

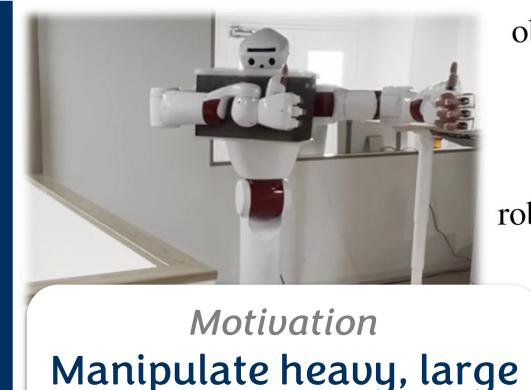


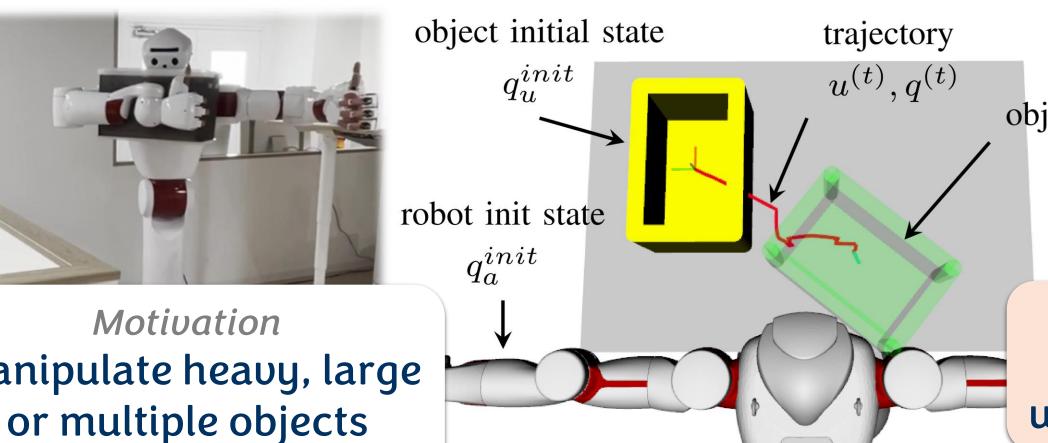
## Multi-contact Optimization for Whole-body Dexterity

Dexterous Humanoid Manipulation Workshop

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Overview





object goal state

Challenge How to drive robot to efficient contact locations

manual/random contact sampling robot manipulability

State-of-the-art

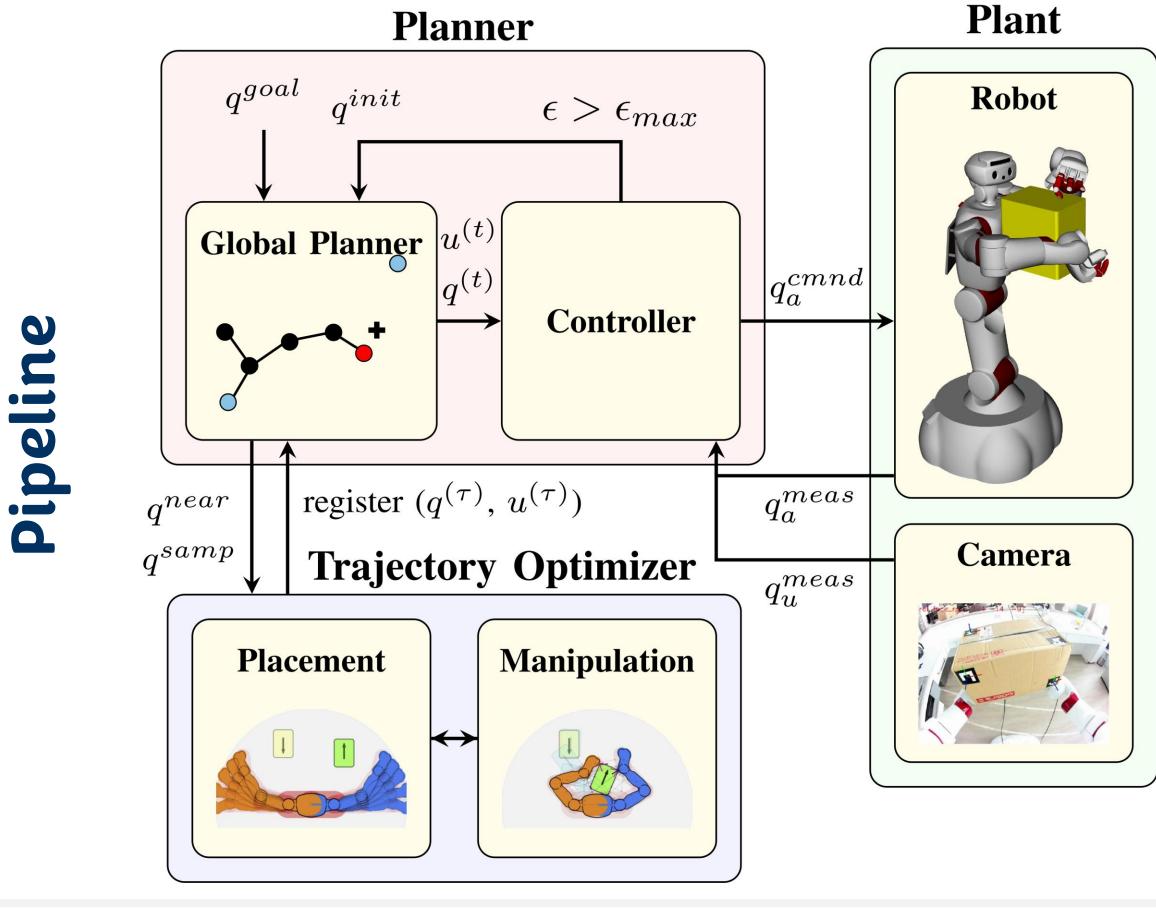
Slow convergence High variation Scalability issue

