

Supplementary Material

Semantic Learning from Keyframe Demonstration using Object

Attribute Constraints

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Algorithm SI: Reproduction Stage

Input : Constraints, The number of reference Objects, Object Attributes and Object Poses in Scene

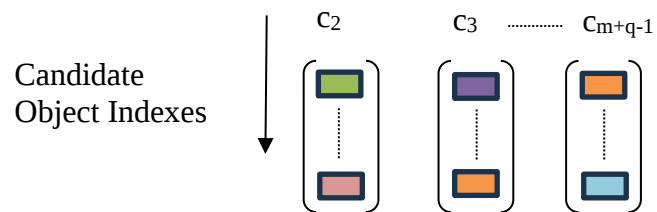
Output : Desired End-effector Poses

Step 1 → **Check constraints for each keyframe group**

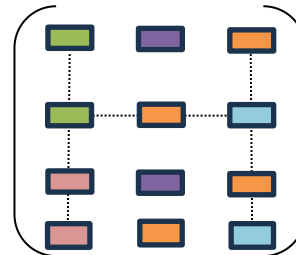
Initialize required keyframe clusters with candidate objects in reproduction
 $m-1$: the number of reference objects' group, q : the number of situational objects

Find the candidate objects for keyframe group c_i , $i = \{2, 3, \dots, m+q-1\}$

Initialize Candidate Object Vectors →



Candidate Object Matrix →



Remove rows, if any two columns have the same object indexes

Step 2	→ If they exist, apply spatial Relation constraints between reference objects and situational objects Take two relevant columns from the candidate object matrix. Compute Spatial Relations for each object pair: $(C_a, C_b), \forall \{a, b\} \in [2, m + q - 1]$ If spatial relation is not equal to the spatial constraint label: Remove the corresponding rows Update Candidate Object Matrix
Step 3	→ If they exist, apply inter-object discrete and continuous constraints between each keyframe group Take relevant columns from the candidate object matrix. If the constraint is discrete : Remove the corresponding rows if the attribute to be constrained is not equal for candidate objects. If the constraint is continuous : Remove the corresponding rows if the attribute to be constrained is not valid for the linear equation.
Step 4	→ If the row number of the result of the candidate object matrix == 1: Actual Reference Object Poses → The poses in the first m-1 column of the matrix Use the desired relative poses between the end-effector and the object, and actual reference object poses : Compute the desired end-effector poses

Table S1 The result of candidate objects for each keyframe in reproduction for the stacking task

	Candidate Objects after Constraints Between Demonstrations	Candidate Objects after Discrete Inter-Object Constraints	Result
Case 1: O₁-O₇	c ₂ : {O ₁ } c ₃ : {O ₇ }	c ₂ : None c ₃ : None	Fail
Case 2: O₁-O₄-O₇-O₈	c ₂ : {O ₁ , O ₄ } c ₃ : {O ₇ , O ₈ }	c ₂ : {O ₄ } c ₃ : {O ₈ }	Success
Case 3: O₂-O₆-O₉	c ₂ : {O ₂ } c ₃ : {O ₆ }	c ₂ : {O ₂ } c ₃ : {O ₆ }	Success

Table S2 The result of candidate objects for each keyframe in reproduction for the sorting task

