

Linearization and Transversality

Sections 8.3 and 8.4

D. Zack Garza

April 2020

Linearization and
Transversality

D. Zack Garza

Review 8.2

Section 8.3: The
Space of
Perturbations of
 H

Section 8.4:
Linearizing the
Floer Equation:
The Differential
of F

Review 8.2

Linearization and
Transversality

D. Zack Garza

Review 8.2

Section 8.3: The
Space of
Perturbations of
 H

Section 8.4:
Linearizing the
Floer Equation:
The Differential
of F

Section 8.3: The Space of Perturbations of H

Goal

Linearization and
Transversality

D. Zack Garza

Review 8.2

Section 8.3: The
Space of
Perturbations of
H

Section 8.4:
Linearizing the
Floer Equation:
The Differential
of F

Goal: Given a fixed Hamiltonian $H \in C^\infty(W \times S^1; \mathbb{R})$, perturb it (without modifying the periodic orbits) so that $\mathcal{M}(x, y)$ are manifolds of the expected dimension.

Goal

Linearization and
Transversality

D. Zack Garza

Review 8.2

Section 8.3: The
Space of
Perturbations of
 H

Section 8.4:
Linearizing the
Floer Equation:
The Differential
of F

Start by trying to construct a subspace $\mathcal{C}_\varepsilon^\infty(H) \subset \mathcal{C}^\infty(W \times S^1; \mathbb{R})$, the space of perturbations of H depending on a certain sequence $\varepsilon = \{\varepsilon_k\}$, and show it is a dense subspace.



Define an Absolute Value

Linearization and
Transversality

D. Zack Garza

Review 8.2

Section 8.3: The
Space of
Perturbations of
H

Section 8.4:
Linearizing the
Floer Equation:
The Differential
of F

Idea: similar to how you build $L^2(\mathbb{R})$, define a norm $\|\cdot\|_\varepsilon$ on $C_\varepsilon^\infty(H)$ and take the subspace of finite-norm elements.

- Let $h(\mathbf{x}, t) \in C_\varepsilon^\infty(H)$ denote a perturbation of H .
- Fix $\varepsilon = \{\varepsilon_k \mid k \in \mathbb{Z}^{\geq 0}\} \subset \mathbb{R}^{>0}$ a sequence of real numbers, which we will choose carefully later.
- For a fixed $\mathbf{x} \in W$, $t \in \mathbb{R}$ and $k \in \mathbb{Z}^{\geq 0}$, define

$$|d^k h(\mathbf{x}, t)| = \max \left\{ d^\alpha h(\mathbf{x}, t) \mid |\alpha| = k \right\},$$

the maximum over all sets of multi-indices α of length k .

Note: I interpret this as

$$d^{\alpha_1, \alpha_2, \dots, \alpha_k} h = \frac{\partial^k h}{\partial x_{\alpha_1} \partial x_{\alpha_2} \cdots \partial x_{\alpha_k}},$$

the partial derivatives wrt the corresponding variables.

Define a Norm

- Define a norm on $C^\infty(W \times S^1; \mathbb{R})$:

$$\|h\|_{\infty} = \sum_{k \geq 0} \varepsilon_k \sup_{(x,t) \in W \times S^1} |d^k h(x, t)|.$$

- Since $W \times S^1$ is assumed compact (?), fix a finite covering $\{B_i\}$ of $W \times S^1$ such that

$$\bigcup_i B_i^\circ = W \times S^1.$$

- Choose them in such a way we obtain charts

$$\psi_i : B_i \longrightarrow \overline{B(0,1)} \subset \mathbb{R}^{2n+1} \quad (?).$$

- Obtain the computable form

$$\|h\|_{\infty} = \sum_{k \geq 0} \varepsilon_k \sup_{(x,t) \in W \times S^1} \sup_{i, z \in B(0,1)} |d^k (h \circ \psi_i^{-1})(z)|.$$

Define a Banach Space

Linearization and
Transversality

D. Zack Garza

Review 8.2

Section 8.3: The
Space of
Perturbations of
H

Section 8.4:
Linearizing the
Floer Equation:
The Differential
of F

- Define

$$C_\varepsilon^\infty = \left\{ h \in C^\infty(W \times S^1; \mathbb{R}) \mid \|h\|_\varepsilon < \infty \right\} \subset C^\infty(W \times S^1; \mathbb{R}),$$

which is a Banach space (normed and complete).

