Assembly Planning from Observations under Physical Constraints

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Willow team

- Originally, **computer vision and image processing** team
- More recently, moving towards **robotics**
- Based in building C, 4th floor
Espace Robotique (Building C, 5th floor)
The subject:

Assembly Planning from Observations under Physical Constraints
Assembly planning?

- Put **primitives together with a robot**
Assembly planning from observations?
Not a new topic

Winston et al., early 1970s
“Minsky Copy Demo”
Difficulties

Both cases: **errors to handle**
Our problem
First step: understand the target

- **Target** = set of rigid objects
- **Contacts** between objects
- Objects have **6D poses**

⇒ **6D object pose estimation**

CosyPose on assemblies

- But often **failures due to occlusions**
Method overview

Inputs

(a) Object detection + 6D Pose estimation

Target Image

Available primitives

Poses of visible objects V
Task planning: STRIPS

**Predicates**
- `OnTable(a)`
- `Clear(a)`
- `Rot(a)`
- `On(a, b)`
- `OnAlongX(a, b, c)`
- `OnAlongY(a, b, c)`

**Operators**
- `PutOn(a, b)`
  - **Precond:** `Clear(a) □ Clear(b) □ OnTable(a)`
  - **Postcond:** `Clear(a) □ On(a, b)`
- `PutOnAlongX(a, b, c)`
  - **Pre:** `Clear(a) □ OnTable(a)`
  - **Post:** `Clear(a) □ OnAlongX(a, b, c)`
- `PutOnAlongY(a, b, c)`
  - **Pre/Post:** …
- `Rotate(a)`
  - **Pre/Post:** …
From operators to equilibrium constraints

Poses of primitives $\{q^P_i\}_{i \in P} \Rightarrow$ Set of constraints $C(q^P_1, \ldots, q^P_N) \leq 0$
Formulating the goal

\[
\begin{align*}
\min & \quad \sum_{i \in V} \| q_i^P - q_i^V \|_2^2 \\
\text{s.t.} & \quad C(q_1^P, \ldots, q_N^P) \leq 0
\end{align*}
\]

- Poses of all available objects
- Only previously seen objects
- Pose errors

Match the reconstruction with the target

Ensure we build a stable structure

Equilibrium constraints
Method overview

Inputs

Object detection + 6D Pose estimation

Poses of visible objects $V$

Available primitives

Physically-constrained assembly

State → Physical constraints → Opti Solver + Interpenetration Removal → Completed poses
Method overview

Inputs

Target Image

Available primitives

Object detection + 6D Pose estimation

Poses of visible objects $V$

Physically-constrained assembly

State  \rightarrow  \text{Physical constraints}  \rightarrow  \text{Opti Solver + Interpenetration Removal}  \rightarrow  \text{Completed poses}

Reward computation

4 / 4 Reward
Monte-Carlo tree search
Summary of the method

(a) Object detection + 6D Pose estimation

(b) Monte Carlo tree search

(c) Physically-constrained assembly

(d) Reward computation
Results
Some reconstructions
Evaluation on the robot

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Conclusion

- Method connecting **several fields**:
  - Task planning
  - 6D Pose estimation
  - Convex optimization
- Combine vision and robotics with **robustness**
  - Provide **guarantees, interpretable** model
- Still, robotics is tough
  - ⇒ **Hence our research**
Thank you for your attention!


https://www.di.ens.fr/willow/research/assembly-planning/
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