Incremental Learning of Retrievable Skills For Efficient Continual Task Adaptation

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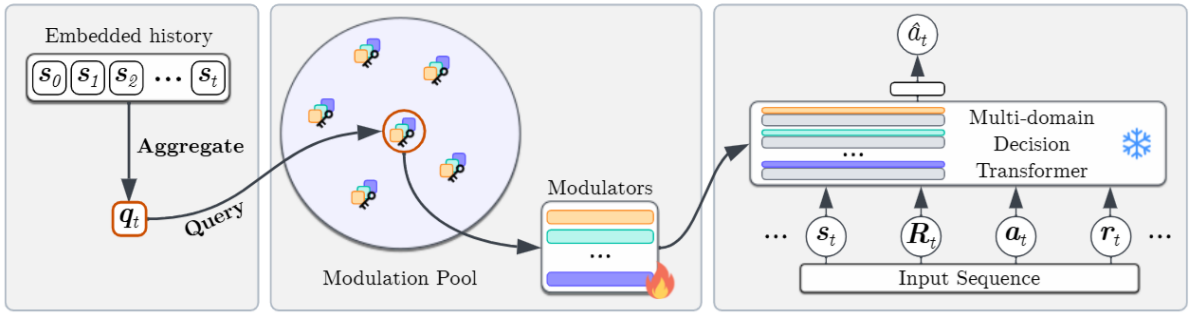
NeurIPS 2024

Motivation : Adapter-based Continual Learning



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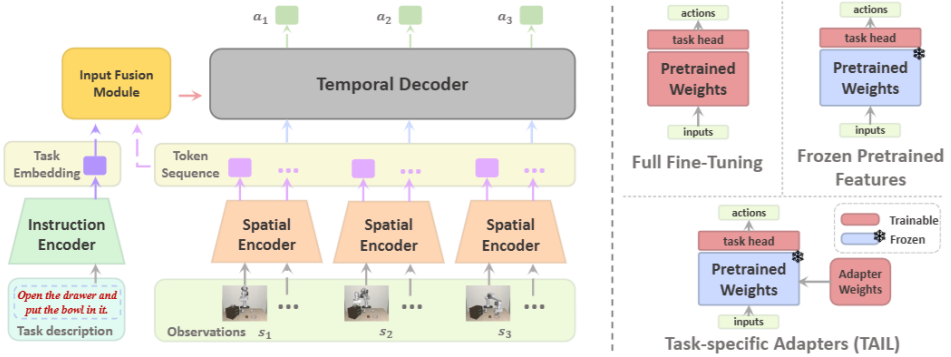

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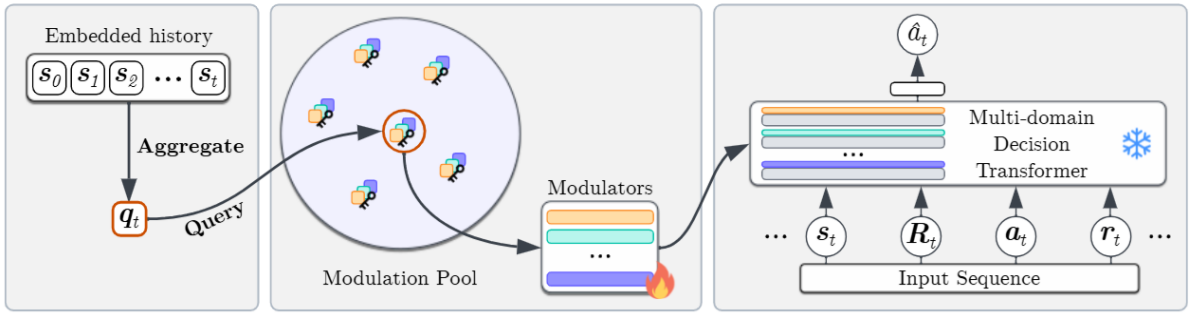

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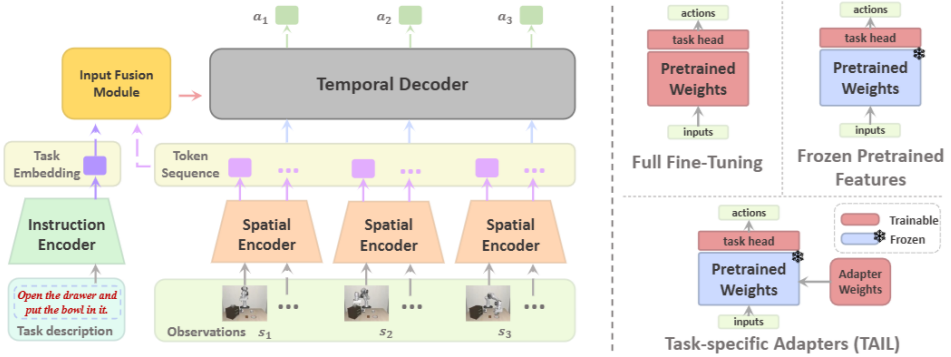

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- When and how can we achieve positive backward transfer, similar to humans?
- How can these tasks be managed flexibly in dynamic environments?

Challenges in Continual Imitation Learning

1. Requirement for comprehensive expert demonstration

- Inefficient, especially for long-horizon tasks.
- Sometimes impossible to collect expert demonstrations.

2. Frequent task shifts in non-stationary environments

- The continual shifting of tasks in non-stationary environments
- Difficulty in adapting to unseen tasks

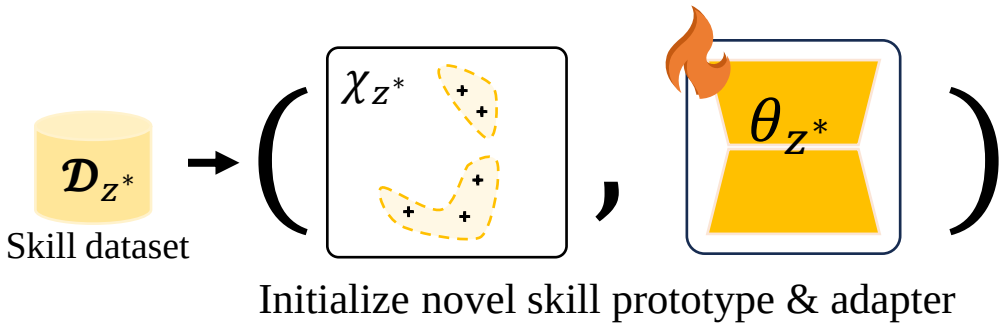
3. Actual privacy concerns

- Accumulating knowledge in model parameters can raise privacy issues.
- Sensitive information may be implicitly retained.