Reproduction Scenes	Candidate Objects after Constraints Between Demonstrations	Candidate Objects after Inter-Object Discrete Constraints	Candidate Objects after Inter-Object Continuous Constraints
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Case 1: $O_{10}-O_{11}-O_{12}-O_6-O_7-O_{13}$	c2: $\{O_{10}, O_{11}, O_{12}, O_6, O_7\}$	c2 : $\{O_{10}, O_{11}, O_{12}\}$	c2 : $\{O_{10}\}$
	c3: $\{O_{13}\}$	c3 : $\{O_{13}\}$	c3 : $\{O_{13}\}$
	c4: $\{O_{10}, O_{11}, O_{12}, O_6, O_7\}$	c4 : $\{O_{10}, O_{11}, O_{12}\}$	c4 : $\{O_{11}\}$
	c5: $\{O_{13}\}$	c5 : $\{O_{13}\}$	c5 : $\{O_{13}\}$
	c6: $\{O_{11}, O_{12}, O_7\}$	c6 : $\{O_{11}, O_{12}\}$	c6 : $\{O_{12}\}$
	c7: $\{O_{13}\}$	c7 : $\{O_{13}\}$	c7 : $\{O_{13}\}$
Case 2: $O_1-O_3-O_7-O_6-O_5-O_8-O_{13}$	c2: $\{O_1, O_3, O_7, O_6, O_8\}$	c2: $\{O_1, O_3, O_7, O_6, O_8\}$	c2 : $\{O_6\}$
	c3: $\{O_{13}\}$	c3: $\{O_{13}\}$	c3 : $\{O_{13}\}$
	c4: $\{O_1, O_3, O_7, O_6, O_5, O_8\}$	c4: $\{O_1, O_3, O_7, O_6, O_5, O_8\}$	c4 : $\{O_7\}$
	c5: $\{O_{13}\}$	c5: $\{O_{13}\}$	c5 : $\{O_{13}\}$
	c6: $\{O_3, O_7, O_5, O_8\}$	c6: $\{O_3, O_7, O_5, O_8\}$	c6 : $\{O_8\}$
	c7: $\{O_{13}\}$	c7: $\{O_{13}\}$	c7 : $\{O_{13}\}$
Case 3: $O_7-O_{10}-O_8-O_{12}-O_{11}-O_1-O_{13}$	c2: $\{O_7, O_{10}, O_8, O_{12}, O_{11}, O_1\}$	c2: $\{O_{10}, O_{11}, O_{12}\}$	c2 : $\{O_{10}\}$
	c3: $\{O_{13}\}$	c3: $\{O_{13}\}$	c3 : $\{O_{13}\}$
	c4: $\{O_7, O_{10}, O_8, O_{12}, O_{11}, O_1\}$	c4: $\{O_{10}, O_{11}, O_{12}\}$	c4 : $\{O_{11}\}$
	c5: $\{O_{13}\}$	c5: $\{O_{13}\}$	c5 : $\{O_{13}\}$
	c6: $\{O_7, O_8, O_{12}, O_{11}\}$	c6: $\{O_{11}, O_{12}\}$	c6 : $\{O_{12}\}$
	c7: $\{O_{13}\}$	c7: $\{O_{13}\}$	c7 : $\{O_{13}\}$

Table S3 The result of candidate objects for each keyframe in reproduction for the serving task

<i>Reproduction Scenes</i>	<i>Candidate Objects after Constraints Between Demonstrations</i>	<i>Candidate Objects after Spatial Constraints</i>	<i>Candidate Objects after Inter-task Discrete Constraints</i>
Case 1: $O_4-O_3-O_{10}-O_6-O_7$	c2 : $\{O_4, O_3, O_{10}\}$	c2 : $\{O_3, O_4\}$	c2 : $\{O_4\}$
	c3 : $\{O_6\}$	c3: $\{O_6\}$	c3 : $\{O_6\}$
	c4 : $\{O_7\}$	c4 : $\{O_7\}$	c4 : $\{O_7\}$
	c5: $\{O_4, O_3, O_{10}\}$	c5: $\{O_3, O_4\}$	c5 : $\{O_3\}$
	c6 : $\{O_4, O_3, O_{10}\}$	c6 : $\{O_{10}\}$	c6 : $\{O_{10}\}$

Case 2: O ₁ - O ₂ - O ₇ - O ₉ - O ₄ -O ₁₄ - O ₁₁ -O ₆	c2 : {O ₁ , O ₂ , O ₄ , O ₉ , O ₁₁ }	c2 : {O ₁ , O ₂ , O ₄ , O ₉ }	c2 : {O ₉ }
	c3 : {O ₆ }	c3 : {O ₆ }	c3 : {O ₆ }
	c4 : {O ₇ , O ₁₄ }	c4 : {O ₇ , O ₁₄ }	c4 : {O ₁₄ }
	c5 : {O ₁ , O ₂ , O ₄ , O ₉ , O ₁₁ }	c5 : {O ₁ , O ₂ , O ₄ , O ₉ }	c5 : {O ₄ }
	c6 : {O ₁ , O ₂ , O ₄ , O ₉ , O ₁₁ }	c6 : {O ₁₁ }	c6 : {O ₁₁ }
Case 3: O ₄ - O ₆ - O ₁₂ - O ₁₃ - O ₇ - O ₅ -O ₁₁	c2 : {O ₅ , O ₁₁ , O ₁₂ , O ₁₃ , O ₄ }	c2 : {O ₁₃ }	c2 : {O ₁₃ }
	c3 : {O ₆ }	c3 : {O ₆ }	c3 : {O ₆ }
	c4 : {O ₇ }	c4 : {O ₇ }	c4 : {O ₇ }
	c5 : { O ₁₁ , O ₁₂ , O ₄ }	c5 : {O ₁₂ }	c5 : {O ₁₂ }
	c6 : { O ₁₁ , O ₁₂ , O ₄ }	c6 : {O ₄ }	c6 : {O ₄ }