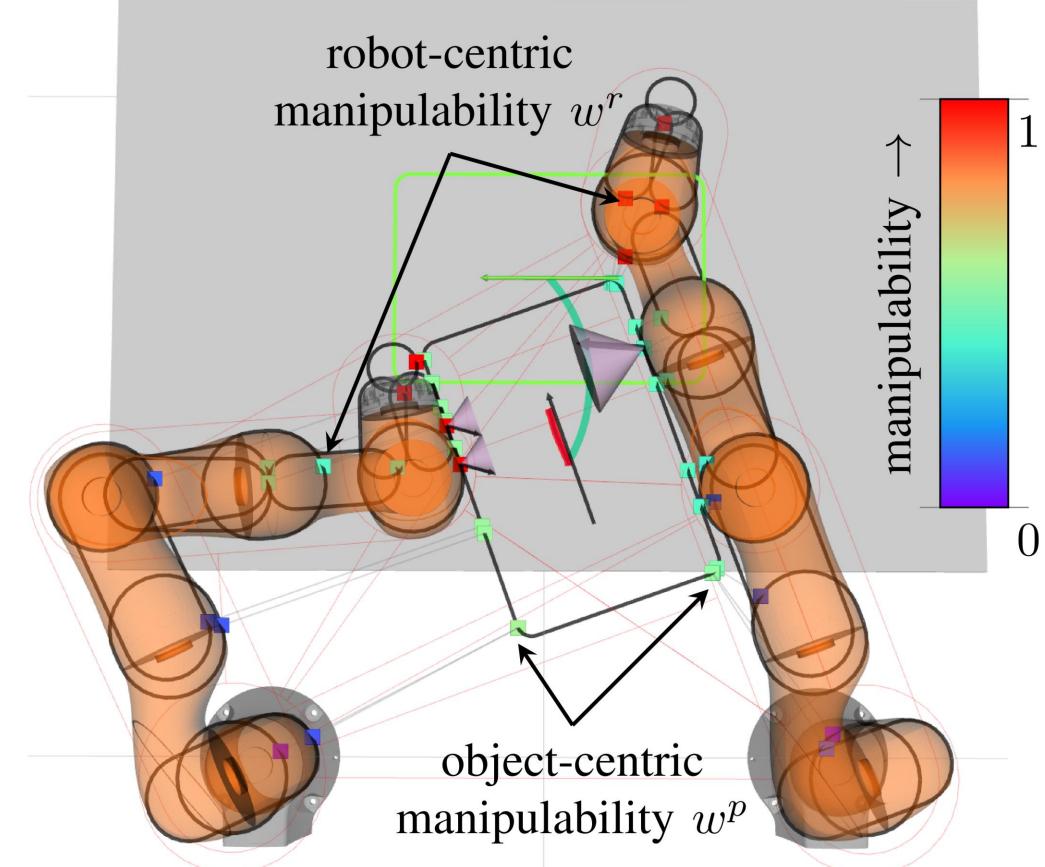
Results 77% faster planning Higher success rate More repeatability Hardware transfer