IsCiL : Incremental skills for Continual imitation Learning

How to solve? : Retrievable skills

1. **Prototype-based skill incremental learning** [training]
2. **Task-wise selective adaptation** [evaluation]



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How to solve? : Retrievable skills

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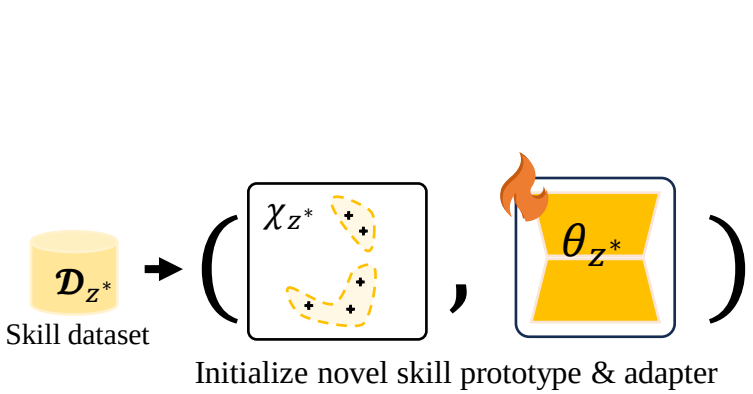
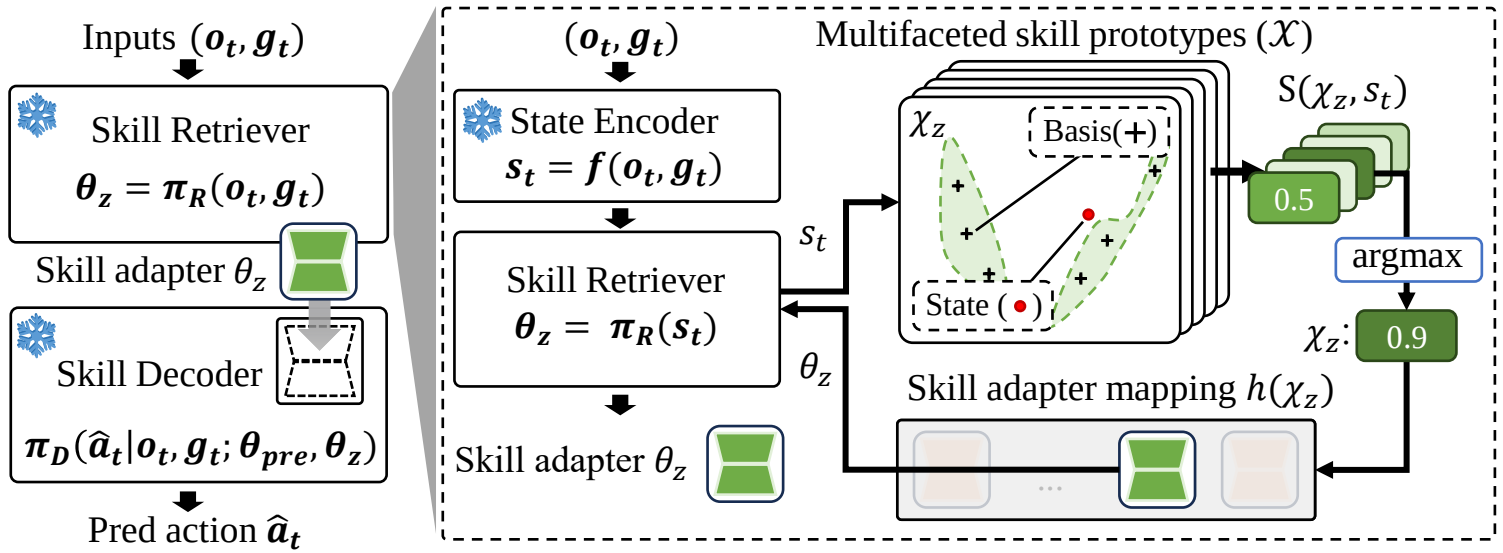
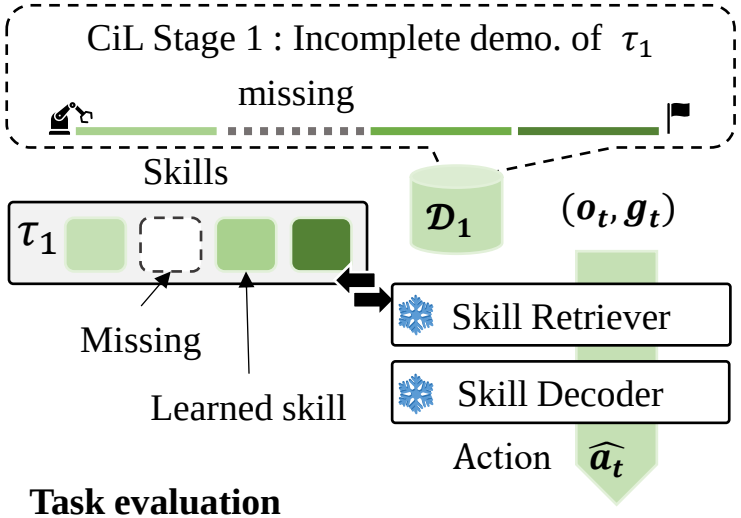


