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There are arbitrarily large minimal 2-pinning configurations

Xavier Goaoc* Hyo-Sil Kim† Jung-Gun Lim‡

Let ℓ be a line and \mathcal{C} a collection of disjoint convex sets in \mathbb{R}^d . We say that ℓ is a *transversal* to \mathcal{C} if it intersects each of its members and that \mathcal{C} *pins* ℓ if, in addition, no arbitrarily small perturbation of ℓ is a transversal to \mathcal{C} . We say that \mathcal{C} *k-pins* ℓ if for any k -flat Π containing ℓ , $\Pi \cap \mathcal{C}$ pins ℓ in Π (so pinning and d -pinning are the same in \mathbb{R}^d). A *minimal k-pinning configuration* is a pair (ℓ, \mathcal{C}) where \mathcal{C} k -pins ℓ but no proper subset of \mathcal{C} does.

When \mathcal{C} consists of disjoint balls, all its transversal that meet the balls in the same order make up a connected set in line space [1]. So, by continuity, \mathcal{C} pins ℓ if and only if no other transversal to \mathcal{C} realizes the same order as ℓ . Since two lines span a space of dimension at most 3, this implies that \mathcal{C} pins ℓ if and only if it 3-pins it. As a consequence, all minimal 3-pinning configurations of disjoint balls in \mathbb{R}^d have size at most $2d - 1$ [1, 2]. Here, we prove that the situation is different for 2-pinning:

Theorem 1. *A minimal 2-pinning configuration of size $n \geq 6$ in \mathbb{R}^3 exists if and only if n is even.*

For simplicity we assume that the objects are smooth, e.g. balls. Our proof is essentially combinatorial:

1. Sign sequence. Let ℓ be an oriented line in \mathbb{R}^2 tangent to O_1, \dots, O_n in that order. Its *sign sequence* is a word in $\{-, +\}^n$ where the i^{th} letter is $+$ if and only if O_i is on the right of ℓ .

2. Encoding. We now return to 3-space, assume that \mathcal{C} 2-pins ℓ and choose some arbitrary orientation on ℓ . The tangent planes to the objects of \mathcal{C} at their contact point with ℓ partition the space into n sectors. For all planes containing ℓ lying in the same sector, the sign sequence of the associated planar configuration is the same (up to exchanging $-$ and $+$). We denote by $\sigma_0, \dots, \sigma_{n-1}$ the sign sequences obtained successively as we go through all sectors around ℓ .

3. Translating geometric properties. The family $(\sigma_0, \dots, \sigma_{n-1})$ corresponds to a geometric configuration (\mathcal{C}, ℓ) if and only if (1) there exists a permutation π of $\{1, \dots, n\}$ such that σ_i differs from $\sigma_{i-1[n]}$ from the inversion of its $\pi(i)^{\text{th}}$ letter. Then, observe that \mathcal{C} 2-pins ℓ if and only if (2) every σ_i contains an alternating triple. Last, notice that no proper subset of \mathcal{C} 2-pins ℓ if and only if (3) for any $1 \leq i \leq n$ there is some t such that σ_t loses all alternating triples if its i^{th} letter is deleted.

4. Wrapping up. For odd n , rules (1)–(3) are incompatible. For even n , the sequence defined by

$$\sigma_0 = + - +^{n-2} \quad \text{and} \quad \pi = (4, 1, 6, 3, 8, 5, \dots, n, n-3, 2, n-1)$$

satisfies rules (1)–(3) and thus corresponds to a minimal 2-pinning configuration.

References

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