Problem Manipulate with whole-body surface

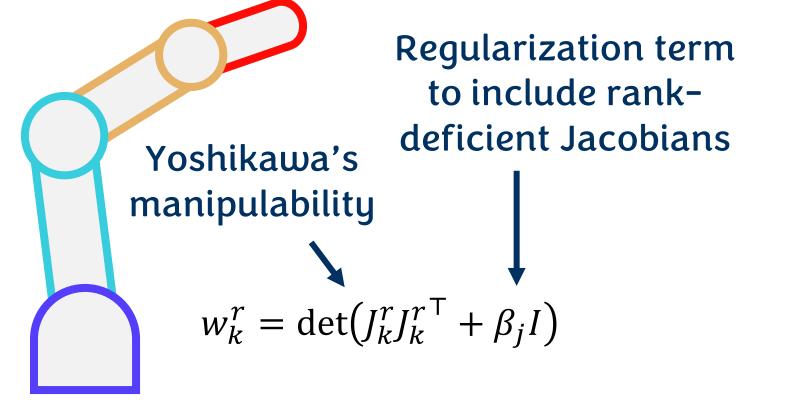
Our approach Contact optimization

Our contribution Cost design with object and robot manipulability

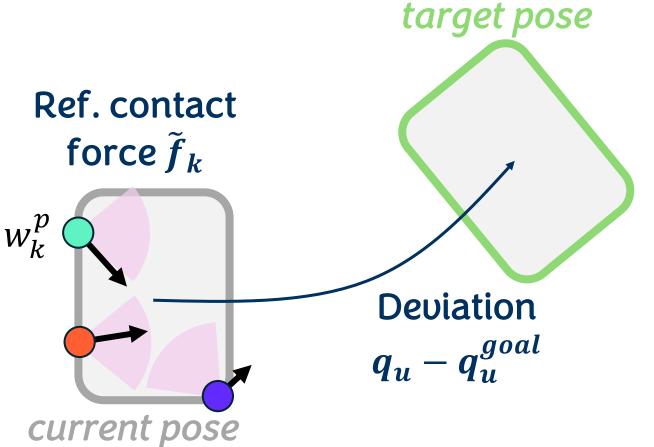


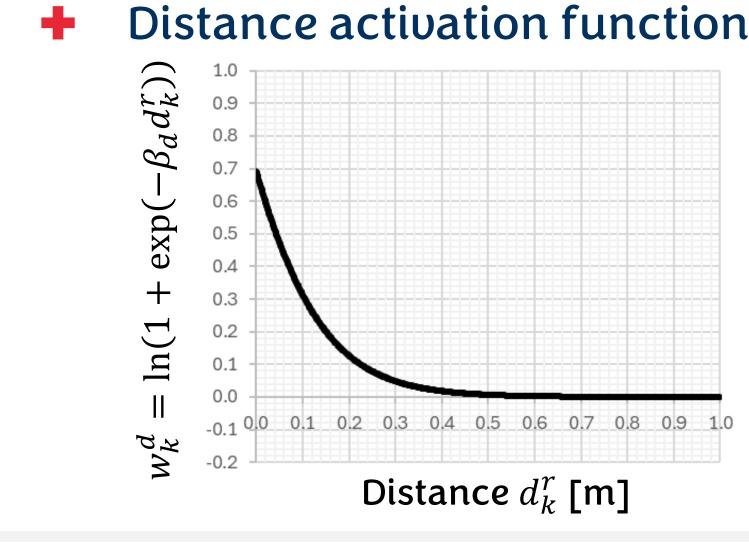


#### Distance activation function Object-centric manipulability



Robot-centric manipulability





### Trajectory Optimization Cost Design

$$\min_{u} \mathcal{G}_{p}(q^{N_{cf}}) + \mathcal{G}_{r}(q^{N_{cf}})$$
with  $q^{+} = q + \mathbf{M}^{-1}\mathbf{K}u$ 