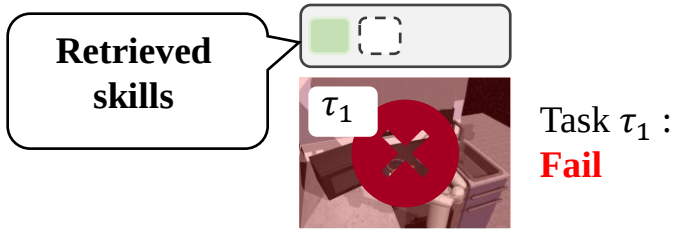


IsCiL : Incremental skills for Continual imitation Learning

Prototype-based skill incremental learning



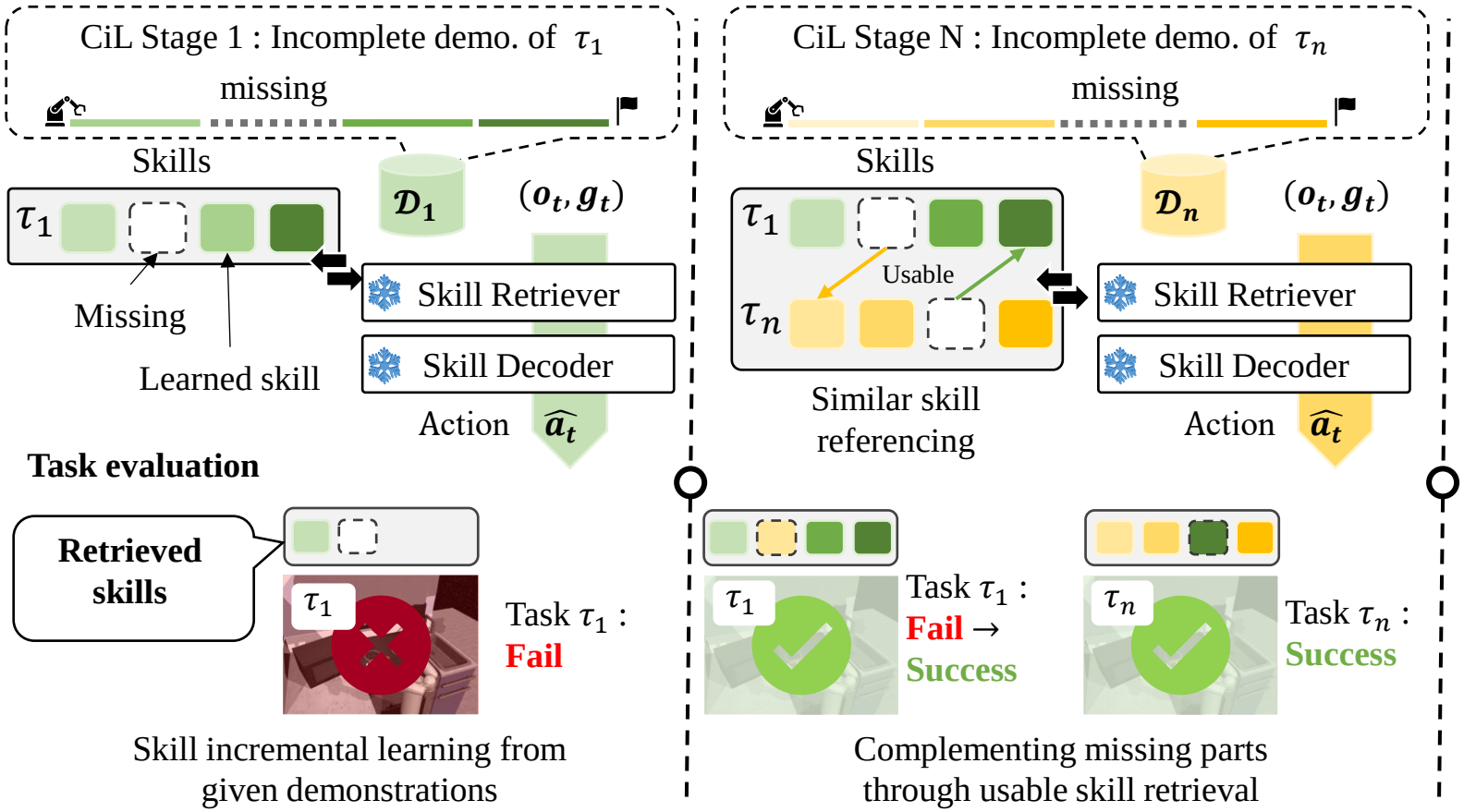
Task evaluation



Skill incremental learning from given demonstrations

IsCiL : Incremental skills for Continual imitation Learning

Prototype-based skill incremental learning



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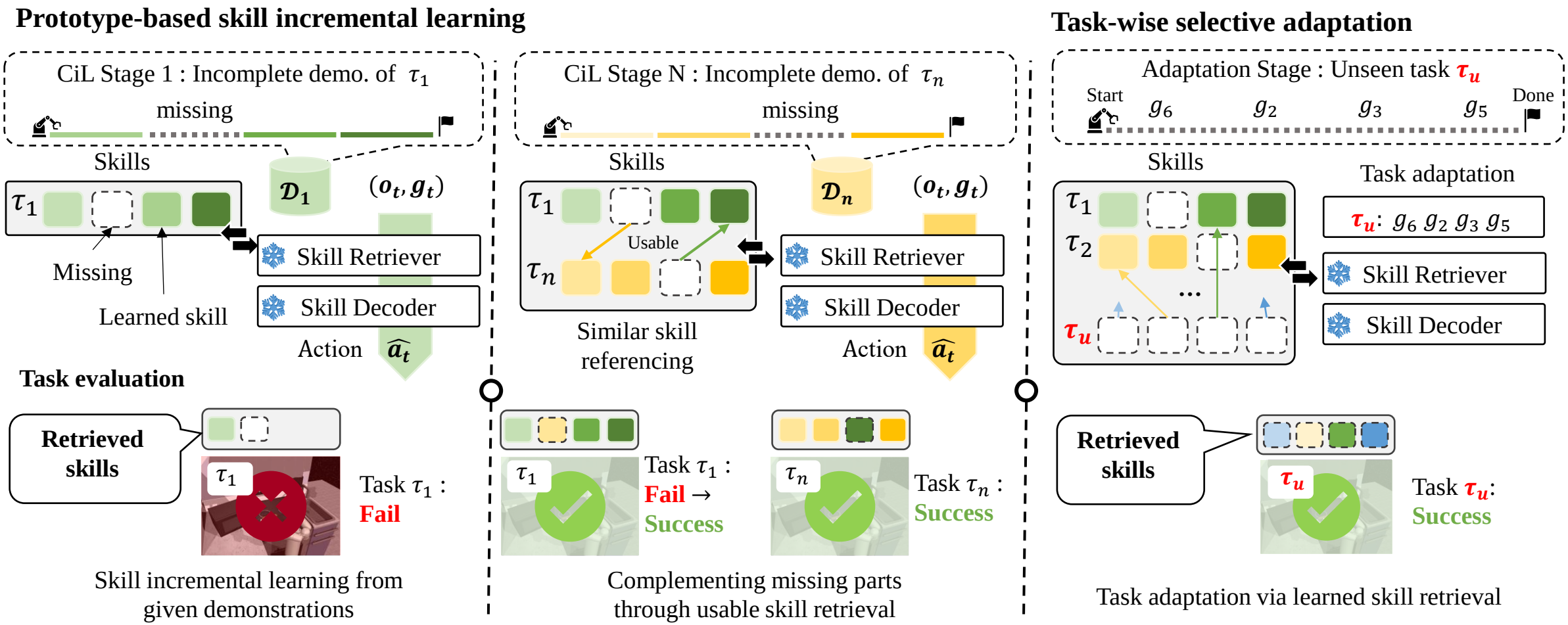
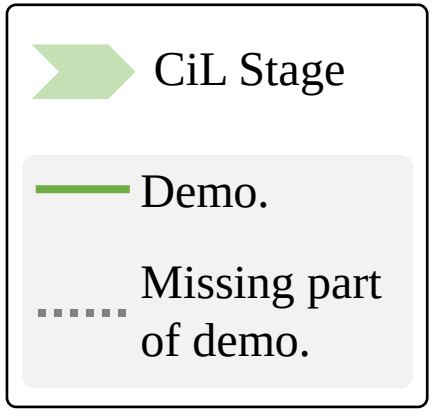


