Systolic inequality on Riemannian manifolds with bounded Ricci curvature

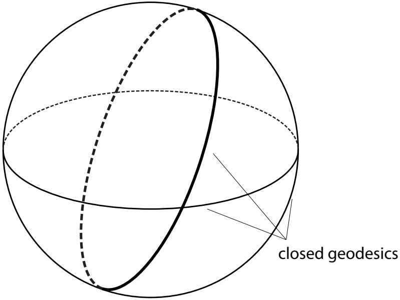
Zhifei Zhu

Seminar talk at Lanzhou University

2024.11.22

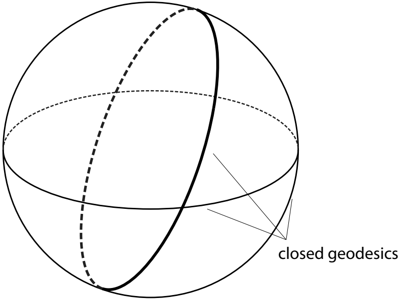
Definition

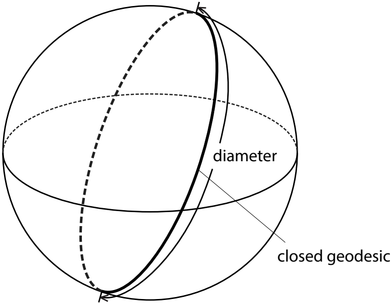
The systole sys(M) is the least length of a non-trivial closed geodesic.



Definition

The systole sys(M) is the least length of a non-trivial closed geodesic.





Loewner inequality

Suppose that M is homeomorphic to T^2,

$$sys^2 \leq \frac{2}{\sqrt{3}} Area(M)$$

Loewner inequality

Suppose that M is homeomorphic to T^2,

$$sys^2 \leq \frac{2}{\sqrt{3}} Area(M)$$

Pu's inequality (1949)

Suppose that M is homeomorphic to $\mathbb{R}P^2$,

$$sys^2 \leq \frac{\pi}{2} Area(M)$$

C. Croke (88), (improved by A. Nabutovsky-R. Rotman(02), S. Sabourau(04), and Rotman(06))

Suppose that M is homeomorphic to S^2,

$$sys^2 \leq 32Area(M)$$

C. Croke (88), (improved by A. Nabutovsky-R. Rotman(02), S. Sabourau(04), and Rotman(06))

Suppose that M is homeomorphic to S^2,

$$sys^2 \leq 32 Area(M)$$

Conjecture. (E. Calabi, J. Cao (92); Croke (88))

The best constant is $2\sqrt{3}$.

Question. (M. Gromov (83))

Is it true that the systole of an n-dimensional Riemannian manifold can be bounded by constant(n)vol$(M)^{1/n}$?

Remark.

Similar questions can be asked about diameter and other geometric quantities. Note that if M is not simply-connected, then an upper-bound of systole in terms of diameter is trivial.

Example. (F. Balacheff, C. Croke and M. Katz (09))

There exists (Zoll) Riemannian metric on S^2 such that $sys > 2D$, where D is the diameter.

Example. (F. Balacheff, C. Croke and M. Katz (09))

There exists (Zoll) Riemannian metric on S^2 such that $sys > 2D$, where D is the diameter.

Croke (88) (9D), improved by M. Maeda (94) (5D), Sabourau(04) (4D), and Nabutovsky-Rotman(09) (4D)

Suppose that M is homeomorphic to S^2,

$$sys \leq 4D$$

Higher dimensional manifolds, Nabtovsky-Rotman (03)

Let M be a closed Riemannian manifold with sectional curvature ≤ 1 and volume $\leq V$. Then

$$sys \leq 2\pi(V+1)^{c(n)V^n}.$$

Higher dimensional manifolds, Nabtovsky-Rotman (03)

Let M be a closed Riemannian manifold with sectional curvature ≤ 1 and volume $\leq V$. Then

$$sys \leq 2\pi(V+1)^{c(n)V^n}.$$

Nabtovsky-Rotman (03)