$$\mathcal{G}_{p}(q) = -\beta_{p} \sum_{k \in \mathcal{C}} w_{k}^{p}(q)w_{k}^{d}(q)$$

$$\mathcal{G}_r(q) = -\beta_r \sum_{k \in \mathcal{C}} w_k^r(q) w_k^d(q)$$

$$w_k^d(q) = \ln\left(1 + \exp\left(-\beta_d d_k^r(q)\right)\right)$$

$$w_k^p(q) = \left(1 - \left(\frac{\phi_k(q)}{\pi}\right)^2\right) \left\langle \frac{\tilde{f}_k^n(q)}{f_{lim}} \right\rangle_0^1$$

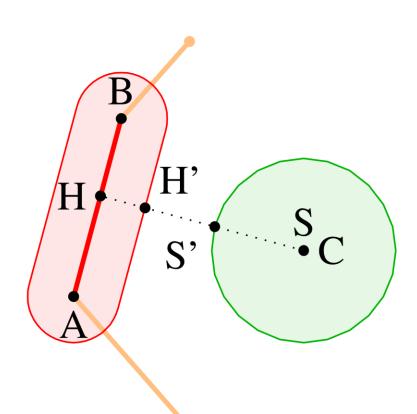
$$\frac{w_k^r(q) = \det(J_k^r(q)J_k^r(q)^\top + \beta_j I)}{\phi_k(q) = \arctan(\tilde{f}_k^t(q), \tilde{f}_k^n(q))}$$

$$\tilde{f}_k^n(q) = J_{u,k}^n(q)(q_u - q_u^{goal})$$

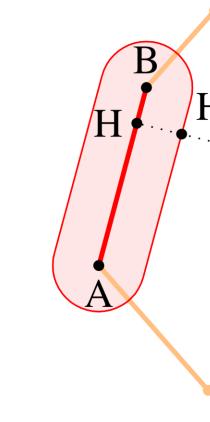
$$\tilde{f}_k^t(q) = J_{u,k}^t(q)(q_u - q_u^{goal}),$$

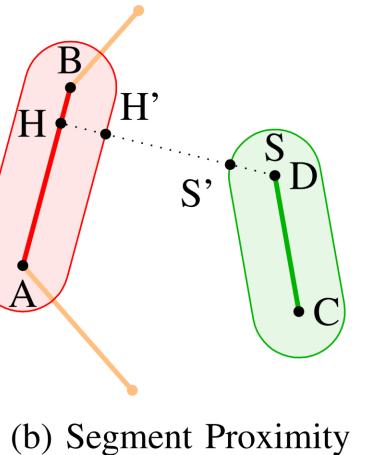
Our cost design enables autonomous and efficient contact planning

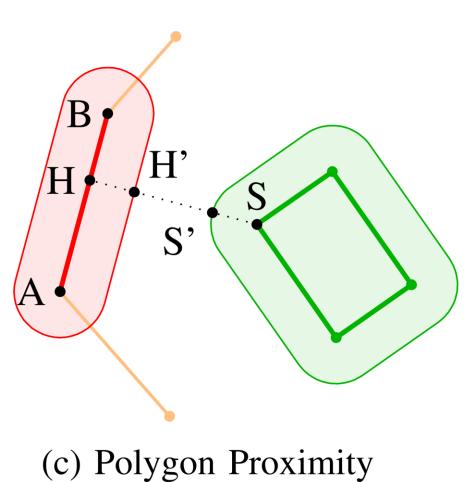
# Representation

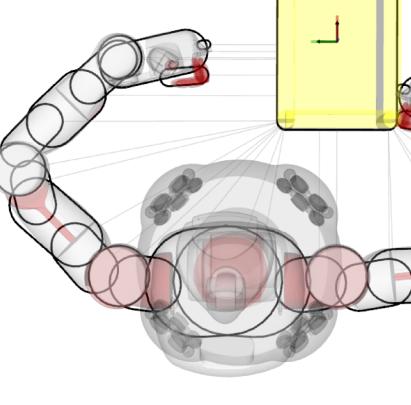


(a) Point Proximity









(d) Contact surface representation

#### Closed-form of proximity points

$$h_{0} = \left\langle \frac{AB^{\top}[CD]^{2}AC}{AB^{\top}[CD]^{2}AB + \varepsilon} \right\rangle_{0}^{1}$$

$$s = \left\langle \frac{CD^{\top}(h_{0}AB - AC)}{CD^{\top}CD + \varepsilon} \right\rangle_{0}^{1}$$

$$h = \left\langle \frac{AB^{\top}(sCD + AC)}{AB^{\top}AB + \varepsilon} \right\rangle^{1}$$