Experiment Settings and Scenarios

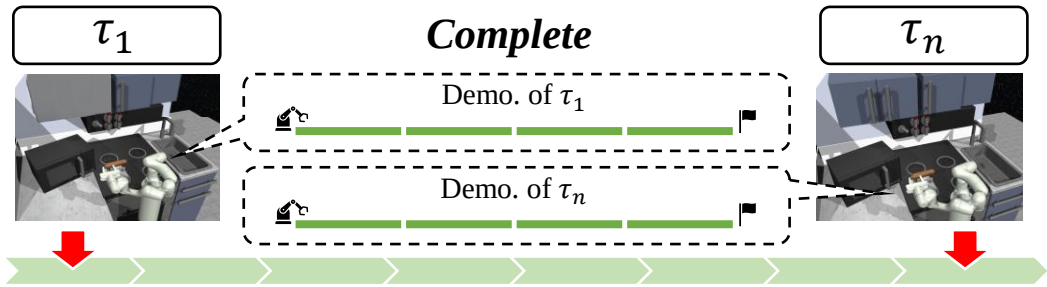


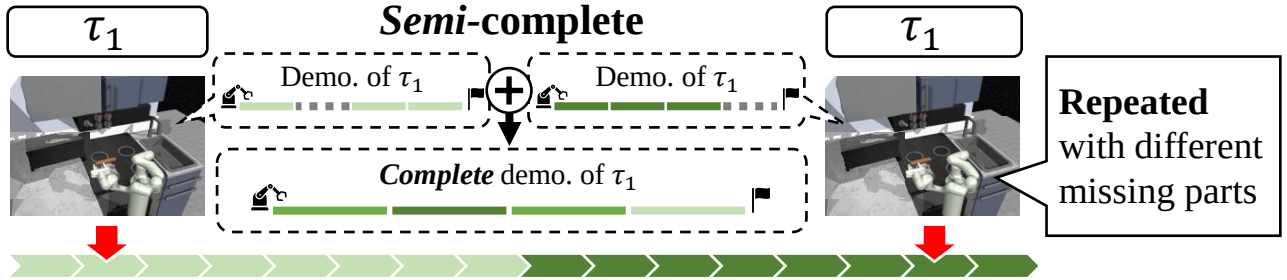
Experiment Settings and Scenarios

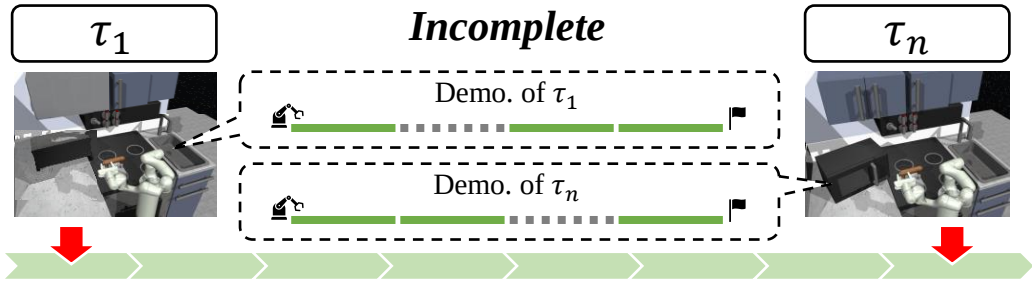
CiL Stage

Demo.

Missing part of demo.