Let M be a closed Riemannian manifold with sectional curvature ≥ -1, diam $\leq D$ and volume $\geq V > 0$. Then

$$sys \leq exp(\frac{exp(c_1(n)D)}{min\{1, V\}^{c_2(n)}}).$$

N. Wu and Z. (19)

Let M be a closed simply-connected 4-dimensional Riemannian manifold with Ricci curvature $|Ric| < 3$, diam $\leq D$ and volume $\geq V > 0$. Then

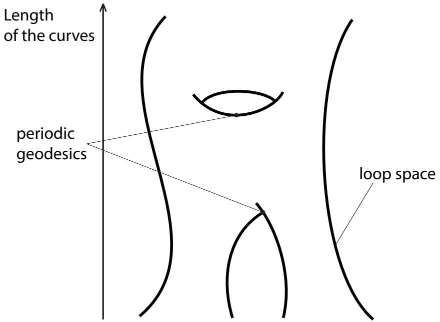
$$sys \leq F(V, D).$$

Moreover, F can be explicitly computed if M is Einstein.

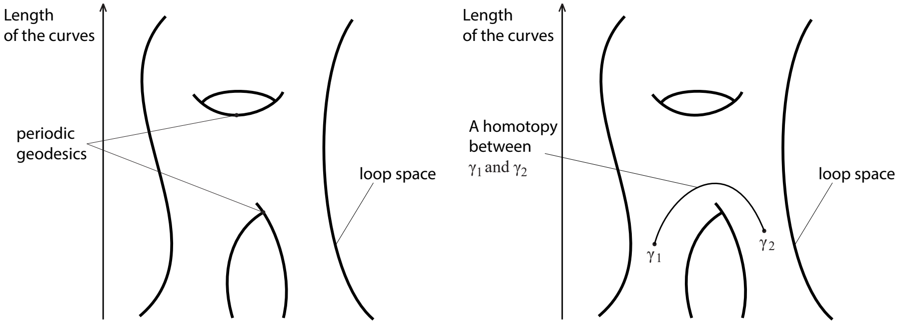
Intuition

- Morse theory
- Width of a homotopy
- Cheeger-Naber Structural theorem

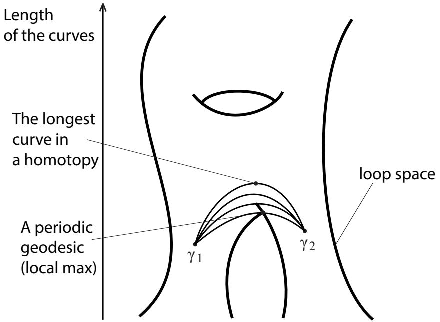
Morse theory (Lusternik-Fet)

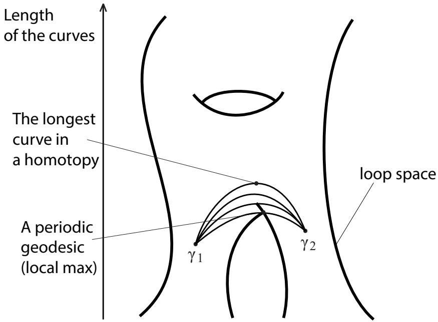


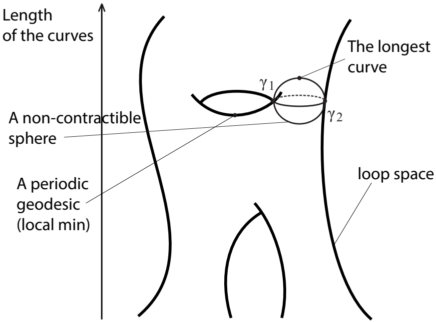
Morse theory (Lusternik-Fet)