- Show that the sequence $\{\varepsilon_k\}$ can be chosen so that C_ε^∞ is a *dense* subspace for the C^∞ topology, and in particular for the C^1 topology.

Theorem

Such a sequence $\{\varepsilon_k\}$ can be chosen.

Lemma

$C^\infty(W \times S^1; \mathbb{R})$ with the C^1 topology is separable as a topological space (contains a countable dense subset).

Sketch Proof of Theorem

Linearization and
Transversality

D. Zack Garza

Review 8.2

Section 8.3: The
Space of
Perturbations of
H

Section 8.4:
Linearizing the
Floer Equation:
The Differential
of F

- By the lemma, produce a sequence $\{f_n\} \subset C^\infty(W \times S^1; \mathbb{R})$ dense for the C^1 topology.
- Using the norm on $C^n(W \times S^1; \mathbb{R})$ for the f_n , define

$$\frac{1}{\varepsilon_n} = 2^n \max \left\{ \|f_k\| \mid k \leq n \right\} \implies \varepsilon_n \sup |d^n f_k(x, t)| \leq 2^{-n}$$

which is summable.

Why does this imply density? I don't know.

Modified Theorem

Linearization and
Transversality

D. Zack Garza

Review 8.2

Section 8.3: The
Space of
Perturbations of
H

Section 8.4:
Linearizing the
Floer Equation:
The Differential
of F

The next proposition establishes a version of this theorem with compact support:

Theorem

For any $(\mathbf{x}, t) \in U \in W \times S^1$ there exists a $V \subset U$ such that every $h \in C^\infty(W \times S^1; \mathbb{R})$ can be approximated in the C^1 topology by functions in C_ε^∞ supported in U .

Then fix a time-dependent Hamiltonian H_0 with nondegenerate periodic orbits and consider

$$\left\{ h \in C_\varepsilon^\infty(H_0) \mid h(x, t) = 0 \text{ in some } U \supseteq \text{the 1-periodic orbits of } H_0 \right\}$$

Then $\text{supp}(h)$ is “far” from $\text{Per}(H_0)$, so

$$\|h\|_\varepsilon \ll 1 \implies \text{Per}(H_0 + h) = \text{Per}(H_0)$$

and are both nondegenerate.

Linearization and
Transversality

D. Zack Garza

Review 8.2

Section 8.3: The
Space of
Perturbations of
 H

Section 8.4:
Linearizing the
Floer Equation:
The Differential
of F

Section 8.4: Linearizing the Floer Equation: The Differential of F

Goal

Linearization and
Transversality

D. Zack Garza

Review 8.2

Section 8.3: The
Space of
Perturbations of
H

Section 8.4:
Linearizing the
Floer Equation:
The Differential
of F

Choose $m > n = \dim(W)$ and embed $TW \hookrightarrow \mathbb{R}^m$ to identify tangent vectors (such as Z_i , tangents to W along u or in a neighborhood B of u) with actual vectors in \mathbb{R}^m .

Why? Bypasses differentiating vector fields and the Levi-Cevita connection.

We can then identify

$$\mathrm{im} \mathcal{F} = C^\infty(\mathbb{R} \times S^1; \mathbb{R}^m) \quad \text{or} \quad L^p(\mathbb{R} \times S^1; W),$$

and we seek to compute its differential $d\mathcal{F}$.

We've just replaced the codomain here.

Definitions

Linearization and
Transversality

D. Zack Garza

Review 8.2

Section 8.3: The
Space of
Perturbations of
 H

Section 8.4:
Linearizing the
Floer Equation:
The Differential
of F

Recall that

- x, y are contractible loops in W that are nondegenerate critical points of the action functional \mathcal{A}_H ,
- $u \in \mathcal{M}(x, y) \subset C_{\text{loc}}^\infty$ denotes a fixed solution to the Floer equation,
- $C_{\searrow}(x, y)$ was the set of solutions $u : \mathbb{R} \times S^1 \rightarrow W$ satisfying some conditions.

Recall:

$$C_{\searrow}(x, y) := \{u \in C^\infty(\mathbb{R} \times S^1; W) \mid \lim_{s \rightarrow -\infty} u(s, t) = x(t), \lim_{s \rightarrow \infty} u(s, t) = y(t), \left| \frac{\partial u}{\partial t}(s, t) \right| \text{ and } \left| \frac{\partial u}{\partial t}(s, t) - X_H(u(s, t)) \right| \rightarrow 0\}$$