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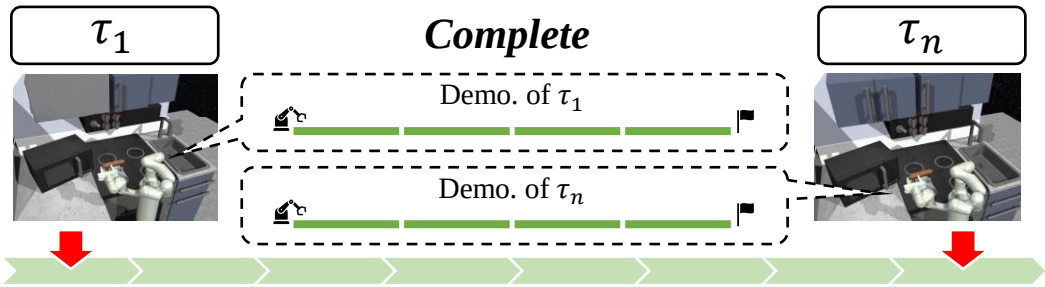
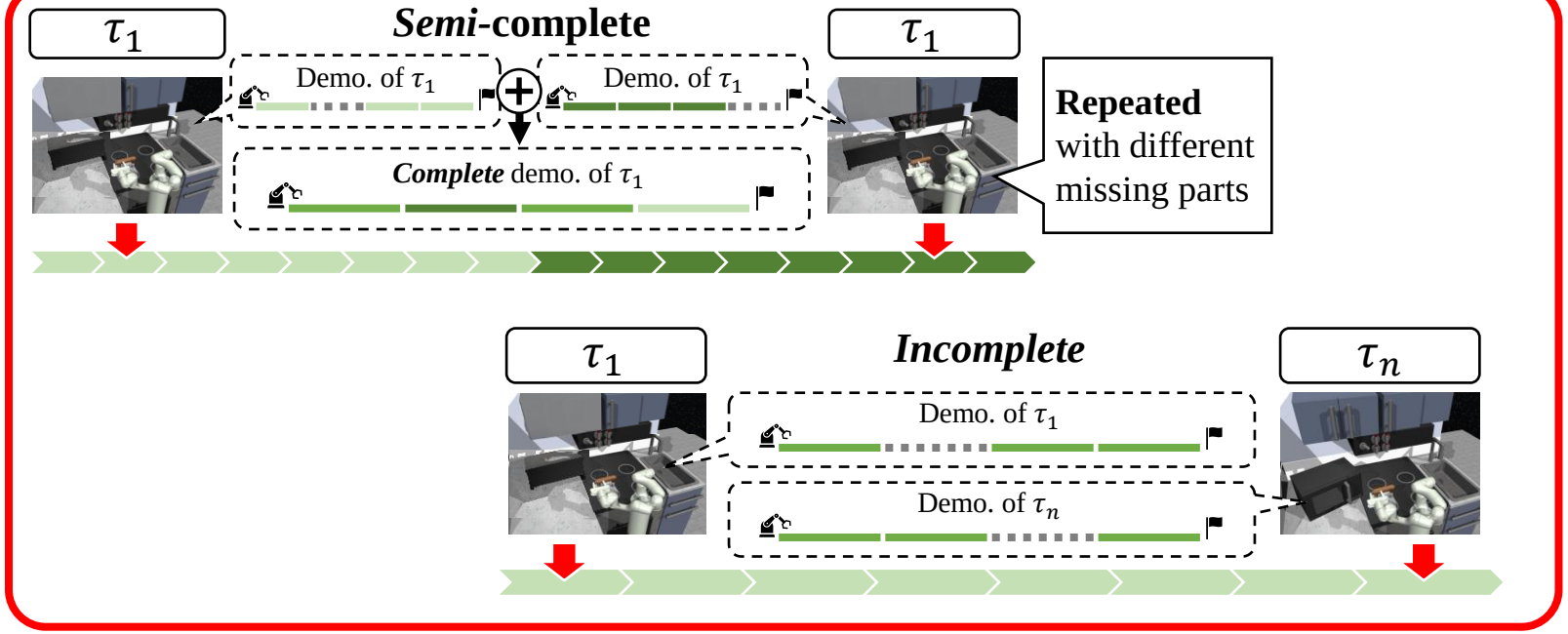




Results : Incomplete demonstration

Stream	Evolving Kitchen-*Complete*			Evolving Kitchen-*Semi*			Evolving Kitchen-*Incomplete*		
CiL-algorithm	FWT (%)	BWT (%)	AUC (%)	FWT (%)	BWT (%)	AUC (%)	FWT (%)	BWT (%)	AUC (%)
Pre-trained	-	-	24.3±0.5	-	-	29.1±0.9	-	-	24.3±0.5
Seq-FT	90.9±2.6	-63.7±2.7	35.0±0.7	37.1±2.1	-25.1±2.7	16.5±0.7	32.7±4.3	-19.6±3.0	15.7±0.5
EWC	34.2±0.8	-19.5±4.2	17.1±2.7	27.2±1.3	-18.0±1.3	12.2±1.4	19.3±2.3	-3.2±11.3	10.4±1.7
Seq-LoRA	77.5±2.6	-55.2±1.8	28.3±1.5	37.4±3.8	-25.5±3.2	15.9±1.6	32.9±2.5	-19.9±2.9	14.5±0.2
L2M	24.7±4.8	-2.5±4.5	22.7±1.6	19.2±4.4	0.2±1.3	19.1±4.8	17.5±4.0	-2.0±3.2	15.8±4.8
L2M-g	38.2±3.4	-6.5±3.7	32.3±1.4	37.9±3.7	-4.5±3.1	32.1±1.2	37.5±10.0	-6.5±6.9	31.0±8.8
TAIL-g	85.3±8.0	-49.9±6.7	41.5±1.7	55.0±1.5	-21.1±2.2	37.2±2.4	53.2±1.7	-20.0±2.0	35.4±0.7
TAIL-τ	86.2±5.6	0.0±0.0	86.2±5.6	41.2±2.5	0.0±0.0	41.2±2.5	33.8±3.0	0.0±0.0	33.8±3.0
IsCiL (ours)	79.3±1.7	11.0±1.6	**89.8**±0.5	68.1±2.2	8.6±0.6	**75.8**±1.8	61.8±0.9	13.7±2.9	**74.0**±1.9
Multi-task	93.3±1.7	-1.6±2.3	92.3±1.8	75.4±4.5	8.0±5.5	83.2±1.1	71.7±1.1	12.6±0.8	83.0±1.1

Stream	Evolving World-*Complete*			Evolving World-*Semi*			Evolving World-*Incomplete*		
CiL-algorithm	FWT (%)	BWT (%)	AUC (%)	FWT (%)	BWT (%)	AUC (%)	FWT (%)	BWT (%)	AUC (%)
Pre-trained	-	-	0.0±0.0	-	-	0.0±0.0	-	-	0.0±0.0
Seq-FT	88.9±3.1	-73.6±4.2	24.9±0.4	38.9±5.9	-27.5±5.5	13.2±0.9	41.4±2.0	-33.0±2.0	12.2±0.8
EWC	25.7±3.8	-18.0±0.2	10.5±3.5	13.9±1.4	-9.1±1.8	6.2±1.8	18.2±2.8	-11.6±2.1	8.5±0.9
Seq-LoRA	85.6±2.9	-75.1±2.3	21.4±1.2	32.2±5.2	-18.2±4.9	16.0±2.3	38.1±1.6	-30.6±0.9	11.7±0.9
L2M	72.1±5.3	-6.6±2.1	65.9±3.3	41.0±2.1	6.3±3.0	47.0±0.7	26.1±1.1	5.7±2.8	31.4±2.0
L2M-g	64.2±3.9	-19.3±4.4	48.6±2.0	44.5±2.0	3.4±2.5	48.2±0.2	33.2±2.0	-0.6±0.9	33.1±2.2
TAIL-g	90.0±3.0	-56.8±0.4	39.5±2.9	43.2±7.8	-17.6±3.5	27.4±5.1	51.4±2.5	-21.4±0.6	32.5±2.3
TAIL-τ	85.7±5.9	0.0±0.0	**85.7**±5.9	27.5±0.7	0.0±0.0	27.5±0.7	39.7±1.0	0.0±0.0	39.7±1.0
IsCiL (ours)	81.7±0.4	2.7±0.9	84.3±1.1	60.0±1.1	9.3±1.4	**68.9**±0.5	63.2±1.5	8.7±2.7	**71.2**±4.2
Multi-task	88.6±3.6	2.8±3.5	90.7±1.2	55.0±3.6	27.6±4.1	80.9±0.3	73.2±1.7	12.6±1.2	84.2±1.3