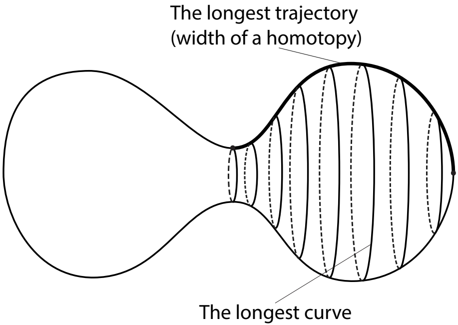
Morse theory



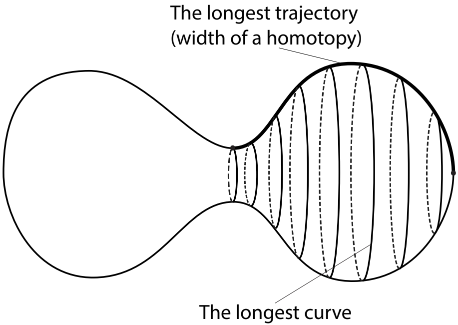

Length
of the curves
The longest
curve in
a homotopy
A periodic
geodesic
(local max)
γ1
γ2
loop space


Length
of the curves
The longest
curve
γ1
γ2
A non-contractible
sphere
A periodic
geodesic
(local min)
loop space

Width of a homotopy



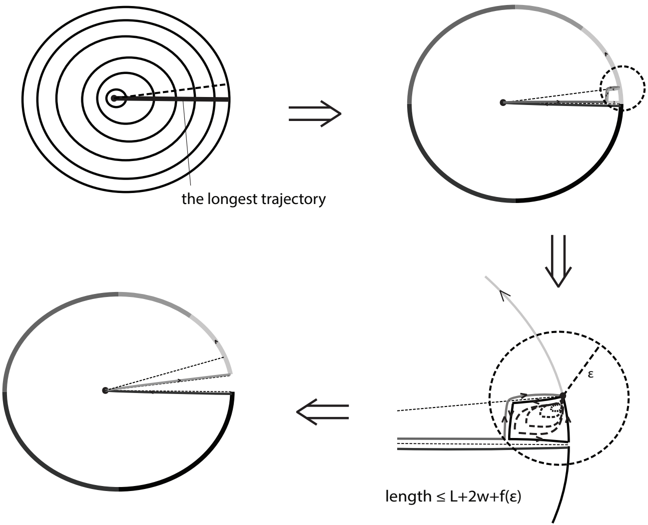
Width of a homotopy



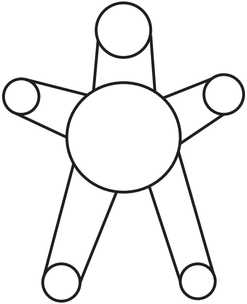
Lemma. (Alex Nabutovsky and Regina Rotman)

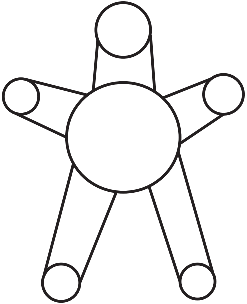
Control of the width. $\Rightarrow$ Control of the longest curve during a homotopy.

Width of a homotopy

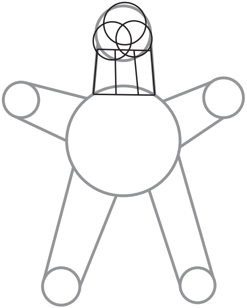


Structural theorem (Jeff Cheeger and Aaron Naber, 2015)



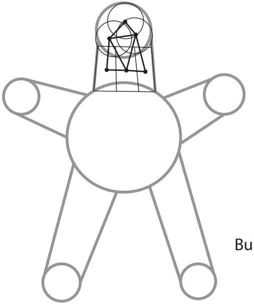


A manifold
(with body and
neck regions)



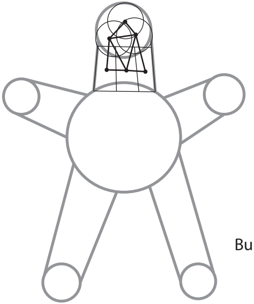
A manifold
covered by
“good sets”

