From Caging to Grasping

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Alberto Rodriguez, Matthew T. Mason and Steve Ferry

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Caging

I. Non-prehensile manipulation.

II. Waypoint to a grasp.
Caging

I. Non-prehensile manipulation.

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Caging

I. Non-prehensile manipulation.

II. Waypoint to a grasp.
From Caging to Grasping

- Two-fingered manipulators:
  - ✓ Squeezing and Stretching conditions.
  - ✓ Infallible strategy to reach a grasp.
  - ✓ All two-finger cages are "pre-grasping" cages.
Two-Finger Caging

Generalize over:
- Workspace dimension.
- Object shape.
- Finger number.

- Robots have more than 2 fingers.
- Robots do not have point fingers.
N-Finger Caging

✓ Can we always infallibly grasp an object beginning from a cage?
N-Finger Caging

✓ Can we always infallibly grasp an object beginning from a cage?
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N-Finger Caging

✓ Can we always infallibly grasp an object beginning from a cage?

✓ Not all cages are "pre-grasping" cages.

Game Over
Game Over?
Game Over?
✓ Differentiate between “good” and “bad” cages.
✓ Rethink what caging means.
### Game Over?

<table>
<thead>
<tr>
<th>Move as a Rigid body</th>
<th>2 fingers</th>
<th>N fingers</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>All cages are “pre-grasping” cages</strong></td>
<td><strong>All D-cages are “pre-grasping” cages</strong></td>
<td><strong>Not all cages are “pre-grasping” cages</strong></td>
</tr>
<tr>
<td><strong>Preserve distance D between fingers</strong></td>
<td><strong>All F-cages are “pre-grasping” cages</strong></td>
<td></td>
</tr>
</tbody>
</table>
Caging Revisited

2-fingers

\[ D : \mathcal{M}_2 \rightarrow \mathbb{R} \]

\[ D^{-1}(d_0) \]

No escape path while \( D = d_0 \)

No escape path while \( D \leq d_0 \) or \( d_0 \leq D \)

N-fingers

\[ F : \mathcal{M}_n \rightarrow \mathbb{R} \]

\[ F^{-1}(f_0) \]

No escape path while \( F = f_0 \)

No escape path while \( F \leq f_0 \) or \( f_0 \leq F \)

Note: Equivalent if \( n = 2 \) and \( F = D \).
Theorem

If object is a standard topological ball

All $F$-cages are either $F$-squeezing, $F$-stretching, or both.
Corollary

All $F$-cages are “pre-grasping” cages.

- Conditions on the object:
  - ✓ Standard topological ball.
  - ✓ Piecewise smooth boundary.

- Conditions of $F$:
  - ✓ Arbitrarily large/small values map to non-caging.
  - ✓ Semialgebraic.
F - Example I

- Energy of finger formation:

\[ F = \frac{1}{2} \sum_{i,j \in 1 \ldots n, i \neq j} d^2(p_i, p_j) \]

**F-squeezing cage if** \( F < 2d_c^2 \)
F - Example II

- Maximum finger-finger distance:

\[ F_{\text{max}} = \max_{i,j \in 1 \ldots n} d(p_i, p_j) \]

- \( F_{\text{max}} \)-squeezing cage if \( F_{\text{max}} < d_c \)
• Minimum finger-finger distance:

\[ F_{\text{min}} = \min_{i,j \in 1\ldots n} d(p_i, p_j) \]

\[ F_{\text{min}} \text{-stretching cage if } F_{\text{min}} > d_c \]
Summary

• Pre-grasping cages:
  ✓ Some cages better than others to grasp an object.

• Revisited caging definition:
  ✓ Introduced scalar functions F.
  ✓ All F-cages are pre-grasping cages.
  ✓ Keep the cage: Maintain value of F.
  ✓ Grasp the object: Increase/decrease F.

\[
F\text{-cages} \subseteq \text{Pre-grasping cages} \subsetneq \text{Cages}
\]
Possible Applications

• Decentralized caging control.

• Caging with other than points or disks.

• General vs. tuned F.

• Caging driven grasping:
  ✓ Pick a grasp of an object.
  ✓ Find a suitable F.
  ✓ Open/close the grasp to find a maximal F-cage.
  ✓ Grasp the object beginning from the F-cage.