FWT: Assesses learning of new tasks using prior knowledge.

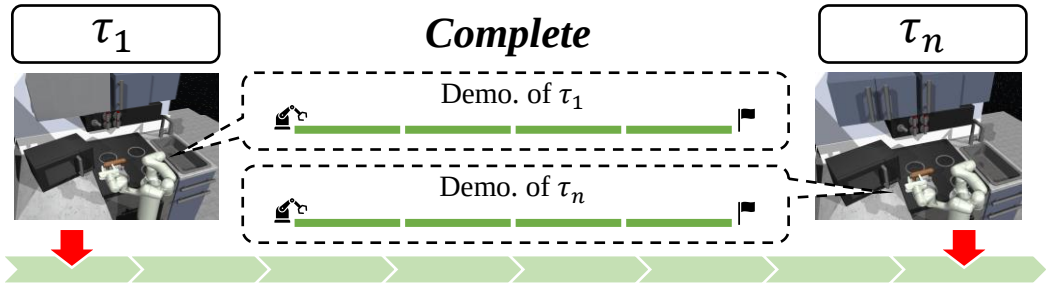
BWT: Measures impact of new learning on past tasks.

AUC: Indicates average performance across all stages.

- **IsCiL efficiently improves AUC performance**
- **IsCiL shows positive backward transfer**

Results : Unseen task adaptation

Stream	Evolving Kitchen-*Complete* Unseen					Evolving World-*Complete* Unseen				
Algorithm	FWT (%)	BWT (%)	AUC (%)	FWT-A (%)	AUC-A (%)	FWT (%)	BWT (%)	AUC (%)	FWT-A (%)	AUC-A (%)
Seq-FT	72.3±1.6	-47.7±1.6	30.4±0.2	27.8±0.6	19.5±0.1	52.9±3.6	-26.7±1.8	30.1±2.1	16.3±1.8	24.0±2.6
EWC	21.0±15.9	-14.0±2.0	16.8±1.6	18.1±4.2	14.4±1.6	16.5±1.9	-8.1±0.8	9.6±2.6	6.1±1.3	8.3±2.1
Seq-LoRA	62.4±3.8	-41.5±3.3	25.4±0.9	28.1±0.0	18.2±0.0	45.2±0.4	-35.8±1.3	14.5±0.9	6.4±2.5	8.2±1.8
L2M	22.3±2.3	0.3±1.5	22.7±3.5	15.3±3.2	21.2±4.1	55.1±3.7	-1.4±3.3	53.6±1.0	40.3±2.4	41.2±2.0
L2M-*g*	33.8±0.9	-4.3±1.2	30.0±0.4	22.2±0.6	24.1±0.7	43.3±1.6	-8.2±3.6	35.7±1.6	24.2±1.5	25.7±1.7
TAIL-*g*	67.6±7.4	-34.9±5.4	36.8±3.2	34.7±2.2	30.1±1.5	53.2±1.4	-27.1±1.2	29.2±0.3	18.6±0.9	19.1±0.6
IsCiL (ours)	69.5±2.5	16.3±2.2	**84.4**±1.3	**52.1**±7.5	**72.8**±2.1	64.3±2.6	-0.5±3.5	**63.9**±0.6	**45.8**±4.7	**45.3**±0.9
Multi-task	85.3±1.7	3.7±1.8	88.8±0.0	70.8±0.0	79.0±0.1	85.4±0.9	5.6±0.5	90.4±0.5	78.3±2.9	85.9±0.4



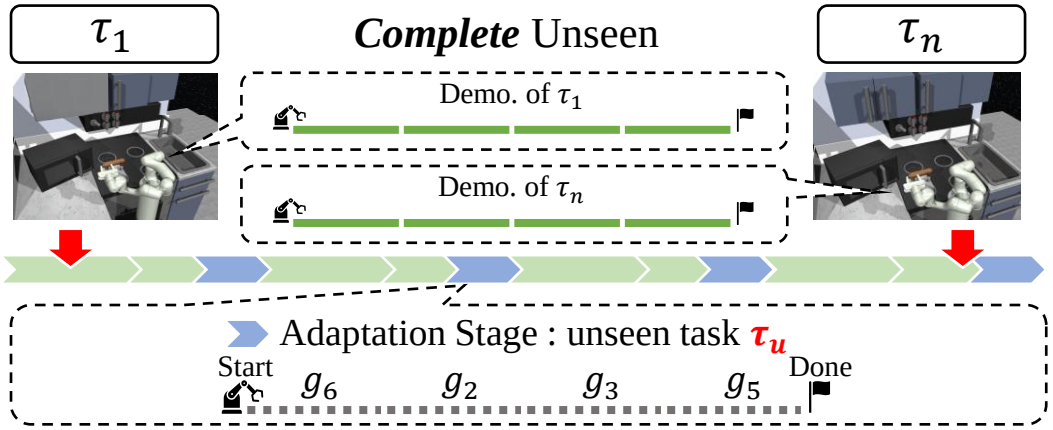
FWT-A: Assesses learning of unseen tasks using prior knowledge.

AUC-A: Indicates average performance of unseen tasks across all stages.