Structural theorem

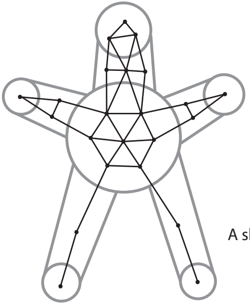


Build a skeleton

Structural theorem

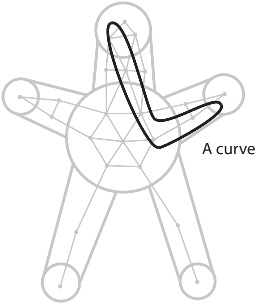


Build a skeleton

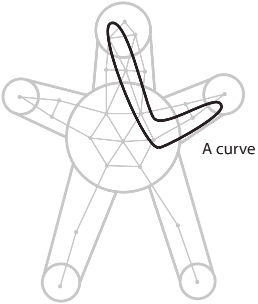


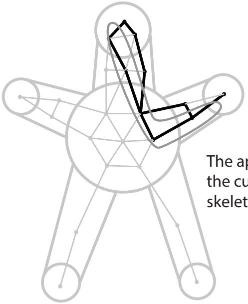
A skeleton

Structural theorem

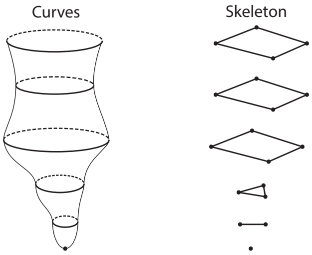


Structural theorem

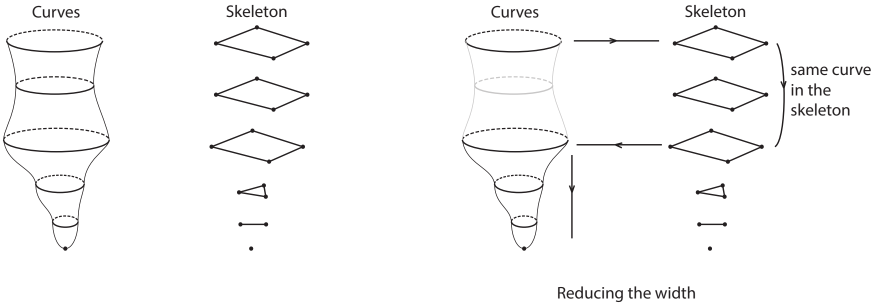




Structural theorem



Structural theorem



Difficulty

The number of the edges in the approximation of $\gamma \sim \frac{\text{length}(\gamma)}{r_h}$ may not be bounded by any function of v and D.

Difficulty

The number of the edges in the approximation of $\gamma \sim \frac{\text{length}(\gamma)}{r_h}$ may not be bounded by any function of v and D.

Observation 1

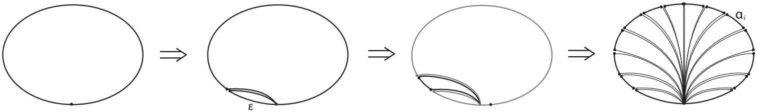
Every closed curve is homotopic to a wedge of "almost" geodesic digons α_i through a homotopy of width bounded by $2D + \varepsilon$.

Difficulty

The number of the edges in the approximation of $\gamma \sim \frac{\text{length}(\gamma)}{r_h}$ may not be bounded by any function of v and D.

Observation 1

Every closed curve is homotopic to a wedge of "almost" geodesic digons α_i through a homotopy of width bounded by $2D + \varepsilon$.



γ is homotopic to Vᵢαᵢ

Observation 2

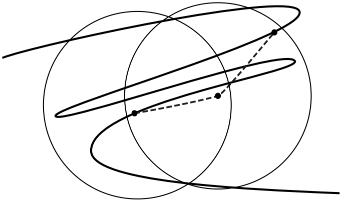
If each α_i can be contracted to a point with width $< W_i$, then $\vee\alpha_i$ can be contracted with width $2 \cdot \max_i W_i$.

Observation 2

If each α_i can be contracted to a point with width $< W_i$, then $\vee \alpha_i$ can be contracted with width $2 \cdot \max_i W_i$.

Observation 3

The number of the edges in the approximation of a minimizing geodesic must be small (≤ 5).



Summary

- Morse theory on the loop space & Sweep-out of the manifold.
- Width of a homotopy: geometrically approachable.
- Cheeger-Naber Structural theorem: may compute width via combinatorics.