i)}}\ 1}{\sqrt{\det\frac{\partial K}{\partial x}}}$$

Note: $\frac{\partial K}{\partial x}$ is linear operator at points where $K(x) = 0$

$L_K = \frac{\partial K}{\partial x}$: $L_K u = -[K, u]\big|$.

We see that answer does not depend on choise of $\underline{w}$.

$$\int \sim \frac{1}{\sqrt{\det\frac{\partial K}{\partial x}}}$$

Our formula is a special case of DHL formula. (In particular $H(x_i)=0$).
On the other hand this formula emphasizes the role of vector field K: It states that

$$\int e^{it(dW + L_K W)} = \sum_{x_i : K(x_i)=0} \frac{c}{\sqrt{\det \frac{\partial K}{\partial x}}}$$

depends only on K at locus in the case if W is an "arbitrary" K-invariant 1-form.
(of course dW is not-degenerate)

It is useful to study DHL formula in its supersymmetric manifestation.
(See 1. A. Nersessian. "Antibrackets and localisation of (path) integral." $\boxed{\text{JETP Lett. } \underline{58}, 1 (1993)}$
2. A. Schwarz, O. Zaboronsky "Supersymmetry and localization" CMP (1995 or 1996)

(See for details next etude)

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