- **IsCiL effectively handles Unseen tasks**

Results : Unseen task adaptation

Stream	Evolving Kitchen-*Complete* Unseen					Evolving World-*Complete* Unseen				
Algorithm	FWT (%)	BWT (%)	AUC (%)	FWT-A (%)	AUC-A (%)	FWT (%)	BWT (%)	AUC (%)	FWT-A (%)	AUC-A (%)
Seq-FT	72.3±1.6	-47.7±1.6	30.4±0.2	27.8±0.6	19.5±0.1	52.9±3.6	-26.7±1.8	30.1±2.1	16.3±1.8	24.0±2.6
EWC	21.0±15.9	-14.0±2.0	16.8±1.6	18.1±4.2	14.4±1.6	16.5±1.9	-8.1±0.8	9.6±2.6	6.1±1.3	8.3±2.1
Seq-LoRA	62.4±3.8	-41.5±3.3	25.4±0.9	28.1±0.0	18.2±0.0	45.2±0.4	-35.8±1.3	14.5±0.9	6.4±2.5	8.2±1.8
L2M	22.3±2.3	0.3±1.5	22.7±3.5	15.3±3.2	21.2±4.1	55.1±3.7	-1.4±3.3	53.6±1.0	40.3±2.4	41.2±2.0
L2M-*g*	33.8±0.9	-4.3±1.2	30.0±0.4	22.2±0.6	24.1±0.7	43.3±1.6	-8.2±3.6	35.7±1.6	24.2±1.5	25.7±1.7
TAIL-*g*	67.6±7.4	-34.9±5.4	36.8±3.2	34.7±2.2	30.1±1.5	53.2±1.4	-27.1±1.2	29.2±0.3	18.6±0.9	19.1±0.6
IsCiL (ours)	69.5±2.5	16.3±2.2	**84.4**±1.3	**52.1**±7.5	**72.8**±2.1	64.3±2.6	-0.5±3.5	**63.9**±0.6	**45.8**±4.7	**45.3**±0.9
Multi-task	85.3±1.7	3.7±1.8	88.8±0.0	70.8±0.0	79.0±0.1	85.4±0.9	5.6±0.5	90.4±0.5	78.3±2.9	85.9±0.4



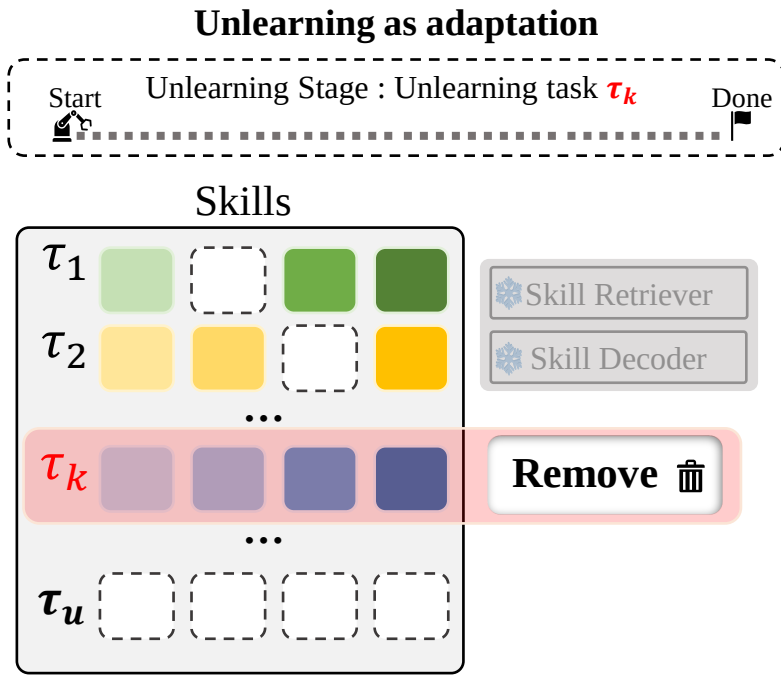
FWT-A: Assesses learning of unseen tasks using prior knowledge.

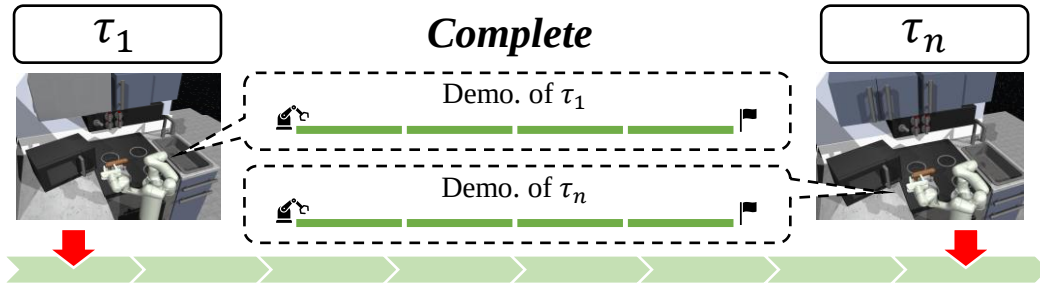
AUC-A: Indicates average performance of unseen tasks across all stages.

- **IsCiL effectively handles Unseen tasks**

Results : Unlearning for privacy

Stream	Evolving Kitchen-*Complete* Unlearning			Evolving Kitchen-*Incomplete* Unlearning		
Algorithm	FWT (%)	BWT (%)	AUC (%)	FWT (%)	BWT (%)	AUC (%)
TAIL-τ CLPU	86.2±5.6	0.0±0.0	86.2±5.6	33.8±3.0	0.0±0.0	33.8±3.0
IsCiL (ours)	75.0±7.2	11.2±5.5	85.2±1.8	61.4±2.9	12.4±2.9	72.7±2.9





- **IsCiL effectively handles unlearning requests**
- **It remains robust in *incomplete* settings**