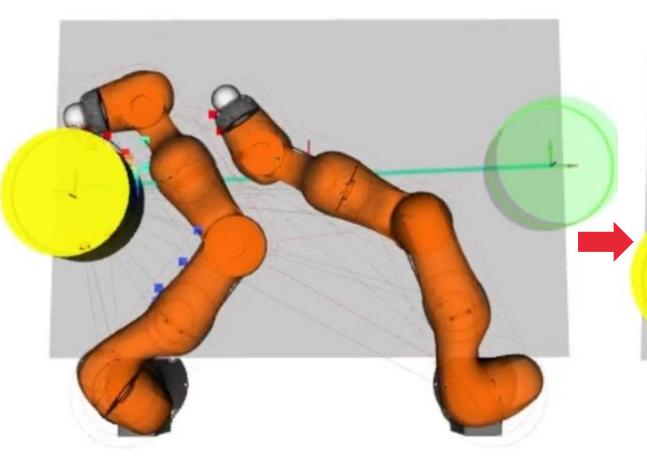
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Scenario 1

| Pla                   | nning time               | Scenario 1              |      |      |      | Scenario 2           |                  |      |      |      | Scenario 3        | Scenario 4           |                  |
|-----------------------|--------------------------|-------------------------|------|------|------|----------------------|------------------|------|------|------|-------------------|----------------------|------------------|
| $q_a^{init}$          | [deg]                    | -40.1, 0, 0, 40.1, 0, 0 |      |      |      |                      | 0, 0, 0, 0, 0    |      |      |      |                   | -45, 0, 0, -45, 0, 0 | 0, 0, 0, 0, 0    |
| $q_u^{init}$          | [m, m, deg]              | 0.60, -0.20, 0.00       |      |      |      |                      | 0.65, 0.00, 0.00 |      |      |      |                   | 0.50, -0.55, 0.00    | 0.40, 0.00, 0.00 |
| $q_u^{goal}$          | [m, m, deg]              | $0.60, 0.20, \theta$    |      |      |      | $0.35, 0.00, \theta$ |                  |      |      |      | 0.50, 0.55, -90.0 | 0.80, 0.00, 0.00     |                  |
| $\theta$              | [deg]                    | 0                       | 45   | 90   | 135  | 180                  | 0                | 45   | 90   | 135  | 180               | -                    | _                |
| OURS                  | success <sup>1</sup> [%] | 100                     | 100  | 100  | 100  | 93                   | 100              | 100  | 100  | 100  | 100               | 100                  | 100              |
|                       | mean [mn]                | 1.2                     | 1.9  | 5.7  | 6.5  | 16.0                 | 0.5              | 0.4  | 5.3  | 7.8  | 5.3               | 5.6                  | 2.6              |
|                       | min [mn]                 | 1.0                     | 1.7  | 3.4  | 4.6  | 6.0                  | 0.3              | 0.4  | 4.6  | 4.5  | 3.1               | 5.2                  | 2.3              |
|                       | max [mn]                 | 1.3                     | 2.1  | 11.2 | 10.1 | -                    | 0.7              | 0.5  | 8.1  | 12.5 | 12.9              | 6.1                  | 2.7              |
| Baseline <sup>2</sup> | success <sup>1</sup> [%] | 100                     | 70   | 7    | 0    | 0                    | 93               | 40   | 33   | 7    | 0                 | 100                  | 20               |
|                       | mean [mn]                | 3.9                     | 13.5 | 29.1 | -    | -                    | 9.7              | 20.9 | 22.7 | 28.7 | -                 | 15.2                 | 27.9             |
|                       | min [mn]                 | 0.3                     | 0.6  | 5.9  | -    | -                    | 0.4              | 0.3  | 0.5  | 2.7  | -                 | 8.2                  | 12.1             |
|                       | max [mn]                 | 26.1                    | -    | -    | -    | -                    | _                | -    | -    | -    | -                 | 21.4                 | _                |



Higher success Less variation



Scenario 3