Results : Unlearning for privacy

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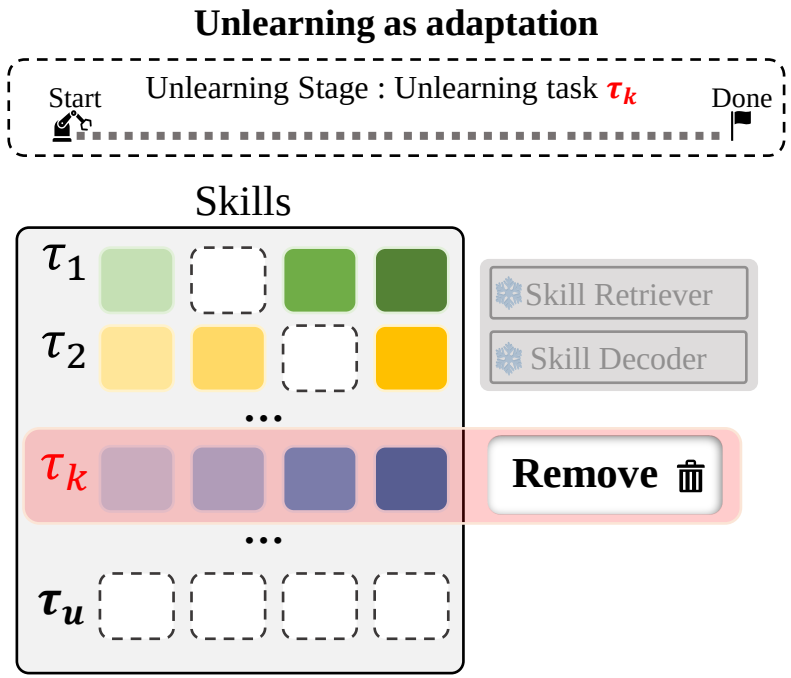

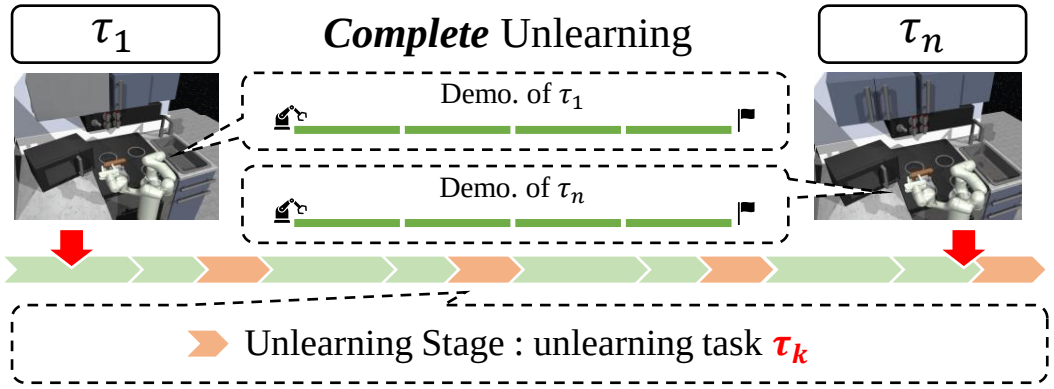

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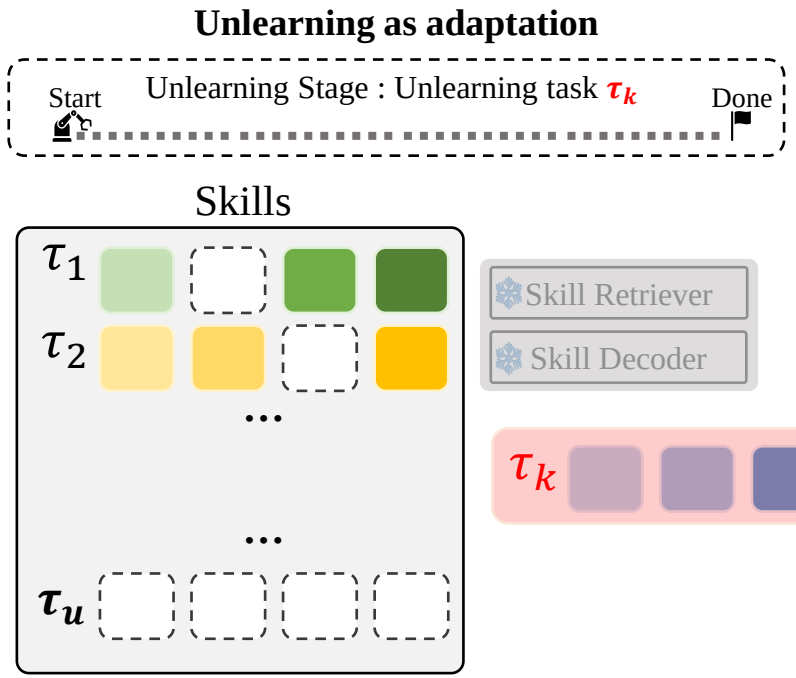

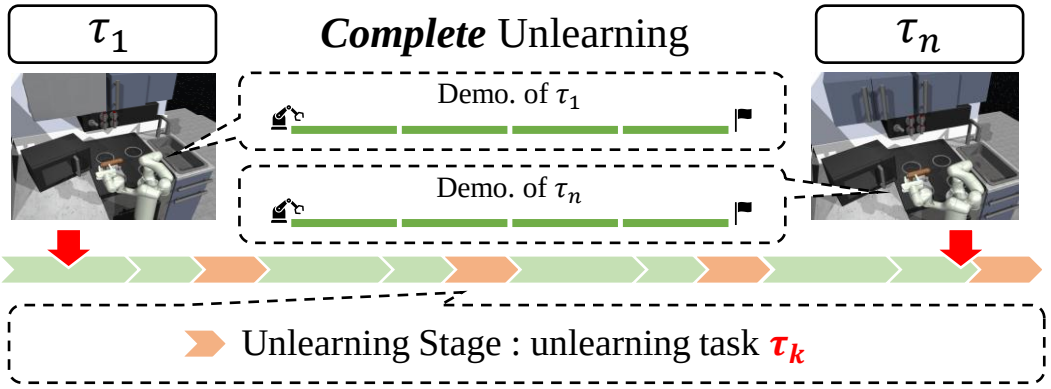

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- **It remains robust in *incomplete* settings**

Conclusion

Flexibility of retrievable skills

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Flexibility of retrievable skills

1. Require comprehensive demonstration

2. Frequently shifting tasks in non-stationary environments

3. Actual privacy concerns

problems

Conclusion

Flexibility of retrievable skills

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Enhance bidirectional transfer without rehearsal

Unseen task adaptation using existing skills

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Generalization : Model Merging & Task Arithmentic
Efficiency : Caching algorithm for Retrieval Process